EFFECTS OF HIGH-DENSITY POLY-ETHYLENE AND BAKELITE ON PERFORMANCE EVALUATION OF HOT MIX ASPHALT

MUHAMMAD YASIR
(00000326981)

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the requirements for the degree

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Signature: ______________________

Supervisor's name: **Dr. INAMULLAH KHAN**

Date: 21- Aug - 2023

Signature (**HOD**): ______________________

Date: 21-8-23

Signature (**Dean/Principle**) ______________________

Date: ______________________

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By

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DEDICATION

Dedicated to my beloved Country, my teachers and Family.

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LIST OF ACRONYMS

ASTM - American Society for Testing and Materials

AASHTO - American Association of Highway & Transportation Officials

BS - British Standard

DOT - Department of Transportation

AC - Asphalt Concrete

HMA - Hot Mix Asphalt

ARL - Attock Refinery Limited

NC - Nano-clay

HWTT - Hamburg Wheel Tracking Test

IDT - Indirect Tensile Test

ITS - Indirect Tensile Strength

M_R - Resilient Modulus

NHA - National Highway Authority

OBC - Optimum Binder Content

SGC - Superpave Gyratory Compactor

SHRP - Strategic Highway Research Program

TSR - Tensile Strength Ratio

UTM - Universal Testing Machine

V_a - Air Voids

VFA - Voids Filled with Asphalt

VMA - Voids in Mineral Aggregate

PMB - Polymer Modified Bitumen

FHWA - Federal Highway Administration

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ABSTRACT

Extreme temperatures and loads can seriously harm flexible pavements, so it's important to take practical precautions to increase their lifespan. Bitumen, an important element in flexible pavements, is essential for improving pavement performance. Recent and past studies used several wastes/ modifiers to enhance the bitumen pavement performance; however, there is a lack of study on the use of Bakelite and high-density polyethylene (HDPE) which is environmentally friendly polymers. Therefore, the current study aims to use environmentally friendly polymers such as Bakelite and high-density polyethylene (HDPE) at a varying percentage to investigate the effect of HDPE and Bakelite on the performance evaluation of hot mix asphalt. In this study, we look at how two ecologically friendly polymers, Bakelite and high-density polyethylene (HDPE), affect the performance of hot mix asphalt. Because of its high melting temperature, HDPE is particularly suited for usage in hot areas, making it a good contender for increasing asphalt performance under difficult conditions. We used the Marshall mix design method to get optimal bitumen content and an acceptable blend. The bitumen was mixed with various ratios of Bakelite (6%) and HDPE (3%, 6%, and 9%). Following that, we ran a battery of performance tests on both control and modified samples, including resilient modulus (M_R), indirect tensile strength, moisture susceptibility, and Hamburg wheel tracking. The results indicate an increase in performance by adding HDPE and Bakelite as modifiers. The outperformer off the mixtures were noted to be 6% Bakelite and 6% HDPE for which the resilient modulus is enhanced by 1.7 times the control mix, moisture susceptibility is reduced by 15.3% and rut resistance tweaked by 27.4%. While for rutting the best combination is 6% Bakelite and 9% HDPE which shows enhancement of 42.3%, but for this combination the other properties reduces gradually.

CHAPTER 1

1.1 Introduction

The context, problem statement, and goals of this research project are thoroughly covered in this chapter. Brief on methodology and thesis organization are discussed at the end of this chapter. This chapter presents the overview of the overall research work carried out.

1.2 Background of the study

Due to the severe traffic circumstances, where axle loads and traffic intensities are on the rise, and the tough weather conditions, including very high summer temperatures, roads are experiencing considerable rutting, moisture damage, and stripping failures. These failures in the road structures are causing hurdles to road users and leading to accidents and vehicle wear and tear. These issues are causing damage to human lives and the economy of the country. Pakistan is situated in a temperature zone where temperature variation is higher near the coast and progressively cooler in northern areas. The total road network in Pakistan is approximately 259197 km, maintained annually. National Highway Authority (NHA) has reserved 53484.49 Million PKRs for road maintenance in their jurisdiction i.e 12300km in 2022. This maintenance cost can be reduced by building high-performance roads.

Unfortunately, 60/70 or 80/100 penetration grade asphalts are used in Pakistan to build highways, which makes them unsuitable for highway pavements and unable to withstand high temperatures and loads. These penetration-graded asphalts frequently fail due to plastic deformation at high temperatures and brittle cracking at low temperatures. This is due to the high wax content in these asphalts, which causes softening in hot weather and lowers stability, adhesion, and ultimately strength (Al-Hadidy et al., 2011). As a result, we must either switch to the super-pave design or adapt the asphalt that is now being produced by our refineries. Utilizing locally accessible modifiers like polyethylene bags, Bakelite, fibers, rubber, and other inexpensive additions is more cost-effective than switching to super-pave. According to research on additives, polymers were shown to be the most significant of their many forms (Ali et al., 2021). Additionally, the pavement design field has many potential uses for polymer-modified asphalt. The benefits include a decreased risk of rutting, an extended useful life, and a thinner pavement (Al-Hadidy et al., 2011). Greater temperature and moisture susceptibility, along with increased stiffness from the inclusion of polymers, lead to increased rut resistance in asphalt. Additionally, polymers are applied to aggregates as a coating material to give them a rougher surface and make them more moisture-resistant.

Even though there are many different types of polymers, only two primary types are used for pavement modification: elastomers and plastomers. Bakelite is categorized among plastomers. Plastomers make bitumen less elastic and less flexible at low temperatures, but at higher temperatures, they make it stronger since it is more rigid and has less penetration (Gorkem et al., 2009). Two processes are typically used in the creation of modified asphalt. The wet approach creates modified asphalt by combining the modifier with asphalt and heating the mixture to its melting point. The modified asphalt is then combined with the heated aggregates to produce asphalt concrete. The modifier is fully mixed into the heated aggregates during the dry process before being added to them in the heated liquid form during mixing (Olard et al., 2010).

The performance metrics resilient modulus, indirect tensile strength, rutting test, and moisture susceptibility of asphalt concrete mixes are investigated to determine the impact of Bakelite and HDPE as a modifier. The modified asphalt concrete specimens were prepared with HDPE percentages (3%, 6%, 9%) and 6% Bakelite Content. Both modified and unmodified samples were prepared by Marshall Mix design, using NHA- B gradation and 60/70 penetration grade asphalt. The Marshall Mix design (ASTM D 6926, 2014) was used to determine the optimum bitumen content (OBC), which was then utilized to prepare both conventional and modified samples. To compare the effectiveness of the qualities of traditional and modified mixes, performance tests such as resilient modulus, indirect tensile strength, rutting test, and moisture susceptibility of asphalt were carried out.

1.3 Problem statement

Highway agencies (NHA) in Pakistan make significant annual investments in pavement design, building, maintenance, and rehabilitation to deliver the desired service level by lowering suffering. However, the most harmful element for flexible pavements in Pakistan is permanent deformation, commonly known as rutting. Rutting is a poor interlock between aggregate and bitumen that results in a vertical distortion in the wheel path. Rutting may also be the result of poor mix design, such as having too much asphalt or not enough aggregate particles. A flexible pavement's lifespan could be shortened by rutting, which also raises several safety issues.

This study is crucial for anybody who is a road user since it offers high-quality pavement for long-term road serviceability. Ensure that the pavement is strong and long-lasting so that it won't deteriorate or rut. A thicker layer of asphalt can be used to increase the durability of asphalt pavement, or different types of modifiers can be used to improve the material's properties (Moghaddam et al., 2011). There are numerous techniques to enhance the HMA combinations. By introducing additives such as polymers and nanoparticle-modified binders into HMA, pavement structures can be made more durable. This increases pavement structure longevity because additives can withstand continuous vehicle-applied pressures.

The goal of this study is to evaluate the performance of the HMA mix design employing HDPE and Bakelite, hence identifying its efficacy by increasing the resilience modulus, other stability variables, and rutting in HMA pavement. This study examines Bakelite and HDPE modified binder on Hot Mix Asphalt using Super pave gyratory samples and Marshal samples, and evaluation of performance tests, i.e., resilient modulus, moisture susceptibility, ITS, and rutting factors through HWTT. Modified asphalt concrete specimens were prepared with 6%Bakelite and 3%, 6%, and 9% of HDPE. The Hamburg Wheel Tracking is used to test the rutting behavior of HDPE at various concentrations when combined with 6% Bakelite. Additionally, Marshal samples are prepared to conduct testing utilizing the Universal Testing Machine (UTM) to determine resilient modulus (MR), ITS, and moisture susceptibility. From experimental analysis, polymer percentage in HMA was obtained that has a substantial effect on resilient modulus, rut resistance, and moisture susceptibility.

1.4 Research objectives

- To examine efficacy of using ***Bakelite*** and ***HDPE*** in Hot Mix Asphalt (HMA).
- To evaluate the ***Resilient Modulus*** $(\boldsymbol{M_R})$ and ***Moisture Susceptibility*** of HMA having Bakelite and HDPE through Universal Testing Machine (UTM).
- To investigate ***Rut Resistance*** by using Hamburg Wheel Tracking Test (HWTT).

1.5 Organization of the thesis

Five chapters make up this thesis:

The first chapter contains an introduction, the problem description, the objectives of the research, and the scope of the study.

The second Chapter contains the comprehensive literature review carried out for research. Detailed literature has been studied regarding HMA asphalt and the usage of Bakelite and HDPE as a modifier.

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

The fourth Chapter is about the results and analysis. In chapter 4, we have discussed the results obtained from performance tests and we have quantified relative improvement In the HMA mixture's performance indicators/properties.

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

Chapter 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the theory and previous research on hot mix asphalt (HMA) pavement types and material qualities.

- First, I have discussed Marshall Mix design and its other properties.
- Next, a brief introduction to polymerization, its types, and different polymers.
- Finally, the effects of polymers as additives on the properties of asphalt concrete.
- The foremost focus is on the properties of Bakelite and HDPE as a thermosetting Plastomers, which influences their use as additives in this study.

2.2 Generalized background

The economy of a nation is significantly influenced by the road transportation system. It offers access to numerous locations across the nation. Roads are built using asphalt as the binding agent all over the world. It is a petroleum byproduct. Around 102 million tons of bitumen are utilized annually on average throughout the world, with 70 percent going toward building roads. Researchers are looking for alternatives to limit the usage of bitumen in the road industry as a result of the yearly growth in demand. Bitumen burns at a high temperature and emits poisonous gases; it has a serious negative impact on health. Both the environment and human health are negatively impacted. As a result, it is necessary to hunt for alternatives or swap out a specific amount of bitumen for another substance. Although there has been a modification of asphalt for 60 years, interest in it has increased significantly over the last 15 years. In recent years, increased traffic volumes, excessive loads, and tire pressure have all played a role. Because of this, HMA pavements have prematurely started to rut. Industrial waste and byproducts including plastic, ash, oils, and chemicals can be used as HMA additives rather than being discarded and disposed of to lessen environmental pollution and financial strain. It is also important to consider whether public institutions are prepared to pay for pavements' high initial costs in exchange for their extended expected lifespans.

2.3 HMA

Hot mix asphalt (HMA), also known as bituminous paving mix, effectively blends graded particles combined and covered with bitumen (MS-4 Asphalt Handbook). The aggregates and asphalt need to be heated to make the bitumen fluid enough to mix properly. Durability and cost-effectiveness should be the key priorities while designing HMA. When pavement is built improperly, it fails before its intended lifespan, which results in a loss in terms of repair and reconstruction costs.

Using the appropriate building materials and flexible pavement design parameter values is the most effective way to lower the chance of future repair and maintenance concerns (MS-4 Asphalt Handbook). Bitumen is the most expensive component in HMA pavements. Bitumen should be developed to be long lasting and resistant to pavement distresses such as stripping, raveling, and rutting to provide durable and affordable pavements. The bitumen can be made more resilient by adding particular modifiers that improve its characteristics and increase its resistance to damages brought on by moisture, rutting, and other pavement distresses.

2.3.1 HMA Types

Depending on the gradation of the employed aggregate, the hot mix asphalt is separated into three different mixes. These three combinations are classified as being dense, open, and gap-graded (MS-2 Asphalt Institute)

2.3.1.1 Dense Graded Blends

Dense-graded bituminous mixes are those that are made mostly of well-graded aggregates, or filler and aggregates of all sizes combined with an asphalt cement binder. The dense graded mixes contain aggregates with the nominal maximum size. These mixtures perform well for friction, patching, and structure.

2.3.1.2 Open-Graded Mixes

A high proportion of coarse aggregates and a low proportion of fine aggregates are combined with bitumen to create the open-graded bituminous mix. These mixtures are used to create a surface texture that is porous and allows water to drain into the mix. Due to the absence of fines in the mix, open-graded bituminous mixes have a different mix design process than dense-graded bituminous mixes. Additionally, compared to dense-graded mixtures, open-graded mixes contain less bitumen.

2.3.1.3 Gap Graded Mixes

A gap-graded asphalt mix is often identical to an open-graded mix. However, compared to open-graded mixes, the fine aggregate in the mix is typically more substantial. Crushed stone, bituminous gravel and synthetic sand are the components of gap-graded mixtures. There are no or very few middle-sized aggregates between #4 and #30 sieves.

2.4 Classification of modifiers

Modifiers and additives fall under many categories. However, (Terrel et al., 1986), proposed a very general categorization, and (Roberts et al., 1996), gave a modified version, which is described here.

2.4.1 Fillers

A few examples of mineral fillers are lime, Portland cement, fly ash, and aggregate dust (Roberts et al., 1989), The ideal asphalt content is decreased when the filler is added, but density and stability are improved. The ideal asphalt content is decreased as a result of the filler's ability to fill holes in aggregates. The filler makes the mixture stiffer at high temperatures. Lime is used as an anti-stripping agent. Other fines, especially those containing clays, can increase HMA's capacity for stripping.

2.4.2 Extenders

Increased asphalt content gained popularity following the 1973 oil embargo. As a result of a shortage, prices for asphalt cement increased. The Federal Highway Administration (FHWA) promoted research into ways to extend the lifespan of asphalt binders by partially substituting sulfur and lignin. Lignin and sulfate are byproducts of some industries. Sulfur is produced when natural gas is denaturalized and when pulp and paper are made. Market prices determine how much Sulphur is used as an extender. If the cost is higher than asphalt, its use cannot be justified. Sulfur is added to polymer-modified asphalt mixtures to improve storage stability (Rodriguez,2001). Lignin has not been utilized in commercial HMA; rather, it has only been studied in the laboratory as a potential extender and substitute for asphalt cement (Roberts et al., 1996;Terrel et al., 1986)

2.4.3 Polymers

Long chains or groups of molecules known as polymers are created chemically from tiny molecules (poly) known as monomers. The physical qualities of a polymer are established by the chemical structure and arrangement of its constituent monomers. In contrast to butadiene, polystyrene is a soft, elastic monomer used to make plastics. Copolymers are formed when two distinct monomers are mixed together in a block or random fashion. Hydrogen bonding and chemical reactions are specific interactions between asphalt and polymers, which can occur when a polymer is added to the asphalt. Based on their strain properties at low temperatures, polymers can be categorized into two groups:

(a) Elastomers and (b) plastomers.

2.4.3.1 Elastomer

Elastomers that have been stretched are better able to endure the deformation caused by tension and quickly return to their normal shape after the load has been removed. Elastomers provide minimal strength to asphalt cement up until they are stretched. Tensile strength is increased by elongation.

Elastomers are primarily intended to:

- Produce a firmer HMA that can tolerate high temperatures.
- To prevent fatigue by making the HMA more elastic at moderate temperatures.
- To make materials more rigid to prevent thermal cracking at low service temperatures.

Complex rubber components may not impart the same properties as a pure polymer when combined with HMA. Additionally, the reactions of various modifiers to various asphalt cement types vary. As a result, it is difficult to predict whether a particular polymer will have the desired effects. As a result, Super-pave mix design and evaluation approaches are utilized to determine whether the stated goal can be achieved by adding rubber modifiers.

Asphalt cement can be altered in several ways using elastomers. Many of these are offered for sale in the market under different brand names. Natural rubber, styrene-butadiene rubber (SBR), styrene-butadiene-styrene (SBS), styrene-isoprene-styrene (SIS), polychloroprene latexes, and crumb rubber modifiers are all examples of elastomers or rubber latexes. Styrene-butadiene (SBR), polychloroprene (Neoprene), and polybutadiene (a random copolymer) are the three main components of latex (PB). It is a type of synthetic latex rubber that sets thermally and is composed of a mixture of polymer particles dispersed in water. The evaporation of the water present in an applied emulsion causes SBR droplets to collect on the asphalt particles' surface. This improves the properties of the asphalt by forming a continuous honeycomb polymer network that runs the length of the binder. This improves the properties of the asphalt by forming a continuous honeycomb polymer network that runs the length of the binder.

SBR increases the asphalt binder's adhesion and cohesion qualities as well as its resistance to permanent deformation, oxidative aging, ductility and toughness at low temperatures, and flexural fatigue resistance. Additionally, it increases the pavement's resistance to skidding. SBR latex is frequently used for micro surfacing, chip sealing, and slurry sealants (latex-modified asphalt emulsion). An elastic thermoplastic polymer is the SIS Block Copolymer (Styrene Isoprene-Styrene). It does not flow or distort at high temperatures. It has increased flexibility and muscle strength. It has good blend stability when used sparingly. The SIS block copolymer enhances the adhesion of the asphalt to the aggregate particles. It does, however, lessen the penetration resistance. It has a significant viscosity when at higher temperatures.

A thermoplastic rubber Copolymer SBS Block Thermoplastic elastomer type is an SBS block copolymer. It originates from pellets, crumbs, or ground-up materials stored in bulk sacks. Typically, SBS makes up 5% of the asphalt binder. SBS increases bitumen flexibility at low temperatures, abrasion resistance, fatigue resistance, flow, and deformation resistance at high temperatures, and asphalt binder adhesion and cohesiveness. Although relatively expensive, it is very flexible at low temperatures. SBS is employed in both roofing and paving. Natural rubber can also be used in paving applications. It is more rut-resistant and ductile than other materials. However, natural rubber must be partially digested and manually homogenized due to its low compatibility and large molecular weight.

The most typical source of recovered rubber tires. Tire disposal could be made simpler by employing recovered rubber as a modifier to enhance pavement performance, which could be effective given the rise in the number of used tires and the difficulties associated with their disposal. It lessens reflective cracking in asphalt overlays and reduces rutting and shovel resistance. It also promotes HMA flexibility. Additionally, using thinner lifts will result in longer-lasting durability. It costs cheaper as well. An example of recycled rubber that has been used to enhance pavement performance is a crumb rubber modifier (CRM). Old tire rubber that has been salvaged is known as crumb rubber. It is produced using rubber scraps that have been mechanically ground to a diameter of less than or equal to 0.25 inches.

2.4.3.2 Plastomers

Plastomers are composed of a rigid, deformable three-dimensional network. They are brittle but quickly gain a lot of strength. Plastomers can break when stretched despite having a high beginning strength. Asphalt can be modified with plastomers such as Bakelite, PVC, EPDM, Polyolefin, Polyethylene/Polypropylene, and Ethylene Acrylate copolymers. 15 percent of the world market for asphalt modifiers is made up of plastomers. Low-Density Polyethylene (LDPE) is used in polymeric materials. You can utilize polyethylene, whether it's new or recycled. The polyethylene- and virgin-binder-containing composition is changed using LDPE. LDPE-modified asphalt must be mixed and compacted at high temperatures (37°F hotter than the HMA in the control group), as this material has a high viscosity. Under 132 °C, polyethylene crystallizes, making the compaction of LDPE-modified asphalt largely irrelevant.

In addition to improving asphalt aging resistance, LPDE also boosts high-temperature viscosity, improves high-temperature deformation resistance, and is reasonably cheap. However, it is unstable and difficult to spread in asphalt. It also has a modest elastic recovery and adding more polymers results in better properties. LDPE has only a few applications in paving and is primarily used in industries. Ethylene and vinyl acetate are the main components of the thermoplastic polymer known as EVA.HMA that is based on EVA has greater stability over extended periods and is unaffected by minute temperature variations in mixing. It is provided in bulk sacks and comes in transparent to off-white pellet form. A heated asphalt binder between 149°C and 171°C is used to combine the EVA. For the best mixing, low shear or light agitation is needed. EVA is often employed at 2% to 5% of the weight of the asphalt binder. At high temperatures, EVA improves the rigidity modulus and adhesion between the asphalt binder and particles.

2.4.3.3 Combinations

Additionally, properties that are impossible to accomplish with just one modifier can be achieved by combining elastic and plastic polymers. For instance, a plastic polymer can enhance high-temperature rutting resistance during the summer, but it cracks during the winter when the temperature is low. In this situation, introducing a rubber material might enhance HMA's performance in cold climates. However, when two polymers are combined, it's possible that they won't be chemically compatible, and the outcome could be harmful. Combining two or more polymers might also be too expensive.

2.5 Thermoplastic Polymers

The structural development and reformation characteristics of thermoset and thermoplastic plastomers and elastomers vary depending on the temperature. The complex, cross-linked structure that is created when thermoset polymers are heated for the first time is kept when they are cooled but cannot be undone when they are reheated. Thermoplastic polymer when cold generates a clearly defined, interconnected matrix that, when reheated, can be turned around or reset.

2.6 Limitation of modified bitumen

Modified asphalt may have the following drawbacks:

- Although the cost of modified bitumen is high initially, when the polymer is used, the pavement's lifespan can be increased by up to 10 times, which lowers the life cycle cost of the material.
- The compatibility of a polymer with a binder depends on how well its properties match those of bitumen; occasionally, a solo polymer doesn't improve bitumen's properties, but when combined with another polymer, it performs well.
- Storage, a suitable temperature for mixing, and the amount of time the Polymer Modified Bitumen (PMB) are kept at a high temperature before laying.

2.6.1 Stability and Compatibility Problems

Physically stable mixes are created using conventional mixing techniques and appropriate materials. The physical properties of bitumen may or may not be improved by these mixes. Slightly compatible polymers need specific mechanical, chemical, or thermal processes to enhance asphalt. Asphalt heterogeneous mixtures with minimal cohesion and ductility resulting from the mixing of incompatible polymers. The right compatibility between asphalt and polymers is crucial for achieving the best pavement performance and preventing separation during storage, pumping, and application of asphalts. PMB cannot be applied to paving because of its poor storage stability. The amount of polymer added to the binder, the molecular weight of the polymer, the presence of asphaltenes, and the aromaticity of the maltene phase all have an impact on how well PMB holds up to storage.

The introduction of cross-linking substances, such as sulfur, can enhance the storage stability of asphalt, (Becker et al., 2001). Sulfur is thought to chemically bind bitumen and polymer through sulfide and polysulfide bonds. UV microscopy is used to verify PMB compatibility and blend completion. A fluorescent microscope is used to collect samples and analyze them every hour. Finely dispersed polymer particles in an asphalt matrix are referred to as homogeneity. A homogeneous mixture is shown in Figure 2-1, whereas a heterogeneous mixture is shown in Figure 2-2. A softening point variation test could be used to establish compatibility. A metallic toothpaste tube is filled with PMB, which is then baked for three days at 160°C. The softening points of the samples are then determined and compared after being taken from the top and bottom of the blend, respectively. It must be made sure that there is no more than a 40°C differential in temperature between the upper and bottom halves of the mixing tank. A high number denotes instability or trouble with phase separation (Rodriguez, 2001).

Figure 2-1 Homogenous mixture

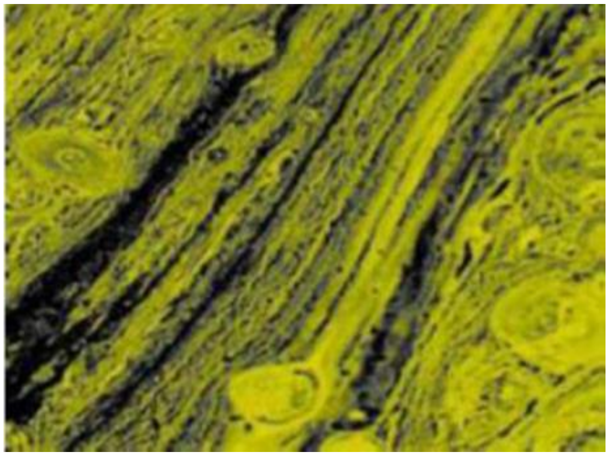


Figure 2-2 Non-Homogeneous

2.7 ASPHALT POLYMER INTEGRATION

- A typical method for integrating polymers with asphalt is to add latex polymer to it. The process is straightforward.
- Addition of a solid polymer to asphalt (e.g., Pellets). This method requires prolonged mixing and shearing to produce uniform polymer dispersion in asphalt when employing SIS and SBS block copolymers.

2.8 PROPERTIES OF THE MATERIALS FOR A BITUMINOUS MIX

The hot mix asphalt (HMA) layer plays a crucial role in the entire road design. It absorbs the large magnitude stresses because it is the top layer. The components used to create bituminous mixes must therefore be tested.

2.8.1 Aggregates assessment

The aggregate acceptability must be determined before a mix can be prepared using the Marshall Apparatus. Los Angeles abrasion, impact, crushing value, and shape tests are among the procedures frequently used. Other tests, such as gradation, specific gravity, and absorption, must be carried out if the material satisfies the requirements of these test results. The tests and their aggregate specifications are given in Table 3-1.

Table 2-1 Tests and Specifications for Aggregates

Test Type	Designation	Specification
Shape Test (%)	Flakiness Index Elongation Index	ASTM D4791 ≤ 15
Impact Test (%)	ASTM D5874	≤ 30
Abrasion Test (%)	ASTM C131	≤ 30
Specific Gravity	Coarse Fine	ASTM C127 ASTM C128

2.8.2 Bitumen Assessment

Similar to aggregates, determining bitumen acceptability is important to create bituminous paving mixes. Therefore, before creating a bituminous mixture, certain tests must be performed on the bitumen. The tests and requirements that bitumen must meet in order to qualify as a binder are given in Table 2-2.

Table 2-2 Tests and Specifications for Binder

Test Type	Designation	Specification
Penetration @ 25 (°C), mm	ASTM D 5	60 − 70
Flash point (°C)	ASTM D92	232 (min)
Fire Point (°C)	ASTM D92	270 (min)
Specific gravity	ASTM 70	1.01-1.06
Ductility Test, cm	ASTM D113	>100

2.8.3 Evaluation of Asphalt Concrete Mix

Marshall Mix design criteria are used to create hot mix asphalt with the required dimensions, and it must adhere to National Highway Authority design standards. If this is not done, the HMA mix should be destroyed and a fresh trial blend should be made and tested until and unless it satisfies the design requirements of NHA. The NHA requirements for wearing the Marshall-designed course mix ((ASTM D 6926, 2014) in heavy traffic conditions are shown in Table 2-3.

Table 2-3 NHA Class B Specifications for Asphalt Concrete Mix

Design Criteria	Specification
Compaction, blows at each end	75
Stability (Kg)	1000 (min)
Flow, 0.25mm (0.01inch)	8 – 14
VA (%)	3 – 5
VMA (%)	16 (Max)
Loss of Stability (%)	20 (Max)

2.9 METHOD OF MAKING BITUMINOUS PAVING MIXES

Using the Marshall Apparatus is the conventional procedure for creating bituminous paving mixes (ASTM D 6926, 2014). Aggregates with the ideal amount of bitumen, heating the mixture to the right temperature, and specimen compaction are necessary for the laboratory preparation of bituminous pavement mixtures. A total of 1200 grams of aggregate and filler are heated to temperatures between 105°C and 110°C. In addition, bitumen is heated (160°C–165°C). After being heated separately, bitumen and aggregates are combined at a temperature between 154°C and 160 °C. This temperature must be comparable to that of the asphalt mixing plant.

For the manufacture of a laboratory bituminous mixture, a mechanical mixer is advised because mixing a big amount of material by hand would be too challenging. To ensure that the bitumen covers the aggregate uniformly, extensive mixing is required. The mold needs to be heated before being compacted. The prepared material is then put into the mold and crushed with blows on either side with a rammer at 138°C to 149°C, depending on the traffic situation. It is permissible to alter the mix fraction of aggregates to achieve the compacted thickness of 2.5 inches (MS-2 Asphalt Institute).

2.10 Compaction of bituminous paving mixes

The Marshall Procedure standard method for designing bituminous mixes (ASTM D 6926, 2014) suggests using three different types of Marshall compaction apparatus: compaction hammers with a manually held handle, compaction hammers with a fixed hammer handle, and compaction pedestals.

2.10.1 Compaction hammers with a manually held handle

The manually operated hammers typically have a flat, round compaction foot, a sliding mass weighing 4.54 kg, a height of fall of 457 mm, and a spring-loaded swivel. A finger safety guard should be included with the manual compaction hammers.

Due to a surcharge on top of the handle, the compaction hammer is mechanically operated with a base that rotates continuously. The moving weight for the tamping face must be 4.54 kg, and the height of the fall must be 457.2 mm. The base has a spinning mechanism built into it. Both the base rotation and the hammer blow rate must be between 18 and 30 revolutions per minute.

2.10.2 Compaction Pedestal

The tampering Pedestal is made out of a nominal eight-by-eight-inch hardwood post that is about 18 inches long and is crowned with a 12-by-12-inch steel plate that is one inch thick. The wood should be between 42 and 48 lbs./ft3 in dry density on average.

2.11 Volumetric analysis of HMA

Volumetric examination of the parameters of compacted bituminous paving mixtures provides information about the performance of the pavement (MS-2 Asphalt Institute). The input parameters for computing these volumetric properties are obtained using a variety of test protocols, such as specific gravity tests for aggregates, bitumen, and bituminous mixes. The following phase is the measurement of the volumetric properties of the bitumen, aggregates, and bitumen after mixing and compaction.

- % Of voids filled with asphalt (VFA)
- Range of acceptable Air Void Contents (Va)
- A minimum number of Voids in the Mineral Aggregate (VMA)

2.11.1 Voids in Mineral Aggregate (VMA)

The spaces in compacted bituminous pavement mixtures are visible in VMA. These voids, which are stated as a percentage of the total volume of the mix, are the sum of the air voids and the bitumen content that is effective (exclusive of the absorbed bitumen). In order to determine the VMA, we need to know the aggregate's bulk specific gravity. The specific gravity is determined by the volume of the compacted paving mixture. Subtracting the total volume from the bulk volume yields the VMA. Following is the equation for calculating VMA:

$$VMA = 100 - \left[\frac{G_{mb} P_s}{G_{sb}}\right] \tag{1}$$

Where,

$VMA = Voids\ in\ mineral\ aggregate\ (percent\ of\ bulk\ volume).$

$P_s = Percent\ of\ total\ aggregates\ in\ the\ mix.$

$G_{mb} = Bulk\ specific\ gravity\ of\ the\ compacted\ mix$ (ASTM D 2726)

$G_{sb} = Combined\ specific\ gravity\ of\ aggregates.$

VMA is a key factor in determining a mix's durability; if its value is low, the mix won't be durable. In contrast, a considerable score suggests low stability and high flow issues and will be too expensive to make. The bitumen film surrounding the particles depends on the aggregate size and bitumen volume. A minimum VMA asphalt mix is more cost-effective, but it compromises durability since the bitumen oxidizes more quickly, the films are more permeable to water, and the mix's strength is decreased. Consequently, the VMA needs to be high enough to accommodate both bitumen and air voids.

2.11.2 Percent Air Voids

The coated aggregates in a compacted bituminous paving mixture consist of tiny air spaces between them called air voids. Air void content influences durability. The following equation can be used to determine how many air voids there are in a compacted mixture.

$$\mathrm{Va} = 100 \left[\frac{(G_{mm} - G_{mb})}{G_{mm}}\right] \tag{2}$$

Where,

$G_{mb} = Bulk\ specific\ gravity\ of\ the\ compacted\ mix.$

$G_{mm} = Maximum\ theoretical\ specific\ gravity\ of\ the\ mix.$
$Va\ =\ Air\ voids\ in\ compacted\ mixture, percent\ of\ total\ volume.$

2.11.3 Voids Filled With Asphalt

VFA is the percentage of the spaces between the aggregates (VMA) filled with bitumen. According to the following criteria, the absorbed asphalt is excluded from VFA:

$$\mathrm{VFA} = 100\left[\frac{\mathrm{VMA}-\mathrm{Va}}{\mathrm{VMA}}\right] \tag{3}$$

Where,

$VFA\ = Voids\ filled\ with\ asphalt.$

$VMA = \ Void\ is\ mineral\ aggregates$

$Va\ =\ Air\ voids\ in\ the\ compacted\ mix$

2.12 Stability, Flow & Quotient Test

Density, VMA, VA, and VFA are used to evaluate bituminous mixture and mix design in addition to the Marshall stability and flow (ASTM D6927). Additionally, Marshall Stability assesses an asphalt mix's capacity to withstand a compression load applied while the flow is the deformation recorded at maximum force (ASTM D 6926, 2014). The ability of asphalt concrete to withstand rutting under strong loads is another definition of stability (Kuloglu et al. 1999).

However, the flow can adapt to small, progressive deformations without cracking. Consequently, it is the opposite of stability (Kuloglu et al. 1999). The Marshall Quotient measures a material's resistance to deformation by comparing its stability to flow (Hınıslıoğlu et al., 2004).

2.13 Ratio of Tensile Strength

The indirect tensile strength (ITS) of conditioned specimens is compared to the unconditioned specimens to get the tensile strength ratio (TSR).

$$\mathrm{TSR} = \frac{\mathrm{ITS\ (Conditioned)}}{\mathrm{ITS(Dry)}} \tag{4}$$

$ITS\ (Conditioned) = Indirect\ Tensile\ Strength\ of\ Conditioned\ Specimen$

$ITS\ (Dry) = Indirect\ Tensile\ Strength\ of\ dry\ Specimen$

The AASHTO T283 tensile strength ratio (TSR) test was used to determine how susceptible specimens of compacted bituminous mix were to damage brought on by moisture. The most used test method to assess the possibility of moisture-induced damage to HMA pavements is AASHTO T283 (Huang et al., 2010). It is crucial to assess whether the modified HMA is sufficiently strong to survive damages brought on by moisture because the HMA created can be vulnerable to moisture in the finished pavement. During testing, the indirect tensile strengths of both conditioned and unconditioned specimens are measured. Their ratios are then used to calculate the TSR of the test specimens.

2.13.1 Indirect Tensile Strength Test

This test assesses the tensile strength of the HMA mixtures, which affects their cracking behavior (Tayfur et al., 2005). Finding the splitting tensile strength in a compression testing machine at 25 °C and a deformation rate of 2 inches/min will yield the ITS for both conditioned and dry samples. The following equation can be utilized to determine ITS;

$$ITS = \frac{2P_{max}}{\pi t d} \tag{5}$$

Where,

$P_{max} = Maximum\ load\ (kg)$

$t = Thickness\ of\ the\ specimen\ (cm)$

$d = Diameter\ of\ the\ specimen\ (cm)$

2.13.2 Tensile Strength Ratio Test

After testing the conditioned and unconditioned specimens for indirect tensile strength, the tensile ratio test (TSR) is determined. It is a comparison between the conditioned and unconditioned indirect tensile strengths of a group of specimens with identical material and size properties. The TSR test result evaluates the mixtures' continued stability against moisture damage (Huang et al., 2010). The minimum value for any TSR test must fall within the range of 70% to 80% according to (ASTM D4867, 2014)and AASHTO T283 standards; otherwise, the mix must be discarded and a fresh one must be prepared. The mix provides sufficient resistance to moisture damage if the TSR is more than 90%. Less moisture susceptibility is indicated by higher TSR values, and vice versa.

2.14 Resilient Modulus of Bituminous Paving Mixes

The resilient modulus is defined as the ratio of repetitive stress (loads) to recoverable strain (M_R).

$$M_R = \frac{\sigma_d}{\varepsilon_r} \tag{6}$$

Where σ_d is the stress that is repeatedly applied axially. For instance, it is theoretically considered that the bitumen binder employed in surface course materials is completely elastic. However, it was discovered that this is not the case in actuality, and minor deformations are seen every time a load is applied. However, if the bitumen being used has a higher strength and the load being applied is light and repeated frequently, the deformations after each load application become practically recoverable, and the binder can be classified as elastic. The stress-strain behavior during a repeated stress test is shown in Figure 2-3. In the same Figure, the process is shown to progress when more stress repetitions are applied. As the number of cycles approaches 100 to 200, the material responds elastically and deformation is reversible. The material initially experiences persistent distortion brought on by plastic strain (Huang 2003).

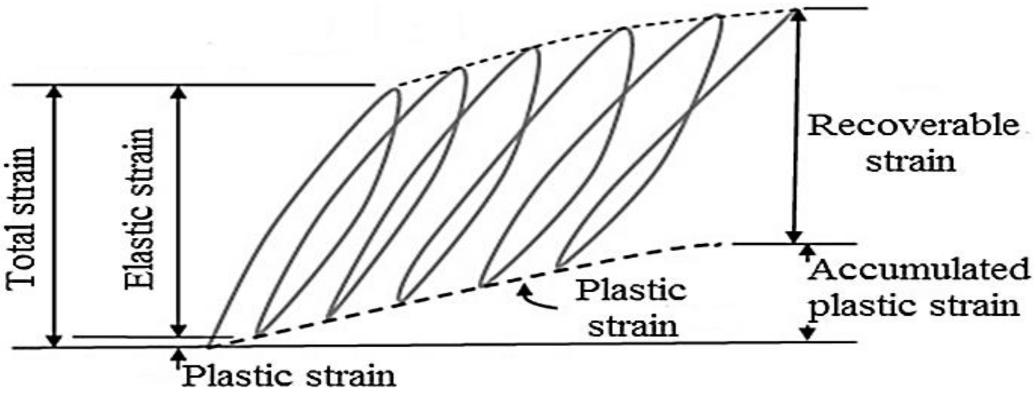


Figure 2-3 Recoverable strain under cyclic load (Huang 2003)

2.14.1 Indirect Tensile Strength Test

The indirect tensile strength test, which is defined as ASTM D6931, is used to compare the quality of paving binding materials and mixes to find out how likely they are to fracture and rut. A cylindrical specimen with a 4-inch diameter is subjected to a pointed compressive load parallel to the vertical diametric plane at a constant deformation rate of 50 mm/min at a temperature of 25°C. The reason for choosing this loading configuration is that it promotes a satisfactory homogenous tensile stress distribution in the vertical diametric plane and perpendicular to the applied load (Yoder et al., 1991). Splitting of the specimen is the end outcome. Figure 2.4 displays the stress distribution.

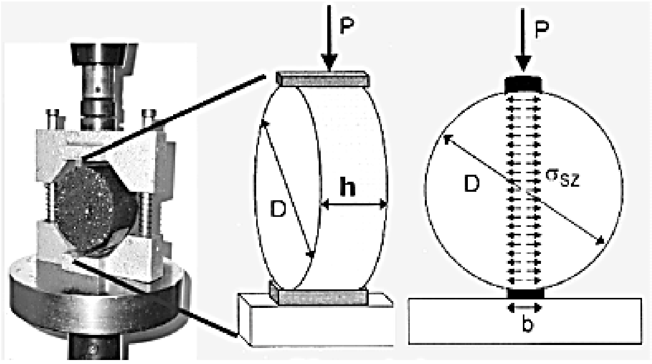


Figure 2-4 Schematic for indirect tension test

2.14.2 Resilient Modulus Test

The robust modulus test can be run on both laboratory-compacted specimens and results from the field. The resilient modulus of bituminous paving mixes depends on the following factors:

- Level of compaction (number of gyration or number of blows)
- The test setup used (Indirect tension vs. triaxial)
- Temperature (High or low)
- Geometry
- Loading factor (Loading duration and rest period, waveform, strain level)
- Binder

The (ASTM D 4123) indirect tension test, which measures resilient modulus, advises applying the load in the form of alternate loading and unloading, commonly known as the haversine load form. Three parts make up this test procedure: ITS determination on a single specimen, conditioning for 100 load pulses, and finally finding the real resilient modulus.

2.14.2.1 Determination of Pretest Tensile Strength

Before starting the resilient Modulus test, it is advised by ASTM D6931 to conduct an ITS on one of the specimens that are representative of other specimens in terms of size and material properties. A baseline for the preconditioning peak loading force is chosen by performing an indirect tensile strength test.

2.14.2.2 Preconditioning

The sample should be preconditioned by being kept at a set temperature and time in the equipment's compartment. According to the ASTM D6931 test technique, the indirect tensile strength of the bituminous paving mix is used to determine the applied loads for preconditioning. During preconditioning, the peak loading force must be between 10 and 20 percent of the peak load determined by the indirect tension test at 25°C. The specimen contact loads, also known as sitting loads, must be 4 percent of the maximum load to guarantee good contact between the loading strip and the specimen. There should be 100 to 200 load applications during each preconditioning cycle. The least quantity of load applications, however, is determined by the stable deformation in a particular situation.

2.14.2.3 Resilient Modulus Determination

The RM is determined by applying five load pulses with virtually continuous deformation after the ITS and conditioning operations. The primary determinants of resilient modulus are temperature, bitumen concentration, load duration, specimen diameter, and aggregate gradation. The resilient modulus of bituminous paving mixes is calculated using the following equation:

$$E = \frac{P(\bar{\upsilon}+0.27)}{Ht} \tag{7}$$

Where,

$E = Resilient\ Modulus\ (MPa)$

$P = Peak\ loading\ force\ (N)$

$\bar{\upsilon} = Poisson\ ratio\ (assumed\ as\ 0.4)$

$H = Recovered\ horizontal\ deformation\ of\ specimen\ (mm)$

$t = Thickness\ of\ specimen\ (mm)$

2.15 Bakelite (Phenol-Formaldehyde)

The oldest family of thermosetting polymers is the phenols. This family of polymers contains the ring-structured alcohol named phenol. Primarily, petroleum distillates like propylene and benzene are used to make phenols. When phenol and formaldehyde (CH2O) combine, the resulting monomer is used to produce phenol resins.

Hard, rigid plastic is created when three monomers combine to produce a rigid network structure. By fusing these monomers into a three-dimensional network, polymerization is obtained. Heat is necessary for the cross-linking reaction; however, it can occur in different stages. The first and second stages are A and B. As crosslinking has not yet begun in stage A, there has been little to no crosslinking of any real significance. This period is known as the pot life. Then, during the B stage, often known as the transition period, cross-linking gradually takes place. The majority of thermosetting polymers can stay in this state for up to 24 hours and are sticky and rubbery at this point (Markovic et al., 2013).

Under the brand name Bakelite, the first PF polymer for commercial use was created in the early 20th century. Typically, compression-molded electrical components like switches, distribution caps, and the like were made of Bakelite. However, phenols are still primarily used for this purpose due to their favorable characteristics, such as low moisture absorption, high-temperature resistance, high compressive strength, creep resistance, less brittle nature, and cost-effectiveness in comparison to most thermosets and few thermosetting polymers (Sperling, 2011).

2.15.1 Effect of Bakelite Content

The resilient modulus is a critical characteristic for asphalt concrete mixtures, and this study's main goal is to determine how Bakelite affects those properties. It represents structural strength and material quality and describes the elastic behavior of asphalt concrete under dynamic loading conditions. The resilient modulus test findings will indicate whether Bakelite should be added as an addition to polymer-modified asphalt if they demonstrate any improvement over the control mix.

2.15.2 HDPE

The term "high-density polyethylene" (HDPE) or "polyethylene high-density" (PEHD) refers to a thermoplastic polymer that is produced from the ethylene monomer. It is a polymer that is made up of a significant number of repeating units, which are also referred to as monomers on occasion. The typical chemical formula for it is (C2H4)n. A catalytic technique can be used to create the hydrocarbon polymer high-density polyethylene from ethylene. Here, catalysts such as Ziegler-Natta catalysts, chromium/silica catalysts (Phillips catalysts), and metallocene catalysts are frequently utilized. High-density polyethylene (HDPE) possesses linear molecules or polymer chains that are tightly packed together and display a low degree of branching. The formation of a substance that is extremely crystalline and dense takes place as a result of the presence of a powerful intermolecular force. HDPE is renowned for having a high strength-to-density ratio. In addition to being more durable and opaque, it has a higher temperature tolerance (up to 248 degrees Fahrenheit or 120 degrees Celsius for limited periods of time).

2.16 Findings on Bakelite and HDPE

It was found that a modified mix with 6 percent Bakelite by weight of the ideal bitumen content offers the highest protection against moisture damage, and rutting, and improves the stability of the HMA mix when compared to the other modifier percentages. This was true while evaluating the ideal bitumen content. After the change, the altered mix's Marshall stability and quotient values increased by roughly 22 and 44 percent, respectively. The results also revealed a 3.5% rise in the tensile strength ratio, indicating an improvement in HMA's ability to withstand moisture-induced degradation and strength retention (Ali et al., 2021).

The results of the experimental work showed that the mechanical features and performance of HMA are significantly improved by the use of a PMB binder. Additionally, it reveals that using RAP as a replacement for coarse aggregate significantly improves the mechanical properties and performance of HMA as compared to using fine aggregate as a replacement or with a control mix (AL-Ghurabi et al., 2021).

Several performance and conventional experiments were conducted to assess whether or not Nano-clay coupled with EVA and HDPE may improve the properties of asphalt. The results of the trials showed that the polymer Nano composite can increase the asphalt binder's resistance to rutting and low temperatures, regardless of whether the asphalt binder displays linear or nonlinear viscoelastic behavior (Mansourian et al., 2019).

In both the Hamburg wheel tracking test and the Dynamic modulus test, different amounts of Bakelite were used to assess the material's rutting resistance and stiffness properties. The results demonstrate that the percentage reduction in rut depth at the optimal Bakelite level of 6% was 29% for class A combinations and 38% for class B mixtures, respectively, when compared to controlled mixtures. This contrasts with the decrease in rut depth that resulted from regulated mixing. Similar to this, it was found that for class A combinations and class B mixtures, the percentage increase in dynamic modulus values at 50°C was 36 and 46%, respectively (Yousaf et al., 2014).

Bakelite and crumbed rubber were used as asphalt modifiers. The positive outcome demonstrates that the addition of 12 percent of crumb rubber and Bakelite significantly enhances the properties of the asphalt mixture, nearly doubling the Marshall Stability strength compared to the control sample, higher density, control flow within the recommended range, and higher stiffness show strong resistance against rutting and permanent deformation. The thermoplastics [crumb rubber] and [Bakelite] are two examples of materials manufactured from recycled tires. The study's conclusions indicate that Bakelite and crumb rubber both can enhance mechanical qualities. However, Bakelite shows noticeably better results than crumb rubber in terms of enhanced strength and stiffness (Ahmad et al., 2019). Asphalt was used in the experiment, along with various ratios of HDPE and LDPE. The inclusion of both forms of plastic trash reduced the density of the asphalt mixture, according to the results, because it increased the number of air gaps. The partial replacement of natural aggregates with LDPE and HDPE boosted the stability and flow characteristics by up to 15%. With plastic particles, asphalt's dynamic modulus also increased (Ullah et al., 2021).

2.17 Summary

In earlier experiments, polymers like Bakelite and HDPE were investigated as a moderator in asphalt mixtures (HMA). According to earlier studies, the kind and quantity of modifiers employed in asphalt mixes, among other variables, affect the qualities of the modified HMA. The asphalt mixture in this investigation will include Bakelite and High-Density Polyethylene (HDPE).

After their incorporation as a modifier, different performance tests will be applied to the modified mixes. Additionally, the WTT, ITS, TSR, and M_R performance tests that were employed in this study are addressed.

CHAPTER 3

METHODOLOGY

3.1 General

This chapter describes the created approach for completing the research's stated objectives. The first phase of the study examined the characteristics of bitumen modified with HDPE and Bakelite. The qualities that were examined include bitumen ductility, softening point, flash point, and fire point. In the next phase gathering the appropriate materials, preparing samples for Marshall mix designs, and using those OBCs to create Marshall and Super Pave Gyratory Samples for Performance Testing and Evaluating the Importance of Polymers as a Modifier in Asphalt Concrete Specimens including Bakelite and High-Density Polyethylene (HDPE). The Double Wheel Tracker test, Moisture sensitivity test, and ITS test were done as performance tests. A conclusion was drawn, followed by some recommendations.

3.2 Research Methodology Framework

NHA Class B mix gradation for wearing courses was chosen, and Figure 3-1 illustrates the methods used for this study. The most common standards for wearing courses in Pakistan are NHA (B). By using the Marshall mix design (ASTM D 6926, 2014), it was possible to determine the ideal bitumen content (OBC), which was utilized to create both control and modified specimens. The modified asphalt concrete specimens were prepared by a wet process using 60/70 penetration grade bitumen, 6% Bakelite, and HDPE (3%, 6%, and 9% by weight of OBC). The second step involved conducting performance tests on control and modified specimens, such as Marshall Stability, flow quotient, and retained stability (AASHTO T283) to compare their results and determine the ideal Bakelite and HDPE percentage, which demonstrated improved strength, flow, and resistance to moisture-induced damages. Ultimately, the resilient modulus (ASTM D 4123) test was carried out on the manufactured samples along with tests for moisture susceptibility, double wheel tracker, and ITS under conditions of temperature (25°C), load duration (100 ms), and load duration (300 ms).

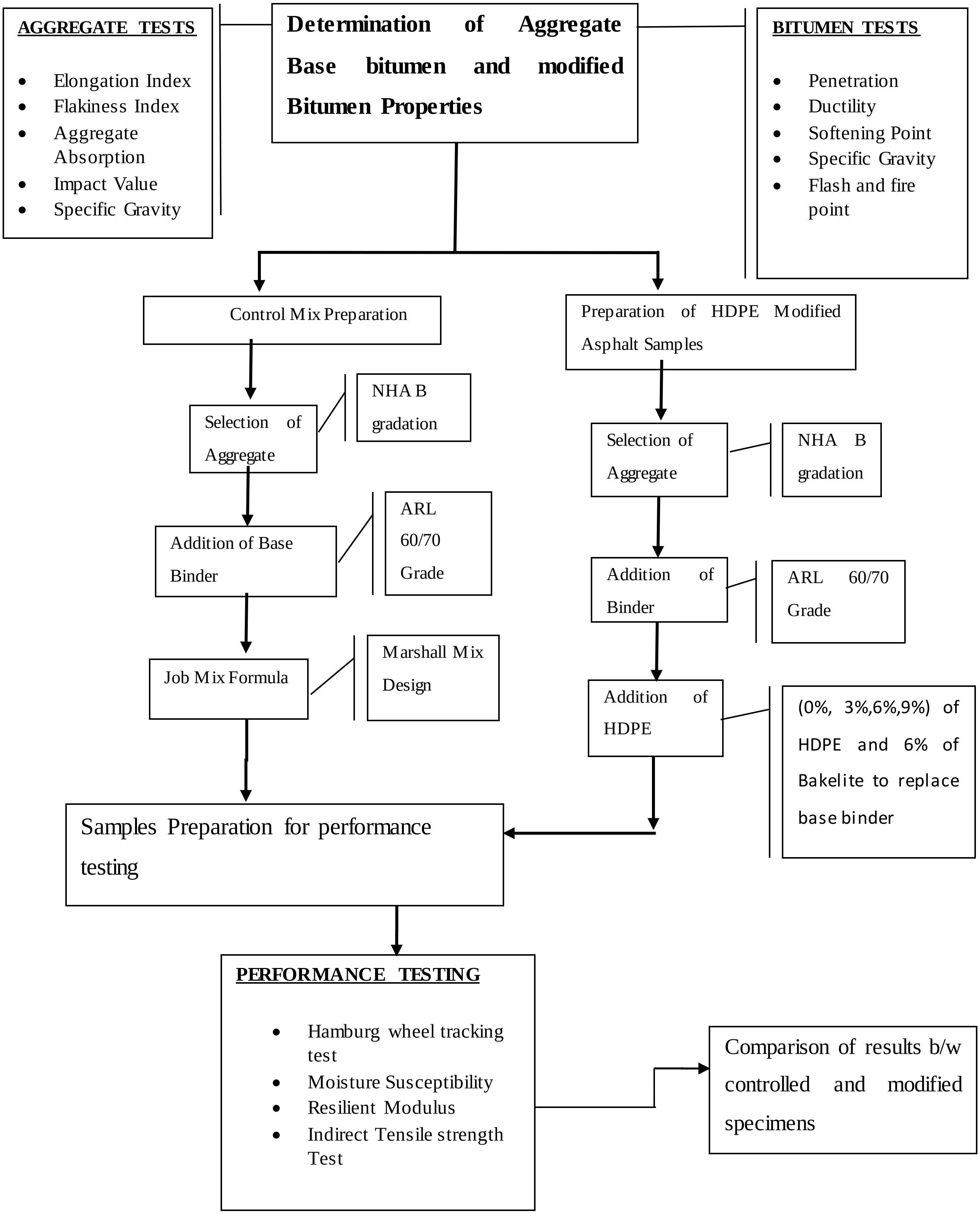


Figure 3-1 Methodology adopted

3.3 Characterization of the materials used

3.3.1 Material selection

Coarse aggregate, fine aggregate, and bitumen were among the materials used for this investigation that underwent laboratory assessment. These components were chosen by the hot mixed asphalt pavement standard specifications (ASTM D 3513-1). the dense gradation was utilized in this study. Because Hot Mix Asphalt (HMA) pavements are created utilizing this form of gradation.

3.3.2 Bitumen

The most widely used bitumen in Pakistan, 60/70 penetration grade, was the binder employed in this investigation. It came from the Attock Oil Refineries in Rawalpindi. Before sampling, the bitumen was examined for laboratory characterization as a binder using ASTM and AASHTO criteria and standards.

3.3.3 Aggregates

Nearly 95% of the resistance to permanent deformation is provided by the aggregate structure in the mix, with the remaining 5% coming from the asphalt binder. To withstand repeated load applications, aggregates create a robust stone skeleton. HMA properties are substantially influenced by the gradation, surface texture, and shape of the aggregates. Aggregates with an angular and rough texture have more shear strength than spherical aggregates with a smooth texture. Following the norms and specifications for material characterization set out by ASTM and AASHTO, mandatory testing on the employed aggregates and asphalt binder was conducted.

Figure 3-2 Crush Plant in Babuzai

3.3.4 HDPE

The HDPE was obtained in granules form from the coller factory in Peshawar.

Table 3-1 Properties of HDPE

Properties	Results
Density	0.948-0.953 g/cm^3
Softening point	122^{o}C
Tensile strength at yield	190 Kg/cm^2
Flexural modulus	8000 Kg/cm^2

3.3.5 Bakelite

The ground form of the Bakelite utilized in the study was purchased from Azmat Polymers PVT Ltd in Gujranwala. The part of the Bakelite that passed through the #100 sieve after being sieved was utilized. Table 3-2 below displays the findings.

Table 3-2 Properties of Bakelite

Properties	Results
Specific gravity	1.36
Melting point range	150-165^{o}C
Decomposition temperature range	270-350^{o}C
Sieve analysis	Passing sieve#100

3.3.6 Asphalt Binder Tests

Consistency, safety, and purity are the three characteristics of a binder that must be taken into account for construction and engineering applications. As the temperature varies, the asphalt binder's consistency alters. A consistent temperature is required to check the consistency of the asphalt binder. To assess the consistency of the bitumen binder, a penetration or viscosity test is frequently utilized. The reliability and consistency of the data are improved by additional testing, like the softening point and binder ductility tests. In order to characterize the asphalt binder, the subsequent laboratory experiments were performed.

- Penetration test
- Softening point test
- Ductility test
- Flash and Fire point test

3.3.6.1 Penetration Test

A penetration test can be used to determine whether asphaltic materials are permeable. Containers containing samples and needles are used in the penetration test. When the binder is softer, penetration values are greater. Unless otherwise stated, the temperature used during the test was 25°C, the load was 100 grammes, and the test time was 5 seconds, in accordance with AASHTO T 49-03. Three values from each of the ARL 60/70 specimens were collected after penetration tests. All values collected met the necessary penetration criteria.

Figure 3-3 Penetration test equipment

3.3.6.2 Softening point test

Bitumen is a substance with visco-elastic characteristics, however as the temperature rises, it gradually loses strength and softens. The bitumen's softening point is defined as the temperature at which a standard-size sample of bitumen can no longer hold the weight of a 3.5-gram steel ball and has weakened sufficiently for the steel balls to tumble toward the base plate. The softening point of the asphalt was calculated using the ring and ball apparatus in accordance with AASHTO-T-53 standards. Table 3-3 displays the results of the softening point test.

Figure 3-4 Softening point test equipment

3.3.6.3 Ductility test

The ductility of bitumen is a crucial aspect to take into account when describing the performance of an HMA mixture. The degree of ductility shows how bitumen responds to temperature changes. It is defined as the "distance to which a binder specimen lengthens without breaking when its two ends are tugged apart at a specific space, i.e., 5 cm/min, and at 25±0.5ºC temperature (AASHTO T 51-00). The typical circumstances and outcomes for bitumen ductility tests are shown in Table 3-3. Each specimen met the minimum 100 cm ductility requirement.

Figure 3-5 Ductility test equipment

3.3.6.4 Flash and fire Point test

The lowest temperature at which bitumen suddenly flashes in specific circumstances is known as the flash point of bitumen. The fire point is the temperature at which a substance begins to burn under specific circumstances. The flash and fire point tests were performed in accordance with the D3143/D3143M-13 standards. Therefore, it is essential to consider bitumen's applicability in light of ASTM material characterization criteria and specifications while preparing asphalt mixes. The laboratory studies stated above were done to characterize the asphalt binder (ARL 60/70). The bitumen tests are displayed in Table 3-3.

Figure 3-6 Flash and fire point test equipment

Table 3-3 Laboratory Tests Performed on the Bitumen

Test Type	Designation	Results	Standard Limits
Penetration (25°C,100g,5s) mm	ASTM D5-06	63	60-70
Softening point (°C)	ASTM D91	50	49-56
Flash point (°C)	ASTM D92	260	> 232
Fire point (°C)	ASTM D92	292	> 270
Ductility (25°C) cm	ASTM D113	123	> 100
Specific gravity	ASTM D70	1.04	1.01-1.06

3.4 Modified Asphalt Binder Tests

Modified asphalt binders were subjected to tests to evaluate their qualities. Asphalt had 3%, 6%, and 9% HDPE and 6 % Bakelite, respectively. To determine how much modification is necessary for the best outcomes in asphalt, tests including penetration, softening point, and ductility were carried out on modified asphalt.

3.5 Aggregate Testing

The center detail of the mix is the aggregate skeleton, which presents resistance to everlasting deformation and is predicted to provide a strong skeleton for resisting repetitive loads. Various laboratory studies were carried out to ascertain the overall essential characteristics of each stockpile. The following laboratory tests are included:

- Shape Test of Aggregates
- Water Absorption Test of aggregates
- Specific Gravity Test
- Crushing Value Test
- Impact Value Test of Aggregates
- Los Angeles Abrasion Test

For each test, three samples were taken, and the average was used to calculate the results.

3.5.1 Aggregate impact value test

A material's resistance to breaking determines its impact value. An impact testing machine, a tamping rod, and sieves in the sizes 1/2", 3/8", and #8 (2.36mm) were necessary equipment for determining impact value. 350g of aggregate that could pass through a 1/2" sieve but not a 3/8" sieve was used to fill the mold of the impact testing machine in three layers and tamp it 25 times (Each Layer). The sample was placed into the machine's bigger mold, and 15 blows were delivered with a hammer weighing 13.5 to 14 kg from a height of 38 cm. Afterward, the aggregate was taken out and put through sieve #8 for filtration. The amount of aggregate that made it through a 2.36mm sieve was used to calculate the impact value.

Figure 3-7 Impact value test apparatus

3.5.2 Aggregate Crushing Value test

The aggregates must be strong enough to withstand traffic loads in order for the pavement to achieve the desired level of quality and strength. The testing equipment consisted of a steel cylinder with open ends, a base plate, a 150 mm piston diameter plunger, a hole across the cylinder for lifting it with a rod, a cylindrical measure, a balance, a tamping rod, and a compressive testing machine. The sieves were used to filter the aggregates, and those that passed through at 1/2" and retained on 3/8" were chosen. The sample of aggregate was placed into that cylindrical measure in three layers, each of which was tamped 25 times after being cleaned, oven-dried, and weighed (W1). The plunger was then inserted after the sample was moved into the steel cylinder with the three-layered base plate. The load was then added to the object in the compression testing apparatus at a constant rate of 4 tons per minute until it reached a total weight of 40 tons. After being taken out of the steel cylinder, the crushed aggregate was sieved using a 2.36mm sieve. The substance that made it through this filter was gathered and weighed (W2). W2/W1 x 100 is the crushing value.

Figure 3-8 Crushing value test apparatus

3.5.3 Los Angles Abrasion Test

The aggregate's hardness is measured by this test. To prevent deterioration from heavy traffic loads, aggregate must be tough enough. The Los Angeles Abrasion Machine, a balance, a set of sieves, and steel balls were the equipment utilized for this test. For this operation, testing methodology or grading B was used. A total of 5000g (W1) of aggregate and 11 steel balls or charges were added to the equipment, with 2500 g of aggregate being retained on each of the 1/2" and 3/8" sieves. The LA Abrasion machine was turned 500 times at a speed of 30 to 33 rpm. A 1.7mm sieve was then used to sieve the material. It was noted the sample's weight (W2) as it passed through. The abrasion value was calculated using = W2/W1×100.

Figure 3-9 Los abrasion test apparatus

Therefore, when preparing asphalt mixtures, it is crucial to assess the acceptability of aggregates in light of ASTM and BS norms and specifications for material characterization. The performance tests on the aggregates used in these investigations, which used aggregate from the Babuzai quarry, are listed in Table 3-4.

Table 3-4 Laboratory Tests Performed on the Aggregates

Test Description	Specification Reference	Results	Limits
Fractured Particles	ASTM D 5821	97%	90%(Min)
Elongation Index (EI)	ASTM D 4791	3.85%	10%(Max)
Flakiness Index (FI)	ASTM D 4791	8%	10%(Max)
Aggregate Absorption	ASTM C 127 Fine	2.46%	3%(Max)
	ASTM C127 Coarse	0.95%	3%(Max)
Impact Value	BS 812	21%	30%(Max)
Los Angles Abrasion	ASTM C 131	27%	30%(Max)
Specific Gravity	ASTM C128 Fine	2.60	-
	ASTM C 127 Coarse	2.635	-

3.5.4 Water absorption and Specific Gravity Test

Specific gravity is the term used to describe the connection between the weight of an aggregate in a given volume and the weight of an equivalent volume of water. Each type of aggregate—coarse, fine, and fillers—had its specific gravities calculated. Coarse aggregate is that which passes No. 4 sieves, whereas fine aggregate is that which is retained on No. 4 sieves.

3.5.4.1 Coarse aggregate

The S.G of coarse aggregate and water absorption were calculated using tools and methods according to ASTM C 127. A sample of coarse aggregate must be weighed in three different conditions: SSD, oven-dry, and submerged. Then, using these factors, bulk specific gravity and bulk SSD specific gravity are calculated, as well as apparent specific gravity, absorption, and bulk specific gravity. Both of the course-graded stockpiles underwent the test; the results are shown in Table 3-4.

3.5.4.2 Filler and Fine Aggregate

The methods and tools outlined in ASTM C 128 were used to measure the S.G. of fine aggregates. A S.G. test was conducted on fine aggregate to measure the bulk, saturated surface dry and apparent specific gravities. The results are reported in Table 3-4.

Figure 3-10 Specific gravity testing

3.5.5 Aggregate Shape test

The form of the particles has a significant impact on the strength and workability of the asphalt mixture. It also has an impact on the amount of compaction work necessary to attain the requisite density. Therefore, the amount of elongated and flat aggregate particles was measured using the shape test. As illustrated in Table 3-4, flaky aggregate is defined by ASTM D4791 as having a dimension less than 0.6 of its mean sieve size and elongated aggregate as having a dimension greater than 1.8 of its mean sieve size.

Figure 3-11 Shape test equipment

3.6 GRADATION SELECTION

NHA (1998) requirements were followed and NHA class B aggregate gradation was employed for the gradation of highly graded surface courses. The NMAS for class B wearing coarse gradation, according to Marshal Mix Design, was 19mm (MS2). The chosen gradation is shown in Table 3-5, and Figure 3-12 depicts the gradation plotted against aggregate passing rates from the sieve and sieve size.

Table 3-5 NHA Class (B) Gradation

Sieve Designation		**NHA-B Specification Range (% Passing)**	**Our Selection**	**% Retained**
mm	**inch**			
19	**3/4**	100	100	0
12.5	**1/2**	75-90	82.5	17.5
9.5	**3/8**	60-80	70	12.5
4.75	**#4**	40-60	50	20
2.38	**#8**	20-40	30	20
1.18	**#16**	15-5	10	20
0.075	**#200**	8-3	5.5	4.5
Pan	**Pan**	---	---	5.5

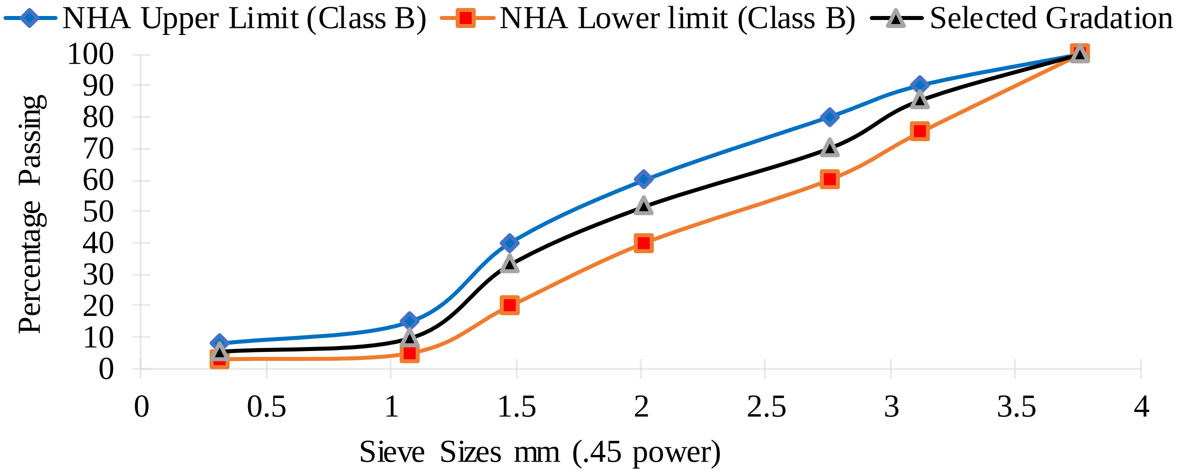


Figure 3-12 Gradation plot of NHA class B with a specific limit

3.7 Preparation of Asphalt Mixes

The weight of the aggregates is used to make asphalt mixtures with various bitumen percentages. These samples are created per the Marshall Mix Design Procedure. Samples were prepared for Performance Testing after OBC determination.

3.7.1 Marshall Specimen preparation

Using various bitumen percentages (3.5%, 4%, 4.5%, 5%, and 5.5%), the OBC for virgin bitumen was established using the Marshall Test. The aggregate must be maintained in an oven at 110°C after being sieved into the various sizes needed for the project. Marshall Mix specimens weigh a total of 1200gm. The weight of asphalt content varies according to the percentages, which range from 3.5% to 5.5% of the mix. Then, depending on the gradation method, the aggregate is made up of various sizes. OBC was determined by measuring Marshall Stability, flow, and volumetric qualities.

Table 3-6 Sample Details

Bitumen	**No of Samples**
3.50%	3
4%	3
4.50%	3
5%	3
5.50%	3
Total	**15**

The aggregates must be heated from 105°C to 110°C after sieving. According to (ASTM D 6926, 2014), 1200 grams of aggregates are required to create a Marshal sample with a 4-inch diameter. The following equation was used to determine the proportion of the mix's total weight that each specimen needed in terms of asphalt cement:

$$MT = MA + MB \tag{8}$$

$$MB = X/100(MT) \tag{9}$$

Where,

$MT = Total\ mix\ Mass$

$MA = Aggregate\ Mass$

$MB = Bitumen\ Mass$

$X = Bitumen\ Percentage$

3.7.2 Mixing of asphalt and aggregates

The mechanical mixer is advised by (ASTM D 6926, 2014) for the proper mixing of bitumen and aggregates. As a result, as soon as the dried, heated aggregates and heated bitumen were taken out of the oven, they were delivered right away to the mechanical mixing apparatus. Figure 3.13 displays the schematic design of a mechanical mixing apparatus. The temperature range for mixing was 160°C–165°C, which is similar to the temperature at which bituminous mixes are produced in Pakistan (NHA Specifications). Furthermore, the Super pave mix design specifies that the binder viscosity range for this mixture should be between 0.22 and 0.45 Pa.sec (SP-2).

Figure 3-13 Mechanical mixer

3.7.3 Conditioning of mixtures after mixing

Before compaction, bituminous mixtures should be conditioned for two hours as recommended by (ASTM D 6926, 2014). Each bituminous mix created by the mixing device was afterward put into a metal container.

3.7.4 Specimen compaction

There are three criteria for compaction according to Marshall Mix design, depending on whether the surface is ready for light, medium, or heavy traffic. For design purposes, we assume that the pavement will be subject to heavy traffic; hence, 75 blows are administered to each side of the sample to achieve compaction. After heating the aggregate with bitumen, the loose mixture is transported to a mold with a base plate. The specimen was positioned with filter paper above and below it. The specimen was inverted for the same number of blows on the other side after completing 75 on one side.

Figure 3-14 Marshal sample compactor

3.8 Specimen extraction from mold

After compaction, the mold is removed from the Marshal Compactor and given some time to cool. An extraction jack was then used to remove the specimen from the mold. The prepared samples were cooled to room temperature on a flat surface.

Figure 3-15 Sample extractor from mold

3.9 Volumetric, Stability, and Flow Determination

The volumetric parameters of the mixes, such as Voids in Mineral Aggregates (VMA), Voids Filled with Asphalt (VFA), Air Voids (VA), and unit weight, were analyzed with the appropriate formulas after obtaining the theoretical maximum specific gravity (Gmm) and the bulk specific gravity (Gmb). The Marshall Mix design criterion is displayed in Table 3.7. In order to calculate the Gmm and Gmb of bituminous pavement mixtures, ASTM D2041 and ASTM D 2726 were employed. The samples were tested using the Marshall Test apparatus for flow and stability after the Gmb determination. The samples were continuously deformed at a rate of 5 mm per minute until they fail. The maximum load in KN was used to determine Marshall Stability. The entire deformation under the highest load was measured as a flow number value in millimeters. According to the Marshall Mix design standards, the stability for a heavily utilized wearing course should not be less than 8.006 KN and the flow number should be between 2 and 3.5. The specimen was taken out of the water bath and tested right away.

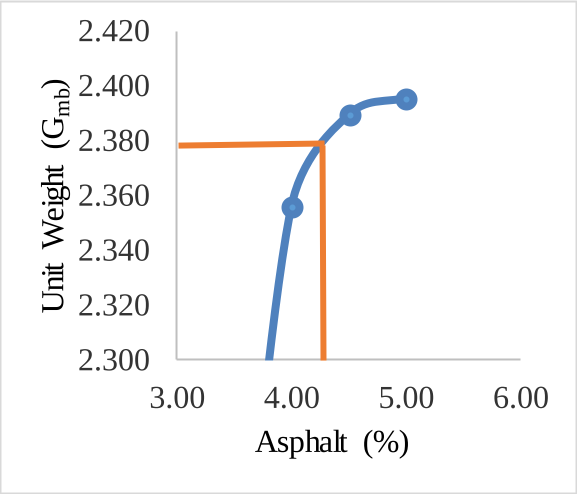
Figure 3-16 Marshall stability and flow testing equipment

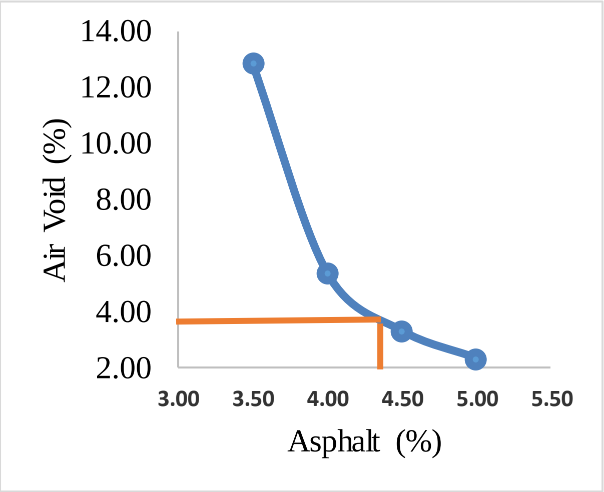
3.9.1 Volumetric properties of Hot mix asphalt

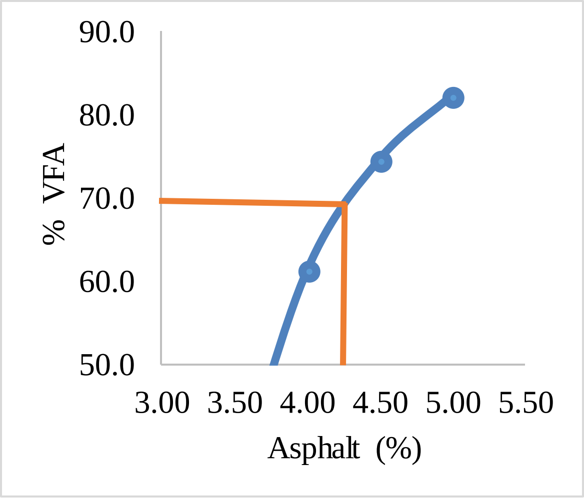
The virgin mix's volumetric characteristics, stability, and flow are shown in Table 3-7 below. To establish the OBC of the virgin mix, graphs connecting asphalt contents and volumetric characteristics, stability, and flow were created under the (MS-2 Asphalt Institute), as seen in Figure 3-17.

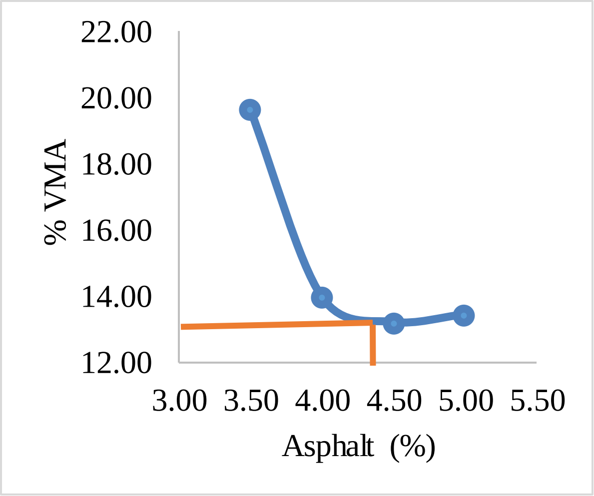
Table 3-7 Volumetric Properties of Bituminous Mix Concrete

AC %	**G_{mb}**	**G_{mm}**	**VA (%)**	**G_{sb}**	**VMA (%)**	**VFA (%)**	**Stability (KN)**	**Flow (mm)**
3.5	2.187	2.509	12.86	2.63	19.68	34.6	10.308	2.25
4	2.356	2.491	5.41	2.63	14	61.4	12.898	2.45
4.5	2.39	2.472	3.34	2.63	13.23	74.7	12.356	2.712
5	2.396	2.454	2.37	2.63	13.46	82.4	10.135	2.91


Unit Weight (G_{mb})
2.420
2.400
2.380
2.360
2.340
2.320
2.300
3.00
4.00
5.00
6.00
Asphalt (%)


Air Void (%)
14.00
12.00
10.00
8.00
6.00
4.00
2.00
3.00
3.50
4.00
4.50
5.00
5.50
Asphalt (%)


% VFA
90.0
80.0
70.0
60.0
50.0
3.00
3.50
4.00
4.50
5.00
5.50
Asphalt (%)


% VMA
22.00
20.00
18.00
16.00
14.00
12.00
3.00
3.50
4.00
4.50
5.00
5.50
Asphalt (%)

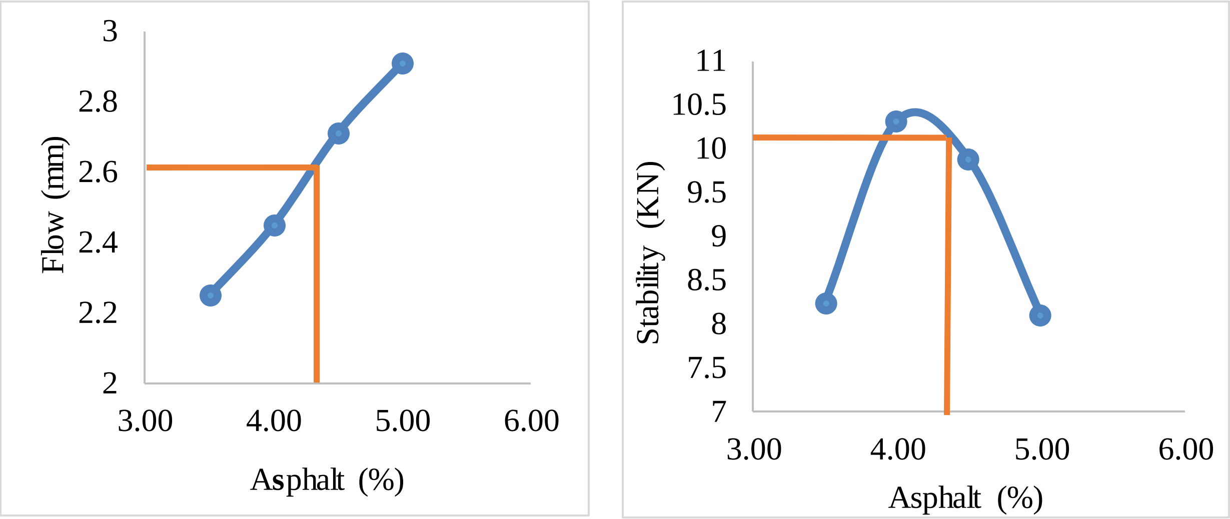


Figure 3-17 (a) to (f) Graphs of volumetric properties of the mix

OBC refers to asphalt with a 4 percent air void content. The mix has an OBC of 4.3%. The plots were used to determine the mix properties, stability, and flow according to OBC. The job mix formula for the virgin mixture is shown in Table 3-8. The Table makes it abundantly evident that every attribute, stability, and flow satisfies the requirements. The VMA shouldn't be less than 13 percent, and according to this study's calculations, it was 13.2 percent. VFA's computed value was 70% although it should be between 65 and 75 percent. Standards state that the stability value cannot be less than 8.006 KN, however in this case, it was 10.4 KN. The flow number was measured at 2.6 mm, which is within the permitted range.

Table 3-8 Job Mix Formula

% AC at 4 % Air Voids	**4.3**
G_{mb} at 4 % Air Voids	2.38
VMA at 4 % Air Voids	13.20%
VFA at 4 % Air Voids	70%
Stability at 4 % Air Voids	10.4KN
flow at 4 % Air Voids	2.6mm
Optimum AC %	4.3

3.10 Preparation of samples for performance tests

The Marshall method was used to prepare samples to be checked through UTM for moisture damage, while Super Pave Mix Design was employed to create specimens for double wheel tracker testing. At 105°C to 110°C, the aggregates were heated to constant weight. The mixing and compaction temperatures for HMA were 160°C and 135°C, respectively. The preparation of 6-inch diameter gyratory compacted specimens required 7300gm of aggregates. Samples were heated for 2 hours in the oven for conditioning after mixing aggregates and asphalt binder in the mechanical mixer. Samples were put in the gyratory mold after conditioning, and 125 rotations were employed to compact the specimens. A standard sample measuring 2.5 inches in height and 6 inches in diameter was cut from each specimen for the wheel tracker test using a saw.

3.11 Rutting Analysis of Samples

Rutting is one of the most common permanent deformations of pavement that is brought on by cyclic traffic loads. It is characterized by the accumulation of small deformations in the pavement material along the wheel paths. To analyze rutting propensity, the specimens were assessed utilizing a Double wheel tracker to ascertain their resistance to persistent deformation. A steel wheel with a diameter of 203.2mm and a width of 47mm can be moved across a test specimen by the electrically powered DWT. The steel wheel weighs 1581 pounds, and the average contact stress generated by the wheel contact, with a contact area of 970 mm2, is 0.73 MPa. Similar to how the steel wheel's contact pressure creates the influence of the rear tire of a double axle. The contact area grows larger and the contact stresses change as the rut depth increases. The steel wheel moves backward and forwards over the sample. The sample must be passed by the DWT steel wheel about 60 times per minute. The Centre of the sample is where the wheel travels over the specimen at a speed of almost 1 foot per second. Rutting experiments on dry, wet, and air modes can be performed with the aid of DWT. The dry mode was employed in this study to assess the asphalt mixtures' rutting susceptibility. By modifying the DWT under the anticipated test conditions, these three modes can be utilized. The Double Wheel-Tracking Device used for Rutting Tests is seen in Figure 3-18. Two 2.5-inch-thick specimens were created by sawing the samples from the top and bottom surfaces before the test. The silicone mold from the wheel tracker tray was used to cut these specimens.

The sample was placed on a steel tray and stored underneath the wheel with a bolt. The wheel tracker system was activated. After then, the software received the data of the sample. The wheel was configured to rotate at 25 ppm (passes per minute). To assess the rutting potential of asphalt mixtures, including bitumen (ARL 60/70), the number of passes was set to 10,000 (5000 cycles). To determine rut damage at a temperature of 40°C, the wheel tracker was employed in the dry mode. The wheel on the mounted specimen began to advance and retract once the test begins. The laptop attached to the machine displayed the number of passes. Two passes were considered to be one full to and fro rotation of the wheel. The LVDT (Linear Variable Differential Transformer) simultaneously monitors the wheel's motion and the impression of a rut on the unit in millimeters. When the required number of passes was completed, the machine automatically shuts off. The results were kept for later use.

Figure 3-18 Hamburg wheel tracking test equipment

3.11.1 Stripping Inflection Point (SIP) via IOWA DOT Method

The Iowa DOT's recommendations are used to determine the Stripping Inflection Point (SIP) (Schram et al., 2012). A 6-order polynomial regression is used in the first step of the procedure to fit the curve. The polynomial's first derivative then encounters a local minimum close to the test's beginning, at which point a creep slope is inserted. As the first derivative approaches the test's conclusion and reaches a local maximum, a stripping slope is inserted into the equation. In conclusion, the SIP is shown as the quantity of passes corresponding to intersecting slopes.

3.11.2 Quantitative evaluation of the findings of the HWT test for moisture susceptibility

It is generally accepted that post-compaction, visco-plastic deformation, and moisture deterioration each contributed to the rutting that happened during the HWT test (stripping) (Yildirim et al., 2007). The post-compaction phase, as depicted in Figure 3-19, begins at the commencement of the test and terminates after 1000 cycles. Bitumen's visco-plastic behavior causes compaction from 1000 cycles onto the Stripping inflection point, and after that, moisture damage causes additional deformation in which aggregates lose their connection with the binder. The final phase starts at SIP and concludes when the sample shows 12.5mm of rut depth. To discriminate between these three behaviors and assess the impact of moisture damage on its own, a novel way of analysis is proposed in this work (Lv et al., 2022).

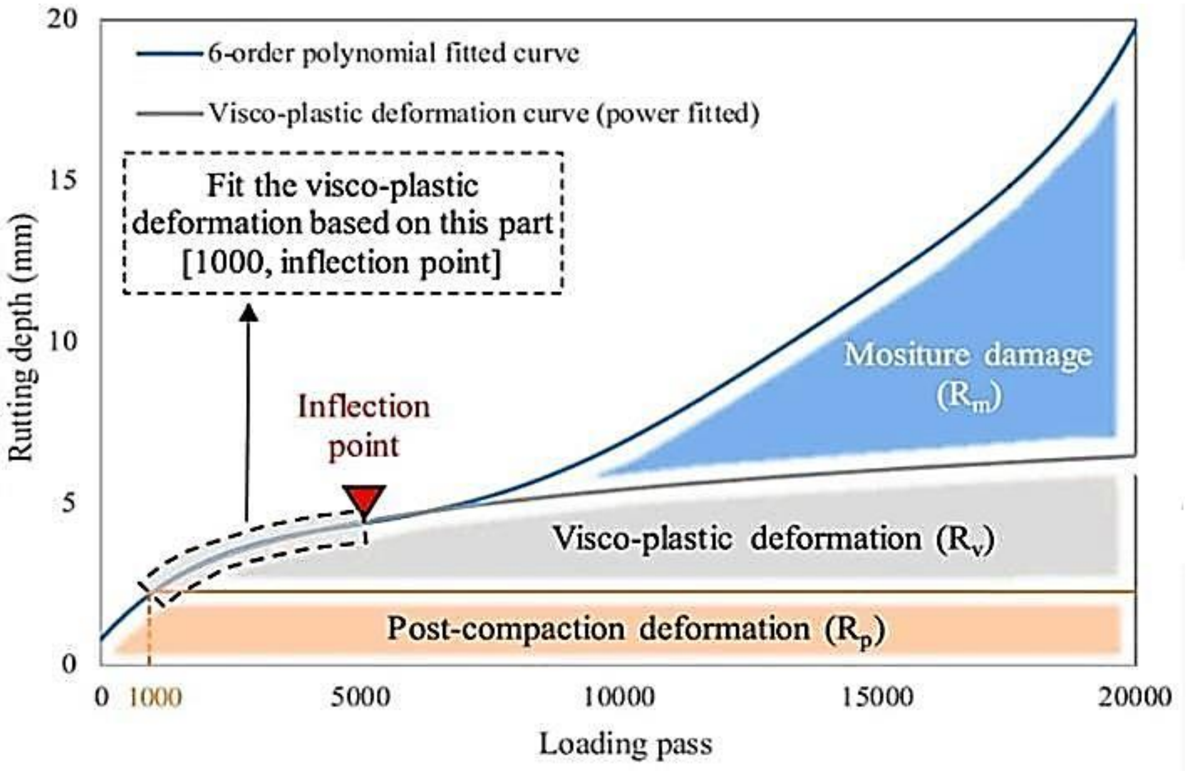


Figure 3-19 Stages of rutting behavior

3.12 Moisture Susceptibility Testing

The moisture susceptibility test was conducted using ASTM D6931 (Moisture-Induced Damage Resistance of Compacted Hot-Mix Asphalt). For each blend, three unconditioned samples were analyzed. Before testing, these unconditioned samples were immersed in a water bath with a temperature of 25°C (77.8°F) for an hour. Three conditional specimens per mix were tested in a separate batch. Following ALDOT-361, samples were saturated, then put in a water bath at 60°C (140.8°F) for 24 hours, followed by an hour in a water bath at 25°C (77.8°F). Both conditioned and unconditioned specimens were loaded 50 mm/min diametrically. Then, using the specimen's dimensions and failure load, the tensile strength for each specimen was determined. To determine the tensile strength ratios, the average conditioned tensile strength was divided by the average unconditioned tensile strength. The employed tensile strength ratio had to be at least 80% (minimum) to be considered acceptable. The equation was used to calculate each subset's tensile strength.

$$St = 2000P/\pi Dt \tag{10}$$

Where:

$St = Tensile\ strength, kPa$

$P = Maximum\ load, N$

$t = Specimen\ height\ before\ tensile\ test, mm$

$D = Specimen\ diameter, mm$

TSR, which shows the potential for moisture damage, is obtained by dividing the tensile strength of the conditioned sample by the tensile strength of the unconditioned sample. The TSR for each mix is calculated using the equation below.

$$TSR = [S2/S1] \qquad (11)$$

Where:

$S1 = Average\ tensile\ strength\ of\ unconditioned\ subset, and$

$S2 = Average\ tensile\ strength\ of\ conditioned\ subset.$

Figure 3-20 Universal testing machine (UTM)

3.13 SUMMARY

The testing of aggregate, bitumen, and modified bitumen is explained in this chapter. Samples of the bituminous mix were then made using the material. OBC was estimated based on the mix's volumetric characteristics. The samples for performance testing, such as the moisture susceptibility and rutting test, were subsequently prepared using OBC. The test procedures for rutting and moisture susceptibility were described at the end of the chapter.

CHAPTER 4

DATA ANALYSIS AND RESULTS

4.1 Introduction

This chapter presents the study and findings of conventional and modified asphalt using Bakelite and HDPE. The conventional specimen is made using a 60/70 grade binder from ARL and aggregates from Babuzai Katlang. Modified specimens contain 6 percent Bakelite and (3, 6, and 8 percent) HDPE in HMA relative to the weight of bitumen. After the Marshal Samples and Super pave gyratory samples had been prepared in line with standards, as was discussed in the previous chapter, performance testing was conducted. Rutting using HWTT, ITS and TSR (tensile strength ratio) Test using UTM-25, and Resilient Modulus test to measure the Stiffness using UTM-25 were completed as performance tests to evaluate the performance improvement of modified and traditional AC mixes.

4.2 Results of Bitumen Properties

The results of bitumen's physical characteristics are displayed in Table 4-1. Results demonstrate that modified and conventional specimens adhere to AASHTO and ASTM criteria.

Type of Test	**Asphalt ARL 60 / 70**					
	Standards	**Base Binder**	**6%Bakelite**			
			0%HDPE	**3%HDPE**	**6%HDPE**	**9%HDPE**
Penetration (dm)	ASTM D5 AASHTO T49	62	56.4	50.3	44.2	38.35
Flash & Fire Point(°C)	ASTM D92 AASHTO T53	261 & 294	206 & 222	220 & 233	245 & 267	280 & 299
Softening Point (°C)	ASTM D36 AASHTO T53	50	55.3	65.2	68.5	70.8

Figure 4-1 Physical Properties of Bitumen

4.3 Results of Aggregate Properties

For this research project, aggregates from the Babuzai plant were purchased. The outcomes of each test run on aggregates are displayed in Table 4-1. The results further show that the aggregates met AASHTO and ASTM requirements.

Table 4-1 Physical properties of Aggregates

Test Description	**Specification Reference**	**Results**	**Limits**
Fractured Particles	ASTM D 5821	97%	90%(Min)
Elongation Index (EI)	ASTM D 4791	3.85%	10%(Max)
Flakiness Index (FI)	ASTM D 4791	8%	10%(Max)
Aggregate Absorption	ASTM C 127 Fine	2.46%	3%(Max)
	ASTM C127 Coarse	0.95%	3%(Max)
Impact Value	BS 812	21%	30%(Max)
Los Angles Abrasion	ASTM C 131	27%	30%(Max)
Specific Gravity	ASTM C128 Fine	2.60	-
	ASTM C 127 Coarse	2.635	-

4.4 Marshall Mix Design

OBC (optimal bitumen content) was calculated using bitumen content at 4% air spaces. The OBC was discovered to be 4.3%, which equates to 4% air space. Using the presented graphs, all additional volumetric characteristics were calculated for the 4.3 percent binder content. The outcomes were compared to the requirements for NHA design. Every result fell within the parameters of the design. Table 4-2 includes information on the outcomes.

Table 4-2 Optimum Binder Content

% AC at 4 % Air Voids (Optimum)	**4.3**
G_{mb} at 4 % Air Voids	2.38
VMA at 4 % Air Voids	13.20%
VFA at 4 % Air Voids	70%
Stability at 4 % Air Voids	10.4KN
flow at 4 % Air Voids	2.6mm

4.5 ITS Test using UTM Machine

According to ASTM D6931-07, the indirect tensile strength test evaluates the tensile qualities of compacted concrete mixtures. The ratio of the tensile strength of unconditioned vs conditioned specimens is known as moisture susceptibility. ALDOT 361 was utilized to condition the samples, which were then deposited in a 60 °C water bath for 24 hours. Three Marshall duplicates of each %age of the Bakelite and HDPE mixture were performed before tensile strength testing. Tests were performed on specimens both with and without moisture conditioning. The testing was carried out on a universal testing machine with monotonic loading, and the samples had dimensions of 100 mm in diameter and 65 mm in thickness. Samples were again conditioned for one hour at 25°C in UTM after being conditioned for 24 hours at 60°C. The conditioned and unconditioned strength values for the tested combinations are shown in Table 4-4. The monotonic loading schematic diagram of the TSR is shown in Figure 4-1. Figure 4-2 contrasts the strengths of the control mixture, which has not undergone any modification, with modified mixtures that have undergone conditioning and contain varying percentages of Bakelite and HDPE. The tensile strength ratio is shown in Figure 4-3, and Figure 4-4 displays the trend in values, which displays the sets of values, or confidence intervals (CI), that are most likely to contain the true mean for each %age. The findings indicate that **6% Bakelite and 6% HDPE** content gives the best results of a **15.3%** Increase in TSR compared to the control mix.

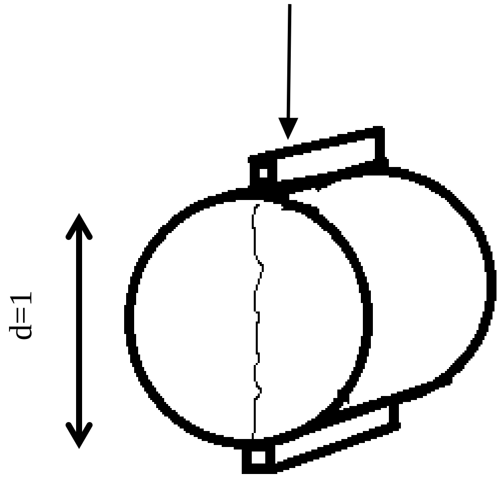


Figure 4-2 Tensile Strength Ratio schematic

Table 4-3 Tensile Strength Ratio Values

Tensile Strength Ratio of HMA							
Modifier	**Indirect Tensile Unconditioned Strength, S1 (KN)**			**Indirect Tensile Conditioned Strength, S2 (KN)**			**TSR = S2/S1 (%)**
	Specimen 1	**Specimen 2**	**Mean**	**Specimen 1**	**Specimen 2**	**Mean**	
0 % BK	5.179	5.179	5.179	4.1432		4.1432	80.00
6 % BK	5.258	5.258	5.258	4.36		4.36	83.00
6%BK+3% HDPE	6.135	6.135	6.135	5.37		5.37	87.60
6%BK+6%HDPE	6.452	6.452	6.452	6.149		6.149	95.30
6%BK+9%HDPE	6.416	6.416	6.416	5.608		5.608	87.41

The space content of air voids for bitumen in AC mixtures is increased by the inclusion of High-Density polyethylene (HDPE) and Bakelite. However, the combination of **6% Bakelite and 6% HDPE** has enhanced the moisture susceptibility of AC mixes, and the results show that this combination has surpassed all others.

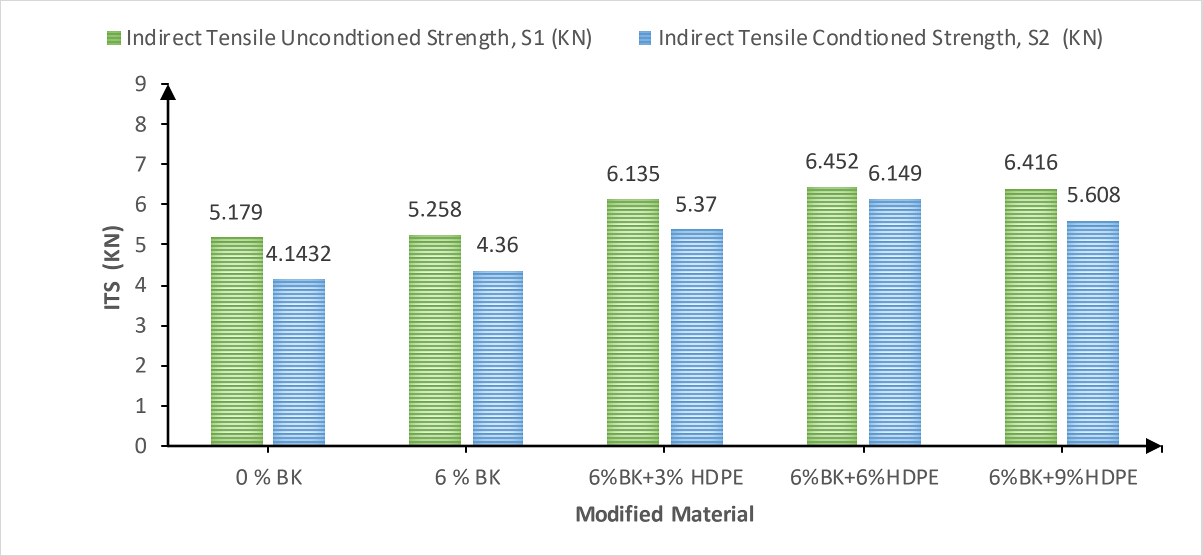


Figure 4-3 ITS Conditioned and Unconditioned comparison

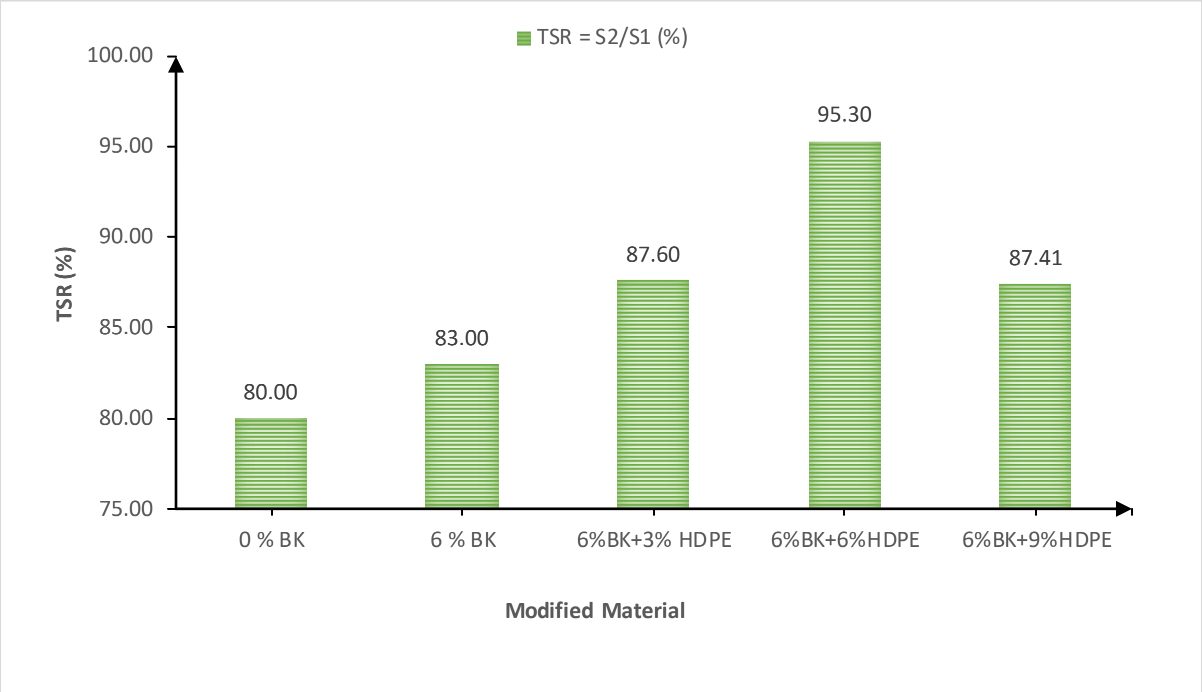


Figure 4-4 Tensile strength ratio of Bakelite and HDPE-modified HMA

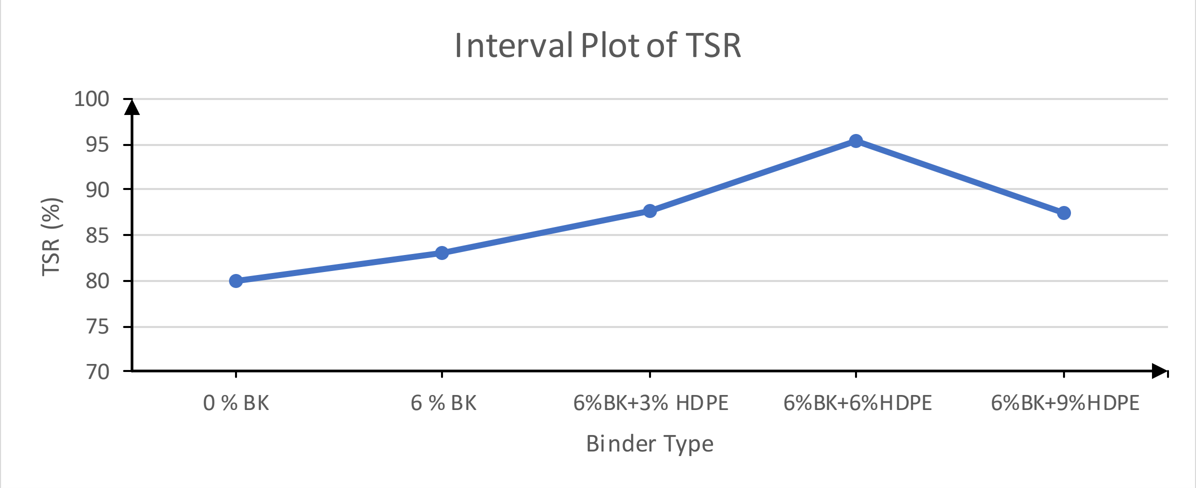


Figure 4-5 Tensile strength ratio trend

4.6 Resilient Modulus Results

The resilient modulus measurement can be used to assess how the roadway structure responds to loads from moving cars. When a material is subjected to cyclic loading, a relative measure of mixture stiffness known as resilient modulus is recorded. The resilient modulus test is used to assess the material quality and collect information for pavement design. Resilient modulus is an important statistic for studying pavement response to traffic stress and predicting pavement performance.

For the stiffness modulus performance test under (ASTM D 4123) three copies of each %age of the Bakelite and HDPE combinations are prepared. The software that comes with the test equipment calculates the modulus for each load pulse. As illustrated in Figure 4.5, the IDT for resilient modulus is carried out on a cylindrical specimen with conventional Marshall specimen parameters (Dia 100mm and Thickness 65mm) using a haversine waveform and a force applied vertically in the vertical diametric plane. The resilient modulus can be determined by applying a load and measuring the horizontal elastic deformation that results from that load. This load and deformation criterion should be taken into account for each pulse when calculating the resilient modulus. Using the equation for the MR value given below:

$$M_R = \frac{P\,(0.27+\upsilon)}{(\Delta h)\,t} \tag{12}$$

Where:

$Mr = Resilient\ Modulus$

$P = Cyclic\ Load$

$t = Thickness\ of\ Specimen$

$\Delta h = Recoverable\ horizontal\ deformation$

$\upsilon = Poisson\ ratio$

Figure 4.6 displays respectable values of resilient modulus of control and Bakelite and HDPE-modified AC mixes. Figure 4.7 depicts the trend in data, which demonstrates the sets of values, or confidence intervals (CI), that are likely to include the true mean for each %.

The results indicate that the combination of 6% Bakelite and 6% HDPE produces the best outcomes. According to the findings, this modifier combination increased the **M_R by 1.7 times** compared to the original control mix. The values increase but after the 6% HDPE, the values start decreasing. This result indicates that **6% Bakelite and 6% HDPE** is the better combination.

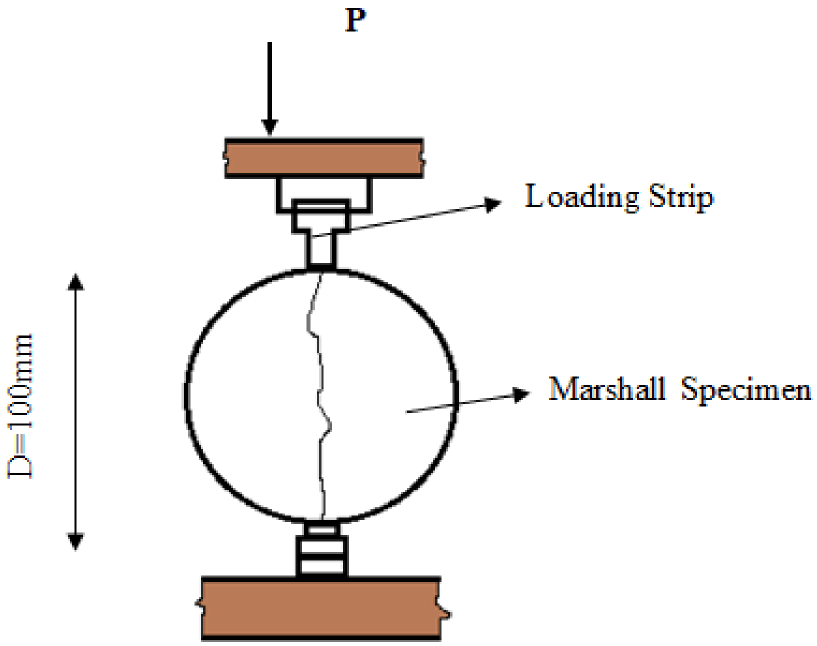


Figure 4-6 Schematic diagram for MR

Table 4-4 Average Resilient Modulus Values

Description	Average Resilient Modulus (MPA)
60/70 Grade Bitumen	3387
6% Bakelite	3742
6% Bakelite + 3% HDPE	3841
6% Bakelite + 6% HDPE	4866
6% Bakelite + 9% HDPE	4332

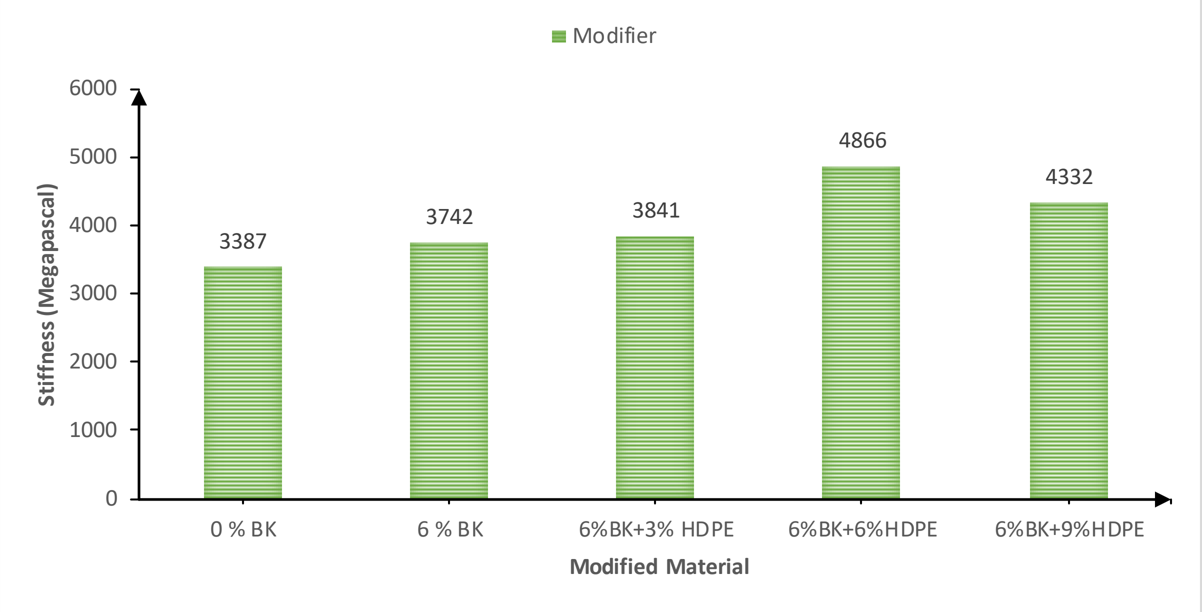


Figure 4-7 Resilient modulus values

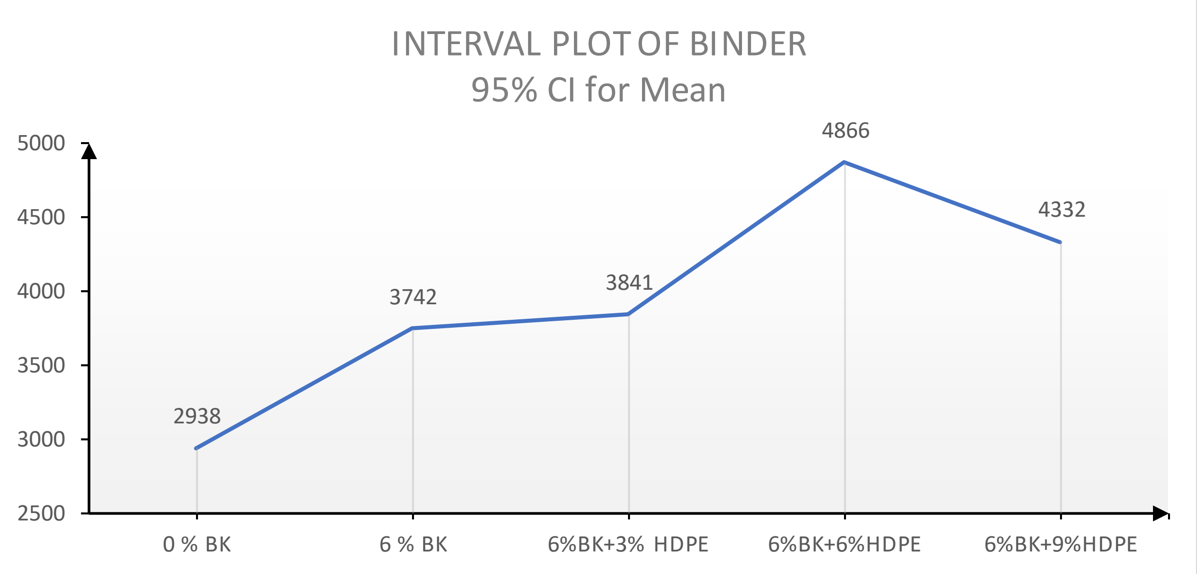


Figure 4-8 Trend Graph of Resilient Modulus

4.7 HWTT Test

Wheel tracking experiments were carried out using Super pave gyratory compacted samples with a diameter of 6" and a height of 2.5 " in order to examine the relative rut depth of the original and modified HMA samples. The software measured and displayed the rut depth after subjecting the samples (Control 60/70 and modified with 6 percent Bakelite and 3 percent, 6 percent, and 9 percent HDPE) to 5000 cycles at a speed of 25 rpm. The test results for rut depth for each specimen vs different modifier percentages throughout the period of 5000 cycles are shown in Table 4-6. The rut depth against each Bakelite and HDPE combination illustrated in Figure 4.8 is plotted. The trend among values is shown in Figure 4-9, along with the sets of values, or confidence intervals (CI), that are most likely to contain the true mean for each %age.

As shown in Table 4-6, 10 samples with 6% Bakelite and different HDPE percentages were organized for the HWTT test. These samples were saw-cut to assess the possibility of rutting with a wheel tracker. All the samples have high rut resistance.

Table 4-5 Hamburg Wheel Tracking Test Result

Modifier	**Rutting Depth(mm) at 40°C and 5000 cycles**
0%Bakelite + 0%HDPE	3.28
6% Bakelite + 0%HDPE	2.68
6% Bakelite + 3%HDPE	2.42
6% Bakelite + 6%HDPE	2.38
6% Bakelite + 9%HDPE	1.89
Rut depth shall be less than 12.5mm	

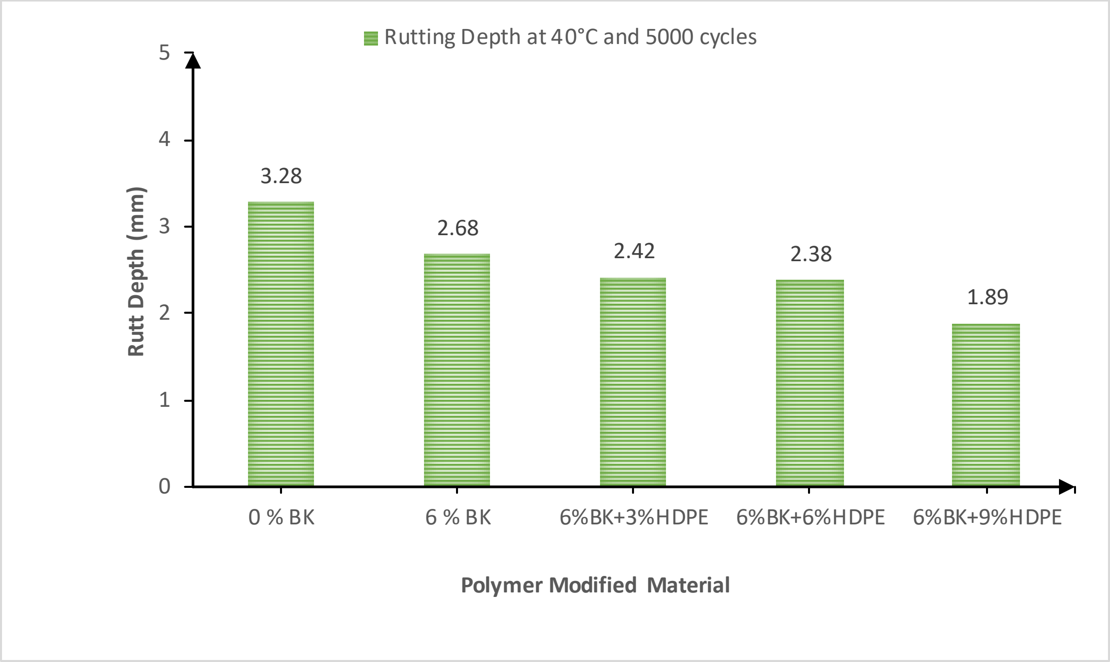


Figure 4-9 Rut depth results

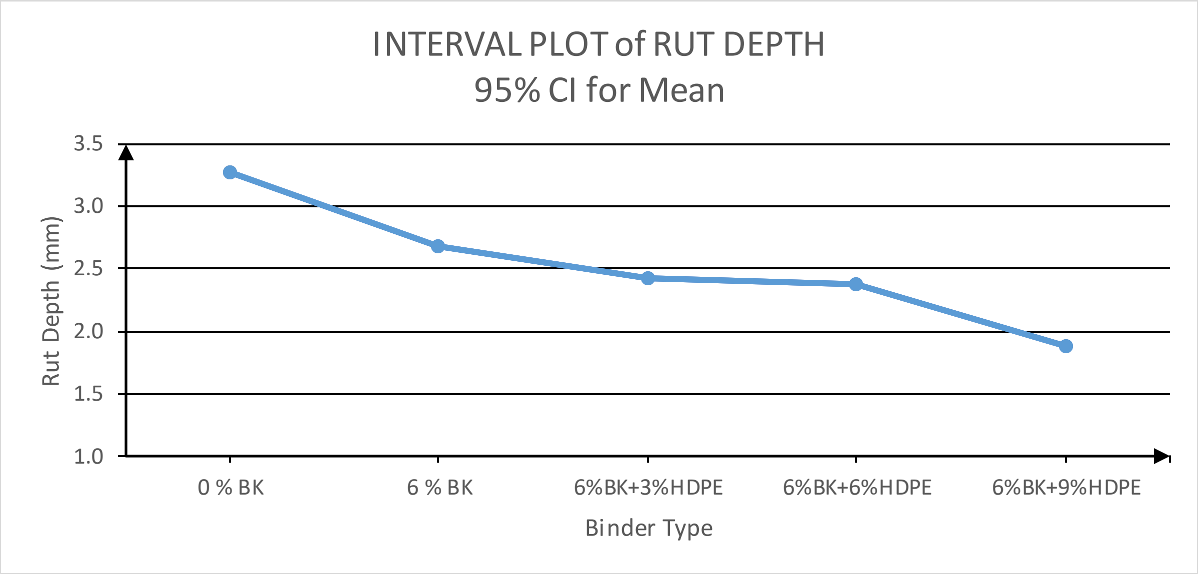


Figure 4-10 Trend Graph for Rut Depth

4.8 Summary

It is evident from the study's findings that adding Bakelite and HDPE to asphalt concrete mixtures can enhance the properties of the asphalt. In comparison to other conceivable combinations, it has been discovered that adding 6 percent Bakelite and 6 percent HDPE yields the highest performance. It has been reported that the material's stiffness, resilience to rutting, and susceptibility to moisture have increased as a result of the addition of Bakelite and HDPE. The results show that a **6% Bakelite and 6% HDPE** composition offers the highest performance, with a **15.3%** increase in TSR over the control mix. The inclusion of this modifier combination, according to the results, increased the **MR by 1.7** times over the original control mix. According to rutting tests, adding **6% Bakelite and 9% HDPE** can reduce rutting by up to **42.3%** compared to using a control mixture.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of research

The main aims of this study were to describe the characteristics of the modified and unmodified asphalt mixtures. The bitumen of the penetration grade 60/70 that was obtained from ARL and aggregate from Babuzai were the main components of the unaltered mixtures employed in this study. Bitumen penetration grade 60/70 from ARL, Babuzai aggregate, Bakelite and HDPE were used to prepare modified mixtures. HDPE was purchased from Peshawar. Bitumen was changed by the addition of 6 percent Bakelite and HDPE in various amounts of 3 percent, 6 percent, and 9 percent. Both conventional and performance tests were conducted after the typical sample preparation outlined in prior chapters. The performance tests that were carried out include the Wheel Tracking Test to gauge the rutting resistance of both modified and unmodified asphalt concrete mixes, the Indirect Tensile Strength Test to assess moisture susceptibility, and the Resilient Modulus Test to assess stiffness.

5.2 Conclusions

Based on the test results the following conclusions have been extracted.

- This research study verifies the use of Polymers in asphalt as the properties of asphalt increase with its addition.
- **6% Bakelite and 6% HDPE** composition offer the highest performance, with a **15.3%** increase in TSR over the control mix.
- **6% Bakelite and 6% HDPE** composition increased the **MR by 1.7** times over the original control mix.
- Adding **6% Bakelite and 9% HDPE** can reduce rutting by up to **42.3%** compared to using a control mixture.

5.3 Recommendation

- In light of the aforementioned findings, it is suggested that a 6 percent Bakelite, and 6% HDPE content be used for increased strength, stiffness, resistance to rutting, and moisture susceptibility.
- It is recommended to use Bakelite as a fine aggregate instead of mixing it in Bitumen.
- This study is based on NHA “A” Class gradation. For further studies, it is recommended to use NHA “B” class gradation.
- Aggregates other than Babuzai can be used for further research such as Margalla etc.
- For new research it is recommended to check HDPE for Low-Temperature Stiffness Performance using BBR.
- Compositions of 6% Bakelite with the addition of other percentages of HDPE beyond 9% are recommended for further study to know the increase or decrease in Rut resistance with higher percentages of HDPE.

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