INFLUENCE OF AGING ON THE PROPERTIES OF WASTE POLYMER MODIFIED ASPHALT BINDER

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A thesis submitted to National University of Science and Technology

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in

Transportation Engineering

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THESIS ACCEPTANCE CERTIFICATE

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DEDICATION

Dedicated to my benevolent husband, exceptional mother in law, angelic kids, and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment.

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(Engr. Zohra Jabeen)

ABSTRACT

Lengthening the service life of pavement had been the primary goal of road sector agencies. The severity of traffic demand that is being placed on our pavements is increasing significantly day by day. Likewise the rapid development, increase in traffic load and volume, and insufficient maintenance is leading to severe distresses of road surfaces like rutting and cracking. Thereby the high quality bitumen is inevitable to handle the above mentioned issues. The bitumen modification is one of the quality tool being used by the engineers since two decades for improvement of the service life of pavements by enhancing the pavement quality.

A promising strategy that has been widely accepted for improving the pavement deficiencies, is the use of commercial polymers for asphalt binder modification. However their high cost is the major hurdle in their use, especially in the developing countries. Instead of these commercial polymers researchers are using waste plastic polymers to attain the same benefits. Their cost effectiveness and environment friendly quality is making them the most popular asphalt binder modifier all over the world. The current study aimed at studying the influence of aging on the properties of waste polymer modified asphalt binder. Two such polymers, waste PET (polyethylene terephthalate i.e. plastic bottles) and waste LDPE (low-density polyethylene i.e. plastic bags) were collected from the vicinity, than cleaned, uncapped and shredded to a size less than 0.5mm and blended separately with 60/70 penetration grade bitumen at four different concentrations (2%, 4%, 6% and 8% by weight of bitumen). Penetration, Ductility, Rotational viscosity and Ring and Ball tests were performed on the unaged modified binder samples, short term aged (using rolling thin film oven test (RTFO)) modified binder samples, and long term aged (using pressure aging vessel test (PAV)) modified binder samples. The chemical changes were studied using Fourier Transform Infrared Spectroscopy (FTIR), and morphological changes were studied using Scanning Electron Microscopy (SEM). The results showed decrease in penetration and ductility values, whereas increase in softening point and viscosity values. The sulfoxide and carbonyl index values decreased, that is the indicator of the improvement in the oxidation resistance. The results of the morphological analysis showed good compatibility of the modifiers with asphalt binder. To sum up, it could be said that the use of these non-biodegradable waste polymers is not only enhancing the properties of the binder but is saving the cost of the material as well as environment from pollution.

Keywords: Aging; Viscosity; Modified Asphalt Binder; Waste Polymers; Waste PET; Waste LDPE; Environmental Impact.

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List Of Abbreviations

ASTM	American Society of Testing Materials
AASHTO	American Association of State Highway and Transportation Officials
PET	Polyethylene Terephthalate
LDPE	Low Density Polyethylene
W-PET	Waste Polyethylene Terephthalate
W-LDPE	Waste Low Density Polyethylene
PMB	Polymer Modified Binder
WPMB	Waste Polymer Modified Binder
HMA	Hot Mix Asphalt
SBS	Styrene Butadiene Styrene
FTIR	Fourier Transformed Infrared Spectroscopy
SEM	Scanning Electron Microscope
CPEC	China Pakistan Economic Corridor
TRB	Transportation Research Board
SHRP	Strategic Highway Research Program
FHWA	Federal Highway Administration
PG	Performance Grade
UV	Ultraviolet
RV	Rotational Viscosity
ARL	Attock Refinery Limited
PAV	Pressure Aging Vessel
RTFO	Rolling Thin Film Oven

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Asphalt binder is a generic term used to represent the principal binding agent in hot mix asphalt (HMA). It has been used for centuries as an engineering material [1]. Direct use of natural bitumen as an adhesive, waterproofing agent, sealant, pavement binder, preservative was introduced long before refining [2]. In ancient times people used to take it directly from natural fields or lakes. The naturally occurring deposits of asphalt is called crude bitumen and are classed as pitch. The largest pitch lake that contains around 10 million tons of bitumen, is located in southwest Trinidad named as La Brea. The first refined bitumen was produced in USA by refining crude oil, in early 1900s. After that the bitumen consumption all over the world has increased and 85% of which was in pavement works [3]. Bitumen was first used in Europe (1830s) as a pavement material, followed by France and England .

The socio-economic development of any country is mainly dependent on its communication and transportation sector. The transport system in Pakistan consists of air transport, railways, sea ports and roads. Out of which the road network carries more than 96 percent of traffic making it the backbone of the country's economy. Therefore its sustainability becomes priority for boosting economic growth.

Hence it is inevitable to invest into the extension, development and timely maintenance of road infrastructures and have proper pavement management systems. Being developing country our focus should be more on sustainability and cost effective methods for fixing all major distress issues. The use of flexible pavements is more economical in terms of maintenance with additional quality of smooth riding but with the traditional construction materials, the pavements are failing before the end of service life. Rutting and cracking are the major failure issues on such roads. Therefore, high quality, more reliable, sustainable and environment friendly construction materials are needed [4].

In order to handle the dramatic increase in the traffic volume as well as the demand for high quality pavement, researchers have been trying hard to improve the comprehensive performance of the asphalt binder by adding different modifiers. [5, 6]. The most common modifier that gained recognition worldwide in pavement industry is polymer. Polymer modification has the capability to improve asphalt binder properties at different range of temperatures. It increases the resistance against permanent distresses and failures before the end of design life. The pavements service life increases and maintenance cost reduced significantly by increasing the viscosity of asphalt binder at higher temperatures and improving the ductility at lower temperatures [7, 8]. It increases the binder's elasticity and reduces the temperature susceptibility as well [9, 10]. Incorporating polymers to asphalt binder could improve the aging resistance [11, 12]. Different polymers are being used by the researchers successfully, including thermoplastic elastomers and plastomers [13].

The commercial polymers such as polyethylene and its by products, styrene-butadiene-styrene (SBS), and ethylene-vinyl-acetate (EVA), are being used successfully for flexible pavement quality improvement all over the world, but in developing countries it's use is still limited due to their high cost. Rather in most recent studies waste polymers are being used instead as a bitumen modifier successfully. They are cost effective and environmental friendly as well along with the quality of enhancing asphalt binder properties [14, 15]

The polymer modification is not only getting popular in its virgin state, rather the waste polymers are also being used extensively these days all over the world. The main reasons of incorporating waste materials include the dramatic increase in the cost of construction material, preservation of natural resources, and lastly but not the least waste material's huge amount that is polluting environment because of its non-biodegradable nature. Researchers concluded that the use of waste polymers can enhance the performance of flexible pavements same as the commercial polymers. Moreover their use has some extra advantages like saving the environment from pollution and resources also that are being scarce day by day. In other words, we can say that their use results in overall lower product costs as well as is a step towards resolving the non-biodegradable i.e. plastic waste disposal issues without compromising the properties of asphalt binder rather enhancing the flexible pavement quality [16].

1.2 PROBLEM STATEMENT

Increase in traffic demands and shortage of resources, forces the highway agencies to switch from pavement reconstruction to pavement preservation and rehabilitation programs. Significant savings with improvement in the network condition is already in practice in developed countries. To preserve the natural resources and decrease the negative impacts of developments on environment, it is essential to adapt such latest techniques, which will help Pakistan in providing improved and better performing transportation infrastructure facilities to its road users.

There is another severe problem that has become a global issue these days i.e. waste materials. Pakistan is generating around 30 million tons of solid waste yearly and is increasing by 2% to 3% per year. It comes at the fourth position, as stated by a report on solid waste management in 2016 by United Nations Development Program (UNDP). Now all over the world this plastic waste is being used in the manufacture of bricks, roads etc. Being a developing country, the polymer modification is not the perfect solution to all of our problems. Rather use of waste polymers instead of commercial polymers, that is being studied throughout the world these days, is the focus in this research. Waste polymers have been used as bitumen modifiers and their aging effect on different properties were studied, using RTFO, PAV, and different empirical tests like penetration, viscosity, ductility, and ring and ball test.

1.3 RESEARCH OBJECTIVES

The objectives set for this research are as follows:

- To determine the physical properties of waste polymer modified asphalt.
- To study the aging effect on the properties of waste polymer modified asphalt binder.
- To examine the effect of modifiers on morphology and chemical composition of the binder.

- To analyze the flow behavior of WPMB using Rotational Viscometer.
- Cost analysis of asphalt binder modified with W-PET and W-LDPE.

1.4 SCOPE OF STUDY

Present study focuses on the use of locally available waste polymeric additives as a modifier, than thoroughly examine the aging phenomenon on the properties of modified asphalt binder. The aging of waste polymer modified asphalt binder is observed with RTFO and PAV in laboratory. Physical and performance testing was then conducted for different samples of aged and unaged WPMB. Flow behavior was analyzed using RVT at two temperatures i.e. 135^0C and 165^0C. Chemical and morphological analysis was also carried out with SEM and FTIR.

1.5 THESIS OUTLINE

Chapter 1: This chapter depicts brief background and motivation for the research related to aging susceptibility of asphalt binder. It also provides an approach to the statement of problem, hypothesis as well as objectives of this research.

Chapter 2: This chapter provides an overview of the previous researches already carried out on the proposed topic. Moreover it also includes an overview of the aging mechanism of asphalt binder, how to modify it and what are the effects of various modifiers on physical and performance properties of asphalt binder.

Chapter 3: This chapter includes the details about the materials used in this research and the research methodology. The primary materials include 60/70 penetration grade asphalt binder, waste polyethylene terephthalate (W-PET) and waste low density polyethylene terephthalate (W-LDPE). The testing approach includes both the physical properties and the visco-elastic parameters to be evaluated.

Chapter 4: Explained the results obtained from extensive laboratory testing. Includes analysis done by using Microsoft excel.

Chapter 5: It is comprised of the conclusive comments based on the research findings as well as recommendations and suggestions for further research in future.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Transportation infrastructure has direct relationship with Economic Development, as it facilitate the efficient movement of goods and labor for production. The regional productivity will increase with the reduction in effort and time that is required to produce goods. Therefore the healthy road transport network is must for boosting economy of a country. The kilometer-age of paved roads of a country is often used as an index to calculate its development [17]. Hence it is inevitable to invest into the development, extension and maintenance of road transport infrastructure.

For a long time, asphalt is used for the building of pavements while asphalt binder is the main constituent of asphalt. Now a day, pavements are failing before reaching the end of their design life, due to rapid increase in the traffic loading and number of vehicles. Mix rutting is one of the major failure encountered on such roads. Demands of current and future traffic loadings cannot be fulfilled by traditional pavement materials. Therefore there is an urgent need of good quality, environment friendly, safe and reliable pavement materials [4]. Various types of modifiers and polymers are added in asphalt to improve its life and performance. Mechanical properties of asphalt binder are improved when we use crumb rubber as a modifier. Moreover addition of polymer in asphalt increase pavements life and help in reduction of maintenance costs [18]. Different types of polymers have been used by the researchers for asphalt pavement quality enhancement, like Styrene-Butadiene- Styrene (SBS) [19], polyethylene [20], polypropylene [21]etc. According to the previous studies the mechanical properties as well as physical and rheological characteristics of the asphalt binder are enhanced by the addition of these polymer modifiers. They enhance the resistivity of asphalt binder against different distresses and pre-mature failures.

2.2 ASPHALT BINDER HISTORY

Asphalt binder is produced by petroleum refineries. It is used to make a dense mass by binding the aggregate particles together. Aging effects, temperature susceptibility and visco-elasticity are the three major properties of the asphalt binder that affects directly to the performance of asphalt binder. Aging of the asphalt binder is considered as one of the major cause of early deterioration of flexible pavements. It is defined as the oxidation of light components of asphalt binder that becomes reason of its hardening during the construction phase as well as the service life of pavement.

Asphalt binder is also characterized by its viscous and elastic nature and this property of asphalt binder is termed as visco-elastic property. Visco-elastic behavior is interrelated with the thermo-mechanical nature of the asphalt binder and then it governs mechanical properties of HMA mixes by controlling its time-temperature dependence. When the temperature is high or more than 100°C, asphalt binder behaves entirely as a viscous fluid and its consistency becomes equal to the motor oil or some other lubricant. Similarly asphalt binder changes its behavior and acts most likely as an elastic solid at very low temperatures hence maintain its original shape when loaded and unloaded, this property characterized its linear viscoelastic behavior. At the intermediate temperature, in most of the pavement systems asphalt binder exhibits both the properties of elastic solid and viscous fluid.

2.3 ASPHALT BINDER COMPOSITION

In the European specifications, asphalt binder is defined as “virtually in volatile, adhesive and waterproofing material derived from crude petroleum, or present in natural asphalt, which is completely or nearly completely soluble in toluene, and very viscous or nearly solid at ambient temperatures”.

Asphalt binder is a combination of very complex molecules that are the result 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 are called asphalt binder.

2.3.1 Elemental Composition

Asphalt binder is a nitrogen compound showing a highly complex constitution. Many different chemicals present in the asphalt binder structure make its chemistry complex. To resume asphalt binder, many of the chemicals consist in carbon and hydrogen atoms. Moreover, atoms, such as nitrogen, sulphur and oxygen are usually present. Some traces of metal have also been found. The most frequent being vanadium and nickel. Table 2-1 represents the elemental composition of asphalt binder (Bitumen components- composition of bitumen-Bitumen Characterization,")

Table 2-1: Elemental Composition of Asphalt Binder

Carbon	80-84 wt.%
Hydrogen	8-12 wt.%
Sulphur	0-9 wt.%
Nitrogen	0-2 wt.%
Oxygen	0-2 wt.%
Vanadium, Nickel, Iron, Aluminum, Silicon	Traces

2.3.2 Chemical Composition

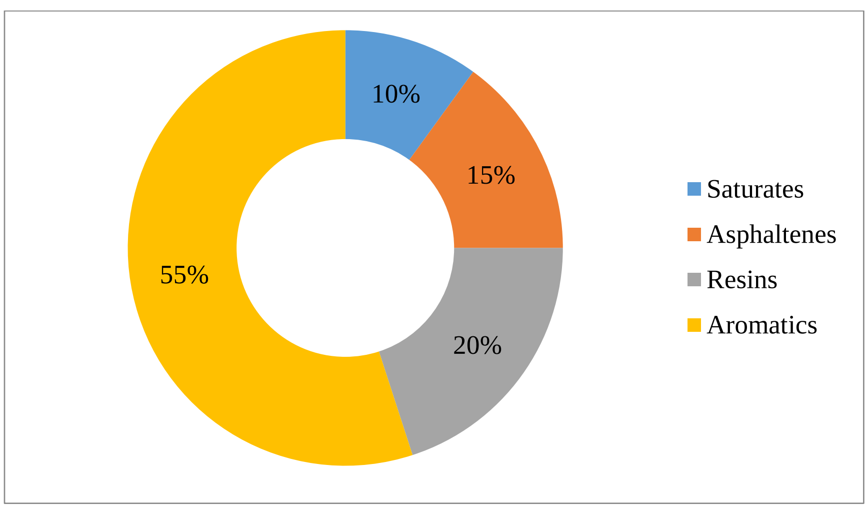

Figure 2-1: Chemical Composition of Asphalt

The chemistry of asphalt binder is often simplified into four generic groups, often referred to as SARA, which help to define the behavior of asphalt binder.

These are as follow, firstly the saturates, these are colorless, non polar oils. Secondly the aromatics, these tend to be dark brown, non polar viscous liquids. Thirdly, resins, these are dark brown, polar semisolid or solid. Finally the asphaltenes, these are dark brown or black very polar solids. The relative proportion of these SARA components dictates the physical behavior of the asphalt binder. For example, asphaltenes contribute significantly to the solid nature of the asphalt binder. The resins to the addivity of the asphalt binder and the aromatics dictate how well dispersed the asphaltenes are and so will also influence the solid liquid balance of the asphalt binder. Therefore the balance of the SARA is the fundamentally important in how the asphalt binder behaves in service.

2.4 ASPHALT BINDER AGING

Asphalt binder is a complex heterogeneous mixture of hydrocarbons that behaves as a visco-elastic material. It's mechanical and thermodynamic behavior varies with temperature [22]. Asphalt durability mainly depends on two chemical factors; compatibility of its components and resistance to change due to oxidative aging. Asphalt reaction with oxygen in environment is the main cause of hardening and brittleness [23]. So change in the chemical composition of bitumen due to high temperature and oxygen in atmosphere, during construction as well as its service life period is called as aging, that is one of the main cause of early deterioration of pavement. [24]. There are two main types of aging i.e. short term aging and long term aging. The aging occurs during the production of asphalt mixture is called short term aging. It occurs at a very fast rate due to the high temperature. It becomes reason of changes in the rheological properties of the binder as a very thin film of the material is exposed to air during the process. [25]. Whereas the aging during the in-service life of pavement occurs due to the long term exposure to atmosphere, and the temperature is relatively lower. The rate of hardening at this stage depends on the surrounding environment as well as the in-place air void content. But the atmospheric oxidation of molecules is the primary cause that leads to the formation of highly polar and strongly interacting functional groups that contains oxygen. During the first stage of hardening there is an abrupt increase in the viscosity of the binder i.e. short term aging, whereas in the long term aging the increase in viscosity is linear and slow at an almost constant rate [26].

Most important factor affecting the service life and causing the failure of bituminous pavement is the phenomena of aging [27]. The pavement flexibility is being affected badly by the aging mechanism during its service life [28]. Whereas the extent of aging is directly dependent on the chemical composition of the asphalt [29].

Siddiqui and Ali, 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 [30].

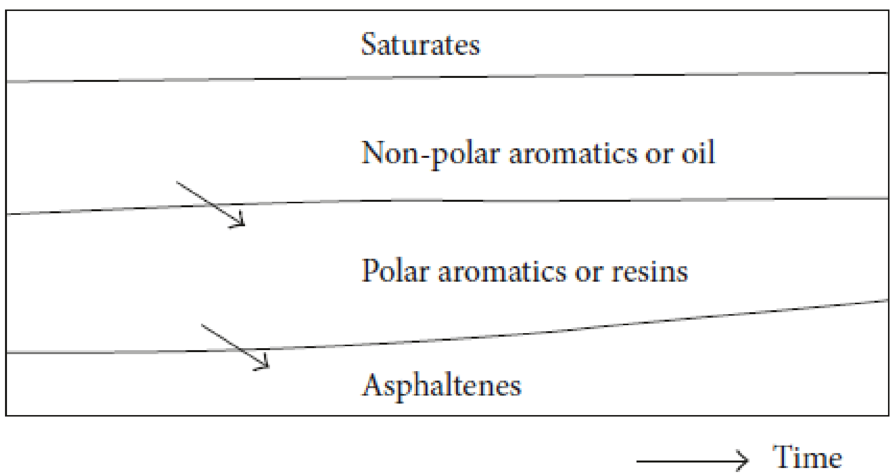

Figure 2-2: Effect of Aging on Chemical Composition of Asphalt Binder [24]

Chemical composition of the 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 [31].

Siddiqui and Ali conducted a study on the aging behavior of Arabian asphalt and found that the percent weight of oxygen and sulphur as carbonyl and sulfoxide groups respectively increased in asphaltenes after the aging phenomena [32].

Hence the steps in the process of oxidation effect in asphalt binder structure can be grouped as dehydrogenation, formation of sulfoxide from oxidation of alkyl sulfurs, formation of ketones from oxidation of benzyl carbons and formation of carboxylic acids along with the dicarboxylic anhydrides [33].

Different factors affecting the aging process of asphalt binder includes type of binder, mixture compaction and its impact on proportion of voids, binder content, chemical composition, origin of asphalt binder, environmental condition, polarity of molecules and exposure to UV radiations [29].

Gawel et al considered the asphaltenes ratio as a parameter to understand the aging behavior of asphalt pavements in India [27].

2.4.1 Short Term Aging

This phenomena take place when the asphalt binder material is mixed, transported, stored and compacted during the construction [29]. Short term aging comprises almost 70% of total aging [34]. Rolling Thin Film Oven (RTFO) is used to stimulate it in laboratory conditions. Short-term aging temperature and added chemical type directly influence the recovery behavior of the binder [35]. Aging occurring within 2 to 3 years after the application of asphalt mixture in field also fall in the short term aging category.

2.4.2 Long Term Aging

Long term aging occur throughout the service life of asphalt pavement due to exposure to sun and UV radiations [29]. Long term aging is a reversible process in which chemical composition of asphalt are changed while rheological properties remain unchanged [36].

Pressure Aging Vessel (PAV) is used in laboratories to find out the effect of long term aging. The asphalt binder samples were subjected to increased temperature and 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 [37].

The rheological and chemical properties of asphalt binder are greatly affected by the phenomena of aging. Aging reduces the elasticity of asphalt binder and thus causing distresses like rutting, thermal cracking, fatigue and moisture damage. Than these distresses end up in reducing the service life of pavement. Effect of aging on asphalt binder can be studied by using following techniques i.e. Dynamic Shear Rheometer (DSR), Rotational Viscosity test, Ring and Ball Test, High pressure gel permeation chromatography (HP-GPC), Scanning Electron Microscopy (SEM), Penetration Test, and Fourier Transformed Infrared Spectroscopy (FTIR) [29].

2.5 ASPHALT BINDER MODIFICATION

Polymer modification is the polymer integration in asphalt binder either by chemical action or mechanical means [35]. Various amendment to asphalt are being explored owing to increasing demand for higher performance [38].

Porto *et al.*conducted a thorough literature review of the latest research papers regarding the asphalt binder chemistry and its modification. They concluded that, in the modification of asphalt, chemical composition of the virgin binder is important. Many modifiers improve the performance characteristics of asphalt binder to some extent but they can also cause some compatibility issues in the production and storage. In this regard the importance of waxes to solve the compatibility problems of polymers in asphalt binder was admitted [39].

Since 1970s, several number of research articles have been published on the subject of polymer modification of asphalt binder. Effects of several polymers such as styrene ethylene/ butylene-styrene, polyethylene, ethylene-vinyl acetate, styrene-isoprene-styrene, thermoplastic elastomers, ethylene-butyl acrylate, and plastomers are studied in these articles [40]. The results showed considerable improvement in the binder characteristics like better rutting resistance, high stiffness at high temperatures, improved low temperature cracking, moisture resistance and improved fatigue life [41].

Ragni et al. studied the short term aging performance of polymer modified asphalt binder for warm mix asphalt under the effect of varying chemical additives and temperature and find out that short term aging effect on binders performance is reduced by chemical additives. Moreover, they also concluded that the type of chemical additive as well as the aging temperature has a direct impact on the recovery behavior of binder [35]

Chemical and physical properties of the asphalt binder affected by phosphorous compounds were studied by using RTFO and concluded that the aging resistance of the binder was greatly enhanced [42].

Gawel*et al.* 2016 tested naturally obtained oleic imidazoline as anti-oxidant to asphalt binder. Asphalt binder was analyzed before and after RTFO aging. Amount of oxygen uptake was set as criteria to find out the effects of aging on the neat and modified binder. Imidazoline reduced the oxygen uptake of asphalt binder after aging. It improved the colloidal stability of asphalt binder and acted as dispersing agent and anti-oxidant. Hence imidazoline can be used as an ageing inhibitor to asphalt binder which is environmental friendly as well [27].

Chen *et al.* 2016 used organic expanded vermiculite (OVEMT) and inorganic nanoparticles as asphalt binder modifier to examine the asphalt binder's rheological properties. RTFO, PAV and UV aging was done to the samples. XRD was used to examine the microstructure of modifiers. DSR results revealed good improvement with regard to complex module and phase angle which indicates good thermal and UV resistance of the modifiers [43].

Li et al. studied the effects of adding polymer (elastomer, plastomer), oil and polymer plus oil into the base asphalt binder to assess its aging susceptibility. Different levels of aging were achieved using PAV and RTFO. Rheological properties of the asphalt binder were measured with DSR and BBR, and chemical properties were determined using FTIR and GPC. It was observed that the aging susceptibility of asphalt binder is affected negatively by the polymer modification while aging resistance was enhanced by the modification with hybrid (elastomer + plastomer). Aging properties of the binder were not significantly improved by oil modification alone. Therefore it might be concluded that the aging behavior of asphalt depends upon the type and complexity of modification as well as interaction between the two modifiers (oil and polymer) [44].

Rek*et al.*2005 used two asphalt binders from different sources and SBS as modifier to estimate the aging properties of polymer modified binder. Short term aging effects on the binder was stimulated by using RTFO. After aging, chemical and rheological changes in asphalt binder structure were analyzed by using FTIR, dynamic shear rheometer (DSR) and rotational viscometer (RV) tests. Viscosity of asphalt binder from both sources increased after the incorporation of SBS and after aging. Moreover it was also concluded that source/origin of asphalt binder also influence the effect of modifier on aging. However for the assessment of aging behavior of PMB, both chemical and rheological methods are required [45].

2.5.1 Waste Polyethylene Terephthalate Modified Binder

Nuha Mashaan et al, studied the physical and performance properties of waste polyethylene terephthalate (PET) modified asphalt binder. Rolling thin film oven test and dynamic shear rheometer test were conducted to analyse the engineering properties and visco-elastic behavior of waste PET modified asphalt binder. They concluded that 6-8% waste PET modified asphalt binder improved the stiffness and elasticity behavior [46].

Sand Aldagari et al, analysed the aging behaviour of the waste PET modified bitumen. The dynamic shear rheometer (DSR) and a Fourier transform infrared (FTIR) spectroscopy tests were used to study the rheological and chemical changes that occurred due to aging. The binders containing PET when subjected to extended aging, resulted in high resistance to aging [47].

Kumar and Satyanarayana, compared the effect of adding polyethylene (PE) and styrene-butadiene-styrene (SBS) into base asphalt binder. Engineering properties of the modified binder were determined using conventional testing. It was found that both modifiers PE and SBS improve the engineering properties of base binder while SBS modified binder shows more promising results than PE modified asphalt binder [48].

Padhan et al, incorporated some cross-linking additives and specific reactive polymers to handle the issues related to phase separation and storage stability.

Conventional tests, storage stability test and super pave performance tests were performed. Results indicate better improvement in the stability and phase separation issues. Fluorescence microscope showed better dispersion of the modifier resulting in better overall performance of the modified binder [49].

Diab*et al.*2019 carried out a series of tests to explore the aging effect on the engineering properties of PMB. Added polymers include SBS, styrene-acrylonitrile (SAN), polycarbonate (PC), high density polyethylene (HDPE), and polypropylene (PP). They concluded that the aging resulted in more carbon component in all modified samples while the increase in sulphur, nitrogen and hydrogen was not obvious for any polymer modification. Almost all properties of asphalt binder were improved by polymer modification [11].

Kowalski studied the effect of polyethylene type polymers on asphalt modification. Linear low density polyethylene (LLDPE), copolymer EBA and terpolymer EBM, low density polyethylene (LDPE), and high density polyethylene (HDPE) were used as modifiers. Asphalt binder properties before and after RTFO were determined and more softening point and less penetration value was observed. No improvement in elastic recovery was observed except for the polymer EBM [50].

Ghuzlan suggested 3% by weight of bitumen, to be the optimum polyethylene content. At 5% or more the rotational viscosity values were higher making the PMB unworkable [51].

Punith and Amirthalingam, 2007 added different percentages of polethylene (PE) to an 80/100 penetration grade asphalt binder. Hamburg wheel track test, indirect tensile test, dynamic creep test, resilient modulus test were performed on the PE modified mixture. They concluded that the PE modified binder perform better than the conventional binder as they improved the temperature susceptibility and rutting resistance. 5% of the PE content by weight of the bitumen, was suggested as the optimum amount [52].

Muhammad Rafiq Kakar et al, studied the effect of waste polyethylene (PE) and its by-products modified asphalt binder on pavement performance. To examine their effect on the thermal and chemo-mechanical behavior, PE-shreds and PE-

pellets were mixed using high shear mixer with the virgin binder. According to the results the waste polymer modified binder high temperature distresses resistance like rutting improved significantly. At low temperatures the modulus of the binders was comparable. However, attention is needed to be paid on mixture preparation method of the PE blended binders because of the high temperature storage stability problem [53].

2.5.2 Waste Low Density Polyethylene Modified Asphalt Binder

The effects of short-term aging was studied by Abdelhalim Bensada et al, on the physical and rheological properties of waste plastic modified asphalt binder. The modifier used was waste low-density polyethylene (LDPE) plastic waste. Plastic bags i.e. LDPE bags, were collected, cleaned and shredded prior to use. Their chemical behavior was studied by using Fourier transform infrared spectroscopy analysis. The percentage of W-LDPE used by weight of bitumen was 1%, 3%, and 5%. The conventional properties of the modified binder were studied using penetration and softening point test, whereas for the rheological properties dynamic shear rheometer test was conducted. The tests were carried out on the unaged and aged binder samples. According to the results the penetration values decreased and the softening point values increased after the addition of plastic waste. Moreover, at high temperatures the rheological properties were improved leading to an increased rutting resistance of binder. So 3% of W-LDPE amount by weight of bitumen was suggested by them as the optimum value for better aging resistance [54].

The creep behavior of a neat 80/100 Pen asphalt binder concrete mixture and a linear low density polyethylene (LLDPE) modified bituminous concrete was studied by Napiah *et al.* To study the deformation behavior of the asphaltic concrete samples, dynamic creep test was used. 3% of LLDPE observed to be the optimum content at which the mix gave better results as compared to 1% and 2% of LLDPE. 3% LLDPE was suggested by them as an optimum value for gaining maximum benefits like improvement in the mixture stiffness and rut depth as determined by the wheel tracking test [55].

The effect of the polymer structure and its amount on the properties of LDPE modified asphalt binder was studied by K. Lakshmi Roja et al. The low-density polyethylene (LDPE) was used with two melt flow indexes (MFI), i.e., LDPE4 (low) and LDPE70 (high). They were blended separately with the virgin binder, and the percentage by weight of bitumen used ranges from 1 to 5%. Rotational viscometer was used to study the stability of polymer modified binder. The dynamic shear rheometer test was conducted to examine the rheological properties. The best polymer dispersity results showed by the 3% LDPE70 modified binder [56].

The high-temperature rheological properties of the binder modified with waste low-density polyethylene (LDPE) and crumb rubber (CR) was studied by Gabriel Macêdo Duarte et al. The tests includes Rotational viscosity, superpave performance grading, storage stability, multiple stress creep and recovery test. According to the results the storage stability of the modified binders were enhanced by the hybrid modification. The modifiers increased the high-temperature performance of the binders according to the MSCR test results [57].

2.6 LITERATURE RELATED TO FTIR AND SEM

In a study the properties of asphalt binder with the help of Fourier transformed infrared spectroscopy (FTIR) were evaluated. 32 samples of different refineries and different viscosities and aging conditions were used 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 [58].

In a study FTIR and SEM was used 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 and good homogeneity of the modifier in binder [59].

Fourier Transformed Infrared (FTIR) spectroscopy and high pressure gel permeation chromatography (HP-GPC) were used 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 good modifier [60].

Improvements in aging properties of asphalt binder were studied by using SBS and highly reclaimed (HRR). Physical characters, aging mechanism 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 [61].

Ouyang*et al.* 2006 bused 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 [62].

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 [63].

Improvement in the 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 [34].

2.7 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. The methods for improving the aging properties of asphalt binder by its modification with waste polymers and other chemical additives has been discussed in the light of recent researches carried out on the same topic.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

Methodology adopted to perform different tests to achieve the required research objectives are discussed in this chapter. Waste polyethylene terephthalate (PET) and waste low density polyethylene (LDPE) has been used to modify the asphalt and their aging effects on the physical, performance, morphological and chemical properties has been studied. Different test procedures were used to analyze the behavior of unmodified and modified asphalt binder under similar conditions.

3.2 MATERIALS SELECTION

The objective of this research is to study the effects of aging on waste polymer modified asphalt binder. So for this purpose the selection of polymers had been a crucial step. Materials were selected as per the availability and cost efficiency. A major drawback of commercial polymers is their high cost. Researchers are using waste polymers like waste rubber and waste plastic successfully, instead of commercial polymers to deal with this problem [64-68]. Keeping in view the facts and figures, following mixture of material were used for preparation of samples for different experimentation.

- 60/70 Asphalt binder
- Waste polyethylene terephthalate (PET)
- Waste low density polyethylene (LDPE)

3.2.1 Asphalt binder

The Penetration grade of 60/70 bitumen was acquired by the Attock Refinery Limited (ARL) Rawalpindi, and used as a base binder. The above mentioned grade is commonly used in Pakistan and performs better in colder to intermediate temperature regions. Moreover it was easily and abundantly available in our area. Its basic properties are listed in the Table 3-1.

Table 3-1: Physical Properties of Base Binder

S No	Test Description	AASHTO Designation	Results	AASHTO Specification
1	Penetration Test @ 25 (°C)	T 94-03	62	60-70
2	Softening Point (°C)	T 53	49	49/56
3	Ductility Test (cm)	T 51	>100	100 cm
4	Flash Point (°C)	T 48-89	261	232 min
5	Fire Point (°C)	T 48-89	282	-
6	Specific gravity	T 228	1.02	1.04 Max
7	Viscosity Test (Pa.sec)	T 316	0.410	≤ 3 Pa.s

3.2.2 Waste Polyethylene Terephthalate (PET)

Polyethylene terephthalate a non-biodegradable waste, is a thermoplastic polymer. It belongs to the polyester family and its chemical formula is $C_{10}H_8O_4$. It is a clear and strong plastic that is commonly used for food packaging. Mineral water and soft drink bottles are mostly made by this PET plastic. In this research local waste plastic bottles with PET code were collected after proper identification. Than after removal of the stickers, caps, and cap rings the bottles were washed and dried. After that they were shredded to a size ≤ 0.5mm with the help of shredding machine. Figure 3-1 shows the waste and waste plastic bottles. The basic properties of PET are listed in Table 3-2.

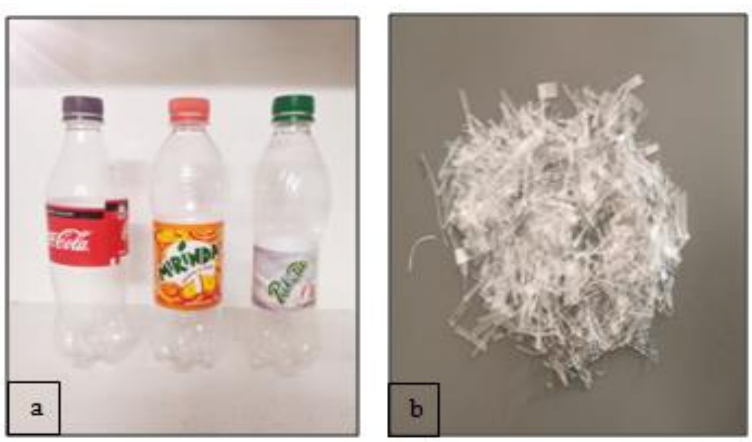

Figure 3-1:(a) Waste PET Plastic Bottles;(b) Waste Shredded PET Plastic

Table 3-2: Physical Properties of Polyethylene Terephthalate (PET)

S No	Properties	Results
1	Chemical Formula	$(C_{10}H_8O_4)_n$
2	Melting Point (°C)	250-260
3	Density (g/cm^3)	1.38
4	Solubility	Insoluble in water
5	Water Absorption (%)	0.16

3.2.3 Waste Low-Density Polyethylene (LDPE)

Low-density polyethylene (LDPE) another non-biodegradable waste, is also a thermoplastic made from the monomer ethylene. It's most common use is in plastic bags. In this research local waste plastic bags with LDPE code were collected after proper identification, cleaned and shredded to a width ≤ 1mm and length ≤ 15 mm. Figure 3-2 shows the waste and waste plastic bags and code of LDPE plastic polymer.

Figure 3-2: (a) Waste LDPE Plastic bags; (b) LDPE Plastic Code; (c) Shredded Waste LDPE Plastic

Table 3-3: Physical Properties of LDPE Plastic

Sr No	Properties	Results
1	Chemical Formula	$(C_2H_4)_n$
2	Melting Point (°C)	108
3	Density (g/cm^3)	≈ 0.914
4	Solubility	Insoluble in water

3.3 PREPARATION OF WASTE POLYMER MODIFIED ASPHALT BINDERS

Samples were prepared by adding waste polyethylene terephthalate (W-PET) into 60/70 penetration grade in different percentages i.e. 2, 4, 6 and 8% by weight of the base binder. A measured amount of neat binder for each percentage of modifier, was liquefied by heating at 150 °C. After that the temperature was increased till 180°C and the premeasured shredded waste PET was gradually added. High rate shear mixer was used keeping the temperature 180°C at 2000 rpm, for about 60 minutes, to get homogeneous blend. In order to avoid segregation and maintain uniform distribution, W-PET modified asphalt binder was prepared in small quantity as needed and was used for sample preparation right after that.

Same procedure was adopted for the preparation of W-LDPE modified asphalt binder samples at four different percentages i.e. 2%, 4%, 6% and 8% by weight of the base binder. Mixing was done at 170°C and 2000 rpm, for about 40 minutes to get homogeneous blends.

3.4 AGING

Aging is the change in chemical composition of bitumen due to atmosphere and the high temperatures [24]. It consists of steric hardening due to the molecular reorganization, volatilization and oxidation due to molecular structure changes [28]. One of the main reason of pavement failure is oxidization i.e. hardening of bitumen over time [69]. This results in the brittleness of bitumen due to stiffness with aging, that ultimately leads to increased potential of cracking [24]. This stiffening due to aging increase the rate of permanent deformation and fatigue as well [28].

3.4.1 Short Term Aging

The aging during mixing, spreading, storage and compaction of asphalt binder termed as short term aging. After short term aging of asphalt binder, evaluation of its physical and performance properties is very important to assess quality of asphalt binder. 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. In laboratory, the effect of short term aging was stimulated by RTFO. The temperature in RTFO was 163ºC and the samples were aged in the chamber for 80 minutes.

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 3-3: Glass Bottles

Figure 3-4:RTFO Oven

3.4.2 Long Term Aging

Exposure to heat and UV radiation during its life span cause long term aging of asphalt pavement. In laboratory, the effect of long term aging was simulated by Pressure Aging Vessel (PAV) test. To simulate the effect of in-service aging of asphalt binder, the binder was exposed to high temperature and pressure for 20 hours. This procedure is described by ASTM D6521. After performing long term aging the residue was tested for conventional and performance tests.

Apparatus includes the following.

- Sample Pan/trays
- PAV
- Vacuum oven

Figure 3-5: Pressure Aging Vessel

Figure 3-6:PAV Samples

3.5 MATERIAL TESTING

Physical and Performance testing were performed on virgin, aged, modified aged and modified unaged asphalt binder. Modified asphalt binder was obtained through extensive physical testing by determining an optimum content of waste PET and waste LDPE. Physical and performance test results, which includes low temperature cracking, rutting resistance and Fatigue resistance of virgin and modified asphalt binder were compared. The methodology adopted in carrying out this research is summed up in a hierarchical chart below;

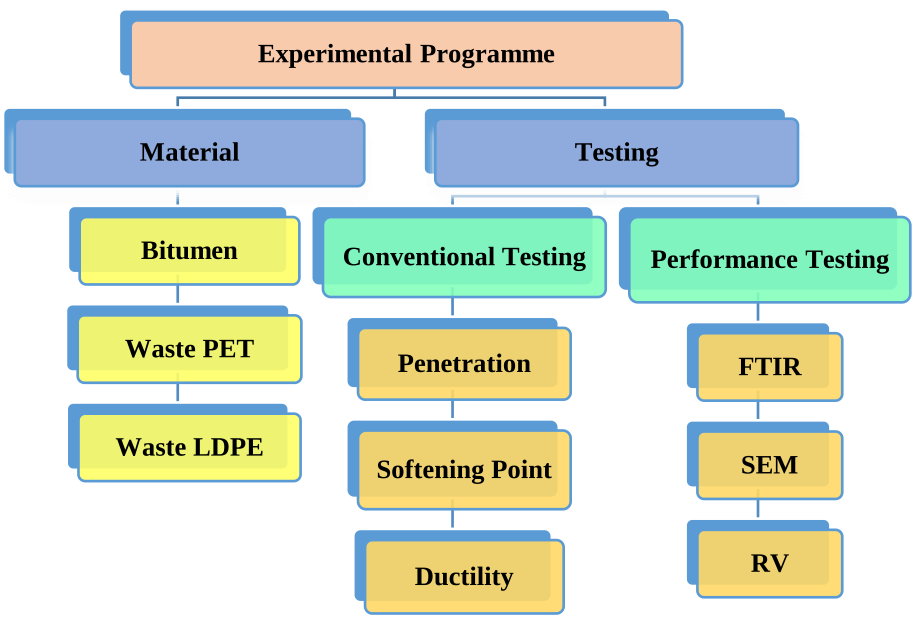

Figure 3-7: Hierarchical chart of Experimental Work

Table 3-4: Test Matrix

Type of Sample	R-PET content (% of bitumen)	R-LDPE content (% of bitumen)	No. of Samples						
			Penetration Test	Softening Point Test	Ductility Test	SEM	FTIR	RVT (135°C)	RVT (165°C)
Virgin Asphalt binder (ARL) (60/70)	-	-	3	3	3	-	-	3	3
Virgin Asphalt binder + R-PET	2	-	3	3	3	3	3	3	3
	4	-	3	3	3			3	3
	6	-	3	3	3			3	3
	8	-	3	3	3			3	3
Virgin Asphalt binder + R-LDPE	-	2	3	3	3	3	3	3	3
	-	4	3	3	3			3	3
	-	6	3	3	3			3	3
	-	8	3	3	3			3	3
Total	-	-	27	27	27	6	6	27	27

3.5.1 Conventional Testing

The conventional tests performed on the unmodified and modified asphalt binder includes penetration, ductility and ring and ball tests.

3.5.1.1. Penetration

To measure the consistency of asphalt binder at 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. Penetration values are more for softer binder. According to AASHTO T49-03 temperature was maintained at 25°C, load was 100 grams, and the test time was 5 seconds. Using ARL 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 item used in penetration test.

- Penetrometer
- Digital timer
- Water bath
- Penetration cup

Figure 3-8: Penetrometer

Figure 3-9: Water Bath for temperature control

Figure 3-10: Screen for Operation & Results

Figure 3-11: Samples for Penetration Test

3.5.1.2 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 according to ASTM D36.

Figure 3-12: Ring and Ball Apparatus

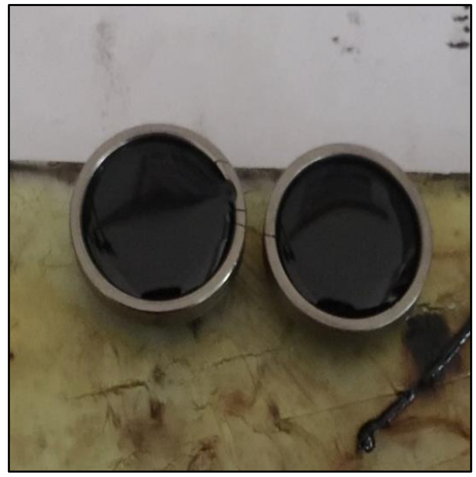

Figure 3-13: Samples for Softening Point

3.5.1.3Penetration Index

Penetration index is the quantitative measure of the asphalt binder response to the variation in temperature according to Pfeiffer and Van Doormaal [70]. 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 its deviation from Newtonian to non-Newtonian. The value of PI ranges from about -3 for highly temperature susceptible asphalt binder to +7 for low temperature susceptible asphalt binder and highly blown asphalt binder. Generally for road construction, asphalt binder have The PI value of asphalt binder between -2 to +2 is considered suitable for road construction. Asphalt binder having PI values smaller than -2 shows brittle behavior and the one with values greater than +2 shows high elastic properties when subjected to higher strains.

From 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 [70].

$$PI = \frac{1952 - 500 \log pen - 20 \text{ softening point}}{50 \log pen - \text{softening point} - 120}$$

Where:

Pen = penetration at 25°C

Table 3-5: 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 indicate 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.

3.5.1.4Ductility

Ductility depicts material's ability to withstand tensile stresses. It is basically the elongation length of the material before breaking when a standard briquette specimen with the material is pulled apart at a specific speed and temperature. It is measured in "cm" and the test was conducted as per ASTM D113-17.

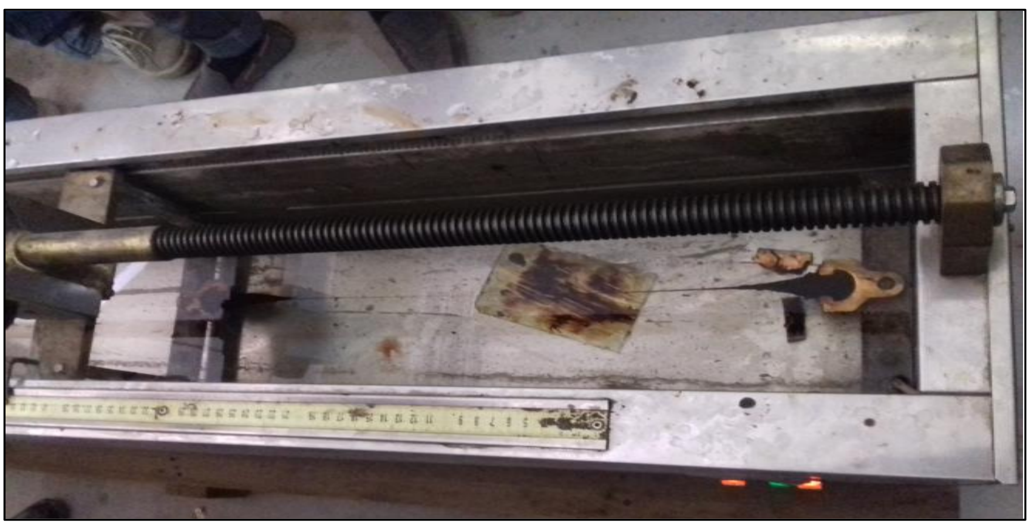

Figure 3-14: Ductilometer

Figure 3-15: Ductility test sample

3.5.1.5 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 asphalt binder to that property of unaged asphalt binder. Physical aging index used in this research work includes penetration aging ratio (PAR), softening point increment (SPI) and ductility retained ratio (DRR). These index are calculated by formulas given below:

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

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

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

3.5.2. Performance Testing

For the determination of dynamic viscosity, rotational viscometer was used. Morphological analysis of aged and unaged modified binder samples was done using Scanning Electron Microscopy, whereas to study the structural modification of the samples and to determine the influence of aging on modified asphalt binder samples Fourier Transform Infrared Spectroscopy was used.

3.5.2.1Rotational 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 Superpave performance grade bitumen description is always carried out at 135°C and 160°C.

Figure 3-16: Rotational Viscometer

Figure 3-17: Spindles Assembly

Rotational viscometer was used to find viscosity of bitumen according to AASHTO T 316. First the chamber of sample, the spindle, and environmental chamber (Thermosel) of viscometer were heated to 135°C and 160°C. Then heated the bitumen till it converted to liquid form for pouring purpose. Stirred the sample carefully to avoid formation of air bubbles due to entrapped air. Poured the sample of bitumen in the sample chamber. Inserted the chamber with sample into temperature controller unit of rotational viscometer and lowered the spindle carefully in sample. The sample was heated in temperature controller unit to test temperature of 135°C and 160°C and permit the sample to achieve equilibrium at the specified test temperature for ten minutes and then the spindle was rotated for twenty revolutions per minute. Three readings were taken from the display screen with a gap of one minute after achieving test temperature and equilibrate. The average of three readings was noted as viscosity of sample.

3.5.2.2 Fourier Transform Infrared Spectroscopy

It is an analytical technique used to study the structural modification of the samples and to determine the influence of aging on modified asphalt binder. In infrared spectroscopy, IR radiations are passed through the modified asphalt binder sample. The wavelength used for this test ranges from 4000 cm^{-1} to 400cm^{-1}. Some of the infrared radiations get absorbed by the sample whereas some of them passed through (transmitted) it. The resulting spectrum shows the molecular absorption and transmission from the sample, and create a molecular finger. This makes FTIR a good tool for chemical identification.

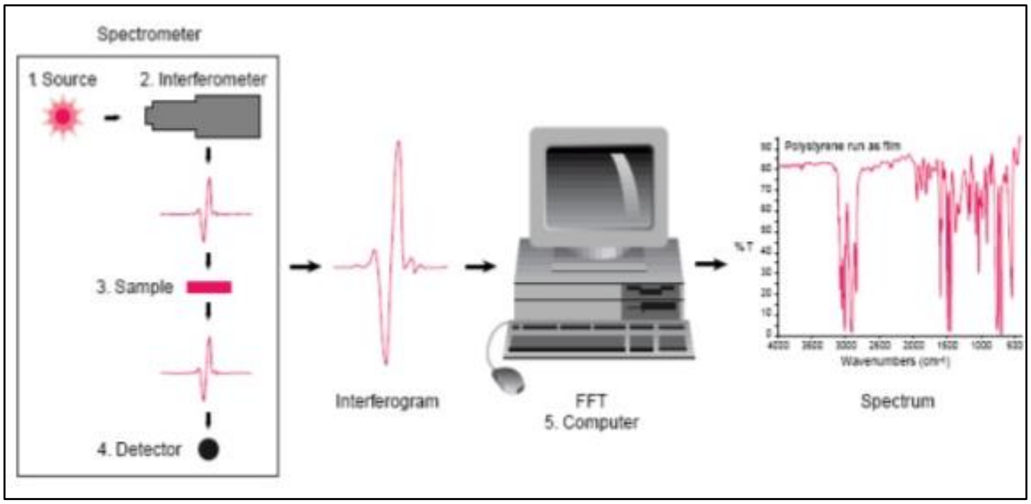

Figure 3-18: Fourier Transformed Infrared Spectroscopy Mechanism

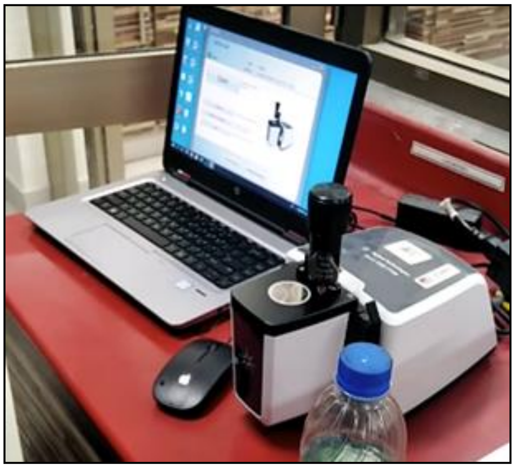

Figure 3-19: Fourier Transformed Infrared Spectroscopy

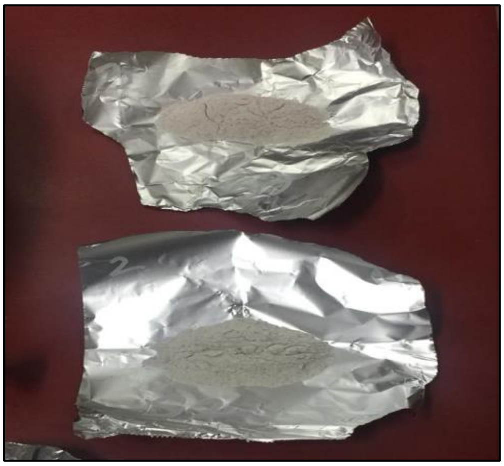

Figure 3-20: FTIR Samples

3.5.2.3 Scanning Electron Microscope

"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 Scanning Electron Microscopy (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.

Samples were prepared by putting a drop of the modified asphalt binder sample on a glass slide and then spreading it uniformly on its surface in the form of a thin layer as shown in the Figure 3-23.

Figure 3-21: Compact Coating Unit

Figure 3-22: CCU Screen

Figure 3-23: Samples for SEM Test

Figure 3-24: Prepared Samples after Sputtering

After preparing the samples, scanning electron microscope (SEM) was used to check the dispersion of modifiers in asphalt binder. 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 samples of the asphalt binder are first coated with a thin film of gold palladium. This process of placing thin film of gold palladium is called 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.

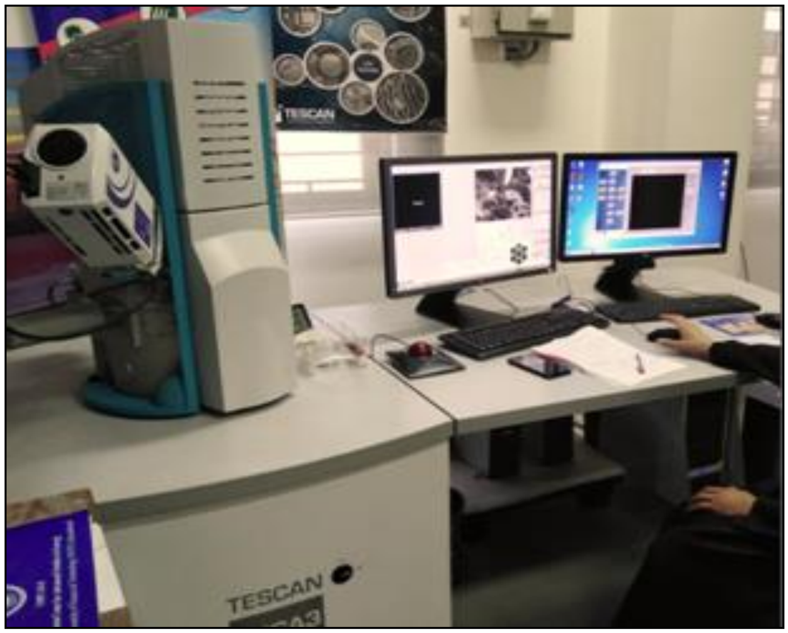

Figure 3-25: Scanning Electron Microscope

3.6 CHAPTER SUMMARY

This chapter 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 includes penetration test, softening point test and ductility 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 were then tested for their rheological, chemical and morphological properties. SEM, FTIR and RV are adopted to evaluate the changes in the properties of modified binders before and after aging.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter all of the results are displayed in the form of tables and graphs. Consistency analysis is done based on the results of penetration and softening point and penetration index (PI) is determined. 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.

4.2 PENETRATION

Penetration results for neat asphalt binder and asphalt binder modified with waste polyethylene terephthalate and waste low-density polyethylene are presented in table 4-1 and 4-2 respectively. Penetration value represents the stiffness and hardening of the asphalt binder at 25^{o}C. Lower penetration value indicates that binder has become stiff. From table 8, it can be observed that with the increase in W-PET content from 2% to 8%, the penetration value of asphalt binder decreased. This shows that the consistency of the modified asphalt binder increased whereas the fluency decreased at normal temperature.

Figure 4-1: Penetration Test of Asphalt Binder

Table 4-1: Penetration results for W-PET modified Asphalt Binder

Penetration			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	65	59	48
2%	57	48	40
4%	49	40	33
6%	41	31	26
8%	38	27	22

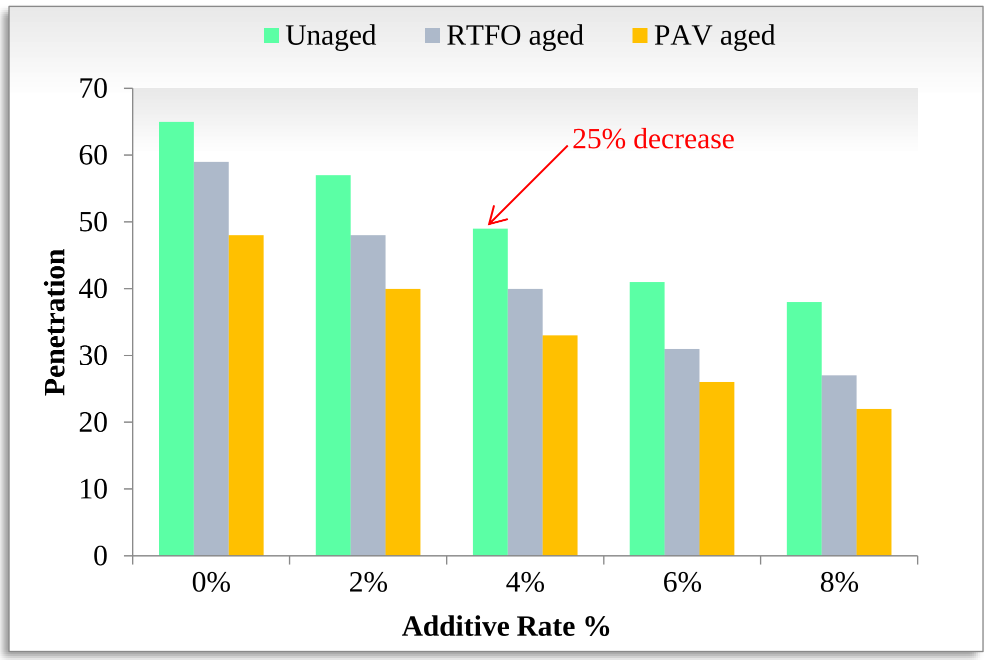

Figure 4-2: Penetration Values of W-PET Modified Bitumen

The decrease in the penetration value of 4% waste PET modified asphalt binder is 25% as compared to the unmodified asphalt binder. Figure 4-3 represents the results of PAR for unmodified and W-PET modified binder after the short term and long term aging. It can be seen that the penetration values of unmodified and modified asphalt binder decreased aging. Moreover, higher the W-PET content, lower the value of penetration aging ratio that shows reduction in the degree of aging of W-PET modified binder. Therefore waste polyethylene terephthalate addition improves the binder’s resistance to oxidative aging.

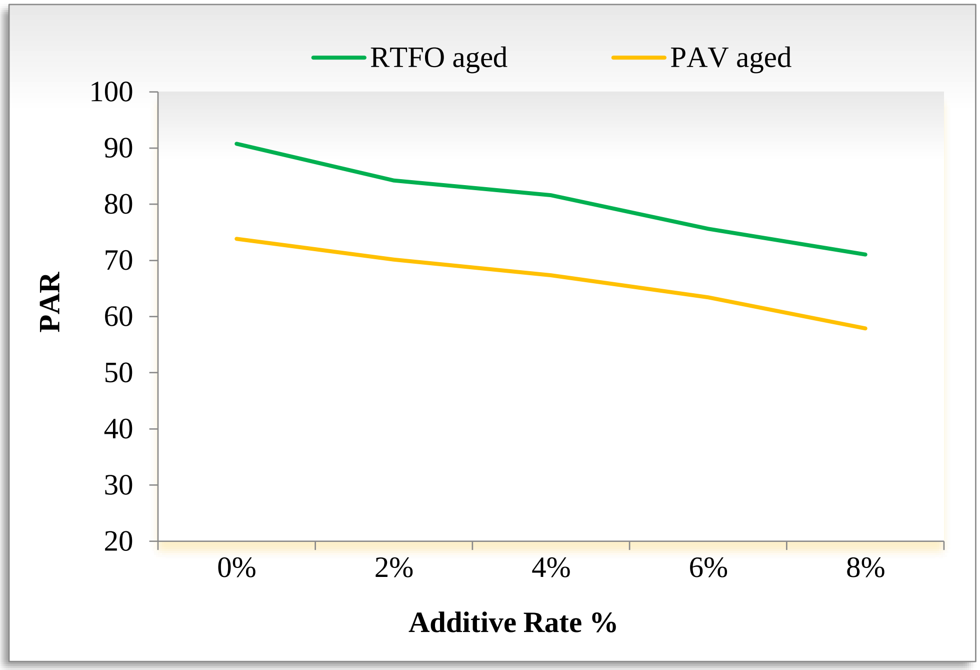

Figure 4-3: PAR Graph for W-PET Modified Asphalt Binder

By the addition of 2% to 8% waste LDPE into the base binder, the penetration value decreased. It indicates that W-LDPE addition decreases fluency and increases the consistency of the modified binder at 25ºC. The results are presented in the form of PAR graph in figure 4-5. The trend observed after aging is quite different from the unaged binder.

Table 4-2: Penetration Values for W-LDPE Modified Asphalt Binder

Penetration			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	68	62	57
2%	63	55	46
4%	54	43	37
6%	46	35	29
8%	37	24	20

The decrease in the penetration value of 4% waste LDPE modified asphalt binder is 21% as compared to the unmodified asphalt binder. The value decreased from 68 to 54 and is further decreasing till 37 for 8% addition of modifier.

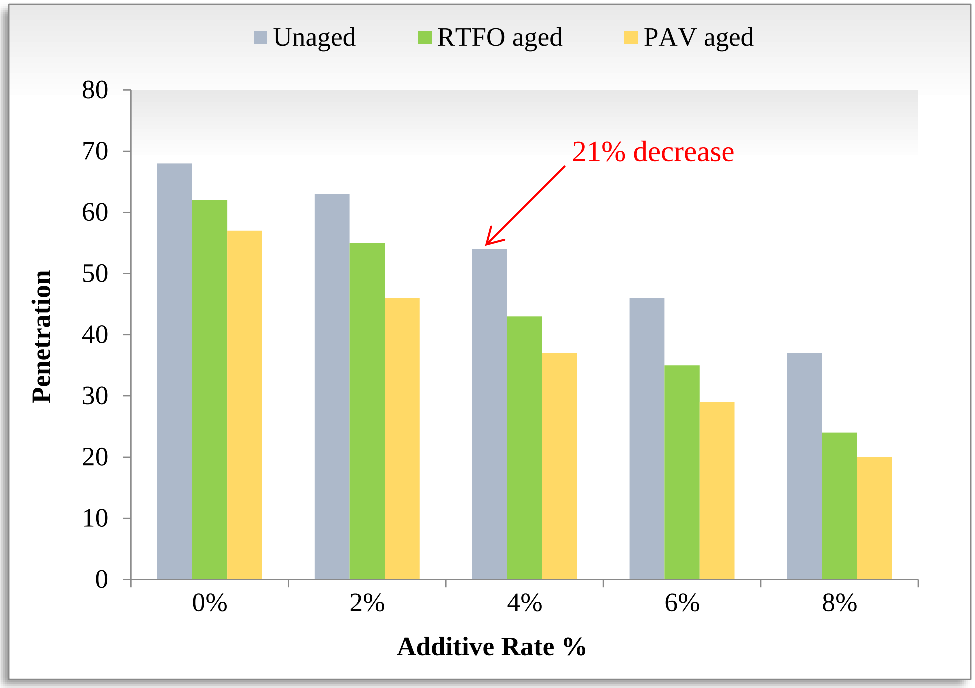

Figure 4-4: Penetration values of W-LDPE modified bitumen

PAR of the W-LDPE modified binder as shown in figure 4-5 reduced significantly which indicates that the modified binder is more resistant to aging susceptibility than the virgin asphalt binder.

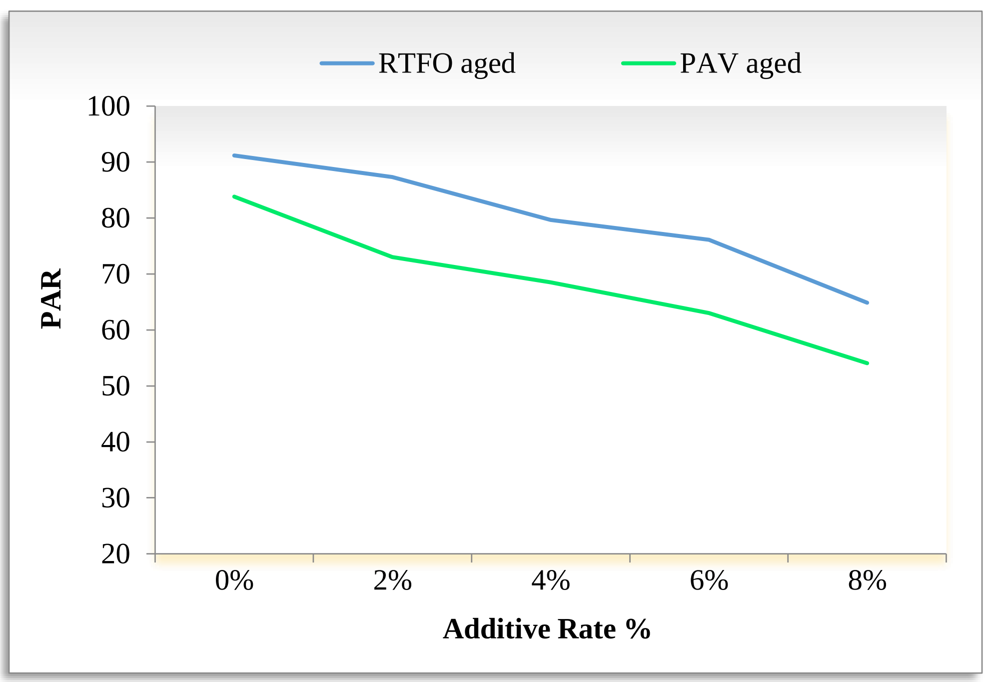

Figure 4-5: PAR Graph for W-LDPE Modified Asphalt Binder

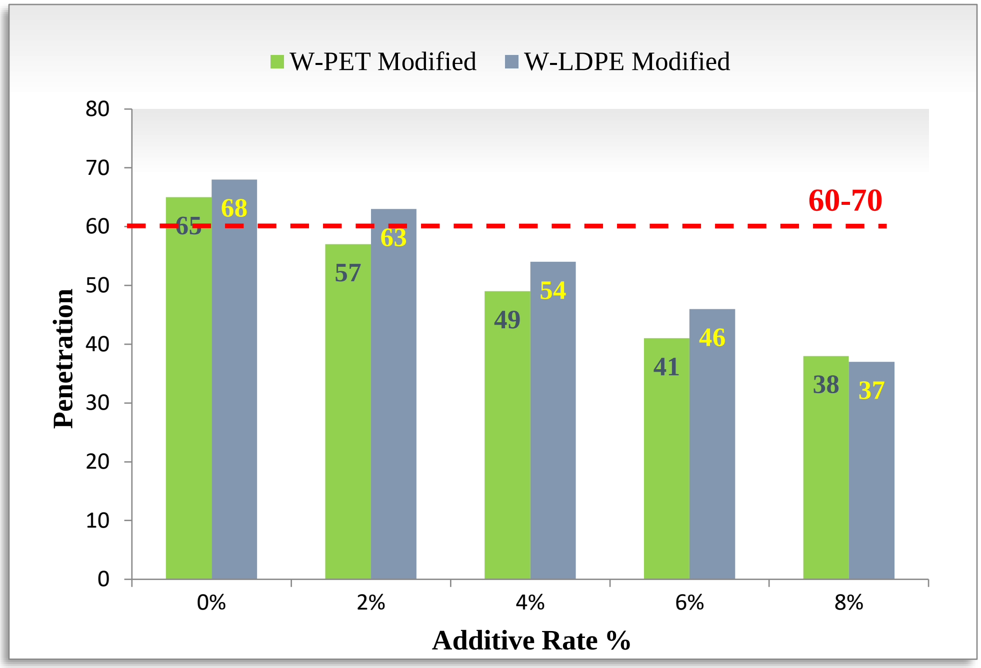

Figure 4-6: Comparison of Penetration Results of Waste Polymer Modified Asphalt Binders

The penetration results for neat asphalt binder and asphalt binder modified with waste polyethylene terephthalate and waste low-density polyethylene are presented in the figure 4-6.

4.3 SOFTENING POINT

Softening point test is generally used to describe an approximate limit between viscous and visco-elastic behavior of asphalt binder, and it represents the degree of resistance of asphalt binder against permanent deformation. By adding 2% to 8% of waste polyethylene terephthalate into the base binder, softening point of the modified asphalt binder increased. This shows that with the increase in the modifier content (even after aging) the high temperature stability is improved. The results can be seen in the form of softening point increment in figure 4.7 and 4.9 respectively.

It can be concluded that with the addition of W-PET, the asphalt binder got more stable against flowing when subjected to high temperatures, which means that the W-PET modified asphalt binder has a better high temperature rutting resistance.

Table 4-3: Softening Point Results for W-PET Modified Asphalt Binder

Softening Point			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	48	50	51
2%	49	51	53
4%	50	52	53
6%	53	54	56
8%	55	57	59

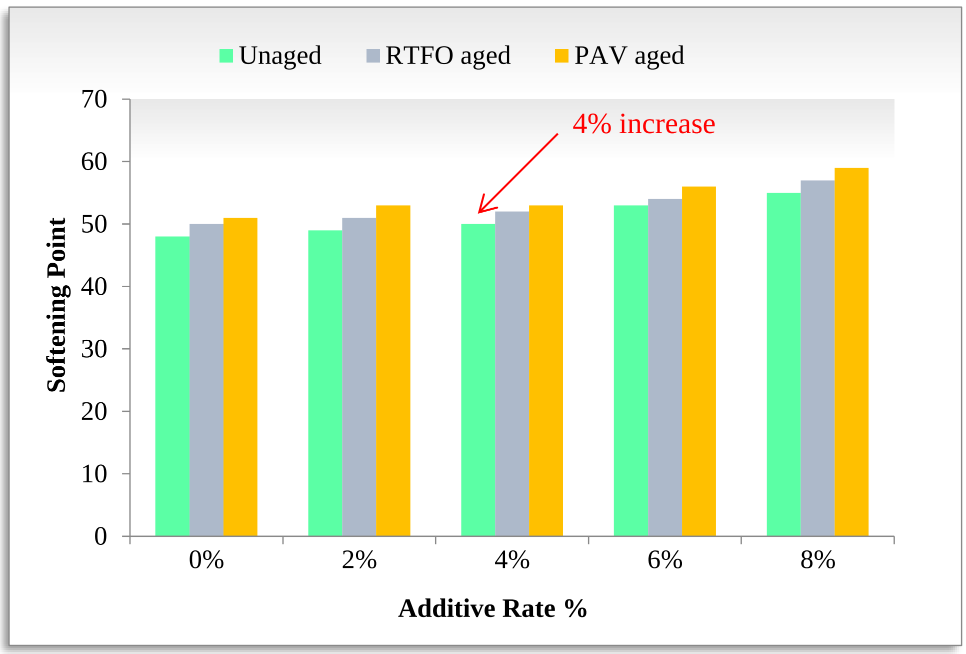

Figure 4-7: Softening Point of W-PET Modified Asphalt Binder

Similar trends are obtained for the softening point temperature of W-LDPE modified asphalt as that of softening point temperature of W-PET modified binder. 4% addition of W-PET resulted in 4% increase in the softening point. The value increased from 48 to 50 and is further increasing till 55 for 8% addition of modifier. It can be concluded that the increase in the modifier content improves the high temperature stability of the modified binder.

Figure 4-8: Softening Point Test of Asphalt Binder

Table 4-4: Softening Point Result for W-LDPE Modified Asphalt Binder

Softening Point			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	48	49	51
2%	50	52	54
4%	53	56	58
6%	57	59	62
8%	60	62	65

The softening point increment in figure 4-7 and 4-9 shows the impact of aging on the virgin binder and modified binder as well. The increase in the softening point value of 4% waste LDPE modified asphalt binder is 8% as compared to the unmodified asphalt binder. The value increased from 48 to 53 and is further increasing till 60 for 8% addition of modifier. It is generally concluded that the addition of W-LDPE made the asphalt binder more stable against flowing when subjected to high temperatures. which means that the W-LDPE modified binder has a better high temperature rutting resistance. That is why higher softening point asphalt cement is preferred in hot regions.

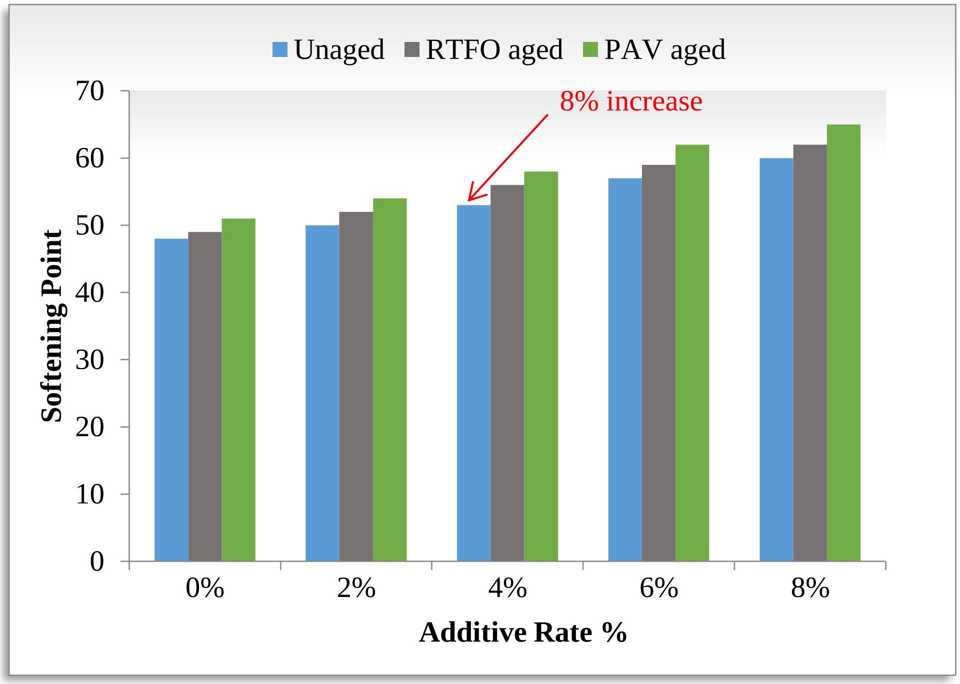

Figure 4-9: Softening Point Result of W-LDPE Modified Asphalt Binder

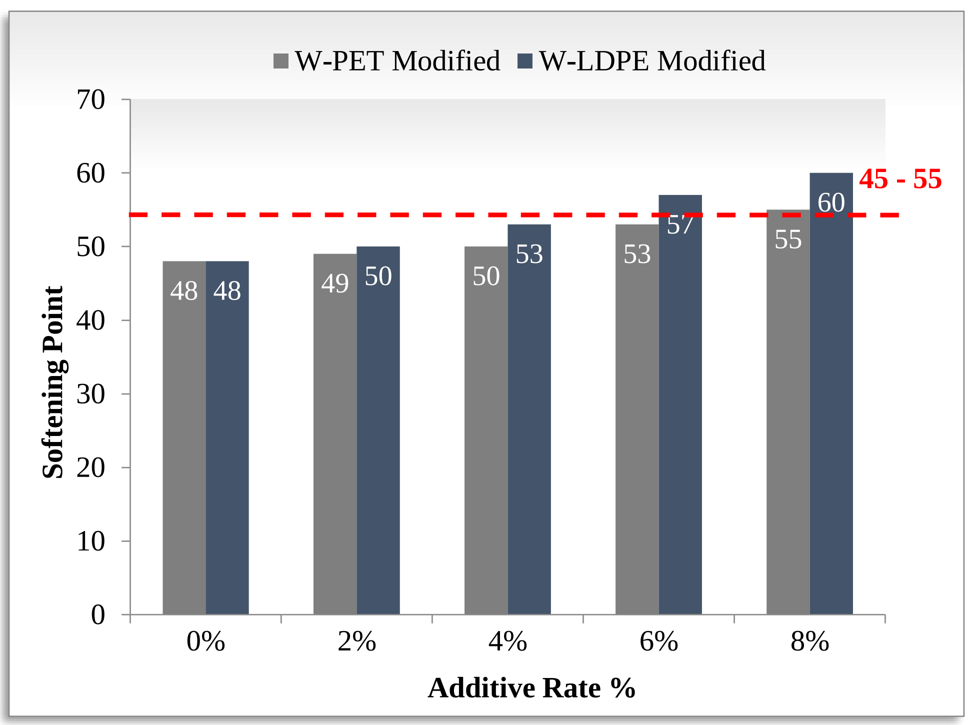

Figure 4-10: Comparison of Softening Point Results of Waste Polymer Modified Asphalt Binder

4.4 PENETRATION INDEX

It is generally known that a high value of PI indicate 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 this research comes within the normal range of -2 to +2 for road paving application and can be seen in figure 4-11. 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 W-PET and W-LDPE the PI value increased which indicates the lower temperature susceptibility of the modified binders. With the increasing percentages of W-PET and W-LDPE i.e. 2%, 4%, 6% and 8%, 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 [71].

At 4% addition of W-PET into base asphalt binder, PI increased by 10% with respect to base binder and the addition of 4% W-LDPE by weight of asphalt binder resulted in 13% increase in the penetration index. This increase in the PI will result in better resistance against thermal cracking at low temperatures, and at high temperatures it results in lower permanent (plastic) deformation.

Table 4-5: Penetration Index for Polyethylene Terephthalate

Penetration Index			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	-1.23	-0.95	-0.65
2%	-1.11	-0.49	-0.45
4%	-1.03	-0.16	-0.08
6%	-0.78	0.00	0.18
8%	-0.35	-0.19	-0.01

Table 4-6: Penetration Index for Low-Density Polyethylene

Penetration Index			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	-1.17	-0.82	-1.05
2%	-1.01	-1.05	-0.98
4%	-0.95	-1.21	-1.37
6%	-0.62	-1.27	-1.18
8%	-0.21	-0.91	-0.90

Moreover, when we compare the PI results of waste polyethylene terephthalate (W-PET) and waste low-density polyethylene (W-LDPE) as shown in figure 4-11, W-LDPE modified binder showed higher values of PI which means higher resistance to thermal susceptibility, lower brittleness and better elastic properties under higher strains.

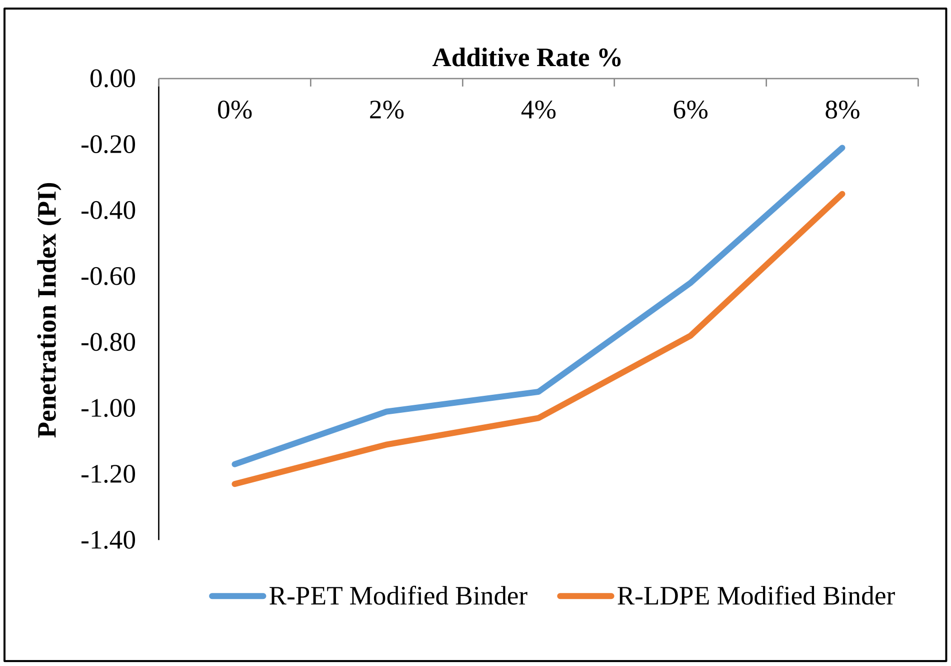

Figure 4-11: Comparison of Penetration Index of W-PET and W-LDPE

4.5 DUCTILITY

Table 4-7 and 4-8 shows the ductility test results of W-PET and W-LDPE modified asphalt binder respectively. Decrease in ductility was observed in case of Polyethylene modified asphalt binder. At 4% addition of W-PET the ductility value reduced from 108 to 87 causing a decrease of 20% with respect to the base binder. This reduction in ductility indicate the stiffening effect of asphalt binder after the addition of W-PET. While for 4% W-LDPE modified binder, the reduction in ductility was 19%. The results after aging showed a constant decrease in the ductility indicating that aging makes the binder stiffer.

Table 4-7: Ductility values for W-PET modified binder

Ductility			
Additive rate %	**Unaged**	**RTFO aged**	**PAV aged**
0%	108	100	88
2%	92	87	79
4%	87	83	77
6%	72	69	65
8%	68	65	62

Table 4-8: Ductility values for W-LDPE Modified Binder

Ductility			
Additive rate	**Unaged**	**RTFO aged**	**PAV aged**
0%	105	94	85
2%	95	87	79
4%	85	79	73
6%	71	67	63
8%	60	57	54

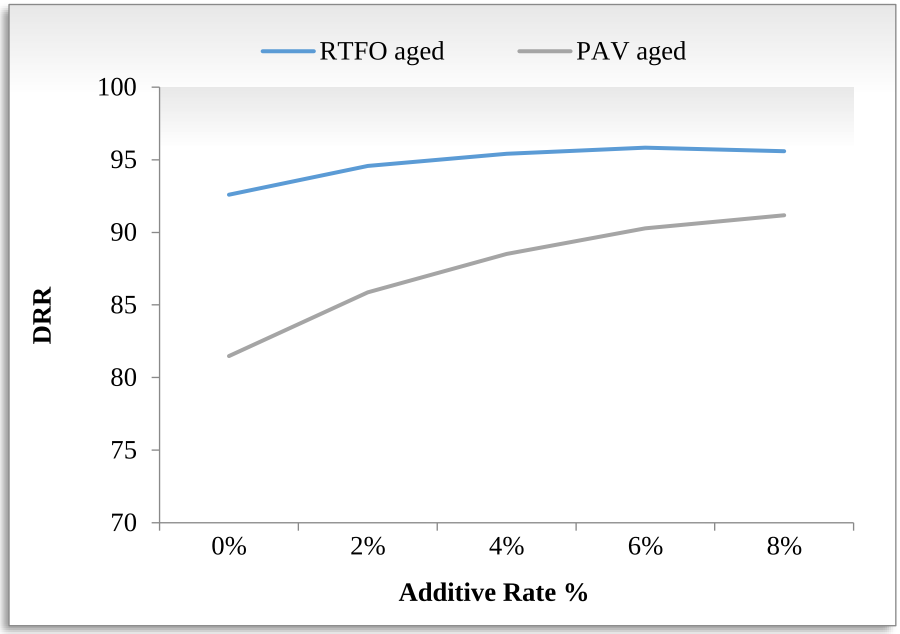

Figure 4-12: Variation in Ductility Retained Ratio for W-PET Modified Binder

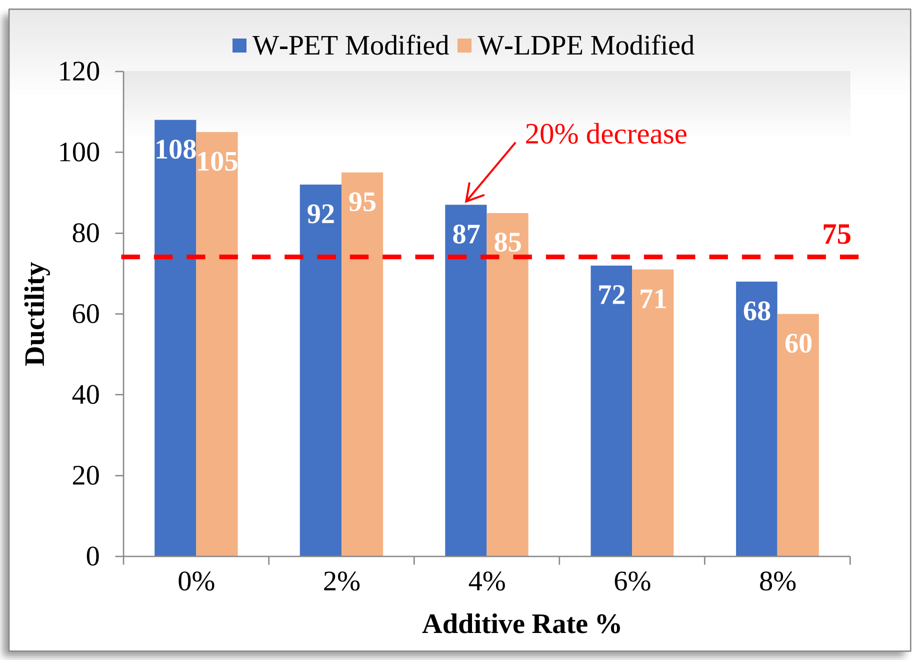

Figure 4-13: Comparison of Ductility Values for Waste Polymer Modified Asphalt Binder

The ductility value decreases as the percentage of modifier increases whereas the DRR is increasing. This represents that the addition of W-PET and W-LDPE can improve the issues related to ductility after aging.

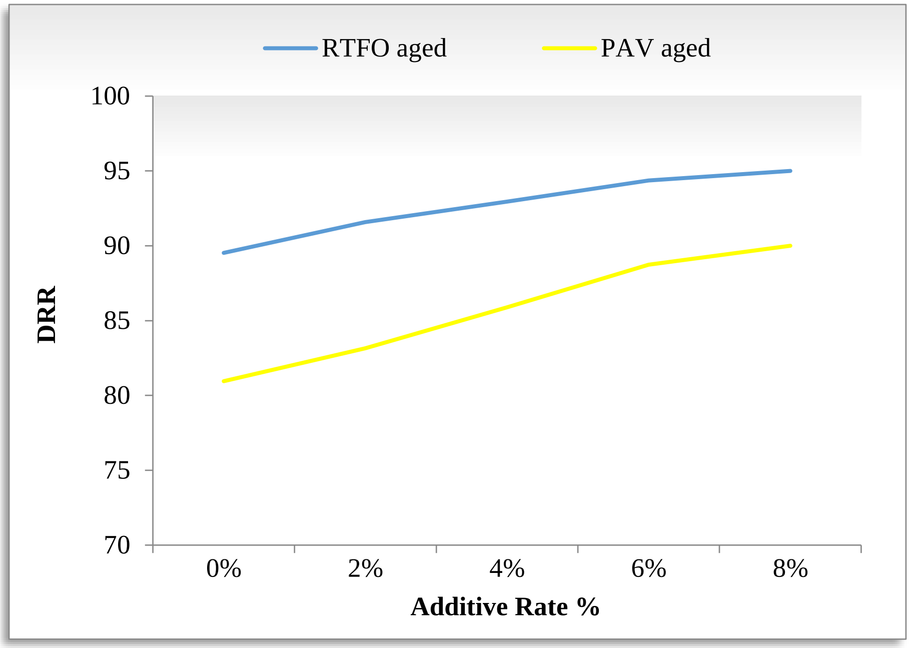

Figure 4-14: Ductility Retained Ratio of W-LDPE Modified Binder

4.6 FOURIER TRANSFORM INFRARED SPECTROSCOPY

Figure 4-15 and 4-17 shows the IR spectra of virgin asphalt binder and asphalt binder modified with Waste PET and Waste LDPE. While looking at the IR spectra of virgin asphalt binder, strong peaks at 2915 cm^{-1} to 2845 cm^{-1} can be seen, which corresponds to the C-H stretching vibrations. The peak at 1594 cm^{-1} refers to C=C aromatic stretching. Peaks around 1720-1750 cm^{-1} shows the C=O carbonyl functional group. Peaks at 1456 cm^{-1} represents the C-H bending of alkane group, whereas at 1373 cm^{-1} represents the C-O stretching respectively. The region between 1030-1070 cm^{-1} represents the S=O stretching of sulfoxide group. Peaks at 863 cm^{-1} and 807 cm^{-1} refers to C=C bending of alkene group whereas peak at 744 cm^{-1} shows C-S or C-H bending.

Almost no or very little change in peaks can be seen when we compare the IR spectra of waste PET and waste LDPE modified asphalt binder. Only change that can be observed is in the intensity of peaks. The range of functional groups is almost same as well. This shows that the modification of asphalt binder with waste PET and waste LDPE is purely physical. No change in the chemical composition is observed.

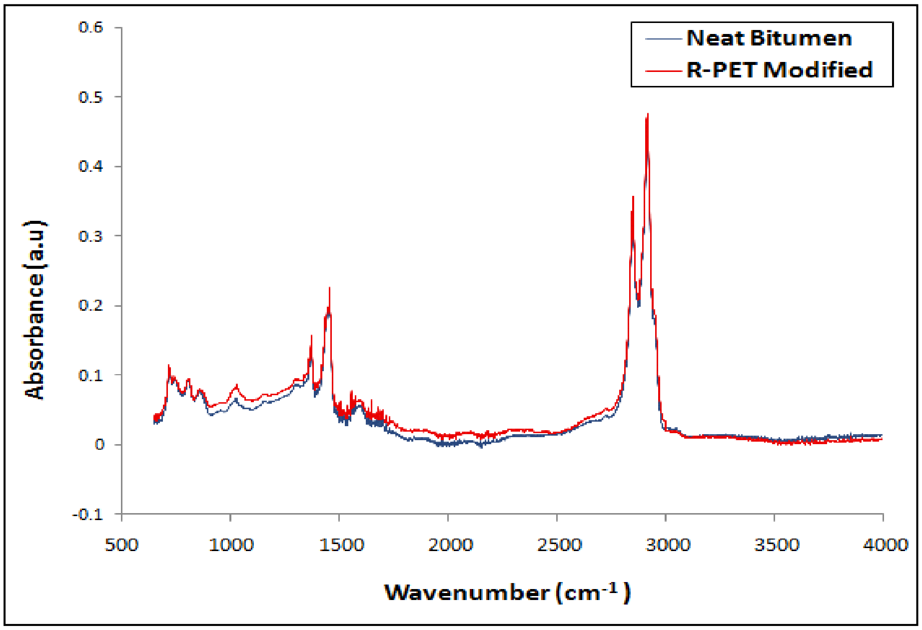

Figure 4-15: IR Spectra of Neat and W-PET Modified Asphalt Binder

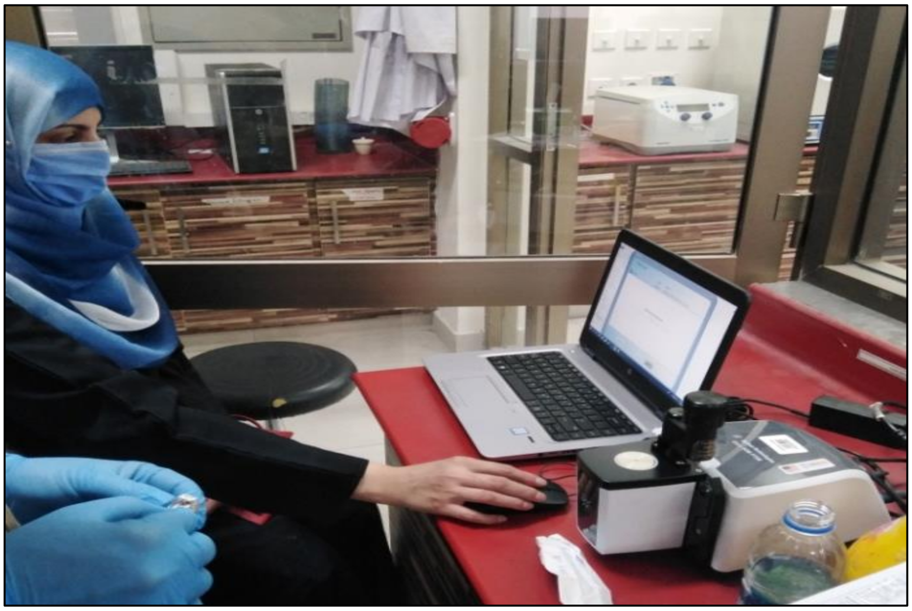

Figure 4-16: Fixing of Sample in FTIR Machine

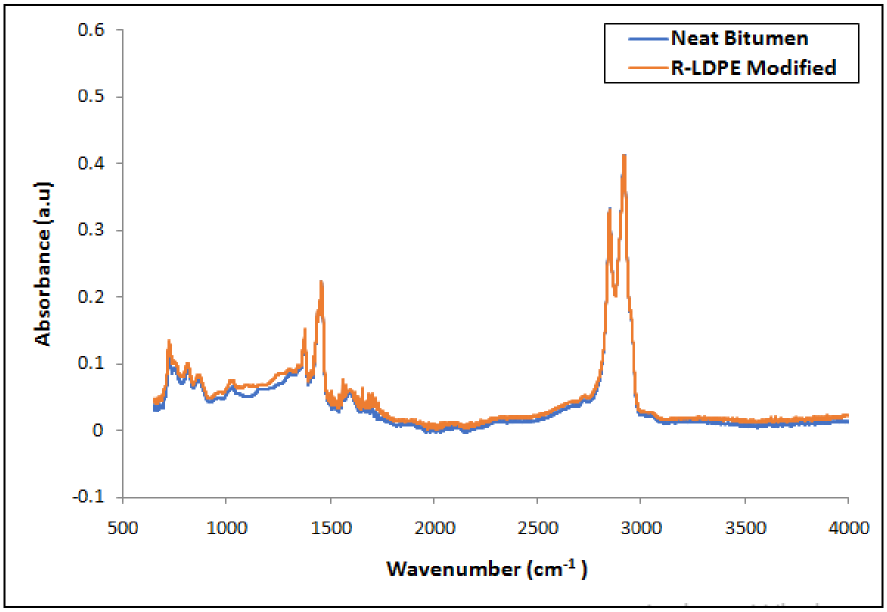

Figure 4-17: IR Spectra of Neat and W-LDPE Modified Asphalt Binder

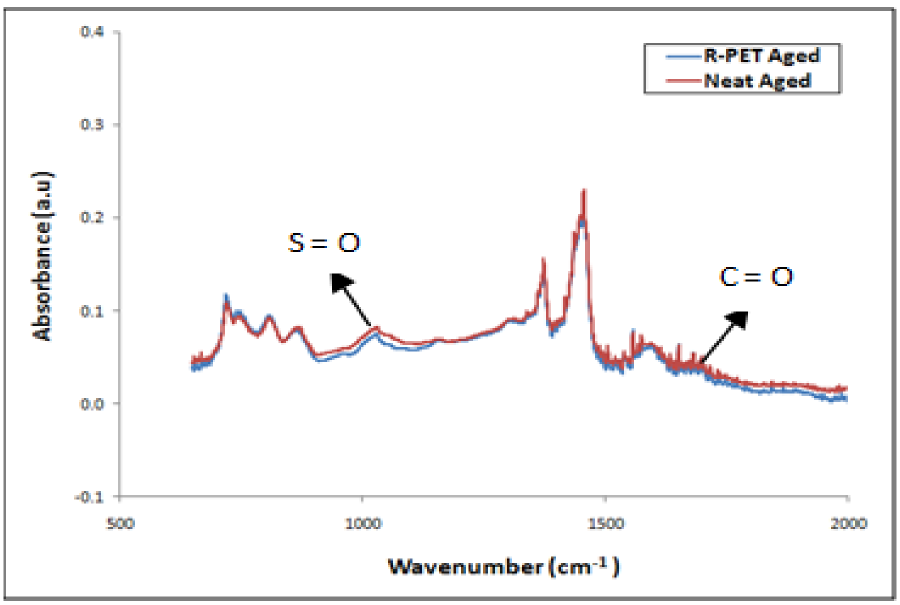

Figure 4-18: IR Spectra of Neat and W-PET Modified Asphalt Binder after Aging

Now when we compare the spectrum of neat and modified asphalt binder after aging, we can clearly see that the addition of PET and LDPE hinders the oxidation rate which can be seen as the reduction in carbonyl and sulfoxide areas of two modified binders with respect to original binders in figure 4-18. The two functional groups i.e. S=O and C=O are responsible for asphalt binder hardening. From the results obtained in the FTIR spectroscopy of modified binders it is concluded that the polyethylene terephthalate and low-density polyethylene are good additives to improve the anti-aging properties of asphalt binder.

The following formulas can be used for computing the carbonyl and sulfoxide indices [72].

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

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

Structural index after the RTFO aging are presented in table 4-9 and figure 4-20. Both of the indices decreased after waste polymer modification as compared to the neat binder. Carbonyl index decreased by 15% in case of 4% W-PET modification whereas it decreased by 19% by adding 4% W-LDPE. Similarly, sulfoxide index decreased by 33% and 39% in case of W-PET and W-LDPE respectively. This decrease in indices indicates the better resistance to oxidation of the modified binders.

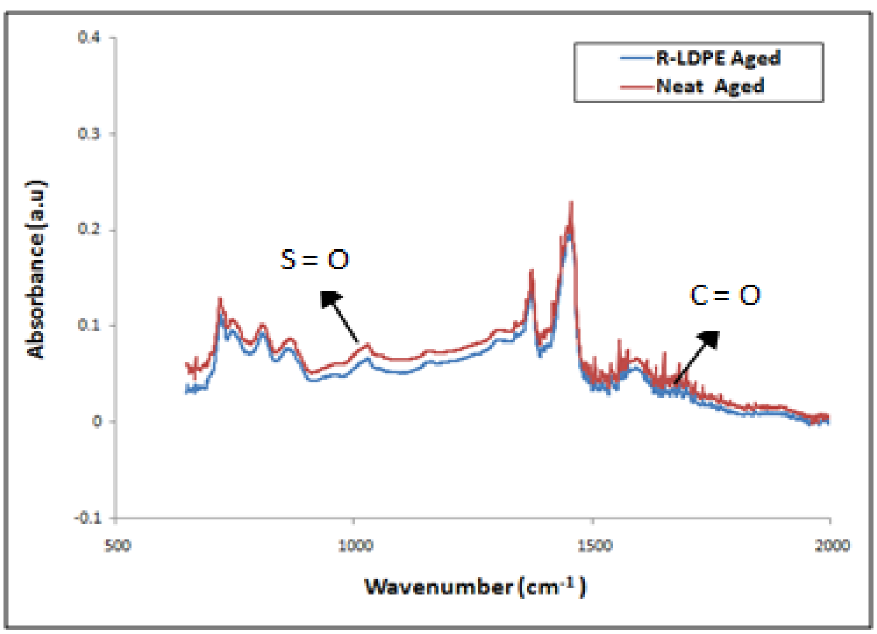

Figure 4-19: IR Spectra of Neat and W-LDPE Modified Asphalt Binder after Aging

Table 4-9: Structural Index after RTFO Aging

Structural Index		
Sample	**Carbonyl Index**	**Sulfoxide Index**
Virgin 60/70	0.052	0.056
Virgin + 4% PET	0.044	0.038
Virgin + 4% LDPE	0.042	0.034

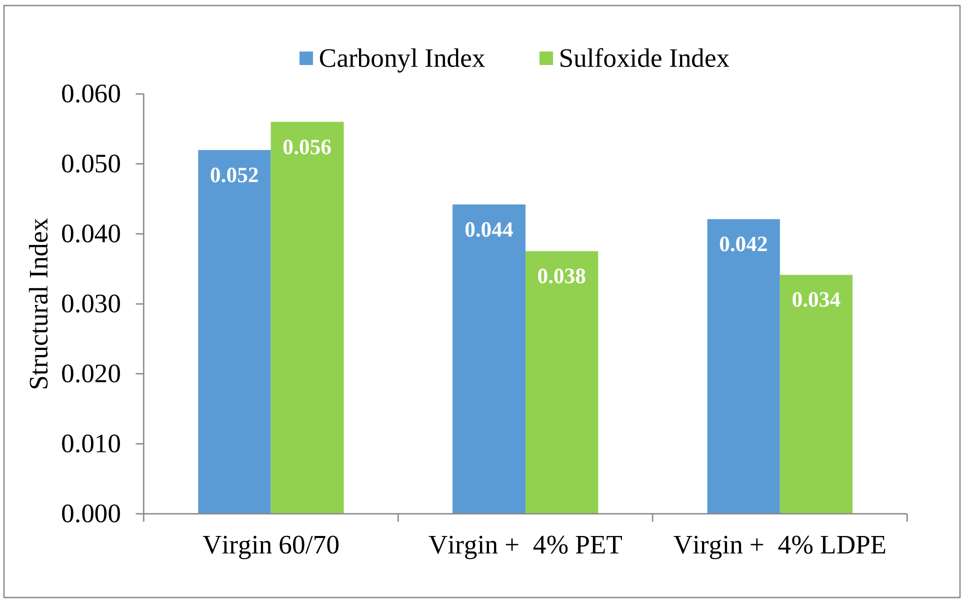

Figure 4-20: Structural Index of Neat and Modified Binders after Aging

4.7 SCANNING ELECTRON MICROSCOPY

SEM was performed to check the changes in chemical structure and homogenous dispersion of modifiers in asphalt binder. As polyethylene is a non-polar polymer, its dispersion in asphalt binder is purely physical in nature. The color of the asphalt binder is black whereas the white patches indicates the presence of modifiers i.e. W-PET and W-LDPE. it is clear from the SEM images in figure 4-21, that with the increase in percentages of added polyethylene terephthalate and low-density polyethylene, the white area is increasing

Figure 4-21 shows the SEM images of the waste modified binders at different resolutions. The roughness of the surface of W-LDPE modified bitumen was more as compared to W-PET modified binder and kept increasing with the increase in percentage of W-LDPE in bitumen from 2 to 8%. Tiny particles of the modifiers can be seen in SEM images. No phase separation can be seen and homogeneous dispersion of the modifier shows good compatibility of the modifiers with base binder.

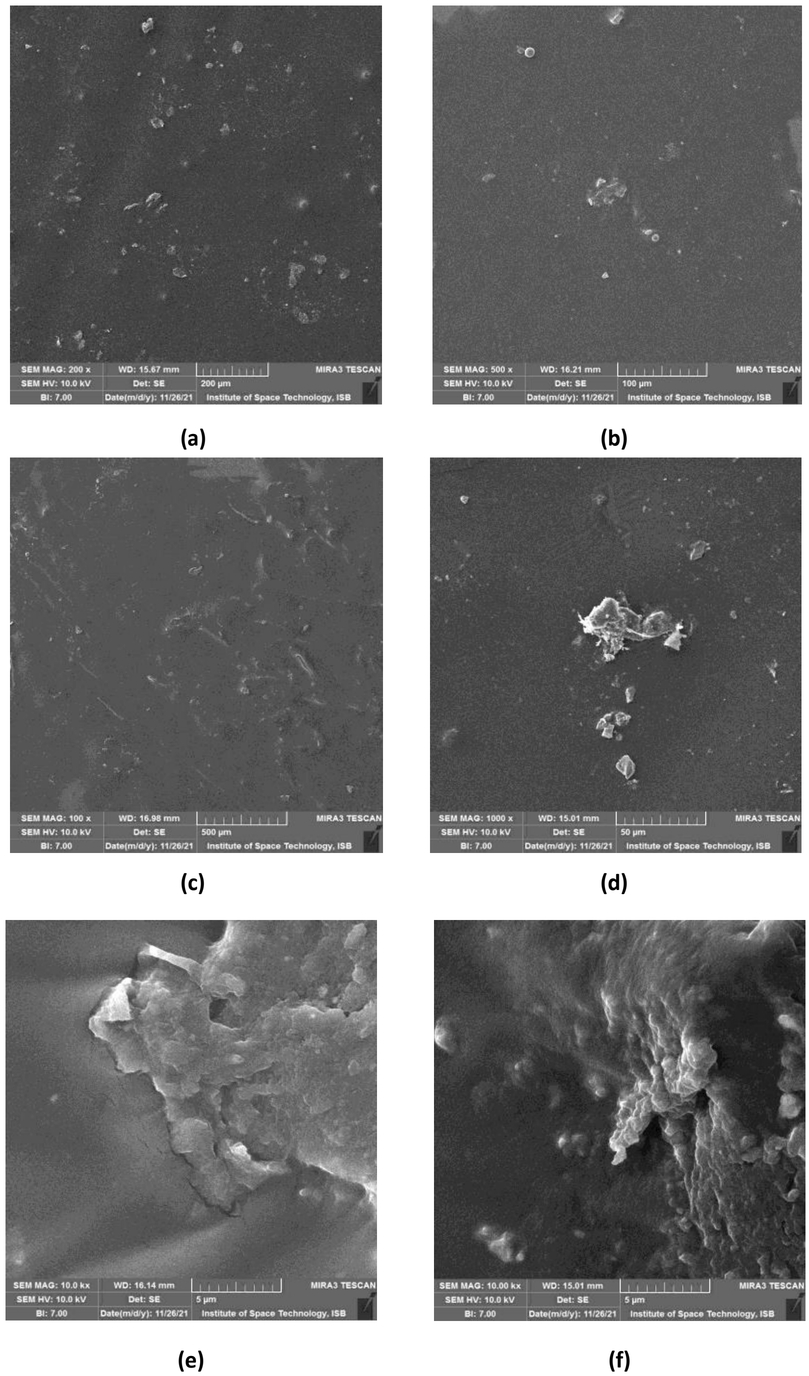

Figure 4-21: SEM images (a) 4% PET unaged, (b) 4% PET aged, (c) 4% LDPE unaged, (d) 4% LDPE aged, (e) 4% PET 5µm, (f) 4% LDPE aged 5µm

The figure 4-21 shows that the particle size of W-PET was smaller than W-LDPE and during blending the particles of both wastes were in liquid form and stick together. In SEM images of 2%, 4%, 6% and 8% waste polymers by weight of asphalt binder, the W-PET and W-LDPE additives were able to be found. According to [73], most of the small polymers that are compatible with some part of neat asphalt binder are easily swollen by them if the additive rate of polymer is less than 5% by weight in the modified asphalt binder.

4.8 ROTATIONAL VISCOSITY

The rotational viscosity (RV) test was conducted to analyze the viscous behavior of asphalt binder at different temperatures. Figure 4-22 and figure 4-23 shows the viscosity results at temperature settings of 135ºC and 165°C at 20rpm, of unmodified and modified asphalt binders before and after aging,.

Table 4-10: Viscosity Values for W-PET Modified Asphalt Binder

Viscosity Pa-s						
Additive Rate	**Unaged (135ºC)**	**Unaged (165ºC)**	**RTFO aged (135ºC)**	**RTFO aged (165ºC)**	**PAV aged (135ºC)**	**PAV aged (165ºC)**
0%	0.41	0.19	0.70	0.25	0.82	0.30
2%	0.53	0.25	0.86	0.30	1.01	0.36
4%	0.96	0.30	1.38	0.34	1.54	0.40
6%	1.26	0.37	1.79	0.41	1.95	0.45
8%	1.78	0.47	2.16	0.49	2.41	0.53

The viscosity of waste modified asphalt binders increased with the increment in the modifier content. This is due to the presence of polymer network, that increases the exerted shear stress, and provide stiffening effect to the binders. According to the Superpave design method the binder viscosity should not be more than 3 Pa.s at 135 ºC. However, In this research all viscosity values are less than 3 Pa.s.

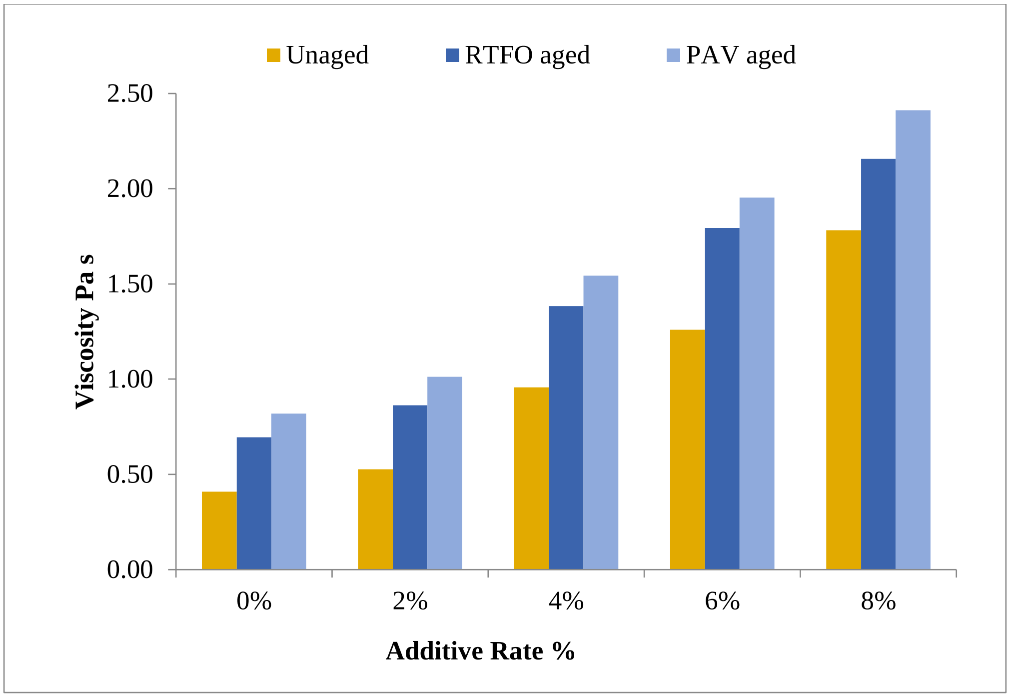

Figure 4-22: Rotational Viscosity Values for W-PET Modified Binder at 135ºC

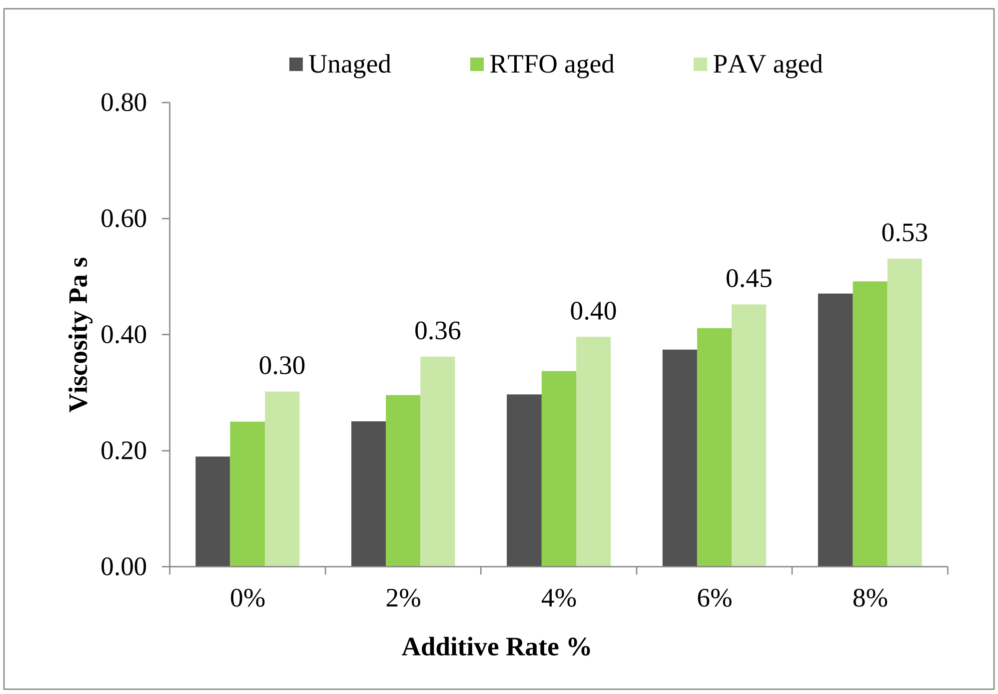

Figure 4-23: Rotational Viscosity Values for W-PET modified Binder at 165ºC

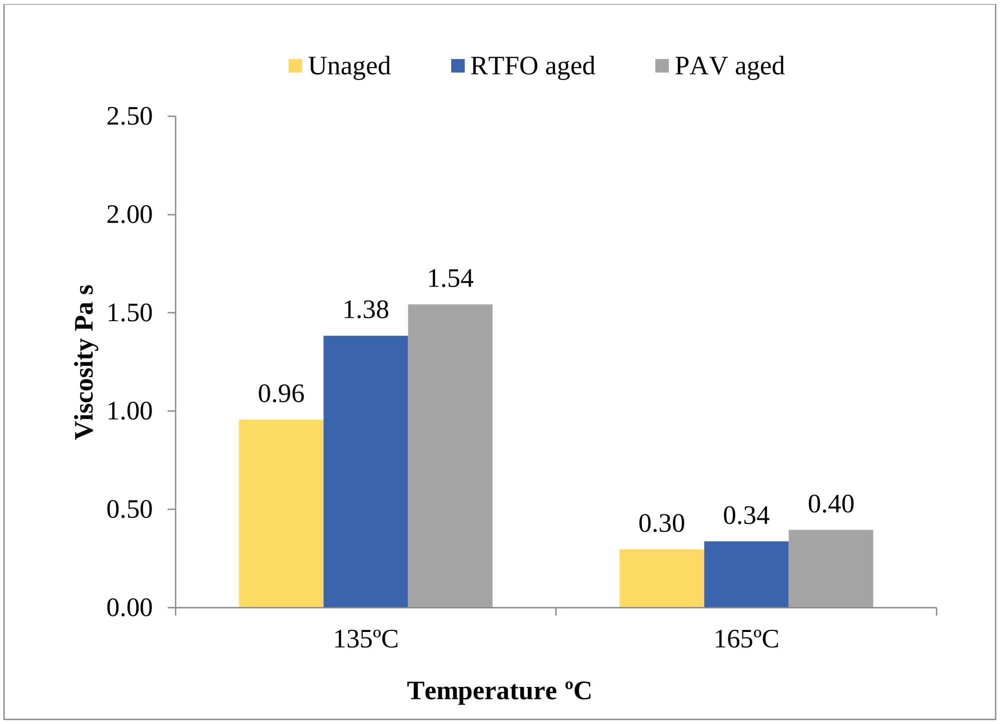

Figure 4-24: Rotational Viscosity Values for 4% W-PET modified Binder

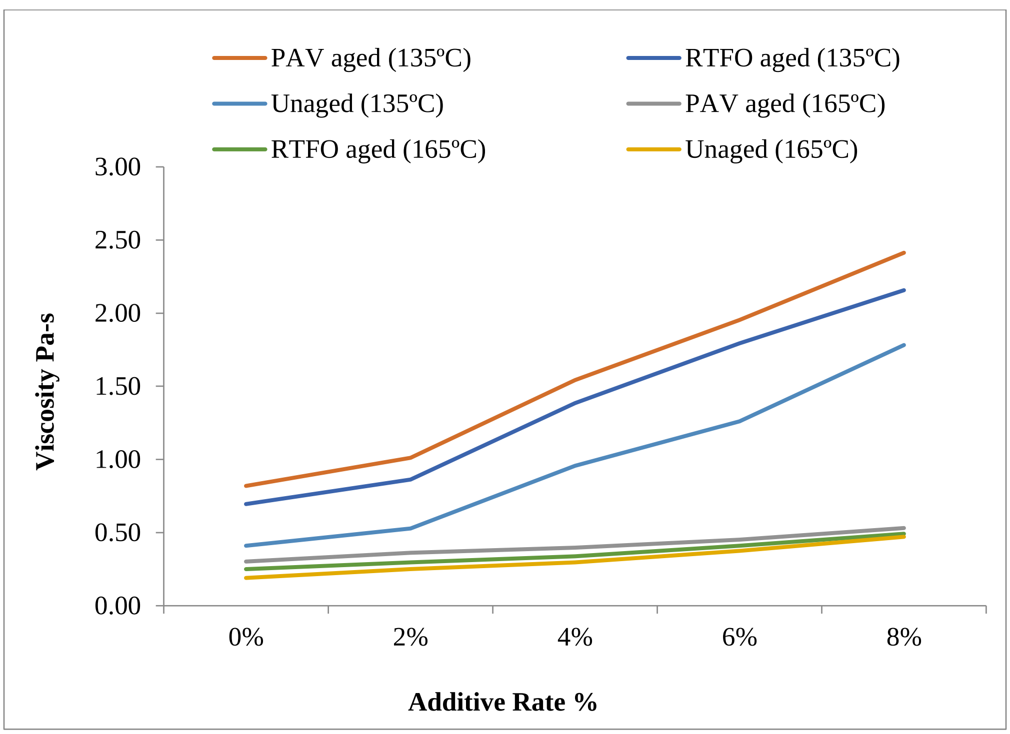

Figure 4-25: Rotational Viscosity Values for W-PET Modified Binder

Table 4-11: Viscosity Values for W-LDPE Modified Asphalt Binder

Viscosity Pa-s						
Additive Rate	**Unaged (135°C)**	**Unaged (165°C)**	**RTFO aged (135°C)**	**RTFO aged (165°C)**	**PAV aged (135°C)**	**PAV aged (165°C)**
0%	0.35	0.17	0.67	0.24	0.87	0.28
2%	0.51	0.21	0.88	0.26	1.10	0.32
4%	0.98	0.27	1.40	0.32	1.64	0.37
6%	1.46	0.36	1.91	0.41	2.05	0.46
8%	1.82	0.48	2.25	0.52	2.51	0.54

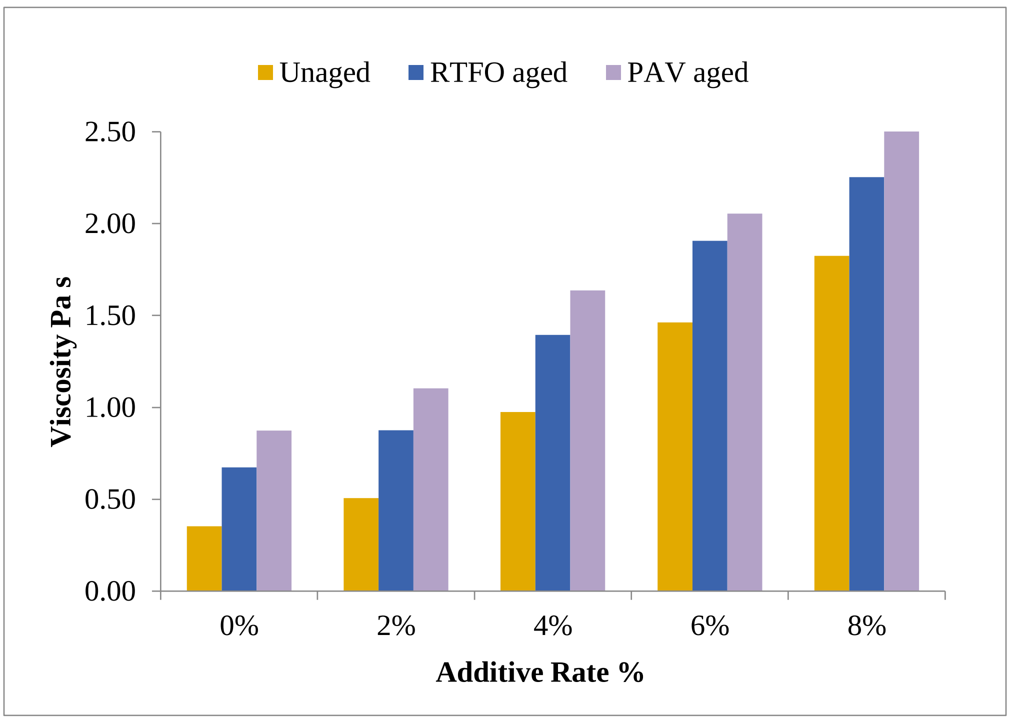

Figure 4-26: Rotational Viscosity Values for W-LDPE modified Binder at 135ºC

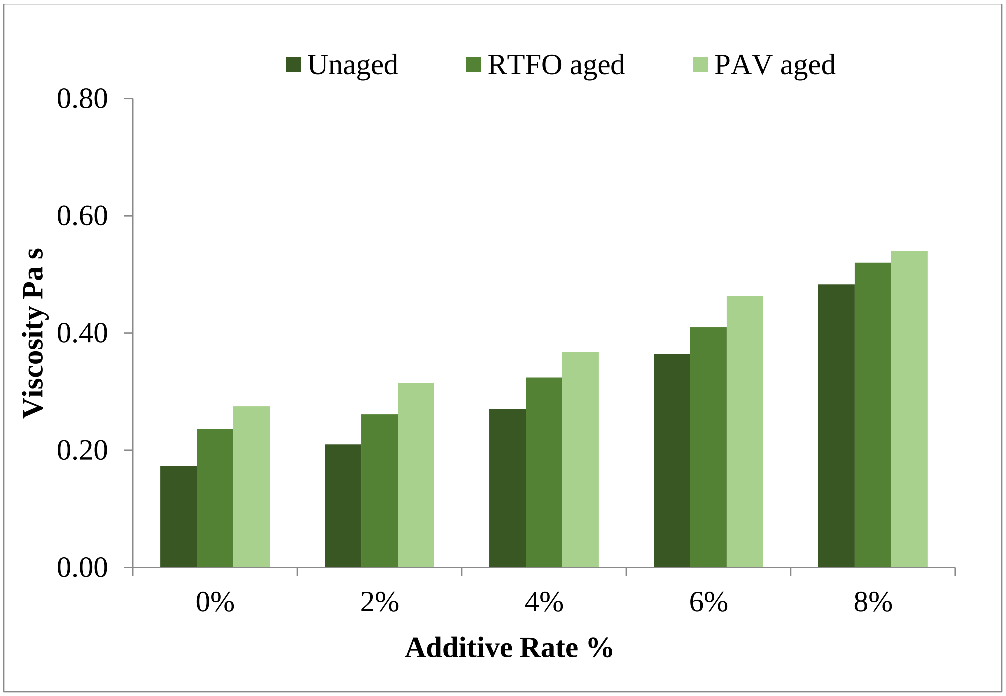

Figure 4-27: Rotational Viscosity Values for W-LDPE modified Binder at 165ºC

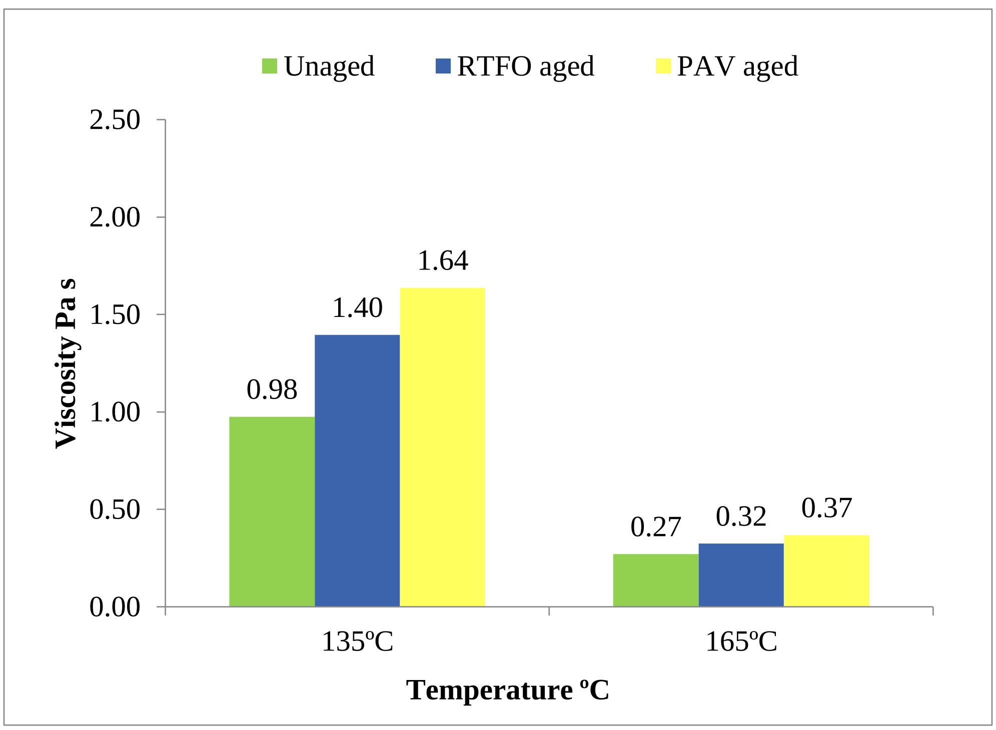

Figure 4-28: Rotational Viscosity Values for 4% W-LDPE Modified Binder

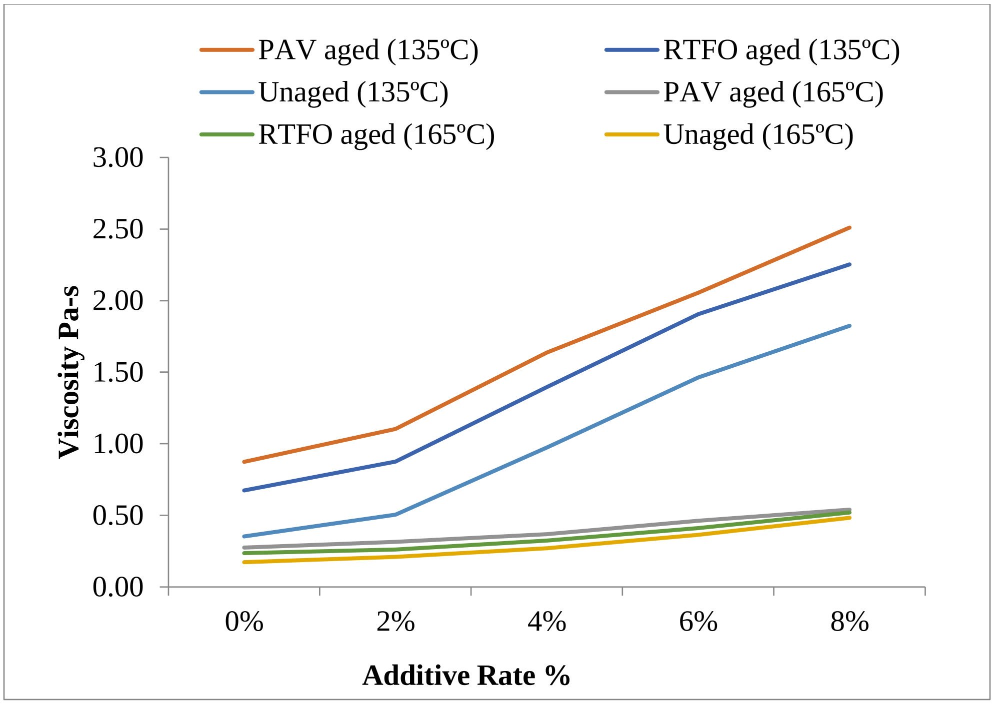

Figure 4-29: Rotational Viscosity Values of W-LDPE modified Binder

4.8.1 Viscosity Aging Index (VAI)

The performance of asphalt binder can be evaluated by its viscosity whereas the aging affect can be measured using viscosity aging index (VAI). A high viscosity aging index shows a high degree of aging [74]. It can be calculated using Eq.(1). Figure 4-30 shows VAI graph for the temperature of 135ºC and 165ºC after RTFO and PAV aging of W-PET modified asphalt binder whereas figure 4-31 shows VAI graph of W-LDPE modified asphalt binder.

$$VAI = \frac{\eta 2 - \eta 1}{\eta 1} \times 100 \qquad \text{Eq.(1)}$$

where,

η1 = viscosity before aging

η2 = viscosity after aging.

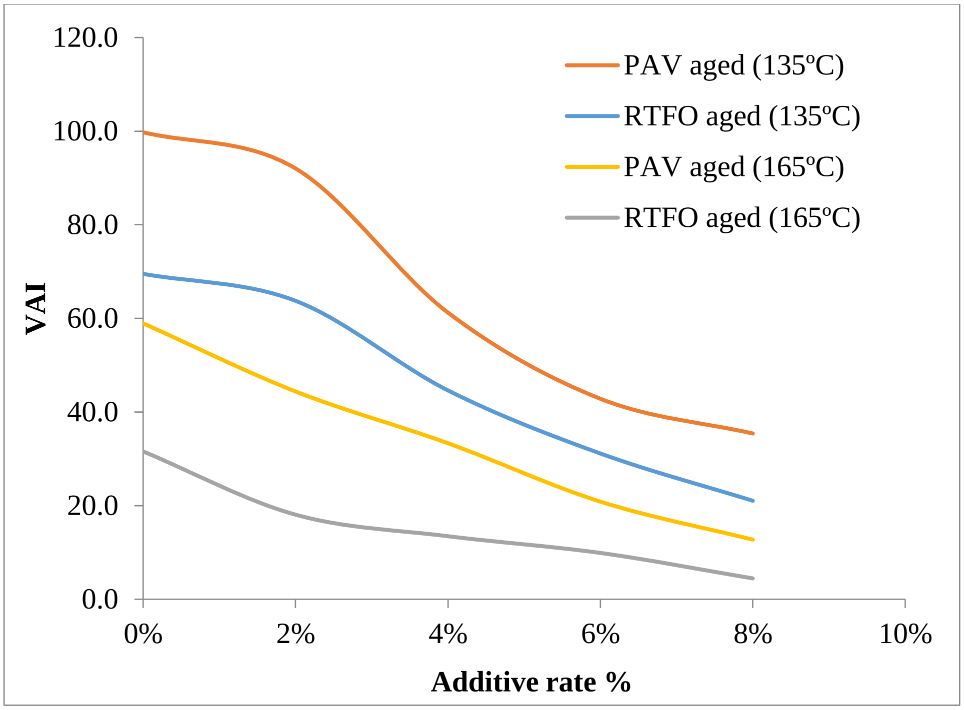

Figure 4-30: VAI graph of W-PET modified Asphalt Binder

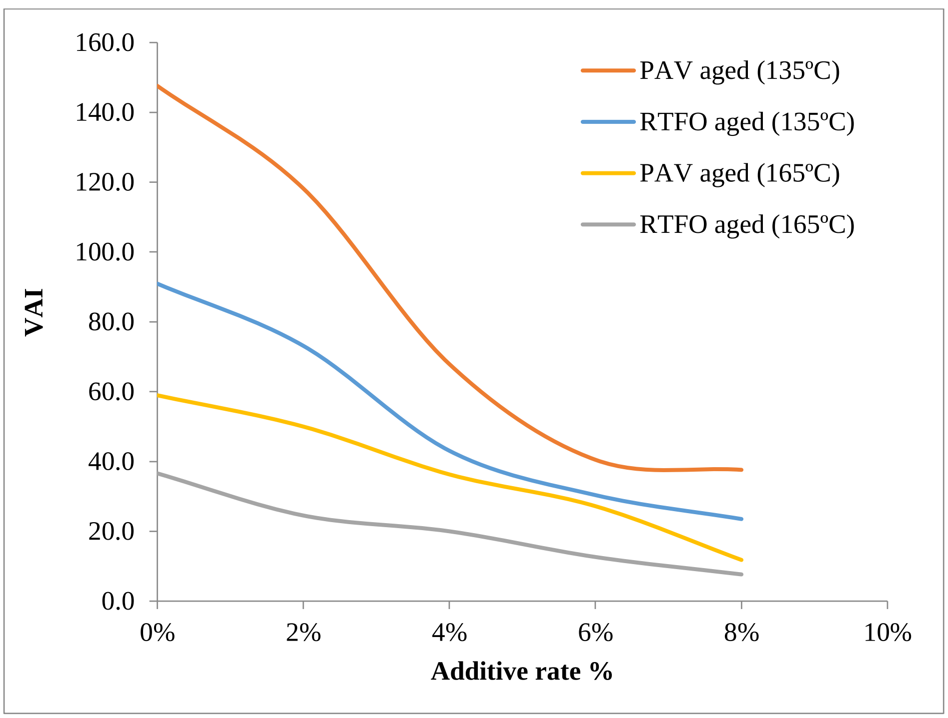

Figure 4-31: VAI Graph for W-LDPE Modified Asphalt Binder

The VAI values of the waste modified binders are lower as compared to the un-modified binders (values at 0% additive rate) for both temperatures i.e 135ºC and 165ºC, and they kept on decreasing with the increment of modifiers. It indicates better aging resistance of the waste modified binders. Moreover it can be seen from the results that this decrease in AVI values is less for 6% and 8% additive. So 4% of waste PET and waste LDPE amounts are recommended as optimum values.

4.9 ENVIRONMENTAL AND ECONOMIC IMPACTS

The high material cost and high energy requirements for the production of HMA has negative impacts on the environment [75].The harmful gases are released during high temperature mixing above 140 ºC, and they pollute the environment [76, 77]. The carcinogenic Polycyclic Aromatic Hydrocarbon (PAH) compounds are released during the mix production [78, 79]. These emissions are reduced to 50% by the use of WMA technologies and hence reducing the exposure of workers to such harmful fumes [80].

When warm mix asphalts and waste materials are used together, it resulted in lower energy consumption as well as it imparts lower negative impact on the environment. The results showed that by adopting this methodology can lead to setting up strategies for eco friendly designs in pavement industry [81].

The use of waste plastic polymers in pavement industry has the potential to enhance its properties dramatically. Moreover it can save cost and environment also from pollution [82]. The melting of plastics may also release some hazardous emissions, which are harmful to the environment. Vasudevan et al, constructed a 1km length road section using waste plastic as a percentage by weight of asphalt binder. They saved around 1 ton of the virgin binder and increased the service life of pavement as well [83]. Sojobi et al, studied that by using waste PET plastic in pavement industry can save the environment from tons of non-biodegradable waste [84].

The cost of one kilometer road section for unmodified mix and modified mix containing 4% waste PET and 4% waste LDPE is compared for cost analysis. Standard lane width of 3.65 meters was assumed here for the thickness of 55 mm. Cost of base, subbase and subgrade was ignored whereas the cost of filler material, aggregates, water and furnace oil kept constant. The cost of HMA surface course is compared and for this purpose NHA class A asphaltic concrete has been taken. 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

4.9.1.1 Virgin HMA

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

Table 4-12: Cost Estimation of 1Km road section

ITEMS					Amount(Rs)
Manpower charges for laying of 1 Km					**23,075.20**
Material					
Code	**Description**	**Unit**	**Quantity**	**Rate (Rs.)**	**Amount (Rs.)**
2024	AGGREGATE 1.1/2"-3/4"	TON	28.88	920.95	26,597.04
2025	AGGREGATE 3/4" - 3/8"	TON	86.63	1119.62	96,992.68
2026	AGGREGATE 3/8"-No.4	TON	57.75	744.35	42,986.21
2027	AGGREGATE NO.4 - NO.200	TON	96.60	597.77	57,744.58
2028	FILLER MATERIAL	TON	18.90	608.37	11,498.19
2041	ASPHALT GRADE 60/70	TON	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
Total					**2,360,506.40**
Overhead Charges					3,873.41
Equipment Charges					**529,219.08**
Grand Total					**2,916,674.0884**

4.9.1.2 HMA When Quantity of Asphalt binder is replaced with 4% W-PET

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

Table 4-13: Cost Estimation of 1Km road section with W-PET Modified Binder

ITEMS					**Amount(Rs)**
Manpower charges for laying of 1 Km					**23,075.20**
Material					
Code	**Description**	**Unit**	**Quantity**	**Rate (Rs.)**	**Amount (Rs.)**
2024	AGGREGATE 1.1/2"-3/4"	CM	28.88	920.95	26,597.04
2025	AGGREGATE 3/4" - 3/8"	CM	86.63	1119.62	96,992.68
2026	AGGREGATE 3/8"-No.4	CM	57.75	744.35	42,986.21
2027	AGGREGATE NO.4 - NO.200	CM	96.60	597.77	57,744.58
2028	FILLER MATERIAL	CM	18.90	608.37	11,498.19
2041	ASPHALT GRADE 60/70	CM	19.38	83967.89	1,627,297.71
2065	WATER	1000LIT	4.00	100.00	400.00
2116	FURNACE OIL	LIT	5400.00	79.44	428,976.00
Total					**2,292,492.41**
Crushing of waste PET Charges					**4,000.00**
Equipment Charges					**529,219.08**
Overhead charges					**3,873.41**
Grand Total					**2,852,660.10**
Total Minimum Assured Savings per km					**64,013.99**

4.9.1.3 HMA When Quantity of Asphalt binder is replaced with 4% W-LDPE

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

Table 4-14: Cost Estimation of 1Km road section with W-LDPE Modified Binder

ITEMS					**Amount(Rs)**
Manpower charges for laying of 1 Km					**23,075.20**
Material					
Code	**Description**	**Unit**	**Quantity**	**Rate (Rs.)**	**Amount (Rs.)**
2024	AGGREGATE 1.1/2"-3/4"	CM	28.88	920.95	26,597.04
2025	AGGREGATE 3/4" - 3/8"	CM	86.63	1119.62	96,992.68
2026	AGGREGATE 3/8"-No.4	CM	57.75	744.35	42,986.21
2027	AGGREGATE NO.4 - NO.200	CM	96.60	597.77	57,744.58
2028	FILLER MATERIAL	CM	18.90	608.37	11,498.19
2041	ASPHALT GRADE 60/70	CM	19.38	83967.89	1,627,297.71
2065	WATER	1000LIT	4.00	100.00	400.00
2116	FURNACE OIL	LIT	5400.00	79.44	428,976.00
Total					**2,292,492.41**
Crushing of waste PET Charges					**2,000.00**
Equipment Charges					**529,219.08**
Overhead charges					**3,873.41**
Grand Total					**2,850,660.10**
Total Minimum Assured Savings per km					**66,013.99**

Table 4-15: Calculation for No. of Waste PET Bottles and Waste LDPE Bags

Asphalt Grade 60/70 used for 1km road section in TON	=	19.38	=	19382.40	Kg
Waste PET or LDPE (4%) used for 1km road section in TON	=	0.81	=	807.60	Kg
No of 500ml PET bottles in 1kg			=	50.00	
No of LDPE bags in 1kg			=	350.00	
Total number of 500ml PET bottles required for 1km road section			=	**40380.00**	**Bottles**
Total number of LDPE bags required for 1km road section			=	**282660.00**	**Bags**

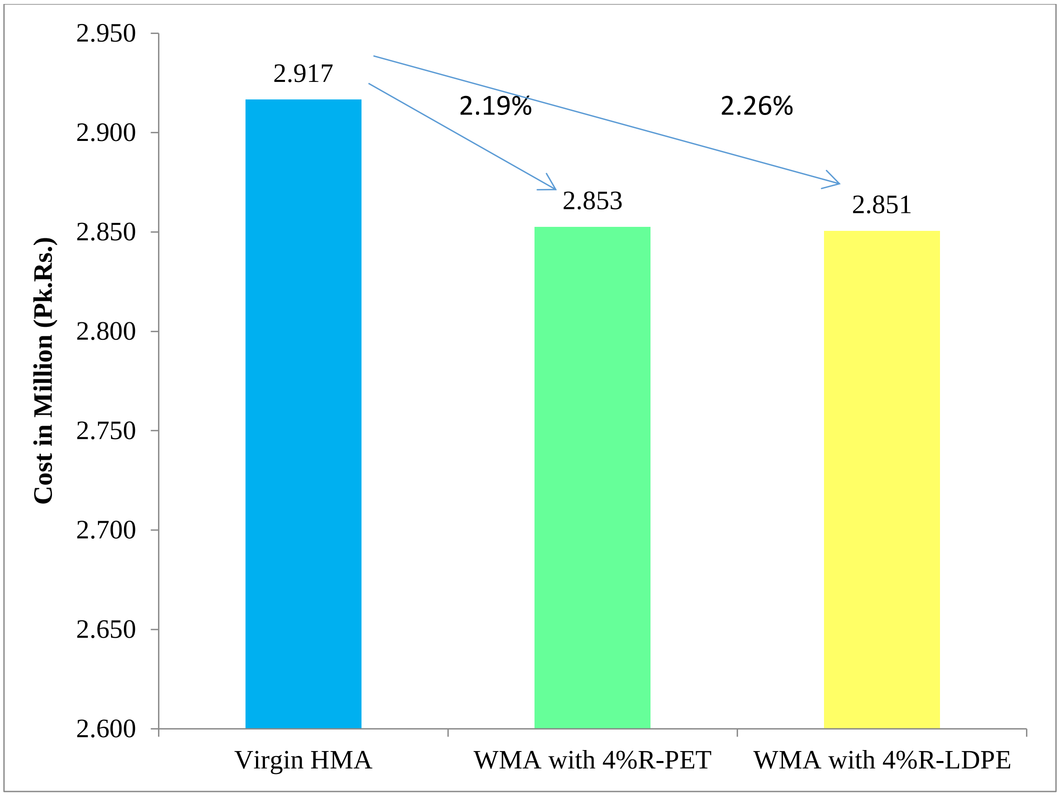

Figure 4-32: Cost Comparison

The percentage decrease in the construction cost of virgin HMA and HMA with 4% waste PET per kilometer per lane (3.65 m) for 5 cm thickness of road section can be seen in Figure 4-32, which shows that HMA will result in cost saving of around 2.19% that is equivalent to 40380 waste PET bottles, and 2.26% in case of W-LDPE modified asphalt binder that is equivalent to 282660 waste LDPE bags. That is only the monetary benefit during construction. The other benefits includes enhanced properties and environment friendly strategy.

4.10 CHAPTER SUMMARY

This chapter is comprised of results of the study presented in the form of table and figures. Consistency analysis is done based on the results of penetration and softening point and penetration index (PI) is determined. 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 modifiers with asphalt binder. Environmental and construction cost comparison shows reduction in harmful effects to the environment and improvement in the financial benefits associated with the use of waste polymers.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

The current study aimed at determining the waste polyethylene terephthalate (PET) and waste low density polyethylene (LDPE) effect on the aging properties of ARL 60/70 grade asphalt binder. The increase in the performance related properties of Asphalt binder has direct impact on the improvement of the service life of roads. 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, the following conclusions can be drawn based on lab test result and logical observations.

- Results indicate that the addition of W-PET and W-LDPE improved the physical properties of binder for both unaged and aged conditions.
- Penetration value of the W-PET modified and W-LDPE modified binder decreased and softening point increased which indicate high resistance of the modified binder against rutting.
- Penetration index increased by 19% for W-PET modified binder and 10% for W-LDPE modified binder. This shows better resistance against thermal cracking of the pavement when the temperature is low, and lower permanent (plastic) deformation when the temperature is high.
- Waste polymer modified bitumen showed lower aging indices as compared to the virgin binder, this shows that incorporation of these wastes improves the oxidation resistance of the modified binders.
- Penetration aging ratio decreased by 10% for W-PET and 12% for R-LDPE after the short term aging which indicate binders improved resistance to oxidative aging.
- Ductility Retained Ratio (DRR) increased in both cases, which represents that the incorporation of W-PET and W-LDPE can handle the issues related to ductility during aging.

- Not a single new peak was observed in FTIR results for both virgin and modified binders after aging relatively to the unaged binder. This indicates that the addition of these wastes in virgin binder is a physical process.
- 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 good compatibility of the modifiers with the virgin asphalt binder.
- The decrease in the viscosity aging index values of W-PET and W-LDPE modified bitumen shows better resistance to oxidative aging. Introduction of 4% W-PET reduced oxidative aging by 40%, whereas 4% of W-LDPE reduced oxidative aging by 50%.
- Cost comparison of HMA with virgin binder and when quantity of binder in HMA is replaced with 4%W-PET and 4% W-LDPE shows cost savings of more than 2% per kilometer per lane (3.65 m) of 5 cm thickness of road, that is equivalent to 40380 waste PET bottles or 282660 waste LDPE bags. which is only the monetary benefit. The other benefits include the environmental sustainability and saving of resources as well.

5.3 RECOMMENDATIONS

This research focused on improving the aging resistance of asphalt using waste polymers. Intermediate and high temperature visco-elastic characteristics of the neat and modified binder were evaluated. Further research should be carried out on the following areas:

- Effect on the low temperature performance and effect on Fatigue properties of asphalt binder and asphalt should be studied before implementing W-PET and W-LDPE modified asphalt binders in cold areas.

- Investigations should be done by using the different combinations of plastic wastes as an asphalt binder modifier and find out their effects on physical and performance properties before and after aging.
- More work should be done in carrying out performance testing such as Rutting, Fatigue, Marshall Stability tests.

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