PERFORMANCE EVALUATION OF HIGH-DENSITY POLYETHYLENE (HDPE) MODIFIED ASPHALT CONCRETE MIXTURES

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A thesis submitted in partial fulfilment of

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By

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DEDICATED

TO

MY BELOVED MOTHER

FAIQA SHAHID

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TABLE OF CONTENTS

LIST OF ACRONYMS

AASHTO	–	American Association of State Highway & Transportation Officials
ASTM	–	American Society for Testing and Materials
AC	–	Asphalt Concrete
ARL	–	Attock Refinery Limited
BS	–	British Standard
CDAS	–	Control Data Acquisition System
CRP	–	Crumb Rubber Powder
DOT	–	Department of Transportation
DSR	–	Dynamic Shear Rheometer
ESAL	–	Equivalent Single Axle Load
FRAC	–	Fiber Reinforced Asphalt Concrete
G_{mb}	–	Bulk Specific Gravity
G_{mm}	–	Theoretical Maximum Specific Gravity
HDPE	–	High Density Polyethylene
HMA	–	Hot Mix Asphalt
IDT	–	Indirect Tensile Test
ITFT	–	Indirect Tensile Fatigue Test
ITS	–	Indirect Tensile Strength
ITSM	–	Indirect Tensile Stiffness Modulus
LDPE	–	Low Density Polyethylene
LVDT	–	Linear Variable Differential Transducer
MQ	–	Marshall Quotient
M_R	–	Resilient Modulus

NCHRP – National Cooperative Highway Research Program

NHA – National Highway Authority

NMAS – Nominal Maximum Aggregate Size

NHDPE – Nano-High Density Polyethylene

OBC – Optimum Binder Content

OPC – Optimum Polymer Content

PE – Polyethylene

PET – Polyethylene Terephthalate

PG – Performance Grade

PP – Polypropylene

SBS – Styrene Butadiene Styrene

SGC – Superpave Gyratory Compactor

SHRP – Strategic Highway Research Program

SMA – Stone Mastic Asphalt

TSR – Tensile Strength Ratio

UTM – Universal Testing Machine

UV – Ultraviolet

V_a – Air Voids

VFA – Voids Filled with Asphalt

VMA – Voids in Minerals Aggregate

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The Pakistan's road network has been continuously deteriorating due to the ongoing rise in traffic volume, increased loads and the insufficient level of maintenance brought on by a lack of funding. In the wake of the rise in usage, the modification of the bituminous binder with polymer additives has been studied in a number of nations throughout the world and in practice over the last four decades. The use of polyethylene material as a bitumen modifier has received a great boost due to its high tensile strength, impact resistance and melting temperature. This study was designed to examine the potential of enhancing the performance characteristics of asphalt mixtures using High-Density Polyethylene (HDPE) as a bitumen modifier in hot mix asphalt concrete (HMA) to focus three of the major distresses associated to flexible pavements such as fatigue cracking, moisture susceptibility and rutting resistance. The Marshall mix design was used first to determine the optimum binder content and then further to test the modified mixture properties. HDPE was blended in four varying proportions of 2.5%, 5.0%, 7.5% and 10.0% by the weight of bitumen and specimens were subjected to performance tests such as Tensile Strength Ratio (TSR), Resilient Modulus (M_R) and Indirect Tensile Fatigue Tests (ITFT).

The study finding conclude that adding High Density Polyethylene (HDPE) to asphalt concrete mixtures substantially improves the properties of the hot mix asphalt. The inclusion of 2.5% HDPE in the HMA has improved the stiffness response by almost **130.47%,** the fatigue life enhanced by **642.0%** and similarly the moisture resistance increased **17.81%** in comparison to conventional mixes. Moreover, the behaviour of the specimens modified with higher polymer contents 5% and 7.5 % remains close to the optimum modifier content which was found to be 2.5% as it showed the best results among all polymer proportions. For validation of performance test results, a statistical analysis of one-way ANOVA with Tukey analysis and correlation was carried out and the analysis confirms the results drawn by this study.

Chapter 1

INTRODUCTION

1.1 Background

Road infrastructure is critical to every country's development. Pakistan is a prosperous nation with a road infrastructure of over 2.5 million kilometres, including 9300 kilometres of Major Highways and 2300 kilometres of motorways servicing millions of daily passengers. Moreover, to safeguard this infrastructure necessitates appropriate, cost-effective, and long-lasting preservation measures that will not only minimize rehabilitation and maintenance costs but also ensure safe, convenient, pleasant, and cost-effective transportation.

Asphalt mixes are a common paving substance being used road building across the world. The longevity of asphalt is critical in a society where road development and sustainability are important concerns (2020). Due to the obvious rising cost of bitumen, long-lasting asphalt blends are gaining popularity. Throughout its life, pavement is subjected to continual transportation and harsh environmental influences, causing degradation of the road on a daily basis. Over the last decade, experts have attempted to develop ways for building roads with a longer life than existing ones (Mansourian 2019). The endurance of asphalt paving mixes is affected by external factors such as weather, moisture, (Abed 2020) and temperature. Premature distresses in asphalt pavements are most commonly caused by moisture degradation. It is the gradual deterioration of asphalt mixes caused mostly by the presence of water.

The most obvious and detrimental consequence of dampness is a decrease in road integrity. Because the evaporation rate from the surface layers is sluggish, the bottom section of the asphaltic layer maintains water for longer (G. A.-R.-W. Moussa 2021). This is one of the hidden effects. Under the weight of transportation, the bottom section of the asphalt layer is in stress. The cohesion and adhesion bond inside the cement matrix begins to degrade in the presence of moisture and imposed traffic loads, resulting in underside early stress fracture.

The introduction of specific polymeric materials to asphalt binders has long been known to increase the properties of asphalt pavement. Plastic, a form of polymer, has shown to be a substance that significantly enhances the qualities of asphalt concrete / cement while also being less expensive or even free if waste materials are incorporated (Q. H. Lv 2019). Plastic is also environmentally benign since it can be readily discarded of without damaging the environment. One of the most efficient polymer additives has been discovered to be polyethylene. Polymer has been used as a modifier in asphalt mixtures since the 1980s and has been evaluated in a number of nations across the globe (Zhou 2020). Polyethylene has been the most widely used plastic so far. It's also a semi-crystalline polymeric material with good endurance, abrasion, and chemical stability, as well as a wide variety of characteristics that make it an efficient additive in road construction.

1.2 Problem Statement

One of the most common causes of flexible pavement failure is moisture damage. It gradually weakens the pavements by eliminating the bitumen layer from the substrate particles, resulting in a loss of attraction between both the aggregate and the bitumen, as well as internal cohesion. For some years, asphalt experts have been concerned about moisture damage (Yin 2020). They're looking for a test procedure that can tell the difference between negative and positive asphalt paving mixes when it comes to moisture resistance. Attempts have been undertaken since the 1900s to develop a test that may detect asphalt mixtures that are more susceptible to moisture absorption. In the development of new roadways, endurance is an important consideration (Ullah 2021). The necessity to characterize the effectiveness of asphalt mixture utilized in diverse projects around the region has always existed. Pakistan is an undeveloped and underdeveloped country, and it cannot manage to spend much money on new road construction and restoration due to the high expense of doing so. The roadways are exposed to harsh weather conditions in the country, with considerable seasonal rainfall and a prolonged snow season in the northern parts. Moisture-related pavement distresses have been characterized as serious stresses and strains, which are harmful in many ways. Causing fatal accidents and in some cases landslides.

1.3 Objectives

The intended objectives of this research study are as under:

- To investigate the suitability and effects of High-Density Polyethylene (HDPE) as a bitumen modifier.
- To evaluate the stiffness response of modified HMA by measuring Resilient Modulus.
- To study the moisture susceptibility of HDPE-modified HMA.
- To investigate the fatigue resistance HDPE-modified HMA through cyclic loading.

1.4 Scope of Study

- For this research, fine and coarse aggregate will be acquired from Margalla quarry and binder of 60-70 penetration grade from ARL plant
- To ensure the standard quality of materials several laboratory tests will be performed on aggregate and binder. Then sieving of aggregate will be carried out based on NHA Class-B gradation.
- To find the Optimum Binder Content (OBC), 15 samples will be prepared with varying bitumen contents of 3.5%, 4%, 4.3%, 4.6% and 5% using Marshall Mix Design
- After determining the OBC, we will find Job Mix Formula (JMF) for conventional / standard and modified HMA samples.
- The modified bitumen will be prepared by using a high shear mixer. Firstly, bitumen will be heated in iron container until it becomes soften. Then after reaching 180o C, HDPE will be added in different proportions i.e. 2.5%, 5%, 7.5% and 10% by weight of bitumen.
- Then the modified bitumen will get mixed, heated and compacted with aggregate to make samples for further performance testing. For three performance tests total 60 number of HMA samples will be prepared and tested. The results obtained from the performance tests mentioned in the following test matrix were interpreted.

Table 1.1 Performance Test Matrix for this Research

Type of Performance Test	Standard	HDPE Percentage (%)	No. of Samples	Total
Indirect Tensile Fatigue Test (ITFT)	EN 12697 – 24D	0%	3	15
		2.5 %	3	
		5.0 %	3	
		7.5 %	3	
		10 %	3	
Resilient Modulus (M_R)	ASTM D7369 - 20	0%	3	15
		2.5 %	3	
		5.0 %	3	
		7.5 %	3	
		10 %	3	

Tensile Strength Ratio Test (TSR) (Un-conditioned)	ASTM D 6931 - 17	0%	3	15
		2.5 %	3	
		5.0 %	3	
		7.5 %	3	
		10 %	3	
Tensile Strength Ratio Test (TSR) (Conditioned)	ASTM D 6931 - 17	0%	3	15
		2.5 %	3	
		5.0 %	3	
		7.5 %	3	
		10 %	3	
TOTAL SAMPLES				**60**

Table 1.2 Marshall Mix Design Samples for Determining OBC

Description	Bitumen Content	No. of Samples
Control Samples	3.5	3
	4	3
	4.5	3
	5	3
	5.5	3
	Total	**15**

1.5 Organization of the Study

The following study is structured around five chapters, each chapter has its own purpose and contribution to the study. Following is a brief overlay of each chapter.

Chapter 1 Introduction. The 1st chapter of the study consists of the basic background of the topic along with the research argument. Moreover, the introduction chapter consists of the aims and objectives of the study and the research questions. The rationale and significance of the study are also provided in this chapter.

Chapter 2 Literature review. The following chapter consists of the relevant data to support the research arguments and fulfil the research objectives. Literature is collected from various pre-existing studies such as books, journals, articles and other credible sources.

Chapter 3 Research Methodology. The following chapters provides the key methods and techniques that the study used to collect and analyse data, so that meaningful conclusions can be derived for the study.

Chapter 4 Results and Analysis. The following chapter aims to collect and analyse data by using the methods identified in the previous chapter.

Chapter 5 Conclusion and recommendations: the following chapter is the last chapter of the study and aims to provide a suitable conclusion to the study along with the recommendations and future implications.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The investigator's purpose in this section is to provide a thorough overview of the literature while keeping the discussion concentrated on the researched topic. It is worth noting that this chapter has been formed around the study aims presented in the previous chapter. Moreover, this chapter presents the previous researches undertaken on the area of interest and explore the sub-topics to establish a comprehension and prior grounds for the development of the framework. Hence, the chapter focuses on previous literature and explores concepts including such as modified asphalt concrete and the elements that influence the performance evaluation of high-density polyethylene (HDPE) have been discussed.

2.2 Introduction to Plastic Polymers

The continual deterioration of Pakistan's road network has been caused by a drastic increase in traffic over the last two hundred years, along with low attention to maintenance due to a lack of finances. To ease this process, modified asphalt mix has been introduced to improve performance of pavements. By inserting materials for example crumb rubber, polymers, and fly ash into the mix, the qualities of the bituminous mixture can be changed. Plastic waste is one of the elements that appears to have the potential to improve pavement strength and function.

Plastic is a substance comprised of several organic polymers with a dense molecular mass. It is solid when finished, but its flow may be moulded at various points during production or processing into finished goods. According to (Jung 2018), plastics have a lengthy shelf life and are difficult to dispose of since their rate of degradation is so sluggish. Thermoses and thermoplastics are the two main categories of plastic. A thermoset hardens when heated, and due to its strength and durability, they are frequently used in the construction sector. Some of the polymers produced by this kind of plastic include polyethylene, polypropylene, polyamide, polyoxymethylene, polytetrafluorethylene, and polyethylene terephthalate. However, according to (G. H. Wang 2021), thermoplastics soften when exposed to heat and restore their original shape when they cool to ambient temperature. Flooring, carpet fibres, credit cards, and other packaging materials are made of these sorts of plastic. Additionally, these plastics include polymers like melamine. Unsaturated, silicone, polyester, phenolic, epoxy resin, and polyurethane.

Plastic appears to be everywhere in today's world. A vast variety of consumer items are packaged, preserved, served, and occasionally even disposed of using it. Additionally, mass manufacture of goods started with the advent of industrialization, and plastic seemed to be a more economical and effective raw material (Pinto 2019). Applications of communication and information technology have essentially changed every significant area of the economy, from agriculture to packaging, transportation, and building design. Plastic, which harms the environment, is available in many different forms. It may be found in both urban and rural locations. It results in water stagnation, which has negative health effects. Plastic debris is a hazard for the environment. It is possible to recycle plastic waste and use it to build roads.

2.3 Utilisation of Plastic in Asphalt Pavements

The examiners have demonstrated that the utilization of changed bitumen in development and upkeep is savvy if the life-cycle cost is mulled over. Bitumen utilized in pavement surfacing ought to have such temperature consistency attributes that the surfacing can resist rutting at very high temperatures caused due to softening of binder and fatigue cracking at lower temperatures which occurs mainly because of brittle nature in cold regions. Modified bitumen has improved stiffness of bituminous surfacing which will result in financial utilization of bitumen and other clearing materials. A portion of the polymer additives that have been utilized throughout the years for the modification of bitumen has been talked about here. Although the use of recyclable plastics in road construction is a relatively invention, no roads made completely of plastic have yet been created, according to (Ma 2021). In Addition, he claims that recycled plastics can be used as a binder modifier or in substitute of aggregates. Further, there is a chance that small amounts of waste plastic might be used in the construction of bituminous roads. By doing this, it helps to improve the strength, stability, and durability of the pavement, which improves the performance and useful life of the road. Adding waste plastic to bituminous mixes boosts durability and strengthens resistance to cracking and moisture damage, which enhances customer satisfaction and decreases accident rates. This is in accordance with field and laboratory standards (Wu 2021). Polymers are added to bituminous mixtures to cut costs and bitumen usage.

For more than 20 years, pure road asphalt binders have been combined with plastomeric or elastomeric components to form polymer-modified binders. Improved cohesiveness, low temperature susceptibility over the whole temperature range to which it will be exposed in service, and reduced viscosity at normal temperatures are all requirements for an effective binder. Traditional binders' passive and active adhesion qualities must be present as well. Finally, its ageing characteristics should be advantageous for both laying and use (Brule 1996). According to (Diehl 2000), the four primary subcategories of polymers are additives/coatings, plastics, elastomers, and fibres. When addressing thermoplastics, thermosets (or thermosetting resins), and elastomers, rubber is further split into natural and synthetic forms. Around 75% of modified binders are elastomeric, 15% are plastomeric, and the remaining 10% are either rubber or have been diversly modified (Diehl, 2000).

(Haider 2020) states that polymers over asphalt pavements improve mechanical characteristics, reduce landfill pollution, and eliminate the need for raw plastics, which might eventually result in cost savings and environmental advantages. However, melting polymers makes it possible to release very little toxic gases that affect the environment. More research is also required, according to (Tong 2020), to strengthen the compatibility of asphalt with plastics, particularly high melting point polymers. It is important to develop efficient compatibilizers for the inclusion of nanomaterials, plastics, and other polymers to the binder mixes in order to enhance their low-temperature properties. In order to establish the long-term durability of plastic modified pavement, it is also necessary to further investigate the effects of bitumen mixes that have been changed with plastic during the ageing process. It is important to consider the interactions between bitumen, aggregate, and polymers as well as the mechanics of employing polymers in the concrete matrix.

2.4 Different Types of Polymers

2.4.1 Polypropylene (PP)

Polypropylene (also known as propene or propylene) is a thermoplastic made from the propene molecule that is strong, brittle, and crystallizes. It's a linear-structured hydrocarbon resin. (Bai 2020). The chemical structure of polypropylene is (C_3H_6). One of the most economical polymers on the market now-a-days is PP. One of the three most widely used polymers in use today is PP, a polymer from the polyolefin family. In the following applications, polypropylene is employed as a plastic and a fibre: Automobile industry, consumer goods, architectural markets, and industrial applications. Packaging accounts for 30% of all polypropylene consumption, whilst electrical manufacturing accounts for 13% of all polypropylene use (Wang C. Z., 2016). Building materials make up 5% of the market, while domestic products and automakers each account for 10%.

It is rather difficult to attach this polymer to other materials or mix it with other polymers, which is one of its major drawbacks. Furthermore, in comparison to other polymers, it has a comparatively low density, according to (Saikrishnan 2020). Additionally, polypropylene has a very high temperature coefficient, which limits its use for high temperature applications by requiring a lot of heat to reshape it. Also polypropylene has a low UV index, which makes it susceptible to degradation or damage from sunshine. Because of its high flammability, this polymer has another drawback and cannot be used in applications involving heat. According to (Sciarretta 2021), this polymer may readily oxidise, rendering it difficult to paint over due to its poor adhesion to other materials. When it comes to aromatics and chlorinated compounds, polypropylene is more sensitive.

2.4.2 Low Density Polyethylene (LDPE)

Low density polyethylene (LDPE) is a lightweight, flexible, and elastic polymer. LDPE is known for its low-temperature elasticity, durability, and chemical resistance. The low-temperature elasticity, durability, and chemical resistance of LDPE are well recognised. Applications requiring mechanical integrity, minimal thermal expansion, or rigidity cannot use it (Na 2018). LDPE is a common option for orthotics and prosthetics whereas, it’s a wonderful option for such applications that ask for a soft polymer to work since it is pharmacologically and pressure robust, as well as simple to make and shape. This type of polymer cannot be employed in the construction of road as stated by (Sogancioglu 2017) due to its poor strength and durability.

2.4.3 Polyethylene Terephthalate (PET)

The primary constituents of PET are ethylene glycol and terephthalic acid, which are combined to make a polymer chain. PET strands are extruded like spaghetti, rapidly cooled, and then shredded into tiny pellets (Nisticò 2020). These pallets are then heated until they are molten liquid, which allows us to shape and size them as required. PET is a clear, strong, and reasonably priced polymer that is frequently used in the packaging of many different goods, particularly drinking bottles and other beverages all over the world. Additionally, practically all bottles of carbonated soft drinks and water sold in the United States are made of PET (Kawai 2020). Furthermore, a key component in PET's energy efficiency is the high strength compared to its low weight, which enables more things to be supplied in less packaging while requiring less petroleum for transportation. Its energy savings are being further increased by continuous advancements in light weighting technologies. The environmental advantages of PET as a packaging material have been consistently proven by life cycle studies.

2.4.4 High Density Polyethylene (HDPE)

(Mazur 2020) states that High Density Polyethylene is a synthetic polymer made up of petroleum. One of the most valuable polymers in the market, which is used in a wide range of products, from food containers to plastic containers, bottle caps to worktables and pipelines. HDPE plastic is noted for its high tensile strength and strength to density ratio, as well as its high impact resistance and melting temperature (Xu 2018). One of this polymeric substance's key benefits is that it is naturally malleable. In this sense, HDPE stands out in particular. Due of its high melting point, HDPE remains rigid until very high temperatures. The plastic may be quickly and readily moulded into a variety of goods as the manufacturer chooses after it has reached its heat capacity. HDPE is a suitable material for underground water delivery infrastructure because it is resistant to moisture, fungi, and deterioration (Kai 2019). HDPE is a strong, temperature-resistant polymer that can be heated to disinfect it, making it the perfect material for foodservice containers. Secondly, HDPE is highly resistant to most acids and bases as well as other naturally occurring substances in soil. Additionally, many typical pollutants, including freshwater, hydrocarbons, oils, and other chemicals, are almost impermeable to the polymer.

Low-density polyethylene (LDPE) is somewhat less dense than HDPE, which has a density range of 0.90 to 0.95g. However, when seen under a microscope, HDPE's linear structure suggests far less splitting, leading to greater molecular interactions and impact resistance than LDPE. Consequently, an HDPE container can readily support a lot more weight (Badache 2018). HDPE is commonly used in place of construction materials, enabling businesses and individuals to accomplish more sustainable and economical production and project goals. It is perfect for a range of applications because to its excellent machinability, rigid durability, and resistance to corrosion. The perfect material for durability, Cost-effectiveness, and renewability is HDPE.

2.5 Plastic Utilisation in Asphalt Mixes

According to (El-Naga 2019), the use of waste materials in pavement design is currently gaining popularity since it enables the utilisation of waste resources without degrading the pavement's quality. Plastic polymers are spreading in practically every industry in the globe and are now a common product. From 2 million metric tonnes in 1950 to 322 million metric tonnes in 2015, the manufacturing of plastics has increased rapidly. According to (Naghawi 2018), the use of recyclable elements in asphalt has been a topic of intense debate in the construction sector. On one side, recycled material might benefit the ecology and the pavements if used properly and after thorough research. On the contrary, it is never a good idea to deploy materials quickly without first doing a detail testing and analysis.

Late last year, interest grew in the use of recovered plastic waste in asphalt mixes. The idea was presented as a means of tackling the issue of plastic trash in towns and cities all over the world while simultaneously attempting to improve the state of asphalt pavements. The two most popular techniques for incorporating recovered plastics into asphalt mixtures are the wet process and the dry process. Polymers are mixed with bitumen at high temperatures to create bituminous binders, which are then blended with aggregates during the wet process. As a result, the wet process needs additional equipment and gear to dissolve. The heated asphalt mixture is then combined with the polymers, which have been crushed into powder. The wet method of combining plastics with asphalt, according to (Lugeiyamu 2021), is a physical process in which plastic particles absorb the lightweight components in asphalt to produce a viscoelastic phase separation at high temperatures. Low melting point polymers, like PE, respond well to this technique.

The effectiveness of recycled HDPE pellets as a modifier in asphalt binder was assessed by (W M N W Abdul Rahman 2011). With HDPE comprising 1 to 5% of the weight of a binder, a softer grade binder (penetration 160/220) was compared to a medium grade binder (penetration 100/150). Conventional testing was used to compare the fundamental characteristics of the standard binder and the HDPE modified binder, and fluorescence microscopy was used to assess the degree of compatibility and morphology. The results demonstrated that HDPE binder modification can enhance bitumen's morphological and conventional properties. The HDPE modified bitumen's increased stiffness or hardness is shown by a decrease in penetration and an increase in softening point and PI. Given the economic and environmental considerations, it has been decided that HDPE modified asphalt is more suitable than conventional hot mix asphalt for use in flexible pavement.

(Hussein A.A. Gibreil 2017) used high-density polyethylene and crumb rubber particles as two different types of modifiers to enhance the physical properties of asphalt. Due of their high marshall quotient and marshall stability values, HMA mixes treated with HDPE and CRP demonstrated enhanced deformation resistance. The findings suggested enhanced resistance to permanent deformation and moisture damage. When high density polyethylene (HDPE) was added to asphalt, (Moatasim Attaelmanan 2011) reported that the Marshall quotient increased byc55% and the tensile strength ratio value increased by more than 85%, providing better resistance against permanent deformation and preventing the mixture from losing strength when exposed to moisture. It enhances stiffness and rupture modulus, which may lessen the possibility of breaking at low temperatures. Additionally, it resulted in lower strain values and greater resilient modulus values. It is recommended that HDPE make up 5% of the binder weight in asphalt to increase its efficacy.

(Fereidoon Moghadas Nejad 2014) employed HDPE as an addition to study the fatigue and rutting behaviour of HMA mixtures in damp and dry conditions. The resistance to rutting and fatigue life of the mixtures were evaluated using the dynamic creep and ITF tests. The findings show that HDPE-modified mixes, because to their enhanced stiffness, offer greater rutting resistance and fatigue life. The resistance to fatigue life and permanent deformation of all specimens were also decreased when temperature was raised. The outcomes further demonstrate that HDPE improves the adhesion between the aggregate and asphalt binder in the presence of moisture.

In research by (Alaa H. Abed 2020), the base asphalt binder of the PG (64-16) grade was modified using Nano High Density Polyethylene (NHDPE) and Styrene Butadiene Styrene (SBS) polymers at afcontentfof13 and 5fpercent, by weight of total asphalt binder percentage, respectively. Despite being less successful than SBS at the same polymer content, the study's results show that NHDPE particles significantly improve the binder's Performance Grade (PG). The findings of the wheel tracking test showed that employing 3% NHDPE instead of 5% SBS improved the performance of the asphalt binder. Instead of SBS polymer, Nano-HDPE was used, which increased resistance to cracking and moisture damage. The impact on tensile strength ratio results for the HDPE were all improved by 10% or less. In conclusion, it was discovered that the Nano-HDPE had significant influence on workability, resistance to rutting, and resistance to cracking. Although the PG grades of the binders demonstrated that SBS outperformed HDPE in terms of enhancing the high-temperature grade.

The potential for using different plastic wastes containing HDPE as polymer additions in hot asphalt mixtures was investigated by (Sinan Hınıslıogˇlu 2004). It was investigated how HDPE modified bitumen affected Marshall Stability and Marshall Quotient (MQ) when it was generated at different blending temperatures, blending times, and HDPE percentages. They discovered that when asphalt concrete is treated with HDPE, the values of marshall stability and the marshall quotient (deformation resistance) significantly increase. For the Marshall test, 4% modifier HDPE, a blending temperature of 165°C, and a blending time of 30 minutes were optimum. MQ increased by 50% as compared to the typical blend. Waste HDPE modified bituminous binders can be said to provide stronger resistance to permanent deformations because to its high marshall quotient and stability, assisting in the recycling of plastic waste while also supporting environmental protection.

The properties and performance of bituminous modified asphalt were compared to different polymer-based waste products, including LDPE, HDPE, and crumb rubber by (Muhammad Bilal Khurshid 2019). The research of normal and modified asphalt mixtures employed performance tests including the Marshall stability test and the Wheel Tracking Test. For HDPE, LDPE, and CR, the ideal polymer concentration was found to be 8% and 10%, respectively. The most rutting resistance was found in HDPE-modified HMA when compared to control, LDPE, and CR modified HMA. The HDPE modified mixture outperformed the control HMA by 78% after 10,000 passes. At optimal polymer content (OPC), CR stability increased by 98% compared to traditional HMA, while HDPE and LPDE stability enhanced by 69% andi58%, respectively. Bituminous mixtures with polymer modifications demonstrated improved stiffness and minimal sensitivity to high-temperature impacts. Polymer-modified asphalt mixture provides greater stability, rutting tolerance, and load bearing capacity than conventional asphalt mixture. Overall, it was discovered that the HDPE modified mixture was the most effectual followed by LDPE and CR.

Researchers examined at the correlation between polyethylene molecular structure and the effectiveness of asphalt mixtures (Ming Liang 2019). In this study, low density, medium density, high density, and linear low density polyethylene are all used. Using a controlled strain HR.01 dynamic shear rheometer (DSR), rheological investigations were conducted to assess the rutting resistance of numerous polyethylene modified asphalt mixes. The bending beam rheometer was used to analyse low temperature creep properties utilising steady state shear tests, frequency sweep tests, temperature sweep tests, and master curves (BBR). Viscosity and complex modulus (G*/sin), two markers of high temperature performance, showed that MDPE modified asphalt outperformed HDPE, LLDPE, and LDPE. The optimum alternative for rutting protection in asphalt enhancement is hence MDPE. The microscope findings showed that LDPE and LLDPE are among the most compatible with asphalt mixes, followed by HDPE and MDPE, due to their tiny particle dispersion and fine shape.

(Shahreena M R Shah 2018) investigated the usage of waste polyethylene as a bitumen modifier in order to compare the characteristics of polyethylene modified and traditional bituminous mixes. LDPE and HDPE were mixed together and applied to the aggregate as a modifier, leaving a thin film on the surface. The results show that for a mixture of 2% HDPE and LDPE, a bitumen combination requires an ideal binder percentage of 4.9 percent, as opposed to 5.1 percent for conventional blends. The modified bituminous mixture with a polyethylene content of 2.0% has approximately double the stability value of the control sample. Recycled plastic was used to modify bitumen (Kofteci 2016). HDPE-based trash was added to bitumen as a modifier at concentrations of 1%, 2%, 3%, and 4%. A stability and flow test was used to evaluate the specimens' performance after which an indirect tensile test (ITT) was used to gauge how susceptible the hot mix asphalt was to water damage. Up to 3% of the control specimens were unaffected by the inclusion of the HDPE modifier. Based on the results, adding by 4% increases stability and water resistance. Additionally, flow values at the rate between specified limits were discovered. Therefore, the flexibility and plasticity of combinations treated with 4% HDPE were unaffected.

Recycled polyethylene was used in (Veeraragavan 2007) as an asphalt modification. According to the fundamental test results, pure asphalt's penetration and ductility decrease when polyethylene content is added, whereas its specific gravity and softening point increase when polyethylene modifier is added. It is recommended to use asphalt with a polyethylene content of 5% by weight for enhanced asphalt concrete performance. The potential application of pyrolysis Low Density Polyethylene as a binder modifier for hot mix asphalt concrete mixture was researched by (A.I. Al-Hadidy 2009). Five different blends, including the control mix, were subjected to rheological testing and other homogeneity-related binder tests. The results showed that changed binders maintained ductility values within the desired range while having a greater softening point. At both high and low temperatures, it also improves shear resistance and deformation resistance.

Table 2.1 Overview of Previous Research Work on HDPE Modified Asphalt Concrete Mixes

Research Paper Description	Polymer Type & Percentage	Test Performed	Outcomes
(Hussein A.A. Gibreil, Cheng Pei Feng, 2007) Construction and Building Materials	HDPE and Crumb Rubber HDPE 4, 5 and 6% CR 5, 10 and 15% 5% HDPE and 10% CR is Recommended	• Indirect Tensile Test • Wheel Tracking Test • Marshall Stability & Flow Test	• The modified asphalt sample's TSR values rose by 15% in comparison to control samples. • Compared to control samples, the modified asphalt sample's dynamic stability rose by 158%. • A decrease in the unaltered asphalt mixes' Marshall stability and Marshall Quotient values of 32.92% and 57.84%, respectively.
(Moatasim Attaelmanan, et al., 2011) Construction and Building Materials	HDPE 1, 3, 5 and 7% 5% is Recommended	• Tensile Strength Test (TSR) • Resilient Modulus Test • Marshall Stability Test • Flexure Stiffness Test	• When compared to control samples, the TSR values of modified samples raised by 18.7%. • The Marshall Stability of the control mix improved by 13% with the addition of 5% HDPE, while MQ increased by 55%. • Addition of 5% HDPE to asphalt, the M_R value increased by 59 percent.
(FM Nejad, A Azarhoosh 2013) Road Materials and Pavement Design	HDPE Only 5%	• Dynamic Creep Test • Indirect Tensile Fatigue Test	• At 40 and 50C, asphalt mixtures with HDPE have more rutting resistance of 61% and 66% w.r.t control mixtures. • The fatigue life of HDPE asphalt mixes increased 15.6% w.r.t controlled samples.
(Sevil Köfteci, 2016) Procedia Engineering	HDPE 1, 2, 3 and 4%	• Marshall Test • Indirect Tensile Test	• HDPE modified mixes enhanced stability by 11% while simultaneously increasing flow value by 5.7% and TSR value by just 3.6% with respect to control samples

Research Paper	**Polymer Type & Percentage**	**Test Performed**	**Outcomes**
(V. S. Punith and A. Veeraragavan, 2007) Journal of Materials in Civil Engineering	LDPE 2.5, 5.0, 7.5 and 10%	• Resilient Modulus • Indirect Tensile Strength Test • Unconfined Dynamic Creep Test • Hamburg wheel tracking tests	• At 5 °C and 25 °C, it was observed that adding 5% polyethylene to asphalt increased M_R value by 23.6 and 28.9%, respectively. • Mixtures containing 5% polyethylene, the percent strain reduction was determined to be 42, 60, 36, and 22% for temperatures of 30, 40, 50, and 60°C, respectively. • At 30, 40, 50, and 60°C, the creep strain rate is reduced by 58, 61, 59, and 68 percent, respectively, for asphalt mixtures with Polyethylene concentration. • The stripping inflection point increased 297% with the inclusion of PE in asphalt.
(Alaa H. Abed, Hussain U. Bahia, 2019) Construction and Building Materials	HDPE and SBS 3% and 5% **(**By weight of base asphalt)	• Wheel tracking test • Indirect Tensile Test (IDT)	• When 3 and 5 percent of SBS were added, the rut depth reduced by 29 and 53 percent, respectively. • While adding 3% and 5% of NHDPE which resulted in a significant reduction in rut depth of 41% and 71%, respectively.

(M Liang, et al.)
 	
International Journal of Pavement Engineering
	HDPE, MDPE, LDPE and LLDPE
	
	Only 5%
		• Rheological Tests
		  ▪ DSR
		  ▪ BBR
		• Fluorescence Microscopy
			• MDPE showed highest rutting resistance followed by HDPE. Whereas, LLDPE sample exhibits good low temperature performance, followed by LDPE.
			• The microscopy results showed that LDPE, LLDPE are best suitable with HMA based on their fine morphology and small particle distribution, followed by HDPE and MDPE.

Research Paper Description	**Polymer Type & Percentage**	**Test Performed**	**Outcomes**
(Wan Mohd Nazmi, et al., 2011) Journal of Engineering & Technology	HDPE 1, 2, 3, 4 & 5%	Only binder tests • Conventional tests (Penetration, Softening point and viscosity) • Fluorescent Microscopy	• An increase in temperature susceptibility is achieved by using 160/220 grade binder in recycled HDPE modified asphalt. • According to the image analysis, the bitumen to polymer phase proportion increased for 1% HDPE modified bitumen from 12% to 20% and for 5% HDPE modified bitumen from 60% to 80%.
(M Bilal Khurshid, et al., 2019) Arabian Journal for Science & Engineering	HDPE, LDPE and Crumb Rubber 4, 6, 8, 10, 12 and 14%	• Wheel-tracking test • Marshall stability test	• Modified HMA with an 8% HDPE content revealed greater stability values, however CR with a polymer percentage above 8% displayed high stability statistics. • CR resulted in a 98% improvement in stability, HDPE 69% and LDPE 58% w.r.t control HMA. • HDPE modified mix resulted in 78%, 35% and 48% reduced rutting compared to control HMA CR and LDPE modified mix, respectively.
(A.I. Al-Hadidy, Tan Yi-qiu, 2009) Construction and Building Materials	LDPE used in SMA 2, 4, 6 and 8% 6% recommended	• Marshall Stability Test • Indirect Tensile Test	• 58% increase in Marshall stability for 6% LDPE modified mixtures and 15.8% decrease in flow value compared to control specimen. • 95% TSR observed for the modified asphalt samples which shows 63% increase as with respect to control samples

(Sinan Hınıslıoglu, 2005) Indian Journal of Engineering	HDPEQ 1, 2, 3 & 4%	• Uniaxial Creep Test • Marshall Stability Test	• Using HDPE at a 2% concentration reduced the permanent strain by 34% while increasing creep stiffness by 52%. • With respect to controlled samples, flow reduced 25% while Marshall stability of modified mixes improved 21%.

2.6 Fatigue failure of asphalt

One of the most frequent causes of failure for an asphalt concrete road surface is fatigue. The concept of fatigue damage for an asphalt concrete pavement is complex, according to (Awad 2017). Despite the fact that experts from several countries have studied the phenomena, the issue of fatigue behaviour for bituminous concretes and asphalt concrete pavements is still crucial today. (Abdo 2017) claims that the structural behaviour technique was utilised to assess fatigue by tracking the onset of fracture development. Fracture mechanics has been widely used to study the fatigue characteristics of asphalt concrete containing various polymers. Furthermore, according to (Wang C. Z., 2016), the HMA layer may fail as a result of fatigue if the asphalt is subjected to heavy traffic loads on a regular basis. These kinds of cracks potentially allow moisture to seep into the asphalt, making the surface rougher. In the worst-case situation, the present cracking is accelerated by the absorbed moisture, resulting in medium to large craters. Tensile stresses at the bottoms of the HMA layers are caused by fatigue failure, which starts at the bottom of the flexible layer. In order to prevent fatigue failure, it is recommended that this tensile strength be reduced to a minimum during the M-E structural design stage of asphalt, according to the research conducted by (Jia 2020).

Additionally, according to (Y. R. Wang 2019), ageing, increasing temperatures, or inadequate drainage can all contribute to fatigue failure. Because the HMA layer lacks suitable durability characteristics, the effects of these components might result in unintended modifications to asphalt. Additionally, fatigue failure is the stage at which interconnecting cracks first appear and may be quickly detected. Over time, the fractures enlarge and expose lower levels of the road's components. By way of intense traffic, the asphalt layer on the surface is frequently torn up into pieces. Furthermore, according to (Y. R. Wang 2019), a patch of asphalt with only minor cracks and few or no of them connecting to form a zigzag alligator pattern is a typical indicator of severe fatigue failure. Furthermore, it doesn't seem like the fractures are eroding the lowest levels of the road's components.

2.7 Moisture Failure of Asphalt

Heated bitumen is placed over hot stone aggregate while creating asphalt pavement. Bitumen is used as a binding agent in construction. However, when water is left on the pavement, it seeps through and creates gaps, a fracture in the pavement (Jan 2018). Only in some circumstances are anti-stripping chemicals used, and the practise raises the price of constructing new roads. To get better results for enhanced pavement condition during wetness, PCA and the use of both new and recycled plastic to modify bitumen are being researched. According to (H. L. Wang 2017), when water infiltrates the pavement systems, moisture failure develops, causing the early failure of hot mix asphalt pavements, mainly because the asphalt binders and particles lose their stickiness. Possible effects of a lack of stickiness include rutting, in which particles are separated from the pavement, and separation of the asphalt layer from the aggregates. Furthermore, (Das 2021) contend that the methods currently used in laboratories to assess HMA moisture resistance were developed to compare mixes containing different types and proportions of aggregate as well as assess the level of resistance to moisture failure of a particular mixture of asphalt and aggregates. Developing a reliable approach is further complicated by moisture failures such as cyclic pressures and/or prolonged continuous exposures to water.

A research by (Chaturabong 2018) makes the case in his study that for determining the percentage of a layer's moisture failure. The most often used measures are resistive modulus, tensile strengths, and simple shear trials. All of these studies may be carried out on HMA materials after treatment to evaluate a mixture's tolerance to moisture failure to uncreated obtained data. By applying a compression radial pressure, the indirect diametral tensile test fractures materials in a diametral plane. The stress-strain curve produced by tensile strength testing is evaluated using the resilient modulus approach. Furthermore, (Teh 2019) demonstrated in their study that it is insufficient to identify moisture failure by comparing the peak magnitudes of velocity with respect to pressure of a moisture conditioning material to those of a known unbroken sample.

2.8 Stiffness of Asphalt

The resilient modulus indicates the material stiffness. Resilient modulus is stress divided by strains for the rapidly applied loads as experienced in the form of vehicular loads on pavement during its lifetime.

$$M_R = \frac{\sigma_d}{\varepsilon_r}$$

Where;

M_R Resilient Modulus

σ_d Repeated (Cyclic) Deviator Stress

ε_r Recoverable Strain

It is self-evident that most pavement materials are not elastic and, as a result, deform permanently with each load application. At this point in the load application process, a tiny amount of permanent deformation accumulates, which is represented by the plastic strain.

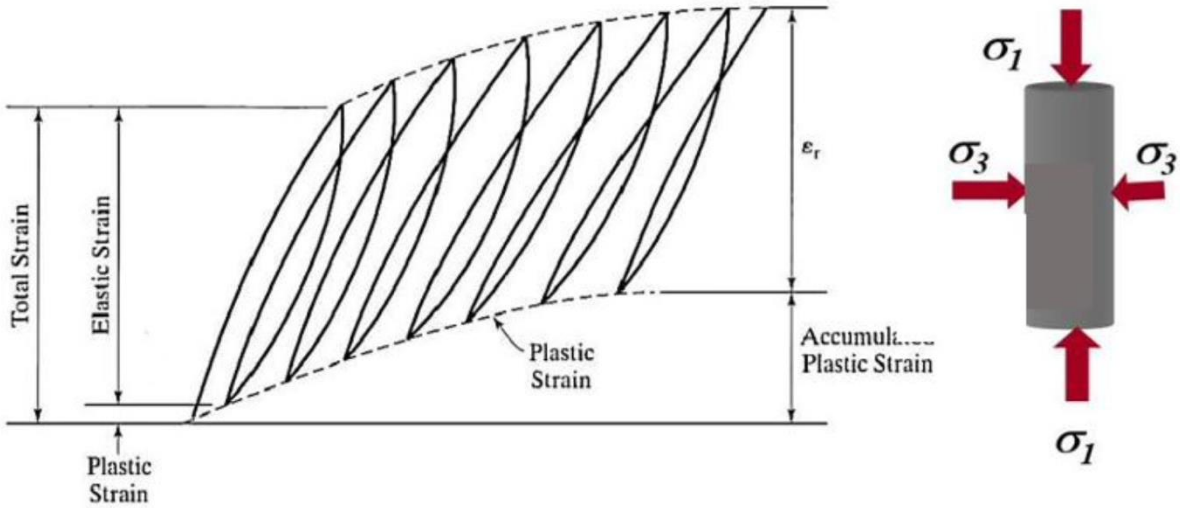


Figure 2.2 Recoverable Strain Under Cyclic Loading

One of the essential characteristics of an asphalt-gravel combination is its elasticity or toughness. The amount of reversible displacement brought on by a load is measured by the specific modulus. This phenomenon piques the concern of pavement engineers since it indicates a material's stiffness characteristic. According to (Amirkhanian 2020), bitumen mixture stiffness is crucial for defining how well a road functions as well as how an asphalt mixture reacts to various loads and environmental factors. The existing pavement has been harmed by cracking and ongoing deformation. Tensile tension caused by the vehicle's wheel weight at the bottom of the pavement layer leads to cracking in the pavement layer (Kalpana 2018). The connection between stress and strain, which denotes the stiffness of the blend, is one characteristic of a combination that can help it attain the strength and durability it needs.

According to (Wang Y. R., 2019), moisture absorption in asphalt mixes happens during mixing and deployment, diminishing the stiffness of the in-place mixture and perhaps leading to compacted difficulties in "sensitive" combinations. As the mixture continues to be mixed by the plants, the moisture will eventually drain, leaving the mixture stiff. Furthermore, the research by (Tarefder 2018) demonstrates that the effect of confinement on stiffness is dependent on mixture stiffness (or binding stiffness), with softer mixes gaining more stiffness when confined than stiffer mixes, and is more apparent at higher temperatures. When confinement is used, this effect can be explained by an increase in pressure distribution inside the test specimen. According to the theory of soil mechanics, the mixture stiffness must be measured using the stress distribution rather than the overall stress. In order to achieve stiffness values that are comparable to those found in unconfined testing, appropriate stress is assumed to be a determinant of binder viscosity. The constrained testing appears to be unneeded for collecting mixture stiffness for comparison evaluations because the unrestrained testing will then give direct access to the binder impact in the mixes.

However, a HMA mix with a low as constructed density is suitable as compared to a mixture with a higher density, this does not mean that the total as-placed density of the mixture is also appropriate since low density mixes are more prone to moisture infiltration and age stiffening. Additionally, (Li 2020) demonstrates in their research how WesTrak failures of coarser mixes with low in-place density and high stiffness due to considerable binder binding imply that increased dilatation may contribute to mix instabilities under intense accelerating traffic stress. Although this kind of sudden failure is infrequent, it is possible dependent on the recovery time and age hardening of the roads. Furthermore, (S. X. Lv 2020) discovered in their research that the ageing of the combinations had considerably modified the relative values; mixtures with softer bindings had aged more than combinations with stronger binders. Although SMA combinations with stiffer original binder grades may have aged slower due to the presence of more binder, some densely graded compositions with softer binder grew stiffer.

2.9 Summary

Following an examination of previous studies on the inclusion of HDPE as a modifier in asphalt concrete mixtures. Based on previous studies properties of the modified mix are dependent on a variety of factors such as type of polymers, the percentage used in asphalt mixes. In this study, four variable percentages of HDPE (2.5, 5%, 7.5% and 10%) will be utilized in the asphalt mixture. After the addition of HDPE as a modifier, the modified mixes will be subjected to different performance tests. Furthermore, performance tests used in this study such as TSR, ITFT and ITSM are also discussed.

Chapter 3

RESEARCH METHODOLOGY AND TESTING MATRIX

3.1 General

This chapter covers the developed methodology for achieving the specified goals of this study, as stated in chapter one, which includes acquiring necessary material, sample preparation for Marshall mix design, performance testing, and evaluating the significance of HDPE variants as a modifier in asphalt concrete specimens. The material characterization of binders and aggregates, as well as the specifics of different tests performed, is clarified. The Marshall mix design method usedto determine the optimum binder content (OBC) for HMA mixes employed in this research is also described. NHA-B gradation is being followed in this study. This investigation utilizes HDPE as a modifier in asphalt concrete. HDPE used with four varying percentages 2.5%, 5.0%, 7.5% and 10.0% whereas the other testing conditions were kept the same throughout the testing matrix. The details of performance tests which includes TSR, Indirect Tensile Fatigue test, Stiffness Modulus test is also discussed.

3.2 Research Methodology

The study was conducted on asphalt concrete specimens with aggregate procured from Margalla quarry along with gradation of NHA-B was adopted with bitumen from ARL refinery of penetration grade 60/70 is utilized in this research study. Conventional and HDPE modified specimens were prepared following the laboratory diagnosis of OBC by Marshall mix design. The control and modified asphalt mixtures replicateswere analyzed for moisture susceptibility, fatigue, and stiffness modulus by performance tests. Testing was conducted in controlled environments as prescribed by the respective specifications. Results obtained from performance tests were analyzed, successive conclusions and recommendations were made as stated in the following chapters. The methodology adopted for this research is illustrated in the following Figure 3.1.

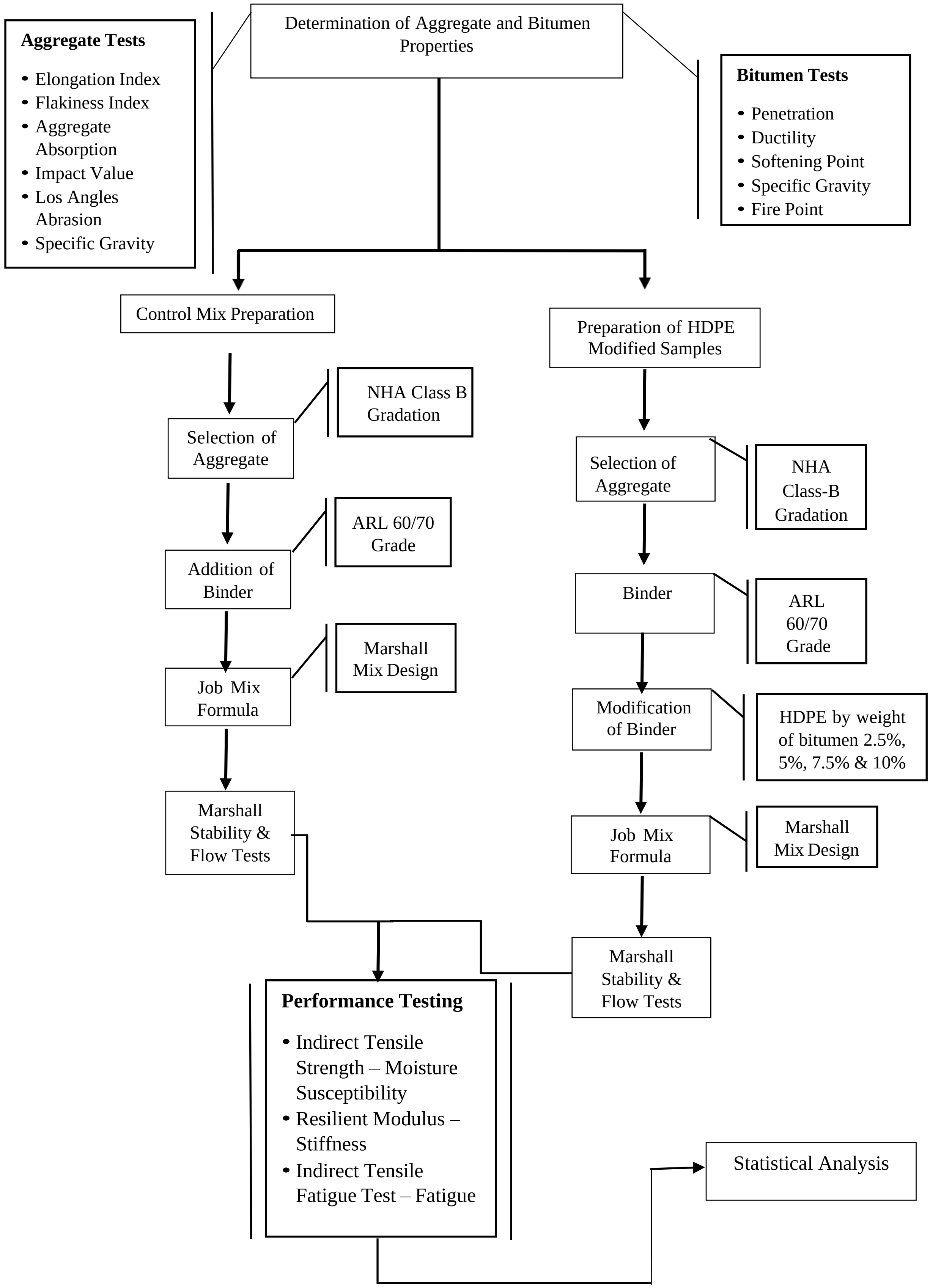


Figure: 3.1 Research Methodology Flow Chart

3.3 Characterization of Selected Material

3.3.1 Material Selection

Fine and coarse virgin aggregate is procured from Margalla quarry and a binder of penetration grade 60/70 from Attock Refinery Limited for this study. A Binder of 60/70 grade has been chosen since it is commonly utilized in Pakistan road infrastructure network and its suitability with the local climatic requirements (colder to mild environment). HDPE was sourced from POLIMAXX, Thailand.

The asphaltic mixture is the composition of aggregates, bitumen, and air. Usually,the aggregate is 95% by weight as it provides the main portion of confrontation to permanent deformation and the remaining 5% is the weight of the bitumen. Air being weightless has no percentage in the mix. Concerning volume asphaltic mix is composed of 85% aggregate, 10% Bitumen and the air occupy the remaining 5% volume. To meet the required standards of asphaltic mixtures, detailed laboratory testing of selected materials, the aggregate and bitumen, is required.

Figure 3.2 Margalla Quarry Site

HDPE polymer is utilized as a modifier in this study. HDPE was sourced from a POLIMAXX by IRPC Public Company Limited in Thailand. In this study, samples were produced with the four varying quantities of HDPE i.e., 2.5%, 5.0%, 7.5% & 10.0% by weight of bitumen to evaluate the effect of different concentrations of polymer on asphalt mixtures in comparison to conventional mix. Properties of HDPE polymer are given in Appendix – I.

Different methods are used to incorporate the HDPE in asphalt mixtures such as the dry method, wet method, or complex method. In this research study, the dry mix method is utilized to incorporate HDPE in asphalt concrete.

Figure 3.3 HDPE Utilized in Research Study

3.3.2 Aggregate Testing

Mineral components such as sand, gravel, and crushed stone are blended with a binding medium to obtain compound materials such as AC. By volume, aggregate comprise for 92-96 percent of HMA. Aggregate is also used in flexible and rigid pavements' base and subbase courses. Laboratory tests were conducted on each stockpile to evaluate the aggregate's key characteristics, such as gradation and specificgravity etc. The following laboratory tests are performed:

Table 3.1 Tests Conducted on Aggregates

S.No:	Tests	Standard
1	Aggregate Impact Value	BS 812
2	Crushing Value Test	BS 812
3	Flakiness and Elongation Index	ASTM D4791
4	Fractured Particles	ASTM D5821
5	Deleterious Material Detection	ASTM C142
6	Resistance to Degradation	ASTM C131
7	Water Absorption	ASTM C127
8	Specific Gravity	ASTM C128

3.3.3 Impact Value Test of Aggregate

The impact value of a material measures its resistance to a rapid shock. This process is carried out as per BS 812. The impact testing equipment, a cylindrical mold with a 75mm diameter and a depth of 50 mm, a tamping rod with a circular section of 10 mm and a length of 230 mm, and sieves with sizes 1/2, 3/8", and #8 were all needed for measuring impact value (2.36 mm). Around 350 g of aggregate was collected and placed in the mold of the Impact Testing Machine in three (3) layers, with each layer tamped 25 times. The sample was placed in the machine's bigger mold, and 15 blows were delivered from a height of 38 cm with weight of hammer 13.5-14kg. The aggregate was extracted and passed through filter #8. The proportion of aggregate passing through a 2.36 mm sieve was used to get the impact value. Results are manifested in Table 3.2.

Figure 3.4 Aggregate Impact Value Apparatus

3.3.4 Aggregate Crushing Value Test

The aggregates must be strong enough to withstand traffic loads to produce a better quality and strength pavement. This test is performed under standard BS 812. Steel cylinder with open ends, base plate, plunger with a piston diameter of 150 mm and a hole across it so that a rod could be inserted to raise it, cylindrical measure, balance, tamping rod, and a compressive testing machine were the tools utilized in thistest. Aggregates were sieved through a series of sieves, with those passing through 12"and retaining 3/8" being chosen. The aggregate sample was washed, oven-dried, and weighed (W_1), and three (3) covers were placed to the cylindrical measure, with each layer receiving 25 tampings. The specimen was then placed in a steel cylinder with a base plate, and the plunger was then inserted. After that, it was tested in a compressingmachine. The weight was added at a constant rate of 4 tons per minute until the total load reached 40 tons. The crushed material was then separated from the steel cylinder and sieved at 2.36mm. The stuff that has passed must be gathered and weighed (W_2). $W_2/W_1\ x\ 100$ was used to determine the crushing value of aggregate. Results are mentioned in Table 3.2.

3.3.5 Flakiness and Elongation Index of Aggregates

The dimensional ratios of aggregate particles of different sieve sizes are determined using the flat and elongated particle test. This characterization is used to detect aggregate that has a propensity for obstructing compaction or has troubleachieving VMA requirements owing to aggregate deterioration. Flat or elongatedparticles tend to lock up (rather than reorient) more easily during compaction, making it more difficult to compress. They also have a propensity to fracture during compactionalong their weak, narrow dimension, resulting in finer aggregate gradation and potentially lower VMA than anticipated. This test is performed under ASTM D4791 guidelines.

Flaky particles are defined as having dimension of less than 0.6 of their mean sieve size. For elongated particles have a length more than 1.8 of their mean sieve size.It may be carried out by following two distinct methods. For all non-Superpaveapplications, the first technique is used, which is identical to the original procedure designed to identify flat and elongated particles. For Superpave requirements, a secondtechnique is used, which mostly involves comparing the maximum and lowest particledimensions. These flat and elongated particles have the potential to lock up more quickly during the compaction process, making the procedure more difficult. Compaction also causes aggregate particles to reorient, and these particles have a propensity to shatter during compaction, resulting in a finer aggregate gradation, whichhelps to minimize Voids in Mineral Aggregates (VMA). The proportion of elongated and flat particles must be less than or equal to 15%, according to ASTM standards. Theresults of a test on a few aggregates are within permissible limits. Results are mentioned in Table 3.2.

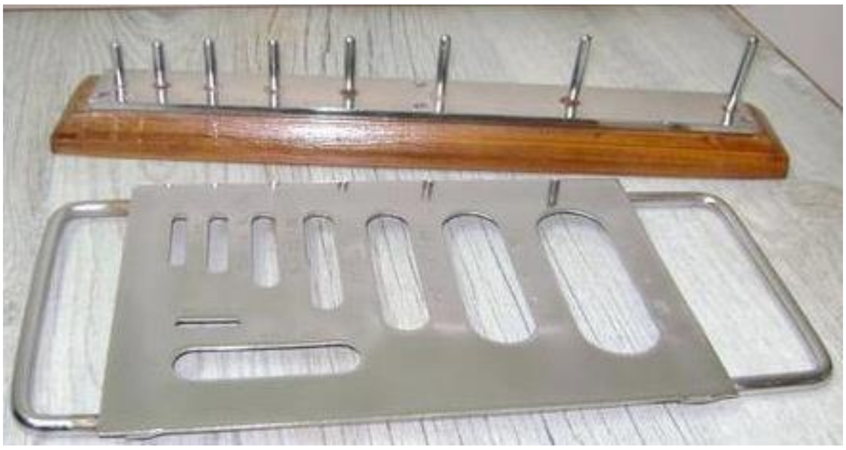


Figure 3.5 Flakiness and Elongation Test Apparatus

3.3.6 Fractured Particles

This test is performed in compliance with ASTM D5821. A fracture particle is an aggregate particle with the lowest number of broken faces as specified. Fractures face refers to the angular, rough surface of an aggregate particle that has been fractureddue to artificial or natural crushing. This test may be used to determine the percentageof a coarse aggregate material that includes fractured particles that satisfy the requirements by counting or mass. By increasing the friction between the particles, it isnecessary to give maximal shear strength to bound or unbound aggregate mixes. It alsoprovides aggregate stability in surface treatment and increases aggregate friction in thepavement's surface. Only coarse aggregate is used in this test. A percentage of greater than 90% is the minimum requirement for coarse aggregate to pass this test. The outcome of the coarse aggregate from the Margalla quarry was 100%, which issatisfactory. The results obtained are mentioned in Table 3.2.

3.3.7 Deleterious Material Test

The main goal of this test is to assess the quantity of clay in the aggregate sample. It is carried out as per ASTM C 142 on aggregate as obtained from the Margalla quarry in the current study. The inclusion of a large quantity of silt and clay, or any other organic particles that may absorb water, is essential to the asphalt concrete's longevity, water tightness, and strength. It's a crude technique for determining the amount of clay and other organic particles in aggregate used to make asphalt mixture. The bitumen and aggregate connection may be weakened or broken because of these particles. For results consult Table 3.2.

3.3.8 Resistance to Degradation

The Los Angeles (LA) Abrasion Test is frequently used to determine aggregate deterioration resistance. This test verifies the aggregate's toughness and abrasionproperties, i.e., its resistance to wear owing to high traffic loads. Because the aggregatein the mix is subjected to high repetitive load levels, which causes fragmentation, deterioration, and crushing, the quality of abrasion resistance is essential to verify. Thistest was carried out in compliance with ASTM C131. The LA Abrasion machine, a weight balance, a set of sieves, and steel balls known as charge were utilized in this test. For this process, testing methodology or grade B was used. The Los Angeles abrasion instrument was filled with 2500 g of aggregate held on 12" and 3/8" sieves, for a total of 5000 g (W_1) of aggregate, as well as 11 steel balls or charges. It was thengiven a 500-revolution spin at 30–33 rpm speed. The material was then sieved using a1.7mm sieve. The weight of the sample that passed through it (W_2) was recorded by $= W_2/W_1 \times 100$ was used to calculate the abrasion value. According to NHA standards, coarse aggregates must have an abrasion value of 30% or less. Results are mentioned in Table 3.2.

Figure 3.5 Los Angeles Abrasion Machine

3.3.9 Water Absorption and Specific Gravity Test

The specific gravity of fine and coarse aggregates is critical in the formation of asphalt paving mixes. Engineers often utilize it in the planning of pavement and building projects. The bulk specific gravity is used to assess the quantity of binder absorbed and the VMA. Specific gravity, which represents the weight volume properties of aggregate material, is sometimes referred to as relative density. It's a material's mass to volume ratio at a constant temperature. Fine aggregates are coarse aggregates that pass-through filter No. 4 but do not pass-through sieve #4. Separately,the specific gravities of coarse and fine aggregate were determined.

3.3.9.1 Specific Gravity of Coarse Aggregates

ASTM C127 is followed to assess the specific gravity and water absorption of coarse particles of aggregate. The aggregates were first passed from sieve #4 and the aggregates that were retained on sieve #4 were firstly dried in an oven and then submerged in water for 24 hours. The aggregates were then rolled on a towel and theirweight in the saturated state was noted. After this, the submerged weight of aggregateswas determined, and their specific gravity and water absorption were calculated. The oven-dried sample does not have any water in it while in the saturated surface dry condition water fills the aggregate pores.

3.3.9.2 Specific Gravity of Fine Aggregates

This test was conducted in compliance with ASTM C128. Aggregates that passed sieve #4 were soaked in water for around 24 hours. The aggregates were then sprayed in a tray to dry to the point where they were saturated on the surface. The conewas put on a flat surface, filled with fine aggregate, then compressed with twenty-five (25) strikes with a tamping rod. The aggregates were seen when the cone was removed.If the particles had the form of the mold, they were not SSD. The same method was used after drying the aggregate again till the aggregate was somewhat slumped with the cone removal. After filling a pycnometer to a certain level with the water, it was weighed. After saturated surface drying, sand was placed in the flask and weighed again. After oven drying sand at a temperature of 110^{o}C, the specific gravity and absorption were determined. Table 3.2 summarizes the results of tests conducted on the aggregates.

Table 3.2 Laboratory Tests Results of Aggregates

Type of Test	Results (%)	Specification	Standards
Fractured Particles	98	90% (Min)	ASTM D 5821
Los Angeles Abrasion	28	45% (Max)	ASTM C 131
Flakiness Index of Aggregate	13	15% (Max)	ASTM D 4791
Elongation Index of Aggregate	3.69	15% (Max.)	ASTM D 4791

Impact Value of Aggregate		19	30% (Max.)	BS 812
Crushing Value		22.47	30% (Max.)	BS 812
Water Absorption	Fine Aggregate	2.25	3% (Max.)	ASTM C 128
	Coarse Aggregate	0.79	3% (Max.)	ASTM C 127
Specific Gravity	Coarse Aggregate	2.628	-	ASTM C 128
	Fine Aggregate	2.622	-	ASTM C 127
Clay Percentage	Fine Aggregate	0.554	-	ASTM C-142
	Coarse Aggregate	2.771	-	ASTM C-142

3.3.10 Binder Testing

Consistency, safety, and cleanliness are the three most essential characteristics of a binder in infrastructure and engineering applications, according to the Asphalt Institute's MS-4 guidebook. The density of the asphalt binder changes as the temperature rises. Therefore, evaluating asphalt binder consistency requires a standardtemperature. To evaluate the consistency of bitumen binder, a penetration test or a viscosity test is commonly employed (Asphalt Institute MS-4, 2003). Other tests, like the binder's softening point and ductility, provide further information and assurance about its consistency. To characterize the asphalt binder, the following tests were carried out in the laboratory.

Table 3.3 Test Performed on Virgin Bitumen

S.No:	Types of Tests	ASTM Standard
1	Flash & Fire Point	ASTM D 92
2	Penetration Test	ASTM D 5
3	Softening Point	ASTM D 36
4	Ductility	ASTM D 113
5	Specific Gravity	ASTM D 70

3.3.10.1 Flash and Fire Point

This test is executed as per the ASTM D92. The temperature at which the fumes of a bitumen sample in Cleveland Open Cup abruptly flare in the presence of an open flame is known as the binder's flash point. The temperature at which the surface of the binder catches fire and produces flames for at least five seconds is known as thefire point. Bitumen was poured into a metal cup until it reached a specific volume. Afterthat, it was heated at a steady pace while a test flare was passed over it at certain intervals. The temperature at which the flash and fire erupted was recorded once the aforementioned criteria were met. Three separate tests were conducted to determine these temperatures for each binder. The flash point should always be higher than 232 °C, according to the standards.

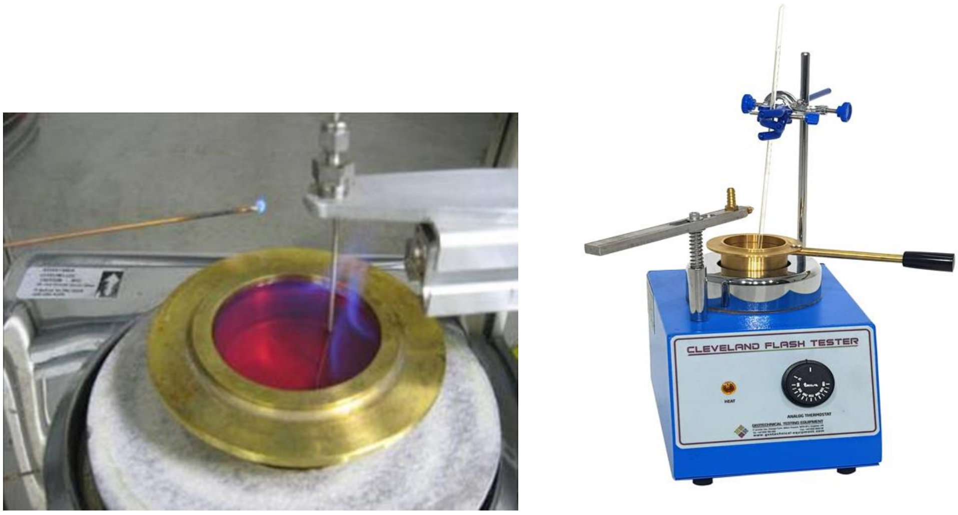


Figure 3.6 Flash and Fire Point of Bitumen Apparatus

3.3.10.2 Penetration Test

Both binders were tested for penetration according to ASTM D5 and AASHTO T 49-03. It is one of the earliest tests for determining the consistency of asphalt binders. It determines the softness and hardness of a binder to categorize it intoseveral standard classes. Soft and thin binder has a higher penetration value. Binder with a low penetration value is preferred in hot areas, while binder with a high penetration value is preferred in cooler climates. To begin, the binder is heated to a sufficient temperature for it to flow and not trap any air, but it should not be heated toomuch, since this will affect the binder's characteristics. The binder is then put into a testcontainer and placed in a temperature-controlled water bath to maintain a constant temperature of 25° C. After the container has reached the required temperature, it is removed and tested in a penetrometer by passing a 100g load through a needle for 5 seconds. Two samples of each bitumen were tested for penetration, with penetrationvalues are taken at five points on each specimen.

Figure 3.7 Bitumen Penetration Test Apparatus

3.3.10.3 Softening Point

The ASTM D36 standard is used to conduct this test using the ring and ball equipment. Although it is a viscoelastic substance, the bitumen softens with increasing temperature and its viscosity lowers. The temperature at which a sample of asphalt binder can no longer withstand the weight of a 3.5g steel ball when submerged in water.As a result, it is the average temperature at which two bitumen discs become sufficientlysoft to enable steel balls to fall 25mm. First, the binder was heated to a temperature that allowed it to flow while maintaining its characteristics. Then it was pressed into horizontal discs using a mold. The balls were put on the discs after being placed in thedevice. The temperature was raised until the binder enabled the balls to fall through thedistance stated above.

Figure 3.8 Ring and Ball Apparatus for Softening Point of Binder

3.3.10.4 Ductility Test of Bitumen

This test is executed in compliance with ASTM D113. The stretching and adhesion properties of the binder are assessed in this test. Bitumen's ductility is regardedas a key and significant physical characteristic. It depicts the behavior of bitumen as temperature changes. This test was conducted at a standard temperature of 25°C. Whena standard sized binder specimen (put in a briquette with a 1 in 2 cross-sectional area) is pulled apart at a pace of 5 cm/minute and a temperature of 25 0.5°C, the distance it lengthens without breaking is called ductility. The specimen must be at least 100cm long to pass the ductility test. Under high and frequent traffic pressures, asphalt mixesare made from less ductile bitumen fracture.

Figure 3.9 Ductility Test of Bitumen Apparatus

Table 3.4 Laboratory Tests Results of Bitumen 60/70

Test Description	Result	Specification
Penetration Test @ 25°C	64	**ASTM 5**
Flash Point (°C)	268	**ASTM D 92**
Fire Point (°C)	293	**ASTM D 92**
Specific Gravity	1.03	**ASTM D 70**
Softening Point (°C)	49.2	**ASTM D 36-06**
Ductility Test (cm)	>100	**ASTM D 113-99**

3.4 Gradation Selection

NHA class B aggregates were used in dense graded surface course mixes in line with NHA (1998) requirements. The NMAS for class B wearing coarse gradation was19 mm, according to Marshal Mix Design. Table 3.5 shows the selected gradation and Figure 3.10 depicts the gradation plotted against % passing and sieve diameters.

Table 3.5 Gradations Selected for Performance 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**

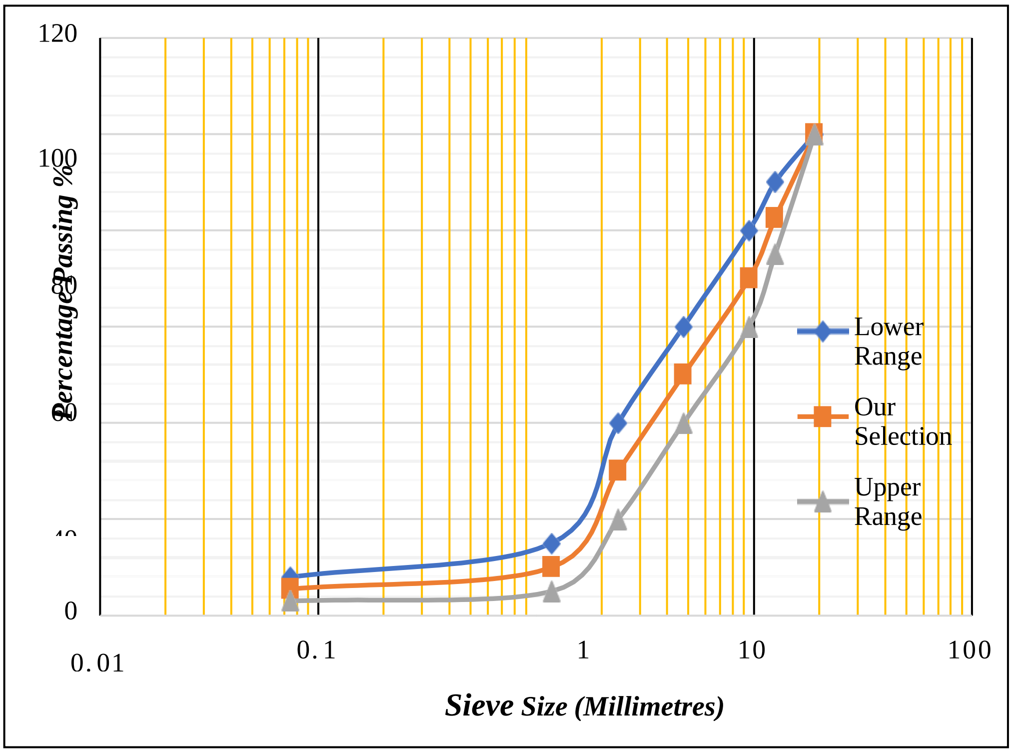


Figure 3.10 NHA Class-B Gradation Plot

3.5 Asphalt Mixture Preparation

Because the pavement built with the optimum combination of aggregate and binder will have excellent performance and a long life span, the fundamental idea for designing asphalt mixes is the optimal combination of aggregate and binder. Because the aggregate structure is essential in preventing deformation, mix design should include a mix that can resist densification under traffic stress while causing minimal changes in air voids after construction.

Five different binder contents were used to produce specimens (3.5, 4.0, 4.5, 5.0 and 5.5 percent). The objective for the five trial blends was to find the mix that performs optimally at a minimal bitumen dosage of 4% void content. The bituminous mixes usedto determine OBC were made according to ASTM D 6926, the industry standard for bituminous sample preparation using the Marshall Apparatus. The volumetric properties, stability, and flow were assessed, the Marshall Mix design criteria were verified, and the OBC was computed at the end. The following procedure was adoptedfor Marshall samples preparation.

3.5.1 Aggregate and Bitumen Preparation

To begin, the collected aggregates were sieved through a series of sieves shown on the gradation table and put in separate buckets. These were dried to consistent weights at 105 °C to 110 °C after sieve examination. After sieve analysis, the aggregates were allowed to dry for several days at a temperature of 105°C to 110°C to achieve a consistent weight. If the Marshall Mix design approach is used, 1200 grams aggregatesare required to compact a 4-inch diameter sample using the Marshall Mix design technique ASTM D6926. The following equations were used to calculate the amount of asphalt cement required for each specimen:

$$M_T = M_A + M_B$$

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

Where,

M_T Mass of Total Mix

M_A Mass of Aggregate

M_B Mass of Bitumen

X Percentage of Bitum

3.5.2 Mixing of Aggregate and Bitumen

The mechanical mixer is recommended by ASTM D6926 for the appropriate mixing of bitumen and aggregates. After extracting the dried, heated aggregates and heated bitumen from the oven, they were immediately transferred to the mechanical mixing equipment. The temperature range for mixing was 160°C to 165°C, which corresponds to the temperature in Pakistan when bituminous mixes are produced (NHA Specifications). Furthermore, the binder viscosity range of 0.22 - 0.45 Pa.sec indicatedby the Superpave mix design matches this mixing temperature (SP-2).

Figure 3.11 Mixer for producing Asphalt Mixture

3.5.3 Conditioning and Compaction of Asphalt Mixture

The ASTM D 6926 guideline suggests that the asphalt mixture be conditioned for two hours before compaction. As an outcome, after mixing, the bituminous mix was transferred to a metal pan and heated at 135°C for compaction. The mix was compactedat 135°C using an Automatic Marshall Compactor after two hours of conditioning. Mold assembly includes the cylinder, base plate, and extension collar. The cylinder is 3 inches tall with a 4-inch interior diameter. Both ends of the mold may be swapped outfor the collar. A piece of filter paper was put in the mold assembly after it was properlycleaned and heated to a temperature between 95°C - 150°C.

The mixture was then scooped and spatulated into the mold, which was then filled aftera piece of filter paper was put over it. The mold assembly was then put on the compaction pedestal in the mold holder. On the mold, the hammer was correctly positioned.

For this study, the design requirements for a dense graded wearing course were ESAL's 30 (millions) or a highly loaded pavement. To mimic heavy traffic, 75 blows were delivered mechanically on the sample's face for compaction purposes. Afterthe blows were finished, the mold assembly was removed, the specimen was inverted,the mold was rebuilt, and the same number of blows were delivered on the specimen'sopposite face.

Figure 3.12 Marshall Compactor

3.5.4 Extraction of Marshall Specimen

The assembly was removed after both sides were compacted, and the sample was allowed to cool to a reasonable temperature before being removed. An extraction jack was then used to remove the specimen from the mold. These removed specimens were laid out on a level surface and allowed to cool to room temperature. These specimens were made with 0.5 percent increments of bitumen content to identify the best performing combination with the least amount of binder and 4 percent air voids onwhich the OBC for asphalt mixture is established.

3.5.5 Number of Specimen Replicates for Each Job Mix Formula

Three specimens were created for every asphalt binder percentage and combination of aggregates. Gradation adopted for the specimen was NHA-B. Five different binder ingredients were used to produce specimens (3.5, 4.0, 4.5, 5.0 and 5.5percent). Five experimental blends were used to determine the combination that works optimally at a minimum bitumen concentration of 4% air voids.

Figure 3.13 Compacted Marshall Specimens

3.6 Diagnosis of Stability, Flow and Volumetrics

Following the measurement of theoretical maximum specific gravity (G_{mm}) and bulk specific gravity G_{mb}, the volumetric characteristics of the mixes, including Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Air Voids (V_a), and unit weight, were determined using their respective formulae. ASTM D2041and ASTM D2726 were used to determine the G_{mm} and G_{mb} of bituminous pavement mixes. The samples were maintained in a water bath for 1 hour at 60°C after G_{mb} determination and then evaluated for stability and flow using Marshall Test equipment.

3.6.1 Bulk Specific Gravity

When the samples have cooled to room temperature, they were inspected for bulk specific gravity according to ASTM D1188. The specimen was first weighted dry,then submerged in water for a while till the voids were filled with water, and then weighted again. Finally, the sample was removed from the water and dried using a towel, with the weight of the saturated surface dry sample recorded. The bulk specific gravities of each sample of the combination were deduced after the test was completed.

3.6.2 Marshall Stability and Flow

Stability refers to the maximum stress that a Marshall sample can withstand at a temperature of 60°C. Since the bulk specific gravity test is non-destructive, the corresponding samples were placed in a water bath at 60°C ± 1°C for almost 30 to 40 minutes before the testing. The samples were removed from the water bath and put in the Marshall testing machine, where they were loaded at a rate of $50.8 mm/minute$ until they reached their maximum load. The number is recorded at the moment when the load begins to drop and is referred to as Marshall Stability. A displacement gauge is connected to the sample frame before the test, and the deformation in the vertical direction is recorded in increments of 0.25 mm. The deformation at maximum load is measured and referred to as the flow value. The resistance to shear and rutting is influenced by the friction and cohesion between particles in the asphalt mixture. This test was performed in compliance with ASTM D 6927.

Figure 3.14 Marshall Test Machine

3.6.3 Maximum Theoretical Specific Gravity

Maximum theoretical specific gravity (G_{mm}) refers to the combined specific gravity of aggregate and bitumen in asphaltic blends when air spaces are removed Air voids are estimated with the aid of Gmm, which is larger than or equal to G_{mb}, and isone of the most crucial attributes of asphalt mixes. The Superpave mix design Gmm isutilized to detect air voids in the field. ASTM D2041 and AASHTO T209 were used toconduct this test. The laboratory developed loose mix sample was initially weighted indry condition. It was then put in the vacuum container, which was then filled with water.To remove the entrapped air, a vacuum of 25–27 mm of Mercury was given to the pycnometer. An agitator was used to agitate the pycnometer. After the agitation, the weight was measured. The G_{mm} of the sample was then determined as the ratio of thesample mass to the volume of water it displaced.

Figure 3.15 Apparatus for Theoretical Maximum Specific Gravity of Asphalt

Figure 3.16 Specific Gravity Frame for Bulk Specific Gravity

3.6.4 Air Voids in Asphalt Mixture

Air voids refer to small pockets of air spaces that are present between coated aggregate particles in the final compacted asphalt mix. Air voids are expressed as a percent of the bulk volume of the compacted mixture (G_{mb}) when compared to themaximum specific gravity (G_{mm}). The quantity of air spaces in a mixture is critical anddirectly linked to stability and durability.

$$Va = 100 \times \frac{Gmm - Gmb}{Gmm}$$

Where;

V_a	Percentage of air voids in the compacted mix by total volume
G_{mm}	Maximum theoretical specific gravity
G_{mb}	Bulk specific gravity of compacted mix

3.6.5 Voids Filled with Asphalt

The voids filled with asphalt consists of the part of the volume the void space in between the aggregates that are filled with bitumen only, not including the air and the absorbed bitumen in aggregates. The formula used to calculate these void percentages is as follows:

$$VFA = \frac{VMA - Va}{VMA} x\ 100$$

Where:

VFA	Voids filled with asphalt (Percentage)
VMA	Voids in mineral aggregate by bulk volume
V_a	Percent Air Voids in the compacted mix

3.6.6 Voids in Mineral Aggregate

The volume of spaces between aggregate particles in a compacted mix, including air voids and effective bitumen that hasn't been absorbed in the aggregates porous voids.

Using the bulk specific gravity of aggregate, the percentage VMA stated concerning thebulk volume of the compacted mix is determined as follows:

$$VMA = 100 - \frac{Gmb\ x\ Ps}{Gsb}$$

Where:

VMA	Voids in mineral aggregate by bulk volume
Ps	Percentage of aggregate by total weight of mix

G_{sb} Aggregate's bulk specific gravity

G_{mb} Compacted mixture's bulk specific gravity

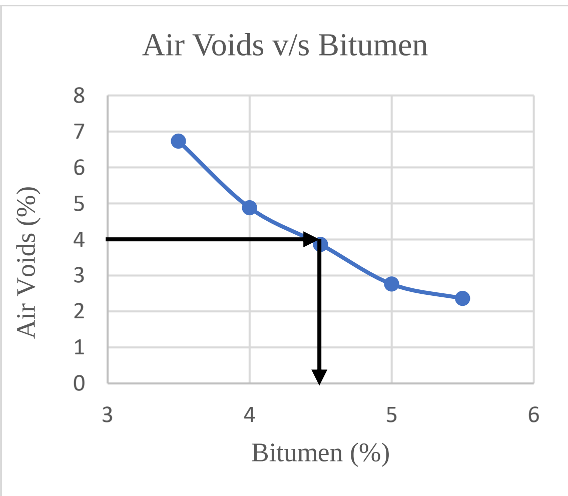
3.7 Marshall Specimen Volumetrics Results

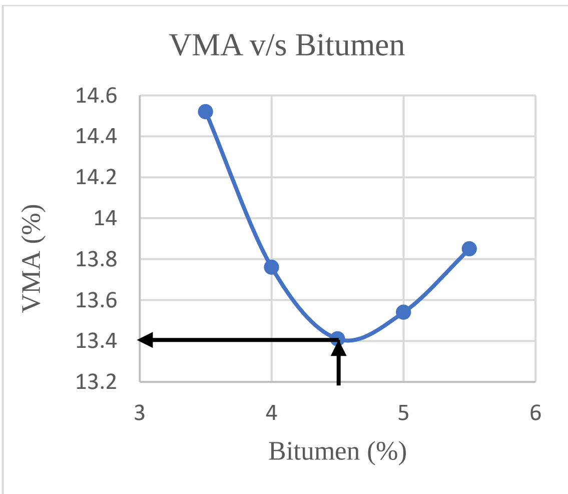
The volumetric properties, stability and flow of this mix are shown in the table Below:

Table 3.6 Volumetric Properties of Marshall Specimens

% AC	Gmb	Gmm	Unit wt (g/cm^3)	Va (%)	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

The curves connecting asphalt content and volumetric properties, stability, and flow were constructed according to the MS-2 manual to estimate the OBC of Asphalt mixtures.





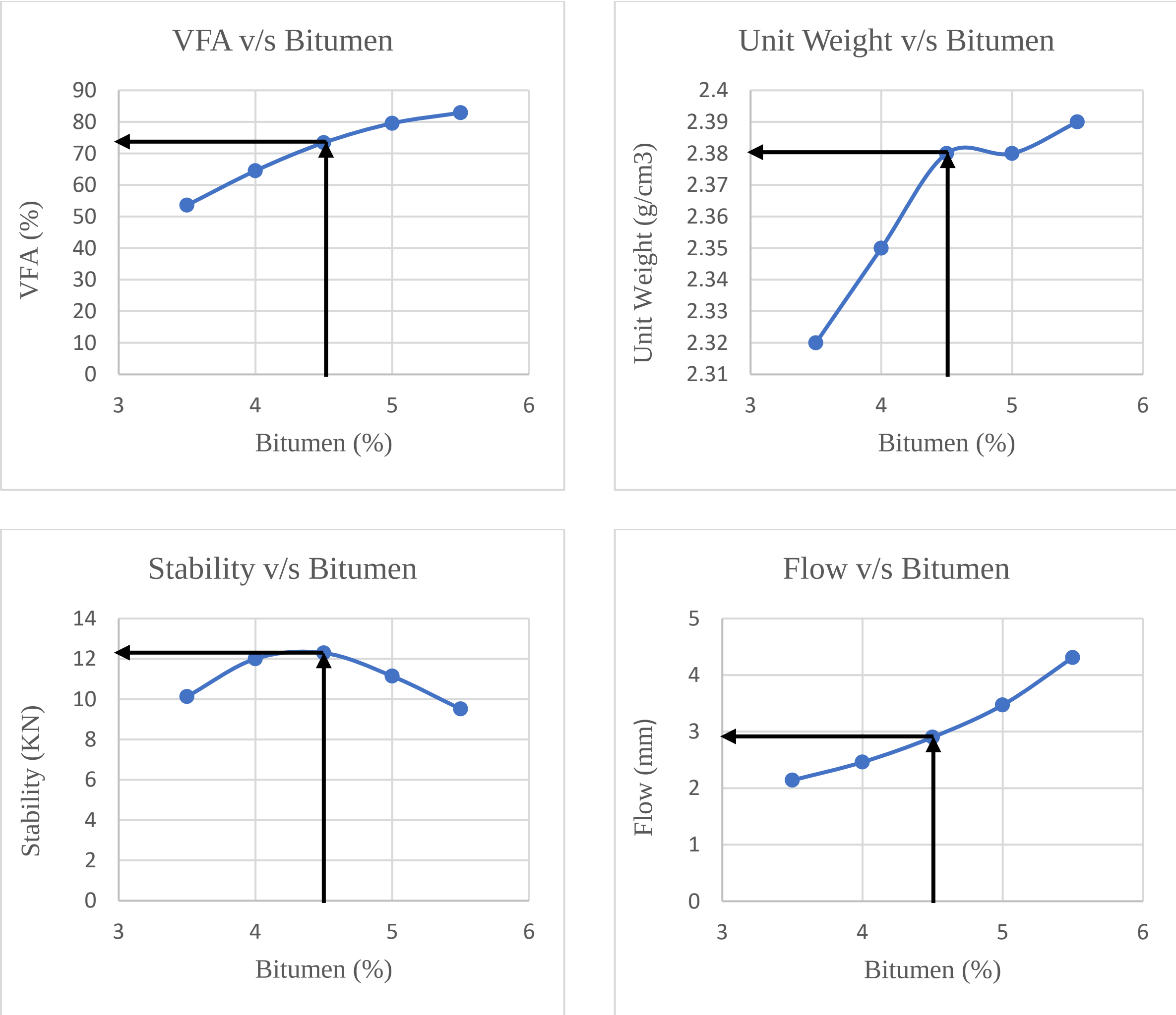


Figure 3.15 Volumetric Properties of Marshall Specimen

3.8 Sample Preparation of High-Density Polyethylene Modified Asphalt Specimens

Marshall samples were utilized to create specimens for moisture damage detection, stiffness and fatigue by Universal Testing Machine. Firstly, aggregates were pre heated up to 110°C 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 160°C. After mixing, samples were put in container and put in oven at 135°C 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. There were five varying contents of HDPE modifier that incorporated into hot mix asphalt samples by weight of bitumen and 3x replicates were produced for each percentage of HDPE i.e., 2.5%, 5.0%, 7.5% and 10.0%, which makes a total of 75 samples that 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.

Figure 3.17 Marshall Samples to be Tested

3.9 Tensile Strength Ratio to Ascertain Moisture Susceptibility

ASTM D6931 was used to conduct the moisture susceptibility test. Unconditioned samples testing was executed on three specimens per combination. Onehour before 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 conducted in compliance with ALDOT-361. The specimens were soaked and placed in a 60°C water bath for 24 hours, followed by an hour in a 25°C water bath. Both unconditioned and conditioned samples were loaded diametrically at a rate of $50 mm/min$. Tensile strength was estimated for each specimen using the specimen measurements and failure load. The average conditionedtensile strength was then determined by the average unconditioned tensile strength to get the tensile strength ratios. Typically, permissible minimum value for the TSR is between 0.7-0.8. The equation used to calculate the tensile strength of every subgroupis following:

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

Where;

S_t	Tensile Strength, KPa
P	Maximum load, N
t	Height of specimen (Before tensile test), mm
D	Diameter of samples, mm

The TSR value indicates the possibility of moisture damage. It is computedas ratio of the conditioned subset tensile strength to unconditioned subset. The equationis used to get the TSR for each combination.

$$TSR = \frac{S_2: Average\ Tensile\ Strength\ of\ Conditioned\ Samples}{S_1: Average\ Tensile\ Strength\ of\ Unconditoined\ Samples}$$

Where:

S_1	Average Tensile Strength of Unconditioned Specimen
S_2	Average Tensile Strength of Conditioned Specimen

Figure 3.18 Conditioning of Samples in Water Bath

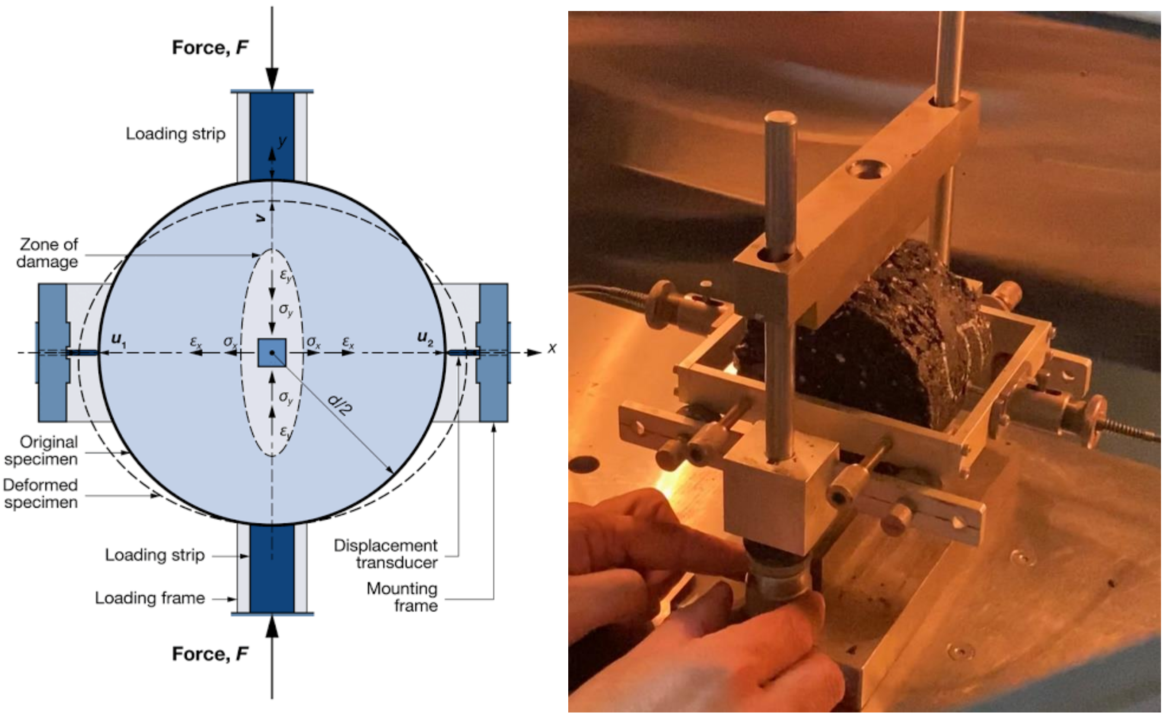


Figure 3.19 Loading Pattern Illustration and Assembly of Indirect Tensile Strength Test

3.10 Indirect Tensile Stiffness Modulus

This information may be used to determine how well a pavement structure responds to applied traffic loads. This test is performed in compliance with EN 12697- 26. It can also be utilized as a significant input for the mechanistic empirical pavement design process. The resilient modulus of a sample is defined as the relationship betweenapplied stress and recovered strain observed during cyclic loading of the sample. Asidefrom 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 asfor 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 analyzing the response of pavements to traffic stress, it is said, is the resilient modulus. Permanent deformation was proven to be more resistant to stiffer pavements. It is important to note that mixeswith a high rigidity (higher M_R) at low temperatures break more quickly than combinations with a low rigidity (lower M_R.).

(Al-Abdul-Wahhab 1991) Marshall specimens were utilized to conduct robust modulus testing on asphalt concrete mixtures that were both unaltered and changed. To execute the robust 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 the samples were put into the loading assembly at two distinct temperatures: 25°C and 40°C, depending on the application. It is necessary to estimate the resilient modulus of a cylindricalspecimen by using the repeated-load indirect tension test.

The resilience modulus of laboratory-prepared hot mix asphalt mixes is determined by the following factors:

1. Type of testing equipment utilized (Indirect Tension by UTM, Triaxial etc.)
2. Compaction Method used (Marshall vs. Superpave Gyratory Compactor)
3. Specimen geometry (Thickness and Diameter)
4. Loading Waveform (Triangular or Haversine)
5. Loading Duration
6. Test Temperature

Load pulse configuration recommended by (ASTM D4123) is in the form of $(1-cos\theta)/2$ from the contact load P to the maximum load P , with periodic load variation.

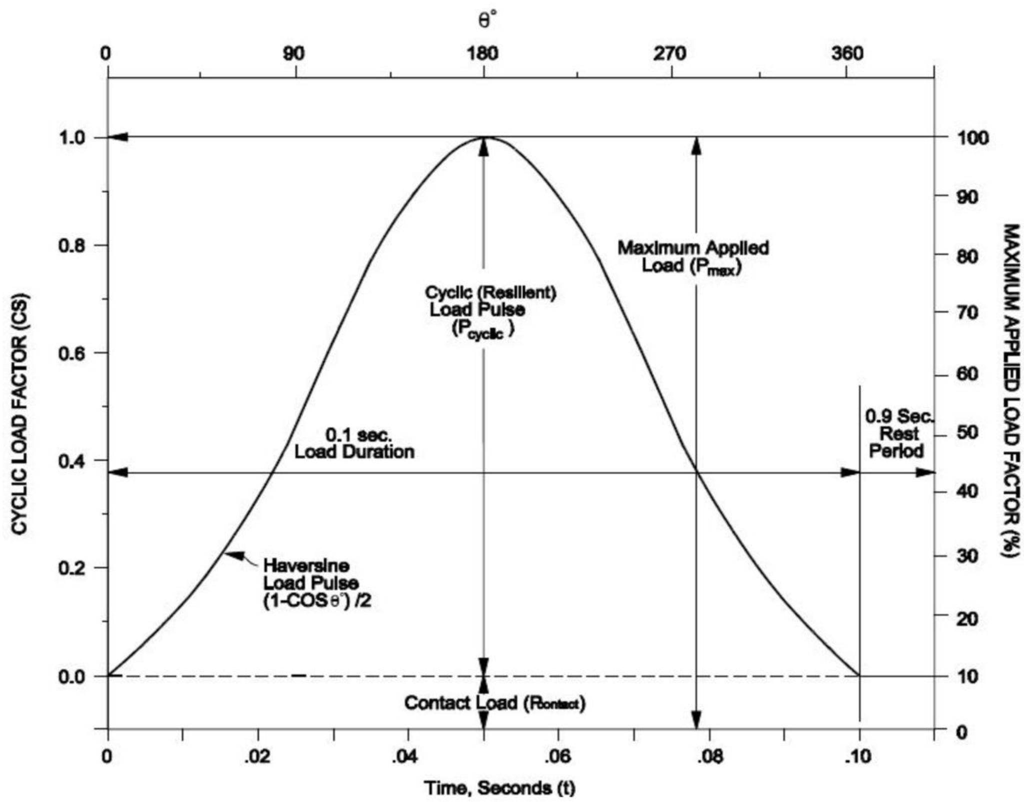


Figure 3.20 Load Pulse Representing the Haversine Loading

In the vertical diametric plane of the specimen, a haversine waveform is given vertically. 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 indirect tensile stress equal to or more than 10% - 50% of the indirect tensilestrength, depending on the material used. To precondition the specimen, it is necessaryto subject it to a minimum of 50 to 200 cycles of stress. The modulus of the test machineis determined by the software program that runs on the machine during each load stroke.Also included were results from the average test findings, which were expressed as the specimen's robust modulus at that 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.

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

Where:

M_R Resilient Modulus

P Dynamic Load

t Specimen Thickness

Δh Horizontal Recoverable Deformation

u Poisson Ratio

Table 3.7 Temperature and Poisson's Ratio for M_R

S.No:	Temperature °C	Poisson's Ratio (u)
1.	5v	0.309
2.	25q	0.358
3.	40z	0.407

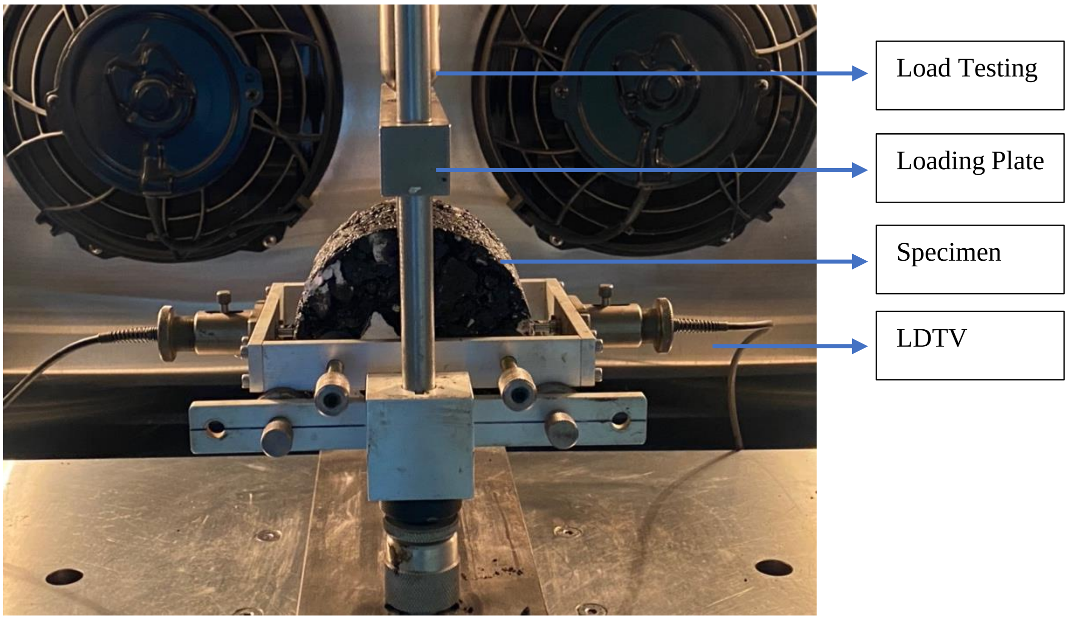


Figure 3.21 Assembly of Resilient Modulus Test

3.11 Indirect Tensile Fatigue Test (ITFT)

The ITFT is used to evaluate the fatigue life of asphaltic 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 bituminous concrete mixes, different stress levels were used to assess the difference between the two types. The stress level used in this test is 4500 Newton, 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 number of strains 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 behavior and damage accumulation, the force, phase angle, and dissipated energy per cycle per volume will change during the dynamic ITFT 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. The sample location and deformation strips that were utilized to evaluate the fatigue life are depicted in the following figure.

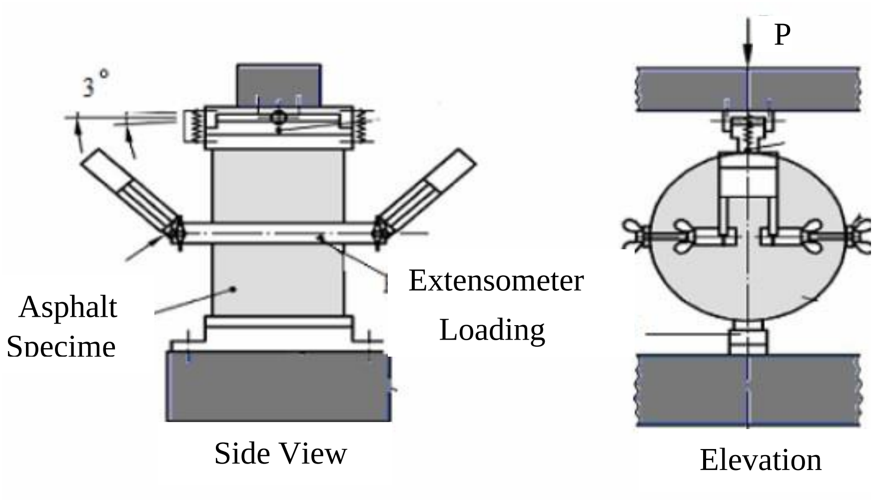


Figure 3.22 Illustration of Loading and Deformation Strips for ITFT

The interrelation among the sample failure (number of cycles to failure) and initial stress or strain can be described using the 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

3.12 Summary

This chapter discusses the laboratory testing of aggregate, binder to prepare bituminous paving mixtures in a controlled environment. To produce the bituminous mix, only those materials have been utilized that met or exceeded the required criteria.Volumetric characteristics of the bituminous mix were computed, and the overall bulkdensity (OBD) was established. The testing technique that was used for the resilient modulus, moisture susceptibility, ITFT testing of asphalt mix specimens has been described in greater detail.

Chapter 4

RESULTS AND ANALYSIS

4.1 Introduction:

This chapter describes the results and analysis for mixes of conventional and modified hot mix asphalt concrete. Aggregate from Margalla quarry and binder penetration grade 60/70 from ARL were the two main ingredients in the conventional mixes. Asphalt concrete was modified using modified mixes that contained HDPE in proportions of 2.5%, 5.0%, 7.5%, and 10.0%. Performance testing was carried out following the preparation of samples as described in the preceding chapter in accordance with standards. Three performance tests were conducted: the ITS Test to evaluate moisture resistance, the Resilient Modulus Test to measure stiffness response and the Indirect Tensile Fatigue Test to gauge fatigue resistance of both modified and unmodified asphalt concrete mixes.

4.2 Bitumen Physical Properties Result

The study made use of the physical attributes of bitumen that was obtained from ARL 60/70 penetration grade. The results of the tests show that the bitumen met the specifications. Table 4.1 provides a summary of the tests that were performed.

Table 4.1 Summary of Bitumen Consistency Test Results

Test Description	Result	Limit Range	Specification
Penetration Test @ 25^{o}C	64	60 – 70 mm	ASTM D5
Softening Point	49.2	49^{o}C – 56^{o}C	ASTM D36-06
Ductility Test	104	100 cm	ASTM D113-99
Flash Point (^{o}C)	268	Min 232^{o}C	ASTM D92
Fire Point (^{o}C)	293	Min 270^{o}C	ASTM D92

4.3 Aggregates Physical Properties Result

Margalla crush was used in the investigation. Our values fall within the acceptable range, according to the findings of standard tests on aggregates and this aggregate is suitable for usage. The results of tests performed on aggregates are summarized in Table 4.2.

Table 4.2 Laboratory Tests conducted on Aggregates

Type of Test	Result	Limit Range	Specification
Fractured Particles	98	90% (Min)	ASTM D 582
Los Angeles Abrasion	28	40% (Max)	ASTM C 131
Flakiness Index	13	15% (Max)	ASTM D 479
Elongation Index	3.69	15% (Max)	ASTM D 479
Aggregate Impact Value	19	30% (Max)	BS 812
Crushing Value	22.47	15% (Max)	BS 812
Water Absorption (Fine Aggregate)	2.25	3% (Max)	ASTM C 281
Water Absorption (Coarse Aggregate)	0.79	3% (Max)	ASTM C 127
Specific Gravity (Fine Aggregate)	2.628	-	ASTM C 128
Specific Gravity (Coarse Aggregate)	2.622	-	ASTM C 127
Clay Percentage (Fine Aggregate)	0.554	-	ASTM C 142
Clay Percentage (Coarse Aggregate)	2.771	-	ASTM C 142

4.4 Tensile Strength Ratio (TSR):

In order to evaluate moisture susceptibility and potential impacts of water penetration in asphalt mixes, the indirect tensile strength (ITS) test was carried out in accordance with the ASTM D 6931-07 standard for measuring dry and wet strength and determining tensile strength ratio (TSR). A batch of 12 Marshall samples for dry group and 12 samples separately for the wet group were prepared. Tensile strength ratio (TSR) of the wet group to the dry group was computed using the results of the indirect tensile strength test and monotonic loading was used throughout the testing on the Universal Testing Machine. Marshall specimens of a diameter 100 mm and a thickness of 62.5 mm were first treated by being submerged in a water bath for 24 hours at 60°C.

The tested combinations' conditioned and unconditioned strength values are listed in Table 4.3. The monotonic loading schematic diagram utilised for the TSR test is shown in Figure 4.1. The tensile strength of the conditioned and unconditioned samples for the HDPE-containing mix samples are shown in Fig. 4.2. Fig. 4.3 shows the Tensile Strength Ratio (wet/dry) of the mixtures with variously adjusted binders.

Table: 4.3 Summary of Tensile Strength Ratio Test

Description	Average Unconditioned Strength (S1) kN	Average Conditioned Strength (S2) kN	TSR = S2/S1 (%)
0.0 % HDPE	5.026	4.188	83.29 %
2.5 % HDPE	5.896	5.786	98.13 %
5.0 % HDPE	5.681	5.510	96.99 %
7.5 % HDPE	5.484	5.301	96.65 %
10 % HDPE	5.435	5.046	92.82 %

The findings show that the dry tensile strength rises by 17.3 percent when the binder is treated with 2.5 percent HDPE, demonstrating that HDPE is more crack resistant at 25°C than the conventional binder. Less fatigue cracking in the field might result from this increase in strength.

Results are shown in figure to show how modifiers affect moisture resistance. For mixtures adjusted by 2.5% and 5.0% HDPE, respectively, TSR increases of 17.81% and 16.44% are shown in Figure 4.3. However, it should be emphasised that compared to the base binder, HDPE significantly improved tensile strength by more than 10% for all HDPE concentrations utilised in the study. Given that the changes are greater than 10%, the TSR values for HDPE changed have improved significantly.

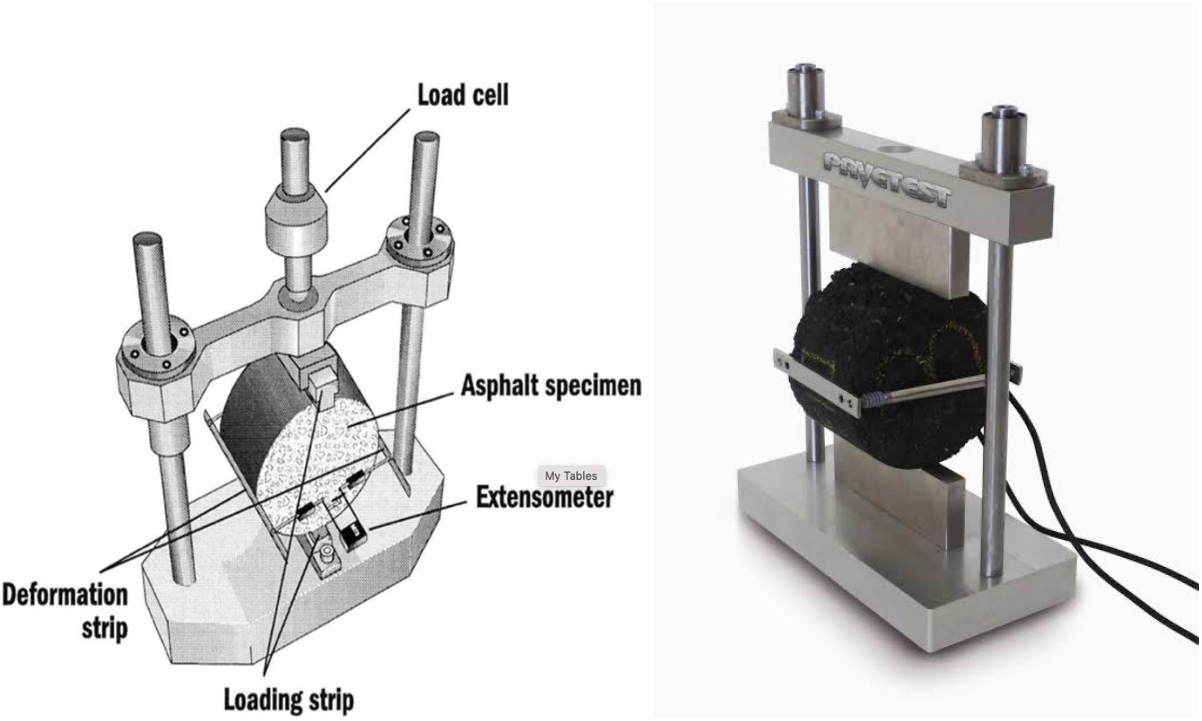
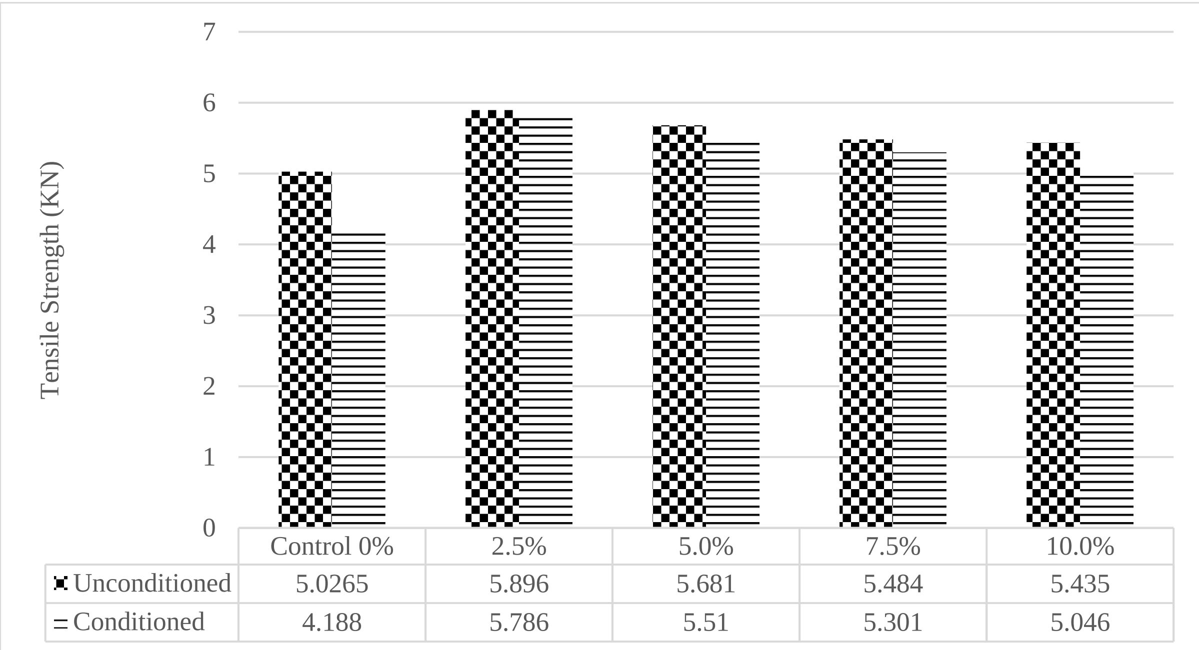


Figure: 4.1 Indirect Tensile Strength Test



	Control 0%	2.5%	5.0%	7.5%	10.0%
Unconditioned	5.0265	5.896	5.681	5.484	5.435
Conditioned	4.188	5.786	5.51	5.301	5.046

Figure: 4.2 Tensile Strength Values of Conditional / Unconditional and Control / Modified Asphalt Concrete Mixture Samples

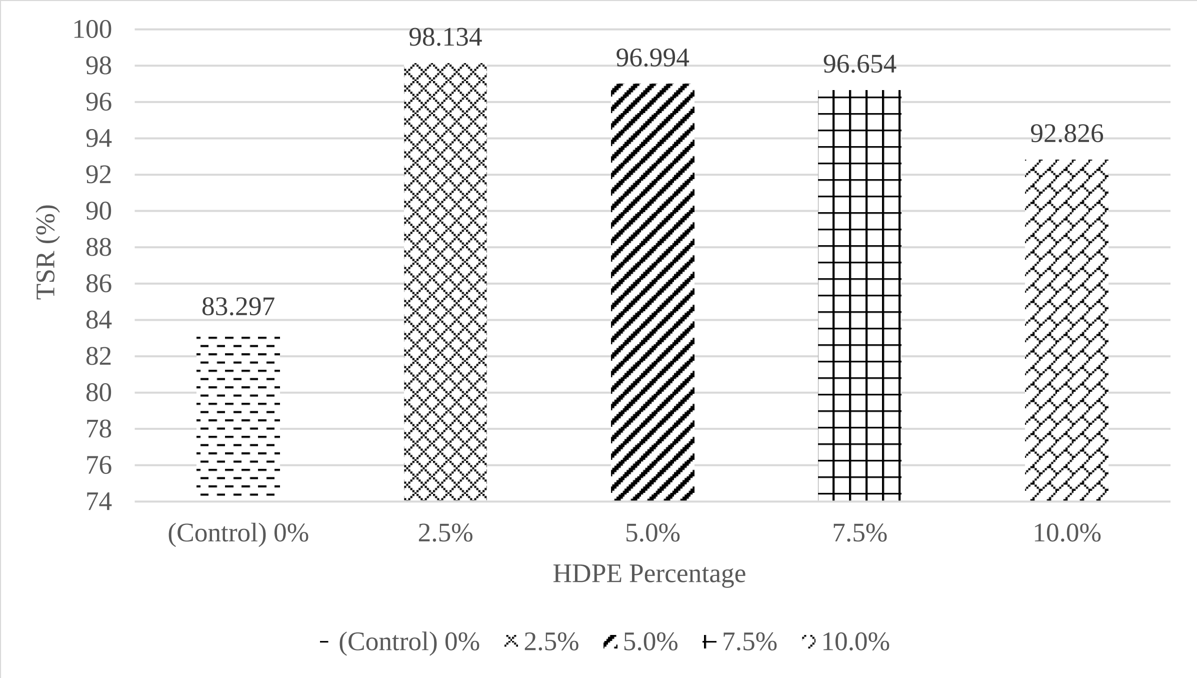


Figure: 4.3 Tensile Strength Ratio of HMA Specimens

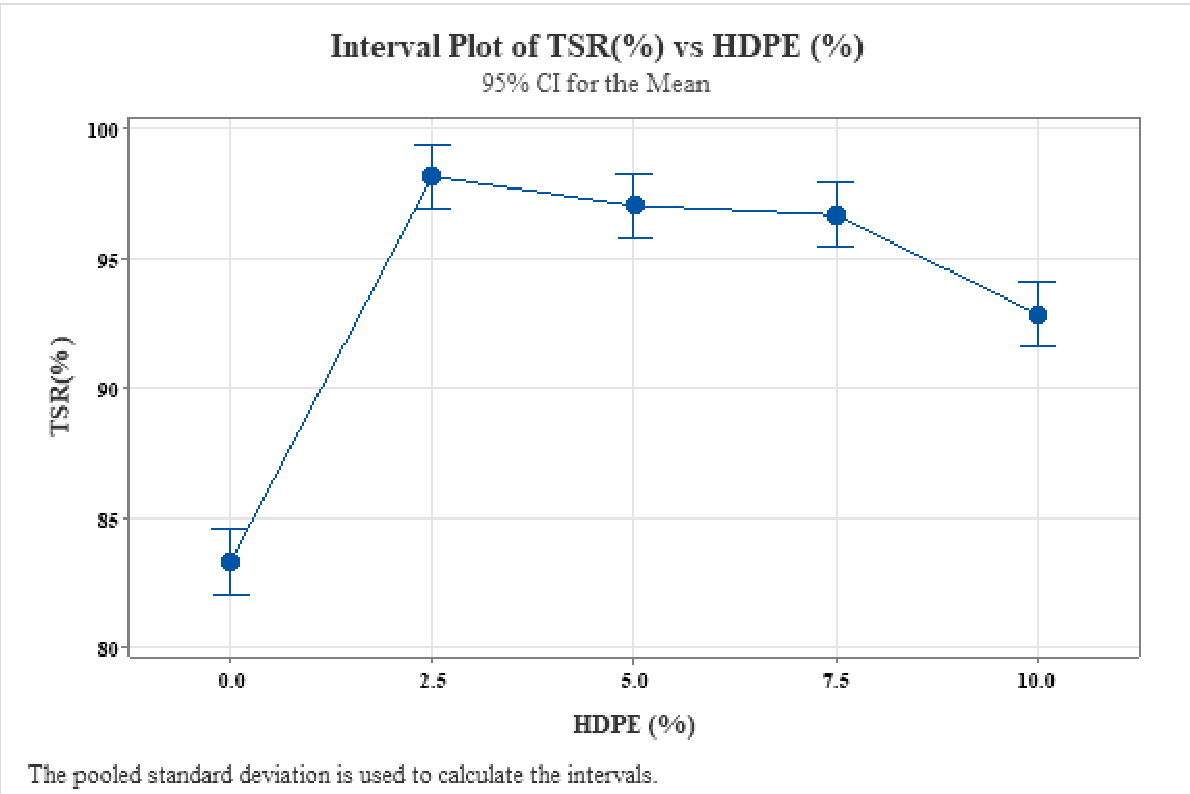


Figure 4.4 Trend Graph of Tensile Strength Ratio

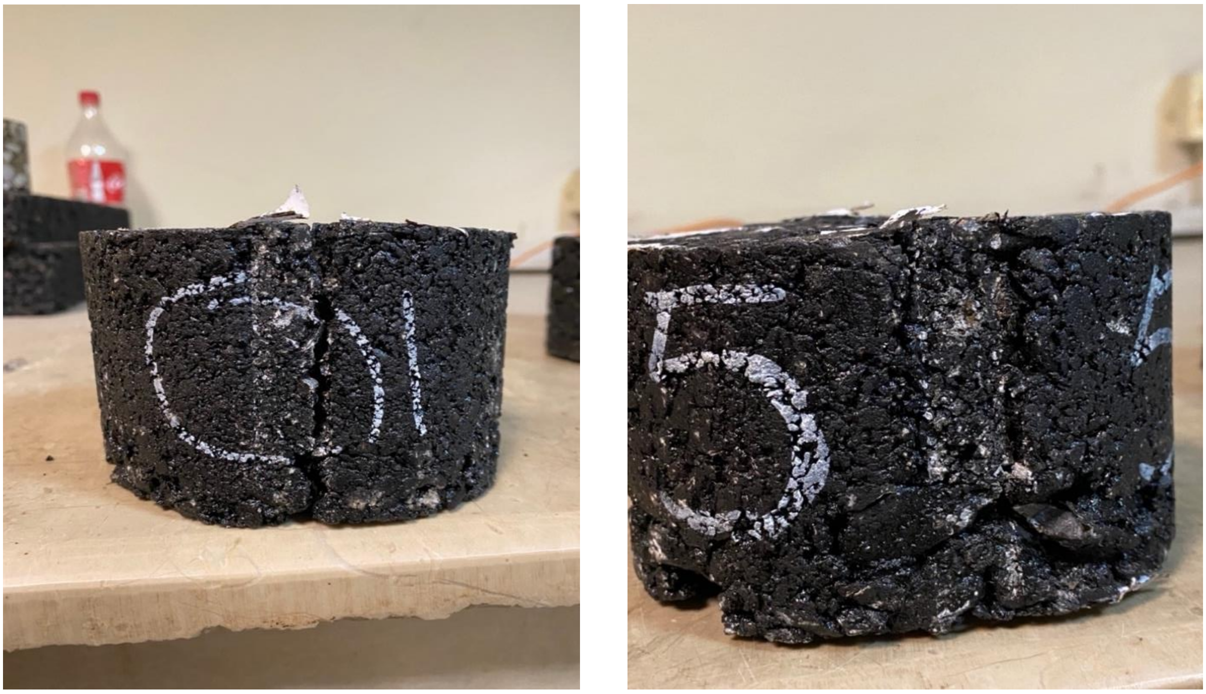


Figure 4.5 Samples After ITS Test

4.5 Resilient Modulus:

The resilient modulus could be utilised to assess the relative quality of materials and as a design or assessment parameter for pavements. The resilient modulus test may provide a better connection to fatigue life than the conventional indirect tensile strength test since it is a dynamic loading test. The resilient modulus measures the ratio of the material's recoverable axial strain to the applied peak deviator stress when it is exposed to a cyclic axle loading. The values of the resilient modulus may be used to investigate how the pavement structure responds to the application of traffic loads.

A total of 15 Marshall samples were prepared, 3 specimens for each HDPE modifier percentage (2.5%, 5.0%, 7.5%, and 10.0%), were prepared for the stiffness modulus performance test in accordance with ASTM D 4123. Using a haversine waveform and a load applied vertically in the vertical diametric plane to a cylindrical specimen with a 100 mm diameter and 62.5 mm thickness, the repeated load indirect tension test for resilient modulus is carried out. To calculate the resilient modulus, the load application and horizontal elastic deformation were taken into account. With the help of the load application and horizontal elastic deformation, the robust modulus value was estimated. The following equation is used to quantify the horizontal displacement caused by the actual load for each load pulse and to compute the resilient modulus:

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

Where:

M_R Resilient Modulus

P Cyclic Load

t Thickness of specimen

Δh Recoverable horizontal deformation

u Poisson ratio

Figure 4.5 illustrates that asphalt mix modified with 2.5 % HDPE has the highest resilient modulus of 6534 mPa among the other modified mixtures, whereas, the conventional asphalt mix revealed the minimum resilient modulus of 2835 mPa. 2.5 percent HDPE has a resilience modulus that has grown by over 130.47 percent at 25°C. The resilient modulus improved by 108.64%, 105.89%, and 94% for the respective percentages of 5%, 7.5%, and 10.0%. This leads to the understanding that even a tiny amount of modifier material causes the resilient modulus values to improve suddenly. The modified asphalt mixes' resilient modulus values were consistently higher than those of the base asphalt mix. As the modifier concentration rises, asphalt mixes' elastic properties get better. The higher viscosity of the mixture, which produces the polymer qualities that contribute to increased resilience capabilities, may be the source of the improvement in resilient modulus. According to these results, using modified asphalt concrete produced stiffer asphalt mixtures with the highest possible load-bearing capacity.

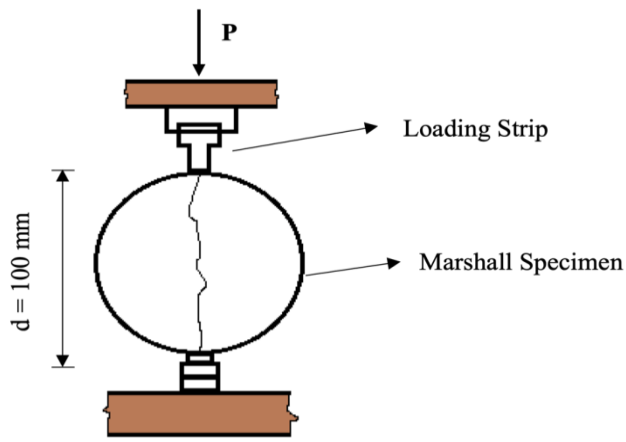


Figure: 4.6 Schematic Diagram for Resilient Modulus Testing

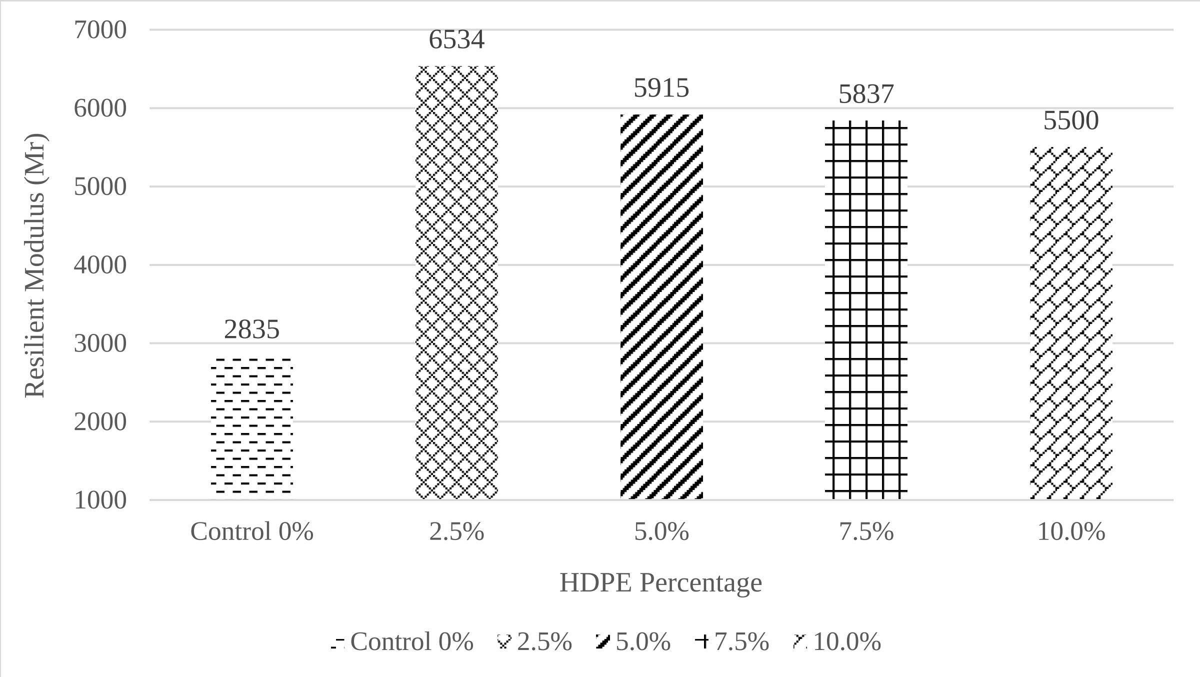


Figure: 4.7 Resilient Modulus Values

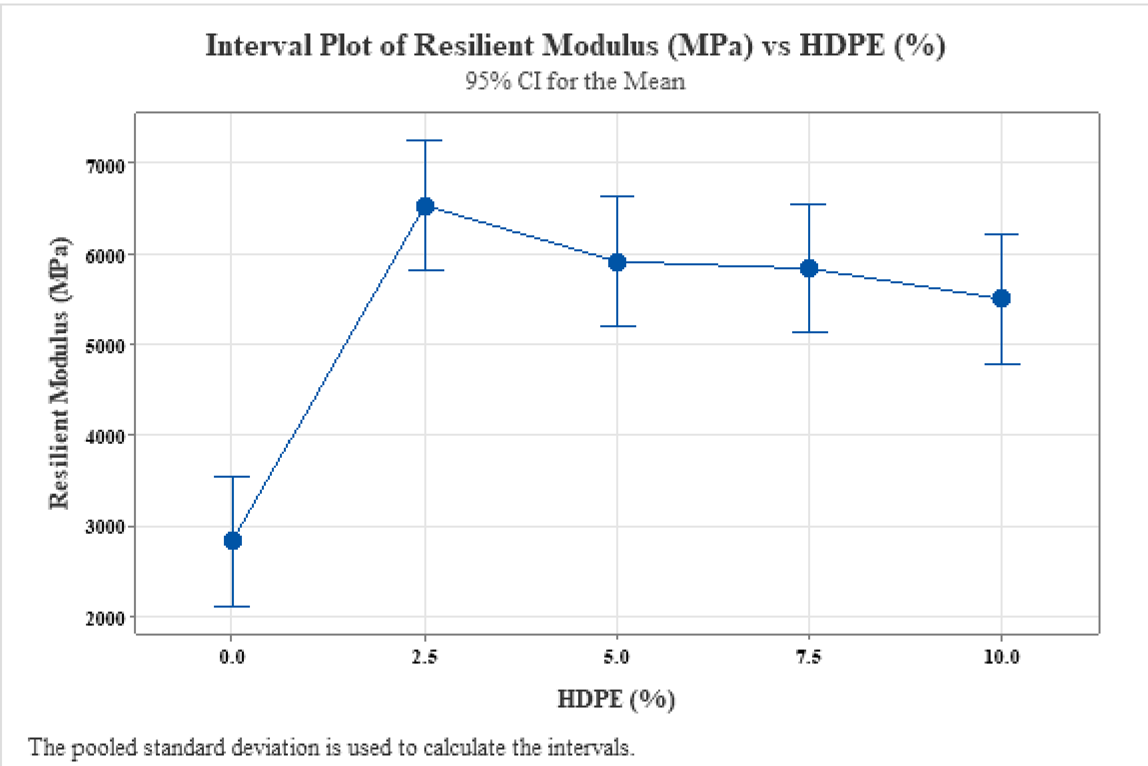


Figure 4.8 Trend Graph of Resilient Modulus Test

Figure 4.9 Samples After Resilient Modulus Test

4.6 Indirect Tensile Fatigue Test:

According to the EN 12697-24:2012 standards, ITFT tests on Marshall samples of asphalt mixtures were performed to ascertain the fatigue behaviour and moisture-induced damage potential. The vertical loading causes horizontal tensile stress and vertical compressive stress to be applied to the specimen diameter. At the centre of the specimen, there is the most tension produced.

For each material, a correlation between tensile strain and the number of cycles till failure was found. A linear relationship was seen when strain was plotted on a logarithmic scale versus the number of cycles till failure; as a result, fatigue life prediction equations were developed.

The maximum tensile strain and stress at the specimen's centre may be calculated using the equation below.

$$\sigma_o = \frac{2P}{\pi \times t \times D}$$

$$\varepsilon_o = \left[\left(\frac{2\Delta H}{D}\right) \times \left(\frac{1 + 3\vartheta}{4 + \pi \times \vartheta - \pi}\right)\right]$$

Where:

σ_o Tensile stress at the centre of the specimen

ε_o Tensile strain at the centre of the specimen

P Maximum load

t Specimen height

D Specimen diameter

ΔH Horizontal deformation

According to the test matrix in chapter 3, three replicate samples were examined for each of the five different percentages of HDPE modifier used in the research's performance test of indirect tensile fatigue. All specimens were tested under the same environmental conditions, a temperature of 25 °C and a loading frequency of 2 Hz creating 15 distinct HMA combinations. Horizontal tensile stress was produced as a result of stress-regulated loading. The fatigue tests in this study were carried out under the following circumstances:

Load Applied = 4500 N

Loading Period = 0.1 seconds

Rest Period = 0.4 seconds

Test Temperature = 25°C

The samples were dry-conditioned in the UTM for an hour at a temperature of 25°C prior to testing. The findings reveal that the mixtures prepared with 2.5% HDPE performed best among all mixes followed by 5% HDPE.

The number of cycles that the specimens could withstand is shown in Figure 4.8. The conventional mixture's fatigue life was 458 cycles, but the 2.5% HDPE-modified mixture's fatigue life was 3401 cycles. Comparing HMA samples modified with 2.5% HDPE to standard specimens, the ability of the reinforced asphalt mixture to withstand more passes was increased by 642%. (458 and 3401 cycles for modified and control mixes, respectively). Even the HMA sample modified with 10% HDPE exhibited the least increase in fatigue life compared to the other modified samples, outperforming the traditional mixes. Furthermore, it can be seen that the dynamic stability rose as the HDPE content increased due to the asphalt binder's polymer modification, which enhances their stiffness.

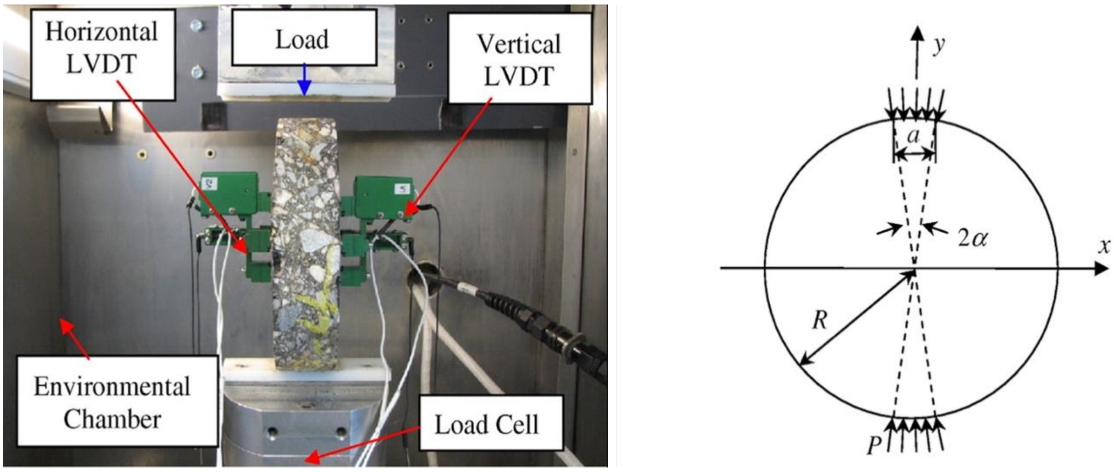


Figure: 4.10 Schematic Diagram & Loading Model Indirect Tensile Fatigue Test

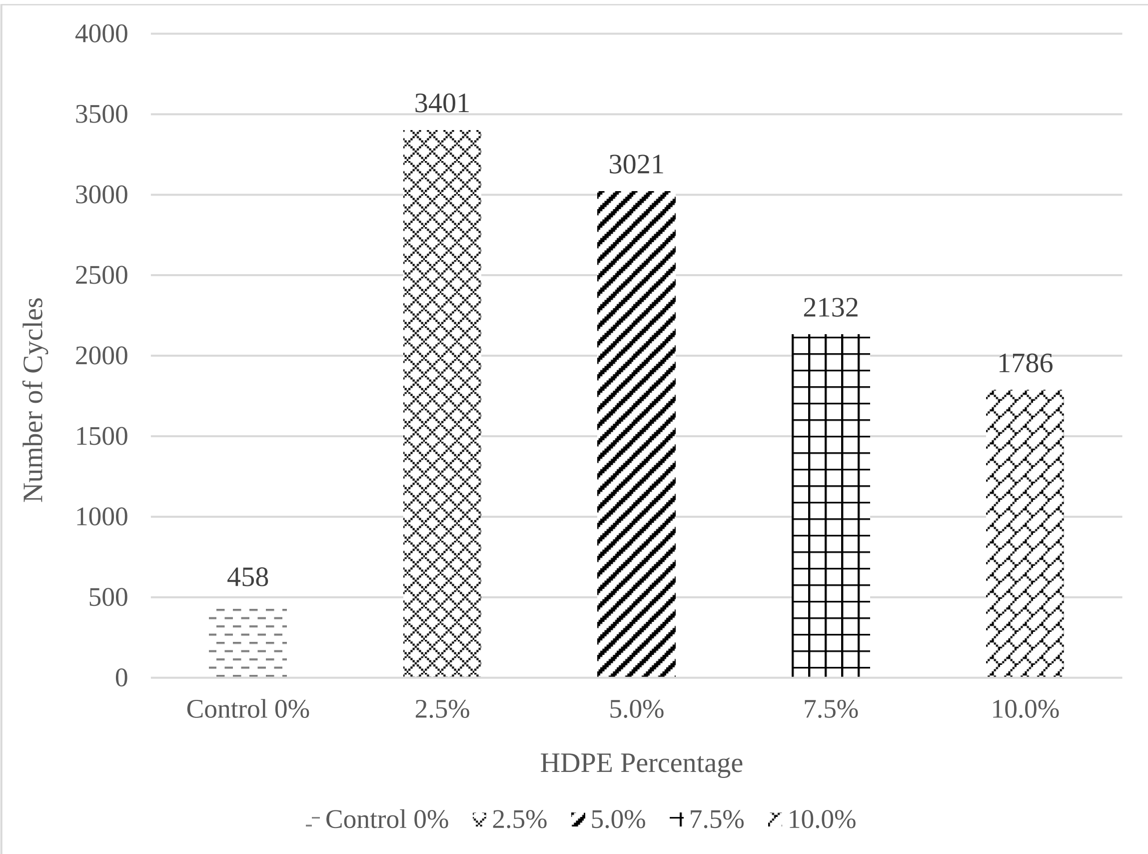


Figure 4.11 Indirect Tensile Fatigue Test Result

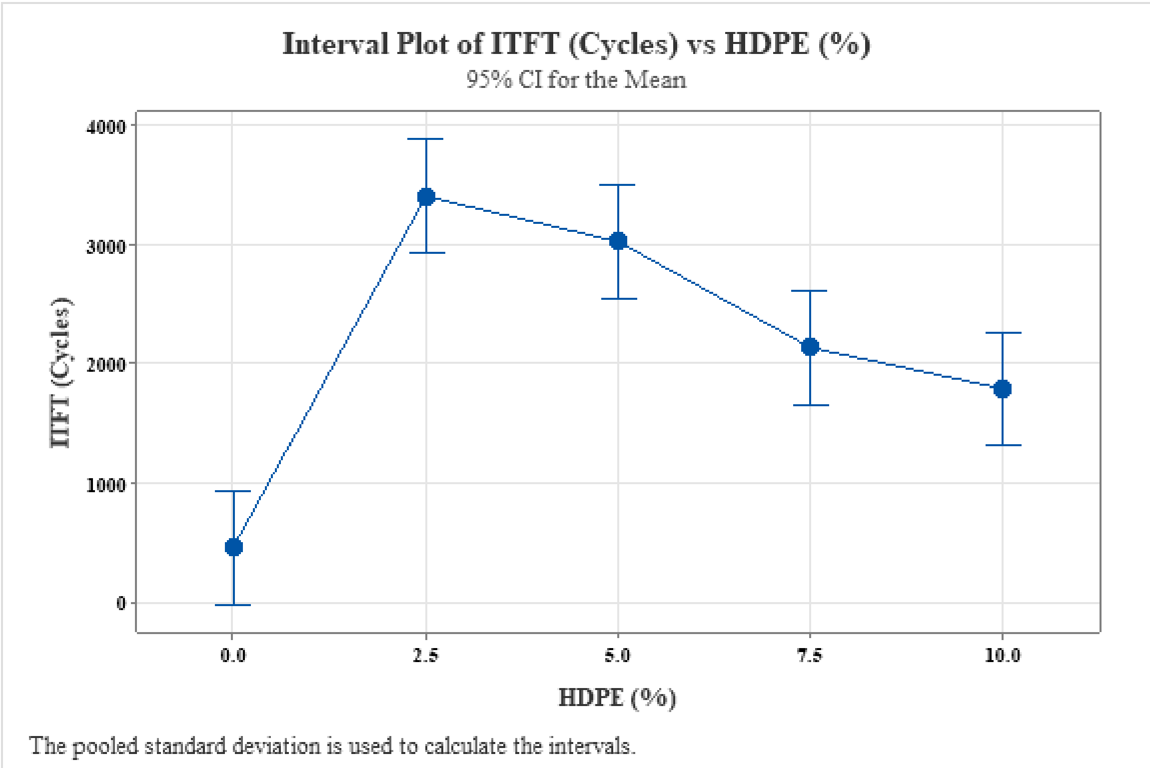


Figure 4.12 Trend Graph of Indirect Tensile Fatigue Test

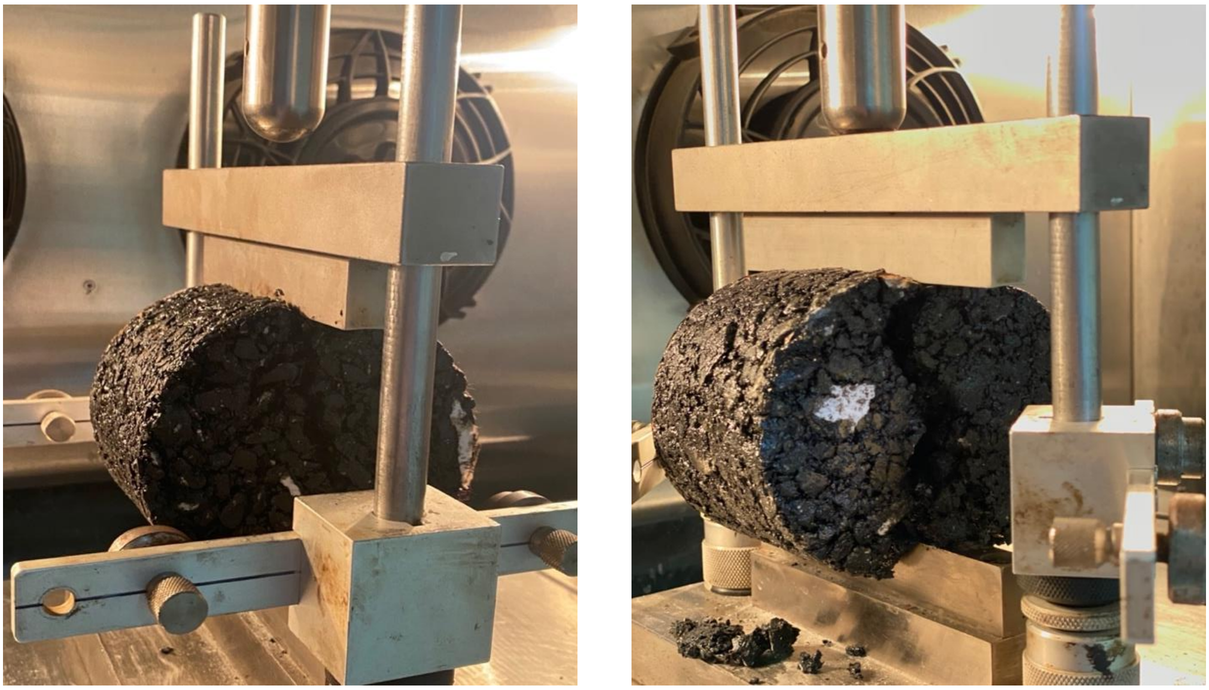


Figure 4.13 Samples After Indirect Tensile Fatigue Test

4.7 Analysis of Variance:

A one-way analysis of variance was performed to assess the test findings and establish the significance of the contributing factors. Additionally, the data were subjected to a pairwise Tukey analysis and correlation analysis. It also establishes the significance of the correlations between the variables and the responses, may be used to compare the means of the various groups. Each group is assigned a letter and each group is linked to a data mean. The findings are shown in the table along with the degree of freedom, P-value, and F-value. A factor must have a P-value that is less than 0.05, or 95 percent confidence level, in order to be deemed significant. The F-value must also be more than 10. Tukey is the most common method for comparing between groups.

4.7.1 Analysis of Variance for Tensile Strength Ratio (TSR):

The table 4.4 is the descriptive table shows all the basic qualities of the data that has been put for the analysis purpose to get the significant results of the study. It includes the mean, standard deviation, 95% of confidence interval for mean and component variance for each percentage of modifier with the N of 3. The highest mean in this table is belong to 2.50% with the mean 98.0% whereas, the lowest mean belongs to the control specimens with 83.33% mean. The table 4.5 shows the degree of freedom and the significance between the dependent variables. The df1 is 4 and df2 is 10 with the significant value of .089 this value is > than 0.05 so we can say that the data is homogeny.

Table 4.4 Descriptive Data Set of Tensile Strength Ratio Test

Source	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Between-Component Variance
					Lower Bound	Upper Bound			
HDPE 0.00%	3	83.33	.577	.333	81.90	84.77	83	84	
HDPE 2.50%	3	98.00	.000	.000	98.00	98.00	98	98	
HDPE 5.00%	3	97.00	1.000	.577	94.52	99.48	96	98	
HDPE 7.50%	3	96.67	1.155	.667	93.80	99.54	96	98	
HDPE 10.00%	3	92.67	1.528	.882	88.87	96.46	91	94	
Total	15	93.53	5.668	1.46	90.39	96.67	83	98	

Model	Fixed Effects			1.000	.258	92.96	94.11			
	Rando m Effects				2.70	86.02	101.05			36.311

Table 4.5 Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
2.741	4	10	.089

Table 4.6 demonstrates the HDPE modifier is significant for the Tensile Strength Ratio test as a response factor as the P-value is less than 0.05 and the F-value is more than 10. Therefore, we could reject the null hypothesis and conclude that some of the means are likely to change with the variation in independent variable which is modifier percentage in this case. For further evaluation we can also do post hoc test to get the clear idea of the analysis.

Table 4.6 Analysis of Variance for Tensile Strength Ratio Values

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	439.733	4	109.933	109.933	.000
Within Groups	10.000	10	1.000		
Total	449.733	14			

Tukey test tells the significance of means with its variables. The results of the Tukey simultaneous test for any conceivable level difference are displayed in the Table 4.7. As can be seen, results of modified samples are insignificant, and the P-value for the difference in significance level is greater than 0.05. This shows that the findings are all insignificant and that most groups are significant for TSR. Most of the significant values are appeared in 0.0% and 10.0% modifier groups because the mean of control samples is quite lower than the samples with optimum modifier content which is 2.5% and this considerable difference reflected in the analysis.

Table 4.7 Tukey Simultaneous Tests for Differences of Means

Factor – I (Modifier Percentage)	Factor – J (Modifier Percentage)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.00%	2.50%	-14.667*	.816	.000	-17.35	-11.98
	5.00%	-13.667*	.816	.000	-16.35	-10.98
	7.50%	-13.333*	.816	.000	-16.02	-10.65
	10.00%	-9.333*	.816	.000	-12.02	-6.65
2.50%	0.00%	14.667*	.816	.000	11.98	17.35
	5.00%	1.000	.816	.738	-1.69	3.69
	7.50%	1.333	.816	.511	-1.35	4.02
	10.00%	5.333*	.816	.000	2.65	8.02
5.00%	0.00%	13.667*	.816	.000	10.98	16.35
	2.50%	-1.000	.816	.738	-3.69	1.69
	7.50%	.333	.816	.993	-2.35	3.02
	10.00%	4.333*	.816	.002	1.65	7.02
7.50%	0.00%	13.333*	.816	.000	10.65	16.02
	2.50%	-1.333	.816	.511	-4.02	1.35
	5.00%	-.333	.816	.993	-3.02	2.35
	10.00%	4.000*	.816	.004	1.31	6.69
10.00%	0.00%	9.333*	.816	.000	6.65	12.02
	2.50%	-5.333*	.816	.000	-8.02	-2.65
	5.00%	-4.333*	.816	.002	-7.02	-1.65
	7.50%	-4.000*	.816	.004	-6.69	-1.31

*. The mean difference is significant at the 0.05 level.

Table 4.8 shows the means and the grouping or sub-sets, which is done by assigning different letters to each group. The homogeneous groups shows that which group have a same mean and which one have different mean so, the group which doesn't share any letter is significantly different and vice versa. It is noticed that only 0.0% HDPE is significantly different because the mean value of first group is 2825.00 while next group value is 5500.00 which clearly indicates the substantial difference. While in contrast, it is eminent in the table that all other samples modified with 2.5%, 5.0%, 7.5% and 10% share the mean in a single group, so it explains that their values are close to next higher or/and lower percentage samples. This test also satisfies the assumptions of ANOVA test.

Table 4.8 Grouping using Tuckey's Analysis and 95% CI

Modifier Percentage (Independent Variable)	N	Grouping for alpha = 0.05		
		A	B	C
0.00%	3	83.33		
10.00%	3		92.67	
7.50%	3			96.67
5.00%	3			97.00
2.50%	3			98.00
Sig.		1.000	1.000	.511
Means for groups in homogeneous subsets are displayed.				

Figure 4.14 presents the distribution of means with respect to a reference zero line. This line implies that there is no significant difference between the groups in any mean that contains zero. The confidence interval for the difference between the means of all control specimens containing 0.0% modifier and 2.5%, 5.0%, 7.5% and 10.0% modified specimens does not include zero, which indicates that the difference is statistically significant. The CI for the subsequent pairs of means all include zero, which indicates that the differences are not statistically significant, whereas, again the 10% samples are significant because their values doesn't coincide the zero line.

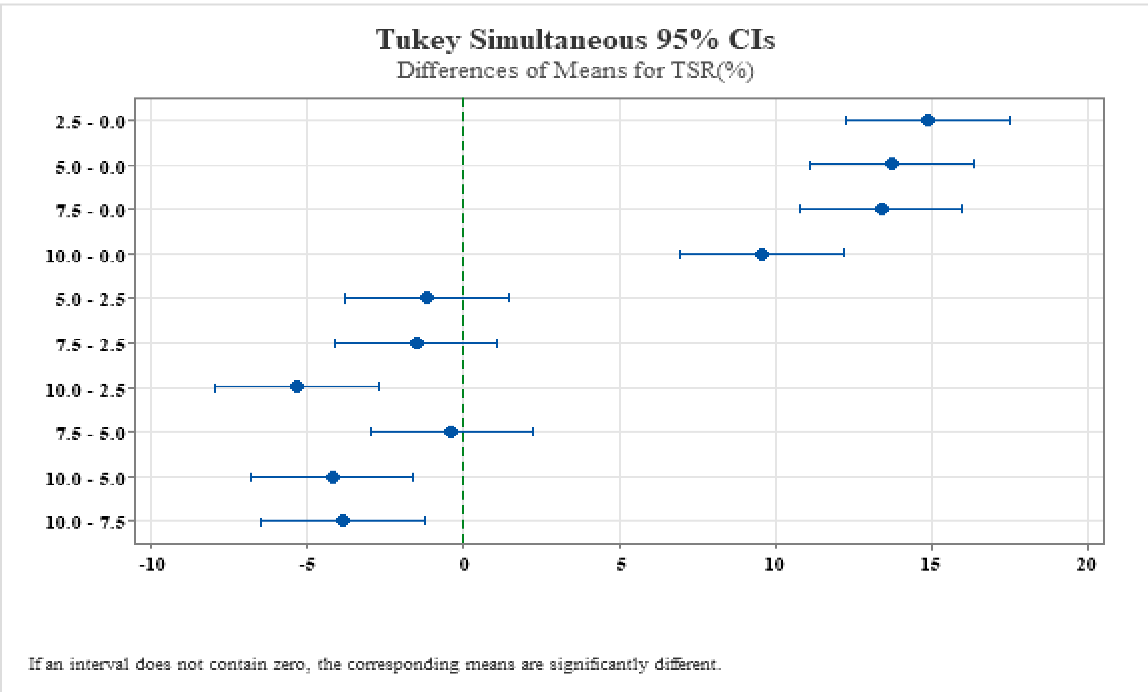


Figure 4.14 Distribution of Means for Tensile Strength Ratio Values

Pearson correlation measure the strength and direction of linear relationship between two variables as shown in the Table 4.20. This coefficient correlation is +1 and -1 this is the defined range of the correlation, wherein -1 shows the perfect negative correlation and on the contrary +1 shows the perfect positive correlation and 0 value shows no correlation at all. All variables have or they carry value of one with them. It also indicates that how two variables are strongly correlated with each other or the degree of association between the variables. Sig 2-tailed shows the p value that is associated with the correlation. The upper numerical description shows how tightly the imaginary line points are lying. On the other hand, the table also shows that if the correlation is high the points will tend to be closer to the line and if the correlation is low then it would be far away from the line. N shows the number of the data because in this table there is no missing data, so the N are same in both cases. If the data has missing values so N would be different, and the correlation will also be different from the other sets. The correlation also tells that the variables are changing in the same direction or in the opposite direction. There are absolute values in the correlation that analyze the magnitude of the correlation.

Table 4.9 Correlation Analysis of the Tensile Strength Ratio Values

Source		**Percentage (Independent Variable)**	**TSR (Dependent Variable)**
Percentage (Independent Variable)	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	15	
TSR (Dependent Variable)	Pearson Correlation	.448	1
	Sig. (2-tailed)	.094	
	N	15	15

4.7.2 Analysis of Resilient Modulus Test:

The table 4.10 is the descriptive table shows all the basic qualities of the data that has been put for the analysis purpose to get the significant results of the study. It includes the mean, standard deviation, 95% of confidence interval for mean and component variance for each percentage of modifier with the N of 3. The highest mean in this table is belong to 2.50% with the mean 6534.00 whereas, the lowest mean belongs to the control specimens with 2825.0 mean.

Table 4.10 Descriptive Data Set of Resilient Modulus Test

Factor	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0.00%	3	2825.00	733.540	423.510	1002.79	4647.21	2184	3625
2.50%	3	6534.00	513.138	296.261	5259.29	7808.71	6160	7119
5.00%	3	5915.00	416.328	240.367	4880.78	6949.22	5467	6290
7.50%	3	5837.00	449.848	259.720	4719.52	6954.48	5416	6311
10.00%	3	5500.00	597.390	344.903	4016.00	6984.00	4850	6025
Total	15	5322.20	1417.378	365.965	4537.28	6107.12	2184	7119

Table 4.11 demonstrates the HDPE modifier is significant for the Resilient Modulus test as a response factor as the P-value is less than 0.05 and the F-value is more than 10. Therefore, we could reject the null hypothesis and conclude that some of the means are likely to change with the variation in independent variable which is modifier percentage in this case. For further evaluation we can also do post hoc test to get the clear idea of the analysis.

Table 4.11 Analysis of Variance for Resilient Modulus Test (M_R) Values

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	25057532.400	4	6264383.100	20.419	.000
Within Groups	3067918.000	10	306791.800		
Total	28125450.400	14			

Tukey test tells the significance of means with its variables. The results of the Tukey simultaneous test for any conceivable level difference are displayed in the Table 4.12. As can be seen, results of modified samples are insignificant, and the P-value for the difference in significance level is greater than 0.05. This shows that the findings are all insignificant and that most groups are significant for M_R. 0.0% HDPE shows the significance value because the mean of control samples is quite lower than the modified samples and this considerable difference reflected in the analysis.

Table 4.12 Tukey Simultaneous Tests for Differences of Means

Factor – I (Modifier Percentage)	Factor – J (Modifier Percentage)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.00%	2.50%	-3709.00*	452.248	.000	-5197.38	-2220.62
	5.00%	-3090.00*	452.248	.000	-4578.38	-1601.62
	7.50%	-3012.00*	452.248	.000	-4500.38	-1523.62
	10.00%	-2675.00*	452.248	.001	-4163.38	-1186.62
2.50%	0.00%	3709.00*	452.248	.000	2220.62	5197.38
	5.00%	619.00	452.248	.659	-869.38	2107.38
	7.50%	697.00	452.248	.561	-791.38	2185.38
	10.00%	1034.00	452.248	.226	-454.38	2522.38
5.00%	0.00%	3090.00*	452.248	.000	1601.62	4578.38
	2.50%	-619.00	452.248	.659	-2107.38	869.38
	7.50%	78.00	452.248	1.000	-1410.38	1566.38
	10.00%	415.00	452.248	.884	-1073.38	1903.38
7.50%	0.00%	3012.00*	452.248	.000	1523.62	4500.38
	2.50%	-697.00	452.248	.561	-2185.38	791.38
	5.00%	-78.00	452.248	1.000	-1566.38	1410.38
	10.00%	337.00	452.248	.941	-1151.38	1825.38
10.00%	0.00%	2675.00*	452.248	.001	1186.62	4163.38
	2.50%	-1034.00	452.248	.226	-2522.38	454.38
	5.00%	-415.00	452.248	.884	-1903.38	1073.38
	7.50%	-337.00	452.248	.941	-1825.38	1151.38
Based on observed means. The error term is Mean Square (Error) = 306791.800.						
*. The mean difference is significant at the .05 level.						

Table 4.13 shows the means and the grouping or sub-sets, which is done by assigning different letters to each group. The homogeneous groups shows that which group have a same mean and which one have different mean so, the group which doesn't share any letter is significantly different and vice versa. It is noticed that only 0.0% HDPE is significantly different because the mean value of first group is 2825.00 while next group value is 5500.00 which clearly indicates the substantial difference. While in contrast, it is eminent in the table that all other samples modified with 2.5%, 5.0%, 7.5% and 10% share the mean in a single group, so it explains that their values are close to next higher or/and lower percentage samples. This test also satisfies the assumptions of ANOVA test.

Table 4.13 Grouping using Tuckey's Analysis and 95% CI

Factor (Independent Variable)	N	Grouping	
		A	B
0.00%	3	2825.00	
10.00%	3		5500.00
7.50%	3		5837.00
5.00%	3		5915.00
2.50%	3		6534.00
Sig.		1.000	.226

a. Uses Harmonic Mean Sample Size = 3.000.

b. Alpha = .05.

Figure 4.15 presents the distribution of means with respect to a reference zero line. This line implies that there is no significant difference between the groups in any mean that contains zero. The confidence interval for the difference between the means of all control specimens containing 0.0% modifier and 2.5%, 5.0%, 7.5% and 10.0% modified specimens does not include zero, which indicates that the difference is statistically significant. The CI for the subsequent pairs of means all include zero, which indicates that the differences are not statistically significant.

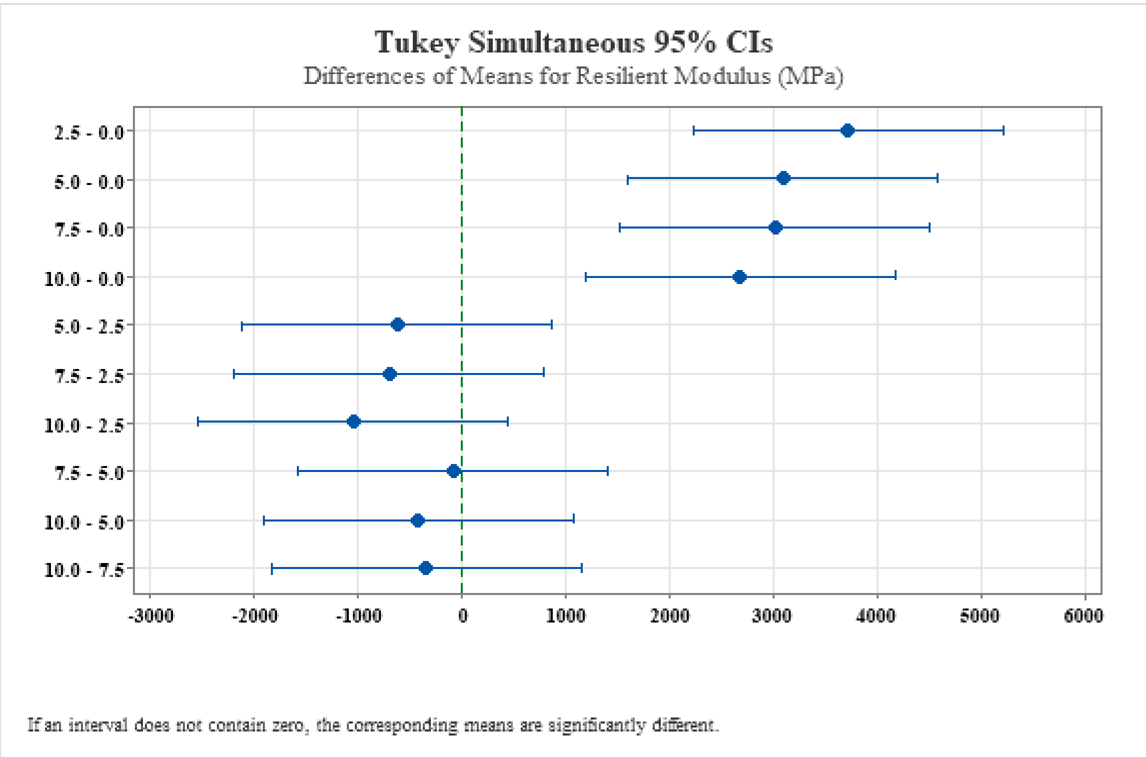


Figure 4.15 Distribution of means for Resilient Modulus Values

Pearson correlation measure the strength and direction of linear relationship between two variables as shown in the Table 4.14. This coefficient correlation is +1 and -1 this is the defined range of the correlation, wherein -1 shows the perfect negative correlation and on the contrary +1 shows the perfect positive correlation and 0 value shows no correlation at all. All variables have or they carry value of one with them. It also indicates that how two variables are strongly correlated with each other or the degree of association between the variables. Sig 2-tailed shows the p value that is associated with the correlation. The upper numerical description shows how tightly the imaginary line points are lying. On the other hand, the table also shows that if the correlation is high the points will tend to be closer to the line and if the correlation is low then it would be far away from the line. N shows the number of the data because in this table there is no missing data, so the N are same in both cases. If the data has missing values so N would be different and the correlation will also be different from the other sets. The correlation also tells that the variables are changing in the same direction or in the opposite direction. There are absolute values in the correlation that analyze the magnitude of the correlation.

Table 4.14 Correlations Analysis of Resilient Modulus

Source		**Percentage (Independent Variable)**	**Result (Dependent Variable)**
Percentage (Independent Variable)	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	15	
Result (Dependent Variable)	Pearson Correlation	.481	1
	Sig. (2-tailed)	.070	
	N	15	15

4.7.3 Analysis of Indirect Tensile Fatigue Test:

The table 4.15 is the descriptive table shows all the basic qualities of the data that has been put for the analysis purpose to get the significant results of the study. It includes the mean, standard deviation, 95% of confidence interval for mean and component variance for each percentage of modifier with the N of 3. The highest mean in this table is belong to 2.50% with the mean 3401.00 whereas, the lowest mean belongs to the control specimens with 458.0 mean. Levene test is displayed in Table 4.16 which shows the degree of freedom and the significance between the dependent variables. The df1 is 4 and df2 is 10 with the significant value of .170 this value is > than 0.05 so we can say that the data is homogeny.

Table 4.15 Descriptive Data Set of ITFT

Factor		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum	Between Component Variance
						Lower Bound	Upper Bound			
0.00%		3	458.0	117.205	67.66	166.85	749.15	337	571	
2.50%		3	3401.0	166.433	96.09	2987.56	3814.44	3211	3521	
5.00%		3	3021.0	696.348	402.03	1291.18	4750.82	2301	3691	
7.50%		3	2132.0	304.685	175.91	1375.12	2888.88	1844	2451	
10.00%		3	1786.0	251.346	145.11	1161.62	2410.38	1596	2071	
Total		15	2159.6	1112.311	287.19	1543.62	2775.58	337	3691	
Model	Fixed Effects			369.417	95.383	1947.07	2372.13			
	Random Effects				515.69	727.80	3591.40			1284226.633

Table 4.16 Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
2.003	4	10	.170

Table 4.17 demonstrates the HDPE modifier is significant for the ITFT as a response factor as the P-value is less than 0.05 and the F-value is more than 10. Therefore, we could reject the null hypothesis and conclude that some of the means are likely to change with the variation in independent variable which is modifier percentage in this case. For further evaluation we can also do post hoc test to get the clear idea of the analysis.

Table 4.17 Analysis of Variance for ITFT Values

Source	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15956595.600	4	3989148.900	29.231	.000
Within Groups	1364690.000	10	136469.000		
Total	17321285.600	14			

Tukey test tells the significance of means with its variables. The results of the Tukey simultaneous test for any conceivable level difference are displayed in the Table 4.12. As can be seen, results of modified samples are insignificant, and the P-value for the difference in significance level is greater than 0.05. This shows that the findings are all insignificant and that most groups are significant for ITFT. Most of the significant values are appeared in 0.0% and 10.0% modifier groups because the mean of control samples is quite lower than the samples with optimum modifier content which is 2.5% and this considerable difference reflected in the analysis.

Table 4.18 Tukey Simultaneous Tests for Differences of Means

Factor – I (Modifier Percentage)	Factor – J (Modifier Percentage)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0.00%	2.50%	-2943.000*	301.628	.000	-3935.68	-1950.32
	5.00%	-2563.000*	301.628	.000	-3555.68	-1570.32
	7.50%	-1674.000*	301.628	.002	-2666.68	-681.32
	10.00%	-1328.000*	301.628	.009	-2320.68	-335.32
2.50%	0.00%	2943.000*	301.628	.000	1950.32	3935.68
	5.00%	380.000	301.628	.719	-612.68	1372.68
	7.50%	1269.000*	301.628	.012	276.32	2261.68
	10.00%	1615.000*	301.628	.002	622.32	2607.68
5.00%	0.00%	2563.000*	301.628	.000	1570.32	3555.68
	2.50%	-380.000	301.628	.719	-1372.68	612.68
	7.50%	889.000	301.628	.085	-103.68	1881.68
	10.00%	1235.000*	301.628	.014	242.32	2227.68
7.50%	0.00%	1674.000*	301.628	.002	681.32	2666.68

	2.50%	-1269.000*	301.628	.012	-2261.68	-276.32
	5.00%	-889.000	301.628	.085	-1881.68	103.68
	10.00%	346.000	301.628	.779	-646.68	1338.68
10.00%	0.00%	1328.000*	301.628	.009	335.32	2320.68
	2.50%	-1615.000*	301.628	.002	-2607.68	-622.32
	5.00%	-1235.000*	301.628	.014	-2227.68	-242.32
	7.50%	-346.000	301.628	.779	-1338.68	646.68
*. The mean difference is significant at the 0.05 level						

Table 4.19 shows the means and the grouping or sub-sets, which is done by assigning different letters to each group. The homogeneous groups shows that which group have a same mean and which one have different mean so, the group which doesn't share any letter is significantly different and vice versa. It is noticed that only 0.0% HDPE is significantly different because the mean value of first group is 458.00 whereas, the next group value is 1786.00 which clearly indicates the substantial difference. While in contrast, it is eminent in the table that 5.0% and 7.5% modified samples share the mean with two groups, which explains that their values are close to next higher or/and lower percentage samples. This test also satisfies the assumptions of ANOVA test.

Table 4.19 Grouping using Tuckey's Analysis and 95% CI

Percentage (Independent Variable)	**N**	**Grouping for alpha = 0.05**			
		A	**B**	**C**	**D**
0.00%	3	458.00			
10.00%	3		1786.00		
7.50%	3		2132.00	2132.00	
5.00%	3			3021.00	3021.00
2.50%	3				3401.00
Sig.		1.000	.779	.085	.719

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3.000.

Figure 4.16 presents the distribution of means with respect to a reference zero line. This line implies that there is no significant difference between the groups in any mean that contains zero. The confidence interval for the difference between the means of all control specimens containing 0.0% modifier and 2.5%, 5.0%, 7.5% and 10.0% modified specimens does not include zero, which indicates that the difference is statistically significant. The CI for the subsequent pairs of means all include zero, which indicates that the differences are not statistically significant.

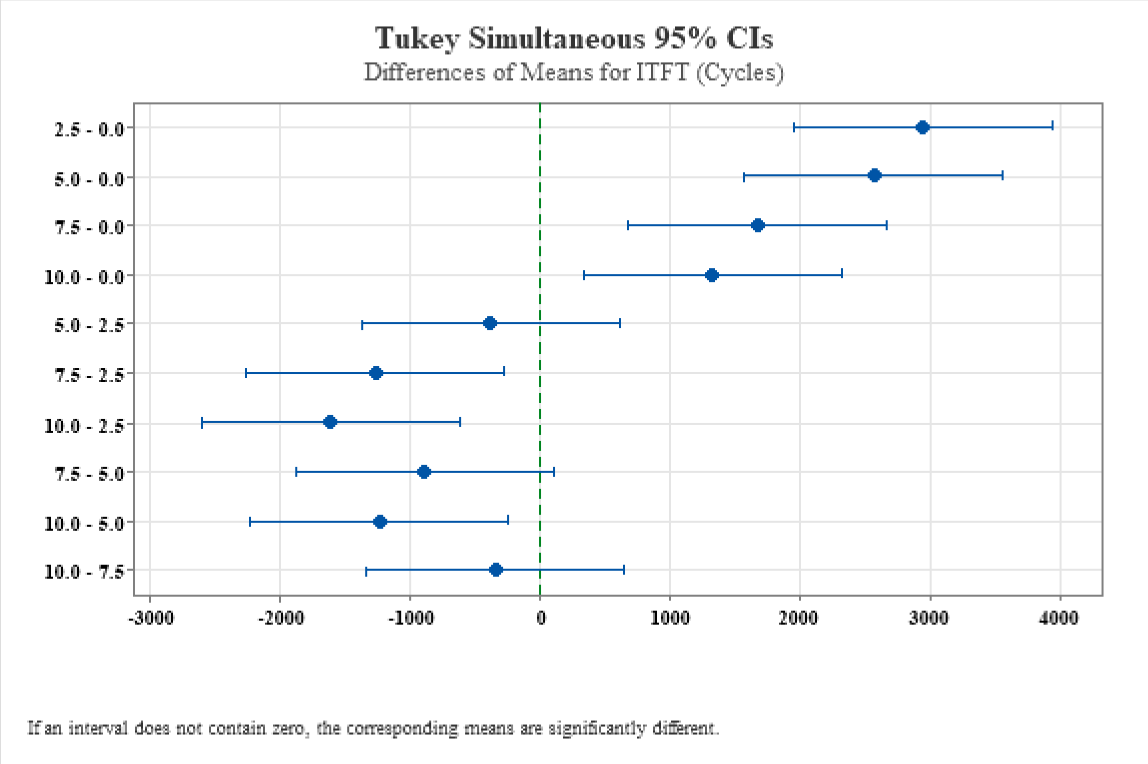


Figure 4.16 Distribution of Means for ITFT Values

Pearson correlation measure the strength and direction of linear relationship between two variables as shown in the Table 4.20. This coefficient correlation is +1 and -1 this is the defined range of the correlation, wherein -1 shows the perfect negative correlation and on the contrary +1 shows the perfect positive correlation and 0 value shows no correlation at all. All variables have or they carry value of one with them. It also indicates that how two variables are strongly correlated with each other or the degree of association between the variables. Sig 2-tailed shows the p value that is associated with the correlation. The upper numerical description shows how tightly the imaginary line points are lying. On the other hand, the table also shows that if the correlation is high the points will tend to be closer to the line and if the correlation is low then it would be far away from the line. N shows the number of the data because in this table there is no missing data, so the N are same in both cases. If the data has missing values so N would be different, and the correlation will also be different from the other sets. The correlation also tells that the variables are changing in the same direction or in the opposite direction. There are absolute values in the correlation that analyze the magnitude of the correlation.

Table 4.20 Correlations Analysis of Resilient Modulus

Source		Percentage (Independent Variable)	Result (Cycles) (Dependent Variable)
Percentage (Independent Variable)	Pearson Correlation	1	
	Sig. (2-tailed)		
	N	15	
Result (Cycles) (Dependent Variable)	Pearson Correlation	.183	
	Sig. (2-tailed)	.515	
	N	15	15

4.8 Summary:

Study finding conclude that adding High Density Polyethylene (HDPE) to asphalt concrete mixtures substantially improves the properties of the hot mix asphalt. The inclusion of HDPE polymer also improves the stiffness response of 2.5% HDPE modified asphalt has been increased by almost **130.47%,** the fatigue life has been enhanced by **642.0%** and similarly the moisture resistance increased **17.81%** of conventional mixes. Moreover, it has been observed that adding small quantity of polymer significantly enhances all properties of a hot mix asphalt specimen which includes stiffness, fatigue resistance and moisture susceptibility. Overall, the asphalt mixtures with 2.5% HDPE showed the best results. For validation of performance test results, a statistical analysis of one-way ANOVA with Tukey analysis and correlation was carried out.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions:

The principal objectives of this research study were to assess the mechanical properties of modified and unmodified asphalt mixtures. Unmodified mixtures were composed of aggregate procured from Margalla and bitumen penetration grade 60/70 obtained from ARL. Modified mixtures were composed of Margalla Crush and HDPE polymer. Four varying modifier percentages were used with respect to optimum binder content for Marshall specimens, while the bitumen was added later as prescribed in the dry mix method. After the preparation of samples in compliance with respective standards, performance testing was conducted. Three performance tests were performed; IDT strength test for determining moisture susceptibility, Resilient Modulus test to determine the rutting/permanent deformation and Indirect Tensile Fatigue Testing to measure the fatigue resistance of modified and unmodified asphalt specimens.

1. Maximum resilient modulus values for 60/70 modified HMA samples are observed for 2.5% with an increase of 130.47% than conventional. Increased M_r makes pavements stiffer and subsequently more resistant to permanent deformation and fatigue cracking.
2. The TSR values of all the asphalt mixtures modified with HDPE were higher than 92% which illustrates that when exposed to moisture, this kind of modifier does not cause the HMA mix to deteriorate. Further, the cracking resistance and moisture damage resistance improved 17.81% when the 2.5% HDPE was used than the conventional HMA.
3. The result showed significant improvement in fatigue behaviour of all modifier contents used when compared with the control mixtures whereas, maximum improvement of 642% was exhibited by 2.5% HDPE modified HMA. Eventually it causes a better bonding of aggregates with asphalt binder which reduces the cracking potential of pavements.
4. At next higher modifier content (5%), the behaviour of the modified binders remains close to that of the modified binder with 2.5% HDPE, while overall substantial increase

has been observed from conventional HMA specimens for all percentages of HDPE modifier.

5. The addition of even small quantity of HDPE modifier in conventional specimens showed sudden enhancement in binder properties and this positive effect could be observed till the optimum percentage of HDPE used in this study.
6. Hence, this research study reveals that among the four types of mixtures prepared by 2.5%, 5.0%, 7.5% and 10% of HDPE, the mixtures with 2.5% HDPE had the most improved moisture resistance, resilient modulus, and fatigue resistance.

5.2 Recommendations:

The following recommendations briefly describe the area in which further research work will be valuable.

1. Only three performance tests were carried out in this study i.e. ITFT, Resilient Modulus and Indirect Tensile Strength test. For future study, other performance tests such as Hamburg Wheel Tracking test (HWT), Dynamic Modulus by SPT, and Four Point Bending Test etc. should also be carried out to completely characterize the asphalt mixtures for rutting, moisture damage and flexural response.
2. In addition to aggregate source the bitumen sources and grades also need to be incorporated in future studies to see the effect of HDPE modifier on various grades of bitumen.
3. Apart from materials, temperature and loading frequency sweep needs to be performed to evaluate modified binder / mixtures for the highest and lowest temperatures prevailing in Pakistan.
4. The fatigue behaviour in the current study has been performed on the different HMA mixtures using the stress-controlled conditions due to the limitation of the equipment available, there is a need to perform similar tests on the same mixes under the strain controlled mode of loading.

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APPENDICIES

HDPE Manufacturer Technical Data Sheet

POLIMAXX

R1760

High Density Polyethylene (HDPE)

Description:

R1760 is a High Density Polyethylene resin for injection molding with high impact strength, excellent surface appearance and good rigidity contain UV stabilizer additive. It is suitable for crates, trays, cases, industrial parts, bins, large housewares, safety helmets packaging of agriculture products pallets, heavy duty articles. It also meets the F.D.A. requirement in the code of federal regulations in 21 CFR 177.1520 for food contact.

Physical Properties:	Method	Unit	Value
Melt Flow Index (2.16 kg/190°C)	ASTM D1238	g/10min.	6
Melt Flow Index (5 kg/190°C)	ASTM D1238	g/10min.	17.5
Density	ASTM D792	g/cm³	0.957
Tensile Strength at Yield	ASTM D638	MPA	29.5
Tensile Strength at Break	ASTM D638	MPA	15
Ultimate Elongation	ASTM D638	%	1000
Hardness Shore D	DIN 53505	-	65.5
Charpy Notched Impact Strength (at 23°C)	DIN 53453	mJ/mm²	4
Vicat Softening Temperature	ASTM D1525	°C	125
Environmental Stress Cracking Resistance (condition B, F_{50})	ASTM D1693	hours	9

Processing Technique

Processing Temperature: 200 – 260°C

However, the actual processing conditions depend on mold design, machine and other environments.

Product Data sheet

Remark: The values presented on the above are typical laboratory average, not to be construed as specifications and may vary within moderate ranges. The applicability or the accuracy of this information or the suitable of our products cannot be guaranteed because the conditions of use on the part or our uses are beyond our control.

REV. 20110601

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APPENDIX – II

INDIRECT TENSILE FATIGUE TEST (ITFT) REPORTS

<u>**APPENDIX – III**</u>

RESILIENT MODULUS TEST REPORTS

APPENDIX – IV

INDIRECT TENSILE STRENGTH TEST

(CONDITIONED SAMPLES)