PERFORMANCE EVALUATION OF BAKELITE AND NANO-CLAY MODIFIED ASPHALT CONCRETE MIXTURES

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A thesis submitted in partial fulfilment of

the requirements for the degree

Master of Science

In

Transportation Engineering

MILITARY COLLEGE OF ENGINEERING (MCE) RISALPUR

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY (NUST)

SECTOR H-12, ISLAMABAD,

PAKISTAN. (2022)

THESIS ACCEPTANCE CERTIFICATE

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DEDICATION

This thesis is dedicated to our **Holy Prophet Muhammad (Peace be Upon Him) and His Companions**; minaret of knowledge and wisdom, my beloved **Parents** who always supported me through thick and thin of my life, my beloved **siblings**, my **wife**, who supported me morally and always motivated me and my respected **advisor Brig Dr Muhammad Irfan**, who's guidance made me able to finish my research work.

ACKNOWLEDGEMENT

I am grateful to Almighty Allah, who enabled me to complete this research. The author would first like to acknowledge the Military College of Engineering for sponsoring this research project.

I would like to extend much appreciation and gratitude to my advisor, Brig Dr. Muhammad Irfan, whose countless inspirations and guidance made it possible to complete my research work. In addition, Brig Dr. Sarfraz Ahmed, in the capacity ofthe committee member, gave me advice and feedback throughout the thesis process. I would like to pay gratitude to the academic members of the Military College of Engineering who provided a lot of knowledge during the academic session in the postgraduate program.

In the end, I express my solemn gratitude with a genuine sense of reverence to my parents for their encouragement, heartfelt prayers, and kind wishes for the successful completion of my studies along with this research work. Mainly, I want to thank my parents from all my heart for always being with me and for motivating meat every point of my life. Without their support, nothing would have been possible.

(*Engr. Naqeeb Ullah Khattak)*

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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

Utilizing polymers complemented with nanomaterials has received great attention to balance the antagonistic effects of polymers while enhancing the performance of the asphalt concrete mixtures. This study investigates the impact of Bakelite polymer and Nano-clay (NC) as an additive on various mechanical properties such as resilient modulus, rutting propensity, and moisture susceptibility of asphalt concrete mixes. The modified asphalt concrete mix was prepared by a wet process that involved the direct mixing of bitumen (60/70 penetration grade) with Bakelite and Nano-clay at high temperature (160˚C-165˚C), followed by adding aggregates (Babozai aggregate) during the mixing process. NHA Class B gradation was employed to find optimum bitumen content (OBC) using Marshall mix design. The modified asphalt concrete specimens were prepared with the Nano-clay percentages (2%,4%,6%, and 8%) with fixed 6% Bakelite. Both modified and unmodified (controlled) samples were fabricated for a series of performance tests, including Resilient Modulus (M_R)/ Indirect Tensile Strength Test (ITS), Moisture Susceptibility/ Tensile Strength Ratio (TSR), were performed using Universal Testing Machine UTM-25. In contrast, the rutting test was also performed using Hamburg Wheel Tracking Test (HWTT). Results indicated that the addition of Bakelite and NC improved the HMA mechanical properties such as enhancing M_R, stability, stiffness and increased resistance against rut susceptibility and moisture damage. In addition, it has been observed that 6% Bakelite with 4% NC content by weight of bitumen in asphalt mixtures outperformed other Bakelite and NC percentages. Results showed that adding this combination of modifiers has enhanced the M_R by 1.6 times that of the controlled mix whereas the rutting test also found that adding 6% Bakelite and 4%Nano-clay could reduce the rutting up to 28.9 % compared to the controlled mix. The findings also indicate that 6% Bakelite and 4% NC content performed the best with a 17.98% increase in TSR compared to the controlled mix. The experimental investigation of these conditions and their interaction were analyzed by the Analysis of Variance (ANOVA) experiment with Tukey's Analysis. The statistical analyses showed that Bakelite and NC content was the most significant factor influencing the resilient modulus and ultimately, the strength of the asphalt concrete mix.

CHAPTER 1

1. INTRODUCTION

1.1 BACKGROUND

In Pakistan, roads are experiencing extreme rutting, moisture damage and stripping, Due to the prevailing traffic conditions where axle loads and traffic intensities are on the rise along with the harsh climatic conditions which include very high temperatures in summer season. To overcome this high quality asphalt is required. Unfortunately in Pakistan, the highways are made using 60/70 or 80/100 penetration grade asphalts which are not suitable for highway pavements and do not perform under extreme loading and temperature conditions. These penetration graded asphalts fail prematurely mainly due to brittle cracking when the temperatures are low and plastic deformation at extreme temperatures. This is because these asphalts contain high amount of wax, which imparts softening when the temperature is high and reduces stability, adhesion and consequently the strength (Al-Hadidy et al., 2011). Therefore, it is essential to shift either to the super-pave design or we can modify the asphalt which is being produced by our refineries. Shifting to super-pave is costly, on the other hand using locally available modifiers like polyethene bags, Bakelite, fibers, rubber and other cheap additives is cost effective. Research carried out on additives indicated that among their different types, polymers proved to be the most significant (Ali et al., 2021). In addition, polymer modification of asphalt possesses a great potential for applications in the field of pavement design. The benefits include reduced rutting potential, increased useful life and reduction in thickness of the pavement (Al-Hadidy et al., 2011). The polymer addition usually results in higher degree of stiffness in asphalt accompanied with enhancement in temperature and moisture susceptibility which results in increased rut resistance. Polymers are also used as a coating material for aggregates where they increase surface roughness and also make aggregates moisture resistant.

The polymer family is sub divided into many types but only two basic types are used pavement modification. These include plastomers and elastomers. Bakelite is classified as plastomer. Plastomers decrease the elasticity of bitumen and low temperature flexibility is decreased but strength is increased at higher temperatures due to increase in stiffness and decrease in penetration (Gorkem et al., 2009)

In the production of modified asphalt, two procedures are normally followed. In the wet method, the modifier and asphalt are mixed and heated to melting points, thus producing modified asphalt. The heated aggregates are then mixed with this modified asphalt to create asphalt concrete. The modifier is incorporated into the heated aggregates during the dry process and thoroughly blended, followed by the addition of a binder in the heated liquid state during the mixing process (Olard et al., 2010) .

This study investigates the effects of Bakelite and Nano-clay as a modifier based on performance parameters including resilient modulus, indirect tensile strength, rutting test, and moisture susceptibility of asphalt concrete mixes. The modified asphalt concrete specimens were prepared with the Nano-clay percentages (2%, 4%, 6%, 8%) 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 optimum bitumen content (OBC) was found using the Marshall mix design (ASTM D 6926, 2014), which was then used in the preparation of both conventional and modified samples. Performance tests including resilient modulus, indirect tensile strength, rutting test, and moisture susceptibility of asphalt were performed to check the comparative performance of properties of conventional and modified mixes.

1.2 PROBLEM STATEMENT

In Pakistan, highway agencies invest heavily every year in pavement design, construction, maintenance, and rehabilitation to provide the desired service level by reducing distress. However, permanent deformation also called as rutting is the most damaging factor for flexible pavements in Pakistan. Rutting is a vertical deformation in the wheel path caused by a weak interlock between aggregate and bitumen. Improper mix design, such as too much asphalt or insufficient aggregate particles, can also result in rutting. Rutting in a flexible pavement could shorten its service life and pose several safety concerns.

As a road user, this study is essential because it provides long-term road serviceability using high-quality pavement. Provide a durable and robust pavement that will not fatigue or rut to prevent accidents. Increasing the durability of an asphalt pavement can be accomplished in one of two ways, either by using a thicker layer of asphalt or enhance the property of asphalt through different kinds of modifiers (Moghaddam et al., 2011). The HMA mixtures can be improved in several ways. Pavement structures can be made more durable by incorporating additives such as polymers and nanomaterials modified binder into HMA, which will increase pavement structure’s durability because additives can captivate distresses applied continuously by vehicles.

The purpose of this study is to assess how well the HMA mix design performs using nanomaterial (Nano-clay) and Bakelite, thus, determining its effectiveness by maximizing the resilient modulus, and other stability factors while minimizing rutting in HMA pavement. This study compares Bakelite and Nano-clay modified binder on Hot Mix Asphalt using Superpave 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 2%, 4%, 6%,and 8% of Nano-clay. Performance test for rutting behavior of different percentages of Nano-clay with 6% Bakelite are done by Hamburg Wheel Tracking Test. Marshal samples are also prepared to carry out tests to find resilient modulus (M_R), ITS, and moisture susceptibility using Universal Testing Machine (UTM). From the analysis of experimental results, Optimum nanomaterial and polymer percentage in HMA was obtained that has a substantial effect on resilient modulus, rut resistance, and moisture susceptibility. The experimental matrix for Marshall mix design and performance testing is shown in Table 1.1, 1.2 and 1.3 given below which describes the performance tests conducted in this research.

1.3 RESEARCH OBJECTIVES

This research is based on achieving the following objectives:

- To examine efficacy of using Bakelite and Nano-clay (NC) in Hot mix asphalt (HMA).
- To identify the optimum of Bakelite and Nano-clay content for modified asphalt concrete.
- To evaluate the Resilient Modulus (M_R) and Moisture Susceptibility of HMA having Bakelite and Nano-Clay (NC) through Universal Testing Machine (UTM).
- To investigate Rut resistance of modified HMA using Hamburg Wheel Tracking Test (HWTT).

Table 1.1: Experimental Matrix of Bitumen Testing

Characterization	**Gradation**	**NHA – B**
	Binder	ARL 60 / 70
	Aggregate	Super Babuzai Crush Plant, Katlang KPK
Materials	**Tests**	**Standard**
Binder	Penetration	ASTM 5
	Softening Point	ASTM D36-06
	Flash & Fire Point Test	ASTM D92
	Ductility Test	ASTM D 113-99
	Specific Gravity	ASTM D70
Aggregates	Aggregate Impact Value	BS 812
	Aggregate Crushing Value	BS 812
	Los Angeles Abrasion Test	ASTM C131
	Flakiness & Elongation Index	ASTM D4791
	Specific Gravity & Aggregate	ASTM C127
	Water Absorption Test	ASTM C128

Table 1.2: Marshall Mix Design Samples for determining OBC

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

Table 1.3: Performance Testing Matrix of Asphalt Concrete Mixtures

Tests	Standards	(Bakelite % + NC %)	Samples	Total
Indirect Tensile Strength Test (ITS)	AASHTO T 322 and ASTM D6931-17	0% + 0%	3	18
		6% + 0%	3	
		6% + 2%	3	
		6% + 4%	3	
		6% + 6%	3	
		6% + 8%	3	
Moisture Susceptibility using UTM	AASHTO T 322 and ASTM D6931-17	0% + 0%	3	18
		6% + 0%	3	
		6% + 2%	3	
		6% + 4%	3	
		6% + 6%	3	
		6% + 8%	3	
Resilient Modulus using UTM	ASTM D7369-20	0% + 0%	3	18
		6% + 0%	3	
		6% + 2%	3	
		6% + 4%	3	
		6% + 6%	3	
		6% + 8%	3	
Rutting Test using HWTT	AASHTO T 324	0% + 0%	3	18
		6% + 0%	3	
		6% + 2%	3	
		6% + 4%	3	
		6% + 6%	3	
		6% + 8%	3	
TOTAL				72

1.4 SCOPE OF THE THESIS

In order to accomplish the goals of this research, the following research methodology was implemented:

- Literature review of the previous research performed on plastics, their findings, testing procedures, material characterization and interpretation of results.
- Selection of gradation curve and materials including aggregates, bitumen and type of modifier.

- Characterization of materials in a lab, including aggregate and bitumen testing.
- Finding optimum bitumen content by Marshall mix design (ASTM D 6926, 2014) corresponding to NHA specifications.
- Using OBC for preparation of modified asphalt concrete samples containing 2%, 4%, 6% and 8% of Nano-clay and 6% of Bakelite by weight of OBC.
- Selection of the optimum Bakelite and Nano-clay content considering the performance in the tests.
- Comparison of conventional (60/70 penetration grade with OBC) and modified (best performance among different Nano-clay and Bakelite contents) mixes.

1.5 COMPOSITION OF THESIS

There are five chapters that make up this thesis.

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

Second Chapter contains the comprehensive literature review carried for research. Detailed literature has been studied regarding HMA asphalt, and usage of Bakelite and Nano-clay as a modifier.

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.

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 HMA mixtures performance indicators / properties.

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

CHAPTER 2

2. LITERATURE REVIEW

2.1 INTRODUCTION

This chapter reviews the previous research done and theory about hot mix asphalt (HMA) and the types and material properties of HMA pavements.

- First, I have discussed Marshall mix design and its other properties.
- Next, a brief introduction about 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 Nano-clay as a thermosetting plastomer and nanomaterial which influences their use as additives in this study.

2.2 GENERAL

Road transportation plays a dynamic part in the economy of a country. It provides access to different places in the country. Asphalt is the binder that is used in the construction of roads all across the world. It is the byproduct of petroleum. On average, about 102 million tons of bitumen is used every year worldwide, out of which 70% is used in road construction. This demand is increasing every year, so researchers are trying to find alternative ways to reduce the use of bitumen in the road industry. Bitumen causes a severe impact on health as it is burnt at a high temperature which produces toxic fumes. It is hazardous to health, and has a detrimental effect on the environment. Therefore, there is a need to look for alternatives or replace a certain percentage of bitumen with another material.

Modification of asphalt has an old history of 60 years, but in the past 15 years, people have taken more interest in asphalt modification worldwide. Increased traffic volumes, oversized loads, and tire pressures have contributed in recent years. This has caused premature rutting failure of HMA pavements. Instead of discarding and disposing of industrial byproducts and waste materials like plastic, ash, oils, and chemicals, they can be used as additives in HMA to decrease environmental pollution and economic burden. In addition, the willingness of government entities to pay for the high initial cost of pavements in exchange for longer service life is also an aspect to look into.

2.3 HOT MIX ASPHALT

The bituminous paving mix or hot mix asphalt (HMA) adequately combines graded aggregates mixed and covered by the bitumen (MS-4 Asphalt Handbook). The aggregates and asphalt must be heated to obtain fluidity of bitumen for proper mixing. In HMA design, durability and economy should be considered at the top. When pavement is poorly constructed, it fails before its design life, again a loss in the sense of repair and reconstruction cost.

The most efficient strategy to reduce the likelihood of future repair and maintenance issues is to choose the right building materials and utilize suitable design parameter values for flexible pavements (MS-4 Asphalt Handbook).

The most expensive material in HMA pavements is bitumen. For durable and economical pavements, the bitumen should be made long-lasting, and resistant to the pavement distresses, like stripping, raveling, and rutting. The bitumen can be made more durable by adding specific modifiers which enhance its properties and make it more resistant to moisture-induced damages, rutting, and other pavement distresses.

2.3.1. Types of Hot Mix Asphalts

The hot mix asphalt is divided into three different mixes, depending upon the aggregate gradation used. These three types of mixes are; dense, open, and gap graded (MS-2 Asphalt Institute)

2.3.1.1 Dense Graded Mixes

Dense graded bituminous mixes are the ones that consist mainly of well-graded aggregates, i.e., all sizes of coarse and fine aggregates and filler mixed with an asphalt cement binder. The dense graded mixes comprise nominal maximum aggregate size. These mixes work well for structure, patching, and friction.

2.3.1.2 Open Graded Mixes

The open-graded bituminous mix is made up of a high amount of coarse aggregates and a low amount of fine aggregates mixed with bitumen. The use of these mixes is to provide an open surface texture that will allow the water to drain into the mix. The mix design procedure of the open-graded mixes is different from dense graded bituminous mixes due to the lack of fines in the mix. Also, the quantity of bitumen is less in open-graded mixes as compared to dense-graded mixes.

2.3.1.3 Gap Graded Mixes

A gap-graded asphalt mixes are usually the same as open-graded mixes. Still, the fine aggregate in the mix is normally more significant than in the open graded mixes.

The materials for gap-graded mixes are crushed stone, gravel with bitumen, and manufactured sand. Middle-sized aggregates between #4 and #30 sieves are missing or present only in minimal quantities.

2.4. MODIFIERS CLASSIFICATION

There are different classifications for modifiers and additives. However, a very generic classification was suggested by (Terrel et al., 1986), and a modified version is presented by (Roberts et al., 1996) and is explained below.

2.4.1. Fillers

Lime, Portland cement, fly ash, and aggregate’s dust are examples of mineral fillers (Roberts et al., 1989). Adding filler reduces the optimum asphalt content while increasing density and stability. Because the filler fills holes in aggregates, the optimum asphalt content is reduced. At high temperatures, the filler causes the mixture to become stiffer. Lime is added as an anti-stripping agent. Other fines, mainly those containing clays, can boost HMA's stripping potential.

2.4.2. Extenders

After the 1973 oil embargo, increasing asphalt content became popular. Asphalt cement became short in supply, inflating the prices. As a result, the Federal Highway Administration (FHWA) encouraged research into prolonging the life of asphalt binders by partially substituting Sulphur and lignin. Some industries produce Sulphur and lignin as byproducts. Sulphur is created during the denaturalization of natural gas and the creation of pulp and paper. The usage of Sulphur as an extender is dependent on market prices. Its use is not justifiable if the price is higher than the asphalt. The addition of Sulphur to polymer-modified asphalt mixtures enhances storage stability (Rodriguez,2001). Lignin has only been investigated in the laboratory as a prospective extender and alternative for asphalt cement, it has not been used in commercial HMA (Roberts et al., 1996;Terrel et al., 1986).

2.4.3. Polymers

Tiny molecules (poly) called monomers chemically link together to form long chains or clusters called polymers. The resulting polymer's physical properties are determined by the monomers' chemical composition and order. Butadiene is a soft elastic monomer, while polystyrene is a hard plastic monomer. When two distinct monomers combine in block or random pattern they form Copolymer, it has unique features. Hydrogen bonding and chemical reactions are specific interactions between asphalt and polymers, which can occur when a polymer is added to the asphalt. Polymers can be divided into two types based on their strain characteristics at low temperatures:

(a) elastomer and (b) plastomer.

2.4.3.1. Elastomer

Stretching elastomers help them withstand distortion produced by tension and help them swiftly resume their original shape after the load has been removed. Until they are stretched, elastomers offer little strength to asphalt cement.

Elongation increases tensile strength. Primarily, elastomers are aimed at;

- Generating a firmer HMA that can withstand high temperatures.
- To avoid fatigue by increasing the elasticity of the HMA at intermediate temperatures.
- To increase stiffness to avoid thermal cracking at low service temperature.

Rubber has complex components, and when mixed with HMA, they may not impart the same qualities as a clean polymer. In addition, different asphalt types of cement respond differently to different modifiers. Therefore, it isn't easy to forecast if a given polymer will produce the intended results. As a result, to see if the given purpose can be satisfied by adding rubber modifiers, Super-pave mix design and evaluation techniques are used.

Elastomers can be used to modify asphalt cement in a variety of ways. Many of these are commercially available under a variety of brand names. Natural rubber, styrene-butadiene rubber latexes (SBR), Styrene-butadiene-styrene (SBS) block copolymers, styrene-isoprene styrene (SIS) block copolymers, polychloroprene latexes, and crumb rubber modifiers are all examples of elastomers or rubber latexes. Latex is made of styrene-butadiene (SBR), polychloroprene (Neoprene), and polybutadiene (a random copolymer) (PB). It is a thermally set elastomer made up of a combination of polymer particles spread in water and is one of the synthetic latex rubbers. SBR droplets cluster along the surface of the asphalt particles as a result of the evaporation of the water contained in an applied emulsion. This creates a continuous honeycombed polymer network that runs the length of the binder, which improves the asphalt characteristics.

SBR improves flexural fatigue resistance, oxidative ageing resistance, ductility and toughness at low-temperature, resistance to permanent deformation, adhesion and cohesion properties of asphalt binder. It also improves the skidding resistance of the pavement. Micro-surfacing, chip sealing, and slurry seals are typical applications for SBR latex (latex modified asphalt emulsion).

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

Thermoplastic Elastomers SBS Block Copolymer SBS block copolymer is a thermoplastic elastomer type. It comes from pellets, crumbs, or pulverized materials in bulk sacks. SBS is usually used at 5% of the asphalt binder. SBS improves flow and deformation resistance at high temperatures, abrasion resistance, fatigue resistance, flexibility of bitumen at low temperature, and improves asphalt binder adherence and cohesion. It's very flexible at low temperatures but also very pricey. SBS is used for both paving and roofing.

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

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

2.4.3.2. Plastomers

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

As a polymeric polymer, Low Density Polyethylene (LDPE) has been employed. Polyethylene, both virgin and recycled, can be used. LDPE is used to modify the content that includes polyethylene and a virgin binder. As we know that LDPE modified asphalt has a high viscosity, it needs to be mixed and compacted at high temperatures (37ºF hotter than the HMA in the control group). Because polyethylene crystallizes below 132 ºC, compaction of LDPE-modified asphalt is largely inconsequential below this temperature.

LPDE enhances high-temperature deformation resistance, increases high-temperature viscosity, improves asphalt ageing resistance, and is relatively inexpensive. In asphalt, however, it is difficult to spread and causes instability. It also has slight elastic recovery and requires a lot of polymers to get improved characteristics. LDPE is mainly utilized in industry and has limited paving uses.

Thermoplastic plastomers polymer EVA is made up of ethylene and vinyl acetate. EVA based HMA show more stability even over long period of time and unaffected by tiny temperature differences in mixing. It is delivered in bulk bags and comes from translucent to off-white pellets. The EVA is mixed into a heated asphalt binder between 149ºC and 171ºC. Light agitation (low shear) or circulation is required for optimal mixing. EVA is commonly used at 2% to 5% of the asphalt binder's weight. EVA enhances stiffness modulus and adhesion between asphalt binder and aggregates at high temperatures.

2.4.3.3. Combinations

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

2.5. THERMOSET AND THERMOPLASTIC POLYMERS

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

2.6. MODIFIED BITUMEN LIMITATIONS

The following are some potential drawbacks of modified asphalt:

- Although modified bitumen has a high initial cost, its life cycle cost may be reduced because the pavement's life can be extended by up to ten times when the polymer is utilized.
- Compatibility of polymer with binder depends on the matching of properties of polymer with bitumen sometimes a single polymer doesn't increase the properties of bitumen, but in combination with other polymer, it perform well.
- Storage, suitable temperature during mixing, and the time the PMB is maintained at high temperatures before being laid.

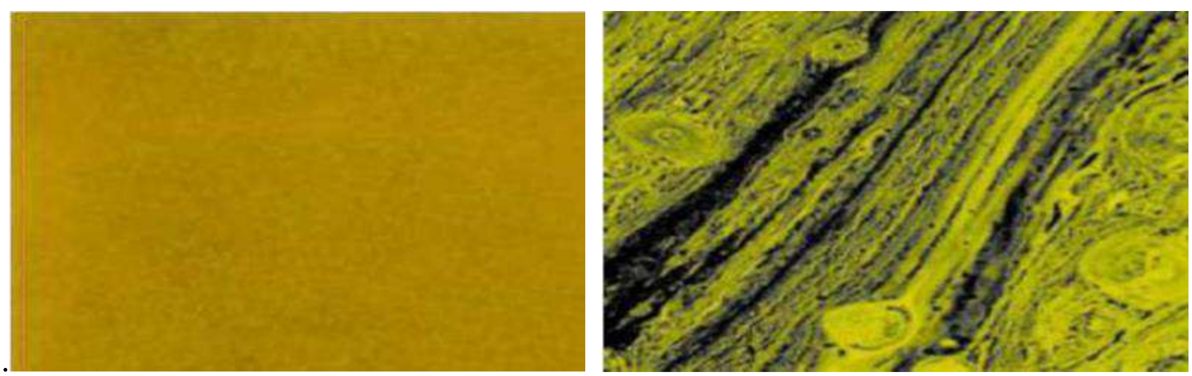
2.6.1. Compatibility and Stability Problems

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

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

According to (Becker et al., 2001) , introducing cross-linking agents like sulfur can improve the storage stability of asphalt. Sulphur, through sulphide and polysulphide bonds, is theorized to bind the bitumen and polymer chemically. PMB compatibility and blend completeness are checked using UV microscopy. Every hour, samples are obtained and examined under a fluorescence microscope. Homogeneity is defined as finely scattered polymer granules in an asphalt matrix. Figure 2.1(a) depicts a homogeneous mixture, whereas Figure 2.1(b) depicts a heterogeneous mixture.

To determine compatibility, a softening point variation test might be utilized. PMB is poured into a metallic toothpaste tube and baked for three days at 160°C. Afterwards, samples are obtained from the top and bottom of the blend, and the softening points of these samples are identified and compared. It must be ensured that the difference in temperatures at the upper and lower portion (of the tank used for mixing) must not be greater than 4ºC. A high value indicates a difficulty with phase separation or a lack of stability (Rodriguez, 2001).



a b

Figure 2.1 : (a) & (b) Homogenous and non-homogenous mixture

2.7. INCORPORATION OF POLYMERS INTO ASPHALT

1) Addition of latex polymer to asphalt is a typical approach for integrating polymers in asphalt. It is a simple and trouble-free procedure.

2) Solid polymer addition to asphalt (e.g., Pellets). When using SIS and SBS block copolymers, this approach necessitates extensive mixing and shearing to achieve uniform polymer dispersion in asphalt.

2.8. MATERIAL PROPERTIES FOR BITUMINOUS MIX

The hot mix asphalt (HMA) layer is very important in the overall design of the road. As it is the uppermost layer, it takes the high magnitude stresses. Therefore, it is necessary to perform the tests on materials used to prepare bituminous mixes.

2.8.1 Aggregates Evaluation

To prepare a mix by using Marshall Apparatus, it is necessary to determine the aggregate acceptability. The tests often performed include Los Angeles abrasion, impact, crushing value, and shape tests. If material satisfies these test results' specifications, other tests must be performed, including gradation, specific gravity, and absorption. Table 2.1 shows the tests with its specifications for aggregates.

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 Evaluation

Like aggregates, it is necessary to determine bitumen acceptability to prepare bituminous paving mixes. Therefore, different tests must be conducted on the bitumen before bituminous mixture preparation. Table 2.2 shows the required tests and specifications the bitumen should pass for its eligibility as a binder.

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 Asphalt Concrete Mix Evaluation

Hot mix asphalt of specified dimensions is designed by 'Marshall mix design criteria', and it should meet the design specifications of the National Highway Authority. Failing to do so, the HMA mix should be discarded, and a new trial blend should be prepared and tested until and unless it meets the design specifications of NHA. Table 2.3 shows the NHA specifications for wearing the course mix designed by Marshall (ASTM D 6926, 2014) for heavy traffic conditions.

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 PREPARATION OF BITUMINOUS PAVING MIXES

The standard method to prepare bituminous paving mixes is by using Marshall Apparatus (ASTM D 6926, 2014). The laboratory preparation of bituminous paving mixes requires aggregates, with optimum amount of bitumen, heating the mixture to the proper temperature, and compaction of specimens. Approximately 1200 gm of aggregates and filler is heated up to 105ºC to 110ºC. Bitumen is also heated (160ºC to 165ºC). Bitumen and aggregates, after heating separately, are mixed at about 154ºC - 160ºC. This temperature must be similar to the temperature of the asphalt mixing plant.

A mechanical mixer is recommended for laboratory bituminous mixture preparation because mixing a large quantity of material by hand is too difficult. Mixing must be thorough such that the bitumen is coated uniformly over the aggregate. Before compaction, the mold must be heated. Depending upon the traffic condition, the prepared material is then placed in the mold and compacted with blows on either side with a rammer at 138ºC to 149ºC. To obtain the compacted Thickness of 2.5-inch, it is allowed to change the mix proportion of aggregates (MS-2 Asphalt Institute).

2.10 COMPACTION OF BITUMINOUS PAVING MIX

The standard method for bituminous mix design by Marshall Procedure (ASTM D 6926, 2014), recommends three kinds of Marshall Compaction apparatus, i.e., Compaction hammers with a manually held handle, compaction hammers with a fixed hammer handle, and compaction pedestal.

2.10.1 Compaction Hammers with a Manually Held Handle

The manually held hammers usually have a flat, circular compaction foot with a spring-loaded swivel and 4.54 kg sliding mass with a height of fall 457 mm. The manual compaction hammers should be equipped with a finger safety guard.

Compaction hammer is mechanically operated with a constantly rotating base due to a surcharge on top of the handle. The tamping face shall have a 4.54 kg moving weight with a height of fall of 457.2 mm. A rotating mechanism is incorporated into the base. The base rotation and hammer blow rate shall be 18 to 30 rpm and 64 blows per minute, respectively.

2.10.2 Compaction Pedestal

The compaction Pedestal comprises a nominal eight by 8-inch wooden post approximately 18-inch long capped with a steel plate approximately 12 by 12-inch and 1-inch thick. The wood should have an average dry density of 42 to 48 lb/ft^3.

2.11 VOLUMETRIC ANALYSIS OF COMPACTED HMA MIXTURES

The pavement service performance is indicated by volumetric analysis of the properties of compacted bituminous paving mixtures (MS-2 Asphalt Institute). Various test procedures, including specific gravity tests for aggregates, bitumen, and bituminous mixes, are used to obtain the input parameters for calculating these volumetric properties. After determining aggregates and bitumen properties and mixing and compaction, the next step is the measurement of volumetric properties of

- Range of acceptable Air Void Contents (Va)
- A minimum amount of Voids in the Mineral Aggregate (VMA)
- Percent of Voids Filled with Asphalt (VFA)

2.11.1 Voids in the Mineral Aggregate (VMA)

VMA shows the spaces between compacted bituminous paving mixtures. These voids are the sum of air voids and the bitumen content that is effective (exclusive of the absorbed bitumen) and are expressed as a percentage of the total volume of the mix. The calculation of VMA is dependent on the aggregate's bulk-specific gravity. The specific gravity is expressed as a percentage of the bulk volume of the compacted paving mixture. Therefore, by subtracting the total volume from the bulk volume, the VMA can be calculated. The equation for the calculation of VMA is as follows:

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

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 prime determinant of the durability of the mixes; if its value is small, the mix will not be durable. On the other hand, a significant value indicates low stability and high flow problems and will be too costly to make. The bitumen film around the particles is a function of the volume of bitumen and the aggregate size. Economizing asphalt with minimum VMA leads to durability problems because, in the absence of sufficient film thickness, the bitumen oxidizes faster, the films are more easily penetrated by water, and the strength of the mix is reduced. So the VMA should be high enough to make room for 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. Durability is a function of air void content. The determination of air voids in a compacted mixture can be calculated using the following equation.

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

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. The absorbed asphalt is excluded in VFA and is determined by following:

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

Where,

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

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

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

2.12. STABILITY, FLOW & QUOTIENT TEST

The Marshall stability and flow, along with density, VMA, VA, and VFA, are used to evaluate bituminous mixture and mix design (ASTM D6927). In addition, Marshall Stability measures the capability of asphalt mix to resist the compression load applied while the flow is the deformation recorded at maximum force (ASTM D 6926, 2014). Stability can also be defined as the measure of the ability of asphalt concrete to rut resistance under heavy loads (Kuloglu et al. 1999).

On the other hand, the flow can adjust to gradual deformations without any cracking. Thus it is the opposite of stability (Kuloglu et al. 1999). Marshall Quotient is a stability-to-flow ratio, indicating a material's resilience to deformation (Hınıslıoğlu et al., 2004).

The specimens' bulk-specific gravity is first calculated, and then the values for stability and flow are calculated using a compression testing machine. The stability of the mix determines the maximum load that the test specimen supports at the steady loading rate of about 2-inch/minute until the maximum load is reached at failure. The loading is stopped when the load starts to decrease. Then, the flow and stability values are directly recorded by a digital meter in the required units. Usually, stability is recorded in kilograms and flow in millimeters. The Marshall quotient is then calculated based on its ratio.

2.13 TENSILE STRENGTH RATIO

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

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

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

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

The tensile strength ratio (TSR) test was conducted according to AASHTO T283 to test the Susceptibility of compacted bituminous mix specimens to moisture-induced damage. AASHTO T283 is the most widely used test procedure to determine the potential of moisture-induced damage to the HMA pavements (Huang et al., 2010). The HMA produced may be sensitive to moisture in the finished pavement; therefore, it is essential to check the adequacy of the modified HMA as a product capable of withstanding moisture-induced damages. The testing procedure involves finding the indirect tensile strength of both conditioned and unconditioned specimens and then taking their ratio to find the TSR for test specimens.

2.13.1 INDIRECT TENSILE STRENGTH TEST

This test measures the tensile strength of HMA mixes, which influences their cracking behavior (Tayfur et al., 2005). ITS for both conditioned and dry samples can be determined by finding the splitting tensile strength in a compression testing machine at 25˚C with a deformation rate of 2 inches/min. ITS can be calculated using the equation

$$ITS = \frac{2P_{max}}{\pi td}$$

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

The tensile ratio test (TSR) is calculated after the conditioned and unconditioned specimens have been tested for indirect tensile strength. It is a ratio of conditioned to the unconditioned indirect tensile strength of a set of specimens that are the same in all material and size characteristics. TSR test result measures retained stability of the mixes against moisture damage (Huang et al., 2010). (ASTM D4867, 2014) and AASHTO T283 standards set the lowest value for any TSR test to be within the constraints of 70% to 80%, failing which the mix is to be discarded and a new mix must be prepared. TSR values above 90% indicate that the mix has adequate resistance against moisture damage. Higher values of TSR indicate less moisture susceptibility and vice versa.

2.14 RESILIENT MODULUS OF BITUMINOUS PAVING MIXES

The ratio of repeated stress (loads) to the recoverable strain is called the Resilient Modulus (M_R)

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

Where σ_d is, the stress is applied axially repeatedly. For example, the binder used in the surface course materials, i.e., bitumen, is assumed to be utterly elastic in theory. Still, in practice, it was found that it is not the case, and small deformations are observed every time a load is applied. But if the bitumen used has higher strength and the applied load is small then repeated many times, the deformations after every load application become almost recoverable, and the binder can be regarded as elastic. The Figure 2.2 depicts the stress-strain behavior under a repeated stress test. The Figure 2.2 illustrates that at first, the material is experiencing permanent deformation due to plastic strain, but as the process continues and more stress repetitions are applied, the deformations start to decrease until the number of cycles reaches 100 to 200, after which the material behaves elastic, and deformation is recoverable (Huang 2003).

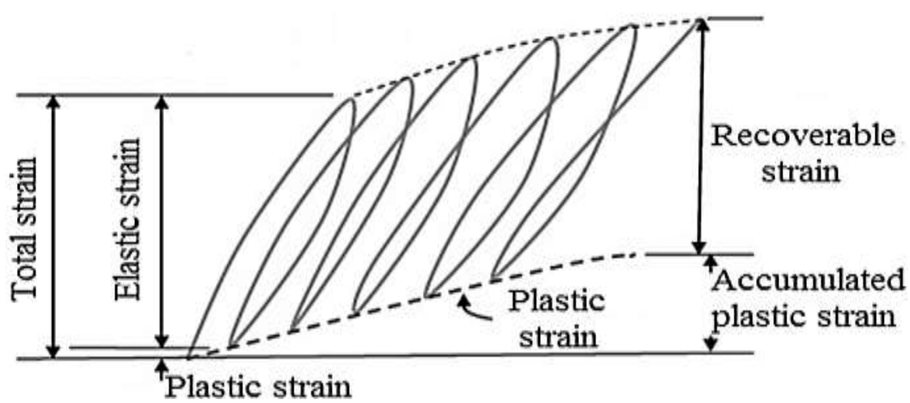


Figure 2.2: Recoverable strain under cyclic load (Huang 2003)

2.14.1 Indirect Tensile Strength Test

The indirect tensile strength test standardized as ASTM D6931 is used to evaluate the comparative quality of paving binding materials and mixes and determine its potential for cracking and rutting.

This test is performed by applying a pointed compressive load parallel to the vertical diametric plane of the 4-inch diameter of a cylindrical specimen at a constant deformation rate of 50 mm/min at a temperature of 25ºC. This loading arrangement is selected because it helps in reasonable homogeneous tensile stress distribution along the vertical diametric plane and perpendicular to the applied load (Yoder et al., 1991). The ultimate result is the splitting of the specimen. The stress distribution is shown in Figure 2.3.

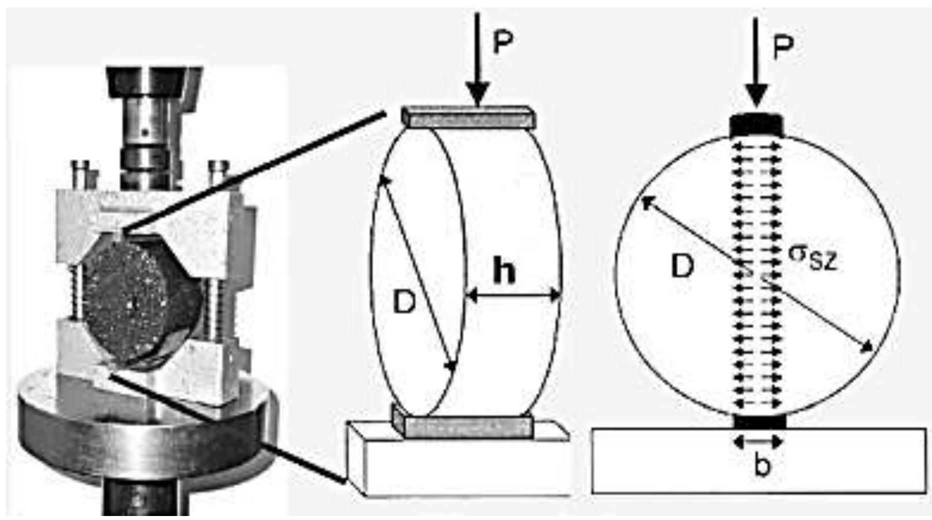


Figure 2.3: Schematic for indirect tension test

2.14.2 Resilient Modulus Test

The resilient modulus test can be performed on scores obtained from the field or on the laboratory compacted specimens. The resilient modulus of bituminous paving mixes depends on the following factors:

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

The test method to measure the resilient modulus is an indirect tension test (ASTM D 4123), and it recommends that the load should be applied in the form of alternate loading and unloading form, also known as haversine load form. This test procedure is divided into three stages: ITS determination on one specimen, conditioning for 100 load pulses, and finally determining the actual resilient modulus.

Pretest Tensile Strength Determination

It is recommended by the ASTM D6931 that before the commencement of the actual resilient Modulus test, the ITS on one of the specimens should be performed that is representative of other specimens in size and material properties. The purpose of performing an indirect tensile strength test is to select the baseline for the preconditioning peak loading force.

Preconditioning

For preconditioning, the sample should be placed in the cabin of equipment for a specified time with a fixed temperature. The selection of applied loads for preconditioning is based on the indirect tensile strength of the bituminous paving mix in accordance with the test method ASTM D6931. The peak loading force during preconditioning shall be 10 to 20% of the peak load found by the indirect tension test at 25ºC. To ensure positive contact between the loading strip and the specimen, the specimen contact loads, also known as sitting loads, must be 4 percent of the maximum load. 100 to 200 load applications each preconditioning cycle are required. However, the stable deformation determines the lowest amount of load applications for a specific circumstance.

Resilient Modulus Determination

Following the ITS and conditioning procedures, the RM is determined by applying five load pulses with nearly constant deformation. The main factors affecting resilient modulus are temperature, bitumen content, load duration, diameter of specimen and gradation of aggregates. The following equation is used to determine the resilient modulus of bituminous paving mixes:

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

Where,

$E = Resilient\ Modulus\ (MPa)$

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

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

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

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

2.16 PHENOL- FORMALDEHYDE (BAKELITE)

Phenols are the oldest family of thermosetting polymers. This polymer family has ring structure alcohol named phenol. The primary process of obtaining phenols is from the petroleum distillates like propylene and benzene. Phenol resins are shaped by the reaction of phenol with formaldehyde (CH_2O), making the following monomer.

Three monomers form a rigid network structure, forming a hard, rigid plastic. Polymerization is obtained by cross-linking these monomers into a 3-D network. The cross-linking reaction requires heat, but it can exist in various stages. The two primary stages are A & B. In stage A, The crosslinking is not yet started, so the individual components sit around before any significant crosslinking occurs. This interval is called pot life. Then, the cross-linking gradually occurs in the B stage, called the transition period. Most thermosetting polymers are rubbery and tacky at this stage, and they can exist at this stage for as long as 24 hours (Markovic et al., 2013).

The first commercial PF polymer was produced in the early 20th century under the trade name Bakelite. Bakelite was used mainly for compression-molded electrical parts such as switches, distribution caps, and the like. However, phenols are still being used mainly for this purpose because they are characterized by their good properties like low moisture absorption, high resistance to temperature, high compressive strength, creep resistance, less brittle nature, and cost-effective as compared to most thermosets and few thermosetting polymers (Sperling, 2011).

2.16.1 Bakelite Content Effect

The primary determination of conducting this research is to find the influence of Bakelite on the properties of asphalt concrete mixes, of which one crucial parameter is the resilient modulus. It characterizes the elastic behavior of asphalt concrete under dynamic loading conditions and represents structural strength and material quality. If the resilient modulus test results show any improvement over the control mix, it will signify that Bakelite may be added as an additive in polymer modified asphalt.

2.17. DIFFERENT RESEARCHES ON BAKELITE AND NANO-CLAY

In order to determine the rutting resistance and stiffness capabilities of Bakelite, various amounts of Bakelite were utilized in the Hamburg wheel tracking test as well as the Dynamic modulus test. When compared to controlled mixtures, the results show that the percentage reduction in rut depth at the optimum Bakelite content of 6 percent was 29 percent for class A mixtures and 38 percent for class B mixtures, respectively. This is in comparison to the reduction in rut depth that occurred with controlled mixtures. In a similar vein, the percentage rise in dynamic modulus values at 50ºC was discovered to be 36 percent for class A combinations and 46 percent for class B mixtures, respectively (Yousaf et al., 2014).

As a modifier for asphalt, Bakelite and Crumbed rubber were utilized. The encouraging result shows that the addition of crumb rubber and Bakelite by 12 percent significantly improves the properties of asphalt mixture almost 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. [Crumb rubber] and [Bakelite] are two types of thermoplastics that are made from recycled tires. According to the findings of the study, both crumb rubber and Bakelite have the capacity to improve the mechanical properties. However, when compared to crumb rubber, Bakelite demonstrates significantly superior outcomes in terms of increased strength and stiffness (Ahmad et al., 2019).

It was discovered that a modified mix containing 6 percent Bakelite by weight of optimum bitumen content provides the best resistance against moisture damage, rutting, and enhancing the HMA mix's stability than the other modifier percentages. This was the case when comparing the optimum bitumen content. The Marshall stability and quotient values of the adjusted mix rose by nearly 22 and 44 percent, respectively, after the modification. In addition, the results showed that the tensile strength ratio increased by 3.5 percent, which suggests an improvement in HMA's capacity to tolerate moisture-induced damage and strength retention (Ali et al., 2021).

The findings of the experimental work revealed that the utilization of PMB binder results in a substantial improvement to both the mechanical characteristics and performance of HMA. Additionally, it demonstrates that the utilization of RAP as a replacement for coarse aggregate results in a significant enhancement in the mechanical characteristics and performance of HMA when compared with the utilization of fine aggregate as a replacement or with a control mix (AL-Ghurabi et al., 2021).

In this study, the impacts of SBS and Nano-clay on asphalt were analyzed. The material was put through Marshal testing, Softening point tests, DSR tests, ductility tests, and penetration grade tests. Both modified and untreated asphalt mixes are evaluated for OBC content. The findings suggested that the addition of Nano-polymer led to respective improvements in toughness and viscosity. This boosted the bitumen's rheological qualities while simultaneously lowering the penetration grade. Both the resilience of asphalt to rutting and the depth of rutting have shown some signs of improvement as well (Mousavinezhad et al., 2019).

In order to determine whether or not Nano-clay combined with EVA and HDPE may improve the qualities of asphalt, a variety of performance and conventional tests were carried out. The findings of the experiments demonstrated that it is possible for the polymer Nano composite to enhance the asphalt binder's resistance to rutting and low temperatures, regardless of whether the asphalt binder exhibits linear or nonlinear viscoelastic behavior (Mansourian et al., 2019).

Ahmed investigates how the performance of asphalt binders is affected when Nano-clay (NC) and ethylene vinyl acetate (EVA) copolymer are mixed together. High temperatures provide a challenge for asphalt binders. The technique of melt blending was used to produce three separate modified binders at concentrations of 1, 3, 5, and 7 weight percent. These binders were NC-, EVA-, and polymer-modified Nano-clay. Measurements of viscosity, a dynamic shear rheometer, and standard tests (penetration and softening point) were utilized to evaluate the material's physical and rheological properties. The results show that EVA and NC are both accurate. Considerably enhance the binding qualities. A specific rise in the rutting characteristic upon binder change suggests that it performs better at high temperatures (Siddig et al., 2018).

2.18 SUMMARY

Nano Materials, such as Nano Clay (NC) and Polymer such as Bakelite, have been examined in earlier studies as a moderator in asphalt mix asphalt (HMA). Based on previous studies, the properties of the modified HMA are dependent on various factors, such as the type and percentage of modifers used in asphalt mixes. In this study, Nano Clay (NC) and Bakelite, will be utilized in the asphalt mixture.

After their addition as a modifier, the modified mixes will be subjected to different performance tests. Furthermore, performance tests used in this study, such as, WTT, ITS, TSR, and M_R are also discussed.

CHAPTER 3

3. MATERIALS AND METHODOLOGY

3.1. GENERAL

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

3.2 FRAMEWORK OF RESEARCH METHODOLOGY

The methodology adopted for this research is show in Figure 3.1. NHA Class B mix gradation for wearing courses was selected. In Pakistan NHA (B) specifications are mostly used for wearing courses. The first step was finding the optimum bitumen content (OBC) by Marshall mix design (ASTM D 6926, 2014), which was then used in the preparation of 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 Nano-clay (2%,4%,6%, and 8% by weight of OBC). The second step was the performance tests, including Marshall Stability, flow, quotient (ASTM D 6926, 2014), and retained stability (AASHTO T283) on control and modified specimens to compare their performance and find the optimum Bakelite and Nano-clay percentage, which showed better strength, flow and resistance to moisture-induced damages. In the end, the resilient modulus (ASTM D 4123) test was performed under temperature (25ºC), load duration (100 ms & 300 ms) conditions, and Double wheel tracker test, moisture susceptibility, and ITS tests were accompanied on the prepared samples. The Experimental investigation of these conditions and their interaction was analyzed by ANOVA and Tukey's analysis by MINITAB-16 software.

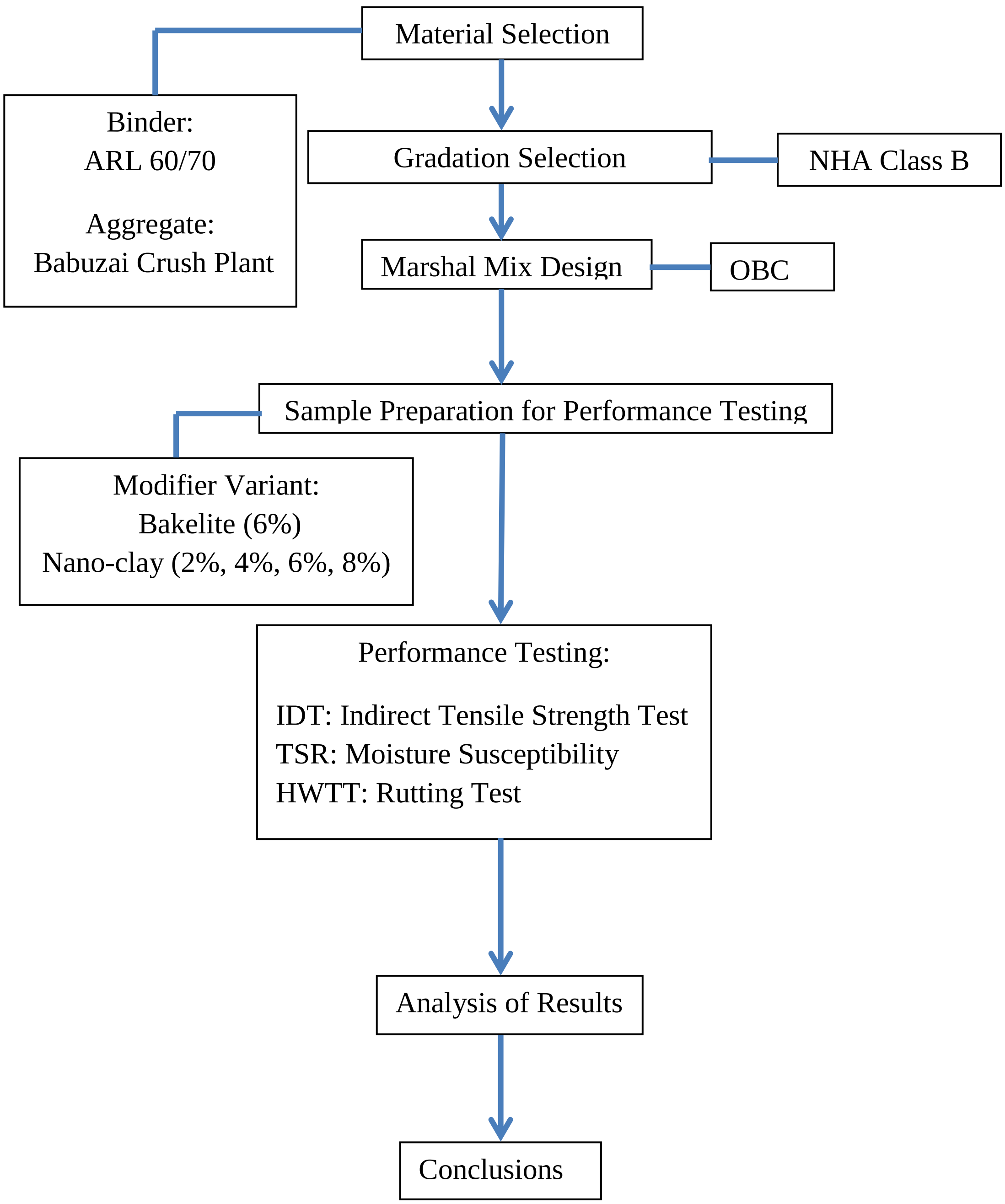


Figure 3.1: Methodology adopted

3.3. CHARACTERIZATION OF SELECTED MATERIALS

3.3.1. Materials Selection

The laboratory characterization of materials selected for this research includes coarse aggregate, fine aggregate, and bitumen. These materials were selected according to the standard specifications for hot mixed asphalt pavements ((ASTM D 3513-1). The dense gradation was used in this research because Hot Mix Asphalt (HMA) pavements are designed using this type of gradation.

3.3.2 Bitumen

The binder used in this study was 60/70 penetration grade, the most commonly used bitumen in Pakistan. It was obtained from Attock Oil Refineries Rawalpindi. Before sampling, the bitumen was tested for laboratory characterization as a binder by specifications and standards of ASTM and AASHTO.

3.3.3 Aggregates (Coarse and Fine)

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

Figure 3.2: Babuzai crush plant

3.3.4 Bakelite

The Bakelite used in the study was obtained from Azmat Polymers PVT Ltd Gujranwala in ground form. The Bakelite was sieved, and the portion of the Bakelite passing the #100 sieve was then used. The results are presented in Table 3.1 below.

Table 3.1: Properties of Bakelite

Properties	Results
Specific gravity	1.36
Melting point range	150-165ºC
Decomposition temp. range	270-350ºC
Sieve analysis	Passing sieve#100

3.3.5 Nano-clay

The Nano-clay used in the study was obtained from Miz Builders, Bahria Orchard Lahore in ground form. The Nano-clay was sieved, and the portion of the Nano-clay passing the #200 sieve was then used. The results are presented in Table 3.2 below.

Table 3.2: Properties of Nano-clay

Description	Remarks
Color	Greyish Yellow
Montmorillonite content	>75%
Moisture content	Max. 10%
API water loss (cm^3)	Max. 15%
PH	9.5
Sieve analysis	99% Pass the sieve No. 200
Free Swell Index	600+ %
Liquid Limit	292%
Plastic Limit	48.55%
Shrinkage Limit	25.70%
Bentonite formula is	$Al_2H_2Na_2O_{13}Si_4$

3.3.6 Tests on Asphalt Binder

For construction and engineering purposes, consistency, safety, and purity are the three properties of binder which are essential to be considered. The consistency of the asphalt binder changes as the temperature changes. To verify the consistency of asphalt binder, a standard temperature is needed. A penetration or viscosity test is typically used to determine the bitumen binder's consistency. Additional tests, such the softening point test and the binder ductility test, increase the reliability and consistency of the data. As a result, the following experiments were carried out in the laboratory to characterize the asphalt binder.

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

3.3.6.1. Penetration Test

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

Figure 3.3: Penetration test equipment

3.3.6.2. Softening Point Test

Bitumen is a material with visco-elastic properties, but as the temperature goes higher, it progressively becomes softer, and its viscosity reduces. The temperature at which a standard-size sample of bitumen can no longer support the weight of a 3.5-gram steel ball and soften enough for the steel balls to fall towards the base plate, is referred as bitumen's softening point. According to AASHTO-T-53 recommendations, the ring and ball equipment was used to determine the asphalt's softening point.. The findings of the softening point test are shown in Table 3.3.

Figure 3.4: Softening point test equipment

3.3.6.3. Ductility Test

An essential feature of bitumen is ductility and a critical component to consider when describing the performance of an HMA mixture. Ductility depicts how bitumen reacts to temperature variations. 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). Table 3.3 shows the standard conditions and results obtained for ductility tests for bitumen. All specimens had seen satisfying the minimum 100cm ductility criteria.

Figure 3.5: Ductility test equipment

3.3.6.4. Flash and Fire Point Test of Bitumen

The flash point of bitumen is the lowest temperature at which it flashes momentarily under certain conditions. The temperature at which a material catches fire and burn under specified conditions is known as the fire point. The D3143/D3143M-13 standards were used to conduct the flash and fire point tests. So, for asphalt mixes preparation, it is also compulsory to check the suitability of bitumen as well in light of ASTM material characterization criteria and specifications. The above-mentioned laboratory tests were performed for the characterization of the asphalt binder (ARL 60/70). Table 3.3 shows the tests performed on bitumen.

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

3.4. MODIFIED ASPHALT BINDER TESTS

Tests were performed on modified asphalt binders to check their properties. 2%, 4%, 6%, and 8% of Nano-clay and 6% Bakelite were used in asphalt. Tests like penetration, softening point, and ductility were performed on modified asphalt to check how much modification is enough for the favorable results in asphalt.

3.5. AGGREGATE TESTING

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

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

Three samples were utilized for each test, and the average was used to determine the results.

3.5.1 Shape Test of Aggregates

The strength and workability of the asphalt mixture mainly depend on the shape of the particles. It also affects the effort required for compaction vital to achieve the necessary density. Therefore, through the shape test, the quantity of elongated and flat aggregate particles was determined. According to ASTM D4791, when an aggregate particle's dimension is less than 0.6 of its mean sieve size, it is classified as flaky aggregate; when it is longer than 1.8 of its mean sieve size, it is classified as elongated aggregate as shown in Table 3.4.

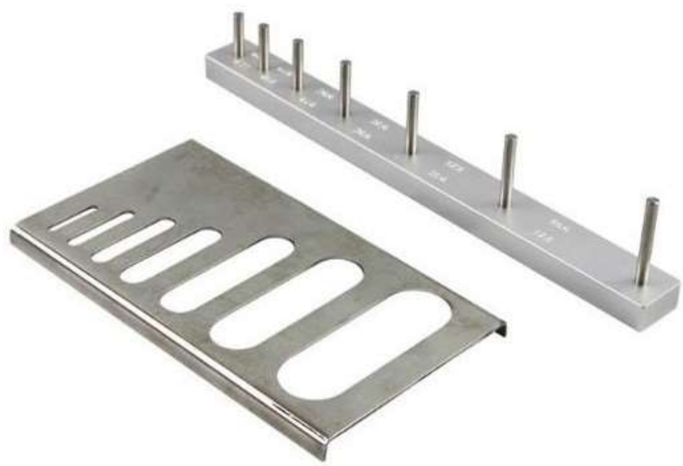


Figure 3.7: Shape test equipment

3.5.2 Aggregates Specific Gravity

The concept of Specific gravity refers to the relationship between the weight of a specific volume of aggregate and the weight of a same volume of water. Specific gravities of coarse aggregate, fine aggregate and fillers were determined individually. The aggregate that is retained on No. 4 sieve is coarse aggregate, while fine aggregates are those passing No. 4 sieves.

3.5.2.1 Coarse Aggregate

S.G of coarse aggregate and water absorption were determined using ASTM C 127 techniques and equipment. It is necessary to determine the mass of a sample of coarse aggregate in three different states: SSD, oven-dry, and immersed. After that, these variables are utilised to determine things like apparent specific gravity and absorption along with bulk specific gravity and bulk SSD specific gravity. The test was accomplished for both course-graded stockpiles; the results are presented in Table 3.4.

3.5.2.2 Fine Aggregate and Filler

S.G of fine aggregates were measured using the procedures and equipment stated in ASTM C

128. S.G test was carried out on fine aggregate to determine the values of bulk S.G, Saturated Surface Dry, and apparent specific gravities, with the result shown in Table 3.4

Figure 3.8: Specific gravity testing

3.5.3 Impact Value Test

The impact value of aggregates is their resistance to breaking. The apparatus required for measuring impact value included an impact testing machine, tamping rod, and sieves of sizes 1/2”, 3/8”, and #8 (2.36mm.) Around 350g of aggregate passing through 1/2” sieve and retaining on 3/8” sieve was taken and filled in the mold of Impact Testing Machine in 3 different layers, tamping 25 times (Each Layer). The sample was transferred into the larger mold of the machine, and 15 blows from a height of 38 cm were given with the hammer weighing 13.5 to 14 kg. The aggregate was then removed and filtered using sieve #8. The impact value was measured by the percentage of aggregate passing through a 2.36mm sieve.

Figure 3.9: Impact value test apparatus

3.5.4 Crushing Value Test

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

Figure 3.10: Crushing value test apparatus

3.5.5 Los Angeles Abrasion Test

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

Figure 3.11: Los abrasion test apparatus

So, It is vital to examine the acceptability of aggregates in light of ASTM and BS standards and specifications for material characterization while preparing Asphalt mixtures. These experiments were carried out using Babuzai quarry aggregate, and the performance tests on the aggregates are mentioned in Table 3.4.

Table 3.4: Laboratory Tests Performed on the Aggregates

Test Description	Specification Reference	Results	Limits
Fractured Particles	ASTM D 5821	96%	90%(Min)
Elongation Index (EI)	ASTM D 4791	3.73%	10%(Max)
Flakiness Index (FI)	ASTM D 4791	9%	10%(Max)
Aggregate Absorption	ASTM C 127 Fine	2.56%	3%(Max)
	ASTM C127 Coarse	0.89%	3%(Max)
Impact Value	BS 812	19%	30%(Max)
Los Angles Abrasion	ASTM C 131	29%	30%(Max)
Specific Gravity	ASTM C128 Fine	2.60	-
	ASTM C 127 Coarse	2.632	-

3.6. GRADATION SELECTION

For densely graded surface course mixtures, NHA (1998) specifications were applied, and NHA class B aggregate gradation was used. According to Marshal Mix Design, the NMAS for class B wearing coarse gradation was 19mm (MS2). Table 3.5 displays the selected gradation, and Figure 3.12 shows the gradation plotted against passing percentages of aggregates from the sieve and sieve sizes.

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

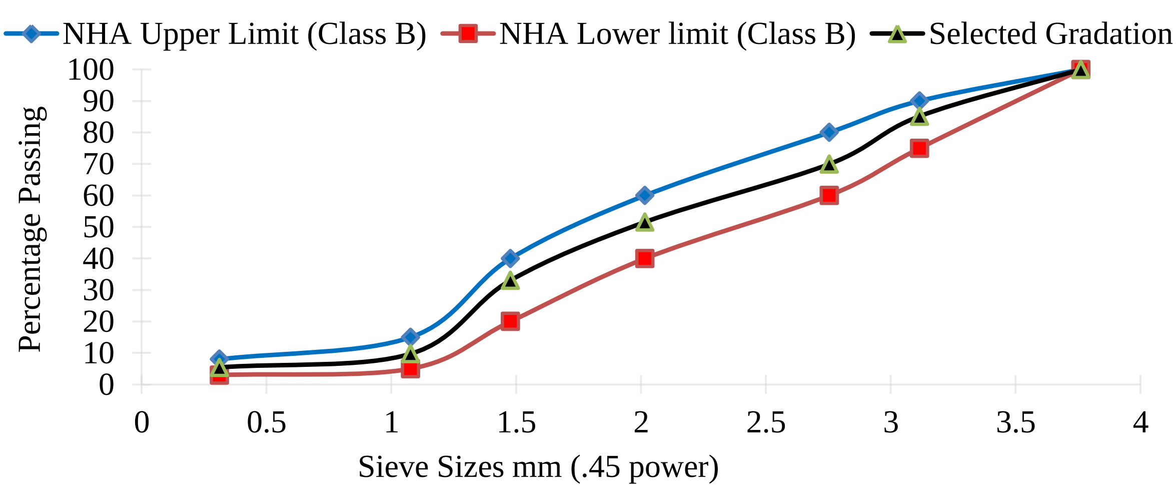


Figure 3.12: Gradation plot of NHA class B with specific limit

3.7. ASPHALT MIXTURES PREPARATION

Asphalt mixtures are prepared to have different bitumen percentages by the aggregates' weight. Therefore, these specimens are prepared per Marshall Mix Design Procedure. After the determination of OBC, samples were prepared for Performance Testing.

3.7.1. Preparation of Bituminous Mixes for Marshall Mix Design

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

Table 3.6: Sample Details

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

3.7.2. Marshal Test Specimen Preparation

After sieving, the aggregates must be heated for 105ºC t0 110ºC. According to (ASTM D 6926, 2014), for making the Marshal sample of diameter 4-inch, 1200grams of aggregates are needed. The amount of asphalt cement required for each specimen was calculated using the following Equation as a percentage of the total weight of the mix:

$$MT = MA + MB$$

$$MB = X/100(MT)$$

Where,

$MT = Total\ mix\ Mass$

$MA = Aggregate\ Mass$

$MB = Bitumen\ Mass$

$X = Bitumen\ Percentage$

3.7.3. Mixing of Aggregates and Asphalt Cement

(ASTM D 6926, 2014) recommends the mechanical mixer for the adequate mixing of bitumen and aggregates. Therefore, after extracting the dried, heated aggregates and heated bitumen from the oven, they were immediately transferred to the mechanical mixing equipment. The schematic diagram of a mechanical mixing machine is shown in Figure 3.13. The temperature range for mixing was 160ºC to 165ºC, which corresponds to the temperature in Pakistan when bituminous mixes are manufactured (NHA Specifications). Moreover, this mixing temperature corresponds to the binder viscosity range of 0.22 - 0.45 Pa.sec as specified by the Superpave mix design (SP-2).

Figure 3.13: Mechanical mixer

3.7.4. Mixture Conditioning after Mixing

Bituminous mixes should be conditioned for two hours before compaction, according to (ASTM D 6926, 2014). As a result, each bituminous mix produced by the mixing machine was placed in a metal container.

3.7.5. Compaction of Specimen

According to Marshall Mix design, there are three criteria for compaction depending on either the surface is prepared for light, medium, or heavy traffic. For design purposes, we consider pavement for heavy traffic, so 75 blows per side of sample are applied to attain compaction. The loose mix obtained from heating aggregate with bitumen is transferred to a mold having a base plate. A filter paper was placed below and above the specimen. After achieving 75 blows on one side, the specimen was inverted for the same blows on the other side.

Figure 3.14: Marshal sample compactor

3.8. EXTRACTION OF SPECIMENS FROM MOULD

After compression, the mold is taken out from Marshal Compactor and allowed to cool for some time. The specimen was then extracted from the mold using an extraction jack. On a flat surface, the prepared samples were cooled to room temperature.

Figure 3.15: Sample extractor from mold

3.9. VOLUMETRIC, STABILITY AND FLOW DETERMINATION

After determining the theoretical maximum specific gravity (G_{mm}) and the bulk specific gravity (G_{mb}), 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. Table 3.7 shows the Marshall Mix design requirement. ASTM D2041 and ASTM D 2726 were used to determine the G_{mm} and G_{mb} of bituminous pavement mixtures. Following the G_{mb} determination, the samples were evaluated for stability and flow using Marshall Test apparatus.

The specimens were deformed at a continuous rate of 5 mm per minute until they failed. Marshall Stability was calculated using the entire maximum load in KN. A flow number value in millimeters was used to measure the overall deformation at the highest load. Marshall Mix design specifications state that the flow number should be between 2 and 3.5 and that the stability for a heavily used wearing course should not be less than 8.006 KN. After extracting the specimen from the water bath, it was immediately tested.

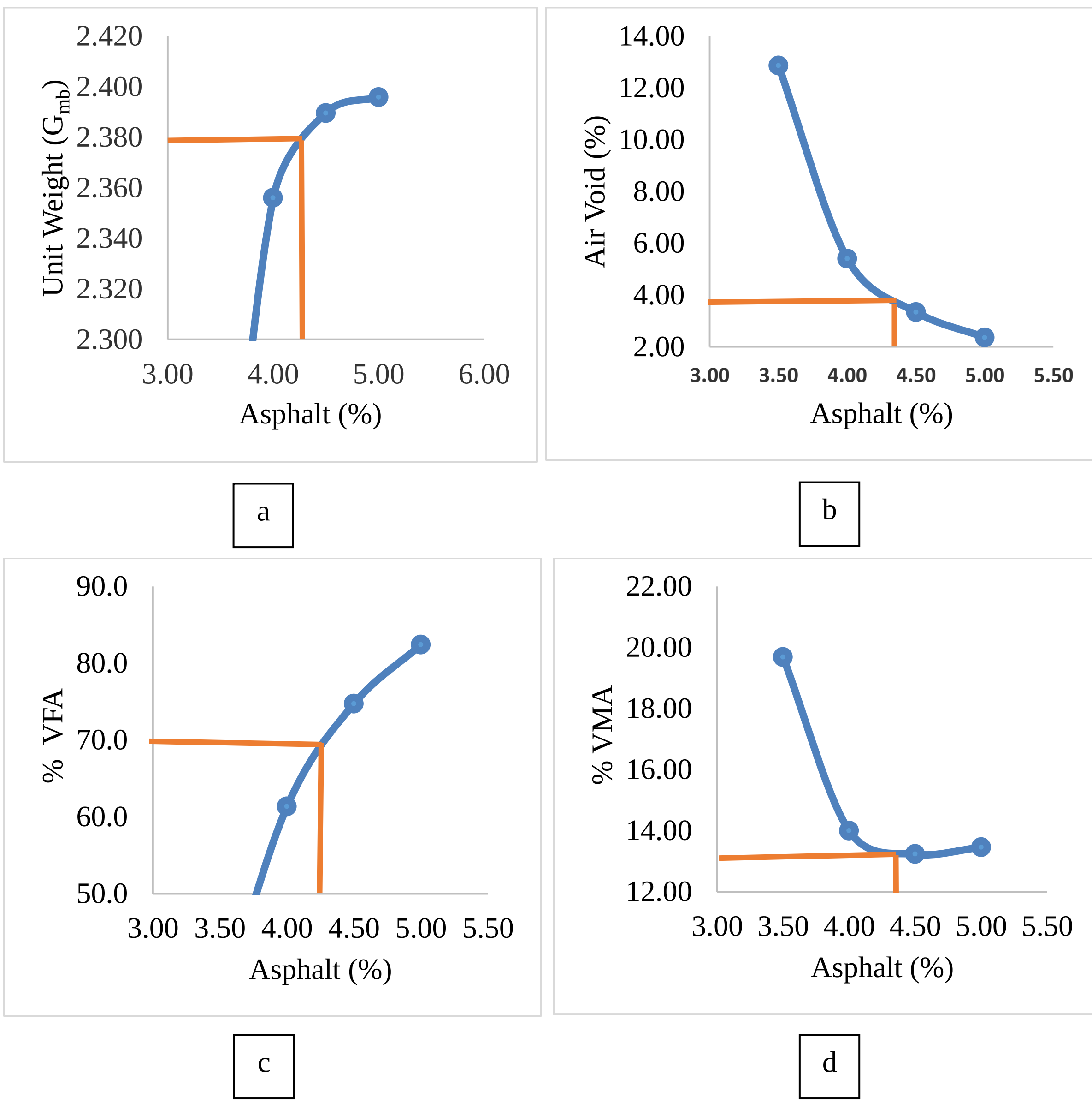
Figure 3.16: Marshall stability and flow testing equipment

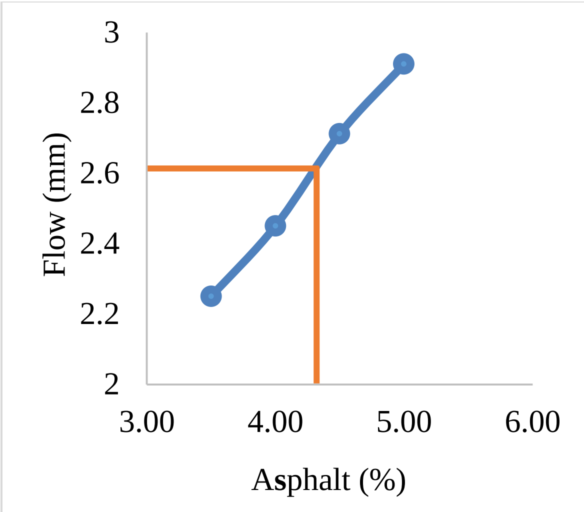
3.9.1. Volumetric Properties of HMA

The volumetric properties, stability, and flow correspond to the virgin mix are, as shown below in Table 3.7. The graphs relating asphalt contents and volumetric qualities, stability, and flow were drawn according to the (MS-2 Asphalt Institute) to determine the OBC of the virgin mix, as shown 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





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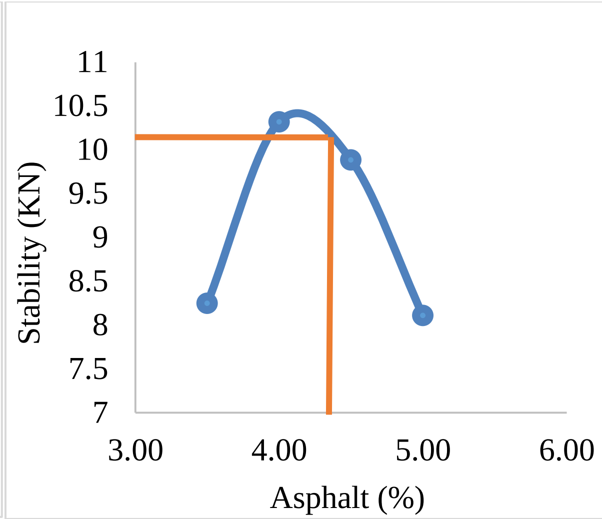

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Figure 3.17: (a) to (f) Graphs of volumetric properties of mix

The asphalt contents at 4% Air void are called OBC. The mix has an OBC of 4.3%. The mix characteristics, stability, and flow according to OBC were determined from the graphs. Table 3.8 shows the job mix formula of the virgin mixture. It is clear from the Table that all of the characteristics, stability and flow meet the criteria. The VMA should not be less than 13%, and its value was 13.2% from the calculations of this study. VFA should be between 65 and 75 percent, and its computed value was 70%. According to the standards, the stability value should not be less than 8.006 KN, yet it was 10.4 KN in this situation. The measured flow number was 2.6 mm, which is within the acceptable limit.

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. SAMPLE PREPARATION FOR PERFORMANCE TESTS

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

3.11. RUTTING INVESTIGATION OF SAMPLES

Rutting is one of the most prevalent pavement permanent deformations, caused by cyclic traffic loads and characterized by the accumulation of minor pavement material deformations in the form of longitudinal depressions along the wheel paths. The specimens were evaluated using a Double wheel tracker to determine their resistance to persistent deformation in order to investigate rutting propensity. The DWT is an electrically powered device that can move a steel wheel with a diameter of 203.2mm and a width of 47mm across a test specimen. The weight of the steel wheel is 1581lbs, and the average contact stress produced by the wheel contact is 0.73 MPa with a contact area of 970 mm^2. Just like the influence of the rear tire of a double axle is produced by the contact pressure of the steel wheel. As the rut depth increases, the contact area expands, and the contact stresses become more varied. In a forward and backward motion, the steel wheel passes over the object. DWT steel wheel must pass the sample roughly 60 times per minute. The highest speed of the wheel over the specimen is nearly 1 ft/sec, which is achieved at the center of the sample. With the help of DWT, rutting tests can be carried out on dry, wet, and air modes. In this research, the dry mode was used to determine the susceptibility of asphalt mixtures to rutting. These three modes can be utilized by adjusting the DWT at anticipated test conditions. Figure 3.18 shows the Double wheel-tracking device used for conducting rutting tests. Before conducting the test, two 2.5-inch-thick specimens were obtained by sawing the samples from the top and bottom surfaces. These specimens were cut using the wheel tracker tray's silicone mold.

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

Figure 3.18: Hamburg wheel tracking test equipment

3.11.1 Stripping Inflection Point (SIP) by IOWA DOT Method

The Stripping Inflection Point (SIP) is determined based on the recommendations provided by the Iowa DOT (Schram et al., 2012). In the first step of the process, a 6-order polynomial regression is applied in order to fit the curve. After that, a creep slope is introduced at the point when the polynomial's first derivative hits a local minimum near to the start of the test. A stripping slope is inserted into the equation when the first derivative hits a local maximum near to the end of the test. In conclusion, the SIP is presented as the number of passes that correspond to the slopes that intersect each other.

3.11.2 Quantitative analysis of HWT test results for Moisture Susceptibility

When it comes to the rutting that occurred during the HWT test (stripping), it is generally agreed upon that post-compaction, visco-plastic deformation, and moisture deterioration each played a role (Yildirim et al., 2007). As shown in Figure 3.19, post compaction phase starts at the start of the test and ends at 1000 cycles. From 1000 cycles till the Stripping inflection point, the compaction is due to the Visco-plastic behaviour of bitumen, and after that, further deformation is due to moisture damage in which aggregates loses the binder bonding. The last phase begins at SIP and ends when 12.5mm rut depth is seen in the sample. In this work, a one-of-a-kind method of analysis is suggested in order to distinguish between these three behaviors and evaluate the influence of moisture damage in isolation (Lv et al., 2022).

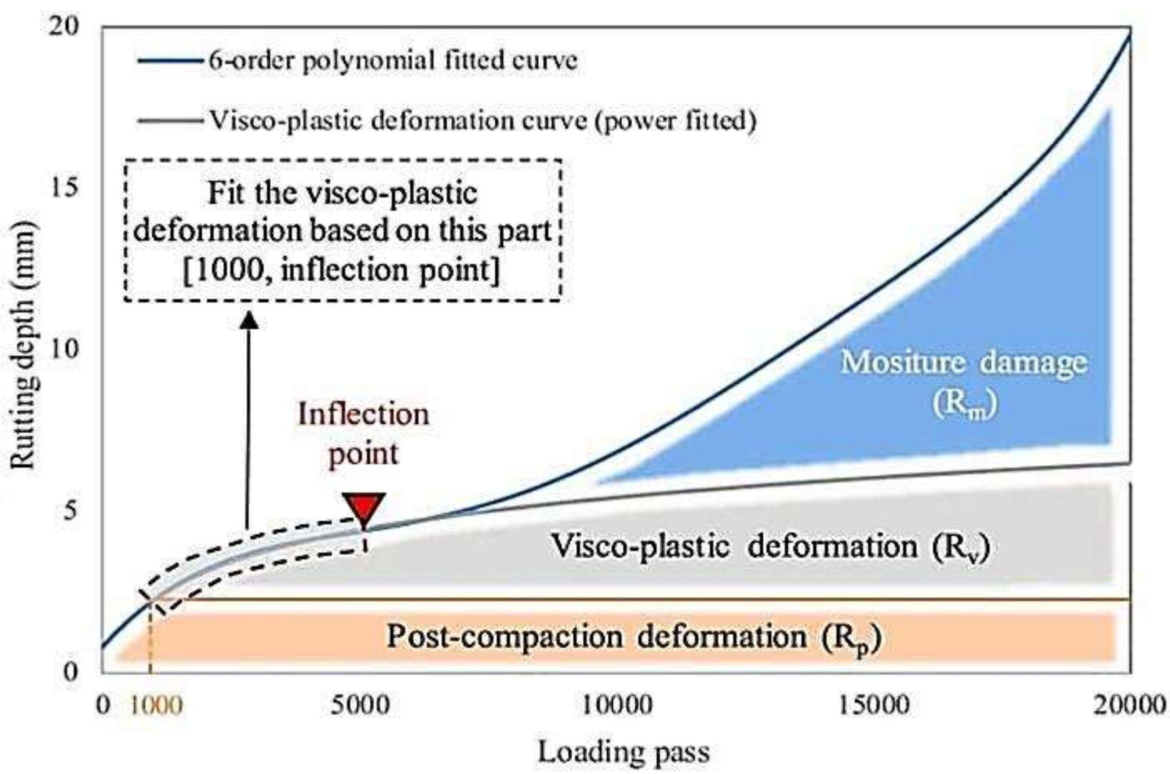

Figure 3.19: Stages of rutting behavior

3.12. MOISTURE SUSCEPTIBILITY TESTING

According to ASTM D6931, the moisture susceptibility test was performed (Moisture-Induced Damage Resistance of Compacted Hot-Mix Asphalt). Three unconditioned specimens per mix were tested. These unconditioned samples were submerged in a water bath set at 25°C (77.8°F) for an hour before to testing. Conditioned specimens were tested in a separate batch of three per mix. Samples were saturated and then placed in a 60°C (140.8°F) water bath for 24 hours, followed by one hour in a water bath at 25°C (77.8°F) according to ALDOT-361. Both unconditioned and conditioned specimens were loaded diametrically at a rate of 50 mm/minute. For each specimen, the tensile strength was then calculated using specimen dimensions and failure load. The average conditioned tensile strength was then divided by the average unconditioned tensile strength to obtain the tensile strength ratios. The acceptable value for the tensile strength ratio employed was 80% (minimum). The tensile strength of each subset was determined by Equation.

$$St = 2000P/\pi Dt$$

Where:

$St = Tensile\ strength, kPa$

$P = Maximum\ load, N$

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

$D = Specimen\ diameter, mm$

When the tensile strength of the conditioned sample is divided by the tensile strength of the unconditioned sample, it will give us TSR which indicates the possibility of moisture damage. Equation below is used to compute the TSR for each blend.

$$TSR = [S2/S1]$$

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

This chapter explains the testing of Aggregate, Bitumen, and Modified Bitumen. The material was then used to prepare bituminous mix samples. The volumetric properties of the mix were calculated, and OBC was determined. OBC was then used to prepare samples for performance testing, i.e., moisture susceptibility and rutting test. At the chapter's end, moisture susceptibility and rutting test methods were elaborated.

CHAPTER 4

4. RESULTS AND ANALYSIS

4.1 INTRODUCTION

The analysis and results of traditional and modified asphalt with Bakelite and Nano-clay are presented in this chapter. 60/70 grade binder from ARL and aggregates from Babuzai Katlang are used to make Conventional specimen. 6% Bakelite and (2%, 4%, 6%, and 8%) NC in HMA to the weight of bitumen is used in modified specimens. Performance testing was carried out once the Superpave gyratory samples and Marshal Samples had been prepared in accordance with standards, as was mentioned in the preceding chapter. Following performance tests were accomplished; Rutting using HWTT, ITS and TSR Test using UTM-25, and Resilient Modulus test to determine the Stiffness using UTM-25 to assess the performance improvement of modified and conventional AC mixtures.

4.2 BITUMEN PHYSICAL PROPERTIES RESULT

Table 4.1 shows the results of physical properties of bitumen. Results show that modified and Conventional specimens are according to the standards of AASHTO and ASTM.

Table 4.1: Physical Properties of Bitumen

Type of Test	Asphalt ARL 60 / 70						
	Standards	Base Binder	6%Bakelite				
			0%NC	2%NC	4%NC	6%NC	8%NC
Penetration (dm)	ASTM D5 AASHTO T49	63	57.3	54.5	48.3	42.92	39.3
Flash & Fire Point(°C)	ASTM D92 AASHTO T53	260 & 292	258 & 270	261 & 274	279 & 298	253 & 281	250 & 278
Softening Point (°C)	ASTM D36 AASHTO T53	50	54.3	56.2	60	64.3	69.1

4.3 AGGREGATES PHYSICAL PROPERTIES RESULT

Crush (Aggregates) from the Babuzai plant was acquired for this research study. Table 4.2 shows the results of all the tests applied to aggregates. Results also show that the aggregates followed the ASTM and AASHTO standards.

Table 4.2: Physical Properties of Aggregates

Test Description	Specification Reference	Results	Limits
Fractured Particles	ASTM D 5821	96%	90%(Min)
Elongation Index (EI)	ASTM D 4791	3.73%	10%(Max)
Flakiness Index (FI)	ASTM D 4791	9%	10%(Max)
Aggregate Absorption	ASTM C 127 Fine	2.56%	3%(Max)
	ASTM C127 Coarse	0.89%	3%(Max)
Impact Value	BS 812	19%	30%(Max)
Los Angles Abrasion	ASTM C 131	29%	30%(Max)
Specific Gravity	ASTM C128 Fine	2.60	-
	ASTM C 127 Coarse	2.632	-

4.4 MARSHAL MIX DESIGN/ JOB MIX FORMULA FOR OBC

Bitumen content at 4% air voids was used to compute OBC (optimal bitumen content). The OBC was found to be 4.3%, which corresponds to 4% air spaces. All other volumetric properties were determined about the 4.3% binder content using the plotted graphs. The results were checked against the NHA design specifications. All the results were within the design limits. The results are mentioned in Table 4.3.

Table 4.3: 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 INDIRECT TENSILE STRENGTH TEST USING UTM

Indirect Tensile Strength Test assesses the tensile properties of compacted concrete mixtures in compliance with ASTM D6931-07. Moisture susceptibility refers to ratio of tensile strength of unconditioned versus conditioned specimens. Conditioning of samples was accomplished with ALDOT 361, by subjecting the specimens in the water bath at 60^{o}C for 24 hours. Before tensile strength testing, a total of 3x Marshall replicates of each percentage of Bakelite and Nano-clay combination. Specimens were tested with and without moisture conditioning. Dimensions of samples were 100 mm in diameter and thickness of 65 mm and testing was done on Universal Testing Machine with monotonic loading. After conditioning for 24 hours at 60^{o}C, samples were conditioned again for one hour at 25^{o}C in UTM. The tested combinations' conditioned and unconditioned strength values are listed in Table 4.4. Figure 4.1 gives the monotonic loading schematic diagram of TSR. Figure 4.2 compares the strengths of the control mixture (which has not been modified in any way) with modified mixtures that contain various amounts of Bakelite and Nano-clay, both with and without conditioning. Figure 4.3 is demonstrating the tensile strength ratio and Figure 4.4 presents the trend among values which shows the sets of values, or confidence intervals (CI), that are likely to include the true mean for each percentage. The findings indicate that **6%Bakelite and 4%NC** content performs the best with a **17.98%** increase in TSR compared to the control mix.

Table 4.4: Tensile Strength Ratio Values

Description	Average Unconditioned Strength (S1) KN	Average Conditioned Strength (S2) KN	TSR =S2/S1(%)
0%Bakelite+0%NC	5.17	4.12	79.69
6%Bakelite+0%NC	5.253	4.47	85
6%Bakelite+2%NC	5.414	4.76	88
6%Bakelite+4%NC	6.01	5.87	97.67
6%Bakelite+6%NC	5.89	5.43	92.19
6%Bakelite+8%NC	5.62	5.01	89.15

The addition of Nano-clay (NC) and Bakelite to AC mixtures increases the space content of air voids for bitumen. An increase in air voids makes modified mixes more moisture susceptible as the NC percentages increase. However, 6%Bakelite with 4% NC has improved moisture susceptibility of AC mixtures, and results illustrate that the **<u>6% Bakelite with 4% NC combination has outperformed</u>** all other combinations.

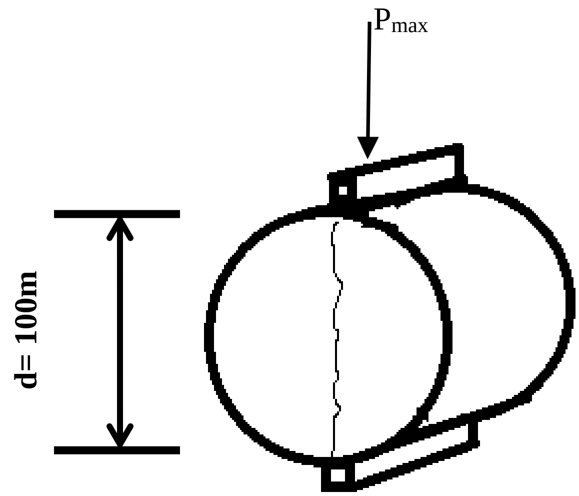

Figure 4.1: Tensile strength ratio schematic diagram

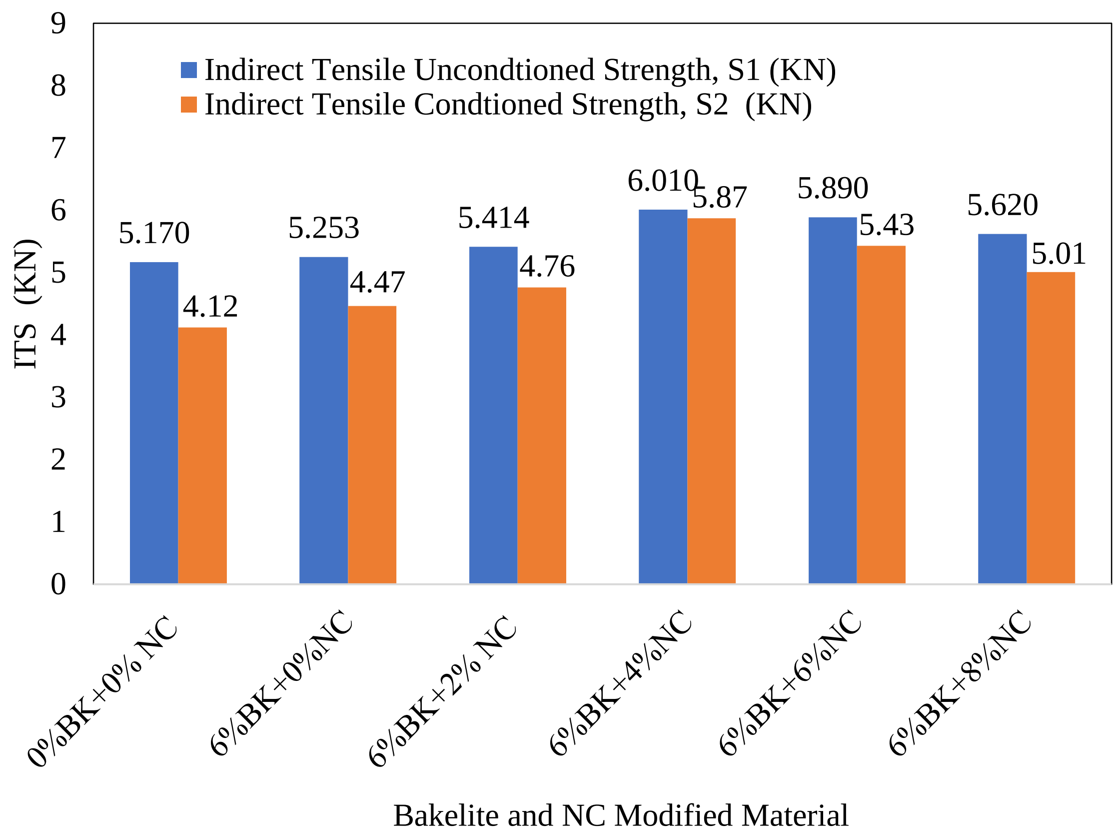

Figure 4.2: ITS Conditioned and Unconditioned comparison

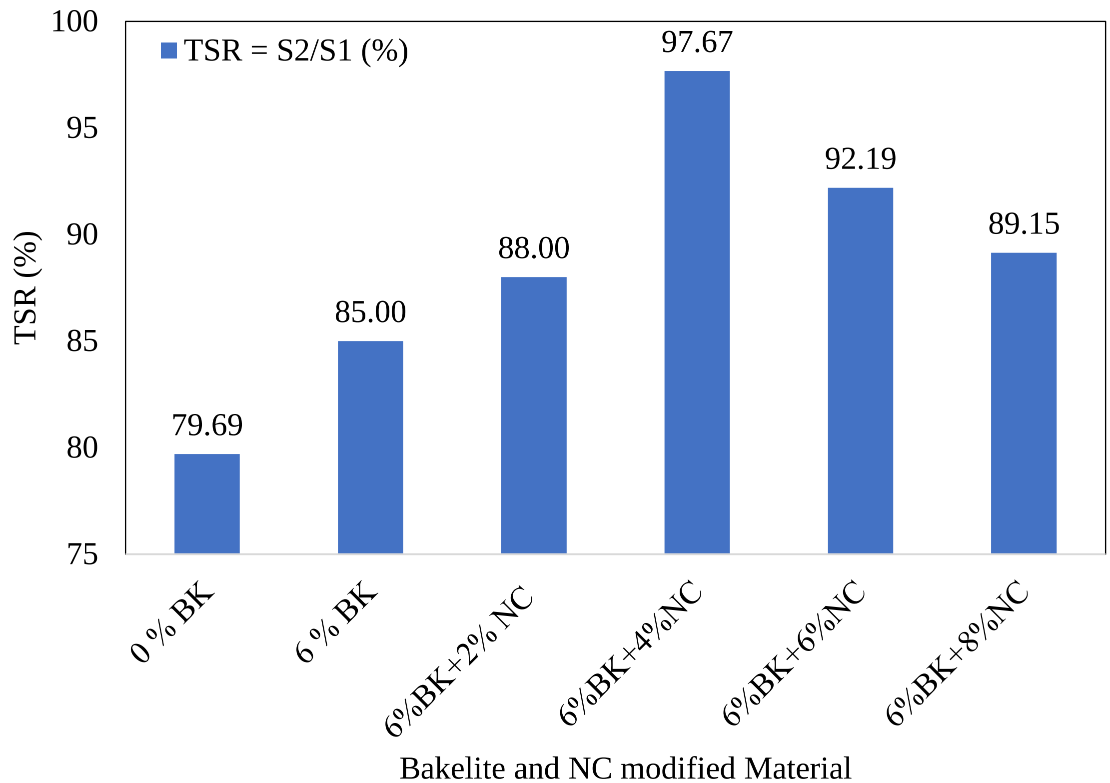

Figure 4.3: Tensile strength ratio of Bakelite and NC modified HMA

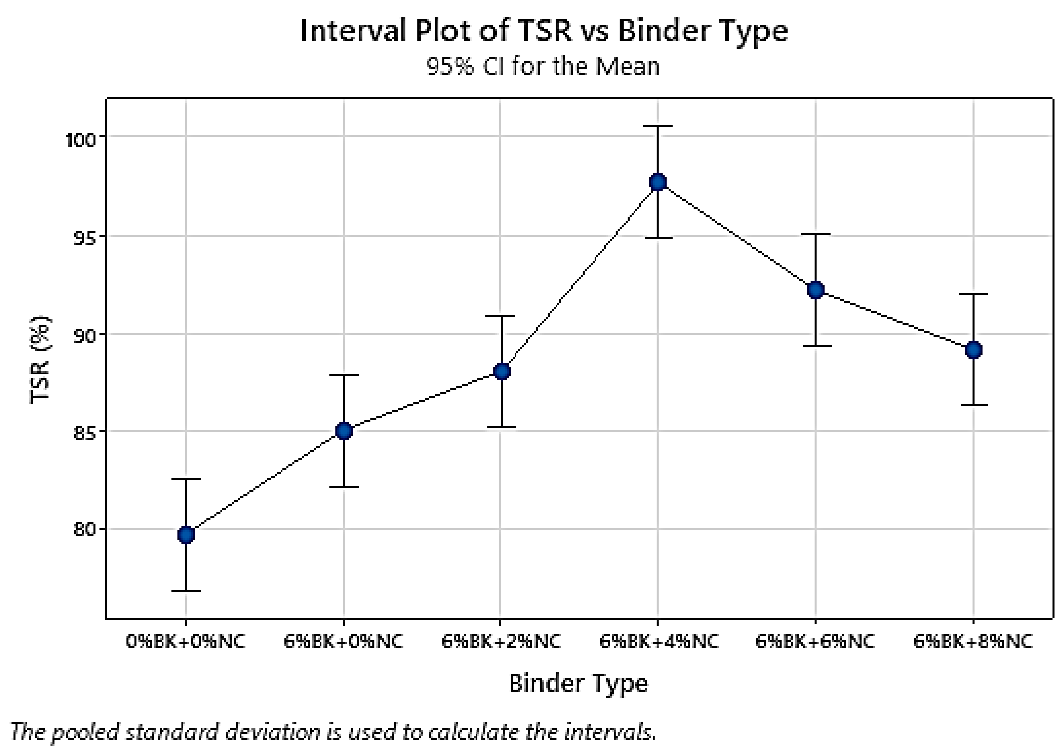

Figure 4.4: Tensile strength ratio trend

4.6 RESILIENT MODULUS

The reading of the resilient modulus can be used to evaluate how the structure of the roadway reacts when loads from vehicles are placed on it. Resilient modulus is a relative measure of mixture stiffness and it recorded when a material is subjected to cyclic loading. The resilient modulus test is used to find the quality of materials and capture data for pavement design. Resilient modulus is a significant metric for predicting pavement performance and analyzing pavement reaction to traffic loading.

3x replicates of each percentage of Bakelite and Nano-clay combinations for the stiffness modulus performance test in compliance with (ASTM D 4123) are prepared. The modulus for each load pulse is computed by the software program that comes with the test equipment. The IDT for resilient modulus is performed using a haversine waveform and a load applied vertically in the vertical diametric plane on a cylindrical specimen with standard Marshall specimen dimensions (Dia 100mm and Thickness 65mm), as shown in Figure 4.5. The application of load and elastic deformation produced horizontally due to that load shows the resilient modulus, and this load and deformation criteria should be considered for every pulse for the calculation of the resilient modulus. Using the following Equation for M_R value:

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

Where:

$Mr = Resilient\ Modulus$

$P = Cyclic\ Load$

$t = Thickness\ of\ Specimen$

$\Delta h = Recoverable\ horizontal\ deformation$

$\upsilon = Poisson\ ratio$

Figure 4.6 shows dignified values of resilient modulus of control and Bakelite and NC modified AC mixes and Figure 4.7 presents the trend among values which shows the sets of values, or confidence intervals (CI), that are likely to include the true mean for each percentage. By results, it is evident that the **<u>6% Bakelite and 4%NC combination gives the best results</u>**. Results show that the addition of this combination of modifier has enhanced the ***M_R by 1.6 times*** of the original control mix. When the modifier content is increased first the value of resilient modulus starts to increase and then start to decline after 6%NC content. So, in the light of these results, it is indicated that ***6% Bakelite and 4% NC is the best combination.***

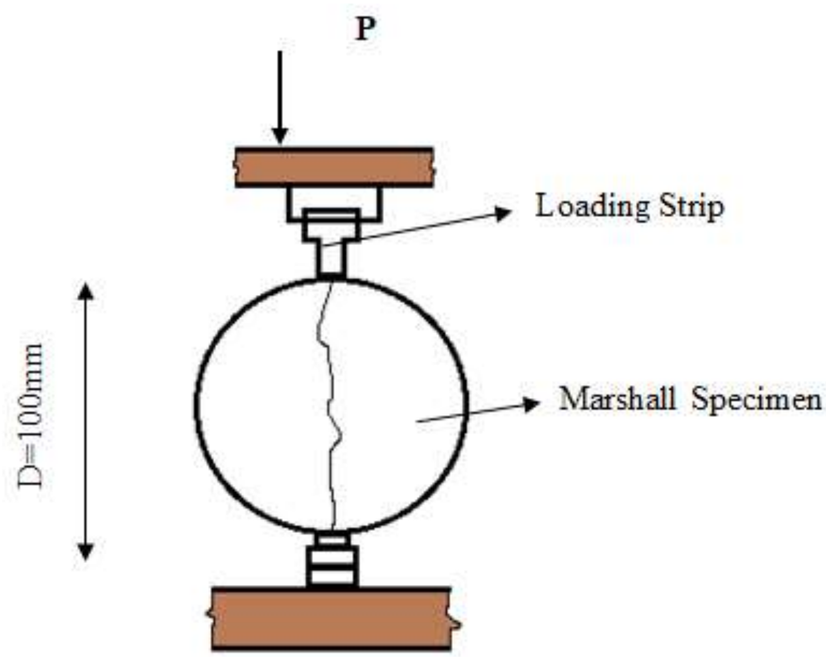

Figure 4.5: Schematic diagram for M_R

Table 4.5: Average Resilient Modulus Values

Description	Average Resilient Modulus (MPA)
60/70 Grade Bitumen	3387
6% Bakelite + 2% NC	3537
6% Bakelite + 2% NC	3857
6% Bakelite + 4% NC	5413
6% Bakelite + 6% NC	4774
6% Bakelite + 8% NC	4456

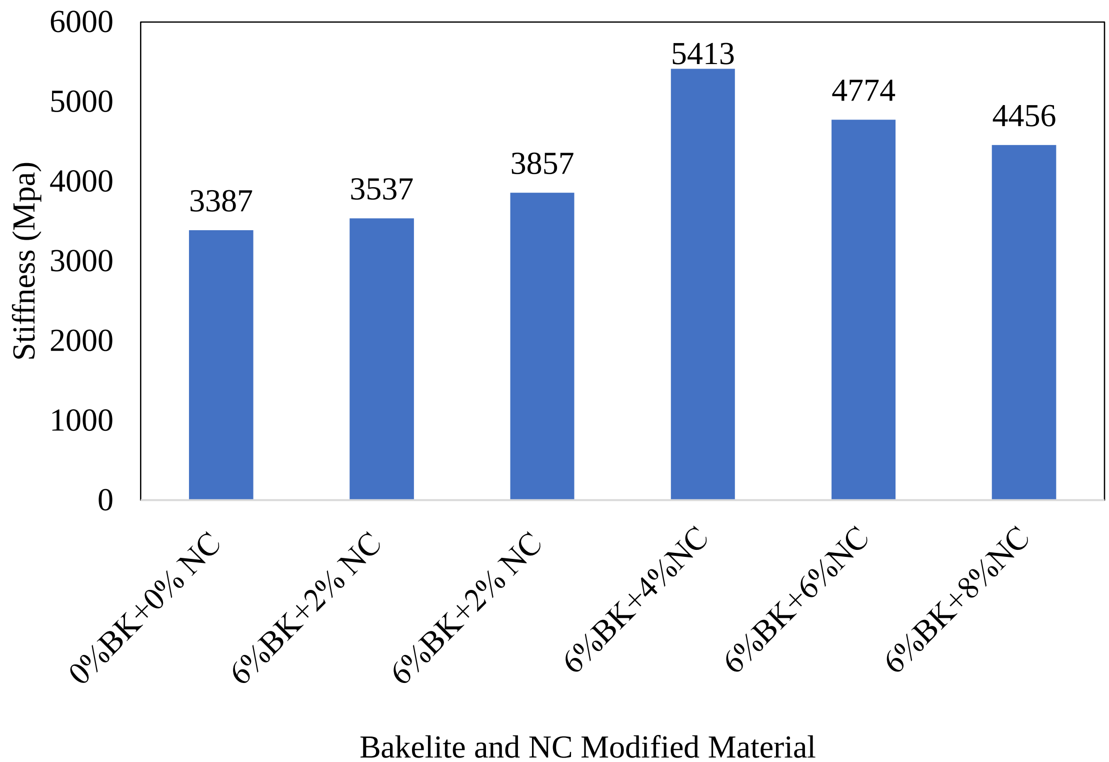

Figure 4.6: Resilient modulus values

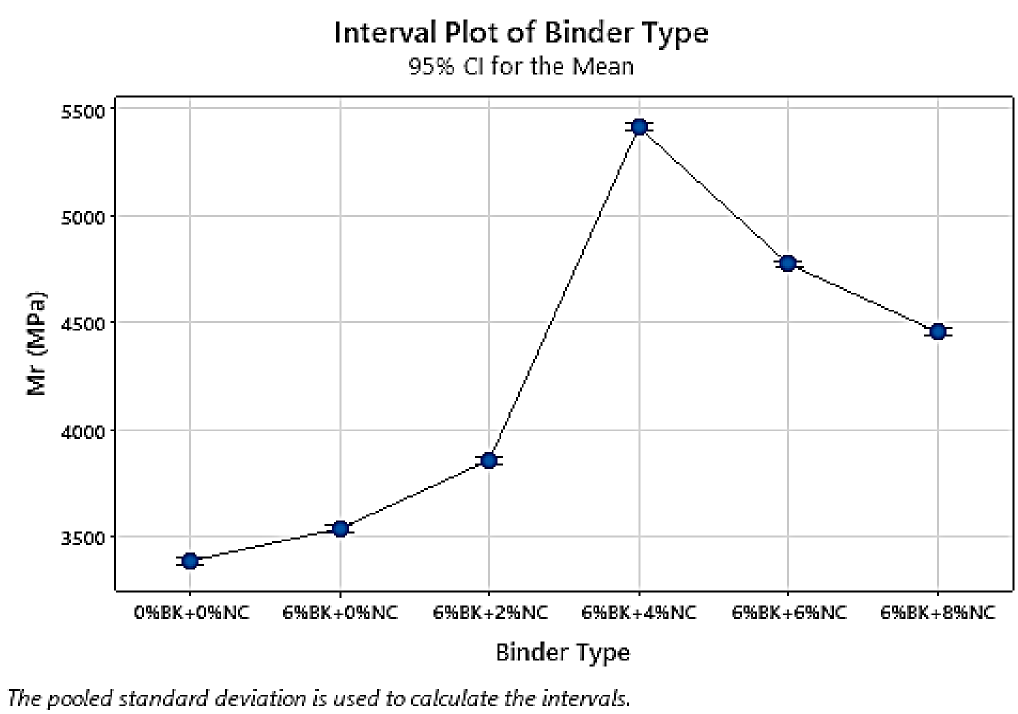

Figure 4.7: Trend graph of resilient modulus

4.7 HAMBURG WHEEL TRACKING TEST

In order to compare the relative rut depth of original and modified HMA samples, wheel tracking tests were conducted using Superpave gyratory compacted samples of diameter 6" and height 2.5". The samples (Control 60/70 and modified with 6% Bakelite and 2%, 4%, 6%, and 8%) Nano-Clay were put through 5000 cycles at a pace of 25 rpm, and the software then measured and plotted the rut depth that resulted. Table 4.6 presents the test findings for rut depth for each specimen versus various modifier percentages during the course of 5000 cycles. The plot is made for rut depth against each combination of Bakelite and NC shown in Figure 4.8. Figure 4.9 presents the trend among values which shows the sets of values, or confidence intervals (CI) that are likely to include the true mean for each percentage.

For HWTT test, 12 samples were arranged with 6% of Bakelite and varying percentages of Nano-Clay as mentioned in Table 4.6, these samples were saw cut for wheel tracker to check its rutting potential. All of the samples exhibited a high level of rutting resistance, although samples with increasing Nano-Clay content showed good resistance up to 4%, after that at 6% and 8% of Nano-Clay the rut resistance decreased significantly. Rutting is less than 12.5mm in all of the samples.

Table 4.6: Hamburg Wheel Tracking Test Result

Modifier	Rutting Depth(mm) at 40°C and 5000 cycles
0%Bakelite + 0%NC	3.25
6% Bakelite + 0%NC	2.65
6% Bakelite + 2%NC	2.41
6% Bakelite + 4%NC	2.31
6% Bakelite + 6%NC	2.43
4.5%SBS + 8%NC	2.56
Rut depth shall be less than 12.5mm	

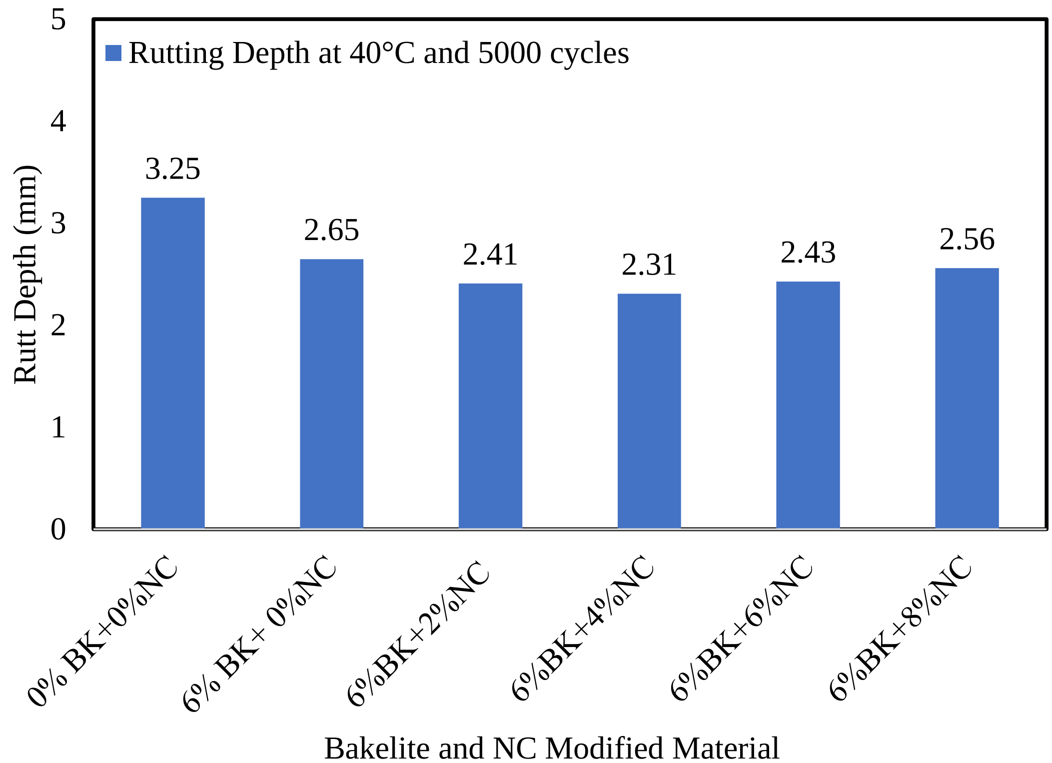

Figure 4.8: Rut depth results

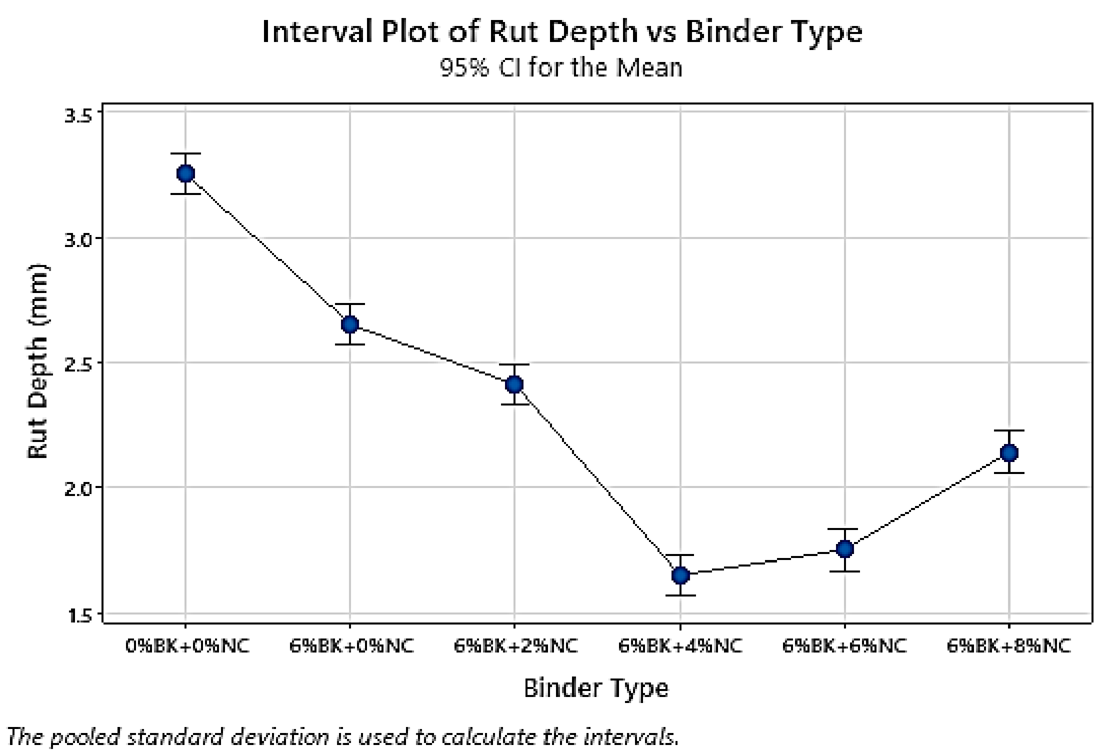

Figure 4.9: Trend graph of rutting

4.8 MOISTURE SUSCEPTIBILITY FROM HWT TEST RESULTS

The results of rut test that is Hamburg Wheel Tracking Test (HWTT) are used to find the stripping inflection point (SIP), which is meant to be the starting point of stripping phase in the rutting. Stripping is the peeling of bitumen cover from the aggregate in HMA mixes. The data collected are plotted against the cycles, and then a 6^{th} degree polynomial fitted line is incorporated as regression line. After that from the equation of the trend/regression line its first derivative is taken, and the values are again plotted against the number of cycles. The lowest first point in the curve is the stripping inflection point. The Figure 4.10 shows the plot of the rut depth value against cycles having a fitted curve, the equation is also shown.

Figure 4.10 also shows plot of the first derivatives of the 6_{th} order polynomial equation shown in Figure 1. these plots predicts that the samples qualify the minimum criteria of the IOWA DOT method, which says that the minimum passes for the stripping inflection point is 1000 passes showing the lowest point is at about 800 cycles (1600 passes). These plots are for base binder values.

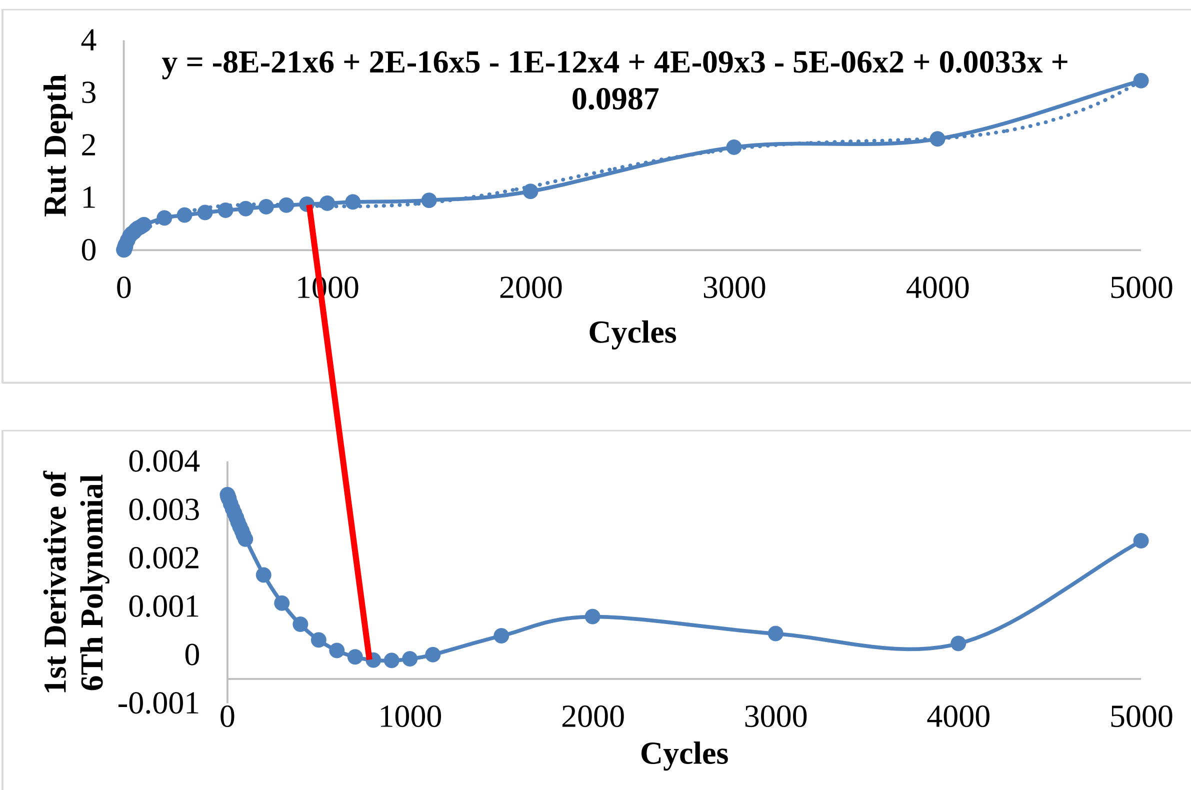

Figure 4.10: Fitting the HWT rutting curve with 6-order polynomial for inflection point.

The following Figure 3 shows plots for the samples having 6%Bakelite and 4%NC content as modifiers. These plots shows that the stripping inflection point is at 3000 cycles (6000 passes), proving the significance of the modifiers been used in this study.

This method a 6th order polynomial fitted curve is adjusted on the plotted curve of rut depth and cycles. Then the equation is generated from the regression line and its first derivative was calculated and plotted against the cycles. The first lowest point or value is the stripping inflection point. The stripping inflection point is believed to be the starting point of moisture damage. The equation is

$$R(N) = p6N^6 + p5N^5 + p4N^4 + p3N^3 + p2N^2 + p1N + p0$$

Where,

R(N) is the rut depth at N cycles

P (0,1,2,3,4,5,6) are the regression coefficients

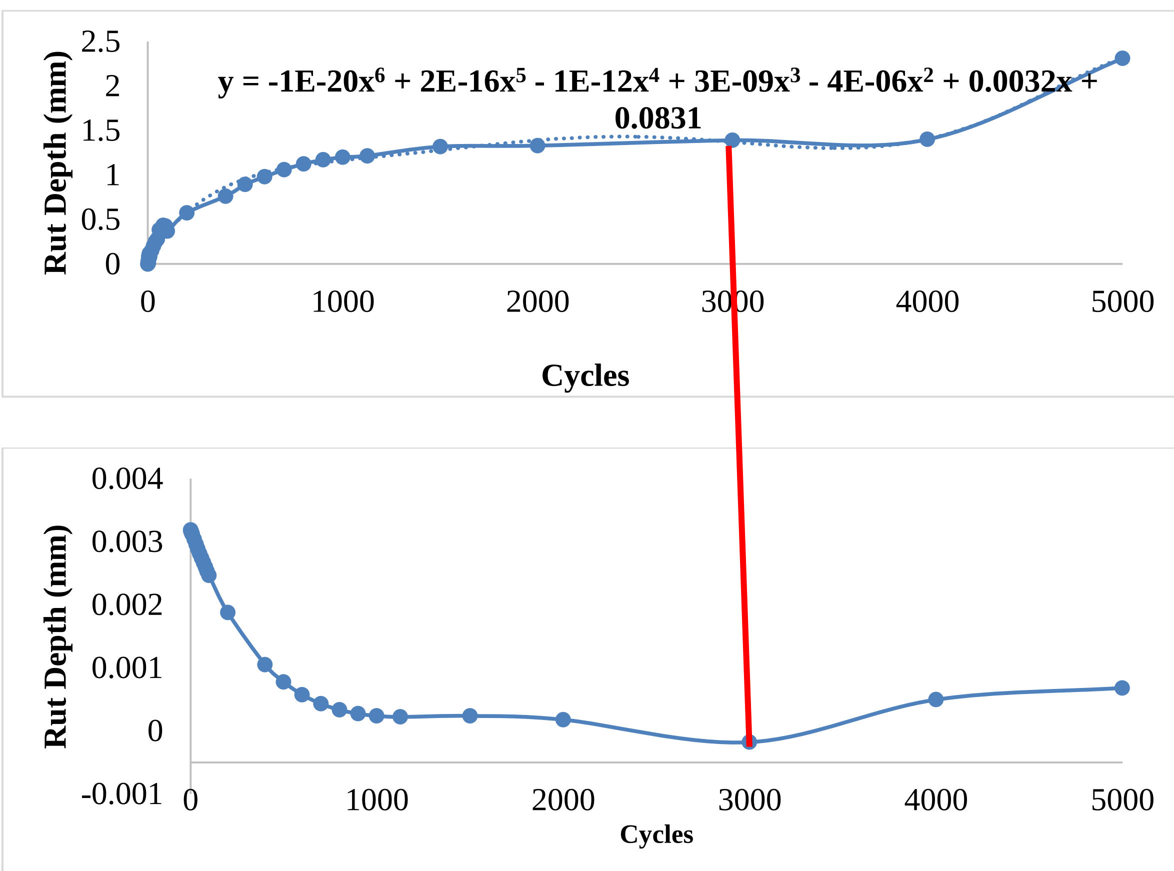

Figure 4.11: Fitting the HWT rutting curve with 6-order polynomial for inflection point.

4.9 ANALYSIS OF VARIANCE

In order to examine the test results and determine the relevance of the components that were involved, a one-way analysis of variance was carried out. In addition, a pairwise Tukey analysis was performed on the data. A comparison of the means of the various groups can be carried out with the use of the Tukey analysis test, which also determines the significance of the relationships between the factors and the responses. A variety of groups, each of which is connected to a data mean, are each given a letter. The Table displays the results, which include the degree of freedom, as well as the P-value and the F-value. For a factor to be considered significant, its P-value should be lower than 0.05, which is the level of confidence of 95 percent. In the same vein, the F-value must be more than 10.

4.9.1 Analysis of Variance for TSR

Table 4.7 shows that the modifier is significant for the TSR values as a response factor as the P-value is less than 0.05 and the F-value is more than 10. Table 4.8 shows the factors (modified bitumen), the means and the standard deviation of the data. Table 4.9 shows the means, and the grouping, which is done by assigning different letters to each modifier percentages. The group which doesn’t share any latter is significantly different. It is noticed that only 6% Bakelite with 4% NC is significantly different.

Table 4.7: Analysis of Variance for TSR values

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	5	564.48	112.896	21.85	0.000
Error	12	62	5.167		
Total	17	626.48			

Table 4.8: Mean and Standard Deviation of the Data

Factor	**N**	**Mean**	**Std Dev**	**95% CI**
0%BK+0%NC	3	79.69	2	(76.83, 82.55)
6%BK+0%NC	3	85	3	(82.14, 87.86)
6%BK+2%NC	3	88	1	(85.141, 90.859)
6%BK+4%NC	3	97.67	2	(94.81, 100.53)
6%BK+6%NC	3	92.19	3	(89.33, 95.05)
6%BK+8%NC	3	89.15	2	(86.29, 92.01)

Table 4.9: Grouping using Tuckey's Analysis and 95% CI

Factor	N	Mean	Grouping			
6%BK+4%NC	3	97.67	A			
6%BK+6%NC	3	92.19	A	B		
6%BK+8%NC	3	89.15		B	C	
6%BK+2%NC	3	88		B	C	
6%BK+0%NC	3	85			C	D
0%BK+0%NC	3	79.69				D

The results of the Tukey simultaneous test for any conceivable level difference are displayed in the Table 4.10. It can be seen that many of the outcomes are not significantly different in which the P-value for the significance level difference is greater than 0.05. This demonstrates that many of the combinations have similarity in their results in case of TSR combination. Figure 4.12 presents the distribution of means with respect to a reference zero line. This line suggests that any mean that contains zero does not imply a substantial difference between the groups.

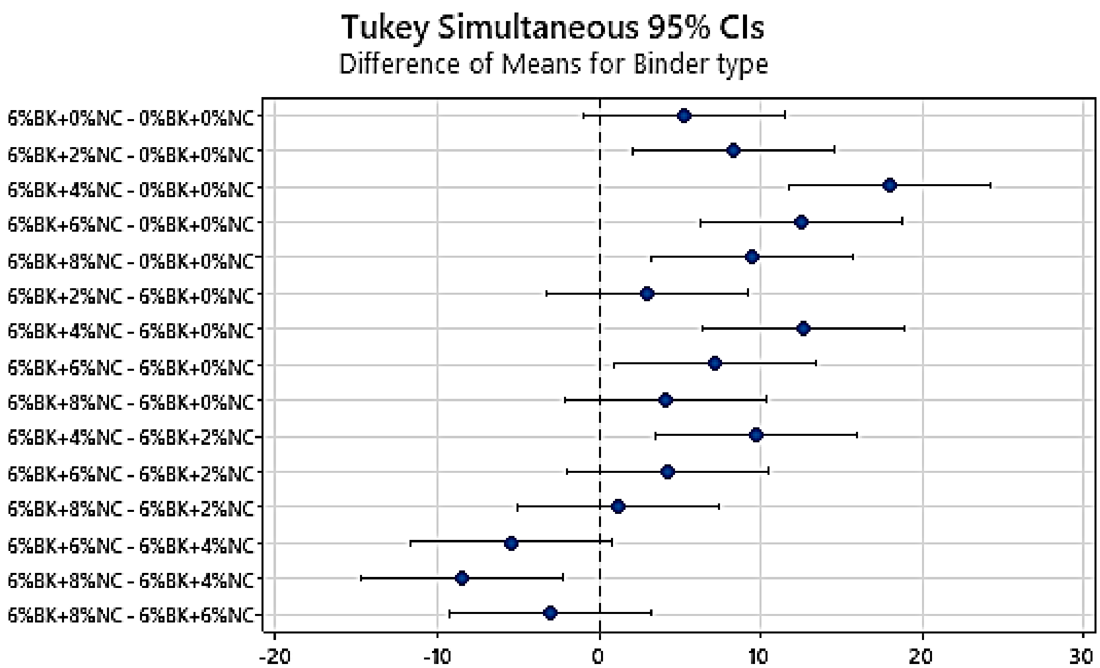

Figure 4.12: Distribution of means for TSR

Table 4.10: Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	Adjusted P-Value
6%BK+0%NC - 0%BK+0%NC	5.31	1.86	(-0.92, 11.54)	0.113
6%BK+2%NC - 0%BK+0%NC	8.31	1.86	(2.08, 14.54)	0.008
6%BK+4%NC - 0%BK+0%NC	17.98	1.86	(11.75, 24.21)	0
6%BK+6%NC - 0%BK+0%NC	12.5	1.86	(6.27, 18.73)	0
6%BK+8%NC - 0%BK+0%NC	9.46	1.86	(3.22, 15.69)	0.003
6%BK+2%NC - 6%BK+0%NC	3	1.86	(-3.23, 9.23)	0.604
6%BK+4%NC - 6%BK+0%NC	12.67	1.86	(6.44, 18.90)	0
6%BK+6%NC - 6%BK+0%NC	7.19	1.86	(0.96, 13.42)	0.021
6%BK+8%NC - 6%BK+0%NC	4.15	1.86	(-2.09, 10.38)	0.291
6%BK+4%NC - 6%BK+2%NC	9.67	1.86	(3.44, 15.90)	0.002
6%BK+6%NC - 6%BK+2%NC	4.19	1.86	(-2.04, 10.42)	0.282
6%BK+8%NC - 6%BK+2%NC	1.15	1.86	(-5.09, 7.38)	0.988
6%BK+6%NC - 6%BK+4%NC	-5.48	1.86	(-11.71, 0.75)	0.098
6%BK+8%NC - 6%BK+4%NC	-8.52	1.86	(-14.76, -2.29)	0.006
6%BK+8%NC - 6%BK+6%NC	-3.04	1.86	(-9.28, 3.19)	0.59

4.9.2 Analysis of Variance for Resilient Modulus

The Table 4.11 shows that the modifier is significant for the M_R values as a response factor as the P-value is less than 0.05 and the F-value is more than 10. Table 4.12 shows the factors (modified bitumen), the means and the standard deviation of the data. Table 4.13 shows the means, and the grouping, which is done by assigning different letters to each modifier percentages. The group which doesn’t share any latter is significantly different.

Table 4.11: Analysis of Variance for M_R Values

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	18457232	3691446	10518.9	0.000
Error	30	10528	351		
Total	35	18467760			

Table 4.12: Mean and Standard Deviation of the Data

Factor	N	Mean	Std Dev	95% CI
0%BK+0%NC	6	3387	22.36	(3371.38, 3402.62)
6%BK+0%NC	6	3537	23.26	(3521.38, 3552.62)
6%BK+2%NC	6	3857	21.47	(3841.38, 3872.62)
6%BK+4%NC	6	5413	16.99	(5397.38, 5428.62)
6%BK+6%NC	6	4774	13.42	(4758.38, 4789.62)
6%BK+8%NC	6	4456	11.63	(4440.38, 4471.62)

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

Factor	N	Mean	Grouping					
6%BK+4%NC	6	5413	A					
6%BK+6%NC	6	4774		B				
6%BK+8%NC	6	4456			C			
6%BK+2%NC	6	3857				D		
6%BK+0%NC	6	3537					E	
0%BK+0%NC	6	3387						F

The results of the Tukey simultaneous test for any conceivable level difference are displayed in the Table 4.14. It can be seen that all of the outcomes are significant, The P-value for the significance level difference is lower than 0.05. This demonstrates that there is no insignificance in the results and all the groups are significant for M_R. This demonstrates that there is a considerable difference in the outcomes of M_R when compared to the control mix, and this difference is proportional to the amount of the modifier that is present in the mix. Figure 4.13 presents the distribution of means with respect to a reference zero line. This line suggests that any mean that contains zero does not imply a substantial difference between the groups.

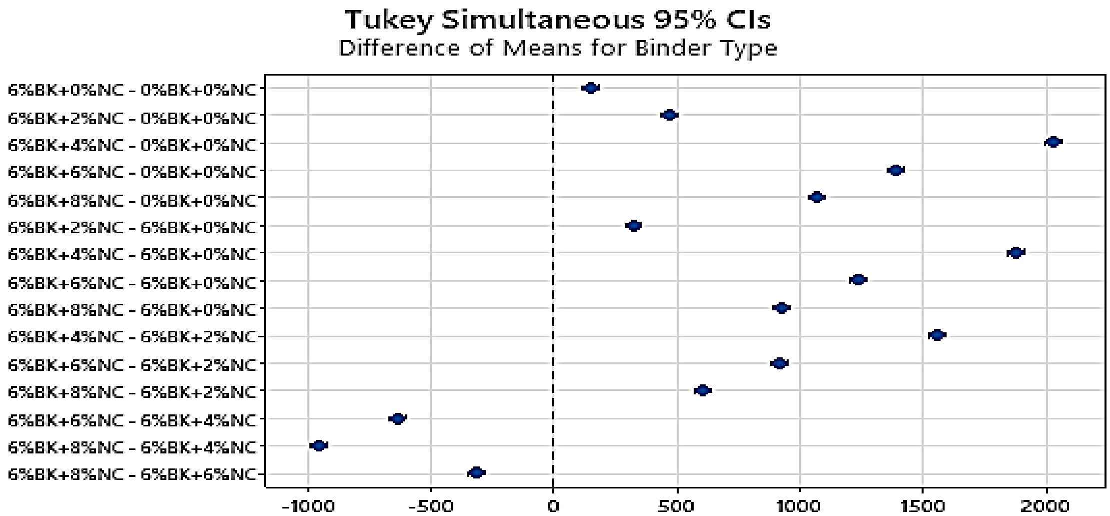

Figure 4.13: Distribution of means for M_R

Table 4.14: Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Mean	SE of Difference	95% CI	Adjusted P-Value
6%BK+0%NC - 0%BK+0%NC	150	10.8	(117.1, 182.9)	0
6%BK+2%NC - 0%BK+0%NC	470	10.8	(437.1, 502.9)	0
6%BK+4%NC - 0%BK+0%NC	2026	10.8	(1993.1, 2058.9)	0
6%BK+6%NC - 0%BK+0%NC	1387	10.8	(1354.1, 1419.9)	0
6%BK+8%NC - 0%BK+0%NC	1069	10.8	(1036.1, 1101.9)	0
6%BK+2%NC - 6%BK+0%NC	320	10.8	(287.1, 352.9)	0
6%BK+4%NC - 6%BK+0%NC	1876	10.8	(1843.1, 1908.9)	0
6%BK+6%NC - 6%BK+0%NC	1237	10.8	(1204.1, 1269.9)	0
6%BK+8%NC - 6%BK+0%NC	919	10.8	(886.1, 951.9)	0
6%BK+4%NC - 6%BK+2%NC	1556	10.8	(1523.1, 1588.9)	0
6%BK+6%NC - 6%BK+2%NC	917	10.8	(884.1, 949.9)	0
6%BK+8%NC - 6%BK+2%NC	599	10.8	(566.1, 631.9)	0
6%BK+6%NC - 6%BK+4%NC	-639	10.8	(-671.9, -606.1)	0
6%BK+8%NC - 6%BK+4%NC	-957	10.8	(-989.9, -924.1)	0
6%BK+8%NC - 6%BK+6%NC	-318	10.8	(-350.9, -285.1)	0

4.9.3: Analysis of Variance for Rut Depth

The Table 4.15 shows that the modifier is significant for the M_R values as a response factor as the P-value is less than 0.05 and the F-value is more than 10. Table 4.16 shows the factors (modified bitumen), the means and the standard deviation of the data. Table 4.17 shows the means, and the grouping, which is done by assigning different letters to each modifier percentages. This shows that the factor which share letter in there grouping are not significant differently.

Table 4.15: Analysis of Variance for Rutting Values

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	5	5.36185	1.07237	245.58	0.000
Error	12	0.0524	0.00437		
Total	17	5.41425			

Table 4.16: Mean and Standard Deviation of the Data

Factor	N	Mean	Std Dev	95% CI
0%BK+0%NC	3	3.25	0.08	(3.1669, 3.3331)
6%BK+0%NC	3	2.65	0.07	(2.5669, 2.7331)
6%BK+2%NC	3	2.41	0.09	(2.3269, 2.4931)
6%BK+4%NC	3	2.31	0.06	(1.5669, 1.7331)
6%BK+6%NC	3	2.43	0.0265	(1.6669, 1.8331)
6%BK+8%NC	3	2.56	0.05	(2.0569, 2.2231)

Table 4.17: Grouping using Tuckey’s Analysis and 95% CI

Factor	N	Mean	Grouping				
0%BK+0%NC	3	3.25	A				
6%BK+0%NC	3	2.65		B			
6%BK+2%NC	3	2.41			C		
6%BK+8%NC	3	2.56				D	
6%BK+6%NC	3	2.43					E
6%BK+4%NC	3	2.31					E

The results of the Tukey simultaneous test for any conceivable level difference are displayed in the Table 4.18. It can be seen that all of the outcomes are significant, The P-value for the significance level difference is lower than 0.05. This demonstrates that there is no insignificance in the results and most of the groups are significant for Rut Depth. The P-value is more than 0.05 for some pairs of difference of level. This shows that some levels are not significant as compared to the lower mean of the 6%BK+4%NC. This demonstrates that there is a considerable difference in the outcomes of Rut Depth when compared to the control mix, and this difference is proportional to the amount of the modifier that is present in the mix. Figure 4.14 presents the distribution of means with respect to a reference zero line. This line suggests that any mean that contains zero does not imply a substantial difference between the groups.

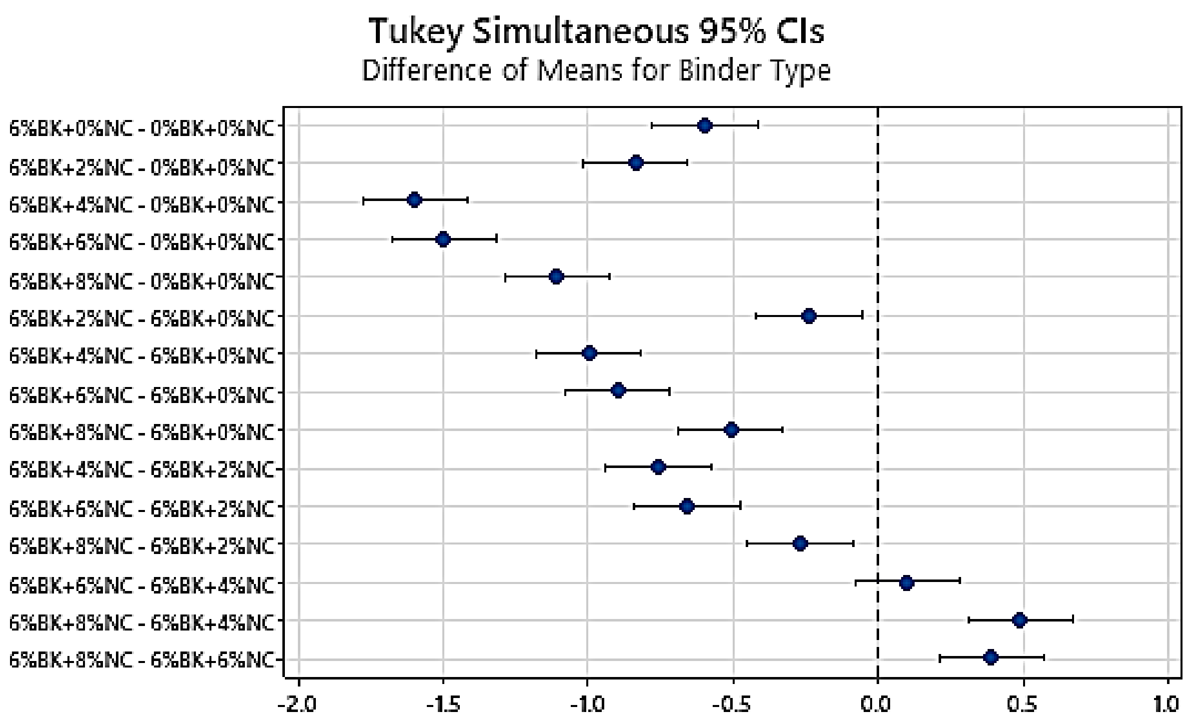

Figure 4.14: Distribution of means for rut depth values

Table 4.18: Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Mean	SE of Difference	95% CI	Adjusted P-Value
6%BK+0%NC - 0%BK+0%NC	-0.6	0.054	(-0.7812, -0.4188)	0
6%BK+2%NC - 0%BK+0%NC	-0.84	0.054	(-1.0212, -0.6588)	0
6%BK+4%NC - 0%BK+0%NC	-1.6	0.054	(-1.7812, -1.4188)	0
6%BK+6%NC - 0%BK+0%NC	-1.5	0.054	(-1.6812, -1.3188)	0
6%BK+8%NC - 0%BK+0%NC	-1.11	0.054	(-1.2912, -0.9288)	0
6%BK+2%NC - 6%BK+0%NC	-0.24	0.054	(-0.4212, -0.0588)	0.008
6%BK+4%NC - 6%BK+0%NC	-1	0.054	(-1.1812, -0.8188)	0
6%BK+6%NC - 6%BK+0%NC	-0.9	0.054	(-1.0812, -0.7188)	0
6%BK+8%NC - 6%BK+0%NC	-0.51	0.054	(-0.6912, -0.3288)	0
6%BK+4%NC - 6%BK+2%NC	-0.76	0.054	(-0.9412, -0.5788)	0
6%BK+6%NC - 6%BK+2%NC	-0.66	0.054	(-0.8412, -0.4788)	0
6%BK+8%NC - 6%BK+2%NC	-0.27	0.054	(-0.4512, -0.0888)	0.003
6%BK+6%NC - 6%BK+4%NC	0.1	0.054	(-0.0812, 0.2812)	0.471
6%BK+8%NC - 6%BK+4%NC	0.49	0.054	(0.3088, 0.6712)	0
6%BK+8%NC - 6%BK+6%NC	0.39	0.054	(0.2088, 0.5712)	0

4.10: SUMMARY

Based on the findings of the study, it is clear that including a combination of Bakelite and Nano-clay into asphalt concrete mixtures has the potential to improve the asphalt's qualities. It has been found that adding 6 percent SBS and 4 percent NC results in the best performance compared to other possible combinations. Because of the large increase in air spaces, the mechanical characteristics of asphalt mixtures are degraded when a higher percentage of Nano-clay is used (4 percent content compared to 6 percent Bakelite content). It has been noted that the incorporation of Bakelite and Nano-Clay has led to an increase in the material's stiffness, resistance to rutting, and susceptibility to moisture. The findings indicate that **6%Bakelite and 4%NC** content performs the best with a **17.98%** increase in TSR compared to the control mix. Results also show that the addition of this combination of modifier has enhanced the ***M_R by 1.6 times*** of the original control mix. From rutting test it is also found that add **6% Bakelite and 4%Nano-clay** can reduce the rutting up to **28.9%** as compared to controlled mix and resistance to stripping in increased by ***3 times.***

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

The principle aim of this research was to study the effectiveness of Bakelite and Nano-clay as an additive for asphalt concrete mixes. This was done by comparing various mechanical properties such as Marshall Stability, flow, Marshall Quotient, moisture susceptibility, Rutting and resilient modulus of modified asphalt concrete mixes versus the control mixes. The control asphalt concrete mix was prepared by using 60/70 penetration grade bitumen occupied from ARL, while in modified mixes same bitumen was added with 6% of Bakelite and 2%, 4%, 6%, and 8% of Nano-clay by weight of optimum bitumen content(OBC). OBC was found by Marshall Mix design criteria (ASTM D6926) which came out to be 4.3% by weight of aggregates. The both modifiers was added by wet process, in which firstly both modifiers are added to the bitumen at selected mixing temperature, and then this mixture is added to heated aggregates. In order to achieve accuracy of the experimental results three specimens were prepared for each combination. The aggregate gradation selected was NHA-B with nominal maximum size of ½ inch. Binder content of 4.3% obtained from OBC was used in the making of all bituminous paving mixes. Mixing and compaction temperatures of 165°C were selected for preparation of mixes. To replicate the extreme loading environment of Pakistan, the specimens were densified with 75 blows at each end for marshal samples. The indirect tensile strength test IDT, moisture susceptibility test, and resilient modulus tests were performed in Universal Testing Machine (UTM-25), Rutting test were performed with Hamburg Wheel Tracking Test HWTT, while the stability, flow, quotient and retained stability tests were performed using Marshall compression testing machine.

5.2 CONCLUSIONS

Based on the results obtained from the Marshall Stability, flow, quotient, retained stability and resilient modulus testing of both conventional and modified asphalt concrete samples and analysis of experimental results, the following conclusions have been drawn.

1. The Bakelite and Nano-clay enhanced various mechanical properties of asphalt concrete mixes like Marshall Stability, flow, moisture susceptibility, indirect tensile strength test, rutting test, and resilient modulus thus it can be used as an additive.
2. Optimum bitumen content (OBC) found by Marshall Mix design criteria (ASTM D6926) came out to be 4.3% by weight of aggregates.
3. Marshall Stability, flow, Marshall Quotient and retained stability test results showed that optimum value for asphalt concrete mixes is 6% Bakelite and 4% Nano-clay by weight of OBC.
4. Marshall Stability, flow, Marshall Quotient test results showed that up to 6% Bakelite content and 4% Nano-clay, strength and flow of the mixes increased.
5. Retained stability test showed that with the addition of Bakelite and Nano-clay, the moisture susceptibility of asphalt concrete decreased thus making it more resistant to moisture damage as compared to conventional mix. The test showed 6% Bakelite content and 4% NC to be the optimum modifier content.
6. The indirect tensile strength test was performed on 4-inch diameter specimens of both conventional and modified mixes at constant deformation rate of 50mm/min at 25C. The strength values obtained with modified specimens were higher than that obtained with conventional specimens.
7. The resilient modulus test results showed a 20% increase for the modified mix containing 6% Bakelite and 4% Nano-clay as compared to conventional mix.
8. Thus it is concluded that modified mixes containing 6% Bakelite and 4% Nano-clay by weight of optimum bitumen content gives the best results as compared to conventional mix with 60/70 penetration grade asphalt. So Bakelite and Nano-clay can be used as a modifier for conventional penetration grade bitumen.

5.3 FUTURE WORK AND RECOMMENDATIONS

1. The scope of this thesis was to analyze the effects of Bakelite and Nano-clay as a modifier for conventional 60/70 penetration grade bitumen. The specimens were tested for Marshall stability, flow, quotient, retained stability (moisture susceptibility), rutting and resilient modulus. In all these tests the specimens were prepared by Marshall Mix design and Gyratory samples for using NHA Class B

gradation, Babuzai aggregate and 4-in specimen diameter. For future study one work the same with using NHA Class A gradation.

2. This study provides a basis to experimentally investigate the effect of Bakelite and Nano-clay on various properties of asphalt concrete specimens like resilient modulus, retained stability, Marshall Stability, flow and Marshall Quotient. For future study other properties, such as dynamic creep, Dynamic Modulus by SPT and flexural stiffness can be tested.
3. In this research, the Bakelite is used with combination of Nano-clay. For future study it can be mixed with other modifiers such as crumb rubber, fibers and other types of plastics.
4. This study compared the properties of modified and conventional 60/70 penetration grade bitumen. For future study one must compare the results obtained by testing 40/50, 60/70, and 80/100 specimens against performance grade specimens.
5. Field performance of Bakelite and Nano-clay modified mixes should be evaluated.

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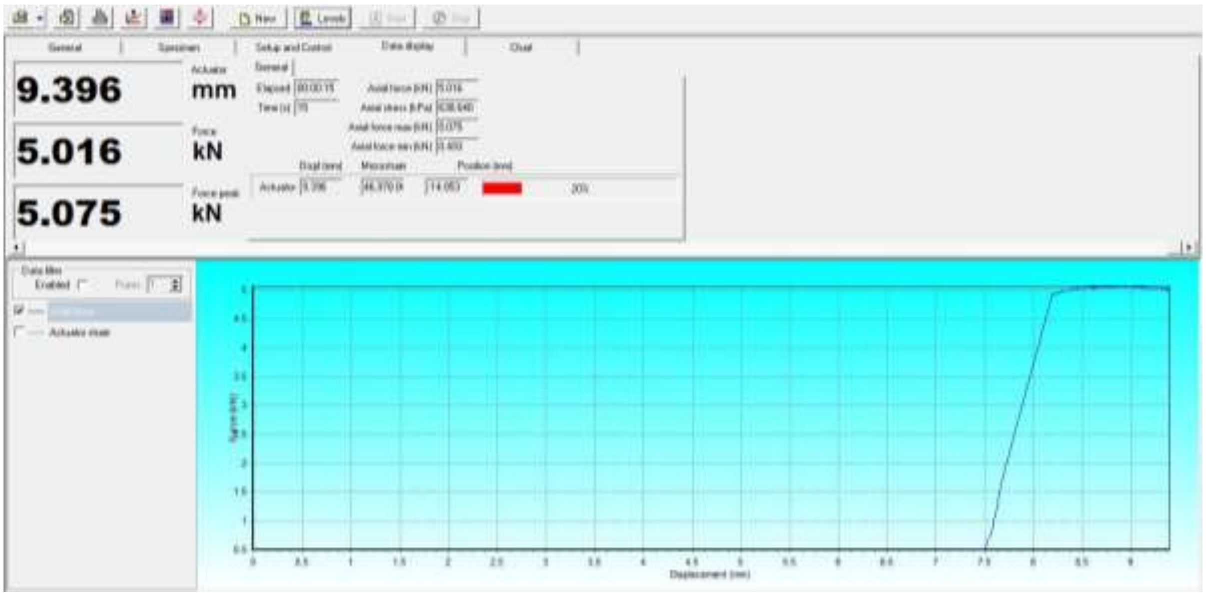
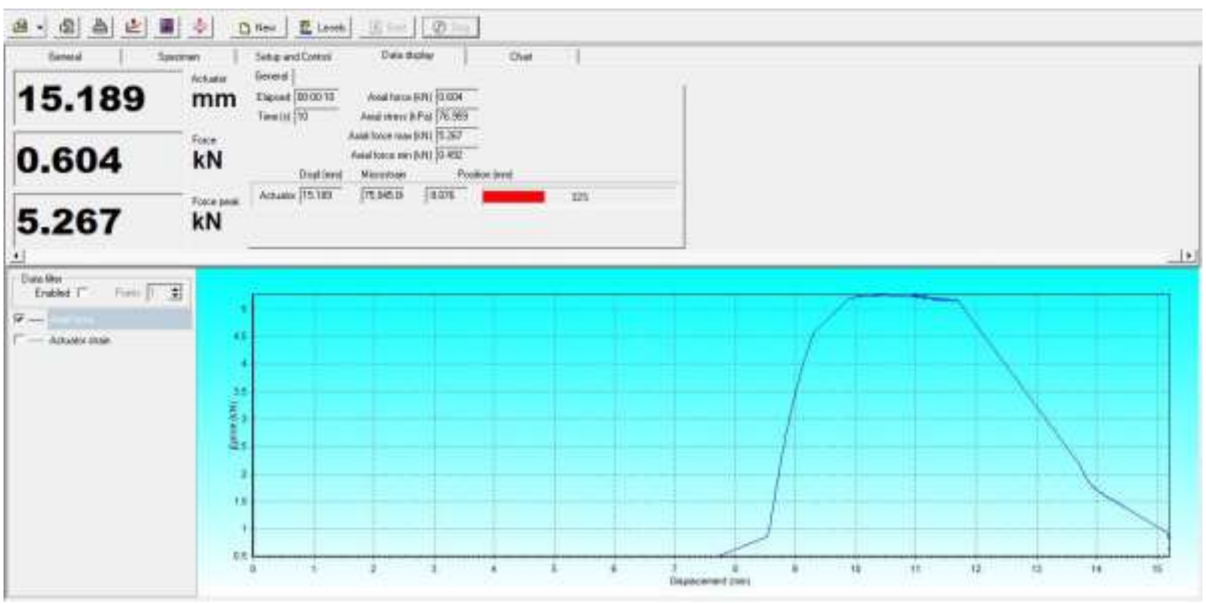
APPENDICES

APPENDIX-I

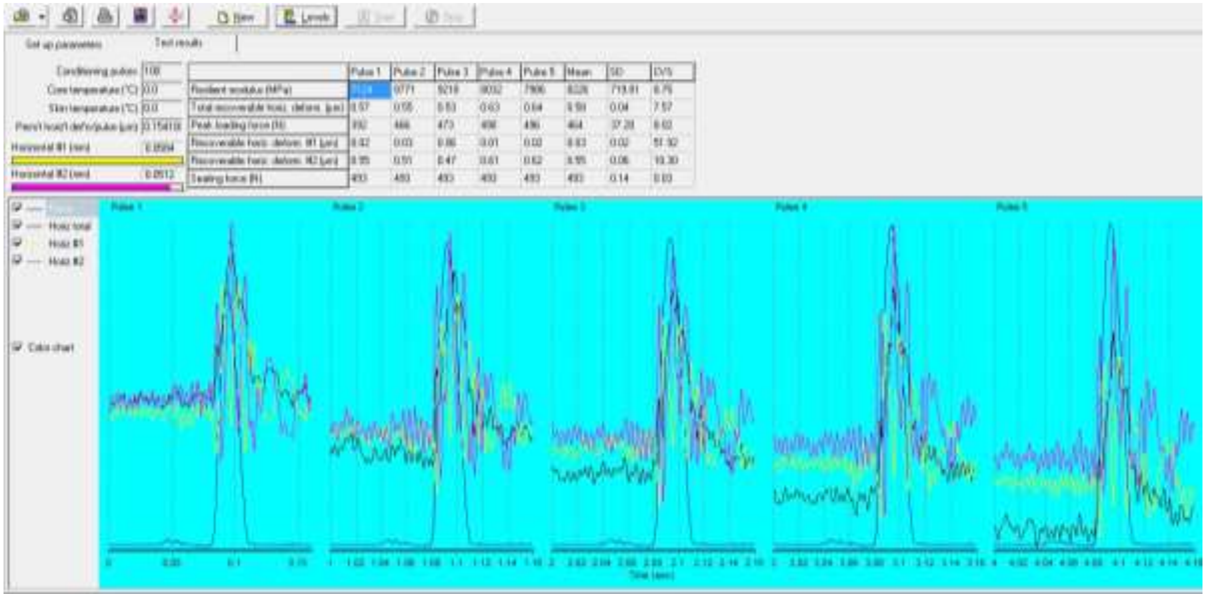
ITS/TSR RESULT SAMPLE

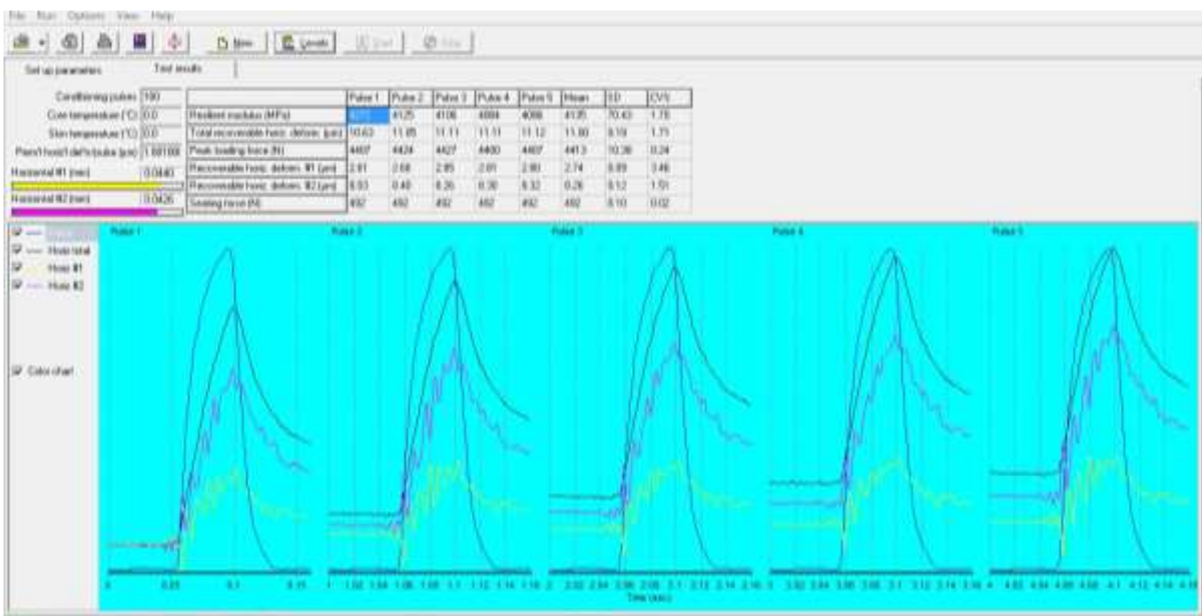




APPENDIX-II

M_R RESULT SAMPLE





HWTT RESULT SAMPLE

General Data

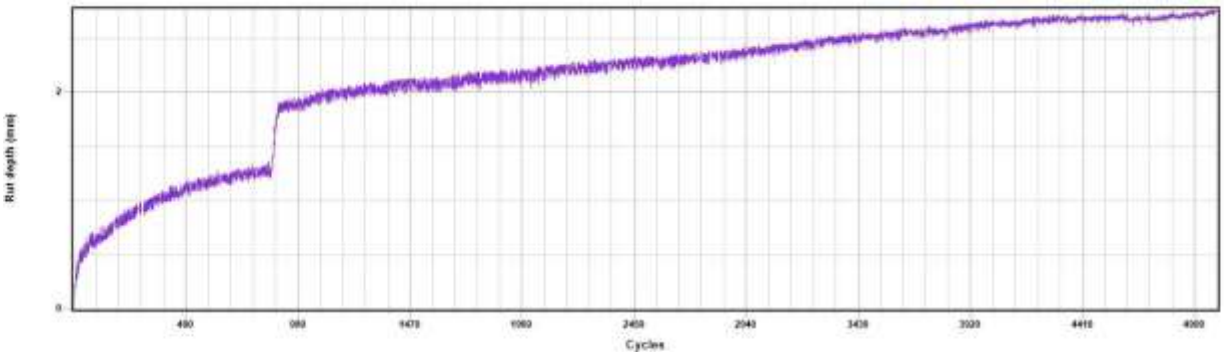
Final rut depth	2.65 mm		
Failure test	NO	End	Cycle number
Density		Void Percentage	
Type of thermal medium	Air	Feedback used	In chamber
Max Temp	40 °C	in Cycles	4953
Min Temp	36.4 °C	in Cycles	120
Customer	<Generic>		

Mixture

Mixture	<Generic>		
Aggregate	Type -	Weight (%) 0.00	Spec. weight 0(kg/m3)
Filler	-	0	0
Bitumen	-	0	0
Calculated Max Density	0 Kg/m^3	Production Type	-
Production Date	23/05/2022		
Compaction Type	-	Time conditioning	-

Start data test

Sample on test	1	Sample Number	1
ID Sample	6B+2NC	Sample Name	opt 1
Date	18/05/2022 13:09:55	Sample Type	Double Cores
Length		Width	
Diameter	150.00 mm	Thickness	68.00 mm
Weight	4.800 Kg	Age	2 dd
Max Rut depth	12	Max Number cycles	5000
Test Temp	25.0 °C	Wheels speed	25.0 cycle/min
Time to start	3 min	Operator	naqeeb mce
Cond. cycles	3 Cycles	Temp Limit.	3.0 °C



SAMPLE 2

General Data

Final rut depth	1.65 mm		
Failure test	NO	End	Cycle number
Density		Void Percentage	
Type of thermal medium	Air	Feedback used	chamber In
Max Temp	40 °C	in Cycles	30 49
Min Temp	37.4 °C	in Cycles	53
Customer	<Generic>		

Mixture

Mixture	<Generic>			
	Type		Weight (%)	Spec. weight
Aggregate	-	0.00		0(kg/m3)
Filler	-		0	0
Bitumen	-		0	0
Calculated Max Density	0 Kg/m^3	Production Type		-
Production Date	23/05/2022			
Compaction Type	-	Time conditioning		-

Start data test

Sample on test	2	Sample Number	2
ID Sample	6B+4NC	Sample Name	sample 2
Date	19/05/2022 12:42:35	Sample Type	Double Cores
Length		Width	
Diameter	150.00 mm	Thickness	68.00 mm
Weight	4.890 Kg	Age	3 dd
Max Rut depth	12	Max Number cycles	5000
Test Temp	25.0 °C	Wheels speed	25.0 cycle/min
Time to start	3 min	Operator	naqeeb
Cond. cycles	3 Cycles	Temp Limit.	3.0 °C