PERFORMANCE EVALUATION OF ETHYLENE VINYL ACETATE MODIFIED BITUMEN AND MIXTURES

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DEDICATION

The Project is dedicated to my beloved parents and teachers whose guidance and prayers enabled us to achieve our education without any reluctant. They extremely tried their utmost to avoid us from any disconnection in our study. They are highly rated people and would always be respected in our sight. We would really pray for their long and healthy lives.

May they live long

(Ameen)

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I pray to almighty ALLAH to guide me in my glorious future to serve humanity in the best possible manners.

(Engr. Hamza Marjan)

ABSTRACT

Interconnectivity necessitates the use of transportation facilities and infrastructure. All highway design agencies seek for acceptable, long-lasting, and cost-effective strategies while designing these facilities. A well-functioning transportation system is critical to the economy of every country. A large number of people in our country travel by means of road on daily basis. In many nations, the rise in road traffic over the previous two decades, combined with a lack of maintenance, has exacerbated the deterioration of road structures. The traffic demands on our roads are much higher than they have been in the past. Many severe road surface distresses were caused by increased traffic load, higher traffic volume, and insufficient maintenance (e.g., rutting and cracking) as a result of the rapid development. Because conventional asphalt combinations are unable to withstand high axle loads and tire pressures, interest in polymer modified asphalt has grown. Polymer modification of asphalt is one of the most effective ways to improve asphalt qualities. The practical temperature range of binders is greatly expanded by polymers. By raising the stiffness of the bitumen and improving its temperature susceptibility, the additional polymer can significantly improve the binder qualities, allowing for the construction of safer roads and the reduction of maintenance costs. This research presents a laboratory investigation of the Ethylene Vinyl Acetate (EVA) polymer modified bitumen. NHA-B gradation, PARCO 60/70 grade bitumen and EVA polymer of TPI Polene Public Company Limited was used. Penetration, ductility, softening point, and viscosity tests were used to evaluate the physical properties of the asphalt binders. Three different percentages of polymers were used i.e., 2%, 4% and 6%. The impact of the EVA polymer on permanent deformation and moisture susceptibility was investigated. A double wheel tracker (DWT) was used to quantify permanent deformation (rutting), and a Universal Testing Machine (UTM) was used to examine moisture susceptibility using an Indirect Tensile Strength (ITS) test. For different percentages of bitumen volumetric properties according to Marshall Mix Design procedure were measured, and then Optimum Bitumen Content (OBC) was evaluated. Performance tests were performed using above mentioned percentages of EVA. The rutting potential of mixes was improved by addition of EVA as compared to control asphalt mixes. Same effect of polymer was on the moisture susceptibility of the prepared samples. This showed that EVA polymer can be used in flexible pavements to reduce permanent deformation and high temperature problems.

Keywords: Ethylene Vinyl Acetate, Polymer modified bitumen, Performance evaluation, Rut Resistance, Indirect Tensile Strength (ITS)

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List of Abbreviations

ASTM	American Society of Testing Materials
EVA	Ethylene Vinyl Acetate
ITS	Indirect Tensile Strength
HMA	Hot Mix Asphalt
UTM	Universal Testing Machine
FA	Fine Aggregate
SHRP	Strategic Highway Research Program
FHWA	Federal Highway Administration
OBC	Optimum Bitumen Content
GDP	Gross Domestic Product
TRS	Tensile Strength Ratio
PMB	Polymer Modified Bitumen
SGC	Superpave Gyratory Compactor
PARCO	Pak Arab Refinery Limited

CHAPTER 1: INTRODUCTION

1.1 Background

Transport is very important to the well-functioning of economic activities and also a key to ensure social well-being and productive growth of population. Transport ensures movement of people and goods which are vital for the growth of the community. Transport infrastructure is very critical ingredient in the economic development at every level of income. It not only plays a significant part in socioeconomic upbringing of any country but is also considered amongst the most valuable assets. According to economic survey of Pakistan, the mode used mostly for transportation is the road transport, which is the fourth largest sector and contributes about more than 12% to GDP. It accounts for over 21% of gross fixed capital formation. Road transport of Pakistan carries over 95% of the freight and passenger traffic. In the previous year, Pakistan's road infrastructure suffered from premature pavement failures due to constant growth in traffic volume.

Pavement rutting is one of the most prevalent and damaging pavement distresses in flexible pavements, and it is caused mostly by axle loads exceeding the allowable limit and high temperatures, and also poor mix design is one of the causes of rutting. Rutting in asphaltic concrete is dependent upon numerous factors which includes, type of binder, aggregates type, gradation, % of bituminous binder, degree of compaction, environmental factors, repeated traffic loading cycles, bearing capacity of subgrade and air voids content. (Khan & Kamal, 2012)

Moisture susceptibility weakens the bond between aggregate and asphalt binder in asphalt mixture which is a major concern for the performance of pavement. Moisture damage is caused by air voids, which has a negative impact on the asphalt mix's durability and strength. Damage caused by moisture can be divided into two categories which is cohesive failure and adhesive failure. Failure which occurs when the binder's strength is diminished due to moisture degradation is cohesive failure, whereas adhesive failure happens when the aggregates adhere to the binder. (O’Sullivan & Wall, 2009)

1.2 Problem Statement

Premature rutting of flexible pavements is one of our country's most serious pavement problems. Pakistan has National highways of 12130 km and Motorways of 3714 km. Most of the road network in Pakistan is flexible pavements with bituminous surfacing as wearing course.

Despite the fact that rutting seen on pavements is the result of failures happening in one or more layers of the asphalt structure and sub-grade, however the failure visible in the topmost layers is considered as the real reason for rutting. For minimizing this distress, it is important to give careful consideration to material determination and mix design. Even though asphalt from refineries meets current criteria, investigations have shown that the failure of flexible pavements is mostly due to the poor strength of regular asphalt mixtures to handle repeated application of wheel load.

To cope with this problem polymer modified asphalt use is increasing, because of the incapability of conventional asphalt mixtures to resist the high tire pressures and axle loads. As a result, polymer modification of asphalt is considered one of the greatest alternatives for improving asphalt qualities. The useful temperature range for binders is greatly expanded when polymers are used. By raising the stiffness of the bitumen and improving its temperature susceptibility, polymer can significantly improve the binder qualities, allowing for the construction of safer roads and the reduction of maintenance costs.

1.3 Research Objectives

The main objectives of this study are:

- To evaluate the physical properties of modified bitumen and virgin bitumen.
- To evaluate volumetric properties of HMA using Marshall Design method.
- To evaluate indirect tensile strength of asphalt mixture using modified and virgin bitumen.
- To evaluate rutting resistance of asphalt mixture containing modified bitumen.
- To evaluate moisture susceptibility of asphalt mixture containing modified bitumen.

1.4 Research Scope

A study strategy was created, with the following tasks stated, to meet the above-mentioned research objectives:

- Previous research finding Literature review was done regarding the failure of the pavements and its potential rut causes and the use of various types of polymers for reducing the rutting potential and the moisture susceptibility of the pavement.

- For determination of the various characteristics of the materials to be used in this research, laboratory evaluation was done for both bitumen and aggregates.
- Both with and without the addition of polymer, samples were prepared to obtain the optimum bitumen content (OBC).
- Specimens were prepared using super gyratory compactor according to AASHTO T-324-04.
- The modified and unmodified specimens were subjected to a double wheel tracker test to determine rut resistance.
- The indirect Tensile strength (ITS) was performed in wet and dry condition at temperature of 25° C to determine tensile strength ratio.
- To determine the HMA's moisture susceptibility TSR is used.
- Analysis of all the results obtained from the various performance tests.

1.5 Thesis Organization

This study is divided into five sections, each of which is described briefly below.

Chapter 1 includes a brief introduction of the rutting failure of pavement and the need to minimize it. It includes the problem statement, objectives of research and scope of research.

Chapter 2 contains a review of the findings of prior studies on the use of polymer modified asphalt pavement and Ethylene Vinyl Acetate Polymer, material characterization, factors affecting the bituminous mixes.

Chapter 3 includes the methodology adopted to achieve the research findings.

Conventional tests on bitumen and aggregates, Samples preparation, Marshall Mix design procedure, performance tests are covered in this chapter.

Chapter 4 includes the details of results obtained and their analysis performed.

Chapter 5 includes the summary of report and also the conclusion and recommendations are included in this last chapter.

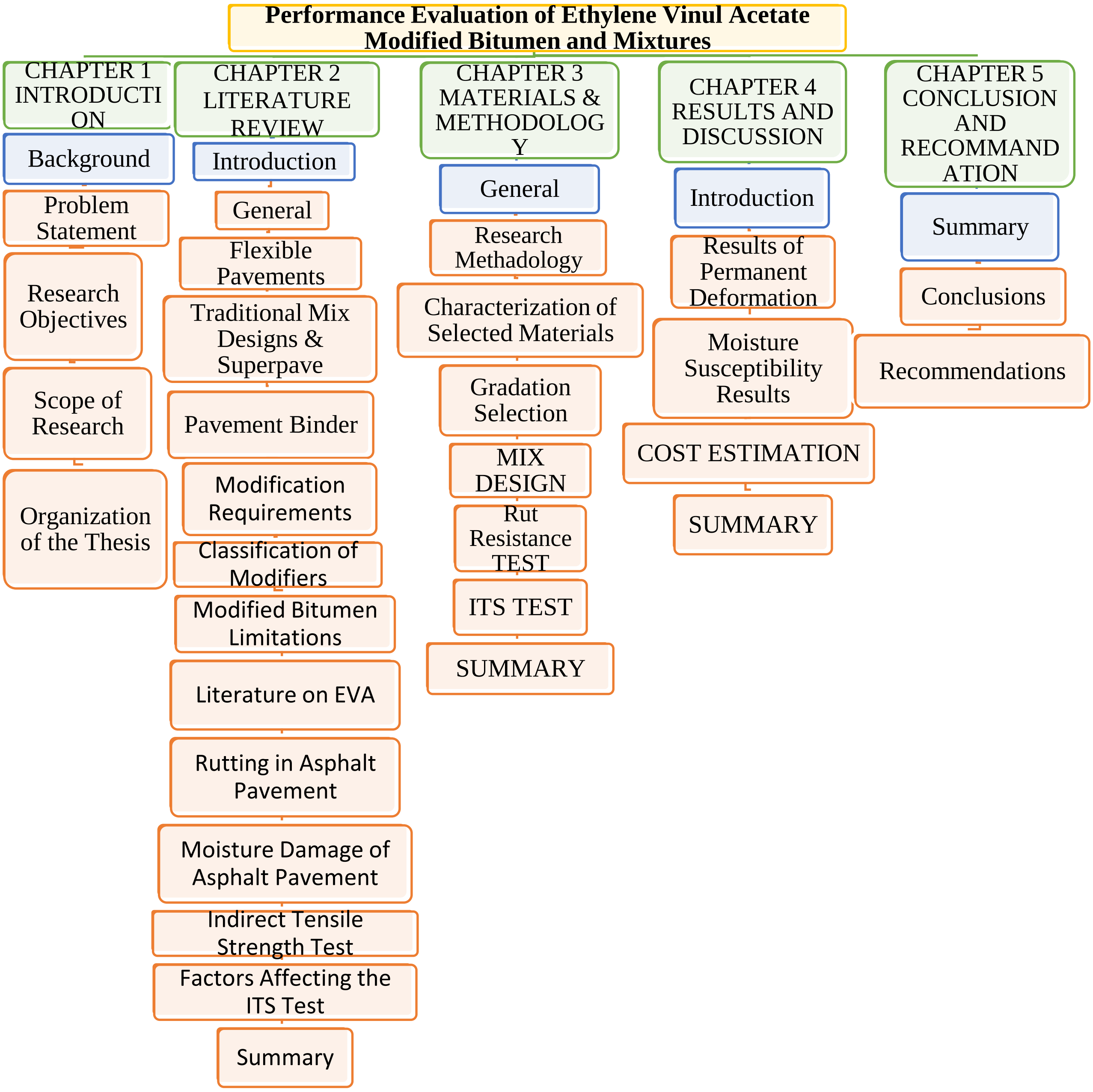

Figure 1.1 Thesis Outline

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter gives a brief review of the literature and theory related to the response of asphalt mixes containing polymers to various performance test such as rutting, ITS and moisture susceptibility. This chapter deals with the various types of modifiers used in asphalt, its effect, and the research carried out the use of ethylene vinyl acetate as a modifier in asphalt and its effect on the performance of HMA pavements.

2.2 General

Road transportation plays an important role in the economy of a country. It provides access to different places of the country, which ultimately provides access to different markets across the country. Asphalt is the binder which is widely used in the construction of roads all across the world. It is obtained as a byproduct of petroleum. On average about 102 million tons of bitumen is used per year worldwide, out of which 70% is used in road construction. This demand is increasing every year, which has let researchers to find alternative ways to reduce the bitumen use in road industry.

Bitumen causes severe impact to health as it is burn at high temperature which produces toxic fumes, extremely dangerous to health and has detrimental effect on environment. Due to the above reasons, there is a need to look for bitumen alternatives or replace certain percentage of bitumen with another material.

Asphalt modification has been used for over 60 years, although there has been increasing attention in the last 15 years. Increased traffic volumes, large loads, and tire pressures have all contributed to this interest in recent years, causing premature rutting failure of HMA pavements. Instead of discarding and disposing of industrial byproducts and waste materials including plastics, ash, certain oils, and chemicals, they can be used as additives in HMA to decrease environmental pollution and economic burden. The readiness of government entities to pay for the high initial cost of pavements in exchange for longer service life.

2.3 Flexible Pavements

Flexible pavement is made up of one or more unbound base courses lying on a properly compacted or stabilized subgrade with an asphalt treated surface or a relatively thin layer of hot mix asphalt on top, and it yields elastically to traffic loading. The HMA pavement's strength comes from the load-distribution features of a layered system designed to keep each underlying layer, including the subgrade, from compressive shear failure. To boost resistance at the surface, superior materials are employed in the top structure due to stress conditions caused by traffic wheel loads. The asphaltic surface layer must be stable under repeated traffic loads, and it must also be resistant to fatigue damage in higher pavement temperatures. The pavement structure in case of flexible pavements should be designed in such a way that it has a good performance and serve many functions including load carrying capacity, skid resistance, riding comfort, safety, surface, and subsurface drainage throughout its design life(Lenz, 2011)

On application of traffic load at the top, pavement layer stimulates different kind of stresses in all the layers. These stresses reduce from top to bottom layer. Therefore, to carry the stresses of high magnitude and for an economical design of pavements, material of good quality and higher strength is always placed on the top of the pavement structure while to distribute the stress or load on wider area to lower the stress magnitude, material of low strength and inferior quality is always placed at the bottom. Typically, Surface course or wearing surface, Binder course, and Subbase course are the layers that make up a flexible pavement structure, Compacted or treated Sub grade and Natural Subgrade.

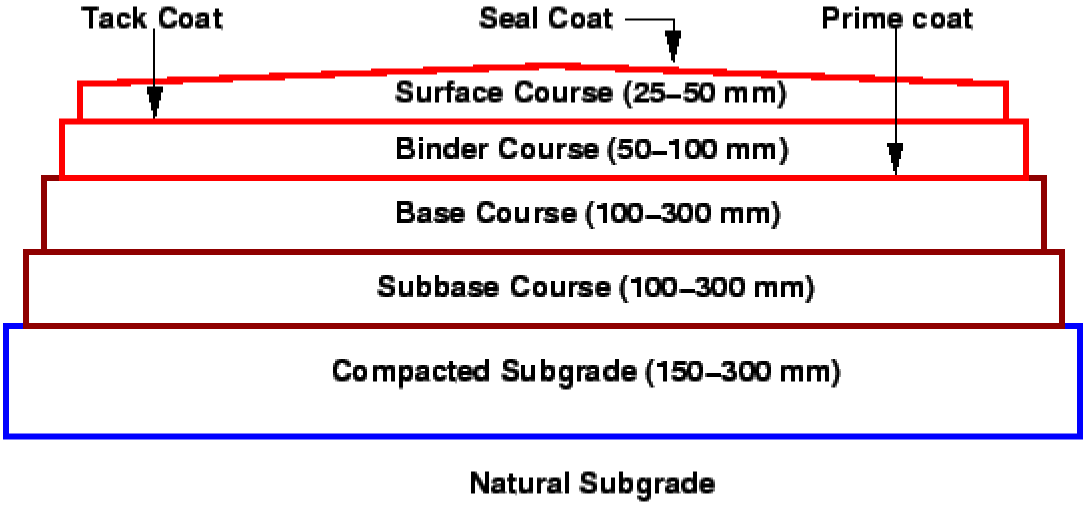

Figure 2. 1 Flexible Pavement Cross Section

Figure shows that an asphaltic surface course is the highest layer of a flexible pavement construction, and it must be strong enough to withstand the forces placed on it, while providing a smooth riding surface for the users. The layer below surface course is asphaltic binder course and beneath that is shown the base course which consists of crushed materials or the stabilized materials. The layer under the base course is the subbase course, which is composed of relatively low quality, less expensive material because, which acts like a filter for drainage between base course and subgrade. The subgrade is on site prepared soil, and it is normally compacted to the optimum moisture content and sometimes stabilized by the addition of asphalt, lime, Portland cement or other modifiers.

2.4 Traditional Mix Designs and Superpave

Traditional mix design method like Marshal and Hveem are based on certain volumetric properties. Hveem method addressed density, kneading action and stability of the mix was incorporated for compaction process. The disadvantage of Hveem method was, that equipment for testing was not portable and expensive. Marshal Mix design was introduced as the researchers believe that Hveem method gives subjective and non-durable Hot Mix Asphalt with small amount of asphalt content. The Marshal method also considers density, voids and all the volumetric requirements for HMA. Testing equipment for Marshal method was portable but Marshal Stability does appropriately measure shear strength of HMA. To address the issues in the traditional mix design methods, The Superpave mix design method was one of the main outcomes of the Strategic Highway Research Program (SHRP).

SUPERPAVE is an acronym of Superior Performing Asphalt Pavement, and the Hveem and Marshall approaches were replaced by the mix design method. The Superpave mix design method is based on the volumetric analysis used by the Hveem and Marshall methods. The Superpave system includes asphalt binder and aggregate selection into the mix design process.

2.5 Pavement Binder

Pavement binder is modified to achieve the following improvements: 1) During the summer, use a viscosity that is high to prevent rutting. 2) Low viscosity of the binder to make asphalt pumping, mixing, and compaction easier. 3) Tripping is reduced by increased adhesion between asphalt and aggregate particles. 4) Thermal cracking resistance requires low stiffness and rapid relaxation qualities at low service temperatures.

It is important to note that all modifiers are not suited for all properties. In some cases, one modifier will improve one property at a time, but other properties might be compromised. Before asphalt modification, some important questions shall be considered: 1) Requirement of improvement? 2) Properties required to be enhanced. 3) Which modifiers will be best for the desired property? 4) For how much time the desired modifier will be stored over the length of time without affecting its properties? 5) Effect on optimum bitumen content using different modifiers and different percentages of modifiers? 6) Can the modified HMA be recycled? 7) Based on life cycle cost analysis, are increased initial cost justified? 8) Health and safety concerns regarding the effect of modifiers on workers?

Before proceeding to asphalt modification, understanding the chemistry of asphalt is crucial. Asphalt is a mixture of mostly organic and organometallic chemicals that is extremely complicated. Asphalt may be split into two chemical groups by precipitation in n-heptane. Asphaltenes and maltenes are two types of asphaltenes. Asphaltenes are polar chemicals that do not dissolve in linear hydrocarbons like n-heptane due to their larger molecular weights. Asphalt with a large proportion of asphaltene is harder and has a higher viscosity, according to general observation. As a result, asphaltene is expected to affect the rheological properties of asphalt in a substantial way. Asphaltenes make up about 5 to 15 percent of asphalt cement. Saturated, aromatic, and resin maltenes are the three types of maltenes. The major function of resin is to disperse asphaltene in oils (saturates and aromatics). Resins are dark brown in color and adhere to particles in HMA mix quite well.

2.6 Modification Requirements

Adjustments are not required for all asphalt binders; nonetheless, following are some of the technical reasons for the changes: 1) increasing the useful temperature range for asphalt. 2) To obtain an elastic mix at low temperatures while minimizing non-load thermal cracking. 3) Strengthens the bond between asphalt aggregates, reducing peeling and moisture susceptibility. 4) At high temperatures, increase the stiffness of mixes. 5) To improve mix abrasion resistance. 6) To increase resilience to fatigue. 7) To increase resistance to oxidation and ageing. 8) To lower the structural thickness that is required. 9) To improve the fuel resistance of pavement that has been exposed to spilled fuel. 10) To increase the pavement's overall performance. 11) Finally, meeting any of the above aims will result in a reduction in the life cost of pavement.

2.7 Modifiers Classification

Different classifications exist for modifiers and additives. However, a very generic classification was suggested by (Terrel R & Walter J, 1986), whose modified version was presented by Roberts et al. (1996)(Roberts, F. L., Kandhal, Prithvi, S., Brown, E.Ray, Lee, Dah-Yinn, Kennedy, 1996) and is explained bellow

2.7.1 Fillers

Lime, Portland cement, fly ash, and aggregate crushing and screening dust are examples of mineral fillers. (F. L. Roberts, P. S. Kandhal, E. R. Brown, 2016) found that adding filler reduces the optimum asphalt content while increasing density and stability. Because the filler fills holes in aggregates, the ideal asphalt content is reduced. At high temperatures, the filler causes the mixture to become stiffer. Lime is employed as an antistripping agent. Other fines, particularly those containing clays, can boost HMA's stripping potential.

2.7.2 Extenders

After the 1973 oil embargo, the idea of increasing asphalt content became popular. Asphalt cement appeared to be in short supply, causing costs to skyrocket. As a result, the Federal Highway Administration (FHWA) encouraged research into prolonging the life of asphalt binder by partially substituting sulphur and lignin. Industrial materials produce sulphur and lignin as byproducts. Sulphur is created during the denaturalization of natural gas, as well as the creation of pulp and paper. The usage of sulphur as an extender, on the other hand, is dependent on market prices. Its use is not justifiable if the price is higher than asphalt. The addition of sulphur to polymer modified asphalt mixtures enhances storage stability, according to (Rodriguez, 2001). Although in commercial HMA operations lignin has not been employed as an extender (Roberts, Kennedy 1996), it has been investigated as a prospective extender and asphalt cement alternative in the laboratory (Terrel, R. L., 1979).

2.7.3 Polymers

A big molecule which is made up of numerous (poly) small molecules (monomers) which combine chemically in long chains or clusters is known as a polymer. The monomers' chemical structure and sequencing of determine the final polymer's physical properties. Copolymers are made up of two distinct monomers that can be organized in a random or block pattern. When these two monomers are combined and reacted, a new polymer known as a copolymer is created with unique features. Hydrogen bonding and chemical reactions are examples of specific interactions between asphalt and polymers, can occur when a polymer is added to asphalt. Polymers can be divided into two types based on their strain characteristics at low temperatures: (a) elastomer and (b) plastomer.

2.7.3.1 Elastomer

Stretching elastomers helps them withstand distortion produced by tension and swiftly resuming their original shape after the load has been removed. Until they are stretched, elastomers offer little strength to asphalt cement. Elongation, on the other hand, increases tensile strength. The primary goal of employing elastomers as HMA modifiers is to generate a stiff HMA at a very high service temperature and a high elastic HMA at intermediate temperature to avoid fatigue, as well as minimal low or unaffected stiffness at a very low service temperature so as to avoid thermal cracking.

The components of rubber are complex by nature, and when they are mixed with HMA, they may not impart the same qualities as a clean polymer. In addition, different asphalt cements respond differently to different modifiers. It is quite difficult to forecast if a given polymer will produce the intended results. As a result, to see if the given purpose can be satisfied by adding rubber modifiers, Superpave mix design and evaluation techniques are used.

Elastomers can be used to modify asphalt cement in a variety of ways. Many of these are commercially available under a variety of brand names. Polychloropene latexes, Natural rubber, Styrene-butadiene-styrene (SBS) block copolymers, styrene-butadiene rubber latexes (SBR), styrene-isoprene-styrene (SIS) block copolymers, and crumb rubber modifiers all are the examples of elastomers or rubber latexes.

Latex made of styrene-butadiene (SBR), polychloropene (Neoprene), and polybutadiene is a random copolymer (PB). It is a thermally set Elastomer made up of a combination of polymer particles spread in water and is one of the synthetic latex rubbers. As the water present in the applied emulsion gets evaporate, SBR droplets agglomerate along surface of the asphalt particles. This creates a continuous, honeycombed polymer network that runs the length of the binder, which improves the asphalt characteristics. SBR improves flexural fatigue resistance, oxidative ageing resistance, ductility at low-temperature and toughness, rut resistance, and asphalt binder cohesion and adhesion properties. It also improves resistance to skidding. Micro surfacing, chip sealing, and slurry seals are all common applications for SBR latex (latex modified asphalt emulsion).

The SIS Block Copolymer (Styrene Isoprene-Styrene) is a thermoplastic elastomeric polymer. At high temperatures, it resists deformation and flow. It has strong strength as well as enhanced flexibility. When used in small amounts, it has good blend stability. The SIS block copolymer improves asphalt adherence to aggregate particles. However, it lowers the resistance to penetration. At layout temperatures, it has a high viscosity.

Thermoplastic Elastomers SBS Block Copolymer SBS block copolymer is a type of thermoplastic elastomer. It comes in the form of pellets, crumb, or pulverized materials in bulk sacks. SBS is usually used at a rate of 5% of the asphalt binder. SBS improves flow and deformation resistance at high temperatures, improves abrasion resistance, improves fatigue resistance, improves indirect tensile strength tests, lowers oxidative ageing of bitumen, boosts low-temperature flexibility and durability, and improves asphalt binder adherence and cohesion. It's very flexible at low temperatures, but it's also very pricey. SBS is used for both paving and roofing.

Paving applications can also benefit from natural rubber. It has a higher ductility and is more resistant to rutting. Natural rubber has a limited compatibility due to its high molecular weight and must be partially decomposed and manually homogenized.

Tires are the most common source of reclaimed rubber. With the rise in the amount of used tires and the challenges that come with their disposal, using recovered rubber as a modifier to improve pavement performance could be an efficient way to make tire disposal easier. It improves rutting and shove resistance, increases HMA flexibility, slows asphalt binder ageing, and minimizes reflective cracking in asphalt overlays. Longer durability can be attained by employing thinner lifts. It is also less expensive. Crumb rubber modifier is an example of recovered rubber that has been utilized to improve pavement performance (CRM). Crumb Rubber is rubber that has been salvaged from old tires. It's created from leftover tire rubber that's been mechanically ground to a diameter of less than or equal to 0.25 inches.

2.7.3.2 Plastomers

Plastomers are made up of a three-dimensional network that is stiff and deformable. They build up a lot of strength quickly, but they're brittle. Plastomers have a high initial strength but can shatter when stretched. PVC, EPDM, Polyolefin, Polyethylene/Polypropylene, and Ethylene Acrylate Copolymer are some of the Plastomers that can be used to modify asphalt. Plastomers account for 15% of the global asphalt modifier market.

As a polymeric polymer, low density polyethylene (LDPE) has been employed. Polyethylene, both virgin and recycled, can be used. To modify the content of a bi-phase binder system LDPE is used that includes neat binder and polyethylene. To avoid upward migration of polyethylene and stratification within the liquid asphalt cement, the modified binder must be stored with agitation. Due of the high viscosity of LDPE modified asphalt, high mixing and compaction temperatures are required. (37^{o}F hotter than the HMA in the control group). Because polyethylene crystallizes below 132^{o}C, compaction of LDPE modified asphalt is largely inconsequential below this temperature. LPDE enhances high-temperature deformation resistance, increases high-temperature viscosity, improves asphalt ageing resistance, and is relatively inexpensive. In asphalt, however, it is difficult to spread and causes instability. It also has little elastic recovery and requires a lot of polymers to get improved characteristics. LDPE is mainly utilized in industry and has limited paving uses.

Thermoplastic Plastomers polymer EVA is a copolymer of ethylene and vinyl acetate. Ethylene vinyl acetate modifiers have been discovered to be store stable even after extended periods of time and are unaffected by tiny temperature differences in mixing. It is delivered in bulk bags and comes in the form of translucent to off white pellets. The EVA is mixed into a heated asphalt binder that is held between 149 and 171°C. Only light agitation (low shear) or circulation is required for optimal mixing. EVA is commonly used at a rate of 2 to 5% of the asphalt binder's weight. EVA enhances stiffness modulus and adhesion between asphalt binder and aggregates at high temperatures.

2.7.3.3 Combinations

Combinations of elastic and plastic polymers can also be utilized to achieve qualities that would be impossible to obtain with just one modifier alone. For example, In the summer, a plastic polymer can improve high-temperature rutting resistance, but at low service temperatures, it cracks. In this case, the addition of a rubber substance could improve HMA's cold weather performance. When mixing two polymers, keep in mind that they might not be chemically compatible, and the result could be dangerous. It may also be prohibitively expensive to combine two or more polymers.

2.8 Thermoset and Thermoplastic Polymers

Thermoset and thermoplastic Plastomers and elastomers are distinguished by their temperature-dependent structural development and reformation features. When thermoset polymers are heated for the first time, they generate a complicated, cross-linked structure that is retained when cooled but cannot be reversed when reheated. When cold, thermoplastic polymer forms a well-defined, connected matrix, which can be reversed or reset when reheated. Table 2.2 summarizes the deformation and thermal properties of a variety of regularly used polymer modifiers.

2.9 Modified Bitumen Limitations

The following are some of the potential drawbacks of modified asphalt: (1) Cost increase. Although modified bitumen has a high initial cost, its life cycle cost may be reduced because the pavement's life can be extended by up to ten times when polymer is utilized. 2) Other issues to consider include mixing temperature, storage, and the amount of time the PMB is maintained at high temperatures before being laid. 3) Stability issues and Compatibility. A polymer may be incompatible with bitumen, slightly compatible, or compatible.

2.9.1 Compatibility and stability Problems

Using traditional mixing processes, compatible materials form physically stable mixes. These mixtures may or may not improve bitumen's physical qualities. To improve asphalts, slightly compatible polymers require particular mechanical, chemical, or thermal procedures. When incompatible polymers are combined with asphalt, heterogeneous mixtures with little cohesion and ductility occur.

To obtain optimum pavement performance, eliminate separation during storage, pumping, and application of asphalts, appropriate compatibility between asphalt and polymers is essential. PMB's poor storage stability will prevent it from being used in paving applications. The storage stability of PMB is affected by the size and amount of polymer molecules, the size and amount of asphaltenes, and the maltene phase aromaticity.

According to (Rodriguez, 2001), introducing cross-linking agents like sulphur can improve the storage stability of asphalt. Sulfur, through sulphide and/or polysulphide bonds, is theorized to chemically bind the bitumen and polymer. PMB compatibility and blend completeness are checked using UV microscopy. Every hour, samples are obtained and examined under a fluorescence microscope. Homogeneity is defined as finely scattered polymer granules in an asphalt matrix. Figure 2.2(a) depicts a homogeneous mixture, whereas Figure 2.2(b) depicts a heterogeneous mixture.

To determine compatibility, a softening point variation test might be utilized. PMB is poured into a metallic toothpaste tube and baked for three days at 160°C. Following that, samples are obtained from the top and bottom of the blend, and the softening points of these samples are identified and compared. The temperature differential between the upper and bottom portions of the blend must be less than 4°C. A high value indicates a difficulty with phase separation or a lack of stability (Rodriguez, 2001)).

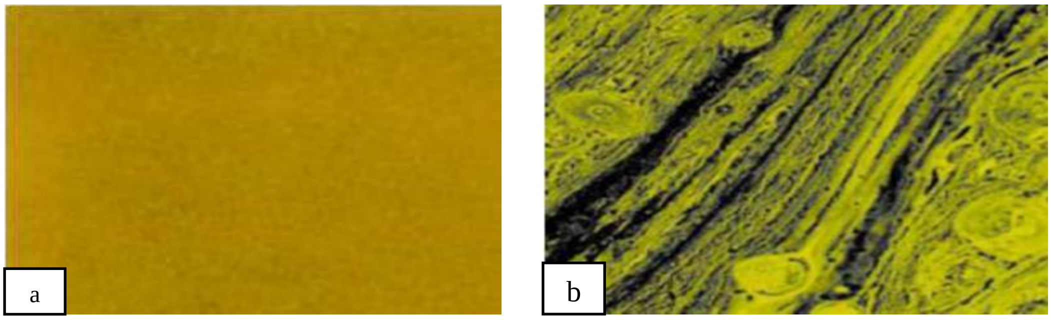

Figure 2. 2(a) & (b) Homogeneous and Non-Homogeneous Mixture

2.10 Incorporation of Polymers into Asphalt

1) Addition of latex polymer to asphalt is a typical approach for integrating polymers in asphalt. It is a simple and trouble-free procedure. 2) Solid polymer addition to asphalt (e.g., Pellets). When using SIS and SBS block copolymers, this approach necessitates extensive mixing and shearing to achieve uniform polymer dispersion in asphalt.

2.11 EVA Literature

Modified bitumen with copolymers of SBS and EVA was investigated. The findings revealed that the type of polymer used, and its content had an impact on the shape and qualities of modified bitumen, as well as the mechanical properties of polymer modified HMA. Samples with low polymer concentration displayed dispersed polymer particles in a continuous bitumen phase, whereas samples with high polymer content revealed a continuous polymer phase. The typical properties of base bitumen, such as penetration, softening point, temperature susceptibility, and so on, were improved through polymer modification. The HMA mechanical properties created using SBS PMB samples, such as Marshall Stability, improved when the polymer % was increased. (Sengoz & Isikyakar, 2008)

In his comparative performance study, (Ameri, Mansourian, 2013) in terms of three important flexible pavement distress modes: rutting, fatigue damage, and low temperature cracking, looked at a range of EVA modified bitumen and blends. The effects of EVA on the performance of asphalt mixtures were also explored. Dynamic creep experiments, indirect tensile fatigue tests, indirect tensile strength tests, and creep compliance tests were performed on modified asphalt mixtures containing 2 %, 4 %, and 6 % EVA, as well as the asphalt mixture containing original base bitumen. According to the results of a dynamic creep test and an indirect tensile fatigue test performed on the EVA-modified asphalt mixtures, the addition of EVA improves rutting and fatigue resistance when compared to asphalt mixtures with original base bitumen. Low temperature cracking resistance of EVA-modified mixes enhanced by 4% when compared to asphalt mixtures containing original base bitumen. According to the findings of this experiment, EVA-modified bitumen has better and more rutting resistance than the original base bitumen. The EVA-modified bitumen is more resistant to fatigue cracking than the base bitumen. EVA percentage has a proportionate effect on bitumen low-temperature cracking resistance. At low and moderate EVA levels, EVA-modified bitumen has better low-temperature cracking resistance than the original base bitumen (2 percent and 4 percent, respectively).

According to (Chegenizadeh et al., 2021)Ethylene-Vinyl Acetate (EVA) had an effect on the fatigue and rutting behavior of stone mastic asphalt (SMA). Wet methods were used to fuse EVA with C320 binder, and SMA mixes were created. The amount of EVA used in the study ranged from 2% to 6%. A four-point flexural beam test, wheel rutting test, Schellenberg test, flow number test, and dynamic modulus test were all performed on the mixtures. In the four-point bending test, the results showed that increasing the amount of EVA enhanced rutting resistance and the cycle to failure. The flow number increases as the EVA concentration is increased. Bitumen drainage was minimized by increasing the EVA concentration. Finally, the master curve was drawn and compared for each EVA concentration. By increasing the quantity of EVA in the mix, the phase angle of the mixtures also reduced. The results of the wheel rutting tests revealed that non-treated SMA blends have a low rutting resistance. Boosted EVA increased rutting resistance, according to the findings. SSTR was also plotted for changing EVA content, but no apparent connection was seen, possibly due to differences in reaction speed between EVA dosages. The fatigue life of SMA-EVA treated samples was dramatically improved as compared to non-treated samples. The incorporation of EVA at 6% was found to be the most effective percentage in this investigation for improving fatigue life. In terms of initial flexural stiffness, the same pattern was seen. The drain-off findings showed a decrease in drain-off values while the EVA percentage rose as compared to non-treated SMA blends. The addition of the EVA polymer to the mix successfully lowered drain-off rates to less than 2%, according to the findings. Adding EVA to the mix increased the FN cycle values, according to the FN test. The higher the FN number, the better the rutting resistance.

Impacts of ethylene vinyl acetate on the traditional properties and rheological properties of pure bitumen were tested. Traditional test methods were used to identify the basic characteristics of PMBs. The results showed that polymer modification improved the base bitumen's traditional qualities such penetration, softening, and temperature susceptibility. UV florescence microscopy was used to study the variation in PMB morphology as a function of polymer concentration. The findings reveal that when polymer concentration increases, rheological models may accurately replicate the effect of polymer modifications by raising initial modulus and decreasing relaxation time and phase angle. Two rheological models were utilized to define the rheological behavior: the Huet modified model and the Prony series model. (Dekhli et al., 2015)

Asphalt performance of mixes made with EVA modified bitumen containing various concentrations of glass fibers in a laboratory setting was performed. To explore the influence of additives on specimens, a total of 11 types of mixes were created, and Marshall and robust modulus tests were done. According to the findings, adding 5% EVA and 0.3 percent glass fiber to the Marshall Stability boosted it by around 25% and 20%, respectively. It was also discovered that using both chemicals at the same time boosted Marshall Stability more than using them separately. The sample comprising 3 percent EVA and 0.3 percent glass fiber, with a weight of 1210 kg, has the highest Marshall Stability. The resilient modulus, on the other hand, showed that increasing the amount of EVA and glass fiber separately and simultaneously at two distinct temperatures of 25 and 40 °C enhanced the asphalt mix's resilient modulus. However, as the temperature rose, the resilience modulus of the asphalt mix decreased. 3EF was chosen as the best asphalt mix based on all of the findings. In comparison to the control sample, adding 3% EVA to the asphalt mix reinforced with 0.3 percent glass fiber increased Marshall Stability (1210 kg). However, increasing the polymer while maintaining a stable glass fiber resulted in a fall in Marshall Stability, with the Marshall Stability reaching 1080 kg after adding 7% EVA polymer. According to the findings, the sample with 3 percent EVA and 3 percent glass fiber has the highest Marshall Stability, which is equal to 1210 kg. The increasing viscosity of bitumen and the armament of the asphalt mix are the causes. As the polymer concentration rises, the flow of EVA polymer-containing samples becomes more erratic. Adding 3% EVA polymer to the flow (3.7 mm) improves it but adding 5% EVA polymer reduces it (3.4 mm). Increasing EVA by up to 7% results in a 3.9 mm increase in flow. (Janmohammadi et al., 2020)

In hot and arid climates, the potential of employing Ethylene Vinyl Acetate (EVA) as a modification of hot mix asphalt for use as a flexible pavement preservation material was investigated. The difference in strength and durability of asphalt modified with EVA at various percentages, namely 2 %, 4 %, 6 %, 8 %, and 10 %, was investigated. All hot mix asphalt (HMA) was created utilizing Marshall Mix design guidelines in terms of Marshall Stability Test to obtain optimal bitumen content, strength, and durability (MS). Indirect Tensile Strength Test (ITS) at various temperatures, Marshall Stability Test (20^{o}C, 40^{o}C, and 60^{o}C), and unconfined Compressive Strength Test (UCS) at 45^{o}C were all performed. Marshal properties, unconfined compressive strength (UCS), and the Indirect Tensile Strength test (ITS) were all performed. The results showed that as the EVA modifier was increased, marshal stability and Marshal Quotient increased. When the EVA modifier is increased, however, Marshal Flow decreases. With an increase in EVA modifier, all values of unconfined compressive strength (UCS) and indirect tensile strength test (ITS) rose. Because EVA is temperature tolerant and may avoid asphalt cracking, it could be utilized as an aggregate alternative for flexible hot mix asphalt in hot and arid climates. According to the results of ITS and UCS testing, Hot Mix Asphalt amended with a 4% EVA mixture performed best at all temperatures. When compared to HMA unaltered with Ethylene-Vinyl-Acetate (EVA) mixes, HMA modified mixtures were more responsive to temperature fluctuations. Temperature has an effect on the ITS; when the temperature rises, the ITS decreases. EVA composition has an impact on the ITS and UCS. Variances in aggregate gradation, OBC, Asphalt type, mix conditions, machine type, and binder content are the reasons for certain differences in ITS and UCS test findings when compared to other study results. Therefore, the addition of Ethylene -Vinyl-Acetate (EVA) as modifier of Hot Mix Asphalt has effect on the properties of HMA. Based on this study, recommendations for further works are drawn as follows: This research was conducted to evaluate the applicability of Ethylene -Vinyl-Acetate (EVA) as hot mix asphalt modifier. IT was found that most of the test values increased as the percent of Ethylene -Vinyl-Acetate (EVA) increases, which can contribute to prevent asphalt permanent deformation. (Aljanadi, 2020)

2.12 Rutting in Asphalt Pavement

Rutting is a major distress mechanism in asphalt pavements that manifests itself as irreversible deformation. Rutting has been the most common mode of failure in flexible pavement as truck pressure has increased in recent decades. Rutting is mostly caused by the accumulation of persistent deformation in the pavement structure's various layers and portions of layers. Studded tires usage on pavements can also cause rutting. Longitudinal irregularity in the magnitude of rutting causes roughness. Due to rutting, skid resistance is reduced and increases the potential for hydroplaning which results in reduced visibility because of water trapping. As rutting developed it leads to cracking of the pavement and ultimately disintegration or failure of pavement takes place. Highways and secondary roads accounts for a substantial percentage of maintenance and associated costs due to these distresses.

described that the average gross weight of trucks has increased and is functioning near to the limits of legal axle loads. Countries with relaxed implementation of the legal axle load limits the trucks operate at axle loads and thus exceed the legal limit of axle load. Due to increase in axle loads and the use of increased pressure in tires results in high stresses due to the contact area between the tire and the pavement which causes larger deformation in flexible pavements in the form of excessive wheel track rutting. Permanent deformation in wearing coarse thus accounts for a larger percentage of rutting on flexible pavements exposed to high tire pressures due to heavy axle load. Thus, rutting is a longitudinal depression in top layer along the wheel path with pavement disruption through the edges of the rut. Major structural failure and hydroplaning caused by rutting is a safety hazard. Rutting can take place in all pavement layers and results from lateral side densification and distortion. (Garba, 2002)

2.13 Moisture Damage of Asphalt Pavement

According to (Ahmed & Ahmed, 2014) moisture damage is the result of moisture effect and can be defined as the loss of strength and durability of asphalt mixes. In asphalt mixes moisture damage can occur if the fine aggregate and asphalt binder lack enough bond strength required for their bond integrity. Moisture damage occurs when moisture interacts with the adhesive between aggregate and binder in asphalt mix, which increase susceptible of asphalt mixture to moisture during cyclic loading.

stated that moisture damage happens when moisture present in air voids adversely affects the durability and strength of the HMA. The two types of moisture damage are Cohesive failure and adhesive failure. Failure which occurs when the binder's strength is reduced owing to moisture damage is cohesive failure, whereas adhesive failure happens when the aggregate and binder are separated. (O'Sullivan & Wall, 2009)

2.14 Indirect Tensile Strength Test

Tensile strength of HMA is very important since it is a decent pointer to confirm the HMA mixture probable of cracking. The mixture which exhibits high tensile stain demonstrates that HMA is extra probable to struggle against cracking and permit higher strains. Indirect tensile strength (ITS) of HMA mixture is done by loading the compacted cylindrical sample diagonally its vertical diameter plane at a standard proportion of distortion (50 mm/min) and at 25º C temperature as per ASTM standard (D6931). The significance of ITS test is determining the potential of bituminous mixes against rutting and cracking. Specimen split when even tensile stress is along perpendicular diametrical plane and vertical to functional load (Yoder & Witczak, 1975). The loading process produces an equal tensile stress perpendicular to the functional load and perpendicular to the perpendicular diametral plane. The ITS test results in the splitting of the HMA sample. The indirect tensile strength (ITS) is determined by applying a constant rate of ram movement to failure, according to ASSHTO TP9-96. The following equation is used to calculate tensile strength:

$$S = \frac{2P}{\pi t d}$$

Where,

d = Diameter of the sample (mm),

t = Thickness of the sample (mm),

P = Peak load (KN).

The stress distribution on the vertical diametric plane ITS is shown in Figure 2.4

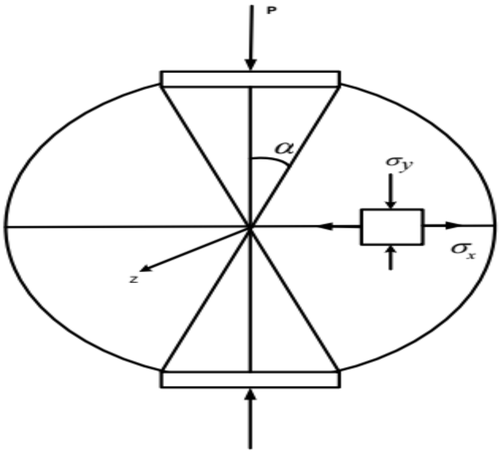

Figure 2.3 ITS Stress Distribution

2.15 Factors Affecting the Indirect Tensile Strength Test

In indirect tensile strength test (ITS) a micro-crack is commenced at the center of the sample and spreads in the direction of the loading strips along the perpendicular direction because of the tensile stresses. Hence, the behavior of the material at the middle of the testing sample is of consideration. Meanwhile the stress and strain dispersal in the ITS test sample is not even, the strain at the middle of the sample is not identical to the average strain which is found by dividing measured movement by gauge length used (Kennedy, 1977).

HMA samples compacted by the SGC are anisotropic. The course of tensile stress in an ITS test is vertical to that in a uniaxial direct tension test. According to research it is extremely probable that HMA is not an isotropic material. Hence, it gives the impression that the anisotropicity of HMA may be a basis for difference of outcomes from the ITS test and the uniaxial direct tension creep test.

2.16 Summary

This chapter includes brief introduction on hot mix asphalt pavement design methods and analysis. It also covers the role of the binder, aggregate, and aggregate gradation in HMA behavior. It also includes the various modifiers used in HMA, limitations of these modifiers and their compatibility with the aggregates and binders. Laboratory evaluation of EVA modified asphalt pavements mixtures and their performance testing. Overview on rut distress in flexible pavement, its types and factors affecting the pavements. Moisture susceptibility and indirect tensile strength test are also discussed briefly.

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1 General

This Chapter includes the methodology adapted for the research work in detail. It includes Material characterization, gradation adopted, specimen preparation, testing, results and analyzing the importance of various factors. The study was carried out to analysis the behavior of Ethylene vinyl acetate in hot mix asphalt. In first part of the research properties of EVA modified bitumen was studied. The properties which were tested are penetration grading, ductility of bitumen, softening point, flash and fire point. In order to determine the OBC, the adopted Marshal Mix design procedure will be discussed in detail. Marshal mix design was conducted, for these marshal samples were prepared and OBC was determined. Then samples for performance testing were prepared at optimum bitumen content. Performance tests which were performed are Double Wheel Tracker test, Moisture sensitivity and ITS Test. Further results were deduced, and conclusions and recommendations were presented.

3.2 Research Methodology

The framework of research is explained clearly in figure. First of all selection of material was done. Then the conventional tests were conducted on the aggregates and binder as per guidelines of AASHTO and ASTM. For wearing course mixtures, specimens were made in a lab under controlled settings. Following the discovery of OBC, these specimens were prepared. In the next step Samples were prepared and Performance tests i.e., Double wheel tracker test, Moisture Susceptibility and ITS tests were conducted on the prepared samples. After that, the results were analyzed, and conclusions and recommendations were made, which will be discussed in the next chapters.

3.3Characterization of selected Materials

The process by which material properties were measured is discussed in detail. All properties were measured according to the given standards.

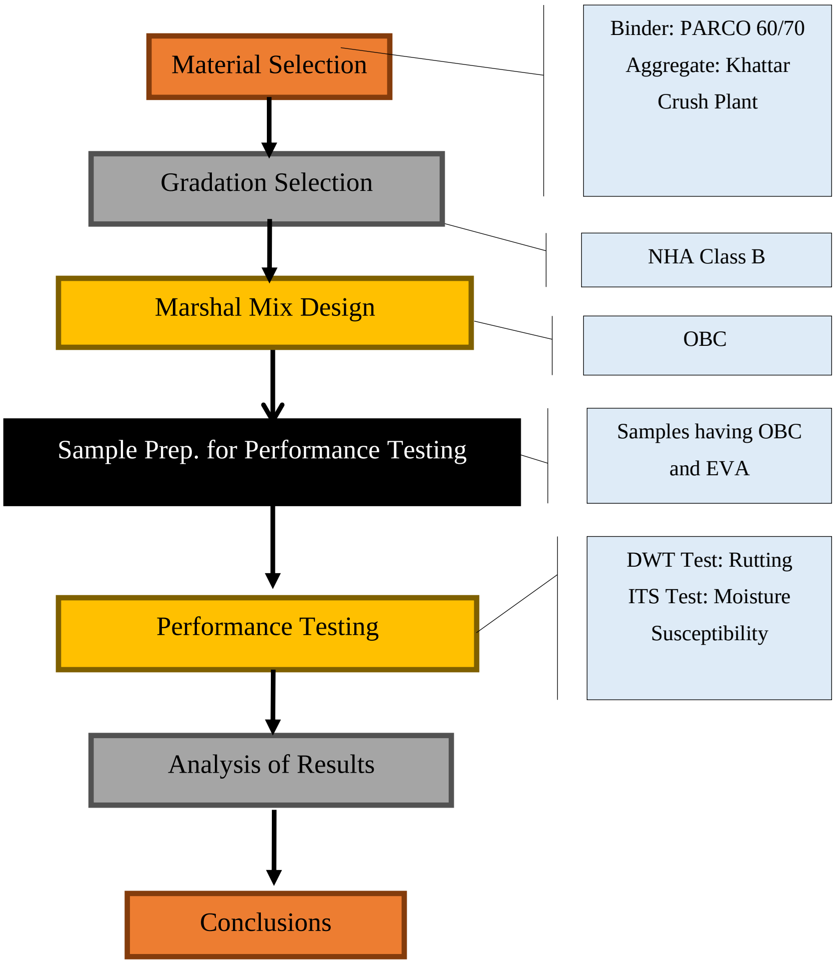

Figure 3.1 Research Methodology adopted

3.3.1 Materials Selection

In this study, coarse and fine aggregates from Khattar quarry were employed, as well as penetration grade 60/70 bitumen obtained from Pak Arab Refinery Limited (PARCO). Grade 60/70 was chosen since it is regularly used in Pakistani practice and is appropriate for chilly to moderate weather.

The aggregate structure in the mix provides most of the resistance to permanent deformation (almost 95%), with the asphalt binder providing the remaining 5%. Aggregates create a robust stone skeleton to withstand repeated load applications. The gradation, surface texture, and form of the aggregates have a significant impact on HMA characteristics. Shear strength is higher in angular and rough-textured aggregates than in smooth-textured spherical aggregates. Mandatory testing on the used aggregates and asphalt binder were carried out in accordance with ASTM and AASHTO standards and specifications for material characterization.

Ethylene Vinyl Acetate polymer of TPI Polene Public Company Limited was used. EVA is then used as a modifier in bitumen to prepare a polymer modified HMA. Performance tests were then conducted on modified and un-modified HMA to analyze results and compare the outcome.

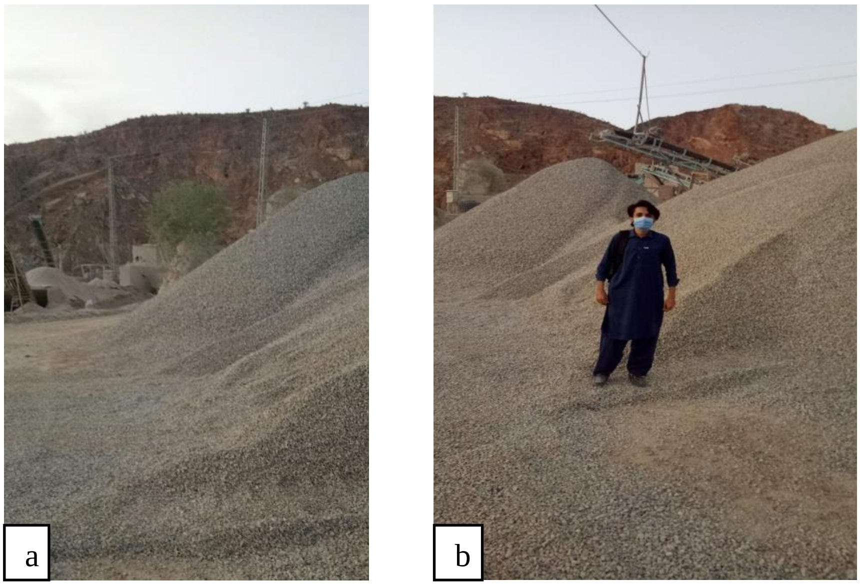

Figure 3.2 (a) & (b) Khattar Crush Plant

3.3.2 Aggregate Testing

The center element of the mix is the aggregate skeleton, which provides resistance to permanent deformation and is expected to provide a strong skeleton for resisting repetitive loads. To determine the aggregate fundamental features of each stockpile, for example thorough gradation and specific gravity laboratory tests were conducted. Laboratory experiments include the following:

- Shape Test of Aggregates
- Aggregates Specific Gravity and Water Absorption tests
- Aggregates Impact and Crushing values
- Aggregates Los Angeles Abrasion Test

All of the following tests were carried out with three samples, and the average was used as the final result.

3.3.2.1 Shape Test of Aggregates

Strength and workability of asphalt mixture mostly depend on shape of particles. It also effects the effort required for compaction vital to achieve the necessary density. Therefore, through shape test the quantity of elongated and flat aggregate particles were determined. According to ASTM D4791, aggregate particles are categorized as flaky aggregate having smaller dimension less than 0.6 of their mean sieve size, while the aggregate particles will be labelled as elongated with a length of greater than 1.8 of their mean sieve sizes shown in Table 3.1.

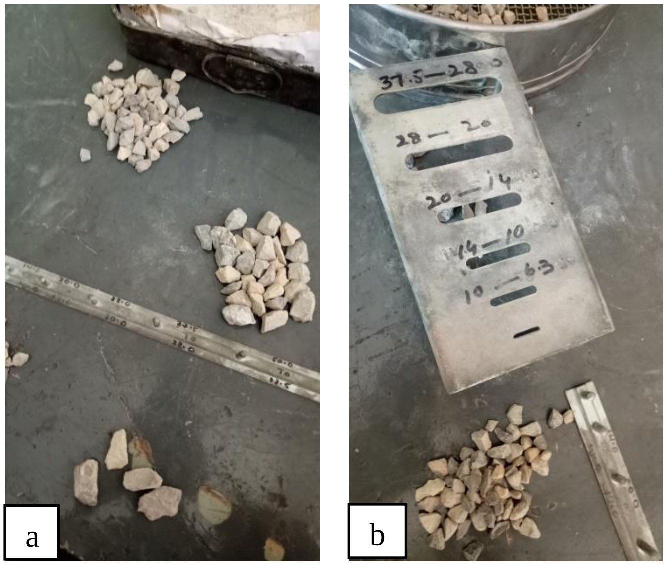

Figure 3.3 (a) & (b) Flakiness & Elongation Tests

3.3.2.2 Aggregates Specific Gravity

Specific gravity represents the weight volume characteristics of a material. Fine aggregate, coarse aggregate, and fillers specific gravities were determined individually. The aggregate that are retained on No. 4 sieve is coarse aggregate while fine aggregates are those passing No. 4 sieve.

Coarse Aggregate

S.G of coarse aggregate and water absorption were determined using ASTM C 127 techniques and equipment. The S.G test for coarse aggregate determine weight of coarse aggregate using three different conditions of sample, which are Oven-dry, dipped in water and saturated surface-dry. The test was accomplished for both of the course graded stockpiles and the results are presented in Table 3.1.

Fine Aggregate and Filler

S.G of fine aggregates were measured using the procedures and equipment stated in ASTM C 128. S.G test was carried out on fine aggregate to determine the values of bulk S.G, Saturated Surface Dry and apparent specific gravities with the result shown in Table 3.1

Figure 3.4 Specific Gravity Testing

3.3.2.3 Impact Value Test

The impact value of aggregate is its resistance to break. Equipment's used in performance of this test were sieves of sizes 1/2”, 3/8” and #8 (2.36mm), tamping rod and impact testing assembly. 350 grams of representative aggregate sample that passed through sieve ½” sieve and retained on 3/8” sieve was placed in impact test apparatus cup in three layers with each layer tamped 25 times. The sample was transferred into the larger mould of the machine and 15 blows from a height of 38 cm were given with the hammer weighing 13.5 to 14 kg. The aggregate was then removed and filtered using sieve #8. The impact value was measured by the percentage of aggregate passing through 2.36mm sieve.

Figure 3.5 Impact value Test of Aggregates

3.3.2.4 Crushing Value Test

To achieve a pavement with higher quality and strength, it is necessary for the aggregates to have enough strength to sustain traffic loads. The apparatus used for this test was steel cylinder having open ends, base plate, plunger with a piston diameter of 150 mm and a hole provided across it, so that a rod could be inserted for lifting it, cylindrical measure, balance, tamping rod, and a compressive testing machine. Aggregates were passed through a set of sieves and that passing through ½” and retaining on 3/8” were selected. Sample of aggregate was washed, oven dried and weighed (W1) and then added into that cylindrical measure in three layers, each layer being tamped 25 times. The sample was shifted into the steel cylinder with base plate in three layers and the plunger was inserted. It was then placed in compressing testing machine and load was applied at a uniform rate of 4 tons/minute until the total load was 40 tons. Crushed aggregate was then removed from the steel cylinder and passed through 2.36mm sieve. The material that passed through this sieve was collected and weighed (W2). Aggregate Crushing value was calculated by = W2/W1 x 100

Figure 3.6 Crushing Value Test

3.3.2.5 LOS Angeles Abrasion Test

This test determines hardness of road aggregate. Aggregate must be hard enough to resist wear due to heavy traffic loads. The apparatus used for this test included Los Angeles Abrasion machine, balance, set of sieves and steel balls. Testing methodology or grading B was adopted for this procedure. 2500 g of aggregate retained on ½" and 3/8" sieves each, which is a total of 5000g (W1) of aggregate along with 11 steel balls or charges were placed in the Los Angeles abrasion machine. For 500 revolutions, the machine was operated at a speed of 30 to 33 rpm. The material was then sieved through a 1.7mm sieve. The weight of the sample that passed through it (W2) was recorded. The abrasion value was found out by = W2/W1× 100

Figure 3.7 LOS Angeles Abrasion Test Apparatus

So, It is vital to examine the acceptability of aggregates in light of ASTM and BS standards and specifications for material characterization while preparing Asphalt mixtures. These experiments were carried out using Khattar quarry aggregate, Table 3.1 show the tests performed on the aggregates,

Table 3.1: Test results of Aggregates

Test	Specification		Result	Limits
Flakiness Index	ASTM D 4791		15%	≤15%
Elongation Index	ASTM D 4791		2.3%	≤15%
Aggregate Absorption	Fine	ASTM C127	0.6%	≤3%
	Coarse		0.9%	≤3%
Impact Value	BS 812		19%	≤30%
Specific Gravity	Fine Agg	ASTM C128	2.58	-
	Coarse Agg	ASTM C127	2.63	-
LOS Angles Abrasion	ASTM C131		21%	≤45%

3.3.3 Tests on Asphalt Binder

For the construction and engineering purposes, consistency, safety, and purity are the three properties of binder which are essential to be considered. The consistency of asphalt binder changes as the temperature changes. As a result, for testing asphalt binder consistency, a standard temperature is required. The consistency of bitumen binder is usually assessed through penetration or a viscosity test. Other tests, such as the softening point test and the binder ductility test, add to the consistency information and confidence. As a result, the following experiments were carried out in the laboratory to characterize the asphalt binder.

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

3.3.3.1 Penetration Test

Penetration of asphaltic materials can be found out through penetration test. The penetration test comprises containers having specimen and needles. Penetration values are higher when the binder is softer. According to AASHTO T 49-03, the temperature utilized was 25°C, the load was 100 grammes, and the test time was 5 seconds, unless otherwise specified. Using PARCO 60/70 specimens, three values from each specimen were taken after performing penetration tests. All values obtained fulfilled the required criteria of penetration.

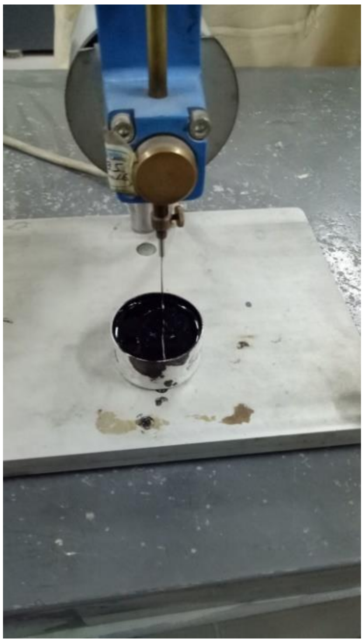

Figure 3.8 Penetration Test

3.3.3.2 Softening Point Test

Bitumen is a material with visco-elastic property, but as the temperature go higher it progressively becomes softer and its viscosity reduces. The temperature at which a standard-size sample of bitumen can no longer support the weight of a 3.5-gram steel ball is referred to as the bitumen's softening point. As a result, the mean temperature at which the two rings of binder soften enough to allow the 3.5 grams steel balls to fall 25 mm and touches base of the jar is known as the bitumen softening point. According to AASHTO-T-53 recommendations, the ring and ball apparatus was used to evaluate the softening point of asphalt. The findings of the softening point test are shown in Table 3.2.

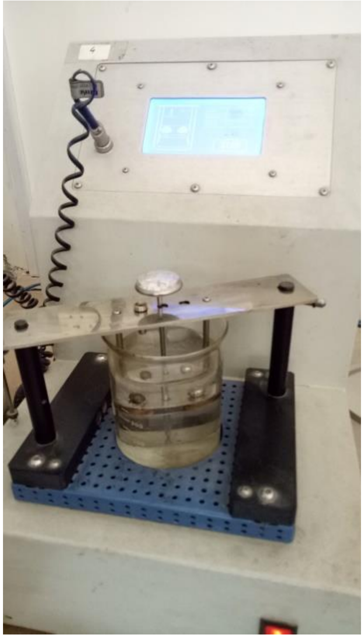

Figure 3.9 Softening Point Test

3.3.3.3 Ductility of Asphalt

Ductility is an important property of asphalt binder and an important component to consider when describing the performance of an HMA mixture. Ductility depicts how bitumen reacts to temperature variations. It is defined as the " the length in cm that a standard sample of the asphaltic material will be stretched without breaking at specific speed that is 5 cm per minute and at specified temperature of 25 ± 0.5°C defined by (AASHTO T 51-00). Table 3.2 shows the standard conditions and results obtained for ductility tests for bitumen. All specimens had seen satisfying the minimum 100cm ductility criteria.

Figure 3.10 Ductility Test

3.3.3.4 Flash and Fire Point Test of Bitumen

The flash point of bitumen is the lowest temperature at which it flashes momentarily under certain conditions.

The temperature at which a material will catch fire and burn under specified conditions is known as the fire point. The D3143/D3143M-13 standards were used to conduct the flash and fire point tests.

Figure 3.11 Flash & Fire Test

3.3.3.5 Viscosity Test of Asphalt Binder

The ratio of applied shear stress to rate of shear is known as viscosity. It's a metric for flow resistance. This test defines the method for viscosity measurement of bitumen at high temperature from 60^{o}C to over 2000^{o}C. Concept of torque is used by rotational Viscometer. It measures the torque that is required to rotate an object that is submerged in fluid (Bitumen in this case) and relates it to the viscosity of the fluid. This test is conducted in accordance with test standard ASTM D 4402 – 06. Results are shown in table 3.2.

Figure 3.12 Viscosity Test

So, for asphalt mixes preparation, it is also compulsory to check the suitability of bitumen as well, in light of ASTM material characterization criteria and specifications. The above-mentioned tests were carried out in laboratory to characterize the asphalt binder (PARCO 60/70). Table 3.2 shows the results of tests performed.

Table 3.2 Tests results on Bitumen

S No.	Test Description	Specification	Result
1	Penetration test@25°C	ASTM D: 5-06	66
2	Flash Point(°C)	ASTM:D-92	286
3	Fire Point(°C)	ASTM:D-92	308
4	Softening point(°C)	ASTM D 36 – 95	51
5	Ductility Test(cm)	ASTM-113-99	119
6	Viscosity Test (Pa.sec)	ASTM D 88 – 94	0.27
7	Specific Gravity	ASTM D 70	1.07

3.4 Modified Asphalt Binder Tests

Tests were performed on modified asphalt binders to check their properties. 2%, 4%, and 6% of EVA was used in asphalt. Tests like penetration, softening point and ductility were performed on modified asphalt to check the effects of modification on properties of asphalt. The results of various tests are shown in Table 3.3.

Table 3.3 Test results on Modified Binder

% Of EVA in bitumen	Penetration Value	Softening point	Ductility
2	64	53	105
4	61	55	100
6	54	58	80

3.5 Gradation Selection

For dense graded surface course mixtures, NHA (1998) requirements were used, the aggregate gradation employed was NHA class B. Nominal maximum size for this gradation was (3/4") or 19mm according to MS-2. The gradation selected is shown on in table 3.4 per percent passing against each sieve and corresponding gradation curve is plotted in Fig 3.13.

Table 3.4 NHA Class B Gradation

S.No	Sieve Size mm	NHA Specification Range (% Passing)	Mid gradation Selected (% Passing)	% Retained
1	**19**	**100**	**100**	**0**
2	**12.5**	**75-90**	**82.5**	**17.50**
3	**9.5**	**60-80**	**70**	**12.50**
4	**4.75**	**40-60**	**50**	**20**
5	**2.38**	**20-40**	**30**	**20**
6	**1.18**	**5-15**	**10**	**20**
7	**0.075**	**3-8**	**5.5**	**4.50**
8	**Pan**	**-**	**-**	**5.50**

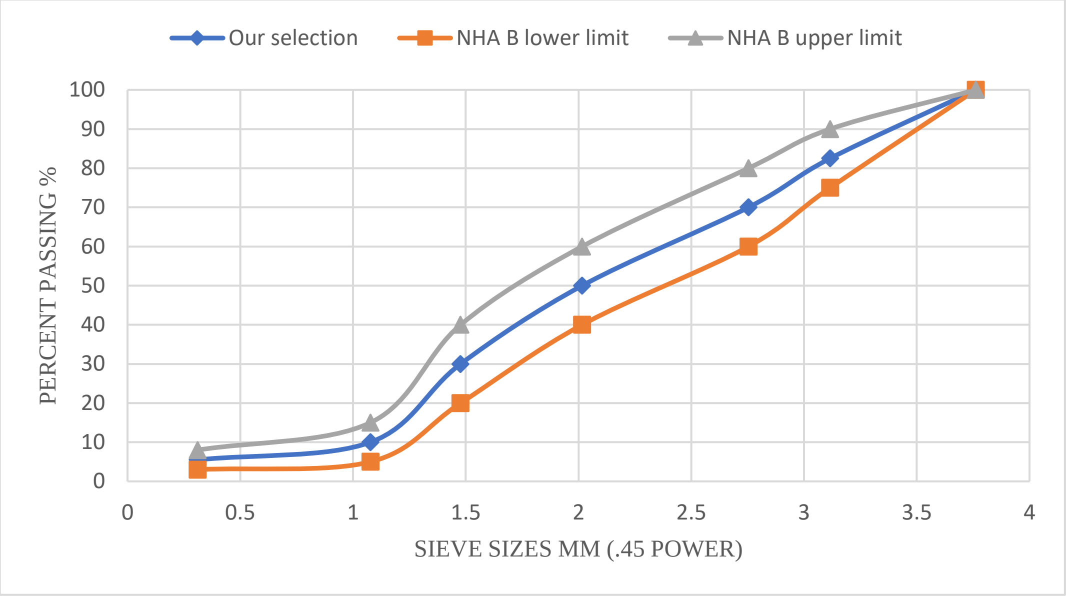

Figure 3.13 NHA Class-B Gradation plot with Specified limit

3.6 Asphalt Mixtures Preparation

Asphalt mixtures are prepared having different percentages of bitumen by weight of aggregates. These specimens are prepared per Marshall Mix Design Procedure. After determination of OBC, samples were prepared for Performance Testing.

3.6.1 Preparation of Bituminous Mixes for Marshall Mix Design

Optimum bitumen content (OBC) was determined through Marshall Test for virgin bitumen using different percentages of bitumen (3.5% 4% 4.5% 5% 5.5%). After sieving the Aggregate into different sizes required for the project, these aggregates were then oven dried at 110 °C. The total sample weight of Marshall Mix is 1200gm. The weight of Asphalt content varied according to its percentage which is from 3.5% to 5.5% of mix. The aggregate then used is composed of different sizes according to gradation used. Marshall Stability, flow and volumetric properties were measured to obtain OBC.

3.6.2 Preparation of Bituminous Mixes

Aggregates were dried at 105°C to 110°C to a constant weight after sieve examination. 1200 gram of aggregate is required for the Marshall Mix design method (ASTM D6926) to prepare a compacted 4-inch diameter sample. The amount of bitumen required for each specimen was calculated using Equation 3.2 as a percentage of the total weight of the mix:

$$M_T = M_A + M_B \quad (3.1)$$

$$M_B = X/100(M_T) \quad (3.2)$$

Where,

M_T = Total mix Mass

M_A = Aggregate Mass

M_B = Bitumen Mass

X = Bitumen Percentage

3.6.3 Mixing of Aggregates and Asphalt

The mechanical mixer is recommended by ASTM D6926 for effective mixing of bitumen and aggregates. After extracting the dried, heated aggregates and heated bitumen from the oven, they were immediately transferred to the mechanical mixing equipment. The schematic diagram of a mechanical mixing machine is shown in Figure 3.14. The temperature range for mixing was 160°C to 165°C, which corresponds to the temperature in Pakistan when bituminous mixes are manufactured (NHA Specifications). Moreover, this mixing temperature corresponds to the binder viscosity range of 0.22 - 0.45 Pa.sec as specified by Superpave mix design (SP-2).

Figure 3.14 Mechanical Mixer

3.6.4 Conditioning of Mixture

Bituminous mixes should be conditioned for two hours before compaction, according to ASTM D6926. As a result, each bituminous mix produced by the mixing machine was placed in a metal container.

3.6.5 Specimen Compaction

According to Marshall Mix design, there are three criteria for compaction depending on either the surface is prepared for light, medium or heavy traffic. For design purpose we consider pavement for heavy traffic so 75 blows on each side of specimen are applied to achieve compaction. The loose mix obtained from heating aggregate with bitumen is transferred to mould having base plate. A filter paper was placed below and above the specimen. After achieving 75 blows on one side, specimen was inverted, and 75 blows were applied in other side of specimen. This compaction was achieved manually.

Figure 3.15 Compaction Equipment

3.7 Volumetric, Marshall Stability and Flow determination

Volumetric parameters, including Voids Filled with Asphalt (VFA), Voids in Mineral Aggregates (VMA), unit weight, and Air Voids (VA) were evaluated using formulas after the measurement of bulk specific gravity (Gmb) and theoretical maximum specific gravity (Gmm). Table 3.5 shows the Marshall Mix design requirement. ASTM D2041 and ASTM D2726 were used to determine the Gmm and Gmb of bituminous pavement mixtures. Following the Gmb determination, the samples were immersed in a water bath at 60°C for 1 hour before tested for flow and stability using Marshall Test apparatus.

When sample was placed in Marshall equipment, it was loaded with constant deformation rate of 5mm/minute to the limit where the sample fails to take more load. Marshall Stability was calculated using the entire maximum load in KN. Maximum load that mix sample can bear before failing is the stability value and the strain in the sample occurring at maximum load is recorded as flow number in millimeters. According to Marshall Mix design criteria, for pavement surface designed for heavy traffic should not have stability value less than 8.007 KN and Flow value should be 2 to 3.5 mm. After extracting the specimen from the water bath, it was immediately tested.

Figure 3.16 Marshall Stability & Flow Testing Equipment

3.7.1 Volumetric Properties of HMA

The volumetric properties, stability and flow correspond to the virgin mix are as shown below in Table 3.5

Table 3.5 Volumetric Properties of the Mix

Volumetric Properties of Mix								
S.No	**Binder %**	**Flow (mm)**	**Stability (KN)**	**G_{mb}**	**G_{mm}**	**Air Voids (VA)**	**VMA**	**VFA**
1	3.5%	2.21	10.72	2.24	2.47	6.72	15.42	48.62
2	4.0%	2.52	12.61	2.27	2.45	5.32	15.26	53.72
3	4.5%	2.8	13.15	2.31	2.44	4.42	14.85	64.23
4	5.0%	3.3	12.82	2.35	2.42	3.48	14.62	71.57
5	5.5%	3.8	11.56	2.39	2.41	2.68	15.16	75.25

The graphs relating asphalt contents and volumetric qualities, stability, and flow were drawn according to the MS-2 handbook to determine the OBC of virgin mix, as shown in Figure 3.17.

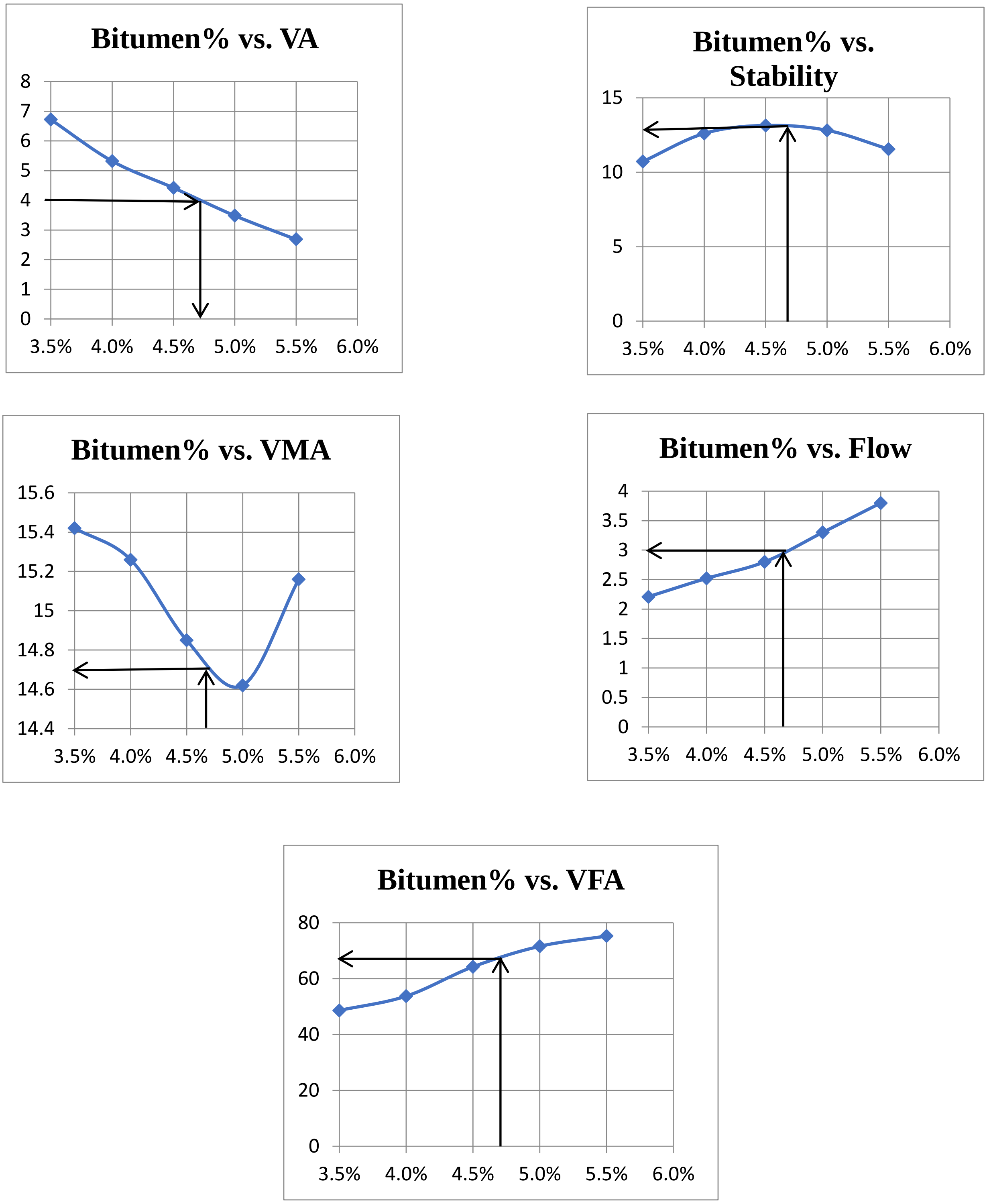

Figure 3.17 Graphs of Volumetric properties of the Mix

The asphalt contents at 4% Air void are called as OBC. The mix has OBC of 4.72%. The mix characteristics, stability and flow according to OBC were determined from the graphs. Table 3.6 shows the job mix formula of virgin mixture. It is clear from the table that all of the characteristics, stability and flow meeting the criteria. The VMA should not be less than 13% and its value was 14.68% from calculations of this study. VFA should be between 65 and 75 percent, and its computed value was 67 %. According to the standards, the stability value should not be less than 8.006 KN, yet it was 12.9 KN in this situation. The measured flow number was 3.1 mm, which is within the acceptable limit.

Table 3.6 Job Mix formula

Parameters	Value Measured	Limits	Remarks
OBC	4.72	-	-
VMA (%)	14.68	≥13	Pass
VFA (%)	68	65-75	Pass
Stability (KN)	13	≥8.006	Pass
Flow (mm)	3	2-3.5	Pass

3.8 Preparation of Sample for Performance Tests

Superpave mix design was utilized to create specimens for double wheel tracker testing and for moisture damage Marshall method was used to prepare samples to check through UTM. The aggregates were heated to constant weight at 105°C to 110°C. HMA had a mixing temperature of 160°C and a compaction temperature of 135°C. 6000gm of aggregates were required to prepare 6-inch diameter gyratory compacted specimens. After mixing aggregates and asphalt binder in mechanical mixer samples were placed for conditioning in oven for 2 hours. After conditioning samples were placed in the gyratory mould and a total of 125 gyrations were used to compact the specimens. For the wheel tracker test, a standard sample of 2.5 inches in height and 6 inches in diameter was obtained using a saw cutter on each specimen. Saw cutting of specimens, for conducting tests are shown in Figure 3.18.

Figure 3.18 Gyratory sample preparation & Saw Cutting

3.9 RUTTING INVESTIGATION OF SAMPLES

Rutting is one of the most prevalent pavement permanent deformations, caused by cyclic traffic loads and characterized by the accumulation of minor pavement material deformations in the form of longitudinal depressions along the wheel paths. The specimens were evaluated using a Double wheel tracker to determine their resistance to persistent deformation in order to investigate rutting propensity. The DWT is an electrically powered device that can move a steel wheel with a diameter of 203.2mm and a width of 47mm across a test specimen. The weight on the steel wheel is 1581.0 lbs, and the average contact stress produced by the wheel contact is 0.73 MPa with a contact area of 970 mm^2. Just like the influence of rear tire of a double axle is produced by the contact pressure of steel wheel. As the rut depth increases, the contact area expands, and the contact stresses become more varied. In a forward and backward motion, the steel wheel passes over the object. DWT steel wheel must pass the sample roughly 60 times per minute. The highest speed of the wheel over the specimen is nearly 1 ft/sec, which is achieved at the center of the sample. With the help of DWT rutting test can be carried out on dry, wet and air modes. In this research dry mode was used to determine the susceptibility of asphalt mixtures to rutting. These three modes can be utilized by adjusting the DWT at anticipated test conditions. Figure 3.35 shows the Double wheeltracking device used for conducting rutting tests. Before conducting the test, two 2.5-inch-thick specimens were obtained by sawing the samples from the top and bottom surfaces. These specimens were cut using the wheel tracker tray's silicon mould.

The steel tray containing the sample was stowed under the wheel and secured. The wheel tracker system was activated. The sample information was then entered into the software. The wheel's speed was set to 25 ppm (passes per minute). The number of passes was set to 10,000 (5000 cycles) as required for determining the rutting potential of asphalt mixtures including grade 58 bitumen (PARCO 60/70). Wheel tracker was used by selecting dry mode for determination of rut damage at 40°C temperature. Finally, the test was run, and wheel started moving forward and backward on the mounted specimen. The number of passes were shown on the laptop connected with machine. One complete to and fro movement of the wheel was taken as 2 passes. The LVDT (Linear Variable Differential Transformer) measures the impression of rut in millimeters of unit at the same time with the motion of wheel. The machine automatically stopped when required number of passes were achieved. Results were saved for further use.

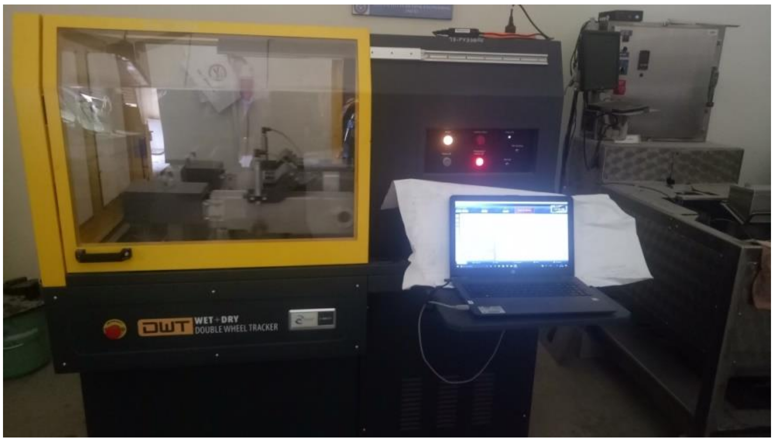

Figure 3.19 Double Wheel Tracker Device

3.10 MOISTURE SUSCEPTIBILITY TESTING

According to ASTM D 6931-07, the moisture susceptibility test was performed (Moisture-Induced Damage Resistance of Compacted Hot-Mix Asphalt). Three unconditioned specimens per mix were tested. One hour before testing, these unconditioned specimens were immersed in a water bath at 25°C (77.8°F). Conditioned specimens were tested in a separate batch of three per mix. Samples were saturated and then placed in a 60°C (140.8°F) water bath for 24 hours, followed by one hour in a water bath at 25°C (77.8°F) according to ALDOT-361. Both unconditioned and conditioned specimens were loaded diametrically at a rate of 50 mm/minute. For each specimen the tensile strength was then calculated using specimen dimensions and failure load. The average conditioned tensile strength was then divided by the average unconditioned tensile strength to obtain the tensile strength ratios. The acceptable value for tensile strength ratio employed was 80% (minimum). The tensile strength of each subset was determined by Equation 3.3

$$St = 2000P/\pi Dt \qquad (3.3)$$

Where:

St = Tensile strength, kPa

P = Maximum load, N

t = Specimen height before tensile test, mm

D = Specimen diameter, mm

The TSR, which is the ratio of the conditioned subset's tensile strength to that of the unconditioned subset, indicates the possibility for moisture damage. Equation 3.4 is used to compute the TSR for each blend.

$$TSR = [S2/S1] \qquad (3.4)$$

Where:

S1 = Average tensile strength of unconditioned subset, and

S2 = Average tensile strength of conditioned subset.

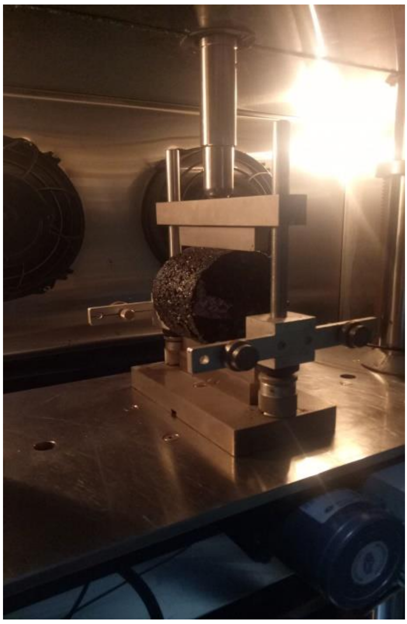

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Figure 3.20 ITS Testing using UTM

3.11 Summary

This chapter explains the testing of Aggregate, Bitumen and Modified Bitumen. The material was then used to prepare Bituminous Mix samples. The volumetric properties of mix were calculated and OBC was determined. The OBC determined was then used to prepare samples for performance testing i.e., Moisture Susceptibility and Rutting Testing. In the end of Chapter Moisture Susceptibility and Rutting Test methods were elaborated.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The most common type of distress found on HMA pavements in Pakistan is rutting and it mainly occurs due to higher temperatures coupled with heavier axle loads. Therefore, employing the Double Wheel tracker tests, are technically as well as practically reasonable as to investigate rutting susceptibility. Along with rutting, moisture also acts as a destructive agent which results in earlier collapse of pavement and by checking moisture damage via UTM is the easiest method.

This study is based upon the utilization of EVA as modifier in HMA, to see the effects of polymer modification on rutting and moisture susceptibility. Different percentages of EVA by weight of bitumen were used to determine optimum modifier content to be used further in the preparation of HMA samples for performance tests of the pavement. EVA was procured from Lahore. Samples for performance tests were prepared after determining OBC. The gradation used was NHA Class B.

Rutting susceptibility and moisture damage have already been discussed in length in the Literature Review, and techniques and test parameters used in tests have already been discussed in Chapter 3 (Research and Testing Methodology). This chapter contains a detailed examination of data derived from experimental outcomes, as well as detailed test results. The acquired results were analyzed using Microsoft Excel statistical software.

4.2 Results of Permanent Deformation (Double Wheel Tracker)

Permanent deformation was evaluated by comparing the control specimen’s resistance to rutting, with EVA modified asphalt mixtures. Gyratory compacted specimens were prepared for control samples and samples containing 2%, 4%, and 6% EVA and OBC making HMA, by using NHA class B wearing course.

Under dry conditions, wheel tracker tests were performed on specimens prepared for rutting. A total of eight samples were prepared for the wheel tracker test, these samples were saw cut for wheel tracker to check its rutting potential. The controlled specimens all showed good rutting resistance. Rut resistance increased when EVA percentage increased. All specimens passed the 12.5 mm wheel tracker test.

Table 4.1 DWT Test Results

No. of cycles	Rut Depth (mm) for unmodified HMA	Rut Depth (mm) for HMA modified with 2% EVA	Rut Depth (mm) for HMA modified with 4% EVA	Rut Depth(mm) for HMA modified with 6% EVA
0	0	0	0	0
1000	2.26	2.04	1.98	1.79
2000	2.58	2.33	2.22	2.04
3000	3.14	2.86	2.57	2.31
4000	3.67	3.29	2.99	2.78
5000	4.02	3.72	3.45	3.16

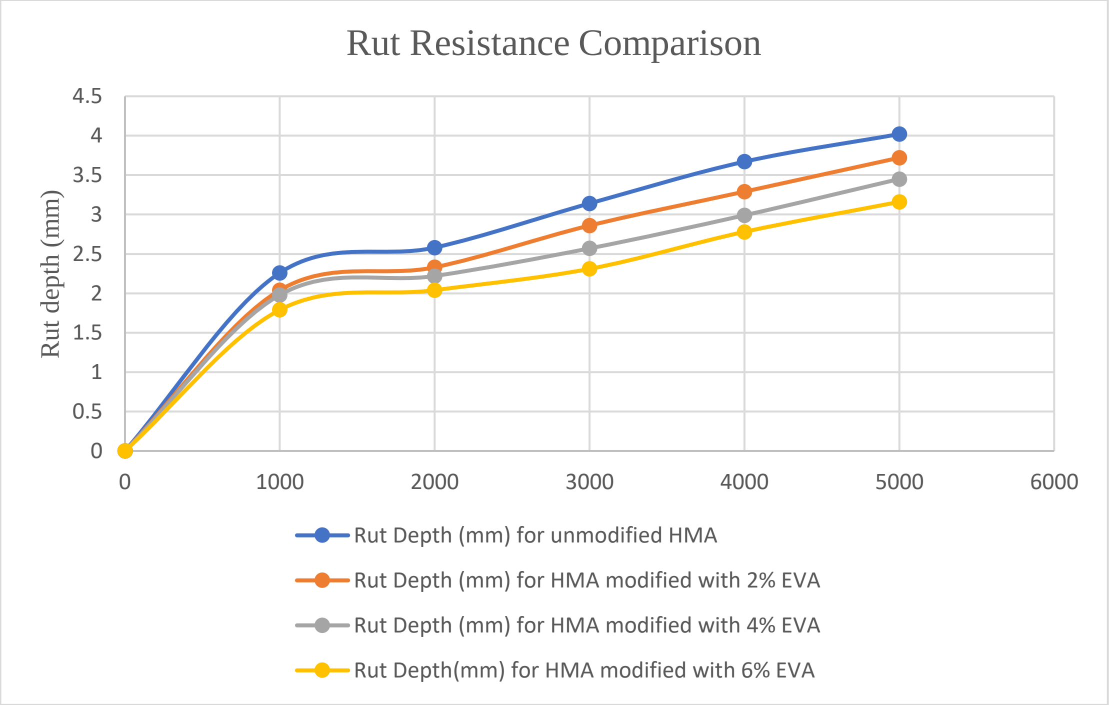

Figure 4.1 Rut resistance Comparison of Modified & Un Modified Samples

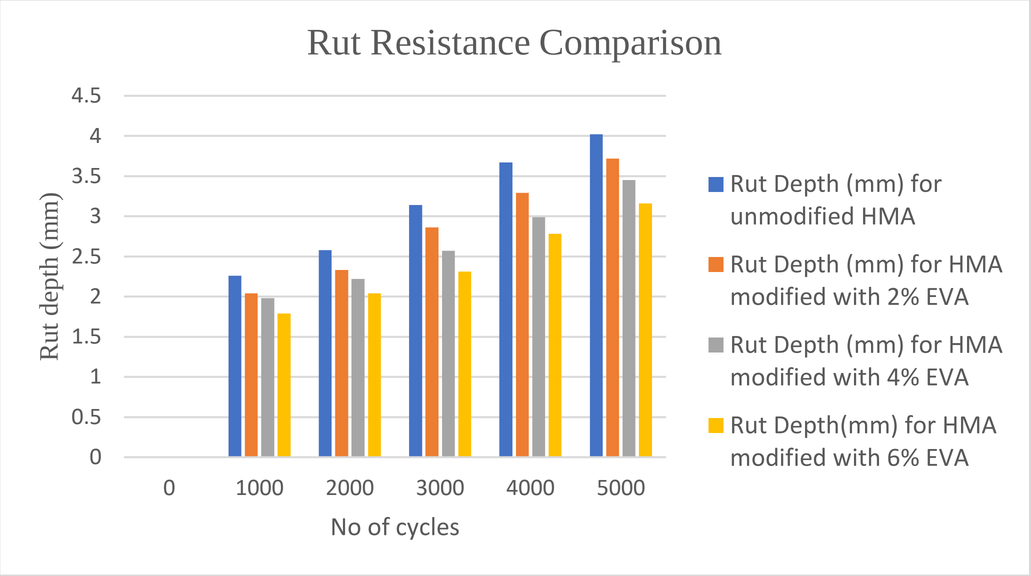

Figure 4.2 Graph of Rut resistance Comparison of Modified & Un Modified Samples

4.3 Moisture Susceptibility Results

Following the completion of the mix design, the mixes were subjected to a moisture susceptibility test in accordance with ASTM D 6931-07. (Moisture-induced damage resistance of compacted hot-mix asphalt). ALDOT 361 was used to condition the samples while they were being processed. A total of 16 samples were prepared and tested for ITS test (8 samples were tested unconditioned and 8 samples were tested after condoning). Eight of the samples were tested un-conditioned, while the remaining Eight specimens were subject to a 60°C warm-water soaking cycle for 24 hours following one-hour conditioning at 25°C before being tested for ITS. The conditioned specimens were not subjected to any freeze-thaw conditioning cycles. Table 4.3 and 4.4 shows the raw conditioned and unconditioned strength values for the combinations. The results demonstrate that adding EVA increases strength.

Tables 4.5 summarize the moisture sensitivity results. A TSR of at least 80% is required per Superpave standards. The TSRs for the calculated blends were all above 80%.

Also, the ITS data reveal that all conditioned samples have a lower strength value than unconditioned samples.

Table 4.2 Test matrix for moisture Susceptibility

Test matrix for moisture Susceptibility			
EVA%	Unconditioned Samples	Conditioned Samples	Sub-Total
0	2	2	4
2	2	2	4
4	2	2	4
6	2	2	4
		Total	16

Table 4.3 Tensile Strength Results for HMA containing EVA (Unconditioned Samples)

Tensile Strength Results for HMA containing EVA **(Unconditioned Samples)**						
EVA (%)	Height (mm)	Mean(mm)	Diameter (mm)	Load (kN)	Mean Load(kN)	Tensile Strength (kPa)
0	65.92 65.35	65.6	101.2	7.87 7.95	7.91	758.52
2	65.47 65.71	65.6	101.2	8.15 8.09	8.12	778.66
4	65.75 65.21	65.5	101.2	8.28 8.36	8.32	799.06
6	65.95 65.43	65.7	101.2	8.48 8.55	8.51	814.82

Table 4.4 Tensile Strength Results for HMA containing EVA (Conditioned Samples)

Tensile Strength Results for HMA containing EVA **(Conditioned Samples)**						
EVA (%)	Height (mm)	Mean (mm)	Diameter (mm)	Load (kN)	Mean Load(kN)	Tensile Strength (kPa)
0	64.35	65.0	101.2	7.43	7.47	722.94
	65.56			7.51		
2	65.66	65.5	101.2	7.74	7.71	740.47
	65.28			7.69		
4	65.85	65.6	101.2	7.94	7.90	757.57
	65.41			7.86		
6	65.91	65.6	101.2	8.05	8.01	768.11
	65.35			7.98		

Table 4.5 TSR Values

EVA (%)	**Conditioned strength (kPA)**	**Unconditioned strength (kPA)**	**TSR Value**
0	722.94	758.52	95.3
2	740.47	778.66	95.09
4	757.57	799.06	94.8
6	768.11	814.82	94.2

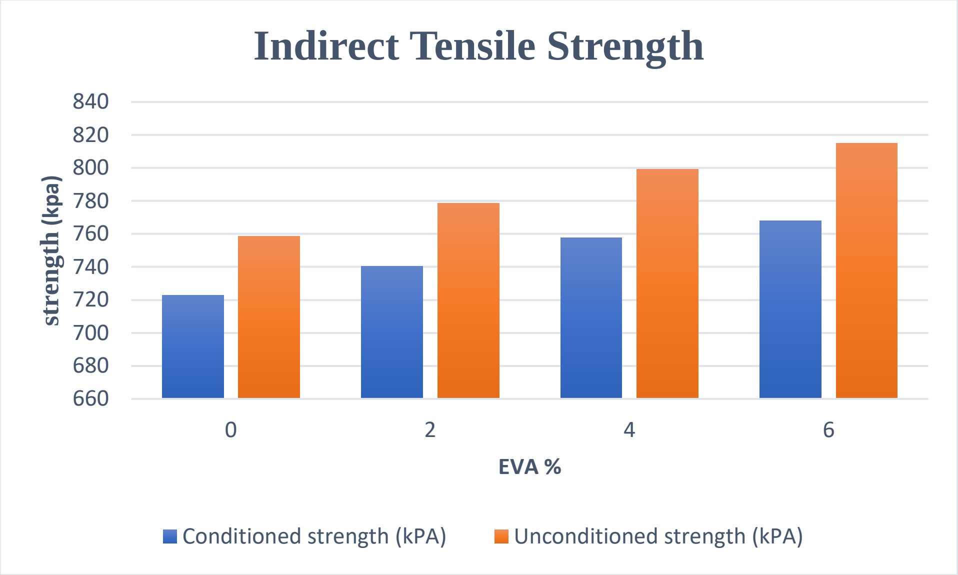

Figure 4.3 ITS Comparison

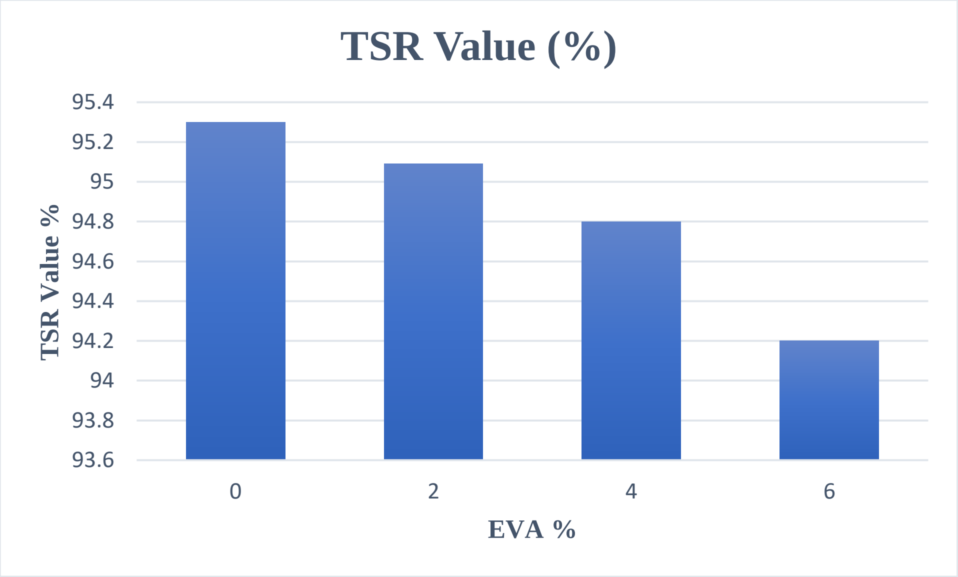

Figure 4.4 TSR Value

4.4 Summary

In this chapter the detailed analysis of the results obtained after laboratory testing has been discussed. The results obtained from the DWT and UTM are discussed in reference to increase in RUT potential, ITS values and TSRs. The data analysis results were presented in tables and graphs. The results of wheel tracker test, ITS test for controlled specimens and specimen containing EVA were presented in the form of bar charts. Comparison of results is done and discussed in detail, which showed that EVA mixes has greater resistance to rutting as compared to the controlled specimens, while ITS values for EVA modified mixes is somewhat lower than that of unconditioned samples.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The goal of this research was to determine the performance of EVA polymer modified HMA using the Superpave mix design and to determine whether the properties of HMA had improved. The results of a simple performance test and a universal testing system were used to assess the performance of asphalt mixtures. To characterize the performance of asphalt mixtures, EVA was utilized as a modifier. It was determined what the optimal binder and polymer content should be. For performance evaluation of pavement, double wheel tracker and UTM were used. NHA Class B wearing course gradation, PARCO Bitumen of grade 60/70 and aggregate was brought from Khattar. EVA used was of TPI polene private company limited. For determining OBC, Marshall Method was utilized. After determining OBC, samples were prepared for performance testing. For rutting samples were prepared by gyratory compactor. For ITS and moisture susceptibility samples were prepared by Marshall compactor. The key findings of performance testing, their results and conclusions are as follows.

5.2 Conclusions

Conclusions of this study based on the results are as follows:

- Penetration grade of bitumen 60/70 decreased by addition of EVA thus making it hard and stiff. Softening point of bitumen 60/70 increased by addition of EVA while Ductility of bitumen 60/70 decreased by addition of EVA.
- By performing asphalt binder penetration tests and ductility tests on different EVA contents with respect to virgin bitumen with the value of EVA content as 4% of the virgin bitumen shows that 4% EVA won’t change the binder grade and other properties.
- A criterion for Optimum Bitumen Content was set at 4% air voids and OBC calculated was 4.72%. Other properties were also well within their ranges.
- Samples prepared using gyratory compactor having EVA modified asphalt binder for rutting susceptibility testing shows better rutting resistance than the samples prepared with conventional asphalt binder.

- A rut resistance increase of 14% was observed by using EVA polymer modified bitumen as compared to unmodified bitumen prepared samples.
- The results of ITS values for samples with EVA modified asphalt binder reveal that the strength values have increased because of the mix having more viscous material performing better under tension, but moisture susceptibility (TSR) value shows a slight decrease but still above the limit.
- By considering all the factors we can use EVA as a replacement of virgin bitumen in HMA.

5.3 Recommendations

- Tensile Strength Ratio tests were performed for the project to determine the moisture susceptibility of specimens. Rutting susceptibility test was performed to check the rut resistance of the modified HMA. Other tests such as Dynamic Creep Testing for Rutting, Stiffness modulus, fatigue testing, resilient modulus test should be performed to using different percentage of EVA to have a more knowledge of it and have a more categorized EVA behavior in HMA.
- It is suggested to evaluate the performance of EVA modified asphalt, trail section be constructed after extensive testing to verify that EVA modified asphalt suits the climate condition of country and to the adverse traffic loadings.
- More research on the effect of modification on the rheological characteristics of binder is needed.
- This research was performed using virgin EVA polymer, as we have knowledge of its effect on HMA behavior it is recommended to also use waste EVA polymer to check its properties with bitumen and have a more cost effective modified HMA.

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APPENDICES

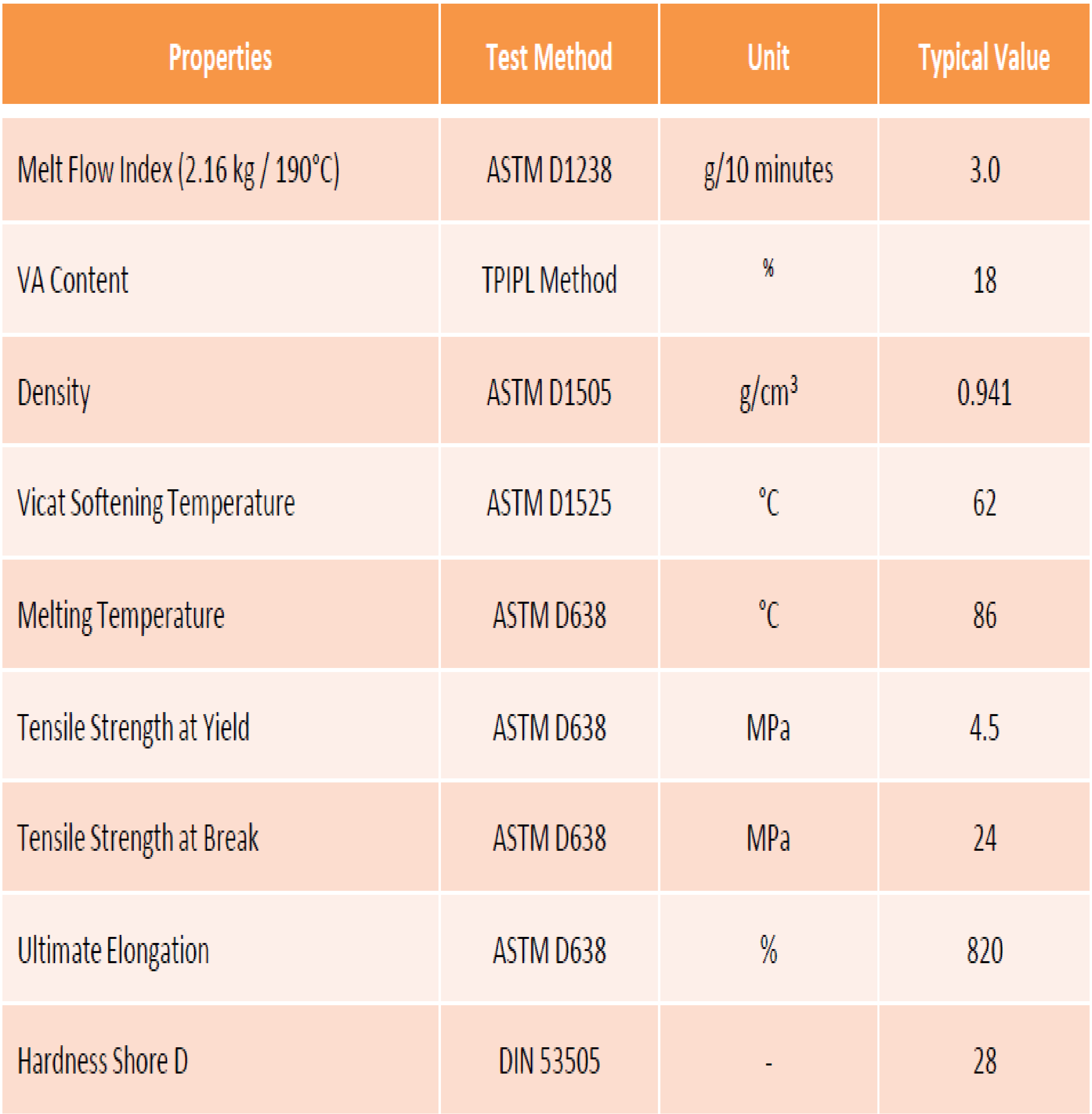
APPENDIX I

Appendix I: Gradation Limits of Coarse and Fine Aggregate

Gradation of Coarse Aggregates (ASTM C33)			
Sieve Sizes (mm)	**Percent Passing (%)**		
	Lower Limit	**Upper Limit**	**Our Gradation**
25.00	100	100	100.00
19.00	90	100	92.57
12.50	20	55	41.35
9.70	0	15	13.90
4.75	0	5	3.84

Gradation of Fine Aggregates (ASTM C33)			
Sieve Sizes (mm)	**Percent Passing (%)**		
	Lower Limit	**Upper Limit**	**Our Gradation**
4.75	95	100	100
2.36	80	100	93.71
1.18	50	85	75.13
0.59	25	60	56.22
0.29	5	30	21.51
0.15	0	10	4.62

Appendix II: Ethylene Vinyl Acetate Properties



Properties	Test Method	Unit	Typical Value
Melt Flow Index (2.16 kg / 190°C)	ASTM D1238	g/10 minutes	3.0
VA Content	TPIPL Method	%	18
Density	ASTM D1505	g/cm³	0.941
Vicat Softening Temperature	ASTM D1525	°C	62
Melting Temperature	ASTM D638	°C	86
Tensile Strength at Yield	ASTM D638	MPa	4.5
Tensile Strength at Break	ASTM D638	MPa	24
Ultimate Elongation	ASTM D638	%	820
Hardness Shore D	DIN 53505	-	28

Appendix III: Marshall Test Report

Marshall Test Report

Project: Hamza Marjan (MS Thesis)			Aggregate Source: Khattar			Bitumen: PARCO 60/70									
		Mass, grams of compacted Specimen					Mass, grams of loose Mix								
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	In Air (A)	In Water (C)	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb =A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer + Glass Lid + Water (b)	wt: of Sample + Water + Pycnometer and Lid (c)	Max. S.G. (loose Mix) (Gmm) =a/b-(c-a)	% Air Voids	% VMA	% VFA	Stability	Flow mm
3.5-A	67.52	1178	698	1196.72	498.72	2.362	1173	6773	7477.5	2.503	6.876	15.760	49.28	9.050	2.33
3.5-B	68.21	1161	685	1199.85	514.85	2.254	1184	6773	7476.7	2.465	7.254	15.61	49.04	10.950	2.23
3.5-C	65.47	1185	657.5	1220.71	563.21	2.104	1167	6773	7462.2	2.442	6.031	14.89	47.54	12.18	2.08
Average	67.067	1174.666667	680.1667	1205.76	525.5933	2.240	1174.666667	6773	7472.133	2.470	6.72	15.420	48.62	10.72	2.21
4.0-A	69.74	1165	674	1161.65	487.65	2.389	1163	6773	7450.4	2.395	6.06	14.37	53.85	13.694	2.55
4.0-B	69.43	1186	691	1233.54	542.54	2.186	1179	6773	7487.6	2.539	5.33	15.65	54.72	11.645	2.49
4.0-C	66.36	1177	685.5	1212.12	526.62	2.235	1175	6773	7461.6	2.416	4.57	15.76	52.59	12.491	2.52
Average	68.51	1176	683.5	1202.437	518.9367	2.270	1172.333333	6773	7466.533	2.450	5.32	15.26	53.72	12.61	2.52
4.5-A	65.24	1163	679.5	1165.7	486.2	2.392	1188	6773	7475.5	2.447	5.21	16.25	62.51	14.561	2.992
4.5-B	64.75	1194	685.5	1179.9	494.4	2.415	1181	6773	7476.05	2.471	3.58	13.79	66.23	13.258	2.783
4.5-C	63.91	1175.5	698.4	1252.09	553.69	2.123	1186	6773	7465.2	2.402	4.47	14.51	63.95	11.631	2.695
Average	64.633	1177.500	687.800	1199.230	511.430	2.310	1185.000	6773	7472.250	2.440	4.42	14.85	64.23	13.15	2.8
5.0-A	68.72	1169	685.5	1162.44	476.94	2.451	1172	6773	7469.9	2.467	3.47	13.83	72.25	12.723	3.357
5.0-B	69.33	1178	701.4	1230.83	529.43	2.225	1177	6773	7455.04	2.378	3.12	15.64	70.92	13.652	3.328
5.0-C	67	1183	697	1195.31	498.31	2.374	1168	6773	7457.3	2.415	3.85	14.39	71.54	12.085	3.215
Average	68.35	1176.667	694.633	1196.193	501.560	2.350	1172.333	6773	7460.747	2.420	3.48	14.62	71.57	12.82	3.3
5.5-A	62.58	1188	686.4	1252.09	565.69	2.378	1163	6773	7457.7	2.432	3.83	15.91	73.87	11.834	3.878
5.5-B	64.79	1192.3	679	1153.64	474.64	2.512	1149	6773	7461.6	2.496	2.35	14.28	76.29	12.492	3.647
5.5-C	64.61	1158	702	1209.89	507.89	2.280	1161	6773	7429.6	2.302	1.86	15.29	75.59	10.324	3.875
Average	63.993	1179.433	689.133	1205.207	516.073	2.390	1157.667	6773.000	7449.633	2.410	2.68	15.16	75.25	11.56	3.8

The End