PERFORMANCE EVALUATION OF LOW DENSITY POLYETHYLENE (LDPE) MODIFIED RAP CONTAINING ASPHALT CONCRETE MIXTURES

SYED BAQIR UL HUSNAIN

(00000317565)

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Signature: ______________________________

Name of Supervisor: **Brig Dr Sarfraz Ahmed**

Date: __________________________________

Signature **(HOD)**: _________________________

Date: ___________________________________

Signature **(Dean/Principal)**: __________________

Date: _____________________________________

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<u>DEDICATION</u>

This thesis is dedicated to **Muhammad wa Aal e Muhammad (Peace be Upon Him)**; minaret of knowledge and wisdom, my beloved **Mother** who passed away in 2019 during my first week of classes of MS due to pancreatic cancer, my beloved **Father** who always supported me through thick and thin of my life, my beloved **brothers** who cheered me when I was sad, my beautiful **daughters**, who's smile pleased me when I was worried, my **wife**, who supported me morally and always motivated me and my respected **advisor Brig Dr Sarfraz Ahmed**, who's guidance made me able to finish my research work.

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In the end, I express my solemn gratitude with earnest sense of reverence to my parents for their encouragement, heartfelt prayers and kind wishes for successful completion of my studies along with this research work. Specially, I want to thank my father from all my heart for being with me at all times and for motivating me at every point of my life. He is the best dad in the world and without him nothing would have been possible.

(*Engr. Syed Baqir ul Husnain)*

LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation
AC	-	Asphalt Concrete
ARL	-	Attock Refinery Limited
ASTM	-	American Standard Test Method
BS	-	British Standard
CIPR	-	Cold-In-Place Recycling
G_{mb}	-	Bulk Specific Gravity
G_{mm}	-	Maximum Specific Gravity
HIPR	-	Hot-In-Place Recycling
HMA	-	Hot-Mix Asphalt
TSR	-	Tensile Strength Ratio
ITS	-	Indirect Tensile Strength
M_R	-	Resilient Modulus
LDPE	-	Low Density Polymer Ethylene
HDPE	-	High Density Polymer Ethylene
JMF	-	Job Mix Formula
LOS	-	Level of Service
LEA	-	Low Energy Asphalt

NHA	-	National Highway Authority
NMAS	-	Nominal Maximum Aggregate Size
OAC	-	Optimum Asphalt Content
OBC	-	Optimum Bitumen Content
P_b	-	Percent Binder (preferable over "AC"
P_{be}	-	Percent of Effective Binder
PG	-	Performance Grade
RAP	-	Reclaimed Asphalt Pavement
RAS	-	Reclaimed Asphalt Singles
UTM	-	Universal Testing Machine
V_a	-	Air Voids
VFA	-	Voids Filled with Asphalt
VMA	-	Voids in Mineral Aggregate
WMA	-	Warm Mix Asphalt

ABSTRACT

The use of recycled materials and waste in road pavements is increasingly regarded not only as a good choice in terms of sustainability, but also as an appealing option in terms of delivering improved performance in terms of service longevity of pavements. This is particularly true when it comes to recycled plastics and reclaimed asphalt from existing pavement structures.

Majority of thin plastic bags are made of low density polymer ethylene (LDPE), which is frequently used for packing, protection, and a variety of other purposes. However, huge volumes of waste plastic bags pose an environmental hazard because they are considered non-biodegradable materials. Furthermore, roads are always in the process of rehabilitation and a lot of road waste is also produced and this waste is called reclaimed asphalt pavement (RAP). As a result, there is an urgent need to discover beneficial uses for this rising volumes of trash. Past research indicates the use of LDPE improves asphalt concrete properties, however combined effect of utilizing RAP with varying percentage of modifier has not been explored. The purpose of this research is to examine the possibility for enhancing the characteristics of asphalt mixtures using RAP as aggregate replacement and LDPE as a kind of polymer. Specific to our conditions, the study's objectives focus on performance evaluation of RAP containing LDPE modified asphalt concrete mixes.

LDPE was added in different proportions from 2.5% to 7.5% by weight of bitumen by the increment of 2.5 and RAP proportion was kept constant as 30% by weight of aggregate. By adding RAP, bitumen content was reduced from 4.5% to 4.2%. Resultant modified and conventional asphalt mixes were subjected to Tensile Strength Ratio (TSR), Resilient Modulus and Indirect Tensile Fatigue Tests.

Results have indicated that LDPE can be conveniently used in bitumen as a modifier and have improved asphalt mixes. It has been observed that LDPE dosage of 5% works best in the presence of 30% RAP. Higher percentage of LDPE results in stiffer bitumen which may lead to premature fatigue cracking. It has been observed that by addition of RAP and LDPE, improves stiffness, fatigue resistance and moisture susceptibility. *Moisture susceptibility* is **increased by 11.54%** of modified mixes. Moreover, inclusion of LDPE also improves *stiffness* of asphalt mixes up to **1.5 times** of conventional mixes with 30% RAP and 5% LDPE. Furthermore, *fatigue life* of asphalt mixes has been **doubled.** Overall, the asphalt mixes with **30% RAP modified with 5% LDPE** has <u>**best**</u> results.

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Chapter 1

INTRODUCTION

1.1 Background

The current state of our nation needs to reduce investment costs as well as provide an efficient, low-cost and smart highway infrastructure. The system has dramatically increased the need to rebuild and manage our pavements. In the last 25 years, asphalt reclaiming and recycling has made significant progress, and it is now a technically and naturally favoured method of rehabilitating existing pavements.

Asphalt reclamation and recycling meet all of our societal aims of delivering efficient and safe roadways while also considerably reducing energy (oil) consumption and environmental impact when compared to conservative pavement repair. As a result, it has a long-term effect, allowing vendor agencies to increase their available funds. However, they must be used correctly since not all highways are ideal candidates for asphalt recycling. This will provide the travelling public with a dependable and safe driving surface.

The asphalt paving business has long promoted recycling, which includes reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), and tyres. As (Zhao et al. 2013) remark, the practice of asphalt pavement recycling extends all the way back to 1915. However, significant usage of RAP in HMA began in the mid-1970s as a result of skyrocketing asphalt binder prices caused by the oil shortage. Numerous recent studies, such as those conducted by (Zhao et al. 2013)(Baghaee Moghaddam and Baaj 2016), (Tayebali et al. 2015), (Society and Studies 2015), and others, have been conducted to improve the usage of RAP in both WMA and HMA.

Furthermore, as R. West (2009) noted, historical data indicates that RAP mixes can function similarly to virgin HMA mixtures when properly handled. One of the greatest serious problems which are faced by flexible pavements is rutting at early life, which occurs as a result of high temperatures and excessive axle load. Rutting in asphalt concrete is determined by a variety of factors, including the aggregate grade and quality, the stability of the asphalt mix, the classification of binder used and air voids percentage, the ratio of bituminous binder, the compaction effort, the surrounding environment such as moisture and heat, variety of traffic, properties of sub-structure below the pavement such as bearing capacity of sub-grade (Khan, 2008).

Moisture susceptibility, as defined by (O'Sullivan and Wall 2009), is the ability to weak interaction between the asphalt mixes and aggregate and is a key topic of concern for pavement performance, regardless of whether it is a hot mix, warm mix, or RAP. Moisture damage can really be classified as either an adhesive or a cohesive failure depending on how it is caused. An interaction between the bitumen and aggregate breaks down is adhesive failure, whereas a bond between the binder and the aggregate breaks down when the strength of the binder is diminished as a consequence of moisture deterioration is cohesive failure. Many materials, such as aluminium, steel, and plastic, have been recycled due to environmental and economic considerations and RAP is one of these recyclable materials.

RAP is rarely used over 20% to 25% in normal asphaltic mix designs, except it's use in Cold-In-Place Recycling (CIPR) or in Hot-In-Place Recycling (HIPR), which may utilise up to 100% RAP. Variability in aggregate gradation is one of the factors contributing to RAP's restricted usage, particularly when stocks of various RAP sources are not appropriately separated, handled and are not treated to remove inconsistency. Economic hardships and environmental concerns have forced transportation agencies in the United States to increase the amount of RAP in asphalt concrete pavements by 50%. Increased RAP usage has the potential to have an effect on the structural performance and durability of pavements. According to Al-Qadi et al., increased RAP concentration has an effect on the rutting, fatigue, and stiffness properties of HMA (Al-Qadi, Imad L.; Aurangzeb, Qazi; Carpenter, Samuel H.; Pine, William J.; Trepanier).

In addition, a number of innovative methods and materials have been developed that are capable of reducing the temperature at which hot mixed asphalt is mixed and applied without compromising the structural integrity of the pavement. Because of the unique properties of these new materials, mixing and compaction temperatures can be reduced by as much as 40%.

Reduced mixing temperatures result in energy savings for the producer. According to (Evaluation Of Evotherm® For Use In Warm Mix Asphalt, 2006), reduction in temperatures of mixing can result in a 30% reduction in the amount of energy consumed by the fuel. In addition, Zhang et al. (2012) claimed that lower temperatures will aid the decrease of visible or non-visible emissions, and in turn, health concerns, odour issues, and greenhouse gas emissions will be reduced.

Thus, by doing so, we can facilitate asphalt manufacturing in non-accessible areas, where we have limited pollution laws. Because of the lower temperature, shorter haul lengths will be possible, resulting in faster manufacturing progress. Simultaneously, this location will help to reduce the amount of time that is spent during construction, as well as lessen the potential of traffic jamming. Also, the mixes which are created at a more typical temperature might have a longer transport distance and construction duration. Another benefit is that it lowers the working temperature, reducing the oxidative hardening of asphalt, which may contribute to improved performance of pavements, for-instance decreased block cracking, thermal cracking, and the prevention of asphalt mixtures from becoming tender when put.

This is not new as it relates to creating asphalt mixtures at lower temperatures. Professor Ladis Csanyi of Iowa State University completed the first endeavour of manufacturing asphalt with binder in 1956. It was also developed using steam. After this foaming technology has been researched and implemented in many nations, including Australia, the United States, and Europe, it may now be applied to other countries as well. Mastic asphalt has been utilised for the previous two decades as a viscosity modifier in Germany; the primary function of waxes has been to help the product perform better, and fifteen years ago, it was claimed that reducing the mixing and compacting temperatures was a priority.

In recent years, there has been rapid increase in the use of additives in bituminous concrete mixtures to improve its properties. Low Density Polymerethylene (LDPE) has been used by many researchers to modify bitumen and improve the properties of bitumen mixes. (Panda and Mazumdar 2002). Plastic roads mainly are composed of plastic carry bags, disposable cups and LDPE bottles that are collected from the trash. When these components are mixed with hot bitumen, the plastic melts to form an overall oil coat. Durability of roads made of plastic garbage is much higher than roads made with conventional materials. While a typical 'highway quality' road lasts four to five years. It is claimed that plastic bitumen roads can last up to 10 years. Rainwater will not pass through it due to plastic added in bitumen. So it is expected that, addition of LDPE will reduce the road repairs. And as each kilometre of road with an average width requires over two tonnes of polyblend, using plastic will help to reduce non-biodegradable waste.

Plastic road construction may have a modest price premium over the old-fashioned way of doing things. Even so, there's no need to hold back on using it given the numerous advantages it offers. Plastic raises the bitumen's melting point and helps the road stay pliable in the winter, extending its useful life. Plastic enhances the bitumen's capacity to resist high temperatures by being mixed with it. Bitumen and plastic waste are combined in a certain ratio before being melted and used in the production process. However, even at temperatures as high as 55°C, mixing can still take place because of the stability of plastics. It was demonstrated through rigorous laboratory testing, that the bituminous mixes made with the treated bitumen binder met all of the Marshall mix design parameters for surface course of the road pavement stated in the study. The Marshall Stability Value of the bitumen concrete mixes was much greater than that of the untreated or conventional bitumen, by a factor of two to three. Another noteworthy finding was that bituminous mixtures made with the treated binder were able to survive prolonged immersion in water under unfavourable circumstances (Othman 2010).

Asphalt binder can be improved by mixing in a special polymer, according to research. Additionally, the inclusion of a polymer usually results in improved rutting and thermal cracking resistance. In addition, fatigue damage and stripping were decreased, while temperature sensitivity was increased. As one of the most efficient polymer additives, polyethylene is a frequently used material.(Awwad and Shbeeb 2007a).

Although Low Density Polymerethylene (LDPE) is the most often used plastic in thin plastic bags, it is also frequently used for packing, safeguarding, and a number of other purposes. Because it is believed that the material is non-biodegradable, they viewed the large-quantity of waste plastic bags as a potential environmental concern. There is therefore a genuine demand to identify new and helpful applications for these steadily increasing amounts of trash. Waste plastic bags, a type of polymer, are utilised in this study to see if adding them to the asphalt mixture enhances the mix's characteristics. Researchers want to explore the consequences of varying percentages of LDPE. It is being used as an aggregate coating on asphalt mixtures. Researchers intend to discover the best proportion of LDPE for use in hot mix asphalt (*Giriftinoglu 2007*)

1.2 Problem Statement

The estimated length of Pakistan's road network is slightly more than 260,000 kilometres at the moment, and the NHA Budget allocation indicates that substantial annual funding is required to keep this asset in good condition, but the annual maintenance and preservation funds allocated cover less than 10% of the pavements in need of repair. Thus, recycling is essential not just to conserve dwindling aggregate supplies, but also to reduce the usage of expensive bitumen, as 95 percent of the world's surface transportation infrastructure is paved with HMA.

Pavement recycling is the greatest choice at the moment for constructing pavements while keeping the necessary volumetric density, since several motorway link building and restoration projects have been planned, with HIR and CIR technologies already being deployed and tested in a few locations. Similarly, HMA technology enables us to use state-of-the-art recycling technology to make more utilisation of RAP at a lower temperature than conventional asphalt mixes. By incorporating HMA additives into recycled material, we may reduce the cost of a project, and the cash saved can be utilised to preserve a longer stretch of road or to create new pavements.

The difficulty described above demonstrates the importance of conducting a research to encourage pavement recycling in Pakistan using HMA technology. To that end, this research will examine the moisture susceptibility, fatigue and stiffness response of Low Density Polymer Ethylene (LDPE) modified RAP containing asphalt concrete mixtures. For carrying out the performance testing, Marshall cylindrical specimens were prepared to assess the effect of RAP content in combination with LDPE ranging from 0 to 7.5% by weight of bitumen on asphalt mixtures, and to analyse experimental data collected from moisture susceptibility (TSR), Indirect Tensile Test (IDT), Resilient Modulus (M_R) and Indirect Tensile Fatigue Test (ITFT) using excel. Experimental matrix for Marhsall mix design and performance testing is shown in Table 1-1 and Table 1-2. Table 1-3 describes the performance tests conducted in this research.

Table 1-1: Marshall Mix Design Sample Replicates vs RAP Content

RAP %	Bitumen %	No. of Samples
0	3.5	3
	4	3
	4.5	3
	5	3
	5.5	3
30	3.5	3
	4	3
	4.5	3
	5	3
	5.5	3
Total		**30**

Table 1-2: Experimental Matrix of Bitumen Testing

Characterization	**Gradation**	NHA – B
	Binder	ARL 60 / 70
Binder	**TESTS**	**Standard**
	Penetration	AASHTO T 49 – 93
	Softening Point	AASHTO T 53 – 92
	Flash & Fire Point	AASHTO T 48

Table 1-3: Performance Testing Matrix of Asphalt Concrete Mixtures

TESTS	Standards	RAP %	LDPE %	Samples	Total
Indirect Tensile Strength	ASTM D 6931 - 17	0	0	6	**24**
		30	2.5	6	
		30	5	6	
		30	7.5	6	
Indirect Tensile Fatigue Test	EN 12697 – 24D	0	0	3	**12**
		30	2.5	3	
		30	5	3	
		30	7.5	3	
Resilient Modulus	ASTM D7369 - 20	0	0	3	**12**
		30	2.5	3	
		30	5	3	
		30	7.5	3	
Total					**48**

Total number of samples were 78 including Marshall mix design and performance testing.

1.3 Research Objectives

Research's objectives set forth in the current study are as under:

- To investigate fatigue resistance through cyclic loading RAP containing LDPE modified asphalt mixture.
- To assess moisture sensitivity of LDPE modified asphalt concrete.
- To study the effect on stiffness of asphalt concrete by the addition of LDPE as bitumen modifier.

1.4 Scope of Thesis

For the purpose of achieving the aforementioned study objectives, a plan of research was developed, which is detailed below, with an outline of the research activities as follows:

- Review of previous research articles in the subject of polymer modifiers and RAP for asphalt mix, including revision of books, scientific articles and technical writings.
- In-depth examination of asphalt mix design and production technologies.
- Using the Marshal Mix design process, determining the Optimum Bitumen Content (OBC). Five different bitumen percentages were investigated to find the optimum bitumen percentage for the aggregates utilised, which included 3%, 3.5%, 4%, 4.5% and 5% by mix' weight.
- Finding out what happens when different quantities of LDPE as a modifier are added and how it affects the moisture susceptibility, fatigue and resilient modulus of asphalt specimens. The intended percentages range from 2.5% to 7.5% by weight of OBC.
- Results are analysed to quantify the effect of RAP and LDPE modification of measured performance indicators, e.g. asphalt concrete stiffness response, moisture susceptibility and fatigue moisture.
- Conclusions and recommendations are drawn.

1.5 Organization of Thesis

This thesis is composed of 5 chapters. **Chapter 1** is composed of introduction, problem statement, research objectives and scope of research.

Chapter 2 contains the detailed literature review carried for research. Detailed literature has been studied regarding HMA asphalt, RAP and usage of LDPE as a modifier.

Chapter 3 describes the research methodology. It describes which materials have been used and which tests have been conducted including their background and it describes the meanings of results obtained from performance tests.

Chapter 4 is about the results and analysis. In chapter 4, we have discussed the results obtained from performance tests and we have quantified relative improvement in HMA mixtures performance indicators / properties.

Chapter 5 is all about the conclusions and recommendations. In last chapter, we have emphasized on future research frontiers and how we can adopt the findings of this research study.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter summarizes literature and theory of the characteristics of asphalt mixtures, including RAP and LDPE. Effects of adding RAP and LDPE on the Indirect Tensile Strength (for moisture susceptibility), Resilient Modulus (for stiffness), and the Indirect Tensile Fatigue Test (for cyclic loading) have been discussed according to previous researches as well as their influence on various performance metrics and on forecasting permanent deformation, fatigue, and moisture damage in asphalt mixes using a variety of different experiments.

2.2 Background

It is widely acknowledged that in order to have a healthy economy and a sufficient rate of growth, we require a strong infrastructure, inclusive highways. According to studies, an owner can save money if he maintains a highway with an appropriate degree of service. When the condition of a road drops by 40%, extending a dollar saves $3 to $4 in maintenance costs that would otherwise be required when the quality drops by 80%, according to a World Bank research, as seen in Figure 2-1.

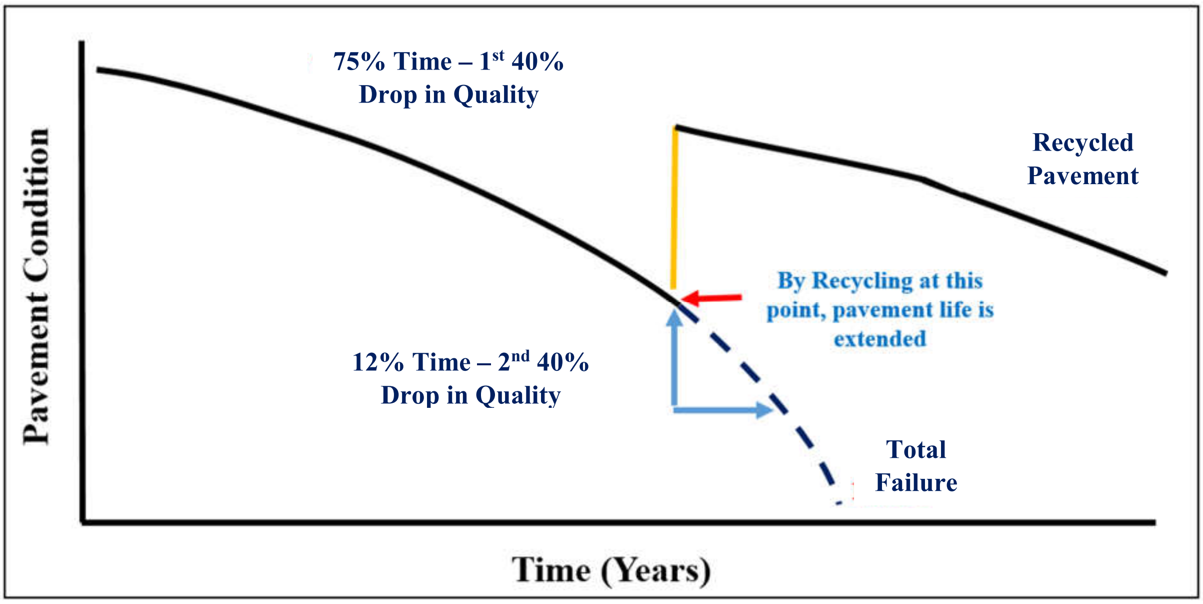


Figure 2-1: Pavement Deterioration and Recycling Rehabilitation VS Time (L et al. 2003)

With increasing traffic and ageing pavements, the rate of pavement degradation rises as well. As a result, the expense of rehabilitation increases dramatically. If we do not rehabilitate or provide other preventative maintenance at the appropriate periods, the roads will quickly deteriorate to the point where expensive reconstruction will be the only alternative available. Fortunately, by performing rehabilitation or other proactive maintenance activities on a roadway, as indicated in Figure 2-2, we may considerably prolong its service life.

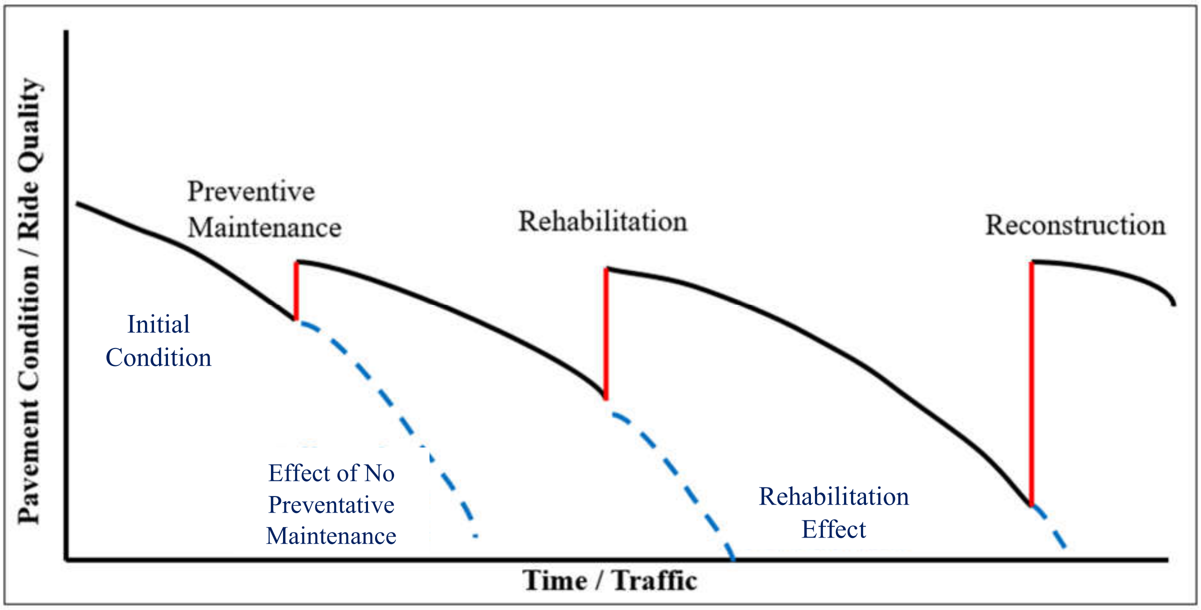


Figure 2-2: Pavement Deterioration VS Time (L et al. 2003)

Aluminium, plastic, steel, and a variety of other materials are recyclable due to environmental and economic considerations. RAP and LDPE are one of these recyclable materials.

2.3 Findings On Use of RAP

In hot recycled bituminous mixtures, RAP values of 10% to 30% are usual. Studies have shown that bituminous mixes perform similarly to conventional ones when run at these speed (Li et al. 2008). RAP component in recycled mixes used in bituminous pavement construction and repair is rising due to environmental limitations. Because of the reduced energy and natural resource use, pavement construction becomes more economically viable and, as a result, more long-lasting (G. W. Maupin, Diefenderfer, and Gillespie 2009).

RAP use techniques and HMA mixture performance tests including RAP have been extensively researched and published in the scientific literature (Kennedy, Tam, and Solaimanian 1998). It's still unclear, though, how much old asphalt is mixed in with the new (virgin) stuff when it's all mixed together. Most people think of RAP as more than just a "black rock" in the new mix. New (virgin) asphalt does mix with the old (aged) asphalt while making new mixes. According to Kandhal and Foo, up to 15% RAP might be utilised without affecting the PG binder grade, but more research is needed. The virgin binder grade should be reduced by one increment on both the high- and low-temperature grades if it contains 15% to 25% RAP. Charts for blending should be utilised when RAP is used in excess of 25% (Kennedy et al. 1998). The NCHRP 9-12 research by McDaniel and Anderson evaluated the laboratory performance of three different mixes, including black rock, complete blending, and real practise, and may be considered the most current comprehensive national study on RAP in HMA (Kennedy et al. 1998). When making the black rock mixes for the next two NCHRP projects, researchers extracted the binder from a RAP mix and then mixed it with virgin RAP aggregate in the correct amounts. The complete blending mixes were made by physically blending the RAP binder into the virgin binder and extracting and recovering the RAP binder into the virgin and RAP aggregates. The blended binder was then combined. For the actual practise mixes, virgin aggregate and virgin binder were combined with RAP that had not been treated to remove the coating. According to the NCHRP 9-12 study, black rock with a RAP concentration of 40% performed much worse in the laboratory than the real practise and total blends. The overall blending and the actual practise mixes had no significant variations. However, at a real hot-mix asphalt factory, RAP is often blended with virgin asphalt and aggregate in less than one minute, thus neither the black rock issue nor the complete blend scenario exist.

Asphalt surface mixes with screened RAP were studied by Huang et al. for laboratory fatigue characteristics (Petit et al. 2004). They discovered that adding up to 30 percent RAP to asphalt mixes improved the mixture's fatigue resistance. This finding appears to be at odds with the widely held assumption that the more RAP in a combination, the brittler it would be and the less resistant it will be to fatigue. Sargious and Mushule, on the other hand, found comparable outcomes.

HMA technology, which originated in USA, is generating considerable attention across the world. When applied at high temperatures, HMA additives increase the workability of asphalt mixes and/or lower the viscosity of the asphalt binder, therefore improving the overall performance of the pavement according to our requirements.

According to (Baghaee Moghaddam and Baaj 2016) recycling HMA is an ancient concept that dates all the way back to 1915, however it gained widespread recognition during the mid-1970s oil shortage. Due to a scarcity of superior aggregates at the site of application and rising asphalt costs, demand for RAP has grown. Which also come with a betterment of environmental and economic benefits. Since the mid-1970's, it is predicted that 10 million tonnes of RAP have been used, with comparable performance qualities and a significant cost savings over virgin HMA mixtures. To extend our survival time on this planet, we must enhance ways for reducing energy consumption, heat generation, greenhouse gas emissions, and fossil fuel use.

Scientists should do the necessary study, and then authorities should impose the notions that make sense. Research on HMA, RAP and plastics must be conducted to determine whether it is rational, economically effective, and ecologically beneficial, and if so, engineers must advance the tools necessary to implement the research.

(Almeida-Costa and Benta 2016) performed study to determine the economic and environmental benefits of HMA mixes. They created asphalt concrete with a high modulus by adding a chemical addition. They calculated the potential maximum cost of additive. It appears from the findings of this investigation that the highest cost attained for hot mixtures demonstrates that their manufacturing is economically viable. Carbon dioxide emissions were reduced significantly, as was energy usage. As a result, it is apparent that we can accomplish all of these environmental and economic advantages by ensuring the pavements are improved.

Due to the reduced durability and stability of cold-mix asphalt compared to hot-mix asphalt, cold mix is utilised in the bottom layers of pavement on low-volume roadways produce HMA has high strength and durability compared to WMA and cold-mix asphalt.

According to (Society and Studies 2015), two factors separate WMA from other asphalt mixes: the finished product's durability and strength, and the temperature regimes under which WMA are made. He added that cold asphalt mixes are typically created at temperatures ranging from 68°F to 120°F, whereas HMA is typically prepared at temperatures ranging from 285°F to 340°F and WMA is typically manufactured at temperatures ranging from 200°F to 275°F.

Due to the reduced durability and stability of cold-mix asphalt compared to hot-mix asphalt, cold mix is utilised in the bottom layers of pavement on low-volume roadways.

According to (McCormack et al. 2014), HMA technology has a plethora of ramifications. According to information collected from manufacturers and material suppliers, HMA can reduce CO_2 emissions and energy usage by addition of different additives.

Improved compaction, according to (Bražiūnas, Sivilevičius, and Virbickas 2013), is a critical performance characteristic. Because of exposure to high temperatures in the manufacturing process, the majority of the asphalt binder in HMA degraded in the laboratory. By adding different additives, it is possible to reduce oxidative hardening, therefore improving the longevity and flexibility of the pavement while decreasing its cracking susceptibility.

(Rossi et al. 2013) asserted that approaches that use lower production temperatures of HMA will have favourable effects on the performance of asphalt pavements. It is anticipated that these technologies will minimise (or, at the very least, no increase) the amount of compaction energy required since they will enhance mix workability and in-place density. According to (Hamzah et al.), sasobit conserves energy by lowering fume emissions and shortening manufacturing cycle durations.

Numerous polymeric compounds have been added into asphalt mixes as additives in a variety of forms to improve the performance of asphalt pavements. Polymer modification of bitumen and asphalt mixtures has a number of advantages. These include increased fatigue resistance, increased resistance to thermal cracking, decreased temperature sensitivity, and resistance to rutting is enlarged (Kalantar et al., 2010).

When it comes to asphalt mixtures, polymers are generally employed to alter the binder (bitumen). Additionally, they may be used to form an aggregates-based covering material for buildings. Aside from that, they can be utilised in asphalt mixes as a partial substitute for particular sizes of aggregates. The properties of modified asphalt mix are dependent on a variety of elements, including the polymer's features, the mixing circumstances, and the polymer's compatibility with the asphalt mix's constituents.

Polymers come in a variety of forms and categories. Nowadays, plastics are one of the most commonly utilised polymers. Numerous studies have been done to assess the appropriateness of wastes produced by plastics for use in asphalt mix. The chapter will examine the usage of plastic wastes in asphalt mixtures and will review prior research in this subject.

The name "polymer" comes from the Greek word for "many parts," which means "many pieces." In chemistry, polymers are enormously large molecules that are created by chemically interacting with a high number of single molecules (monomers) to build lengthy chains of molecules. Physical characteristics of a polymer depend on its chemical structure, including its molecular weight and the order in which its monomers are arranged (Becker, Méndez, and Rodriguez 2001).

Elastomers and plastomers are the two main types of polymers, respectively. Elastomers (rubbers) are elastomeric materials that may revert to their original shape after being loaded. Styrene and butadiene copolymers are commonly used to make elastomers, which are then chemically linked together. The list of materials also includes natural and synthetic rubbers. (e.g. Crumb Rubber Modifier CRM) (Awwad and Shbeeb 2007b) (Hansen et al, 2001.)

However, compared to Elastomers, Plastomers have higher strength and deformation resistance than Plastomers, making them less flexible. In addition to EVA and polyethylene, plastomers include polypropylene-based compounds and others.

Thermoset and thermoplastic materials are the most often used classifications for elastomeric and plastomeric polymers, respectively. It is possible to construct a complex structure in thermoset polymers by heating them first. This structure is maintained after temperature drop, but it is irreversible when the polymer is heated again. On contrary to this, thermoplastic polymers, when cooled, also form a proper structure which is linked together with atoms, but the structure formed by cooling may be reversed by heating the polymer back up again (King & Johnston, 2012).

The summary polymer types shown in Table 2-1 are categorised according to their properties related to deformation and heat.

2.4 Plastic Polymers

Organic polymers with a high molecular mass are the primary building blocks of plastics. Plastics are made from natural materials such as cellulose, coke, gas, salt, and hydrocarbons, which are utilised as raw materials in the manufacturing process. The polymer chain arrangement of a polymer is responsible for a wide range of physical characteristics of the polymer in question. In the vast majority of cases, carbon chains alone or in conjunction with oxygen, sulphur, or nitrogen are used to construct these polymers(*Giriftinoglu, C. The Use of Plastic Waste Materials in Asphalt Pavements. M.Sc. Thesis, Istanbul Technical University, Turkey: 2007*).

2.4.1 Types of Plastics

Any type of plastic is recognized accurately by customer service representatives and recycling facilities thanks to a numerical coding system created by the Society of the Plastics Industry (SPI) in 1988. A coding method is followed by the manufacturers, who embed an SPI code, or number, into the bottom of every plastic object they produce. The following Table 2-2 summarises the most frequently encountered polymers and their applications (*Giriftinoglu, C. The Use of Plastic Waste Materials in Asphalt Pavements. M.Sc. Thesis, Istanbul Technical University, Turkey: 2007*).

Table 2-1: Different Types of Polymers and Their Classification

Polymer Type	Examples	Deformational Classification	Thermal Classification
Natural Rubber (Homopolymers)	Natural Rubber (NR), Polyisoprene, Isoprene, Natural Rubber Latex (NRL)	Elastomer	Thermoset
Synthetic Latex / Rubber (Random Copolymers)	Styrene-Butadiene (SBR)	Elastomer	Thermoset
	Polychloroprene Latex (Neoprene)	Elastomer	Thermoset
	Polybutadiene (PB, BR)	Elastomer	Thermoset
Reclaimed Rubber	Crumb Rubber Modifiers	Elastomer	Thermoset
Block Copolymers	Styrene-Butadiene-Styrene (SBS)	Elastomer	Thermoplastic
	Styrene-Isoprene-Styrene (SIS)	Elastomer	Thermoplastic
	Styrene-Butadiene (SB) Diblock	Elastomer	Thermoplastic
	Acrylonitrile-Butadiene-Styrene (ABS)	Elastomer	Thermoplastic
	Reactive-Ethylene-Terpolymers (RET)	Elastomer	Thermoplastic
Plastics	Low / High Density Polyethylene (LDPE / HDPE), Other Polyolefins	Plastomer	Thermoplastic
	Ethylene Acrylate Copolymer	Plastomer	Thermoplastic
	Ethyl-Methacrylate	Plastomer	Thermoplastic
	Polyvinyl Chloride (PVC)	Plastomer / Elastomer	Thermoplastic
	Ethylene-Propylene-Diene-Monomer (EPDM)	Plastomer	Thermoplastic
	Acrylates, Ethyl-Methacrylate (EMA), Ethyl-Butyl-Acrylate (EBA)	Plastomer	Thermoplastic
	Ethyl-Vinyl-Acetate (EVA)	Plastomer	Thermoplastic
Combinations	Blends of Above	Varies	Varies

Table 2-2: Types of Plastics and Their Applications

Plastic Type	Abbreviation	Examples of Applications
Polyethylene Terephthalate	PET	Sodas and water containing bottles
High Density Polyethylene	HDPE	Cleaners & shampoo bottles, molded plastic cases
Polyvinyl Chloride	PVC or V	Pipes, fittings, credit cards, toys, electrical fittings, pens, medical disposables etc.
Low Density Polyethylene	LDPE	Grocery bags and packaging films
Polypropylene	PP	Bottle caps and closures, diapers, microwaveable meal trays, medicine and syrup bottles, also produced as fibers and filaments for carpets.
Polystyrene	PS	Styforfoam, Take-away food containers, egg cartoons, disposable cups, plastic cutlery, CD and cassette boxes.
Other types of plastics		Any other plastics that do not fall into any of the above categories – for example polycarbonate which is compact discs, eyeglasses, riot shields, security windows.

2.4.2 Plastic Waste Problems

As a result of increasing urbanisation in many areas and population expansion in recent years, there's been a significant increase in the rate of rubbish production for various sorts of waste goods. Some wastes generated today are non-biodegradable, such as blast furnace slag, fly ash, steel slag, scrap tires, and plastics, which will remain in the environment for thousands of years, posing an environmental problem as well as a variety of environmental concerns.

Because of the increasing usage of plastics in a lot of sectors, including packaging, security, structures, agribusiness, high-tech, and water management, the plastics industry has experienced numerous important advancements during the previous two decades. In today's world, plastics are omnipresent and have an almost limitless variety of applications. While the usage of this non-biodegradable commodities are rising, the amount of plastic rubbish produced is also increasing on a daily basis, and the question is how to properly dispose of all of this garbage (Jan, Kumar, and Sengupta 2011).

Thin plastic bags, which are often used for packing, are made of polymers like these and are among the most regularly used. However, due to the chemical inertness of waste plastic bags, their disposal in vast quantities poses a serious environmental concern. As a result, there is an urgent need to discover beneficial uses for this rising volumes of trash. Recycling trash into usable goods is widely regarded as one of the most sustainable solutions to this issue, which is why research into new and inventive applications for waste materials is always progressing (Justo, C.E.G. and Veeraragavan, A., 2002).

2.4.3 Plastic Waste in Pakistan

WWF-Pakistan is one of the country's major conservation groups, aggressively against climate change and environmental degradation. One critical component of environmental protection is reducing pollution, particularly of non-biodegradable items such as plastic.

Reusing and recycling are ethically satisfying activities in and of themselves, as they help significantly to environmental preservation. However, WWF-Pakistan has decided to increase its incentives and provide our eco-friendly participants the opportunity to win various prizes. We provide a variety of discount certificates, products, and chances to enter fortunate drawings and spin the wheel activities for you. The prizes include goods from renowned designers like as Ali Zeeshan, Sania Maskatiya, and Sapphire; discount certificates from Arammish and Cinestar for all your amusement and relaxation requirements; and fantastic deals from Wild Wings, Jessie's burgers, and many more!

Each year, an estimated 8 million tonnes of plastic trash reach the seas. By 2050, it is projected that plastic would outnumber fish in the oceans. Plastics endanger nature since they are non-biodegradable and poisonous. A single plastic bag might take up to 500 years to disintegrate, whereas a single plastic bottle takes around 300 years! Unfortunately, plastics account for 65 percent of total trash in Pakistan; 55 billion plastic bags are used annually, with an anticipated rise of 15%. Immediate and effective actions must be taken to reduce our country's and planet's reliance on plastics. Following table shows the solid waste spawned by many cities in Pakistan (Pakistan - Waste Management).

2.5 Utilization of Plastic Wastes in Asphalt Mixtures

It is possible to utilise waste plastic, which is a form of plastomer polymer, to make asphalt concrete mixtures in three different ways: as a partial replacement for particular size particles, as a dry additive, or as a wet additive.

Dry methods include the incorporation of plastic polymer into hot aggregates in order to form an aggregate coating film, which is generally achieved by plastic melting on the hot aggregate surface prior to the application of bituminous materials. It is possible that this coating layer might improve the interaction between aggregate and binder and engineering properties of aggregates, therefore enhancing the longevity of asphalt mixes, depends on the plastic properties and mixing conditions. The dry technique is only applicable to plastic polymers, and nothing else (Awwad and Shbeeb 2007b) (Gawande et al. 2012).

When using the wet method, asphalt and waste plastic are combined at the same time. Polymer enhancement of asphalt, particularly plastic polymer modification, is a commonly used technology for improving the quality of bitumen by altering its rheological properties by the use of synthetic polymers in combination with bitumen (Gawande et al. 2012). Modification of bitumen with polymer has a number of advantages for asphalt mixtures, including enhanced resistance to rutting, thermal stress, fatigue failure, pavement stripping, and resistance to high temperature. The development of polymer modified bitumen made it possible to substitute traditional bitumen for a wide range of pavement and maintenance use.

Modified bitumen properties are dependent on a variety of parameters, including the characteristics of the polymer and bitumen, the mixing circumstances, and the polymer's compatibility with bitumen. Polymers are integrated into bitumen in two ways. The first way is by mixing bitumen with latex polymer, which aids in polymer dispersion. The second step involves the introduction of solid polymers into bitumen, which frequently demands the use of a high-shear mixer to ensure that the mixture is uniformly dispersed (Becker et al. 2001).

Using a polymer aggregate of equivalent size to replace a portion of the mineral aggregates in an asphalt mixture is another way for integrating plastics into asphalt mixes. This process is generally used to incorporate discarded plastic into asphalt mixtures, and the outcome is a larger amount of plastic in the asphalt mix overall.

2.6 Laboratory Studies Related of Plastics Utilization in Asphalt Mixes

Many researches have been done on the inclusion of polymers into asphalt mixes in order to improve the overall performance of the mixtures. Plastics made from recycled materials, which are a form of polymer, can also be used to substitute a section of aggregates or as a binding modifier; in addition, they can also be used to coat aggregates to make them more resistant to corrosion.

2.6.1 Use of Plastics for Binder Modification

Justo, C.E.G. and Veeraragavan, A. (2002) looked at whether or not asphalt concrete mixtures may use treated plastic bags as a filler. Modified bitumen was made by mixing varying amounts of processed plastic with hot bitumen in varied proportions (0–12% by weight of bitumen) and thoroughly stirring it. According to the findings of laboratory tests, using modified bitumen has proven to be extremely advantageous. Even when subjected to water-logging circumstances, adding processed plastic to asphalt concrete mixes at a concentration of around 8% by bitumen weight improves the mix's stability, durability, and fatigue life, among other attributes (such as flooding). This means that the lifespan of the modified asphalt pavement surface course will be far greater than that of conventional bitumen.

Adding 8% treated plastic by weight to bitumen to generate modified bitumen reduces bitumen by weight in the mix by 0.4 percent, which helps keep asphalt mix costs down overall. According to the findings of Naghawi et al. Using recycled polythylene terephthalate (PET) in asphalt pavements may be advantageous since it generates less permanent deformation of the asphalt surface, which shows up as rutting. This study illustrates this. Water and soda drink bottles commonly use PET bottle material, which can be recycled on a regular basis. Using PET as a polymer addition in asphalt mix, Chen's research sought to determine the material's rut resistance. It will be determined how much PET can be utilised as a bitumen modifier and how much rut resistance PET modified asphalt mixtures have in comparison to regular asphalt mixes in the study. The penetration index, the Marshall Test, and the three-wheel immersion tracking test are just a few of the methods used to gauge rust resistance. However, researchers discovered that 7.5 percent of the conventional mix's bitumen content (OBC) should be plastic, whereas 5.2 percent of the PET modified mix's OBC should be bitumen. When compared to normal asphalt mix formulations, PET modified asphalt binders show greater resistance to permanent deformations because of the plastic's binding feature, according to the study's findings.

Nobinur Rahman et al. 2013 studied the viability of using recycled PET containers as binder polymer additives in asphalt mixtures was investigated. At a temperature of 150 degrees Celsius, waste PET is pulverised and mixed with bitumen in amounts ranging from 2, 4, 6, 8, and 10% (by weight of OBC) by weight. Because of their higher softening point than traditional binders, PET modified binders have exhibited enhanced resistance to persistent deformation and rutting compared to conventional binders. Additionally, the consistency of the PET modified binder is reduced, but its resistance to flow and temperature variations is increased.

2.6.2 Using Plastic as an Aggregate Coating

Awwad and Shbeeb (2007a) evaluated the usage of polyethylene as a type of polymer to improve the properties of asphalt mixes was investigated in depth. LDPE and HDPE polymers were used to cover the aggregates in two different states (ground and unground Low Density Polyethylene (LDPE) and High Density Polyethylene (HDPE)) (HDPE). To test different polyethylene proportions of optimal bitumen content (OBC), the Marshal mix design technique was used to calculate the optimal bitumen content (OBC). Tests were carried out on seven different ratios of polyethylene by OBC weight of each kind and state (6, 8, 10, 12, 14, 16 and 18 percent). Bulk density, stability, and flow rates are measured as part of the testing. The findings indicate that applying 12 percent pulverized HDPE polyethylene modifier enhances the engineering properties of HDPE polyethylene. We found that it enhances stability while simultaneously decreasing density and somewhat increasing air spaces.

According to (Jan et al. 2011) It is possible to increase pavement performance while simultaneously conserving the environment by incorporating waste polymeric packaging material (WPPM) into bituminous mixtures. Milk bags and other HDPE-based carry bags are being used in the research as bituminous mix additives. According to the findings, the ideal dose of WPPM ought to be around 0.3 and 0.4 percent by weight of the asphalt mix, depending on the conditions. Increased dose leads in an unwanted increase in the stiffness of the mix as a result of the increased dosage. It has been observed that including WPPM into bituminous mixes results in substantial improvements in performance metrics like as rutting and deformation measurements. The use of WPPM in road building, according to the authors, can perform as a sustainable method of removing non-biodegradable plastic trash.

Sabina et al. (2009) presented comparison was made between the characteristics of mixtures including plastic/polymer (PP) (eight and fifteen percent by weight of bitumen, respectively) and mixtures without PP. It was shredded to make the waste PP modifier and cooked in an oven to 150-160 degrees Celsius with graded aggregates. The waste PP modifier was then added to the hot aggregates before mixing with OBC. Marshall Specimens were tested for conventional and modified combinations using the Marshall Method. At modifier concentrations of 8 percent and 15 percent, respectively, it was discovered that the marshal stability of modified mixes was 1.21 and 1.18 times larger than that of regular mixes, respectively. In addition, modified mixes improved ITS and rutting resistance by a significant margin. The indirect tensile strength (ITS) of the conventional mix was 6.42 kg/cm2, however it was 10.7 and 8.2 kg/cm2 for modified mixes containing 8 percent and 15 percent, respectively; rutting was (7 mm) for the conventional mix, whereas it was 2.7mm and 3.7mm for modified mixes containing 8 percent and 15 percent, respectively; rutting was (7 mm) for the conventional mix, while it was 2.7mm and 3.7mm for modified mixes As a result, waste polypropylene modified bituminous mixes should be more durable and perform much better in field conditions.

2.6.3 Use of Plastics as Aggregate

Zoorob and Suparma (2000) discovered that the usage of recycled plastics, mostly made up of low-density polyethylene (LDPE) in granular form, can replace (by volume) an equivalent percentage in size of natural aggregates (Plastiphalt). Recycled plastic pellets appear to reduce bulk density by 16% and enhance Marshal stability by around 2.5 times compared to the control mix when 30% of the aggregate by volume is substituted. Plastiphalt combinations have been shown to be more robust and elastic based on the higher observed flow values. Compared to the other two combinations, the Plastiphalt one had a greater ITS value. Most of the time, aged recycled Plastiphalt mixes surpass control mixes made of mineral aggregates when it comes to mechanical characteristics.

2.7 Usage of RAP and LDPE Together

Permanent deformation, high temperatures, and overloading are all possible causes of HMA pavement failure. In recent years, polymer modified asphalt concrete has been developed to solve pavement performance concerns while also taking into account traffic loads. Numerous waste products are generated during factory operations, service industry operations, and home activities. Boosted population expansion increased industry output of different sorts of waste products such as blast furnace slag, plastics, and so on. These issues are especially prevalent in poorer nations. Recycling trash into usable products is one answer to this challenge.

RAP is a crushed and sieved asphalt pavement that has been dug or milled to satisfy specific grading criteria. RAP is used in a variety of nations and at a variety of levels, depending on the country's requirements. It often varies between 10% and 40%. It can also be utilised in higher concentrations up to around 50%, but then new difficulties with the pavement arise. Because RAP aggregate is finer than fresh aggregate, it is advantageous for creating mixes with fine gradation. (Januszke and Holleran 1992) discovered that adding 30% RAP to HMA increases the specimen's resistance to persistent deformation. It exhibits less persistent deformation than standard virgin aggregate specimens. (Kandhal et al. 1995) conducted a thorough evaluation of five projects, each of which included a recycled asphalt-concrete section and a control section, and concluded that there was no significant difference in the properties of the recycled asphalt-concrete sections after 1.5 to 2.5 years of service, with no considerable fatigue cracking, rutting, or ravelling based on visual inspection. (Kiggundu and Newman 1987) concluded that mixes using recycled asphalt binder mature more slowly than virgin mixes. The explanation for this might be that the RAP material ages more slowly as a result of the ageing that has already occurred to it.

Numerous studies have been conducted to evaluate the performance of pavements with varying amounts of LDPE. Several significant studies on the use of polymer in HMA include (Fawcett and McNally 2000) and (Yousefi and Lafleur 1987).

Moisture susceptibility is a phrase that refers to a decrease in the strength and durability of asphalt pavement as a result of moisture interacting with the fine aggregate and binder. The weaker the connection between aggregate and binder, the greater the risk of moisture-induced damage (Ahmed 2014). According to (Wall and O'Sullivan 2009), moisture in the air void of the pavement is a possible source of moisture-induced deterioration. Because damage decreases the strength and durability of the pavement, it must be inspected often to ensure the pavement's long-term performance. Two distinct forms of moisture-induced failure are frequently associated. Cohesive failure, which is caused by the binder's decreased binding strength, and Adhesive failure, which occurs between the binder and aggregate (Zollinger 2005). According to (Theses and Shrum 2010), the decreased compaction temperature results in moisture damage, as the moisture in the aggregate is not properly dried, resulting in damage. Appropriate moisture damage testing must be done to guarantee the pavement performs optimally.

In 1998, the Maine Department of Transportation advised using the Tensile Strength Ratio (TSR) of conditioned to unconditioned samples to determine moisture damage to pavement. The ITS is simple to administer and quite attractive. The samples for testing is straightforward to produce.

Fatigue cracking, according to (Monismith, Epps, and Finn 1985), shortens the life of pavement. The amplitude, frequency, and period of load application were later discovered as having a significant influence on pavement performance. (Sousa et al. 1998) conducted four-point bending fatigue tests to assess the effect of aggregate gradation on the fatigue life of asphalt mixtures. They determined that fine aggregate gradations appear to perform better in fatigue than coarse aggregate gradations, owing to the greater binder concentration required in such mixtures. By raising the binder content, fatigue life is extended and stiffness is reduced. The loss of stiffness might be compensated for simply increasing the stiffness of the RAP binder. The fatigue life of pavement as determined by ITFT is typically shorter than that determined by other techniques (Porter and Kennedy 1975) Under the influence of repetitive loads, the micro-cracks in the pavement coalesce to create macro-cracks; this phase is referred to as crack initiation. Following the crack initiation phase, these fractures coalesce to produce large cracks in the pavement.

Brief Summary of previous literature on the usage of RAP and LDPE is given in the Table 2 – 3.

Table 2-3: Literature Review Summary

Research Paper Description	Polymer / RAP %	Tests Performed	Outcomes
Waste Plastic Films (2021).	Waste Plastic Films 2%, 4%, 6% and 8%	ITS Resilient Modulus	HMA incorporated with 6% LDPE plastic flakes showed promising results and there was increase of 24% in ITS and 13% increase in stiffness.
Plastic Waste Utilization as Bitumen Modifier (2018).	Plastic waste 5%, 10%, 15%, 20% and 25%	Marshall Stability IDT	13% enhancement in the IDT value by the addition of 7% plastic as compared to virgin asphalt mix. Stability was improved upto 42%.
Effect of RAP on rubberized AC (2018)	RAP 20%, 40% and 60%	ITS Resilient Modulus TSR	60% RAP showed better results as compared to conventional asphalt mixes. ITS was enhanced more than 2 times, resilient modulus was enhanced upto 3 times. Fatigue life start to reduce when we enhance the percentage of RAP. 60% RAP showed poor results.
Use of RAP and LDPE (2017).	RAP 10%, 20%, 30% and 40% and LDPE 4%.	ITS ITFT	Samples with 40% RAP and 4% LDPE showed promising results. TSR was increased more than 4% as compared to conventional mix. Specimens with 40% RAP and 4% LDPE sustained more than 5 times number of cycles as compared to virgin mix.

Use of Plastic Waste in Road Construction (2016).	Plastic waste 6%, 8%, 10%, 12% and 14% by wt. of bitumen	Marshall Stability	There was 34% increment in stability by use of 14% plastic by bitumen wt. as compared to 0% plastic content. Till the addition of 12% bulk density of asphalt increased by 1.7% as compared to virgin asphalt.
Rheological Properties of asphalt modified by waste tyre rubber and LDPE (2015).	LDPE 2%, 3%, 4% and 5%	Dynamic Shear Rheometer & Low Temperature Creep Test	These properties are dependent on the modifier percentage. Better values can be obtained by combination of these two. Results show that 10% waste tyre rubber and 3% LDPE combine give best results.
Addition of Plastic waste PP, HDPE and LDPE (2015).	LDPE was added 1% to 8%.	Resilient Modulus	Resilient Modulus was enhanced upto 10% of original HMA mix by addition of LDPE 6%.
Evaluation of Pyrolisis LDPE in AC (2015).	LDPE was added 3%, 4%, 5% and 6%	Marshall Stability	Stability was increased upto 50% and flow was reduced upto 14%. There was 30% reduction in air voids by 5% LDPE addition.
Rutting Investigation by use of waste packaging materials (2011).	Waste Plastic Milk bags (LDPE) 0.1% to 0.6%.	Rutting Stiffness	Rutting is reduced to 3.6 mm from 16.8 mm by use of 0.4% LDPE. Stiffness is increased upto 7% as compared to original value.
Lab investigation of HMA mixed with RAP (2011).	RAP content 40% & 60%	Stiffness Modulus ITS	Stiffness was increased upto 2 times by addition of 40% RAP as compared to virgin asphalt mix. There was 6.2% enhancement in ITS value by addition of 40% RAP.
Evaluation of Sasobit for reducing CO_2 (2010).	Sasobit percentage as 1%, 2%, 3% and 4%	Mixing Temperature & CO_2 emission measurement	Inclusion of sasobit reduced the mixing temperature from 160ºC to 145ºC. Inclusion of sasobit reduces the CO_2 emission and 1.6% sasobit can be used easily without compromising the properties of binder.
Virginia's Higher Specification for Reclaimed Asphalt Pavement (2009).	Different percentages of RAP 21%, 25% and 30%	Tensile Strength Ratio	There was 5% reduction in TSR value as compared to virgin asphalt mix.
Use of Waste Polyethylene and	Literature Review of	Literature Review	Polyethylene is more effect bitumen modifier as it is mixing convenience

PVC as Bitumen Modifier (2008).	different properties		while PVC requires high temperature for mixing and compaction.
Lab evaluation of fatigue characteristics of RAP mix (2008).	RAP 10%, 20% and 30%.	ITS Resilient Modulus ITFT	30% RAP proved best in ITS and there was 25% improvement in ITS as compared to virgin mix. 30% RAP showed promising results in resilient modulus and there was more than 35% enhancement as compared to 0% RAP. 30% RAP showed more than 50% increase in cycles to failure as compared to virgin mix. 30% RAP was best to use along HMA.
The use of Polyethylene in Hot Asphalt Mixtures (2007).	LDPE & HDPE 6%, 8%, 10%, 12%, 14%, 16% and 18% by wt. of bitumen	Marshall Stability	12% HDPE and 10% LDPE proved best in stability. 61% improvement in stability value by adding 12% HDPE and 47% improvement by adding 10% LDPE. 3.5% reduction in flow by 10% LDPE. Air voids increased by 7.1% in by addition of 12% HDPE and 19% increment by addition of 10% LDPE.
Polymer Modified Asphalt (2001).	Lit. review of different polymers.	Literature Review	SBS is mostly used as bitumen modifier but LDPE and HDPE can also be used as modifiers.

2.8 Summary

After examining past research on the use of plastics and plastic wastes as modifiers in asphalt mixes, it is evident that there are a variety of ways to incorporate plastics into asphalt mixes to improve their characteristics. The properties of modified asphalt mix are dependent on a variety of factors, including the type of aggregate, plastic used, the method of usage, and the quantity of plastic added. In this research a constant percentage of 30% RAP will be incorporated along LDPE with varying percentages of 2.5%, 5.0% and 7.5% by weight of bitumen.

Chapter 3

RESEARCH AND TESTING MATRIX

3.1 General

It covers the methods needed to complete the study's objectives, such as obtaining essential materials, preparing specimens, testing, and evaluating the relative importance of various aspects. This investigation utilised several RAP-prepared asphalt concrete specimens as well as a control asphalt concrete specimen. In this chapter, the Marshal Mix design process will be explained in depth for different percentages of RAP, namely 0% (controlled sample) and 30%. The specimens for resilient modulus, moisture susceptibility and indirect tensile fatigue testing were created using the above-mentioned percentages of RAP with the addition of Low Density Polyethylene at three different percentages of OBC, namely 2.5%, 5% and 7.5%. The NHA-B wearing course grading system was utilised to prepare these laboratory specimens, as detailed in this chapter. This chapter will describe the testing equipment utilised, the laboratory tests that were to be done on the specimens, the process used to prepare test specimens, as well as the input parameters used during those tests.

3.2 Research Methodology

To accomplish the objectives, RAP percentage and a control sample were chosen, followed by the addition of various percentages of LDPE. Milled RAP material was collected from the Islamabad-Peshawar Motorway (M1) and transported to the Military College of Engineering at NUST for testing and analysis of fatigue, resilient modulus and moisture damage in Universal Testing Machine (UTM), respectively. Specimens for wearing course mixes were created in the laboratory under controlled circumstances. These specimens were prepared following the laboratory diagnosis of OBC. Following that, the data were analysed and subsequent conclusions and recommendations were made, as stated in the following chapters. The approach for this investigation is depicted in Figure 3-1.

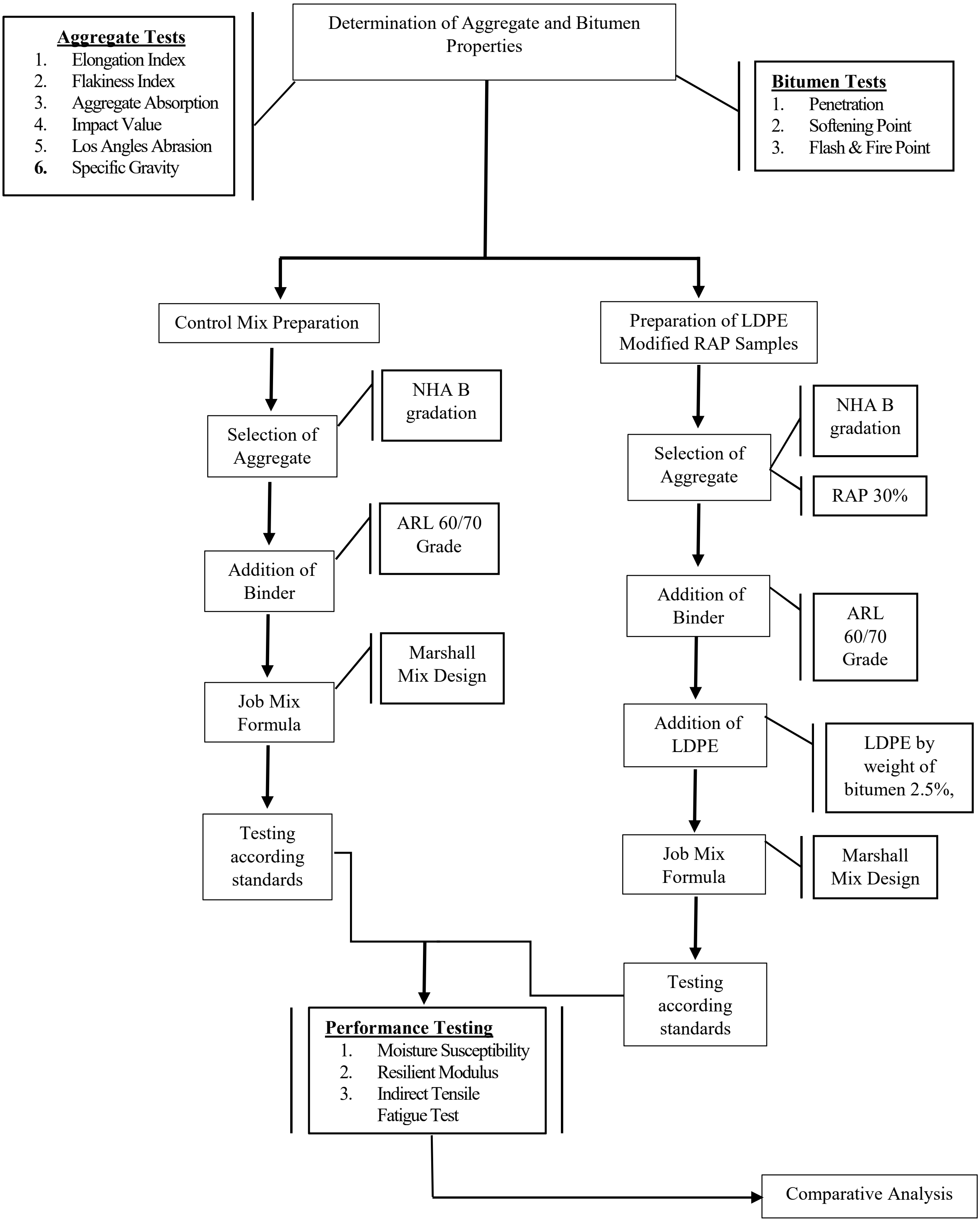


Figure 3-1: Flow Chart of Research Methodology

3.3 Characterization of Selected Materials

3.3.1 Material Selection

Margalla quarry provided the coarse and fine aggregates, and Attock Refinery Limited (ARL) in Rawalpindi provided penetration grade 60/70 bitumen for the project. For the purpose of this study, grade 60/70 was chosen since it is mostly used in practice in Pakistan and is suited for climatic zones with a colder to mild environment. Materials in the form of milled material were taken from the Islamabad-Lahore highway to be used in the construction of the RAP.

The aggregate structure of the mix contributes about 95% of the resistance to permanent deformation, while the asphalt binder contributes the remaining 5% aggregates create a robust stone framework that withstands repeated load applications. The gradation, surface roughness, and form of the aggregates have a significant effect on HMA characteristics. Angled and coarse-textured aggregates give more shear strength than rounded and smooth-textured aggregates. Figure 3-2 shows a RAP quarry obtained from motorway. Mandatory tests on used aggregates and asphalt binder were conducted in accordance with ASTM and BS norms and requirements for material characterisation.

Figure 3-2: RAP Quarry

LDPE was used as a modifier in this research. The product was imported in the form of prills, as seen in Figure 3-3, and was distributed by an authorised distributor. LDPE is typically added at a very low rate by weight of the total binder. LDPE was put straight to the mix bowl charged with aggregates after the necessary quantity of asphalt binder is applied. In this investigation, samples were produced with 2.5%, 5% and 7.5% of LDPE.

Figure 3-3: Low Density Polymerethylene Pellets

3.3.2 Aggregate Testing

The aggregate arrangement is the core component of the mix that resists permanent deformation and is anticipated to create a strong structure for resisting repeated stresses. To determine the aggregate's essential characteristics, such as gradation and specific gravity, laboratory experiments were conducted on each stockpile. Laboratory tests include the following:

- Aggregate Shape Test
- Specific Gravity and Water Absorption Test aggregates
- Aggregate Impact Value Test
- Aggregate Crushing Value Test
- Los Angeles Abrasion Test on aggregate

The tests mentioned above were carried out using three samples and then average was taken for further process.

3.3.2.1 Aggregate Shape Test

The strength and workability of an asphalt mixture are mostly determined by the form of the particles. It also has an influence on the effort required for compaction, which is necessary to reach the appropriate density. As a result, the amount of elongated and flat aggregate particles was measured using a shape test. According to ASTM D4791, aggregate particles are classified as flaky if their dimension is less than 0.6 of their mean sieve size, and as elongated if their length is greater than 1.8 of their mean sieve size, as indicated in Table 4-2.

3.3.2.2 *Specific Gravity of Aggregates*

The specific gravity of an aggregate material is a measure of its weight-to-volume ratio. Gravities of several types of aggregate were measured, including coarse, fine, and filler. Granular material that passes through a No. 4 sieve is referred to as coarse granular material.

Specific Gravity of Coarse Aggregates

Specific gravity of coarse aggregate and water absorption were determined using the ASTM C 127 methods and tools. There are three sample conditions for the coarse aggregate specific gravity test: oven-dry without water in the sample, immersed in water or underwater, and saturated dry on the surface. The test was completed on both the 10-20 mm and 5-10 mm coarse-graded stock piles, with the results reported in Table 4-2.

Specific Gravity of Fine Aggregates

In line with ASTM C 128 techniques and equipment, the specific gravity of fine aggregate and the water absorption of fine aggregate were determined. For fine aggregate and stone dust, a specific gravity test was carried out to determine the bulk, SSD, and apparent specific gravities, with the findings shown in Table 4-2.

Figure 3-4: Fine Aggregate Specific Gravity Apparatus

3.3.2.3 *Impact Value Test*

The aggregate impact value indicates an aggregate's resistance to a rapid shock. The apparatus necessary to determine the impact value includes an impact testing machine, a tamping rod, and 1/2”, 3/8”, and #8 sieves (2.36mm.) Around 350g of aggregate passing through a 1/2” sieve but remaining on a 3/8” sieve was collected and placed in three layers in the mould of the Impact Testing Machine, tamping each layer 25 times. The sample was moved to the machine's bigger mould and 15 blows were delivered from a height of 38 cm using a hammer weighing 13.5 to 14 kg. The aggregate so formed was removed and filtered using sieve #8. The proportion of aggregate passing through a 2.36mm sieve was used to get the impact value.

Figure 3-5: Impact Value of Aggregate Apparatus

3.3.2.4 Crushing Value Test

To create a higher quality and strength pavement, it is required for the aggregates to be strong enough to withstand traffic loads. The apparatus for this test consisted of a steel cylinder with open ends, a base plate, a plunger with a piston diameter of 150 mm and a hole in the centre for inserting a rod for lifting, a cylindrical measure, a balance, a tamping rod, and a compressive testing machine. Aggregates were passed through a series of sieves, with those passing through 12" and retaining on 3/8" being chosen. The aggregate sample was washed, oven dried, and weighed (W_1), and then put in three layers to the cylindrical measure, each layer being tamped 25 times. The sample was placed into the steel cylinder with three layers of base plate. It was then loaded into a compression testing machine at a rate of 4 tons/minute until the total load reached 40 tonnes. The steel cylinder was then removed and the crushed material was put through a 2.36mm filter. We collected and weighed the stuff that went through this filter (W2). The crushing value of aggregate was determined using the formula $= W_2/W_1 \times 100$.

Figure 3-6: Aggregate Crushing Value Apparatus

3.3.2.4 Los Angeles Abrasion Test

This test is used to assess the abrasion resistance of road aggregate. Aggregate must be sufficiently resistant to withstand wear caused by strong traffic loads. This test included a Los Angeles Abrasion machine, a balance, a set of sieves, and steel balls. This process used the testing methodology or grade B. 2500 g of aggregate retained on 12" and 3/8" sieves, for a total of 5000g (W_1) of aggregate, were placed in the Los Angeles abrasion machine, together with 11 balls made of steel or charges. For 500 revolutions, the machine was spinned at a pace upto 33 but more than 30 revolutions per minute. The material was then sieved using a 1.7mm sieve. The weight of the sample that passed through it (W2) was recorded. The abrasion value was calculated using the following formula = $W_2/W_1 \times 100$.

Thus, when preparing Asphalt mixes, it is important to verify the appropriateness of aggregates against ASTM and BS standards and material characterization criteria. These experiments were conducted on aggregate from the Margalla quarry; Table 4-2 summarises the results of the tests conducted on the aggregates.

Figure 3-7: Los Angeles Abrasion Value of Aggregate Apparatus

3.3.3 Asphalt Binder Testing

According to the Asphalt Institute's MS-4 handbook, consistency, safety, and cleanliness are the three important qualities of a binder in infrastructure and engineering applications. The density of asphalt binder varies as a function of temperature. As a result, standard temperature is required for comparing asphalt binder consistencies. A penetration test or a viscosity test are frequently used to determine the consistency of bitumen binder (Asphalt Institute MS-4, 2003). Other tests, such as the softening point and ductility of the binder, offer additional information and confidence in the consistency. Thus, the following experiments were conducted in the laboratory to characterise the asphalt binder.

- Penetration Test of Bitumen
- Softening Point Test of Bitumen
- Flash and Fire Point Test of Bitumen

3.3.3.1 Penetration Test

Penetration testing can be used to determine the penetration of asphaltic compounds. Containers containing specimens and needles are used in the penetration test. A softer binder results in better penetration values. As per AASHTO T 49-03, the temperature utilised was 25°C, the load was 100 grams, and the duration of the test was 5 seconds, unless otherwise specified. Five values were collected from each of two ARL 60/70 samples following penetration testing. All values collected met the penetration test's specified requirements. The outcome of the penetration test is shown in Table 4-1.

3.3.3.2 Softening Point Test

Bitumen is a viscoelastic material; nevertheless, as the temperature goes up, it becomes softer and its viscosity falls, indicating that it is becoming softer. At what temperature a conventional size sample of bitumen cannot sustain the weight of a 3.5-gram steel ball is known as the bitumen's softening point, and it is determined by a series of tests. This means that in most cases, the temperature at which the two bitumen discs soften sufficiently to allow the steel balls to fall 25 millimetres is used to determine the softening point of bitumen. Using ring and ball equipment, the AASHTO-T-53 criteria for determining the softening point of asphalt were seen to be met. Results of the softening point test are presented in the following Table 4-1.

Figure 3-8: Softening Point Apparatus

Figure 3-9: Ring and Ball Apparatus

3.3.3.3 Fire and Flash Point

This property was found using D3143/D3143M-13 standards.

Figure 3-10: Fire and Flash Point of Bitumen Apparatus

3.4 Gradation Selection

NHA class B aggregates were utilised in accordance with NHA (1998) standards for dense graded surface course mixes. According to Marshal Mix Design, nominal maximum aggregate size for class B wearing coarse gradation was 19 mm, with the actual maximum aggregate size being somewhat smaller. Table 3-1 contains the selected gradation, and Figure 3-11 depicts the gradation plotted against % passing and sieve diameters.

Table 3-1: NHA Class – B Gradation Selected for Testing

Sieve Size	NHA Specification Range (% Passing)	Our Selection	Retained
19	100	100	0.00
12.5	75-90	82.5	17.50
9.5	60-80	70	12.50
4.75	40-60	50	20.00
2.38	20-40	30	20.00
1.18	5-15	10.00	20.00
0.075	3-8	5.5	4.50
Pan	. . .	. . .	5.50

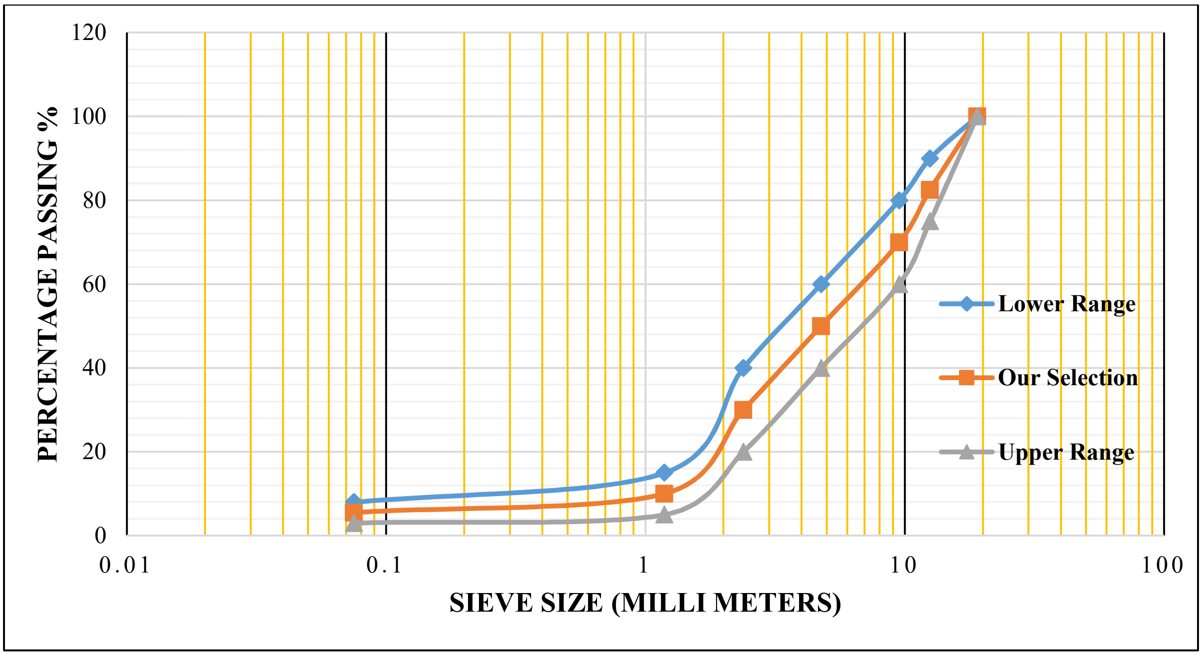


Figure 3-11: Gradation Curve for Virgin Aggregate

3.4.1 Gradation for RAP

This study's primary goal was to determine how differing the ratio of RAP and LDPE in the combination of aggregate and bitumen affected permanent deformation and moisture damage to asphalt. RAP was added to the asphalt mix at a concentration of 30 percent, and LDPE was added at the same concentration as RAP. The Marshall Mix design technique was used to determine the stability and flow values, as well as the volumetric values of the mixture. Tables 3-2 and 3-3 show the results of the experiment, which showed that there were five separate RAP percentages and related aggregates on different sieves. Table 3-2 shows the results of the experiment. Figure 3-18 depicts gradation as a function of the proportion of material going through the sieve and the sieve size.

Table 3-2: RAP Gradation

Sieve Diameter (mm)	RAP (% Retained)
19	0.00%
12.5	7.05%
9.5	11.20%
4.75	21%
2.38	16%
1.18	31.8%
0.075	10.30%
Pan	2.65%

Table 3-3: NHA Class – B Gradation Selected for Testing

Sieve Size	NHA B Lower Limit	NHA B Upper Limit	Our Selection	30% RAP
19	100	100	100	100
12.5	75	90	82.5	86.237
9.5	60	80	70	69.932
4.75	40	60	50	50.91
2.38	20	40	30	34.16
1.18	5	15	10	13.23
0.075	3	5.5	5.5	5.425

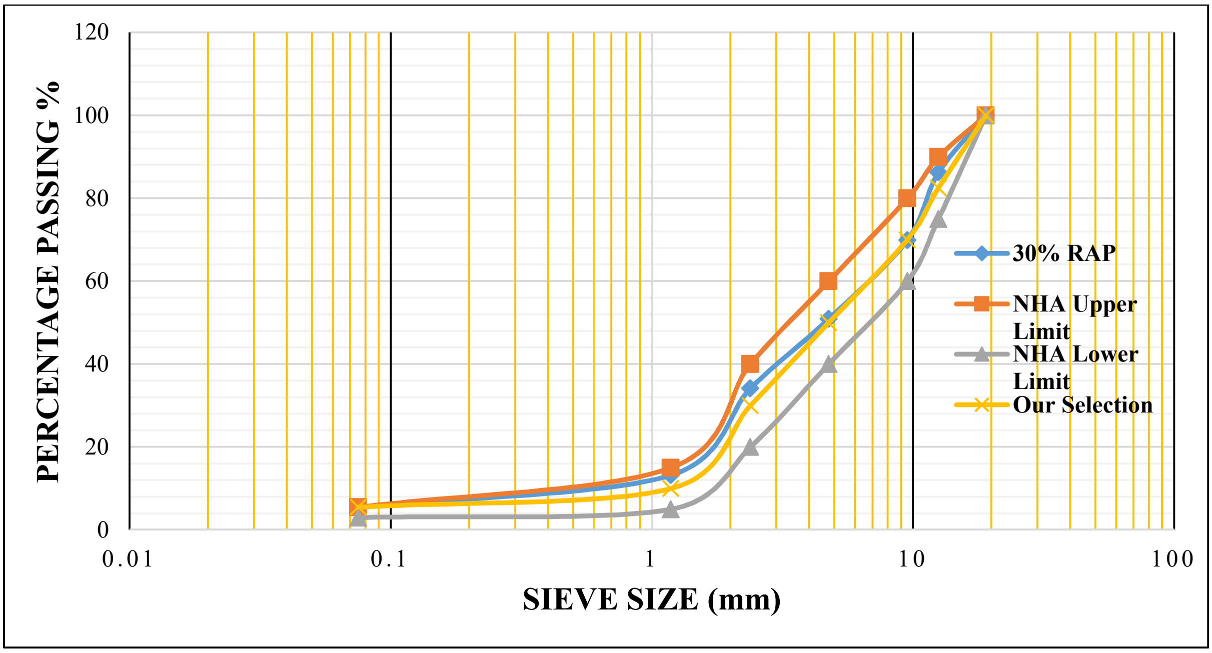


Figure 3-12: RAP Gradation Curve of 30% RAP

3.5 Asphalt Mixture Preparation

As previously indicated, there are two types of mixes. The first is a regulated asphalt mixture. The second is a mixture comprising 30% RAP and three additional percentages of LDPE. Laboratory produced mixes were developed using the Marshal Mix design process after determining the OBC. Following that, samples were prepared according to their OBC using specially 4% air voids. The following heading describes the method for preparing laboratory produced mixtures.

3.5.1 Preparation of Bitumen Mixes for Marshall Mix Design

The bituminous mixtures used to determine OBC were produced in accordance with ASTM D 6926 using the Marshall Apparatus. Due to the fact that there were two distinct gradations in terms of RAP proportions, the OBC for each sort of gradation was established by three revisions of the Marshall Mix design method. The volumetric characteristics, stability, and flow were evaluated, the Marshall Mix design criterion was confirmed, and lastly the OBC was calculated. Marshall Mix was created in the following manner:

3.5.2 Preparation of Aggregates and Bitumen for Mixes

In order to get a constant weight for the aggregates after sieve testing, they were allowed to dry at a temp of 105°C to 110°C. If the Marshall Mix design approach is used, 1200 gram aggregates are required to compact a 4-inch diameter sample using the Marshall Mix design technique (ASTM D6926). In order to estimate the amount of asphalt cement necessary for each specimen, the following equations were utilised:

$$M_T = M_A + M_B$$

$$M_B = \frac{X}{100} \times M_T$$

Where,

M_T = Mass of Total Mix
M_A = Mass of Aggregate
M_B = Mass of Bitumen
X = Percentage of Bitumen

3.5.3 Mixing of Aggregates and Asphalt Cement

The ASTM D6926 standard advises using a mechanical mixer to properly mix bitumen and aggregates. After extracting of the dehydrated, warmed aggregates and warmed bitumen from the oven, they were immediately transferred to the automatic mixing equipment. The schematic diagram of a mechanical mixing machine is shown in Figure 3-13. The mixing temperature range was 160°C to 165°C, which corresponds to the temperature at which bituminous mixes are manufactured in Pakistan (NHA Specifications).

Figure 3-13: Mixing of Asphalt and Aggregate

3.5.4 Mixture Conditioning After Mixing

ASTM D6926 suggests conditioning bituminous mixtures for almost two hours preceding to compaction. As a result, each bituminous mixture obtained from the mixing machine was inserted in a metal container.

3.5.5 Compaction of Specimens

A Marshall Compactor was used to compact the mixtures after they had been preconditioned at a temperature of 135 degrees Celsius for two hours. Each component of the mould arrangement is made up of three pieces: the mould cylinder, the base plate, and the extension collar. The interior diameter of the mould cylinder is approximately 4-inches in diameter and approximately 3-inches in height. The collar extensions and base plate may be swapped out either at the beginning or the end of the mould. The mixture was pressed into the mould with the help of a spatula. During the cleaning and preheating of the mould at 135°C prior to packing, a filtering paper with a diameter equivalent to the mold's diameter was put at the bottom of the mould. When a complete batch was pushed into the mould and spaded in a consistent manner. A layer of filter paper was placed on top of it to protect it from the elements.

The design criterion chosen for this study was a heavily visited pavement or designs with ESALs (millions) 30 for dense graded wearing courses, as determined by the results of the previous study. Because of this, 75 blows were issued to each end in order to simulate excessive traffic flow. The components of the mould were placed into the mould holding on the compaction stage in preparation for compression (application of blows). Using a hammer that was suitably situated over the mould assembly, 75 blows were given to the specimens mechanically. As soon as all of the compressive blows on one side were completed, the mould assemblage was removed from its holder and the specimen was rotated. The mould assembly was then reassembled and the specimen underwent the same number of compressive blows on the other face.

3.5.6 Extraction of Specimens from Mould

After compression, the mould equipment was removed and the sample allowed to cool for a few minutes. The specimen was then extracted from the mould using an extraction jack. On a flat surface, the prepared samples were cooled to room temperature.

3.5.7 Number of Specimens for Each Job Mix Formula

Three specimens were created for every asphalt binder percentage and combination of aggregates. Due to the fact that there were two sorts of gradations, 0% and 30%, 15 specimens of each type were created, along with the total of 30 specimens. Five different binder ingredients were used to produce specimens (3.5, 4.0, 4.5, 5.0 and 5.5 percent). Five experimental blends were used to determine the combination that works optimally at a minimum bitumen concentration of 4% air voids.

Figure 3-14: Compacted Marshall Specimens

3.6 Determination of Volumetric, Stability and Flow

Achieving theoretical maximum specific gravity (G_{mm}) and bulk specific gravity (G_{mb}) allowed us to calculate the volumetric properties of the mixes, including the Voids in Mineral Aggregates (VMA), the Voids Filled with Asphalt (VFA), and the Air Voids (V_a), as well as their unit weight using the specific gravity formulae (G_{mb}). Table 3-4 depicts the Marshall Mix design requirements in more detail. G_{mm} and G_{mb} values for bituminous pavement mixes were determined in accordance with ASTM D2041 and ASTM D2726 standards. Figure 3-18 depicts the results of the G_{mb} determination after the samples were kept in a water bath at 60°C for 1 hour and then tested for stability and flow using Marshall Test equipment, as shown in the Figure 3-15, 3-16 and 3-17.

Figure 3-15: Pycnometer Apparatus

Figure 3-16: Submerged Weight Measurement Apparatus

Figure 3-17: Marshall Testing Machine

Loading was carried out at a steady rate of 5 mm/minute till failure occurred. Marshall stability was defined as the entire maximum load in KN. The entire deformation that happens at maximum load was quantified in terms of a flow number in millimetres. Marshall Mix design requirements (MS-2) specify that the specimen's stability for a heavily frequented worn course should be more than 8.006 KN and the flow number should be between 2 and 3.5. The specimen was promptly tested after being removed from water bath.

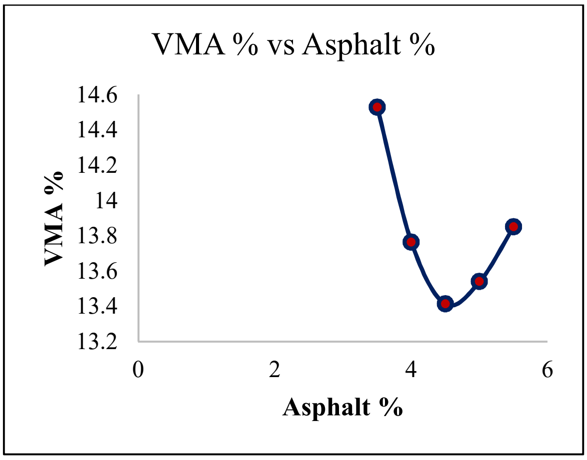
3.6.1 Volumetric Properties Containing 0% Rap

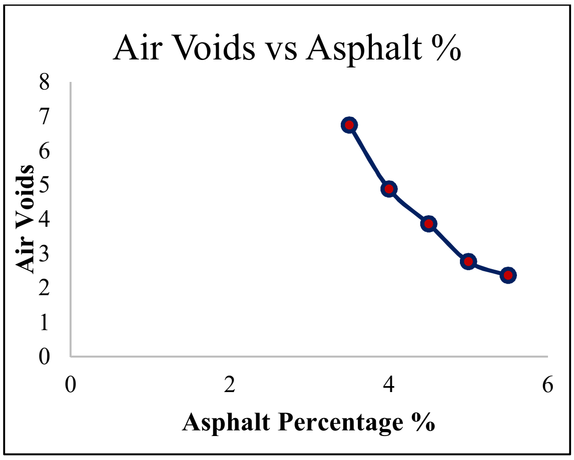
Loading was carried out at a steady rate of 5 mm/minute till failure occurred. Marshall Stability was defined as the entire maximum load in KN. The entire deformation that happens at maximum load was quantified in terms of a flow number in millimetres. Marshall Mix design requirements (MS-2) specify that the specimen's stability for a heavily frequented worn course should be more than 8.006 KN and the flow number should be between 2 and 3.5. The specimen was promptly tested after being removed from water bath.

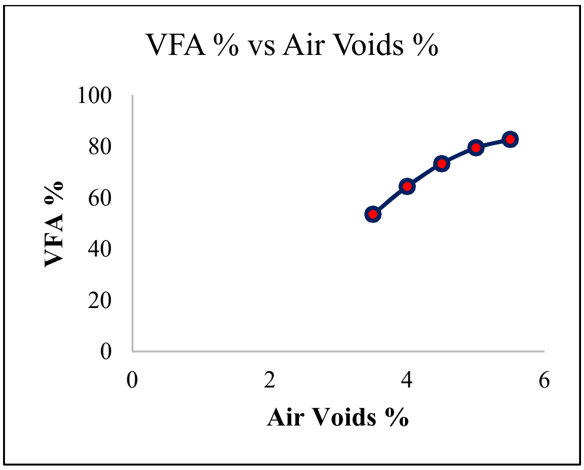
Table 3-4: Volumetric Properties Containing 0% Rap

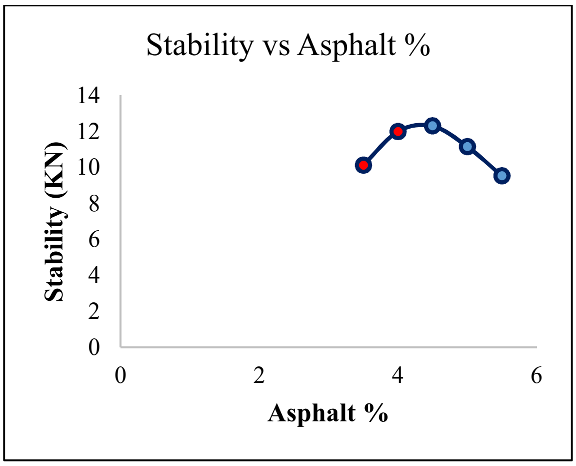
% AC	G_{mb}	G_{mm}	Unit wt (g/cm^3)	V_a (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.325	2.493	2.32	6.73	14.52	53.61	10.13	2.14
4	2.358	2.479	2.35	4.88	13.76	64.53	12.00	2.46
4.5	2.380	2.468	2.38	3.86	13.41	73.41	12.29	2.90
5	2.389	2.457	2.38	2.76	13.54	79.56	11.14	3.47
5.5	2.393	2.451	2.39	2.36	13.85	82.91	9.51	4.31

To determine the OBC of a mix containing 0% RAP, the curves linking asphalt content and volumetric characteristics, stability, and flow were drawn according to the MS-2 handbook.









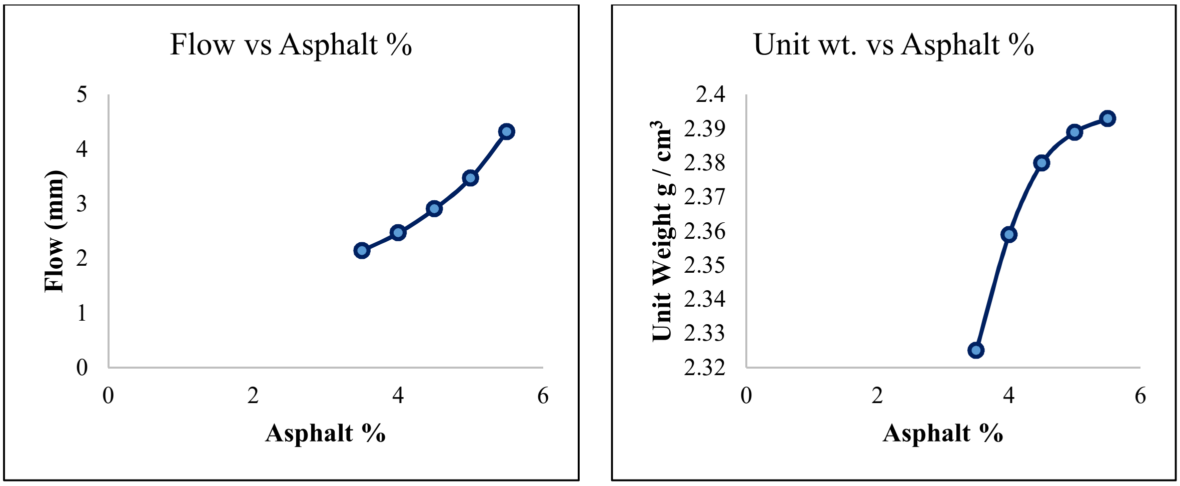


Figure 3-18: Volumetric Properties of 0% RAP

The asphalt composition of 4% air voids is referred as OBC. OBC is 4.50 percent in the blend with 0% RAP. The volumetric characteristics, stability, and flow parameters required by OBC were then determined using the graphs. Table 3-5 illustrates the Job Mix Formula for a combination containing no RAP. The table clearly indicates that all volumetric characteristics, stability, and flow satisfy the standards. At 4% specified air voids, the VMA must not be below 13%, and in this case, it was 13.493 percent. VFA should be between 65 and 75 percent; its estimated value of 70.04 percent falls within this range. According to the requirements, the stability value must not be under 8.006KN, which in this case was 12.324 KN. The measured flow number has been 2.724 mm, which is within the acceptable limit.

Table 3-5: Job Mix Formula for Mix having 0% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents	4.5	NA	----
VMA (%)	13.493	13	Pass
VFA (%)	70.04	65 – 75	Pass
Stability (KN)	12.324	8.006	Pass
Flow (mm)	2.724	2.0 – 3.5	Pass

3.6.2 Volumetric Properties Containing 30% RAP

The volumetric parameters, stability, and flow characteristics of a blend containing 30% RAP are listed in Table 3-6 and Figure 3-19.

Table 3-6: Volumetric Properties Containing 30% RAP

% AC	G_{mb}	G_{mm}	Unit wt (g/cm^3)	V_a (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.330	2.494	2.33	6.56	14.35	59.95	10.83	2.12
4	2.357	2.478	2.35	4.88	13.81	64.64	12.61	2.60
4.5	2.369	2.465	2.36	3.51	13.80	71.78	13.04	2.94
5	2.381	2.454	2.38	2.99	13.84	78.37	11.89	3.23
5.5	2.388	2.448	2.38	2.45	14.02	82.54	10.42	3.73

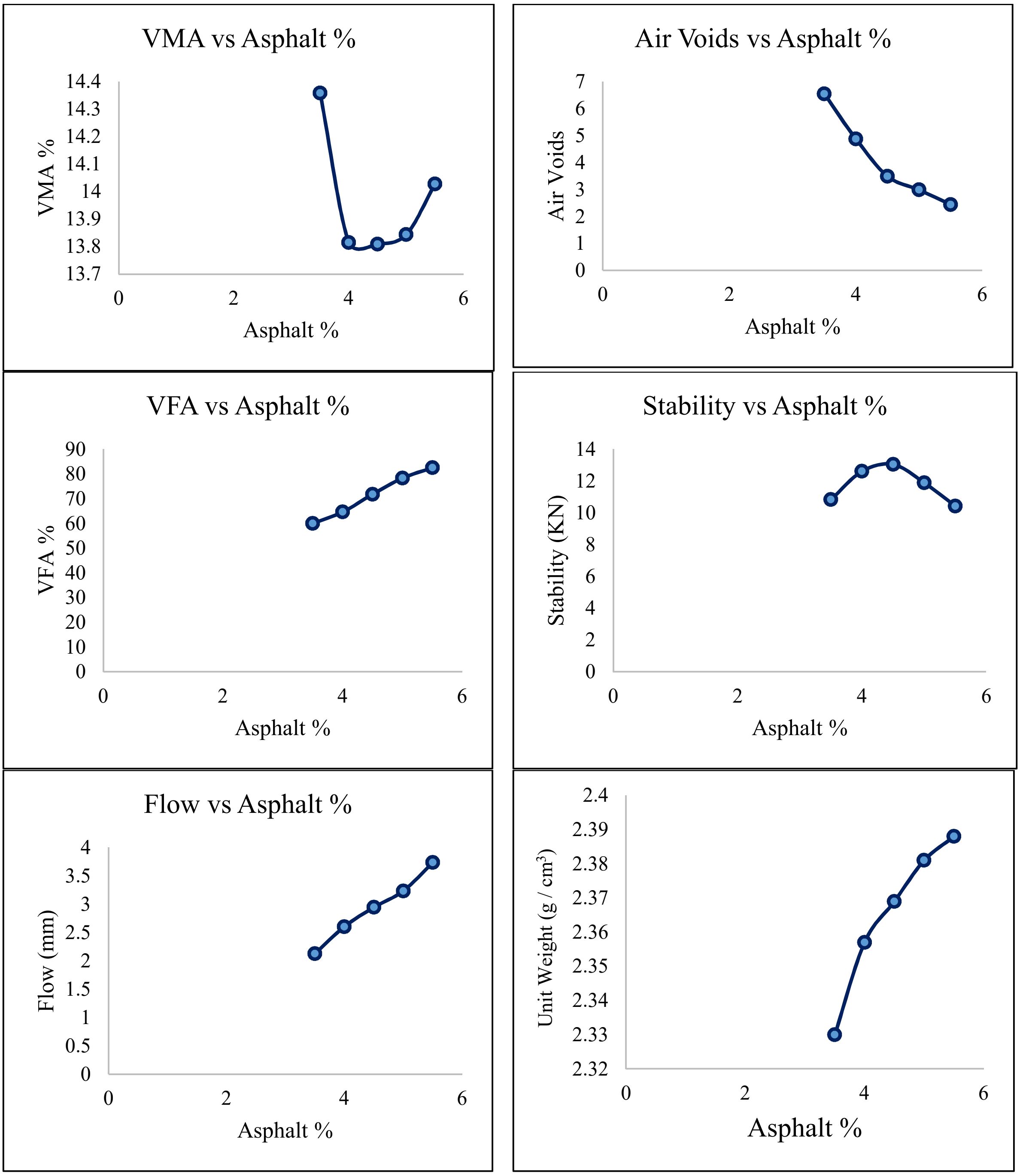


Figure 3-19: volumetric properties of 30% RAP

OBC is 4.20 percent in the asphalt concrete mix with 30% RAP. The volumetric characteristics, stability, and flow parameters required by OBC were then determined using the graphs. Table 3-7 illustrates the job mix formula for a combination containing 30% RAP. The table clearly indicates that all volumetric characteristics, stability, and flow satisfy the standards. At 4% design air voids, the VMA must not be less than 13%, and in this case, it was 13.661 percent. VFA should be between 65 and 75 percent; its estimated value of 70.7 percent falls within this range. According to the requirements, the stability value should never be less than 8.006KN, which was 13.124 KN in this situation. The measured flow number is 2.897 mm, which is within the acceptable limit.

Table 3-7: Job Mix Formula for Mix having 30% RAP

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents	4.2	NA	----
VMA (%)	13.814	13	Pass
VFA (%)	70.7	65 – 75	Pass
Stability (KN)	13.124	8.006	Pass
Flow (mm)	2.897	2.0 – 3.5	Pass

3.7 Sample Preparation for Performance Tests

Marshall samples were utilized to create specimens for moisture damage detection, stiffness and fatigue by Universal Testing Machine. First of all, aggregates were pre heated up to 110ºC and their weight was 1200 gm. After placing the aggregates in oven for 2 hours, bitumen was added in the aggregates as per mix design discussed above. Bitumen and aggregates were mixed with each other in mechanical mixer for 1 minute at 160ºC. After mixing, samples were put in container and put in oven at 135ºC for curing up to two hours. After curing, samples were compacted. Prior to compacting, marshall moulds were oiled and filter paper was placed. 75 blows on each side were given to replicate the traffic conditions. 3x replicates were produced for each test including 30% RAP by weight of aggregate and 2.5%, 5.0% and 7.5% LDPE was incorporated in bitumen by its weight. 60 samples of were prepared for performance testing. Dimensions of samples after compaction were as par as standards. Diameter of samples were 101 mm and their height was 62.5 mm.

3.8 Indirect Tensile Strength Test to Ascertain Moisture Susceptibility

ASTM D 6931-07 was used to conduct the Indirect Tensile Strength Test for determining moisture susceptibility (Resistance of Compacted Hot-Mix Asphalt to Moisture Induced Damage). Unconditioned testing was performed on three specimens per combination. One hour before to testing, these unconditioned specimens were put in a water bath set to 60°C.

Conditioned specimens were evaluated on another set of three specimens per mix. Conditioning of samples was performed in accordance with ALDOT-361, in which specimens were soaked and then placed in a 60°C (1401.8°F) water bath for 24 hours, followed by an hour in a 25°C water bath. At a pace of 50 mm/minute, both unconditioned & conditioned specimens were loaded diametrically. Tensile strength was estimated for each specimen using the specimen measurements and failure load. The average conditioned tensile strength was then determined by the average unconditioned tensile strength to get the tensile strength ratios. The permissible value for the tensile strength ratio was set to 80%. (minimum).

Equation was used to determine the tensile strength of every subgroup is following:

$$S_t = \frac{2000P}{\pi D t}$$

Where:

S_t = Tensile Strength, KPa

P = Maximum load, N

t = Specimen height before tensile test, mm

D = Specimen diameter, mm

The TSR value indicates the possibility for moisture damage. It is calculated as the ratio of the conditioned subset's tensile strength to something like the unconditioned subset. Equation is used to get the TSR for each combination.

$$TSR = \frac{S2: Average\ Tensile\ Strength\ of\ Conditioned\ Samples}{S1: Average\ Tensile\ Strength\ of\ Dry\ Samples}$$

Here:

S1 = Average tensile strength of dry samples, and

S2 = Average tensile strength of conditioned samples

3.9 Resilient Modulus Test

This information may be used to determine how well a pavement structure responds to applied traffic loads. It can also be utilised as a significant input for the Mechanistic Empirical pavement design process. The resilient modulus of a sample is defined as the relationship between applied stress and recovered strain observed during cyclic loading of the sample. It is a key indicator of the stiffness of a combination. Aside from that, the resilient modulus is a preliminary test that may be used to identify the relative quality of the materials and to give information for pavement design as well as for evaluation and analysis purposes. To compare changes in material stiffness as a function of polymer concentration and temperature, the robust modulus is employed. A key statistic for forecasting pavement performance and analysing the response of pavements to traffic stress, it is said, is the resilient modulus. Permanent deformation was proven to be more resistant in the stiffer pavements. It is important to note that mixes with a high rigidity (higher Mr.) at low temperatures break more quickly than combinations with a low rigidity (lower Mr.).

(Al-Abdul-Wahab et al. 1991) Marshall specimens were utilised to conduct robust modulus testing on asphalt concrete mixtures that were both unaltered and changed. In order to execute the modulus test, it is necessary to place the test samples in a governed cabinet and bring them to the required testing temperature. Afterwards, they are placed in an environmental room for a total of at least 12 hours. As soon as the samples reached the appropriate test temperature, they were removed from the temperature container and put into the loading apparatus at temperature of 25°C. It is necessary to estimate the resilient modulus of a cylindrical specimen by using the repeated-load indirect tension test. In the vertical diametric plane of the specimen, a haversine waveform is given vertically in the vertical diametric plane of the specimen. The horizontal elastic deformation was used to determine the application of the load and the value of the resilient modulus. The proposed load magnitude should also create an indirect tensile stress equal to or between 10% to 50% of the indirect tensile strength, depending on the material used. To precondition the specimen, it is necessary to subject it to a minimum of 50 to 200 cycles of stress. The modulus of the test machine is determined by the software programme that runs on the machine during each load strike and it included results from the average test findings, which were expressed as the specimen's resilient modulus at that particular temperature. The resilient modulus is computed using equations by calculating the actual load, horizontal deformation, and recovered horizontal deformation for each load pulse and then multiplying these values together.

$$M_r = \frac{P(0.27 + \vartheta)}{(\Delta h)t}$$

Whereas,

P = Dynamic Load

t = Specimen thickness

Δh = Recoverable horizontal deformation ν = Poisson's ratio

The resilient modulus was determined in accordance with European Standard EN 12697-26. (Test method for HMA stiffness). The temperatures that were utilised are listed in the Table 3-8.

Table 3-8: Temperature and Poisson's Ratio for Mr

Temperature, °C	**Poisson's Ratio, ν**
5	0.30
25	0.35
40	0.40

3.10 Indirect Tensile Fatigue Test

For asphalt concrete mixes, a variety of test procedures are employed to determine their fatigue resistance. The fatigue properties of asphalt mixtures may be evaluated and predicted using three basic approaches, according to (Copper and Pell 1974). Initial strain, wasted energy, and fatigue life are all components of fatigue mechanics. The indirect tension fatigue test was used by (READ 1996) to assess the fatigue life of asphalt concrete mixes. During the indirect tension fatigue test, the horizontal deformation is measured in relation to the load cycle. The specimen is stressed to varying degrees, allowing for the creation of a fatigue connection between the number of cycles to failure (N_f) and the initial tensile strain (ε_t) on a log-log relationship using regression analysis on a range of values. In asphalt concrete mixes, fatigue life (N_f) refers to the number of cycles till failure.

According to (Kim 2003), pavement distress known as fatigue cracking occurs more frequently at moderate temperatures. As a result, the fatigue life of asphalt concrete mixes was studied at a temperature of 25°C. A compressive force acting parallel to and along the vertical diametric plane was examined by (National Research Council (U.S.). Transportation Research Board. 1993) to determine the fatigue resistance of a cylindrical specimen. Because of how this load is applied, the specimen experiences an almost homogeneous amount of tensile stress both parallel to the load direction and along the vertical diametric plane. The relationship between the number of cycles to failure and initial stress or strain can be presented using the following equation:

$$N_f = a\left(\frac{1}{\varepsilon_o}\right)^b \times \left(\frac{1}{S_o}\right)^c$$

$$N_f = d\left(\frac{1}{\sigma_o}\right)^e \times \left(\frac{1}{S_o}\right)^f$$

Where:

N_f	Number of Cycles to Failure
ε_o	Initial Strain
σ_o	Initial Stress
S_o	Mixture Stiffness
a, b, c, d, e, f	experimentally determined coefficients

The indirect tensile fatigue test is used to evaluate the fatigue life of asphalt concrete mixtures. The European Standard EN specifies the procedure for conducting an indirect tensile fatigue test, which may be found here (12697- 24). When determining the fatigue life of asphalt concrete mixes, different stress levels were used to assess the difference between the two types. The stress level used in this test is 4000 Newtons, and the temperature at which the test is conducted is 25 degrees Celsius. The terms "controlled stress" and "controlled strain" refer to two different types of controlled loading. When doing the control stress test, the degree of tension remains constant, but the amount of strain increases as the number of rounds increases. It also has the advantage of speeding up the onset of failure and making it easier to distinguish between types of failure. Damage development and accumulation are measured in terms of the amount of energy consumed and the number of cycles completed. In response to the mixture's behaviour and damage accumulation, the force, phase angle, and dissipated energy/cycle per volume will change during the dynamic indirect tensile fatigue test under controlled stress sinusoidal loading. The ratio of dissipated energy to total energy can be used to calculate the number of rounds necessary for a failure condition to occur.

3.11 Summary

This chapter explained the selection of aggregates, bitumen and modifier used for research purpose. Gradation of aggregates and optimum bitumen content was also discussed. Furthermore, tests performed on aggregates, binder (neat/modified) and Asphalt Concrete Mixture (modified/unmodified).

Chapter 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the results and analysis of modified and unmodified asphalt concrete mixtures. Unmodified mixtures were composed of crush obtained from Margalla and bitumen penetration grade 60/70 from ARL. Modified mixtures were composed of Margalla Crush and RAP obtained from Islamabad to Peshawar (M-1) Motorway. 30% RAP was mixed with virgin aggregates by weight, while the bitumen was modified by the addition of LDPE with varying percentage of 2.5%, 5% and 7.5%. After preparation of samples as explained in previous chapter according to standards, physical properties of bitumen were determined after LDPE modification and compared with virgin bitumen and performance testing was done. Three performance tests were conducted; Indirect Tensile Strength Test for determining Moisture Susceptibility, Resilient Modulus test to determine the Stiffness and Indirect Tensile Fatigue Testing to measure the Fatigue resistance of modified and unmodified asphalt concrete mixtures.

4.2 Bitumen Physical Properties Results

When bitumen was modified with LDPE, we saw changes in physical properties, such as enhancement in softening point value, flash & fire point of bitumen was increased and penetration grade of bitumen was decreased. This indicates that this LDPE modified bitumen can easily be used in hot areas. Summary of results is given in Table: 4-1 below.

Table 4-1: Summary of Bitumen Physical Properties

Type of Test	Test Standards	Asphalt ARL 60 / 70			
		LDPE Percentage			
		0%	2.5%	5.0%	7.5%
Penetration Grade (60 to 70)	ASTM D5 / AASHTO T49	68	63	55	51
Flash & Fire Point (Min 232◦C & Min 270 ◦C)	ASTM D92 / AASHTO T 53	233ºC & 278ºC	239ºC & 288ºC	244ºC & 301ºC	251ºC & 309ºC
Softening Point (49 ◦C to 56 ◦C)	ASTM D36 / AASHTO T53	49.2ºC	50.2ºC	54.5ºC	62ºC

4.3 Results on Aggregates

Margalla crush was used in this study. Standard test results on aggregates showed that our values lie in normal range and this aggregate was good to use. Summary of tests conducted on aggregates is given in Table: 4-2.

Table 4-2: Summary of Aggregate Test Results

Test Description	Specification Reference		Result	Limits
Elongation Index (EI)	ASTM D 4791		**3.69%**	≤15%
Flakiness Index (FI)	ASTM D 4791		**13%**	≤15%
Aggregate Absorption	Fine	ASTM C 127	**2.52%**	≤ 3%
	Coarse		**0.81%**	≤3%
Impact Value	BS 812		**19%**	≤30%
Los Angles Abrasion	ASTM C 131		**28**	≤45%
Specific Gravity	Fine	ASTM C 128	**2.628**	-
	Coarse	ASTM C 127	**2.632**	-

4.4 Indirect Tensile Strength Test

Indirect Tensile Strength Test measure the tensile properties of compacted concrete mixtures in accordance with ASTM D 6931-07. Moisture Susceptibility is a ratio of tensile strength of conditioned verses unconditioned samples. Conditioning of samples was accomplished with ALDOT 361, by putting the samples in water bath at 60ºC for 24 hours. Before tensile strength testing, a total of 3x Marshall replicates of each percentage of LDPE (2.5%, 5.0% and 7.5%) with 30% RAP are compared with conventional mix (without LDPE and RAP). Specimens were tested with and without moisture conditioning. Dimensions of samples were 100 mm in diameter and thickness of 62.5 mm and testing was done on Universal Testing Machine with monotonic loading. After conditioning for 24 hours at 60ºC, samples were conditioned again for one hour at 25ºC in UTM. Table 4-1 summarises the conditioned and unconditioned strength values for the tested mixes. Figure 4-1 is showing the monotonic loading schematic diagram used for TSR test. Figure 4-2 shows strength comparison of control (unmodified mix, without RAP and LDPE) mixture with modified mixture containing 30% RAP with and without conditioning. Figure 4-3 is demonstrating the tensile strength ratio and Figure 4-4 presents the trend among values. The findings indicate that **5% LDPE modification with 30%** RAP performs the best with **11.54%** increase in TSR compared to control mix (without LDPE and RAP).

Table 4-3: Summary of Tensile Strength Ratio Test

Description	Codes	Average Un-conditioned Strength (S1) kN	Average Conditioned Strength (S2) kN	TSR = S2/S1 (%)
RAP 0%, LDPE 0%	R0L0	5.07	4.28	84.47
RAP 30%, LDPE 2.5%	R30L2.5	5.42	4.97	91.70
RAP 30%, LDPE 5.0%	R30L5.0	5.69	5.35	94.22
RAP 30%, LDPE 7.5%	R30L7.5	5.21	4.85	92.96

Control Mix (RAP 0%, LDPE 0%) TSR is 84.47%, which is less than 90% (minimum required by superpave criteria.

Conventional mix does not qualify for moisture susceptibility. Generally, RAP combined with LDPE increase moisture susceptibility. However, LDPE presence has improved moisture susceptibility of mixes despite the presence of RAP and results indicate that **5% dosage of LDPE with 30% RAP** has ***performed better*** than all other combinations.

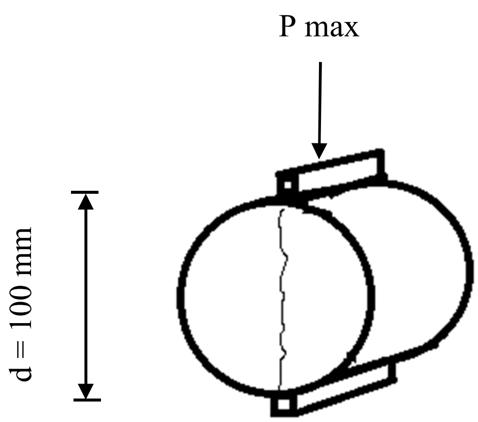


Figure 4-1: Tensile Strength Ratio Schematic Diagram

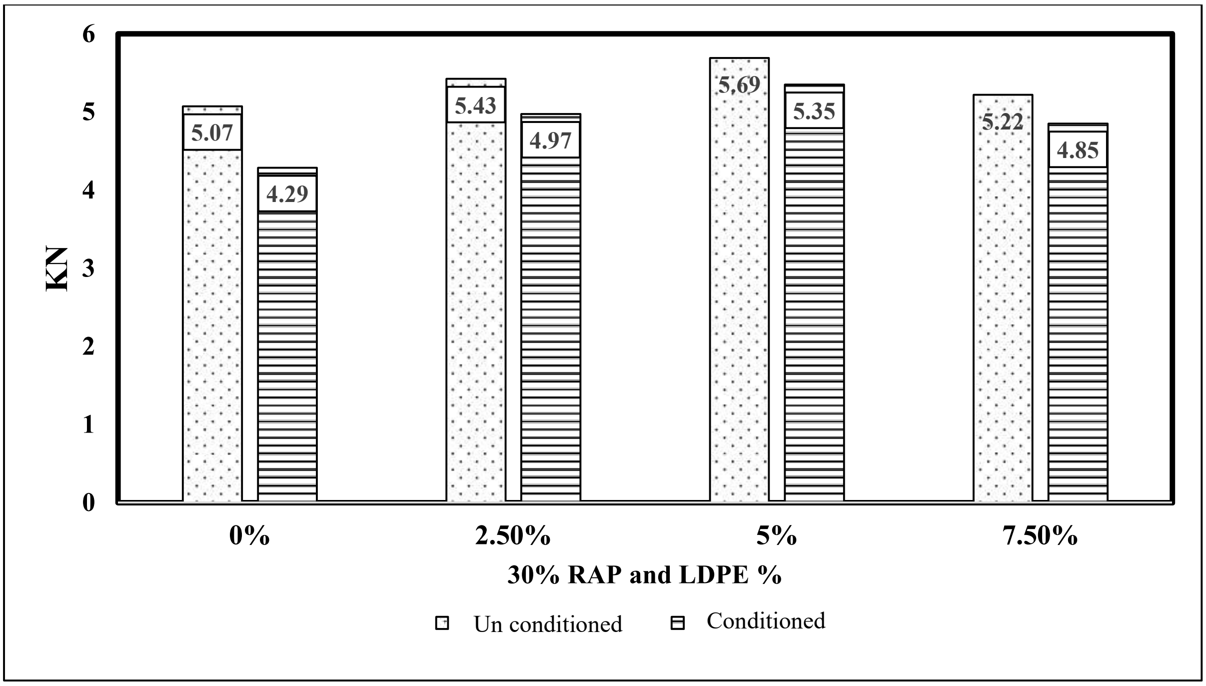


Figure 4-2: Tensile Strength Value for Specimens

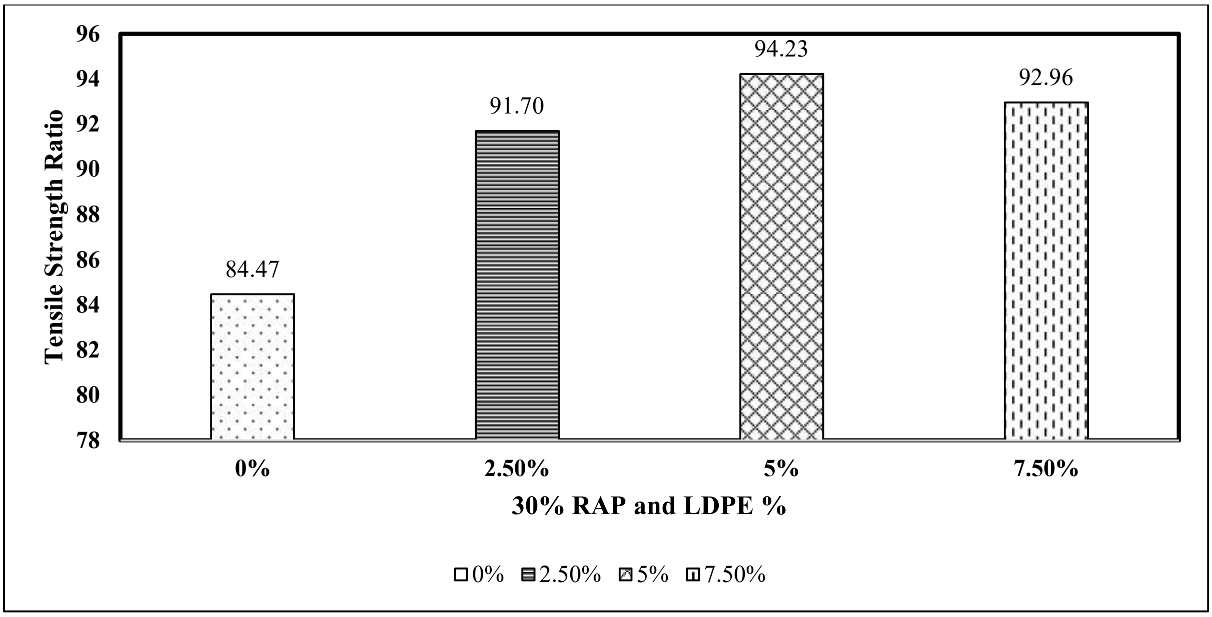


Figure 4-3: Tensile Strength Ratio of Specimens

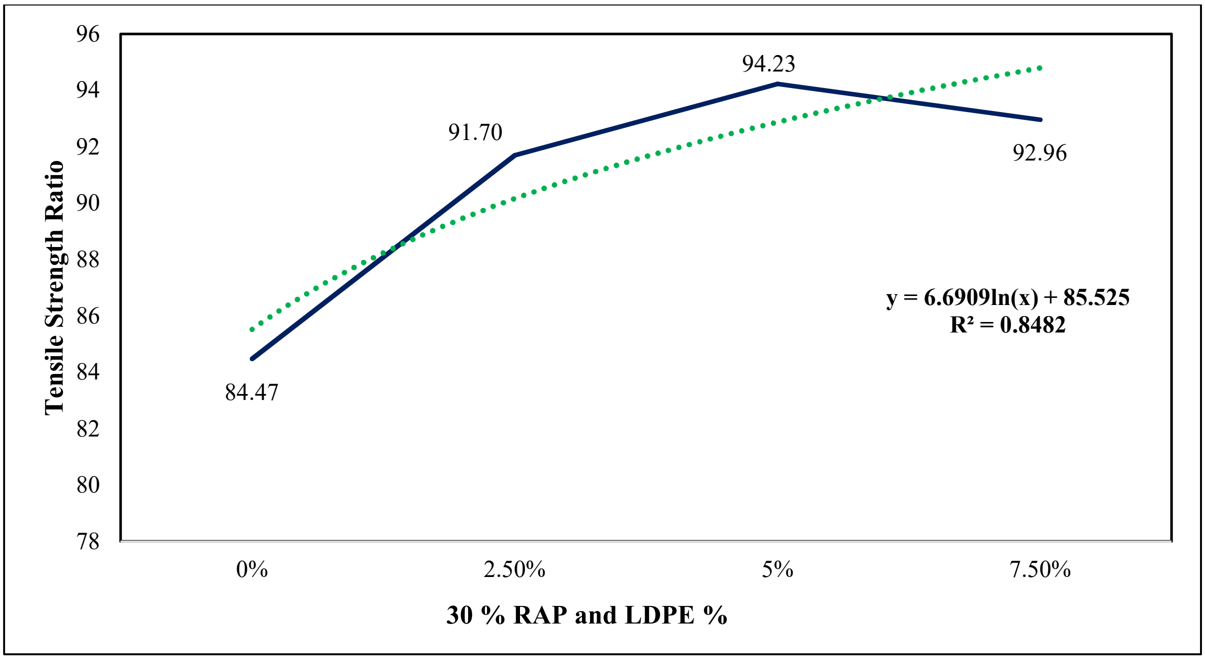


Figure 4-4: Trend Line of TSR

4.5 Resilient Modulus (M_R)

The resilient modulus values can be utilized to analyse the response of the pavement structure due to the application of traffic loads, also important materials property input parameter required mechanistic empirical design procedure. Resilient modulus is defined as the ratio of applied stress to recoverable strain observed when a sample is exposed to cyclic loading and it is a relative measure of mixture stiffness. As well as the resilient modulus is a non-destructive test that can be used to evaluate the relative quality of materials and to generate input for pavement design or pavement evaluation and analysis. It is reported that resilient modulus in an important parameter to predict the pavement performance and to analyse the pavement response to traffic loading.

For the resilient modulus test, 3x replicates of each percentage combined with 30% RAP and varying percentage of LDPE (2.5%, 5.0% and 7.5%) as bitumen modifier was used under the guidelines of ASTM D 4123. The software package, which accompanies the test machine, calculates the modulus for each load pulse. The repeated-load indirect tension test for resilient modulus is conducted by applying a haversine waveform, with a load applied vertically in the vertical diametric plane of a cylindrical specimen as illustrated in Figure 4-5 with 100 mm diameter and 62.5 mm thickness. The load application and the horizontal elastic deformation were used to compute the resilient modulus value. As well as the recommended load magnitude should induce an indirect tensile stress 20% of the indirect tensile strength. The actual load, horizontal deformation is determined for each load pulse to calculate the resilient modulus using following equation:

$$M_R = \frac{P(0.27 + \vartheta)}{(\Delta h)t}$$

Where

P : Dynamic Load

t : Specimen thickness

Δh : Recoverable horizontal deformation

ϑ : Poisson's ratio

Figure: 4-6 shows measured values of resilient modulus of control and RAP containing LDPE modified mixes and Figure 4-7 describes the trend among these values. By observing the results, it is clearly evident that **<u>30% RAP combined with 5% LDPE gives best results</u>**. Results show that addition of RAP with LDPE has enhanced the ***<u>M_R more than 5 times</u>*** of original control mix. When we add LDPE more than 5% combined with 30% RAP, value of resilient modulus starts to decline. So in the light of these results, it is indicated that ***<u>30% RAP combined with 5% LDPE is best combination.</u>***

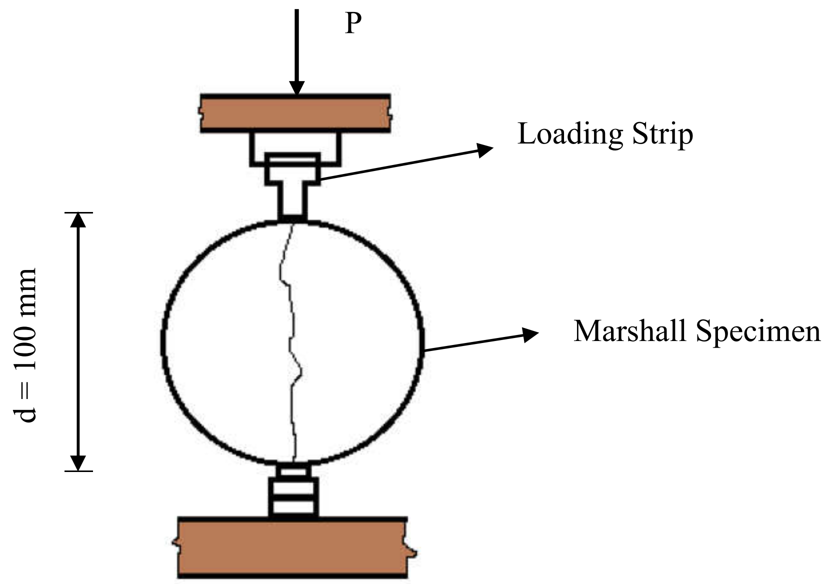


Figure 4-5: Schematic Diagram for Resilient Modulus Testing

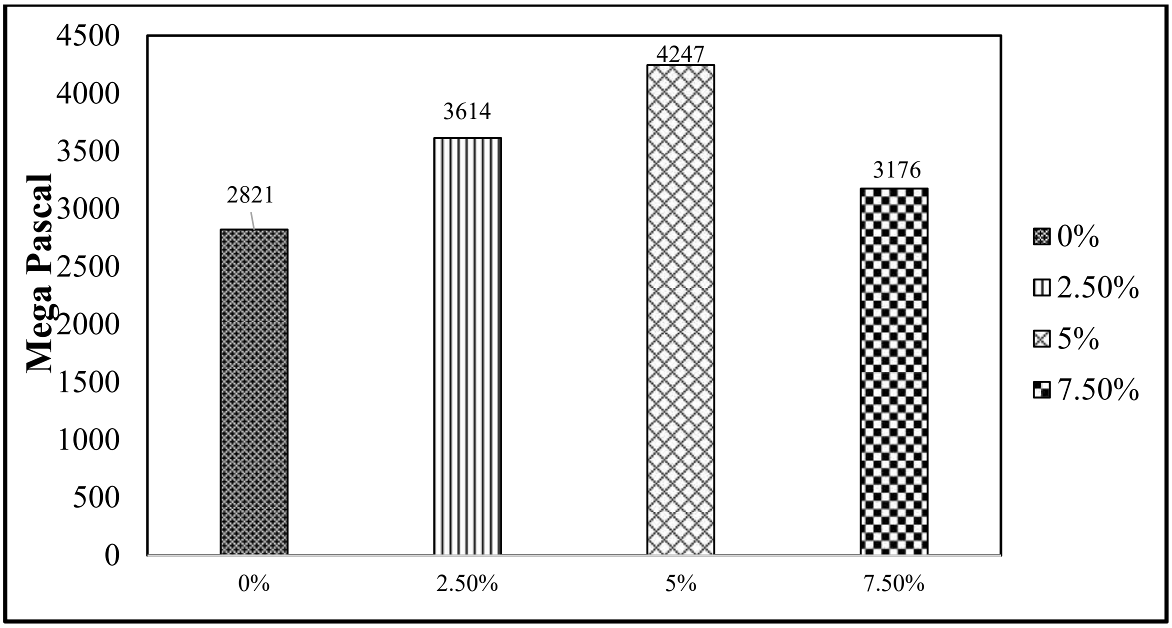


Figure 4-6: Resilient Modulus Values

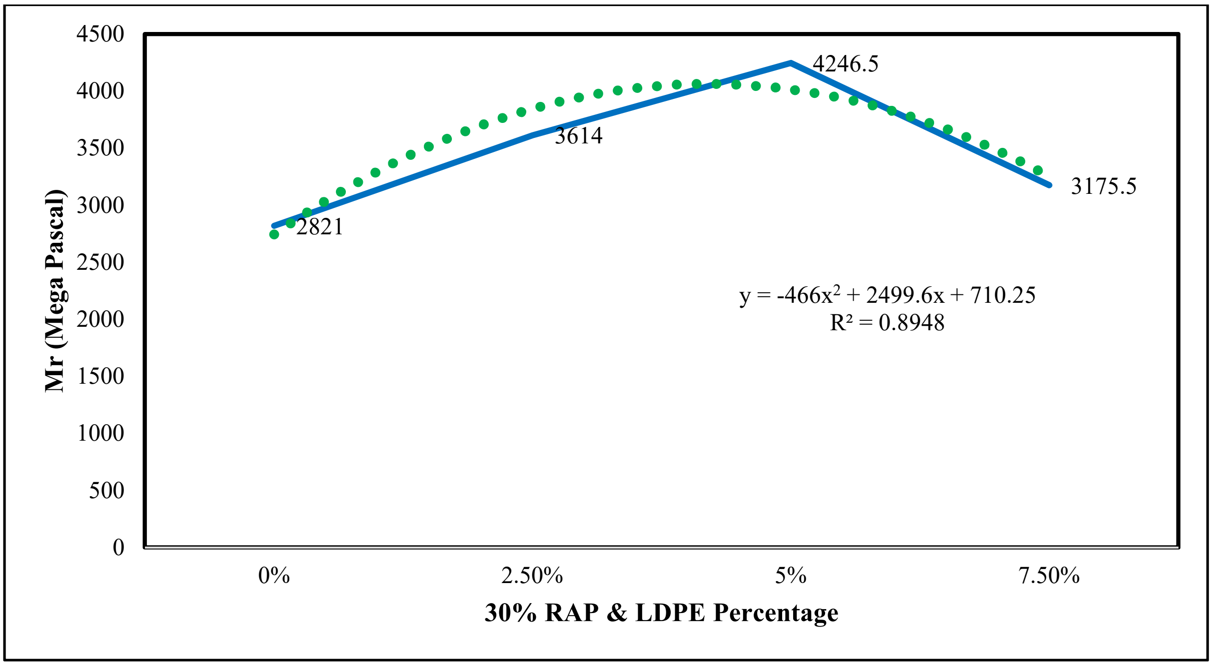


Figure 4-7: Resilient Modulus Trend Chart

4.6 Indirect Tensile Fatigue Test

This test characterises the behaviour of bituminous mixtures under repeated load fatigue testing with a constant load mode under the guidance of EN 12697-24:2012 (E) standard. The fatigue behaviour of bituminous materials is measured in the laboratory under either controlled stress or strain conditions. Controlled stress is more widely used since it reproduces site conditions in which load is applied to the pavement structure. This type of setup was adapted in this research under the load of 3500 N. In this mode, a repeated stress or load of constant amplitude is applied to a sample which causes the stiffness to eventually decrease and, thus, the resulting strain will increase. This test is characterised by relatively short crack propagation periods as failure occurs shortly after the initiation of cracks in the material. The reason for the rapid crack propagation stage is that the formation of crack leads to an increase in the stress at the tip of the crack due to stress concentration (Khalid 2000). A cylindrical Marshall specimen manufactured in a laboratory was used in this test. A cylinder shaped Marshall test specimens were subjected to repeated compressive load with a haversine load signal through the vertical diametral plane. This loading resulted in repeated tensile stress pulses perpendicular to the direction of the applied load which caused the specimen to fail by splitting along the central part of the vertical diameter. The cyclic loading (with rest periods between load cycles) was applied. Fracture (fatigue) life was defined as the total number of load applications before a fracture of the specimen occurs.

3x Marshall replicates of 30% RAP combined with varying percentage of LDPE along conventional specimens with 0% RAP and 0% LDPE were prepared. After preparation of samples, they were placed in a UTM for testing. The following conditions were used to conduct the fatigue tests in this study:

Load Applied = 4000 N

Loading Time = 0.1 seconds

Rest Time = 0.4 seconds

Performance Temperature = 25°C

Figure 4-8 illustrates the test setup used for ITFT. Figure 4-9 demonstrates the number of cycles sustained by specimens and Figure 4-10 shows the trend among values. It was noted that samples containing **30% RAP with 5% LDPE performed best** among all specimens followed by 30% RAP with 2.5% LDPE. Samples with 30% RAP and 5% LDPE, their ability to sustain number of passes enhanced ***more than 2 times*** as compared to conventional specimens. But on the other hand, samples with 30% RAP and 7.5% percent LDPE performed very poorly and their value was less than conventional mix.

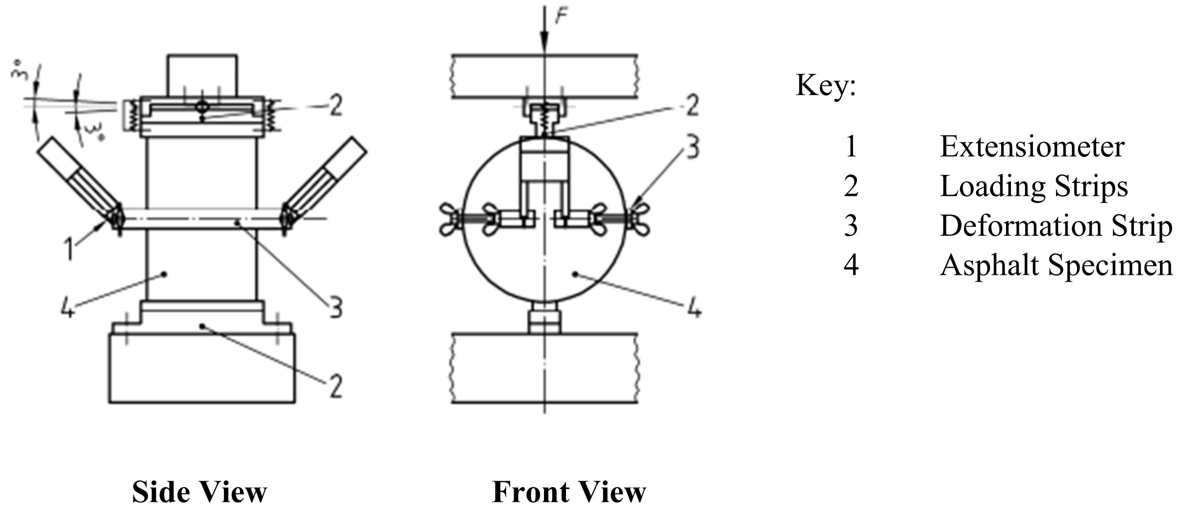


Figure 4-8: Schematic Diagram of ITFT Setup

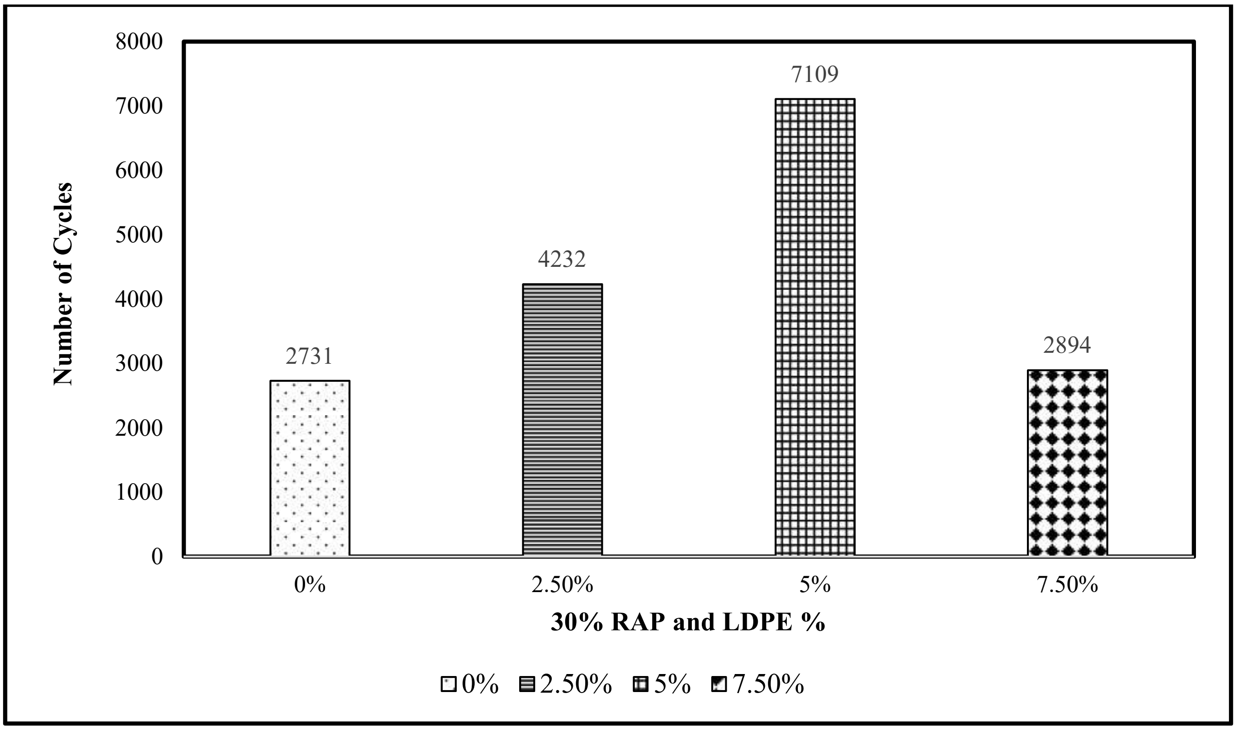


Figure 4-9: Indirect Tensile Fatigue Test Results

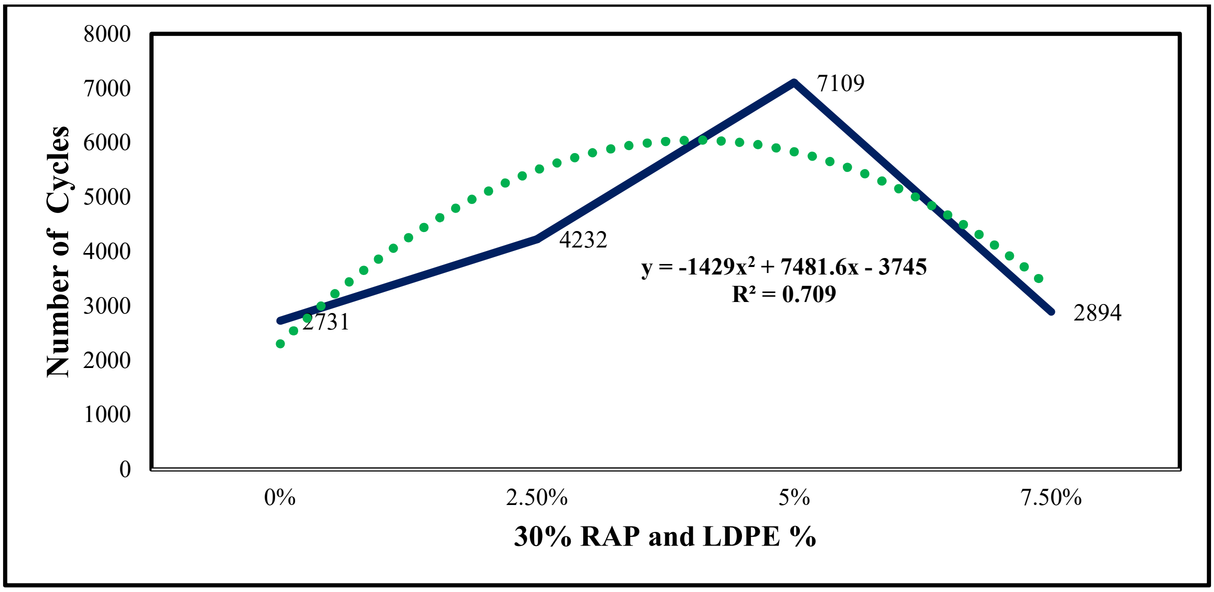


Figure 4-10: Indirect Tensile Fatigue Test Trend Chart

4.7 Summary

This study has showed that adding low-density polyethylene (LDPE) to bitumen can improve the properties of the asphalt. It has been observed that LDPE dosage of 5% works best in the presence of 30% RAP. Higher percentage of LDPE results in stiffer bitumen which may lead to premature fatigue cracking. It has been observed that by addition of RAP and LDPE, improves stiffness, fatigue resistance and moisture susceptibility. *Moisture susceptibility* is **increased by 11.54%** of modified mixes. Moreover, inclusion of LDPE also improves *stiffness* of asphalt mixes up to **1.5 times** of conventional mixes with 30% RAP and 5% LDPE. Furthermore, *fatigue life* of asphalt mixes has been **doubled.** Overall, the asphalt mixes with **30% RAP modified with 5% LDPE** has **best** results.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The main objectives of this research were to characterize the mechanical properties of modified and unmodified asphalt mixtures. Unmodified mixtures were composed of crush obtained from Margalla and bitumen penetration grade 60/70 obtained from ARL. Modified mixtures were composed of Margalla Crush and RAP obtained from Islamabad to Peshawar (M-1) Motorway. 30% RAP was mixed with virgin aggregates by weight, while the bitumen was modified by the addition of LDPE with varying percentage of 2.5%, 5.0% and 7.5%. After preparation of samples as explained in previous chapters according to standards, performance testing was done. Three performance tests were conducted; Indirect Tensile Strength Test for determining Moisture Susceptibility, Resilient Modulus test to determine the Stiffness and Indirect Tensile Fatigue Testing to measure the Fatigue resistance of modified and unmodified asphalt concrete mixtures.

5.2 Conclusions

After conducting laboratory tests on asphalt binder and mixtures with different polymer content, after analysing the data and comparing the results, the following conclusions have been drawn

a) Results of the study verifies that combined use of LDPE and RAP improves modified asphalt concrete properties as performance indicators, such as increase in rutting, fatigue and moisture resistance.
b) RAP is also a waste material and LDPE is also major component of plastic bags and other plastic products. Research conducted indicates that both of these materials can successfully be incorporated in pavement construction.
c) Specimens with 30% of RAP content by aggregate weight and 5.0% of LDPE by weight of bitumen showed best results in all performance test conducted in research with quantitative measures as under
    i. **11.54%** increase modified mixtures moisture susceptibility.

ii. Resilient modulus has shown **1.5 times** increase in the modified mixture once compared with the conventional mix.

iii. By the addition of 5% LDPE and 30% RAP, fatigue life of modified samples has been almost **doubled** as compared to unmodified mix.

d) Addition of LDPE, reduces the penetration grade of bitumen and increase the softening point. It indicates that LDPE modified binder can successfully be utilized in hot areas to minimize the premature failure due to rutting.

5.3 Recommendations

This study finding suggests that RAP containing asphalt concrete mixtures (30%), modified using LDPE at 5% dosage by weight of binder performance relative better than all other listed percentages with respect to mixtures increased stiffness upto 1.5 times, improved moisture susceptibility by 11.54% and fatigue resistance up to 2 times. Therefore, modified mix with recommended composition can be utilized to enhance pavement performance life subjected to heavy axle loads in relative hotter climate.

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APPENDICIES

APPENDIX - I

MARSHALL MIX DESIGN REPORTS (0%)

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: Syed Baqir (MS THESIS)

Sample: Controlled sample (**0% RAP**)

Identification: Margalla Aggregate & ARL 60/70 Bitumen.

Composition of Paving Mixture

		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
				Bulk		Mix or Trial Number				
						1	2	3	4	5
1. Coarse Aggregate		G1		2.632	P1	48.250	48.000	47.750	47.500	47.250
2. Fine Aggregate		G2		2.618	P2	48.250	48.000	47.750	47.500	47.250
3. Mineral Filler		G3		…….	P3	5.308	5.280	5.253	5.225	5.198
4. Total Aggregate		Gs	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement		Gb	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix						2.493	2.479	2.468	2.457	2.451
8. Bulk Sp. Gr. (Gmb), compacted mix						2.325	2.358	2.380	2.389	2.393
9. Effective Sp. Gr. (Gse), total aggregate						2.628	2.633	2.642	2.650	2.665
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.051	0.125	0.250	0.374	0.589
CALCULATIONS										
11. Effective Asphalt content (Pbe)						3.451	3.880	4.262	4.645	4.943
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)						14.528	13.764	13.413	13.540	13.851
13. Air Voids (Va)						6.739	4.881	3.866	2.768	2.366
14. Voids Filled with Aggregate, VFA						53.614	64.538	73.416	79.560	82.916
15.Dust to Asphalt ratio, DA						1.248	1.103	0.998	0.910	0.849

APPENDIX - 1

MARSHALL MIX DESIGN REPORTS (30%)

Worksheet for Volumetric Analysis of Compacted Paving Mixture

(Analysis by Weight of Total Mixture)

Project: Syed Baqir (MS THESIS)

Sample: **30% RAP**

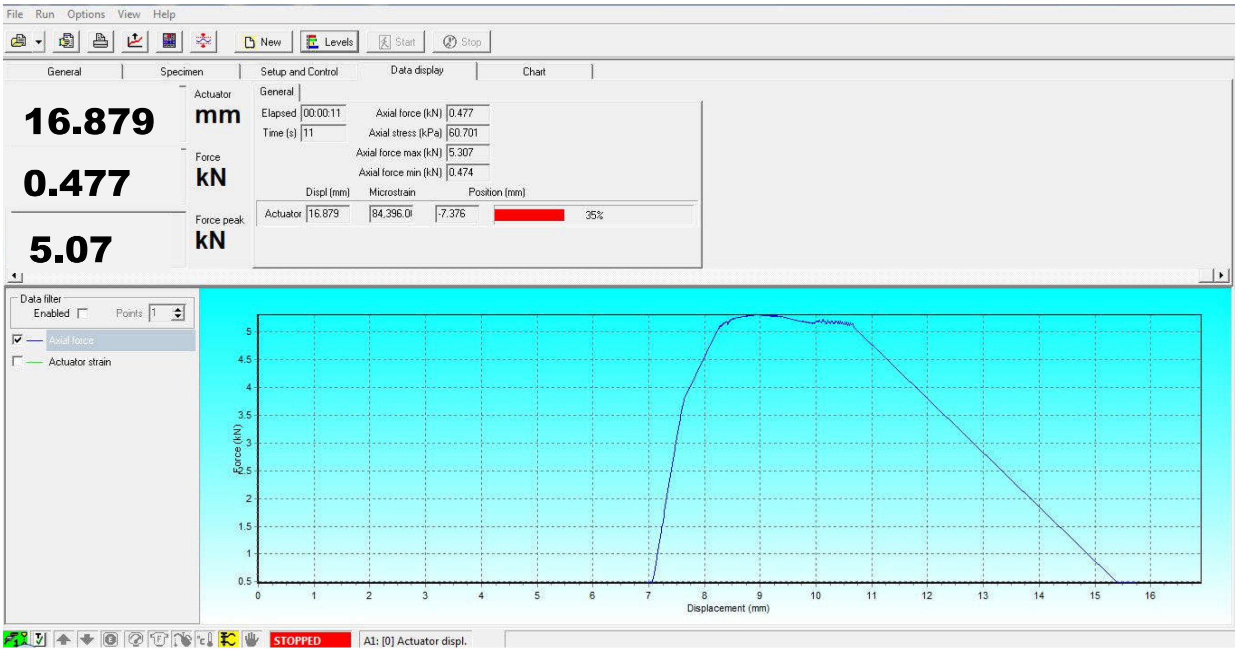
Identification: Margalla Aggregate & ARL 60/70 Bitumen.

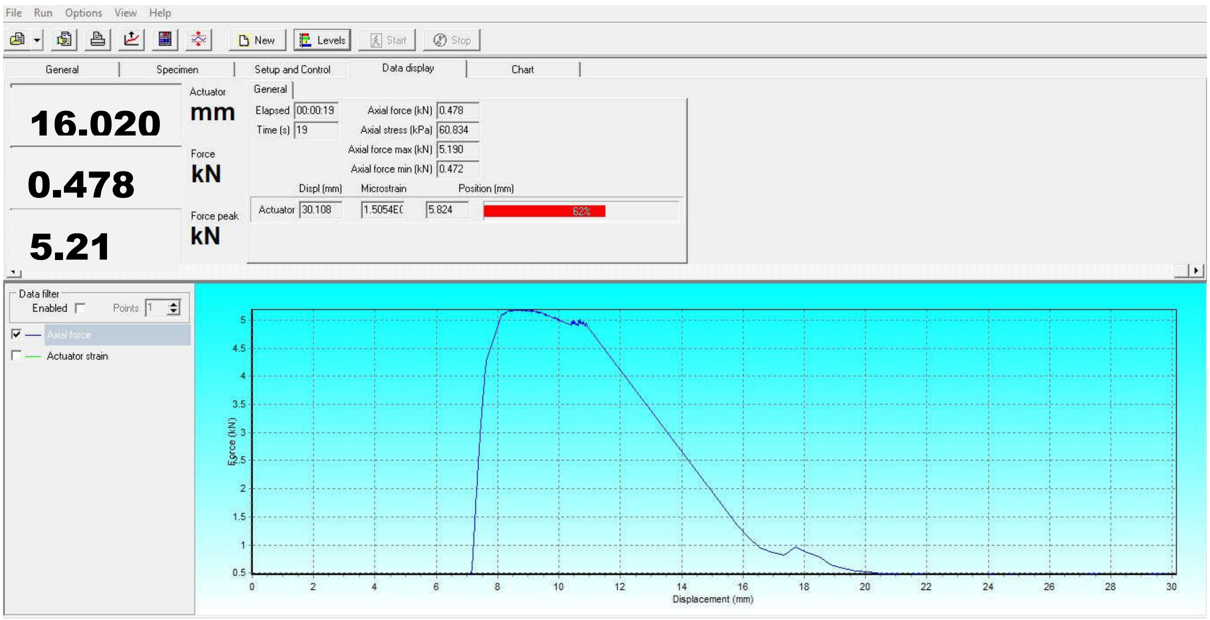
Composition of Paving Mixture

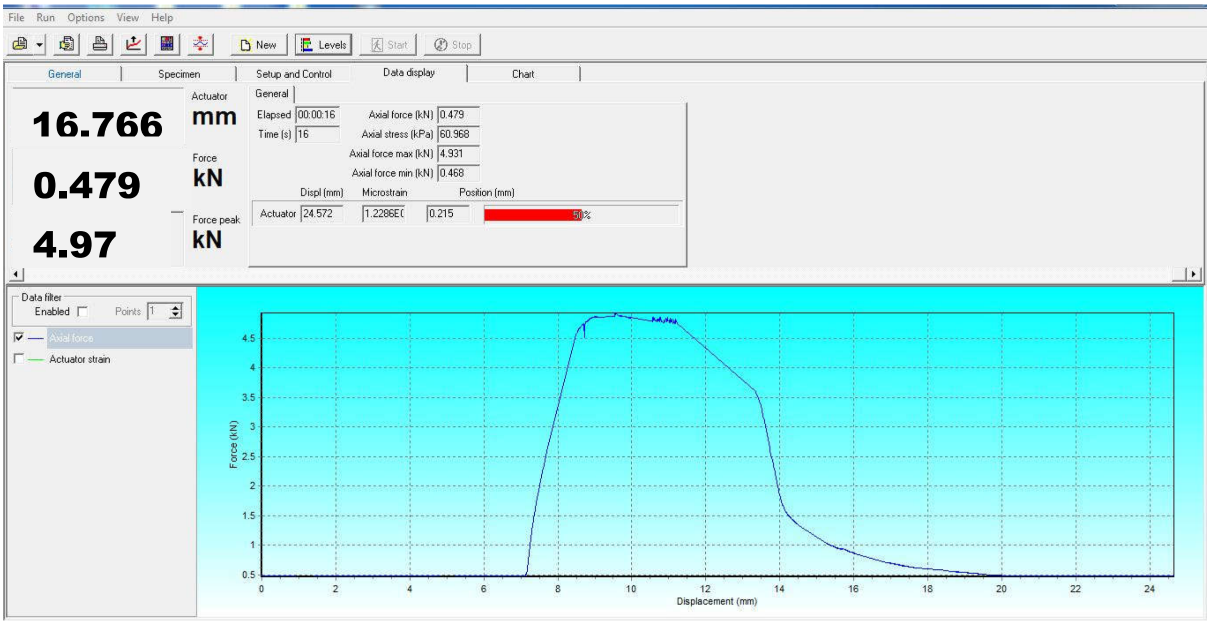
		Specific Gravity, G			Mix Composition, % by Wt. of Total Mix, P					
				Bulk		Mix or Trial Number				
						1	2	3	4	5
1. Coarse Aggregate		G1		2.632	P1	47.461	47.215	46.969	46.723	46.477
2. Fine Aggregate		G2		2.618	P2	49.039	48.785	48.531	48.277	48.023
3. Mineral Filler		G3		…….	P3	5.134	5.107	5.081	5.054	5.027
4. Total Aggregate		G4	---	2.625	Ps	96.50	96.00	95.50	95.00	94.50
5. Asphalt Cement		G5	1.03	-----	Pb	3.50	4.00	4.50	5.00	5.50
6. Bulk Sp. Gr. (Gsb), total aggregate						2.625	2.625	2.625	2.625	2.625
7. Max. Sp. Gr. (Gmm), paving mix						2.490	2.472	2.458	2.455	2.453
8. Bulk Sp. Gr. (Gmb), compacted mix						2.329	2.350	2.365	2.378	2.385
9. Effective Sp. Gr. (Gse), total aggregate						2.625	2.625	2.630	2.648	2.667
10. Absorbed Asphalt (Pba), % by wt. total agg.						0.001	0.004	0.074	0.340	0.627
CALCULATIONS										
11. Effective Asphalt content (Pbe)						3.499	3.996	4.430	4.677	4.908
12. Voids in Mineral Aggregate, VMA (percent of bulk vol.)						14.377	14.053	13.955	13.935	14.136
13. Air Voids (Va)						6.56	4.88	3.51	2.99	2.451
14. Voids Filled with Aggregate, VFA						55.027	64.880	72.887	77.492	80.389
15.Dust to Asphalt ratio, DA						1.181	1.028	0.921	0.867	0.821

APPENDIX – II

TSR Results

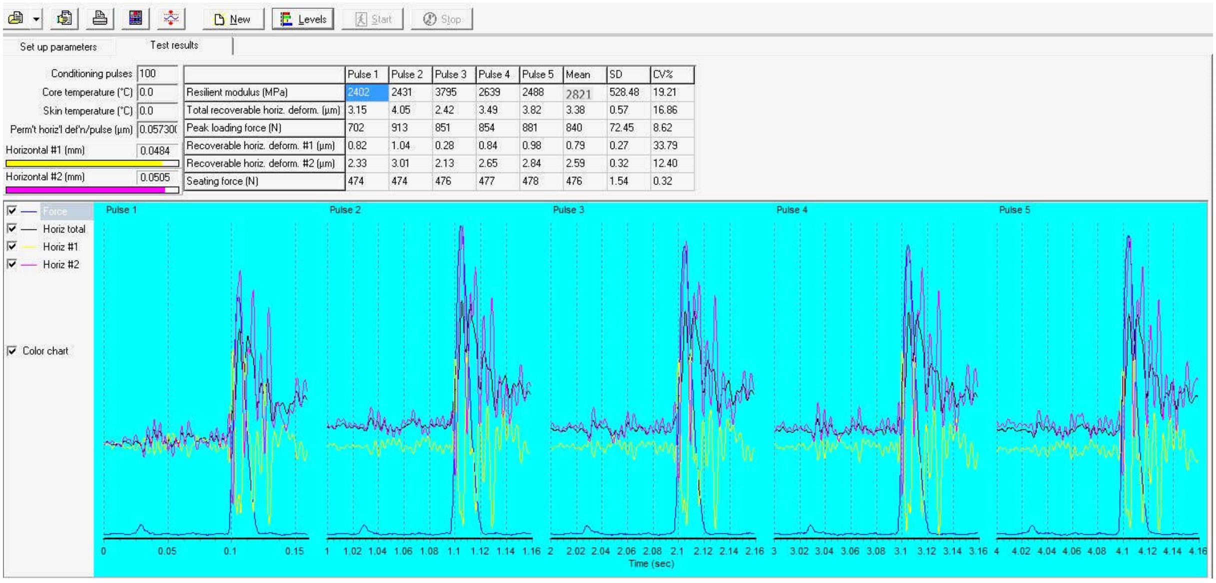




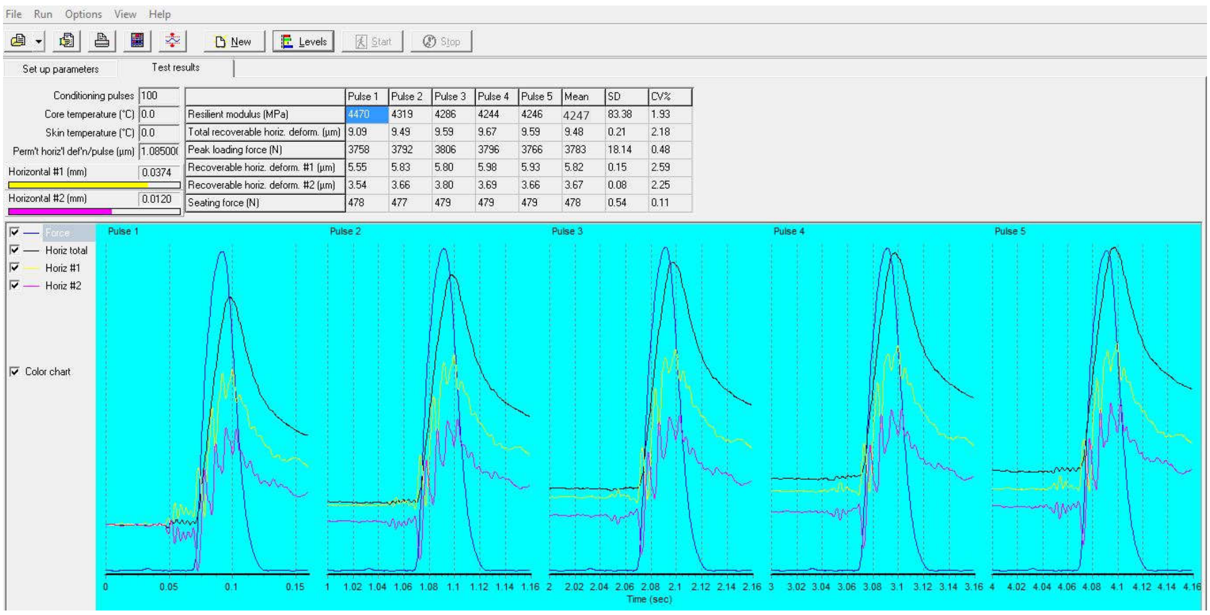

File Run Options View Help
New
Levels
Start
Stop
General
Specimen
Setup and Control
Data display
Chart
Actuator
16.766
mm
Force
0.479
kN
Force peak
4.97
kN
General
Elapsed 00:00:16
Time (s) 16
Axial force (kN) 0.479
Axial stress (kPa) 60.968
Axial force max (kN) 4.931
Axial force min (kN) 0.468
Displ (mm)
Microstrain
Position (mm)
Actuator 24.572
1.2286E(
0.215
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

APPENDIX – III

RESILIENT MODULUS RESULTS



	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	2402	2431	3795	2639	2488	2821	528.48	19.21
Total recoverable horiz. deform. (µm)	3.15	4.05	2.42	3.49	3.82	3.38	0.57	16.86
Peak loading force (N)	702	913	851	854	881	840	72.45	8.62
Recoverable horiz. deform. #1 (µm)	0.82	1.04	0.28	0.84	0.98	0.79	0.27	33.79
Recoverable horiz. deform. #2 (µm)	2.33	3.01	2.13	2.65	2.84	2.59	0.32	12.40
Seating force (N)	474	474	476	477	478	476	1.54	0.32



	Pulse 1	Pulse 2	Pulse 3	Pulse 4	Pulse 5	Mean	SD	CV%
Resilient modulus (MPa)	4470	4319	4286	4244	4246	4247	83.38	1.93
Total recoverable horiz. deform. (µm)	9.09	9.49	9.59	9.67	9.59	9.48	0.21	2.18
Peak loading force (N)	3758	3792	3806	3796	3766	3783	18.14	0.48
Recoverable horiz. deform. #1 (µm)	5.55	5.83	5.80	5.98	5.93	5.82	0.15	2.59
Recoverable horiz. deform. #2 (µm)	3.54	3.66	3.80	3.69	3.66	3.67	0.08	2.25
Seating force (N)	478	477	479	479	479	478	0.54	0.11

APPENDIX – IV

INDIRECT TENSILE FATIGUE TEST RESULTS