PERFORMANCE EVALUATION OF FLEXIBLE PAVEMENT BY USING SBS POLYMER AS ASPHALT BINDER MODIFIER

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Declaration

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DEDICATIONS To

My beloved Parents.

For their support and cooperation, For their Inspiration and courage.

My kind Teachers.

For their parental guidance,

&

My Friends.

For sharing their insight……

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All the praise and thanks belong to Almighty ALLAH, The Most Gracious, The Most Bountiful, the Omnipotent and the Omnipresent, The MASTER OF THE WORLD, Who through His divine book always motivates us to get His unlimited grace and Who has bestowed us the most powerful thing in His world, the brain; and enabled us to complete this project.

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LIST OF ABBREVIATIONS

AASHTO	-	American Association of State Highway and TransportationOfficials
ASTM	-	American Standard Test Method
AC	-	Asphalt Concrete
ARL	-	Attock Refinery Limited
BS	-	British Standard
G_{mb}	-	Bulk Specific Gravity
G_{mm}	-	Maximum Specific Gravity
HMA	-	Hot Mix Asphalt
J.M.F.	-	Job Mix Formula
OBC	-	Optimum Bitumen Content
PMB	-	Polymer Modified Bitumen
PG	-	Performance Grade
SBS	-	Styrene Butadiene Styrene
Va	-	Air Voids
V.F.A.	-	Voids Filled with Asphalt
V.M.A.	-	Voids in Mineral Aggregate
BBR	-	Bending Beam Rheometer

RV	-	Rotational Viscosity
Mr	-	Resilient Modulus
TSR	-	Tensile Strength Ratio

ABSTRACT

A well-known modifier, styrene-butadiene-styrene (SBS), is a high molecular polymer changing the asphalt binders' properties by mixing. A particular quantity of SBS modifier was added to asphalt to create SBS-modified asphalt, which is mixed, sheared, or spread out using various methods. The SBS-modified asphalt enhances the anti-fatigue, low-temperature crack, and high-temperature rutting resistance of asphalt pavement, thus can be very helpful for increasing the service life of asphalt pavement. ARL 60/70 AC, NHA Class B gradation, and SBS YH-791 have been used in this research. In this study, the effects of various SBS modifier dosages (3%, 5%, 7%, and 9%) on the characteristics of asphalt was compared by conventional testing (Specific Gravity, Viscosity, Flash & Fire Point Test) and Performance testing (Resilient Modulus, Moisture Susceptibility, Wheel tracking Test) for characterizing the modified asphalt binder. The optimum bitumen content was obtained using the Marshall Mix Design technique (OBC). Additionally, the current study tried to calculate the Rut Depth of SBS-modified HMA using AI modeling with Multi Expression Programming (MEPX). According to the results, SBS has improved asphalt mixtures and can be easily utilized as a modifier in bitumen. Finally, the results of the ANOVA and Tukey's analysis on ITS and MR revealed that, at a confidence level of 95%, the efficiency of modified asphalt pavements is greatly affected by the modifiers. The optimal SBS dosage for asphalt performance is 5%.

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Chapter 1

INTRODUCTION

1.1 Background

Pakistan's current position necessitates lower investment costs and efficient, low-cost, and smart transportation infrastructure. Our need to restore and manage our pavements has expanded considerably because of the system. Construction of pavements has progressed significantly in recent years, and modification of bitumen binder is preferred technique.

Bitumen set up itself as a reliable binder for producing the pavement structure and wearing course as the demand for paved roads became a universal necessity. The thick density of bitumen allows for the creation of asphalt concrete that is sufficiently workable during the placement process and then compaction at high temperatures.

As the bitumen exhibits viscoelastic behavior at room temperature, it has properties like stability and flexibility that are crucial for durable pavements. Although asphalt binders make only a minor percentage of asphalt mixtures, their viscoelastic qualities are significantly determining how well asphalt mixtures operate.

The asphalt pavement is exposed to a variety of loads and climatic conditions throughout its service life. During their service lives, asphalt pavements undergo various loading and environmental conditions, which can cause a variety of problems. The behavior of the asphalt binder changes with temperature at intermediate and low temperatures. When the temperature rises in the summer, the viscosity, and stiffness of the asphalt binder decrease, which may cause rutting and other issues. In the winter, the asphalt binder becomes harder as the temperature drops, which could lead to thermal cracking. Asphalt mixtures should withstand traffic loads throughout both summer and winter seasons. Bitumen binders, which are viscous substances with thermal and time-dependent behavior, are one of the essential elements of asphalt mixtures. They behave brittle-viscoelastic at low and intermediate temperatures but as a fluid at high temperatures.

The viscoelastic properties of asphalt binders can be used to explain a variety of distresses in asphalt pavements. Winter temperatures cause asphalt pavements to cool and compress, which leads to cracking because the asphalt binder becomes more rigid.

Engineers and material scientists have attempted to adjust the asphalt binder's properties and mixtures using several modifiers to avoid or reduce the issues with asphalt mixtures brought on by the viscoelastic behavior of binders. In an ideal world, a good modifier would increase the complex modulus of an asphalt binder at high temperatures while decreasing it at low and intermediate temperatures.

One of the most popular methods to reduce the distresses brought on by binder behavior and enhance performance is modifying binders using various modifiers and additives. According to a thorough review of the literature, several modifiers, which include polymers, recycled rubber, oxidants, antioxidants, fibers extenders, fillers, recycling agents, and anti-strip agents, have been successfully used.

Modifiers primarily enhance the rheological properties of asphalt binders and their resistance to thermal cracking and rutting at low, intermediate, and high temperatures. Because of their technical and mechanical advantages in asphalt pavements, polymers have attracted a lot of interest among the modifiers used in the asphalt business.

Asphalt binders that have undergone polymerization outperform untreated binders in terms of temperature sensitivity, viscosity and stiffness, and adhesion and cohesion. Additionally, it has been demonstrated that asphalt mixtures including modified polymer binders have improved rutting resistance and crack resistance.

Styrene-butadiene-styrene (SBS) copolymer polymers, for example, have drawn a lot of attention recently for their potential to improve the performance of binders and mixes for asphalt. Asphalt binders benefit from polymers' increased stiffness, viscosity, temperature sensitivity, and adhesion and cohesion. Additionally, it has been discovered that asphalt mixtures with polymer-modified binders have greater rutting and cracking resistance. Binders that have been changed with polymers cost much more than unmodified binders best polymers for bitumen modification are probably SBS block copolymers, which are elastomers that make bitumen more flexible. Polymers improved the asphalt's low-temperature flexibility, according to Becker et al. At higher temperatures, they also observed a loss of strength and resistance to penetration.

According to Isacsson and Lu, the physical arrangement of molecules into a three-dimensional network is what gives SBS copolymers their strength and flexibility. They also learned that the polymer's strength came from its polystyrene end blocks, while its high viscosity came from its polybutadiene rubbery matrix blocks.

When bitumen and SBS are mixed, the elastomeric portion of the SBS polymer absorbs the oil fraction. According to the researchers, it expanded about nine times the initial volume. The investigation's findings demonstrated that an appropriate SBS content significantly changes the properties of the basic bitumen.

SBS polymers are frequently delivered as pellets or powder, which can then be mixed with base bitumen in a low- to the high-shear mixer to dilute to the appropriate polymer percentage. Pellets and base bitumen combine to produce a unique polymer concentration appropriate for a variety of applications (Sengoz and Isikyakar 2008).

Pavement engineers and material scientists must therefore develop cost-effective and ecologically responsible ways to change binders to improve the binder's performance from a variety of perspectives (Behnood and Olek 2017).

Although adding polymers to binders enhances their rheological and viscoelastic qualities, they may have technical and economic drawbacks. Many organizations in the asphalt sector, for example, have given Styrene-Butadiene-Styrene (SBS) a lot of attention because of the benefits it provides. However, SBS has several drawbacks, including a comparatively high price, less resistance to heat, oxidation, and UV radiation than other modifiers, as well as potential compatibility concerns with some of the binders (Hassanpour-Kavanagh, Ahmedzade, et al., 2020).

Hot mix asphalt (HMA) pavements are most distressed by moisture deterioration and ongoing deformation. The adhesive and cohesive interaction within the asphalt-aggregate mixture affects the performance of HMA pavements. The primary mechanisms by which asphalt pavements are harmed by moisture include the loss of cohesiveness (strength) and stiffening of the pavement surface, in addition to the breaking of the adhesion among aggregates and bitumen in association with aggregate disintegration or fracture.

Moisture entering through the aggregates and asphalt, which damages the asphalt coating, causes the loss of adhesion. Asphalt concrete mastic loses cohesion due to softening. The combination of these two techniques may result in the pavement with moisture damage. Numerous factors, including variations in aggregate quality, variations in asphalt binders, a decrease in the depth of the bitumen layer, and inadequate quality control, can result in moisture damage.

The main cause of pavement deterioration is still the pavements made of hot mix asphalt (HMA) are susceptible to moisture. When moisture degradation affects the internal strength of the HMA mix, results in premature ruts, ravels, and cracks of an HMA layer, increasing the pressures brought on by traffic loads. One of the bitumen's key characteristics, determined by the bitumen-specific gravity test, is its specific gravity. It can therefore be used to categorize risk bitumen binders employed in the creation of pavement. It can help identify the country of origin of the bitumen binder.

The specific gravity of straight run and cut-back bitumen is frequently required for estimating spread rates, asphaltic concrete mix characteristics, and other applications. At a temperature of about 250°C, the test of specific gravity is performed. If cooling facilities are unavailable, a temperature of 350°C may be utilized, but this must be indicated clearly in the report. Because measuring specific gravity at elevated temperatures directly is not practical, an approximate value can be obtained by calculating it using the value determined at a lower temperature.

Viscosity is the opponent of fluidity. It is a method of calculating flow resistance. The viscosity of liquid bitumen increases as it approaches a semi-solid condition. The viscosity of a thick liquid is higher than that of a thin liquid on road pavement. High viscosity bitumen binders prevent full compaction, resulting in an unstable mix that is of low stability. Low viscosity bitumen binders lubricate the aggregate's coats as opposed to generating a uniform thin covering for binding action.

The temperature at which bitumen's vapor will momentarily ignite while heating upon meeting a tiny flame is known as the flash flashpoint. Knowing that the consumer will be most interested in this point, the bitumen must not be heated to this level. The flash point identifies the actual temperature at which proper precautions must be taken to reduce the risk of fire while heating and below which such precautions are not necessary. The temperature at which bitumen will burn, however, is substantially lower than this. The temperature at which a fire first ignites is known as the fire point.

Samples are run over by a loaded metal wheel in a hot water bath, and the quantity of loading runs is used to calculate how much deformation occurred. Wheel tracking is used to evaluate an asphaltic material's resilience to rutting under conditions that mimic the impact of traffic. Using an Easy-load method, the mold is loaded into and taken out of the wheel tracker.

The resilient value is a material property that distinguishes unbounded roadway materials (Mr). It is a method of measuring material stiffness that makes it possible to examine material stiffness about several factors like humidity, specific gravity, and stress level. To determine the stiffness of a bitumen beam, the bending beam rheometer (BBR) testing bends the beam while measuring the strain rate. A binder that has experienced both short-term and long-term ageing (LTA/conditioning) is used for the BBR test.

This investigation was conducted in a lab using modified bitumen including SBS copolymer (styrene-butadiene-styrene). By combining a penetration grade of 60/70 unaltered (base) bitumen with an SBS polymer at four distinct polymer contents, polymer-modified bitumen (PMB) specimens have been created. Using traditional techniques, the fundamental properties of the SBS PMB specimens have been identified. Analysis has also been done on the mechanical characteristics of hot-mix asphalt (HMA) that contains SBS PMBs. The BBR test has been used to assess how the addition of polymer affects the short-term as well as the long-term aging properties of HMA. The results demonstrated that polymer treatment improved base bitumen's mechanical and physical properties. Additionally, it was determined that samples at low polymer concentrations showed the presence of scattered polymer particles in a constant bitumen phase. At high polymer content, a phase of the continuous polymer has been seen. Additionally, it was discovered that the HMA's short-term and long-term aging is minimized the polymer addition.

1.2 Research Objectives

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

- To assess the effect of SBS modified Asphalt using conventional tests.

- To investigate rutting resistance of modified asphalt through wheel tracking test.
- To assess moisture sensitivity of the SBS-modified asphalt concrete.
- To determine the response of HMA under repeated loading with various ratios of SBS using Resilient Modulus (Mr), Moisture Susceptibility, BBR, and Wheel Tracking Test compared to conventional asphalt concrete mixtures, respectively.

1.3 Scope of Thesis

To achieve the study above objectives, a plan of research was developed, which is detailed below, with an outline of the research activities as follows:

- Review of previous research articles on SBS modifiers and SBS for asphalt mix, including revision of books, scientific articles, and technical writings.
- In-depth examination of asphalt mix design and production technologies.
- The Marshal Mix design process determines the Optimum Bitumen Content (OBC). Four different bitumen percentages were investigated to find the optimum bitumen percentage for the aggregates utilized, including 3%, 5%,7%, and 9% by mix weight.
- Different quantities of SBS as a modifier are added and its affects on moisture susceptibility, rutting, and resilient modulus of asphalt specimens were determined.
- Results were analyzed to quantify the effect of the modification of SBS on measured performance indicators, e.g., asphalt concrete cracking response, moisture susceptibility, and rutting resistance.

1.4 Material characteristics & Test Standards

Different tests of binder are performed according to ASTM standards. Tests, ASTM standards to perform binder's tests are shown in table 1-1. The detailed summary of performance tests along with the ASTM standards and number of specimens are listed in table 1-3. The properties of SBS are listed in table 1-3.

Table 1-1: Experimental Matrix of Bitumen Testing

Characterization	Gradation	NHA – B
	Binder	ARL 60 / 70
Binder	TESTS	Standard
	Rotational Viscosity	ASTM D 21710
	Bending Beam Rheometer	ASTM B 6648
	Specific Gravity	ASTM D 7076
	Flash & Fire Point	ASTM D 92

Table 1-2 : Performance Testing Matrix of Asphalt Concrete Mixtures

Test	**Standards**	**SBS%**	**Samples**	**Total**
Indirect Tensile Strength	ASTM D 6931 – 17	0	3	15
		3	3	
		5	3	
		7	3	
		9	3	
Wheel Tracking Test	ASTM D 8292-20	0	3	15
		3	3	
		5	3	
		7	3	
		9	3	
Resilient Modulus	ASTM D7369 – 20	0	3	15
		3	3	
		5	3	
		7	3	
		9	3	
Total				45

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

	Item	SBS (YH-791H)
SBS (YH -791H)	Structure	Linear
	Melt Flow Ratio (200˚C, 5kg)	0.1g/10min
	25˚C, 5% Styrene solution Viscosity	2240 mPa. S
	Styrene/Butadiene (S/B)	30/70
	Hardness	76A
	Tensile Strength	20 Mpa
	Volatile %	<1.0

1.5 Organization of Thesis

This thesis is composed of 5 chapters.

Chapter 1 is composed of an introduction, problem statement, objectives of the study, and then scope of research.

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

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

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

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

Chapter 2

LITERATURE REVIEW

2.1 Introduction

To realize the importance of doing the current research, a comprehensive literature review of related studies previously undertaken in various regions of the globe has been reviewed. The literature and theory on the features of asphalt mixes, including SBS, are summarized in this chapter. According to previous research, the effects of adding SBS on the Moisture Susceptibility, Resilient Modulus, Wheel Tracking, Test, and Bending Beam Rheometer, and their impacts on different performance measures and on predicting permanent deformation, rutting, cracking, and moisture damage in asphalt mixes using a variety of experiments, have been discussed.

2.1.1 Background

Road experts must have a strong understanding of service efficacy and its extending strategies with the advent of globalization in the construction of the roads and the growing concern over asphalts pavements' long life-life. The relationship between the microstructure of asphalt pavement and its basic road efficiency is garnering increasing attention from researchers. A full description of the major aspects that determine the ultimate asphalt performance is provided by studies on the parameters of bituminous mixtures at the microscopic level.

It is significant to research the intrinsic structure and composition of asphalt mixtures to get better performance of the asphalt pavements. There is a wide range of literature on the internal features of asphalt mixtures, and there have been a lot of study outcomes (V. Xiao, et al., 2021).

Infrastructure and physical conditions are crucial because the road transportation network in any nation is crucial to that nation's economy. Without suitable and prompt repair, there is no question that the roads would suffer significant damage, needing major repairs that are frequently more expensive than simple repairs that might be finished more quickly. With the ever-increasing cost of asphalt pavements, surface treatments are increasingly being employed as a preventive measure in the maintenance and repair of pavement structures in Iran and around the world (Hesami & Zalnezhad, 2019).

2.2 Flexible pavement

Asphalt pavement appears to be the best pavement structure for building roads and highways all over the world. This is built and maintained using a significant number of non-renewable resources and industrial items, including cement, bituminous roofing material, limestone, aggregate, and other admixtures. Material waste, ecological degradation, resource depletion, and a rise in material costs prompted researchers to explore alternative resources for flexible pavement.

This study gives an overview of recyclable materials that have been used effectively in various strata of pavement structures. Studies show that using secondary materials not only provides an efficient way to dispose of trash but also lowers the price of traditional resources and lowers the overall cost of infrastructure. Through such a study, an effort has been made to establish why, despite having important studies, field adaptation has been limited, as well as to provide realistic solutions for promoting the use of recycled content in flexible pavement (Gautam, Kalla, Jethoo et al, 2018).

2.3 Asphalt binders and modifier

The effectiveness of asphalt mixtures is greatly influenced by asphalt binders. Increased factors related to traffic on the roads, such as load capacity, higher traffic density, and higher tire pressure, as well as a considerable shift in the seasonal and daily temperatures of the pavement, have all been linked to the collapse of asphalt pavements. Several efforts were made by polymeric experts and structural engineers to boost the effectiveness of pavement design by altering the structure of the asphalt mixture to prevent or alleviate these failures.

A good modifier alters the failure qualities of the binder, allowing it to withstand additional deformations before failing. The use of polymeric in asphalt binders enhances their viscoelastic and the asphalt industry has a lengthy history with physical properties. An ingested polymer network is generated when the polymer is correctly combined with the binder, which leads to viscoelastic behavior modifications. However, given the limited solubility of polymers, polymer-modified bituminous binders may have several disadvantages. Numerous investigations have been conducted to understand the structural properties in better ways of polymer-modified asphalt binders.

The influence of various parameters on the characteristics of polymer-modified bitumen binders is described and evaluated. This paper also discusses various material kinds used in the asphalt industry, as well as their influence on the related physical properties, morphology, rheological, and mechanical characteristics of polymer-modified bitumen binder. This report also includes a discussion of the approaches utilized to eliminate or mitigate the drawbacks of standard polymer-modified asphalt mixtures (Benhood & M., 2019).

2.4 SBS

SBS (styrene-butadiene-styrene) is a typical high-molecular-polymer modifier that enables the binder to modify the asphalt binder. A specified quantity of SBS modifiers is added to SBS-modified asphalt through shearing and mixing to make SBS equally distributed in the asphalt. High-temperature permanent deformation resistance, low-temperature crack resistance, and anti-fatigue effectiveness of asphalt pavement are all improved by SBS-modified asphalt.

2.4.1 Findings on Use of SBS

A crucial aspect of asphalt rheology, the time-temperature equivalent hypothesis has had a lot of use in rheological characterization. A novel viewpoint strategy for determining the time-temperature superposition connection of the SBS-modified asphalt binder may be established using the tight relationship between time-temperature conditions and the presence of a phase angle plateau region in the SBS-modified asphalt binder.

A fluorescent microscopy test was used to explain the relationship between the SBS modifier dose and the generated morphological properties in the asphalt matrix in this work. Then, for SBSMA with various SBS doses, the characteristics and causes of rheological behaviors were described and evaluated, respectively. Furthermore, distinct approaches to evaluating the time-temperature coherence connection, various SBSMA binders were used to demonstrate the proposed and demonstrated rheological phenomena depending on their particular applications.

The results demonstrate that the structures produced by SBS as the stop matrix go from the dispersed to the continuous phase when the SBS concentration rises. The sort of area varies depending on the SBS dosage, but all SBSMA binders with more than 2% SBS can show regions in terms of phase angle. For SBS containing a 4 percent dosage of SBS, the time-temperature parameters that correspond to the final condition of each "concave" peak zone are equivalent. The midpoint of "the convex" peak zone's time-temperature parameters for SBSMA with 6 percent and 8 percent dosages of SBS is equal (Z.Chen, H.Zhang, H.Duan, & Wu, (2020)).

An eco-friendly and straightforward method for creating an aminopropyl triethoxysilane-dopamine (APs-DA) composite layer on the surface of MoS2 was established in this study using non-toxic chemicals. By comparison to pure SBS-modified asphalt, APs-DA-MoS2 had better thermal conductivity (high initial breakdown temperature by 28 °C) and was identified by thermal analysis to contain asphalt.

Adding 0.08 percent APs-DA-MoS2 to SBS-modified bitumen (46 °C, 10 Hz) increased the shear modulus (G') by 51.09 percent. This study offers recommendations for producing APs-DA-MoS2 modified bitumen for structural applications due to its simple and environmentally friendly synthesis method, outstanding mechanical qualities, heat resistance, resistance to rutting, and fatigue behavior. in the American construction and roadbuilding industries (Y. Wei, et al., 2020).

Binders in the pavement may be able to withstand loads either linearly or nonlinearly. Few research has focused on viscoelasticity, which is non-linear mixtures, even though their normal viscoelasticity is generally acknowledged. This article discusses the effects of SBS on the linear and non-linear rheological behavior of binders. Using Fourier Transform (FT)-rheology and strain reduction techniques, the nonlinear rheological behavior of plain bitumen binder and the associated SBS modified asphalt binders is examined under higher magnitude oscillations of shear stress.

The complexity of the asphalt's rheological behavior and the elastic percentage, as determined by viscoelastic measurements, rise as SBS content rises. The measurements of the nonlinear viscoelastic show that the intrinsic nonlinearity decreases with increasing frequency and increases with increasing SBS content, while the corresponding nonlinearity of the bitumen binder increases with the rising frequency and decreasing rise in stress. The correlation of stress magnitude can simply follow the sigmoidal function.

According to the FT examination and breakdown results, the discontinuity of SBS-modified bitumen is more noticeable than clean asphalt binder, and it grows as the SBS level does as well. SBS may increase the nonlinearity while reducing the fluidity of the asphalt binder. All the evaluated binders exhibit load weakening and stress cracking in all test settings (L. Shan, X. Qi, Duan, Liu et al., 2020).

In this study, several SBS modifier dosages were applied to the SK70# and SK90# matrix asphalts to standardize indices of the Styrene-Butadiene-Styrene (SBS) asphalt combination. Utilizing test methods utilized and Superpave, the effectiveness of each SBS-modified bitumen was evaluated, and an SBS-modified bitumen effective assessment index was created. The results demonstrated that the inclusion of an SBS modifier resulted in an increase in the viscosity of the asphalt binder at high temperatures, lowered the sensitivity of the temperature of the asphalt mixture, and improved high-temperature performance.

The testing method was not advised for the performance of SBS-modified asphalt due to the variability in the penetration test results brought on by the bitumen's expansion. When compared to the matrix bitumen for SK70# matrix bitumen, the effect of the SBS-modifier on the softening temperature of SK90# matrix asphalt and the melting temperature of SBS-modified bitumen with modifier dosages of 4.5, 5, 5.5, and 6 percent increased 5.7 percent, 12.8 percent, 22.5%, and 26.4 percent, respectively.

As the test temperature lowered, a low-temperature SBS modifier had less of an impact on the bitumen yield. It was advised to utilize the bending beam rheometer (BBR) to investigate how lower temperatures affect the various qualities and functionality of binders (Zhang, H.Wang, You, J.Gao, & Irfan, (2019)).

A low-temperature SBS modifier had less of an effect on the bitumen yield as the test temperature dropped. The bending beam rheometer (BBR) was suggested as a tool for examining how lower temperatures affect the various properties and capabilities of binders.

Bitumen's SBS concentration was kept at 3, 5, and 7%. The ingredient was maintained at 0.1 percent for all mixtures. Limestone and alluvial were the two types of material employed in this study. Results from Marshall Stability have improved with a 5% SBS adjustment. The combination containing 5% SBS displayed the highest indirect tensile strength when compared to other mixes. When compared to riverbed aggregate, limestone aggregate has the highest stability and tensile strength.

It has been discovered that the Zycotherm additive does not affect the mechanical properties of bitumen concrete mixtures. Finally, it was found that accurate re lots were obtained when 5% SBS in asphalt and limestone material were added to asphalt concrete mixtures (H.Singh, T.Chopra, Jain, A.Kaur, & Kamotra, (2019)).

This study's main objective was to determine how the addition of SBS polymeric and hot mix affected the bituminous mix's quality. The SBS polymer dosages were maintained at 3%, 5%, and 7% for all binder mixes, and the Zycotherm additive dosage was maintained at 0.1 percent. All three types of bitumen—base, SBS modified, and Zycotherm modified—were contrasted. In this investigation, two distinct types of aggregate were used to prepare bituminous mixes: limestone and river basin gravel.

Marshall Stability test, Indirect Tensile Strength (ITS) test, and Rheological test were conducted on the binder and modified bituminous mixes to assess their performance. The Marshall Stability test revealed that an SBS dosage of 5% was the best polymeric concentration for both aggregate mixtures. The aggregate bituminous mixes' maximum tensile strength was obtained at an SBS concentration of 5%. It was discovered that when Limestone aggregates were used to prepare bituminous mixtures, the greatest Marshall Stability was reached. The qualities of bituminous mix proportions are unaffected by the addition of Zycotherm.

However, at temperatures above 100°C, Zycotherm additives tend to reduce binder viscosity, resulting in a decreased mixing temperature without sacrificing bituminous binder performance. Rheological tests on several binders revealed that Zycotherm additive effectively has the least impact on modified bitumen rutting resistance. Finally, it was determined that Limestone aggregates with 5% SBS produced the greatest results and that the Zycotherm additive had no significant effect on the mix's mechanical qualities (H.Singh, T.Chopra, S.Kamotra, S.Jain, & Kaur).

Several problems, such as cracking, rutting, bleeding, shoving, and potholing, may emerge early in the asphalt pavements of bitumen surfaces in this modern era due to high traffic speeds, changes in pavement temperature, and vehicle overloading. We can improve the characteristics of bitumen by adding polymers. Our purpose in this post is to learn about thermoplastic elastomers, such as SBS (styrene-butadiene-styrene).

This article will go through the nature of the SBS. SBS was developed to minimize low-temperature cracking, prevent early weathering, and lessen bitumen's temperature sensitivity. SBS PMB improves both traditional (softening point, penetration, etc.) and physical (indirect tensile strength and marshal stability, etc.) qualities. The authors' tests on SBS PMB, including the Marshall Stability Test, the indirect tensile strength test, and the elastic recovery test, are addressed (A.Sharma & Singh).

The focus of this article is to look at some of the current work that has been done to enhance the stability of bitumen by employing nano-additives. Bitumen is a by-product of the crude oil refining process, and as a result, it is a declining product. It has been utilized by humans for centuries in a variety of applications such as sealants, binders, waterproof coatings, and pavement manufactured materials. It's a viscous black liquid with an adhesive quality.

Bitumen is frequently employed in the construction of roadways because of its peculiar ability to change from a solid to a liquid when heated up and vice versa when cooled. Low bitumen softening point causes bitumen to melt in the summer, causing rutting on roads, and cracking in the winter, as bitumen functions naturally at low temperatures. Rising global consumption for bitumen has produced a gap between production and consumption that is widening over time.

Furthermore, modern life has resulted in extremely high traffic volumes and huge loads, necessitating the improvement of bitumen performance. The thermal characteristics of bitumen have been claimed to be improved by utilizing polymer materials such as ethylene-vinyl acetate, rubber, styrene-butadiene-styrene, polyethylene, ethylene-vinyl acetate, rubber, and bio waste, according to research (Deepa, M. Laad, & R. Singh, 2019).

Using various dosages of SBS (Styrene-butadiene-styrene) modifiers, the heat sensitivity, good performance, and low-temperature performance of modified bitumen were compared and examined. The findings show that adding more SBS modifiers enhances the kinematic viscosity, softening point, and high-temperature performance of SBS-modified asphalt.

The penetration of modified asphalt is increased, low-temperature ductility is improved, and the temperature sensitivity of the asphalt is decreased. The penetration of SBS-modified bitumen and the temperature sensitivity of SBS-treated asphalt decrease linearly as the total content of the modifier increases once the content of the modifier is larger than 4%. The technical requirements should be used to select the engineering implementation (C. Zhuang, N. Li, Zhao, & Cai, 2017).

SBS modifications, diverse base bitumen, oil extraction, and stabilizing agents were combined to create SBS-modified asphalts. The contact angles or conductivity between the SBS-modified bitumen and filtered water, glycerol, and formamide were measured using the sessile drop technique. Using the surface energy theory, the total free energy and cohesion power of SBS-modified bitumen were calculated. The effect of the virgin bitumen and SBS modifying types, as well as on the cohesive properties of SBS-modified asphalt, oil extraction, and stabilizing agent contents, were taken into consideration.

The results demonstrated that the cohesiveness of virgin asphalt might be improved by using SBS modifiers. The cohesive power of sectioned SBS-modified asphalt is higher than that of linear SBS-modified asphalt. As the amount of SBS stabilizers and modifiers grew, the cohesiveness of SBS-modified asphalt increased, but it was reduced by the excessive amount of extraction oil. The cohesive properties of the SBS-modified asphalt were improved by the creation of long-lasting three-dimensional networks via cross-linking, wrapping, and grafting among various raw materials (Zhang, Feng, & B.Li, 2017).

As demand for crude oil-based asphalt increases quickly and supply declines, the cost of the asphalt mixture rises. As the cost of asphalt rises, the quest for sustainable and alternative binder materials, including bio-asphalt, appears to have gained popularity. However, numerous prior investigations have found that bio-high-temperature asphalt's performance is inadequate. This study seeks to improve the high-temperature performance of bio-asphalt by adding SBS to the asphalt matrix. The researchers looked at five different types of SBS-modified asphalts. The rotating viscometer (RV) & dynamic shear rheometer were used to test their viscosity, anti-rutting performance, and temperature sensitivity (DSR).

The foundation binder in SBS-modified bio-asphalt has a viscosity index of 50. For the five classes of binders, the bio-oil content of the SBS-modified asphalt was 0 percent, 5,10,15 and20 percent by weight. It was discovered that the viscosity of SBS-modified asphalt was somewhat higher than that of the base binder and that the presence of bio-oil had little effect on the viscosity of SBS bio-binder at high bio-oil concentrations and test temperatures. The blending and the temperatures of compaction of the SBS-modified bio-asphalt were comparable to the 50# base binder when the bio-oil concentration was greater than 10%.

Before the RTFO test, the SBS bio-binder had higher viscosity and weaker anti-rutting performance than the basic binder, although it was not significantly different. After the RTFO test, however, the tendency was in the opposite direction. Meanwhile, the SBS bio-binder is a little less temperature-sensitive than the base binder, and this sensitivity is reduced as the bio-oil content increases before RTFO. When the bio-oil percentage was less than 20%, the thermal responsiveness of the SBS bio-binder remained less than that of the 50# asphalt binders after RTFO and climbed as the bio-oil content increased (Zhang, Wang, Gao et al., 2017).

The purpose of this study is to modify petroleum bitumen's rheological properties using the SBS (styrene-butadiene-styrene) copolymer. The authors have identified numerous rheological characteristics that can be used to assess the long-term viability of modified bituminous materials used in asphalt paving. The bitumen was altered in the lab using a modified bitumen concentrate with a predetermined SBS copolymer concentration of 9%.

The result was a binder with known SBS polymer content percentages of 3%, 4.5, and 5.5. The rheological properties of the tested bitumen have been determined using a DSR dynamic shear rheometer (in a broad range of temperatures between 40°C and 100°C). DSR was utilized to carry out MSCR experiments to determine how sensitive the asphalt mix with the SBS-modified binders was to permanent deformations in the high-temperature range (from 40°C to 82°C).

When the measurements of a dynamic shear modulus |G*| of almost all the bitumen tested are compared, the value of |G*| increases as the proportion of SBS polymer in the tested binder increases, possibly indicating increased resistance to cracking of the asphalt pavement. The MSCR test revealed that increasing the usage of SBS copolymer additives in bitumen results in lower – anti-creep compliance values.

The SBS copolymer increases roadway performance at low cracking by accelerating stress distribution in the bitumen sample. Furthermore, modification mitigates the deleterious effects of aging on the binder's characteristics, which appear as stiffness and a slowing in relaxation (Mielczarek, Dziadosz, Slowik et al., 2020).

The asphalt industry is looking for a solution to hot mix asphalt as concerns about global warming and gas exhaustion grow (HMA). The creation of asphalt mixtures may undergo a revolution thanks to the progress of warm mix asphalt (WMA), a cutting-edge technology. WMA technology enables the mixing, putting down, and compacting of asphalt mixes at significantly lower temperatures than hot mix asphalt (HMA).

The method has the potential to cut production temperatures by up to 30%. Bitumen mixes are often made at temperatures of 150°C or more, based on the binder employed. At as little as 120°C, WMA mixes can be created. In this study, dense bituminous macadam (DBM), Grade 2 was used to test the Marshall properties of HMA (VG-30) and WMA (SBS-PMB40) with organic additives at different dosages. The temperatures used for mixing HMA, and WMA were 155°C, 130°C, and 120°C respectively. The addition of additives increased the WMA mix's stability and Marshall properties, according to the laboratory investigation (Anilkumar & Awanti, 2022).

The advantages of introducing styrene–butadiene–styrene (SBS) to asphalt cement (AC-60/70) in various quantities and types of addition were examined. The physical qualities of asphalt concrete & modifiers were first determined through research. Two forms of grading, six different amounts of bituminous, four distinct contents of polymer, and three kinds of polymer were used to create fifteen asphalt binder compositions. The changed & unaffected control asphalt binders were then used to make Marshall samples.

In the experiments conducted in this study, the results show that asphalt mixes treated with any SBS additive provide the best moisture damage resistance, implying that this modification improves the mechanical and physical properties of the asphalt binder. The total distortion of each specimen was determined in this study utilizing a newly constructed equation combining mixture characteristics factors. In addition, instead of using a power-law law function model for the first phase of ultimate lateral curves, a new logarithmic model generated from the very first 100 preconditioning loads was designed to fit the creep curve (Kalyoncuoglu & Tigdemir, 2011).

Temperature susceptibility is one of the key characteristics that distinguish asphalt binders from other materials. Nowadays, polymer components are frequently employed to broaden the service temperature range and reduce temperature-related harm to asphalt mixes. This study's main goal was to determine how temperature affected the SBS-modified asphalt mixture's toughness index and fatigue metrics.

Utilizing a universal testing machine (UTM) apparatus with a thermal management chamber, the indirect tensile fatigue test, and indirect tensile strength tests were carried out at 10, 20, and 50 °C. The toughness index dramatically decreased at lower temperatures, which showed that the investigated mixes were less flexible. However, the hardness index of mix proportions was greater than conventional mixtures to some extent.

The results showed that under increasing loading conditions, failure of fatigue would be more severe at low and moderate temperatures. Lower loading situations with strain values less than roughly 200–250 deformation, on the other hand, do not result in critical fatigue failure at low temperatures (Modarres, 2013).

The flaws in traditional asphalt cement generated by refineries are the primary causes of asphalt pavement premature failure. Stabilization of the bitumen with additives is one of the strategies to prevent these problems. Modifications have been made with a variety of materials, comprising polymers and nanomaterials, such as nano clays.

This paper discusses the findings of a practical study that looked at the effects of a kind of nano clay plus Styrene Butadiene Styrene, SBS, on the characteristics of penetration grade of 60/70 bitumen. This is because the effects of these two kinds have not been examined in the research. After applying substantial ratios of each addition to the asphalt, the penetration index, softening point, penetration grade, dynamic viscosity, and rheological characteristics which include complex dynamic modulus and phase angle were examined.

The results demonstrate that both additions have a stiffening effect on bitumen, increasing the resistance to irreversible deformation. On the other hand, the stiffening impact depends on the type of chemical used and the amount used to modify it. The SBS copolymer has a greater effect on enhancing resistance to permanent deformation (H.Taherkhani & M.SHafieimatak, (2016)).

The addition of SBS/Nano-silica nanocomposite to asphalt binder and asphalt mixture significantly increased the fatigue life, with testing findings indicating that 6% nano-silica is the ideal quantity. Additionally, a strong correlation between the failure modes of asphalt binders and the asphalt mixture was discovered (Shafabakhsh & Rajabi, 2019).

Fourier-Transform Infrared Spectroscopy was used to examine the compounds' structural details (FTIR). Statistical analysis was used to further examine how gilsonite + SBS affected the mechanical, rheological, and thermal expansion characteristics of asphalt binders. According to the investigation, adding gilsonite with SBS to asphalt mixes decreases temperature susceptibility and improves the mechanical and rheological properties of the asphalt binders.

Additionally, nearly all the changed binders revealed strong correlations between the high-temperature performance grade (HT) and PI, AE, and VTS in the outcomes. The Analysis of Variance (ANOVA) results showed that the modifying dosage has a significant impact on PI, AE, VTS, and viscosity while the binder modification category does not (Mirzaiyan, Ameri, Amini et al., 2019).

The goal of this study is to determine how lime-containing mineral filler and styrene-butadiene-styrene (SBS) affect various properties of hot mix asphalt, particularly moisture resistance. The percentages of SBS added to the asphalt cement were 2%, 4%, and 6%. The lime-treated mixtures contain 2% lime by weight of the total aggregate as a filler.

The engineering features of binder-aggregate and polymer-modified mixtures were assessed using fundamental engineering characteristics such as rotational viscosity (RV), dynamic shear rheometer (DSR), stiffness modulus, Marshall stability, indirect tensile strength, and moisture susceptibility. Tensile strength ratio (TSR) and sustained Marshall stability (RMS) values were determined to determine a mix's resistance to moisture degradation. The effects of SBS with lime freeze-thaw cycles on specimens were evaluated using the TSR test.

According to the results, hot mix asphalt's stability, stiffness, and strength all increase as polymer-modified binders and lime are added. According to Marshall's stability, adding 2% has almost the same results as adding 6% SBS. Lime is added to SBS-modified mixes to increase concordance and speed up the improvement of properties.

The specimens with the highest stiffness modulus, which was 2.3 times greater than the control combination after seven freeze-thaw cycles, and the least amount of tensile strength ratio loss, with a tensile strength ratio of 0.70, were those with both 2 percent lime and 6 percent SBS (Kok & Yilmaz, 2009).

SBS-modified bitumen is frequently used in asphalt paving, however, because of the characteristics of the substance and its effects on buildings and the environment, the production of SBSMA frequently experiences unfavorable modifications. The effects of concentration, asphalt type, processing technology, and environment on phase structure and separation, as well as the effects of SBS kind, concentration, asphalt type, and processing technology on phase structure and separation, have all been thoroughly studied.

Investigations are made into the connections between the phase structure and composition of SBSMA, micromechanics, rheological properties, and other elements. The phase-field technique model, the phasing prediction model, and the phase strategic analysis characteristics of the 2D picture processed using a fluorescence microscope are also produced. The study also discusses the phase stability of the SBSMA mixture with a variety of materials, which might help researchers understand how the field is developing in terms of research (M.Chen, J.Geng, C.Xia, L.He, & Z.Liu, 2021).

Asphalt pavement is inexorably heated by the sun and ultraviolet (UV) rays during its development and construction life. However, the aging impact of UV light is not considered in the current roadway design and review processes. To examine the impact of UV radiation on the aging properties of SBS-modified asphalt binders, UV aging tests on RTFOT-aged samples were carried out with various UV radiation intensities.

In sixteen different testing groups, the rheological parameters and functional group characteristics of asphalt mixes treated with SBS were compared. With a Bending Beam

Rheometer (BBR), Dynamic Shear Rheometer (DSR), SEM and FTIR investigations, and SEM, the aging mechanisms under various UV aging settings were assessed. The results show that UV aging causes a considerable change in rheological properties due to UV radiation, which accelerates the breakdown of SBS and significantly destroys the network structure created by the cross-linking action in the bitumen binder modified with SBS.

Degradation of SBS and changes to the composition of the asphalt mixture base led to colloidal structure transformation and asphalt binder performance loss, which were the features of SBS-modified asphalt mixture aging. According to testing, continual UV exposure can also worsen the asphaltic surface's reduction and cause the asphalt binder's exterior to fracture (Yu, et al., 2019).

As a result, the objective of this study is to determine how well TOR influences the morphology, heat resistance, and rheological properties of CR/SBS-modified bitumen. The results show that TOR significantly affects the temperature sensitivity and anti-rutting of CR/SBS treated asphalt. The anti-cracking performance of CR/SBS treated asphalt, on the other hand, is slightly harmed by TOR, although this has no impact on the crucial low-temperature requirement.

The confirmation of the cross-linked structure between the polymer and the bitumen may also be encouraged by TOR, which would significantly enhance the rheological properties and thermal stability of the CR/SBS modified asphalt. Finally, the composition of neat asphalt has a significant impact on how well-modified asphalt behaves viscoelastic, and a high asphaltene concentration is desirable for enhancing TOR rheological behavior effects (S.Ren, et al., 2020).

The application for recycling outdated SBSMA has drawn a lot of interest. In this work, aged SBSMA was rejuvenated utilizing pure SBSMA, rejuvenator (RA), fundamental bitumen

(SK-7,0), and real SBSMA combined with SK-70. For their conventional performance and rheological behavior, various SBSMA were investigated. The microscopic modifications were examined using Fourier transform infrared (FTIR) spectroscopy, gel permeation chromatography (GPC), and fluorescence microscopy (FM).

The findings demonstrated that RA and pure SBSMA, but not SK-70, significantly influence the emergence of physical and nanostructures in aging SBSMA. The addition of RA significantly increased the aging SBSMA's low-temperature rigidity and elasticity recovery rate in comparison to conventional testing. Additionally, both in physical and rheological features, RA improved the ability of aged SBSMA to relax under stress by increasing creep compliance. These results demonstrate that RA enhanced the breaking resistance of aged SBSMA at low temperatures.

The results of the microscopic studies indicate that RA can reconstruct the network model of old SBSMA in addition to controlling the various components of aged SBSMA. Additionally, the performance of the revived SBSMA is strongly correlated with the SBS copolymer concentration and softening indices. The results show that it is crucial to resuscitate the deteriorating SBSMA by softening the basic bitumen and reestablishing the network structure of the SBS copolymer (Cong, Guo & Mei, 2020).

High-quality bitumen with a composite’s modifier is necessary for such a high-grade road to achieve the standards. In this study, it was successful to create nano-organic palygorskite (O-PAL) using acid stimulation and silane treatment. O-PAL and styrene-butadiene-styrene block polymeric (SBS) modified asphalt was produced via melt blending. By creating a multi-phase uniformity solution with a spinodal reinforced structure, O-PAL composites SBS modified bitumen can enhance the properties of asphalt.

Composite O-PAL SBS with.3% O-PAL The threshold of the asphalt mixtures was increased by up to 40% when O-PAL was added, and modified asphalt had good water stability. O-PAL can delay the aging of the asphalt matrix and the thermal breakdown oxidation of linear SBS. The anti-aging and storage stability properties of the composites modified asphalt are enhanced by the addition of O-Pal. O-PAL and SBS are effective combinations for modified asphalt in humid and high-temperature environments (J.Jin, et al., 2021).

Chapter 3

METHODOLOGY

3.1 General

It contains the procedures for completing the study's objectives, including gathering materials required, preparing samples, and tests, and assessing the importance of different factors. Numerous SBS-modified asphalt concrete specimens, as well as a control binder specimen, were used in this study. The Marshall mix procedure will be detailed in this chapter for various percentages of SBS, including 0% (controlled sample), 3%, 5%, 7%, and 9%. The above-mentioned percentages of SBS were combined with 4.2 percent percentages of OBC to form specimens for resilience modulus, moisture susceptibility, and wheel tracking tests.

These laboratory specimens were prepared using the NHA-B aggregate gradation method, as described in this chapter. This chapter will go through the testing equipment that was used, the experimental tests that were to be performed on the samples, the method of preparing test specimens, and the input parameters that were used throughout these tests.

3.2 Research Methodology

An SBS proportion and a specimen were chosen to meet the objectives. SBS was imported from China's Shijiazhuang Tuya Technology Co. and brought to NUST's National Institute of Transportation for analysis and testing of resilient modulus and moisture susceptibility in the Universal Testing Machine (UTM) and wheel tracking testing in the Double Wheel Tracker (DWT). Samples for surface course mixes were created in a lab setting under strict conditions. Following an OBC diagnosis in the lab, these specimens were prepared. The data was then examined, and findings and conclusions were drawn, as illustrated in the following chapter. The figure 3.1 depicts the method used in this experiment.

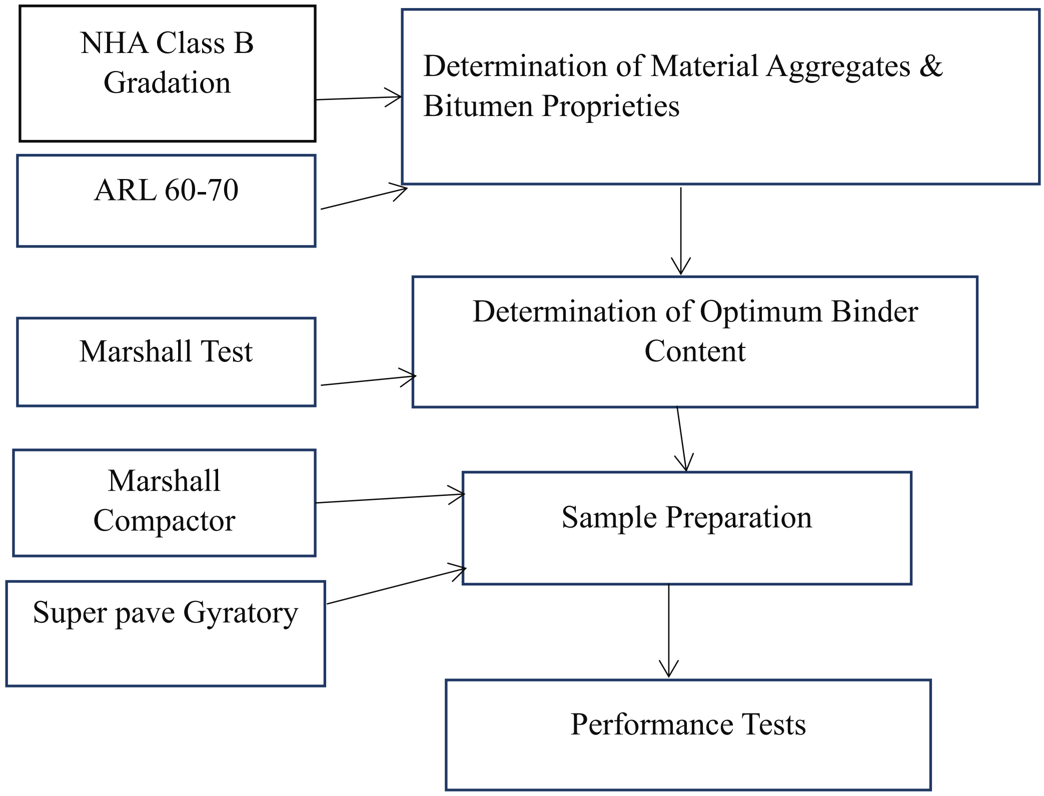

Figure 3-1Test Methodology of research

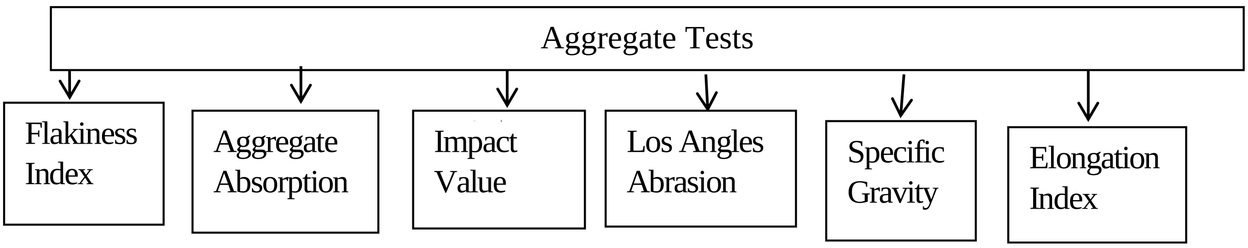

Figure 3-2:Test of aggregates

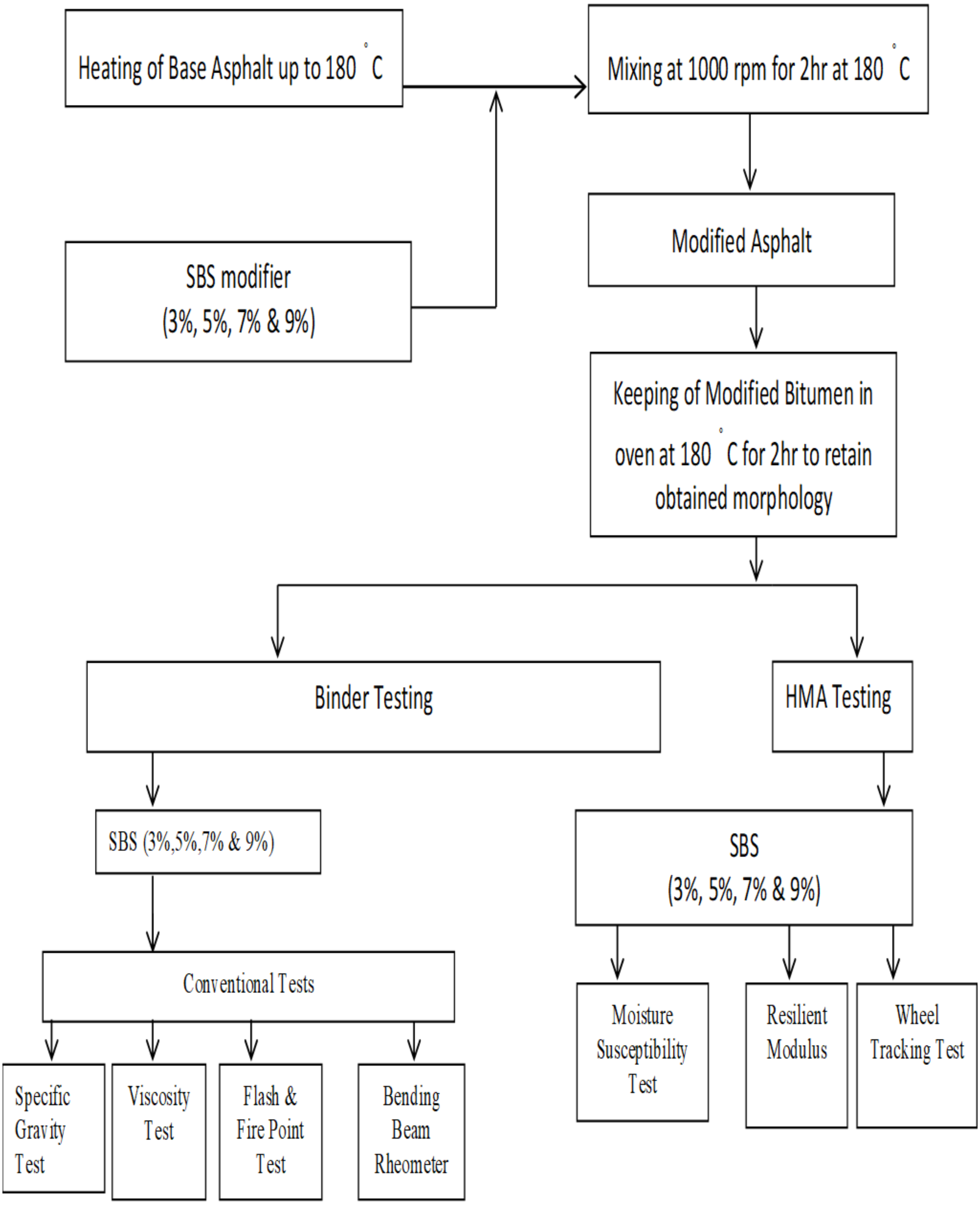

Figure 3-3:Conventional and Performance Tests of Binder and Asphalt

3.2.1 Material Selection

The coarse and fine aggregates were supplied from "Babozai Quarry" located in Kallang Tehsil of District Mardan, and the penetration grade 60/70 bitumen came from Attock Refinery Limited (ARL) in Rawalpindi. Grade 60/70 was selected for this research because it is commonly used in practice in Pakistan and is well suited to climate zones with cooler to milder conditions. Shijiazhuang Tuya Technology Co. in China supplied SBS.

The aggregate framework of the mix contributes roughly 95% of the permanent deformation resistance, while the asphalt binder provides the other 5% aggregates to produce a strong stone framework that can survive repeated load applications. The aggregates' surface roughness, gradation, and shape have a considerable impact on HMA properties. Shear strength is higher in angled coarse-textured and angled aggregates than in rounded or smooth-textured aggregates. Compulsory testing on utilized aggregates as well as asphalt binders was carried out in compliance with ASTM and material characterization criteria.

A well-known modifier with a high molecular polymer, SBS (styrene-butadiene-styrene), makes the asphalt binder miscible with the asphalt binder. When creating SBS-modified asphalt, matrix asphalt is used as the base material, and a certain amount of the SBS modifier is added. The SBS modifier is then equally distributed throughout the bitumen using techniques like shearing and stirring. The SBS-modified asphalt improves the asphalt pavement's resilience to high-temperature rutting and low-temperature cracking, which can significantly enhance its service life.

Figure 3-4:Styrene-butadiene-styrene (SBS)

Traditional lab tests (Viscosity, Specific Gravity, Flash & Fire Point Test) & Performance tests (Resilient Modulus, Wheel Tracking Test, and Moisture Susceptibility) will be used to compare the effects of different dosages (3 percent, 5 percent, 7 percent, and 9 percent) SBS modifiers on the properties of asphalt in our study.

3.2.2 Aggregate Testing

The aggregate structure is the most important component of the mix since it resists permanent deformation and is expected to build a robust structure that can withstand repeated pressures. On each stockpile, laboratory experiments were done to evaluate the aggregate's fundamental features, including gradation and specific gravity. The following are lists of lab experiments:

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

The tests described above were performed on three samples, with the average being used for the next step.

3.2.2.1 Aggregate Shape Test

The shape of the particles affects the intensity and workability of bituminous mixtures. It also has an impact on the amount of work required for compaction, which is required to achieve the desired density. As a result, a shape test was used to determine the number of flat and elongated aggregate particles. Aggregate particles are categorized as elongated if their length is larger than 1.8 of their mean sieve size and flaky if their dimension is less than 0.6 of their mean sieve size, according to ASTM D4791.

Figure 3-5:Flakiness and Elongation Gauges

3.2.2.2 Aggregate Specific Gravity

The weight-to-volume ratio of aggregate material is determined by its specific gravity. The density of a variety of aggregates, such as coarse, fine, and filler, was determined. Coarse granular material is defined as granular material which passes through a No. 4 sieve.

Figure 3-6:Specific Gravity Apparatus

3.2.2.3 Coarse Aggregate Specific Gravity

The ASTM C127 procedures and instruments were used to determine the specific gravity of coarse aggregate as well as water absorption. For the coarse aggregate specific gravity test, there are three sample conditions: oven-dry without moisture, immersed in water and saturated surface dry. The test was done on both the coarse-graded stockpiles of 10-20 mm & 5-10 mm, with the findings determined.

3.2.2.4 Fine Aggregate Specific Gravity

The specific gravity and the water absorption of fine aggregate were determined using ASTM C 128 procedures and equipment. A specific gravity test was performed on fine aggregate and stone dust to determine the SSD, bulk, as well as apparent specific gravities.

3.2.2.5 Aggregate Impact Value Test

The aggregate impact value reveals how resistant an aggregate is to a sudden shock. An impact testing equipment, a tamping rod, and 1/2", 3/8", and #8 sieves are among the tools needed to establish the impact value (2.36mm.) Around 350g of aggregate that passed through a 1/2" sieve but did not pass through a 3/8" filter was collected and layered in three levels in the Impact Testing Machine's mold, tamping every layer 25 times. The specimen was moved to the machine's larger mold, where 15 blows were given with a hammer weighing 13.5 to 14 kg at a height of 38 cm. The resulting aggregate was removed and sifted via sieve #8. The amount of material that passed through a 2.36mm sieve was utilized to calculate the impact value as shown in Fig 3.7.

Figure 3-7:Apparatus for determining Impact Value of Aggregate

3.2.2.6 Aggregate Crushing Value Test

The aggregates must be capable of withstanding traffic loads to create a higher-quality and stronger pavement. A steel cylinder with open ends, a plunger with just a piston diameter of 150 mm, a base plate, and a hole in the center for inserting a lifting rod, a cylindrical measure, a tamping rod, a balance, and a compressive testing machine made up the test apparatus. Aggregates were filtered through with a standard sieve, with those that passed through 12" and remained on 3/8" selected as shown in Fig 3.8.

The aggregate material was washed, oven-dried, and weighed (W1) before being layered three times in the cylindrical measure and tamped 25 times each layer. Three layers of the base plate were used to secure the sample in the steel cylinder. It was then placed at a rate of 4 tons per minute into compression testing equipment until the maximum load reached 40 tons. The crushed particles were therefore filtered through a 2.36mm filter after the steel cylinder was removed. We gathered and weighed the materials that passed through this filter (W2)..

Figure 3-8:Apparatus for determining crushing value of aggregate

3.2.2.7 Los Angeles abrasion

This testing is used to measure how resistant road aggregate is to abrasion. Aggregate must be durable enough to endure the wear produced by heavy traffic. A Los Angeles Abrasion apparatus, a set of sieves, a balance, and steel balls were used in this test as shown in Fig 3.9. Class B gradation was adopted in this process. 2500 g of material retained on 12" and 3/8" sieves was put in the Los Angeles abrasion machine, along with 11 steel balls or charges, for a total of 5000g.

The machine was spun at a speed of up to 500 revolutions per minute for 500 revolutions. More than 30 revolutions per minute, but less than 33. After that, the material was sieved with a 1.7mm sieve. The sample weight (W2) that passed through it was reported.

Figure 3-9:LA abrasion apparatus

As a result, it is critical to check the appropriateness of aggregates according to ASTM and BS standards as well as material characterization criteria while producing Asphalt mixes. These tests were carried out on aggregate from the Margalla quarry site; Table 3-1 summarizes the key findings of the aggregate tests.

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

Elongation Index (EI)	ASTM D 4791		3.2%	< 15%
Flakiness Index (FI)	ASTM D 4791		10.6%	< 15%
Aggregate Absorption	Fine	ASTM C 127	2.28%	< 3%
	Coarse		0.61%	< 3%
Impact Value	BS 812		15.12 %	< 30%
Los Angles Abrasion	ASTM C 131		21.15%	<30%
Specific Gravity	Fine	ASTMC128	2.55	-
	Coarse	ASTM 127	2.63	-

3.2.3 Asphalt Binder Testing

Consistent, safety, and cleanliness are the three most critical attributes of binders in infrastructure as well as engineering applications, according to the Asphalt Institute's MS-4 guidebook. The density of the asphalt binder changes as the temperature rises. As a result, assessing asphalt binder consistency requires a standard temperature. To measure the consistency of bitumen binder viscosity tests are usually performed (Asphalt Institute MS-4, 2003). Other tests, like the flash and fire point, provides more information and assurance about its stability. To characterize the asphalt binder, the following tests were carried out in the laboratory.

- Flash and Fire Point Test of Bitumen
- Rotational Viscosity Test
- Specific Gravity
- Bending Beam Rheometer

3.2.3.1 Performance of Binders Tests

3.2.3.1.1 Flash and Fire Point Test of Bitumen

Flash and fire point test is essential before the construction of roads. The temperature at which a substance is likely to catch fire is measured by the flash and fire point. For various types and grades of bitumen binders, there are differences in the temperature at which the bituminous material's vapor ignites instantly or burns for a short period.

Since bituminous materials are predominantly made of hydrocarbons, they produce a variety of volatile substances when heated. These volatile substances that have been released ignite instantly. And this might be dangerous. For use as a bitumen binder for road pavements, bitumen is heated. When working with hot bitumen during processes like heating, mixing, or application, the temperature should be kept far below the critical temperatures specified by flash and fire points.

Every part of the cup and its accessories should be thoroughly cleaned before being laid aside to dry. In a beaker, warm the bitumen sample to a temperature between 75 and 100 °C, above the substance's approximate softening point. Before turning the bitumen into a liquid, let it fully melt. The cup should be filled with the melted bitumen to the filling mark. Use the lid to help you close the cup.

Make sure the cups and the lid's locating mechanisms are correctly seated. On the stove, set the cup. Insert a thermometer and set the test flame so that it is the size of a bead with a diameter of about 4 mm. Aim for a temperature increase of 5–6 °C per minute as recorded by the thermometer by controlling the rate of heat delivery. A 60 rev/min rate should be used to rotate the stirrer. Apply the first test flame when the temperature reaches around 17 °C before the actual flash point. Stop stirring as soon as the test flame is on the lid. Apply a test flame to any temperature reading up to 104 °C in multiples of 1 °C. Perform the test at 2 °C intervals when the temperature is higher than 104 °C. When using the tool to apply the test flame, control the shutter and test flame burner so that the flame is reduced in 0.5 seconds. It pauses briefly in the reduced position before being swiftly raised to the higher position. Write down the temperature at which a clear flash can be seen within the cup as shown in fig 3-10.

Figure 3-10:Flash and Fire point Apparatus

3.2.3.1.2 Rotational Viscosity Test

The basic RV test measures the torque required to maintain a cylindrical spindle's constant rate of 20 RPM while submerged at a constant temperature, which is commonly 275°F (135°C) in a bituminous binder. This torque is immediately converted into a dynamic viscosity and displayed by the RV. The figure 3-11 shows an illustration of the major machinery.

Figure 3-11:Rotational Viscosity Apparatus

According to AASHTO T 316 and ASTM D 4402, set the viscometer's ambient chamber, sample chamber, and spindle to 275° F (135°C). Heating the unaged asphalt binder until it is pourable is necessary. To prevent entrapping air bubbles, gently stir the sample. Add the required amount of bitumen binder to the sample chamber. The sample size varies depending on the spindle that was selected and the equipment maker.

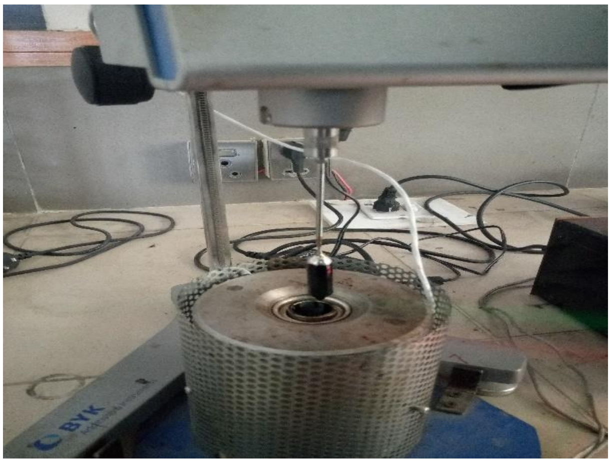

Figure 3-12:RV Apparatus

After placing the sample chamber into the RV temperature controller device, cautiously lower the spindle into the sample. Bring the sample to the required test temperature, usually 275°F (135°C) in about 30 minutes, then allow it to attain equilibrium at test temperature for 10 minutes. As the spindle rotates at 20 RPM, make sure the percent torque represented by the RV reading stays between 2 and 98 percent. After the sample has reached the proper temperature and equilibrated, take three readings of the viscosity from the RV display, allowing one minute between each measurement. The viscosity is determined by averaging three readings.

3.2.3.1.3 Specific Gravity

The stopper and specific gravity bottles are weighed after being cleaned and dried. It should be mentioned that this weight is. The distilled water should be put into one of the bottles, then it should be sealed with a stopper. The water must have just completed cooling and boiling before loading. Place the bottle in a beaker of distilled water with the neck submerged for at least 30 minutes at a temperature of 27 0.1 °C or any other temperature that can be maintained to ascertain the specific gravity. Take the bottles out of the water bath and use a dry cloth to wipe off any excess moisture from the outside of the bottles. Measure the bottle's weight. This weight should be noted as b. After taking, re-dry the bottle. Apply heat cautiously so as not to cause the bitumen sample to evaporate, and then bring it to a fluid state. Warm up the bottle of specific gravity a little. Bituminous samples should be half-filled into a clean, dry specific gravity bottle as shown in fig 3-3. Check to make sure the substance doesn't touch the bottle's sides. When pouring, a small funnel can be used to prevent the substance from coming into contact with the bottleneck.

Figure 3-13:Specific Gravity Apparatus

So that any trapped air bubbles, if any, can escape, let the partially filled bottle sit at a temperature of 60 to 70 degrees. Once the bottle has reached the desired temperature, weigh it. This weight should be noted as c. With the stopper loosely in place, pour freshly boiling distilled water into the bottle containing the asphalt. A bottle with air bubbles should be avoided. In the water bath, place the bottle with the specific gravity and secure the stopper for at least 30 minutes. Remove the bottle from the water bath, then wipe out any extra moisture that has gathered on its exterior with a dry cloth. Find the bottle's weight again. This weight should be noted as d.

3.2.4 Bending Beam Rheometer

Set the desired test temperature in the BBR fluid bath. At all test temperatures, the fluid should be transparent. Ethanol, methanol, and mixes of glycol and methanol are acceptable fluids. To keep the asphalt binder beam from floating, the fluid's specific gravity must be less than 0.0655 lb/ft3 (1.05 kg/m3). Long-term aged (PAV) asphalt binder is heated till it is pourable. To guarantee homogeneity, the sample should be covered as well as occasionally swirled while being heated. Stir to remove air bubbles after pouring the heated sample into two BBR molds, being sure to overpour such that there is an additional sample along the top of the mold. The asphalt binder from this overpour will fill the mold. Using a heated spatula, trim the top of the specimen flush with mold after allowing the mold to cool for 45 to 60 minutes at room temperature. The mold is cooled in an ice bath or freezer at -5°C for 5 minutes or it is simple to remove the beam from it without damaging it. For 60 minutes, condition beams at test temperature in the BBR bath. Assemble the test supports and the test beam. BBR apparatus is shown in fig 3-14.

Figure 3-14:Bending Beam Rheometer Apparatus

For the duration of the test, manually provide a 0.008 lb (35 mN) contact load for no more than 10 seconds to ensure that the loading head and the beam remain in contact. The testing system will automatically start. Using this system, you can: For one second, apply a sitting load of 980 mN (0.22 lb). Lower the seating load to 0.008 lb and give the beam 20 seconds to recuperate (35 mN). Apply the test load of 0.22 lb (980 mN) and hold it steady for 240 seconds. Readings of deflection over time are kept track of throughout this time which are shown in table 3-2. End the test by removing the test load.

Table 3-2 : Performance Testing Matrix of Asphalt Concrete Mixtures

Type of Test	**Test Standards**	**SBS %**				
		0%	**3%**	**5%**	**7%**	**9%**
Specific Gravity	ASTMD 7076	0.965	1	1.03	1.04	1.0 5
Flash & Fire Point (°C)	ASTM D92	233& 278	268& 289	269 & 293	273 & 295	280& 306

3.2.5 Gradation Selection

NHA class B aggregates were used in dense-graded surface course mixes in compliance with NHA (1998) specifications. The size of aggregates size for class B wearing coarse gradation is approximately 19 mm, according to Marshal Mix Design, with the max possible aggregate size being slightly smaller. The selected gradation is listed in Table 3-3, and Figure 3-15 shows the gradatin graph against percent passing and sieve diameters.

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

Sieve Size	NHA Specification Range (%Passing)	Our Selection	Retained
19	100	100	0.00
12.5	75-90	82.5	17.5
9.5	60-80	70	12.5
4.75	40-60	50	20
2.38	20-40	30	20
1.18	5-15	10	20
0.075	3-8	5.5	4.5
Pan	. . .	. . .	5.5

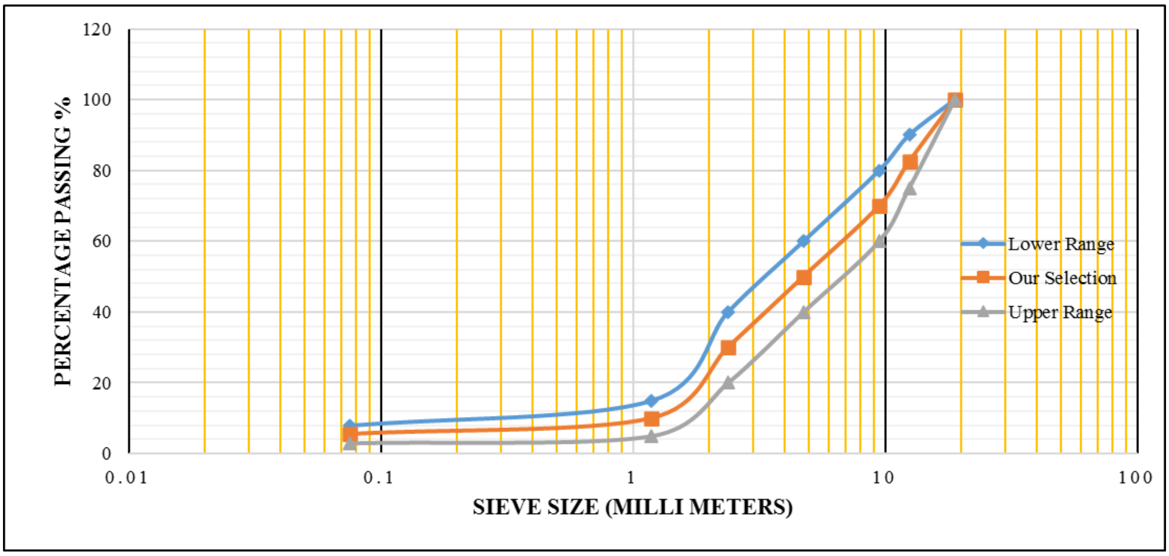

Figure 3-15:Graph of Sieve Size VS Percentage Passing

3.2.5.1 Asphalt Mixture Preparation

There are two main types of mixtures, as previously stated. The first is an asphalt mixture that has been carefully controlled. The second is a blend that contains four percentages of SBS. After identifying the OBC, laboratory-produced mixes were created by using the Marshal Mix design method. The samples were then processed according to their OBC, with a special emphasis on 4 percent air voids. The procedure for preparing laboratory-produced mixes is described in the heading below.

3.2.5.2 Preparation of Bitumen Mixes for Marshall Mix Design

The Marshall Apparatus was used to create the bituminous mixes used to calculate OBC in line with ASTM D 6926. Four samples of the Marshall Mix design approach were used to determine the OBC for each type of gradation. The volumetric properties, stability, and flow were assessed, the Marshall Mix design criterion was satisfied, and the OBC was computed at the end. Here is how Marshall Mix was formed:

3.2.5.3 Aggregates and Bitumen Preparation for Mixes

After sieving, the aggregates were dried at a temperature of 105°C to 110°C to get a consistent weight as shown in fig 3-16. For compaction of a 4-inch diameter specimen using the Marshall Mix design process, 1200 grams of aggregates are required (ASTM D6926).

Figure 3-16:Different Sizes of Aggregate

3.2.5.4 Aggregates and Asphalt Cement Mixing

The ASTM D6926 guideline suggests mixing bitumen and aggregates with a mechanical mixer. The dehydrated warmed bitumen and warmed aggregates were mixed. Figures 3-17 depict a diagram of a mixing. The temperature range for the mixing was 160°C to 165°C, which is the temperature at which bituminous mixtures are made in Pakistan (NHA Specifications)

Figure 3-17:Prepared Asphalt Mixture

3.2.5.4.1 Conditioning of the mixture

Before compaction, ASTM D6926 recommends curing bituminous mixes for about two hours. Consequently, each bituminous mixture that came out of the mixing machine was placed in a metal container.

3.2.5.4.2 Compaction of Specimens

Following a two-hour preconditioning period at 135 degrees Celsius, the mixtures were compacted using a Marshall Compactor. The base plate, the mold cylinder, the base plate, as well as the extension collar, are all three parts that make up the mold arrangement. The inside diameter and height of the mold cylinder are roughly 4-inches and 3-inches, respectively. The collar extensions and base plate can be switched out at any time throughout the molding process. With the help of a spatula, the mixture was squeezed into the mold as shown in fig 3-18. A filter paper with a diameter equal to the mold's diameter was placed at the bottom of the mold during cleaning and preheating at 135°C before packing. When the entire batch was placed into the mold and spaded consistently. To protect it from the elements, a layer of filter paper was laid on top of it. As indicated by the results of the previous study, the design criterion adopted for this study was a heavily congested pavement and designs having ESALs (millions) 30 for dense graded wearing courses. To simulate heavy traffic flow, 75 blows were delivered to each end. In preparation for compression, the mold components were inserted into the mold while it was still in the compaction stage (application of blows). Mechanically, 75 blows were delivered to the specimens using only a hammer that was properly positioned over the mold assembly. The mold assemblage was withdrawn from its frame and the specimen was rotated as soon as all of the compressing blows on one side were completed. The specimen was then reassembled in the mold and subjected to the same amount of compression blows on the opposite face.

Figure 3-18:Samples in Marshal Mold

3.2.5.4.3 Extraction of Mold Specimens

The molding equipment was removed after compaction, and the sample was allowed to cool for a few minutes. An extraction jack was then used to remove the specimen from the mold which is shown in fig 3-19. The test specimens were cooled to room temperature on a flat surface.

Figure 3-19:Hydraulic Jack for Extraction of Samples

3.2.5.1 Number of Specimens

For every mix of aggregates and asphalt binder percentage, specimens were made as shown in fig 3-20. To create the specimens, five different binder components were used (3.5, 4.0, 4.5, 5.0, and 5.5 percent). The combination that performs best at a minimum bitumen content of 4% air voids was determined using five trial mixes.

Figure 3-20:Prepared Asphalt Samples

3.2.6 Determination of Volumetric, Stability, and Flow

According to ASTM D2041 & ASTM D2726 standards, values for bitumen pavement mixtures were established. After the samples were held in a water bath at 60°C for one hour and evaluated for stability and flow using Marshall Test equipment.

3.2.6.1 Volumetric Property

Up to failure, loading was conducted steadily at a rate of 5 mm/minute. The whole ultimate load in KN was used to define Marshall's stability. A flow number in millimeters was used to calculate the total deformation that occurs at maximum load. According to the Marshall Mix design specifications (MS-2), the specimen's stability for an extensively traveled, worn course must be greater than 8.006 KN, and the flow number must be between 2 and 3.5. After being taken out of the water bath, the specimen was immediately analyzed, and values are illustrated in Table 3-4.

Table 3-4: Volumetric Properties of Asphalt

% AC	Gmb	Gmm	Unit wt (g/cm^3)	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.328	2.467	2.328	5.63	15.47	63.57	14.39	1.98
4	2.355	2.460	2.355	4.27	14.49	70.53	15.43	2.43
4.5	2.361	2.448	2.361	3.55	14.27	75.09	15.21	3.02
5	2.347	2.427	2.347	3.30	14.78	77.69	14.12	3.42
5.5	2.342	2.41	2.342	2.82	14.96	81.14	13.19	4.04

To determine the OBC of a mix the curves linking asphalt content and volumetric characteristics, stability, and flow were drawn according to the Asphalt Institute Manual. Curves are illustrated in fig 3-21, 3-22 and 3-23.

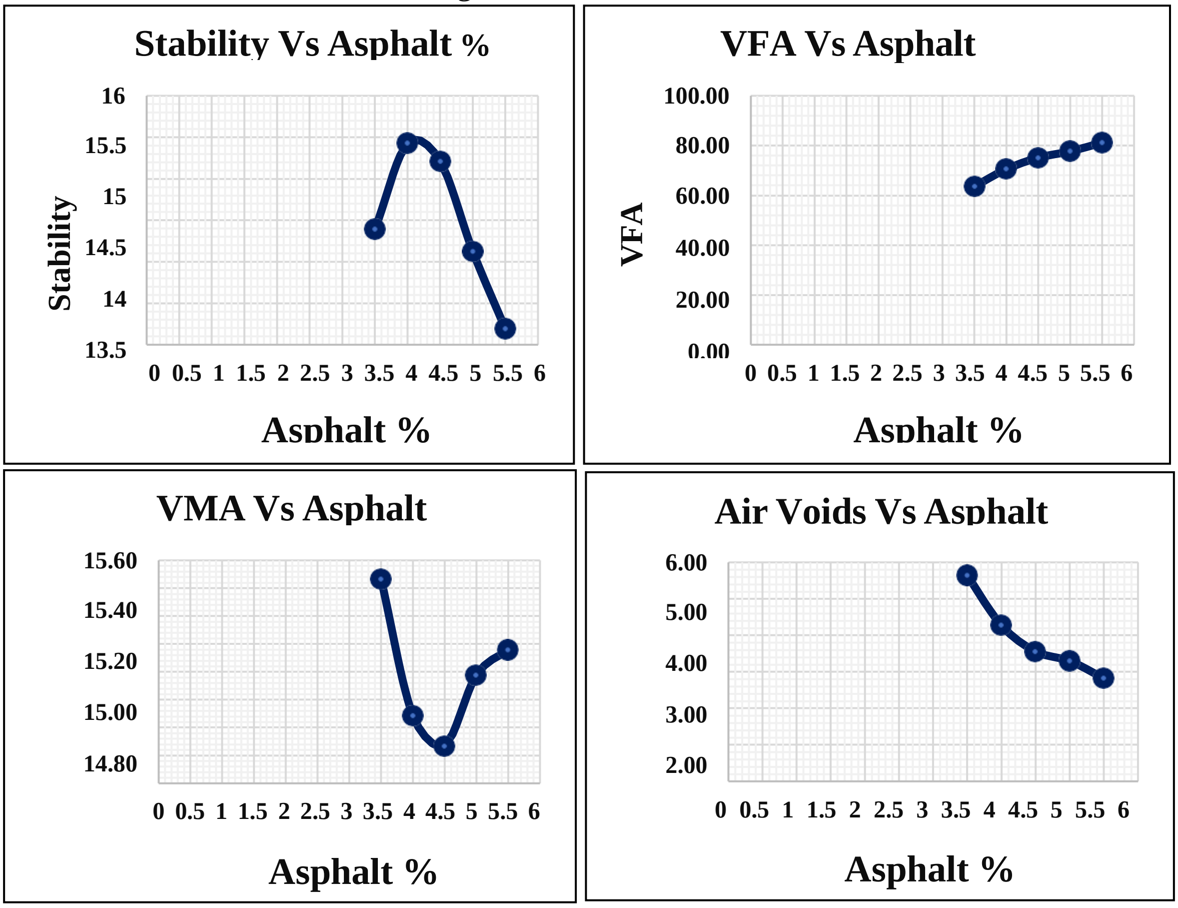

Figure 3-21:Graphs Showing Curves of VMA, VFA, Air Voids & Stability VS Asphalt

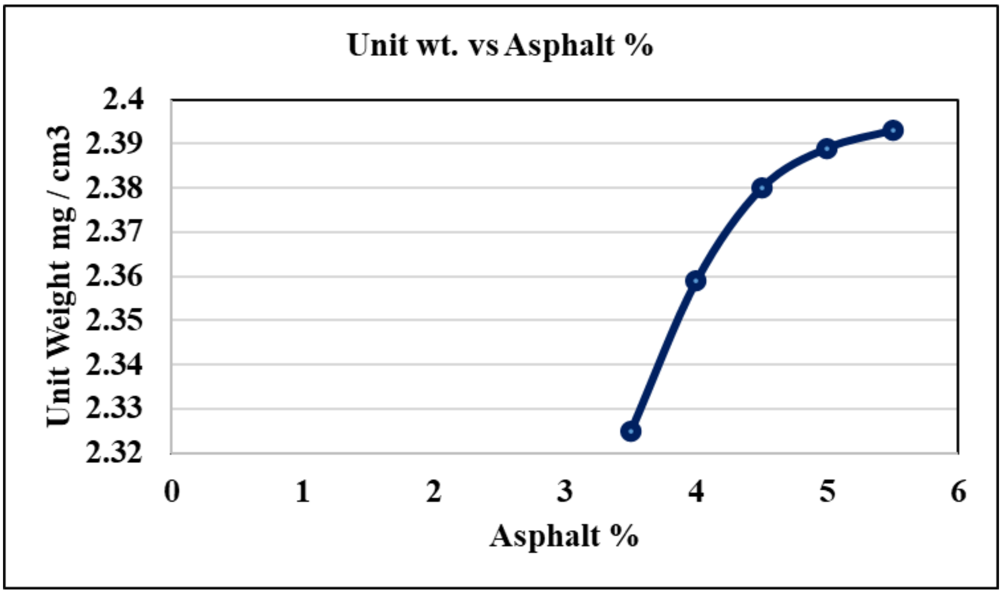

Figure 3-22:Graph of Unit Wt. VS Asphalt

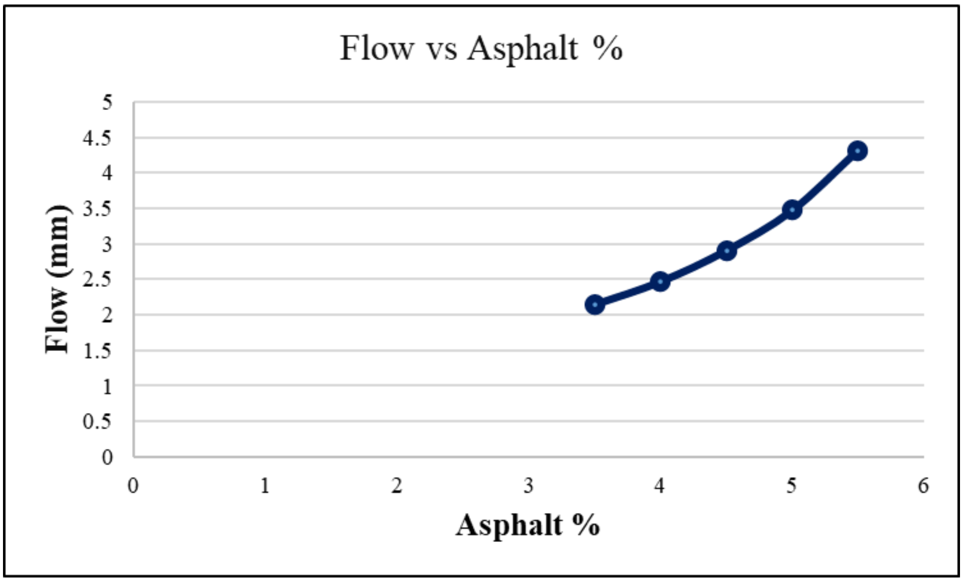

Figure 3-23:Graph of Flow VS Asphalt

OBC is determined at 4% air voids which is 4.20%. The plots were then used to calculate the volumetric properties, stability, and flow parameters needed by OBC. The criterion for a combination is shown in Table 3-5. The table makes it abundantly evident that every volumetric attribute, stability, and flow complies with the requirements. The VMA must not fall below 13 percent at 4 percent specified air voids, and in this scenario, it was 13.493 percent. VFA should lie within the range of 65 and 75 percent; its projected value of

70.04 percent does so. The stability value in this situation was 12.324 KN, exceeding the required stability value of 8.006 KN. The observed flow number of 2.724 mm is within the permitted range.

Table 3-5: Volumetric Properties of Mix at Optimum Binder Content

Parameters	Measured Value	Criteria	Remarks
Optimum Asphalt Contents	4.2	NA	----
VMA (%)	13.493	13	Pass
VFA (%)	70.04	65 – 75	Pass
Stability (KN)	12.324	8.006	Pass
Flow (mm)	2.724	2.0 – 3.5	Pass

3.2.7 Performance Tests

The Universal Testing Machine used Marshall samples to produce specimens for stiffness, fatigue, and moisture damage detection. The aggregates were first preheated to 110 and weighed 1200 grams. Bitumen was added to the aggregates by the mix design outlined above after the aggregates had been in the oven for two hours. Bitumen plus aggregates were combined in a mechanical mixer and heated to 180 degrees for one minute.

After mixing, samples were put in the container and put in the oven at 135^{o}C for curing for up to two hours. Samples were crushed after curing. Marshall molds were greased, and filter paper was added, before compacting. To simulate the flow of traffic, 75 blows were delivered on each side. For each test, three replicates were created, with the aggregate containing bitumen containing 3%, 5%, 7%, and 9% SBS by weight. For performance testing, 30 samples were created. After compaction, sample dimensions matched industry norms. The samples had a height of 62.5 mm and a diameter of 101 mm which are illustrated in fig 3-24.

Figure3-24: Asphalt Samples with SBS%

3.2.7.1 Indirect Tensile Strength Test to Ascertain Moisture Susceptibility

The Indirect Tensile Strength Test was performed by ASTM D 6931-07 to assess moisture susceptibility (Resistance of Compacted Hot-Mix Asphalt to Moisture Induced Damage). Two samples from each combination were subjected to unconditioned testing. These unconditioned samples were placed in a water bath that was heated to 60°C an hour before testing.

The second group of two specimens per combination was used to evaluate the conditioned specimens. Samples were prepared by ALDOT-361, which calls for specimens to be soaked, then placed in a water bath that is 60 °C (140 °F) for 24 hours, then 25 °C for an hour. Both unconditioned and conditioned specimens were subjected to load diametrically at a speed of 50 mm/minute as shown in fig 3-25.

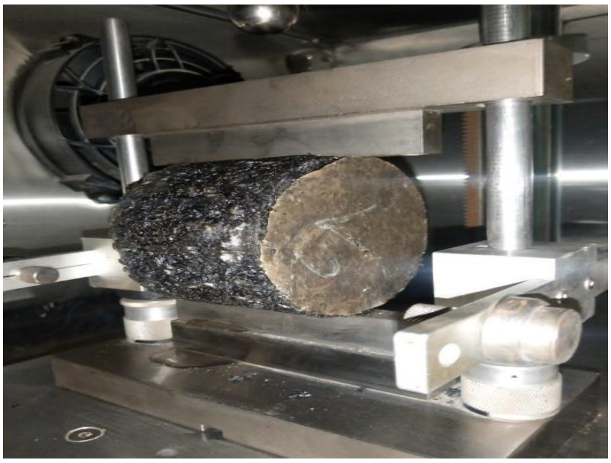

Figure3-25: UTM Apparatus with Asphalt Sample

Each specimen's tensile strength was calculated based on its measurements and failure load. The average unconditioned and conditioned tensile strengths were then divided by each other to produce the tensile strength ratios.

The TSR number indicates whether moisture damage is possible. It is determined as the tensile strength of the conditioned group divided by a group like the unconditioned subset. The TSR for every combination is calculated using the equation.

3.2.8 Resilient Modulus Test

A pavement structure's ability to adapt to imposed traffic loads may be evaluated using this information. It can also be used as a substantial contribution to the process of designing pavement using mechanistic-empirical analysis. The resilient modulus describes the relationship between applied stress and recovered strain observed during the cyclic loading of a substance. It is an important indicator of how rigid a combination is. Additionally, the resilient modulus is a preliminary test that may be used to assess the material quality, give guidance on pavement design, and act as a foundation for evaluation and analysis.

The modulus is used to contrast variations in material stiffness as a function of polymer temperature and concentration. The robust modulus is reportedly a crucial parameter for predicting pavement performance and examining how pavements react to traffic stress. Permanent deformation was observed to be less likely in the stronger pavements. It is critical to keep in mind that at low temperatures, mixtures with a high rigidity (higher Mr.) break more quickly than those with a low rigidity (lower Mr).

(Al-Abdul-Wahab et al. 1991) modulus tests on unmodified and altered asphalt concrete mixtures were performed using Marshall specimens. The test samples must be brought to the correct testing temperature and placed in a controlled cabinet to conduct the modulus test. After that, they spend a minimum of 12 hours in an environmental chamber. The samples were taken out of the water bath and placed into the loading equipment at 25°C as soon as they reached the proper test temperature.

The repeated-load indirect tension test must be used to calculate the resilient modulus of a cylindrical specimen. Specifically, a haversine waveform is supplied vertically in the specimen's vertical diametric plane. The application of the stress and the resilient modulus value was determined using horizontal elastic deformation. Depending on the material employed, the recommended load magnitude should also produce indirect tensile stress that is equivalent to or between 10% and 50% of the indirect tensile strength.

At least 50 to 200 stress cycles must be applied to the specimen to precondition it. The software program that operates on the machine during each load hit determines the test machine's modulus. It also includes results from the averaged test findings, which are expressed as the specimen's robust modulus at that specific temperature. Equations are used to calculate the robust modulus by multiplying the horizontal deformation, actual load, and recovered horizontal deformation for each load pulse. Samples are illustrated in fig 3-26 after the performance of test.

Figure3-26:Samples After Performance of Test

3.2.8.1 Wheel Tracking Test

Asphalt mixtures' resistance to rutting and moisture susceptibility are assessed using the Hamburg (Immersion) wheel tracking test. Although several states alter this process to suit their requirements, AASHTO-T324 is the generally accepted test standard.

Test specimens are prepared for 3,5,7 and 9 percent of SBS. Aggregates, SBS, and OBC are mixed until all aggregates are coated thoroughly. Material is placed in a mold of a gyratory compactor and compacted. Compacted specimens are cooled at room temperature on a clean and flat surface as shown in fig 3-9.

Figure3-27: Superpave Gyratory Samples

Saw-cut specimens are used for the performance of the test. Place polyethylene molds in the mounting tray. Saw-cut specimens are then inserted into polyethylene molds. Secure the molds in the mounting tray by tightening the bolts of the edge plate. Testing device and computer are turned on. The software communicates with the testing device and the test temperature is selected according to AASHTO T 324-11. Rut depth is selected according to the requirements and a test is performed. The wheel tracking device is shown in fig 3-28. The computer screen read out and provides all outputs.

Figure3-28: Wheel Tracking Test Apparatus

3.3 Summary

The selections of aggregates, bitumen, and modifier used for research was detailed in this chapter. Additionally discussed were aggregate grading and the ideal bitumen content. Additionally, experiments on aggregates, binder (neat/modified), and Asphalt Concrete Mixture (modified/unmodified) were conducted.

Chapter 4

RESULTS AND ANALYSIS

4.1 Introduction

The results and analysis of treated and untreated asphalt concrete mixtures are presented in this chapter. Crush from Margalla and bituminous penetration grade 60/70 from ARL made unaltered mixes. Margalla Crush and SBS were used to create modified mixes imported from Shijiazhuang Tuya Technology Co. in China. SBS was added to the bitumen, altering the percentages by 3, 5, 7 & 9 respectively. The physical parameters of bitumen following SBS modification were assessed and compared to virgin bitumen after prepared samples had been prepared as described in the preceding chapter with standards. Performance testing was then conducted. Three performance experiments were performed on unmodified and modified asphalt mixtures: an indirect tensile strength test to assess moisture susceptibility, a resilient modulus test to assess stiffness, and a wheel tracking test to assess rutting resistance.

4.2 Bitumen Physical Properties Results

4.2.1 Results of flash and fire point and specific gravity test

As demonstrated in the table 4-1, bitumen’s properties, including its specific gravity and flash and fire points test, changed after it was treated with SBS. When bitumen was modified with SBS, we saw changes in physical properties, such as enhancement in flash & fire point of bitumen and specific gravity. This reveals that such an SBS-modified bitumen is suitable for use in hot climates.

Table 4-1:Results of Binder's Tests

Type of Test	Test Standards	SBS %				
		0%	3%	5%	7%	9%
Specific Gravity	ASTMD 7076	0.965	1	1.03	1.04	1.0 5
Flash & Fire Point (°C)	ASTM D92	233& 278	268& 289	269 & 293	273 & 295	280& 306

4.2.2 Results of BBR

Various samples are created with varying amounts of SBS in them for the Beam Bending Rheometer test. Different amounts of SBS were mixed into asphalt binder to study the impact it had on bitumen binder. There are further percentages of 3%, 5%, 7%, and 9%. The necessary quantity of basic asphalt is heated to 140°C and mixed for approximately 5 minutes. After increasing the temperature to 160°C, four percentages of SBS—3%, 5%, 7%, and 9% by weight—were gradually added to the base asphalt while being continuously stirred for two hours. This process continued until the mixture was homogeneous.

The BBR test, which can assess low-temperature stiffness and thermal cracking, was used to ascertain the low-temperature performance. To test this, three temperatures—namely, -10 °C, -16 °C, and -22 °C—were chosen. The calculation of creep stiffness uses the conventional beam theory. The formula is as follows:

$$(t) = \frac{\mathbf{PL^3}}{\mathbf{4bh^3\delta(t)}} \quad \text{...} \quad (1)$$

where:

S (t) = flexural creep stiffness at time t, MPa

P = measured test load, N

L = distance between supports, mm

b = width of the test specimen, mm

h = depth of test specimen, mm, and

$\delta(t)$ = deflection at a specific time

The heated samples were swirled to eliminate air bubbles after being combined, and they were then put into aluminum BBR molds. Grease is first applied to BBR molds to make sample removal simple. To ensure that there is an extra sample on top of the mold, the sample is overpoured. This overpouring makes sure the mold is filled. Using a heated spatula, trim the top of the specimen flush with mold after the molds had already cooled for about 45- 60 minutes at room temperature as shown in fig 4-1.

Figure 4-1:BBR molds filled with Bitumen Binder

If you want to remove a beam from a mold without damaging it, you should cool the mold for 5 to 10 minutes in an ice bucket at -5 °C. Condition beams in the BBR bath for 60 minutes at the test temperature. Combine the test beam and test supports. Start the testing system automatically. Lay the 980 mN load down and hold it in place for 240 seconds. Throughout this time, consideration is given to observations of distortion through time. removed the load and ended the test.

Set the BBR liquid bath to the appropriate test temperature before beginning the procedure. At all test temperatures, the liquid must be transparent. ethanol, methanol, and combinations of glycol and methanol are examples of acceptable liquids. To prevent the modified asphalt beam from floating, heat the long-term aged (PAV) asphalt binder until it is liquid enough to pour; the liquid's specific gravity must be less than 0.0655 lb./ft3 (or 1.05 kg/m3).

To guarantee homogeneity, the sample should be heated, covered, and occasionally stirred. Pour the heated sample into the two molds of metal BBR, being careful to overpour so that there is an extra sample all along the top of the mold, and then stir to remove air bubbles.

Let the molds cool completely from 45 to about 60 minutes at room temperature before using a heated spatula to cut the sample top flush with the mold If you wish to remove a beam from a mold without damaging it, you should cool the mold for 5 to 10 minutes in an ice bucket at -5 °C. Condition beams in the BBR bath for about 60 minutes at the test temperature. BBR beams are shown in fig 4-2.

Figure 4-2:Beams of BBR

Placing the test beam on the test supports and manually applying a contact load of about 0.008 lb. (35 mN) within no more than 10 seconds will during the test, make sure the loading head and the beam are still connected. Set the system for automated calibration to operate. For one second, this program delivers a sitting load of 980 mN (0.22 lb). The beam is then given 20 seconds to recuperate while the seating load is decreased to 0.008 pounds (35 mN). The test load of 0.22 pounds (980 mN) is then applied, and the load is maintained for about 240 seconds. During this time, record the readings of the deflection over time. To finish the test, remove the test load.

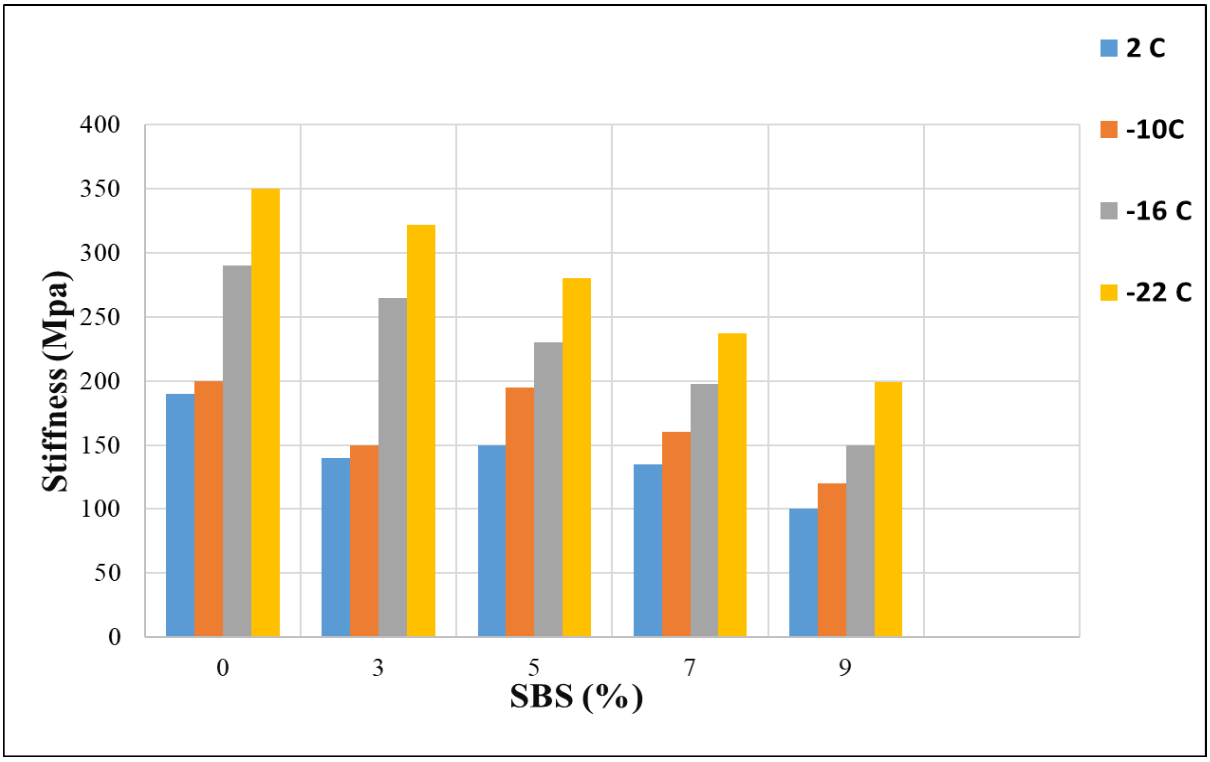

Figure 4-3:Figure Stiffness vs SBS content at different temperatures

To look at how the strength of the asphalt binder changed in response to low-temperature cracking, SBS was added to it in percentages of 3, 5, 7, and 9. To investigate the alteration in performance grade temperature ranges with the inclusion of SBS as a modifier, there were four different temperatures used for the tests. The study found that the asphalt binder's stiffness continued to decrease as modifier content was added.

The results are represented in the figure 4-3, which demonstrates how stiffness changes when SBS content changes at each of the four temperatures. The decrease in stiffness demonstrates that the amount of SBS applied to the asphalt binder as the modifier boosts the strength of the asphalt binder against the low-temperature cracking.

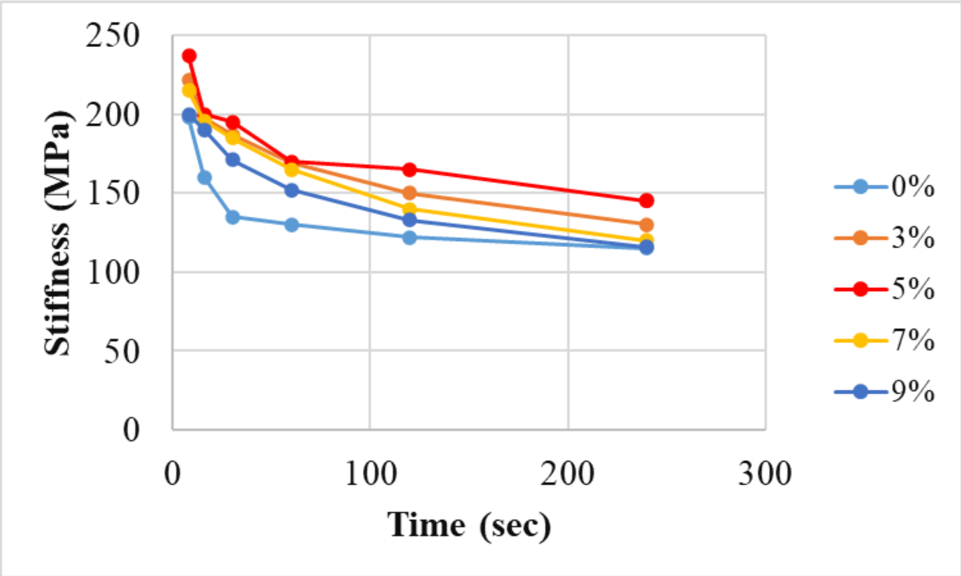

Figure 4-4:Figure Stiffness of unmodified and modified asphalt binder & Time

The figure 4-4 depicts how the modified asphalt binder's stiffness behavior changed during the test.

4.2.3 Results of Viscosity Test

To conduct studies by ASTM criteria, samples for binders are prepared for the SBS content (3%, 5%, 7%, and 9%). To ensure consistent particle dispersion, a fraction of SBS is added to a mixer after the asphalt had been heated to 160°C until it had completely mixed. The rotational viscometer is then used to measure the impact on viscosity.

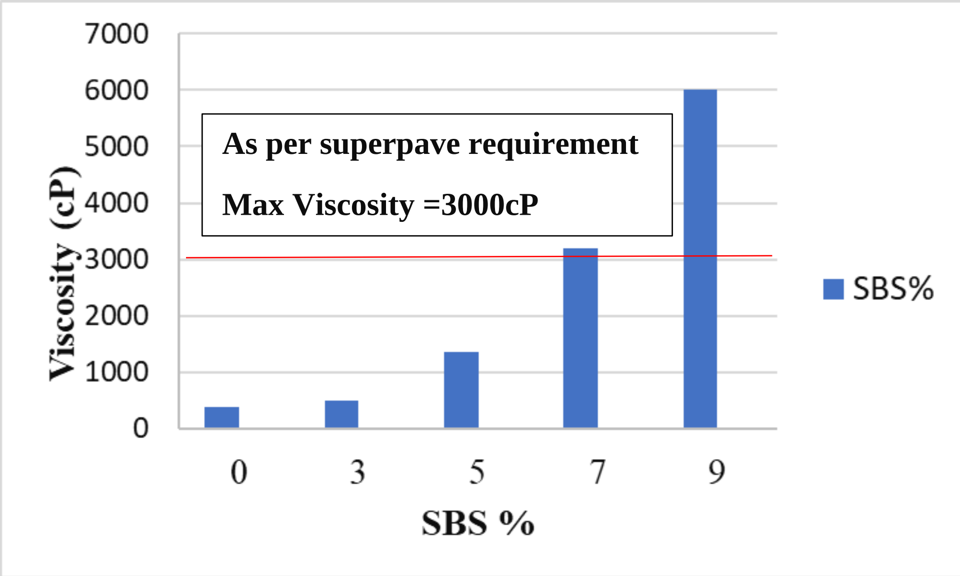

Figure 4-5:Modified Asphalt Binder's Viscosity

The figure 4-5 illustrates the modified asphalt binder's viscosity at 135°C as a measure of SBS content. As the SBS concentration rose from 0% to 9%, the viscosity increased. This is so that when SBS is added SBS absorbs the bitumen's oily part which results in the expansion of the polymer (about eight times the original volume). The swollen polymer eventually begins to disintegrate into the bitumen. The production system and the usage of additives can have an impact on this physical process, which takes time. At 6.8% SBS, it was observed that SBS had a viscosity of 3000 cP. By Superpave requirements, SBS contents above certain values could not be adequate for good workability due to rigidity.

4.3 Results of Aggregates

In this research, the Babozai quarry was used. Our numbers fall within the usual range, according to the findings of standard tests on aggregates, and this aggregate is suitable for usage. The table 4-2 provides a summary of the tests performed on aggregates.

Table 4-2:Properties of Aggregate

Elongation Index (EI)		ASTM D 4791	3.2%	< 15%
Flakiness Index (FI)		ASTM D 4791	10.6%	< 15%
Aggregate Absorption	Fine	ASTM C 127	2.28%	< 3%
	Coarse		0.61%	< 3%
Impact Value		BS 812	15.12 %	< 30%
Los Angles Abrasion		ASTM C 131	21.15%	<30%
Specific Gravity	Fine	ASTMC128	2.55	-
	Coarse	ASTM 127	2.63	-

4.4 Results of Asphalt Concrete Tests

4.4.1 Indirect Tensile Strength Test

According to ASTM D 6931-07, the test of indirect tensile strength evaluates the tensile characteristics of compacted concrete mixtures. The tensile strength of conditioned versus unconditioned samples measure moisture susceptibility. ALDOT 361 was used to condition the samples, which were then submerged for 24 hours at 60 °C in a water bath. Two Marshall samples of each percent of SBS—3 percent, 5 percent, 7 percent, and 9 percent—are compared to the usual mix before tensile strength testing (without a modifier). Both with and without moist conditioning, specimens were evaluated. The samples were tested on a UTM (universal testing machine) with monotonic loading with a diameter of 100 mm and a d thickness of 62.5 mm. Samples were conditioned once more. for one hour at 25^{o}C in UTM after being conditioned for 24 hours at 60^{o}C. The conditioned strength values for the tested combinations are summarized in Table 4-3.

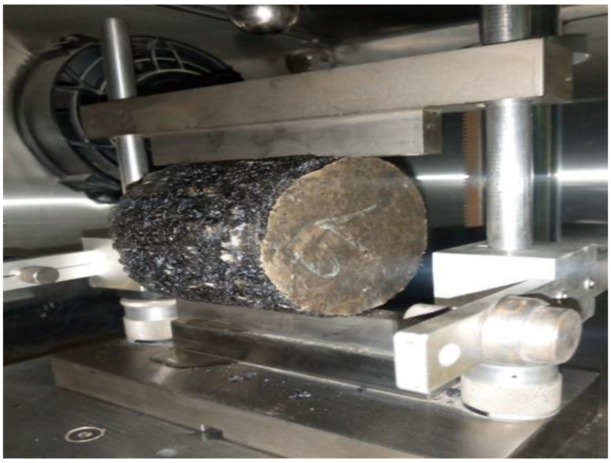

Figure 4-6:Diagram of Moisture Susceptibility Test

The monotonic loading schematic representation utilized for the TSR test is shown in the Figures 4-6.

Table 4-3Representing Strength of Conditioned and Unconditioned Samples

Description SBS (%)	**Average Un-conditioned Strength (S1) kN**	**Average Conditioned Strength (S2) kN**	**TSR = S2/S1 (%)**
0	5.210	4.32	82
3	5.258	4.41	83
5	5.358	4.906	92
7	5.279	4.570	87
9	5.207	3.640	70

For moisture susceptibility, the usual mix is ineligible. SBS generally makes materials more resistant to moisture. A comparison of the strengths of unmodified and modified mixes containing SBS with and without conditions is shown in fig 4-7. The results show that a 5 percent dose of SBS has performed better than all other ratios. SBS presence has enhanced the moisture susceptibility resistance of mixes, nevertheless.

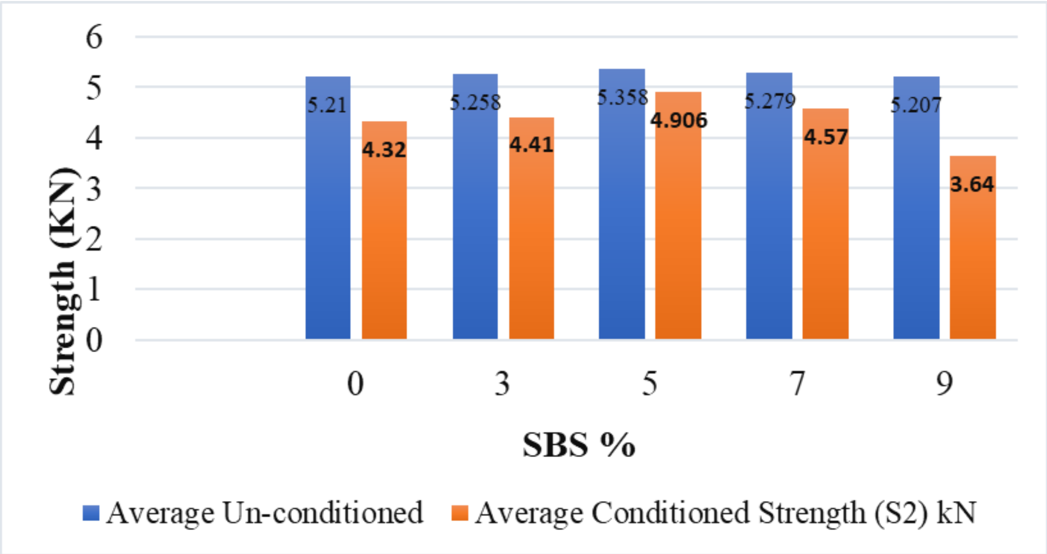

Figure 4-7: Tensile Strength Value for Specimens

The tensile strength ratio is shown in Figure 4-8. According to the results, 5 percent SBS performs the best, increasing TSR over the control mix.

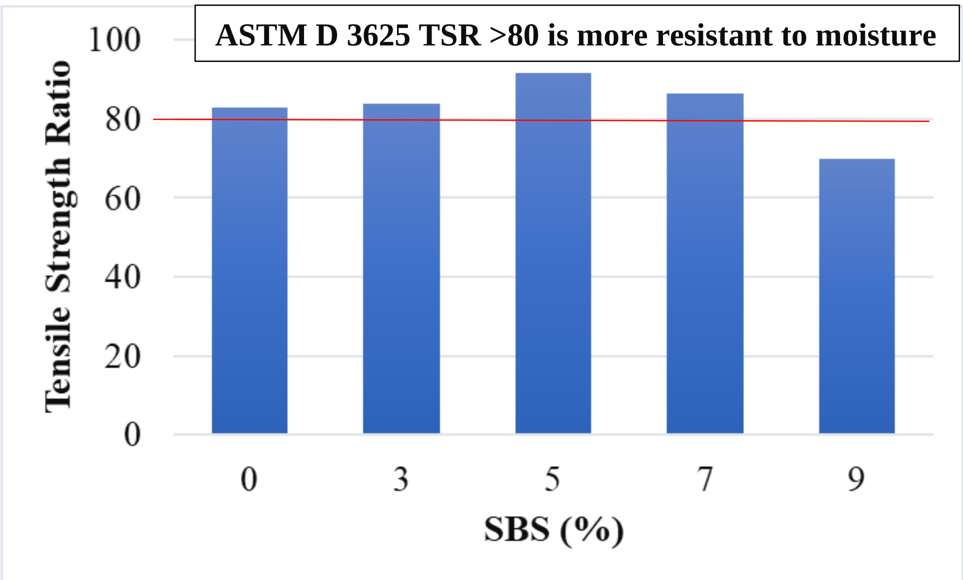

Figure 4-8: Tensile Strength Ratio of Specimen

4.4.2 Statistical Techniques

The analysis of variance (ANOVA)-based statistical comparisons were carried out to assess the project's goals. Each of the aggregate-asphalt binder combinations was subjected to a one-way ANOVA. With the aid of the program Minitab, statistical calculations were carried out to analyze the data. One-way ANOVA was used to examine the influence of different percentages of SBS on moisture susceptibility and stiffness-related properties of modified asphalt mixtures. ANOVA revealed that modified samples differed from unmodified samples. Tukey’s analysis was conducted to examine the significance of ANOVA results. Moisture susceptibility values were taken as a dependent variable.

Method of equal variances was assumed for the analysis. Null Hypothesis (H0) where the means are assumed equal. Alternative Hypothesis (Ha) where not all means are equal and Significance level ($\alpha = 0.05$)

4.4.2.1 Tukey’s analysis of Tensile Strength Ratio

To examine the varying percentages of SBS on moisture susceptibility of SBS-modified asphalt mixtures way ANOVA was conducted. An analysis of variance was performed to see whether the tensile strength ratio of SBS-modified samples differed from corresponding unmodified samples. The table 4-4 displays the results of the ANOVA test. The p-value smaller than 0.05 which means that the null hypothesis should be rejected and the alternative hypothesis that all means are not equal should be accepted. So, the results of ANOVA showed that the SBS as a modifier has a significant influence on the TSR values.

Table 4-4: Results of ANOVA analysis: SBS% VS TSR values

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SBS%	4	1221.24	305.309	61.37	0.000
Error	10	49.75	4.975		
Total	14	1270.99			

4.4.2.2 Tukey Simultaneous Tests for Differences of Means

All possible pairwise differences in means are accounted for using Tukey's method at the same time. Observations are unaffected by each other inside and within groups. A considerable difference in means occurs when an interval does not include a value of 0. From the Table 4-5 it is evident that each interval does not share the same letter, so they are statically different from each other.

Table 4-5: Grouping Information Using the Tukey Method and 95% Confidence

SBS%	N	Mean	Grouping	
5	3	91.5640	A	
7	3	86.613	A	
3	3	72.04		B
0	3	71.06		B
9	3	69.906		B

ANOVA and Tukey's test demonstrates that when SBS is added as a modifier, the tensile strength ratios are affected. As compared to virgin samples, SBS-modified sample exhibit much greater moisture resistance. Tukey's test is applied to all pairwise comparison. The table 4-6 shows the results of Tukey's analysis that is conducted for TSR values. From the table, it can be observed that p-values greater than 0.05 were not different statistically.

However, means of other values are statistically different which are depicted by p-value less than 0.05.

Table 4-6: Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
3 – 0	0.98	1.82	(-5.00, 6.97)	0.54	0.981
5 – 0	20.51	1.82	(14.52, 26.49)	11.26	0.000
7 – 0	15.55	1.82	(9.57, 21.54)	8.54	0.000
9 – 0	-1.15	1.82	(-7.14, 4.84)	-0.63	0.966
5 – 3	19.52	1.82	(13.53, 25.51)	10.72	0.000
7 – 3	14.57	1.82	(8.58, 20.56)	8.00	0.000
9 – 3	-2.14	1.82	(-8.12, 3.85)	-1.17	0.766
7 – 5	-4.95	1.82	(-10.94, 1.04)	-2.72	0.120
9 – 5	-21.66	1.82	(-27.65, -15.67)	-11.89	0.000
9 – 7	-16.71	1.82	(-22.70, -10.72)	-9.17	0.000

While conducting any experiment significance is a random variable that is specified in the experiments sample space and may range from 0 to 1. According to Tukey's test the balanced data as ANOVA is used to calculate Tukey's statistics. The multiple of the estimated standard deviation is the sole factor that cause a difference between confidence limits derived from simultaneous comparison and those derived from single comparison.

Figure 4-9 shows that only one interval has value of zero all others have different values that showed that the intervals are statistically distinct from each other. Therefore, it can be concluded that addition of SBS as a modifier has a great impact on the asphalt mixtures.

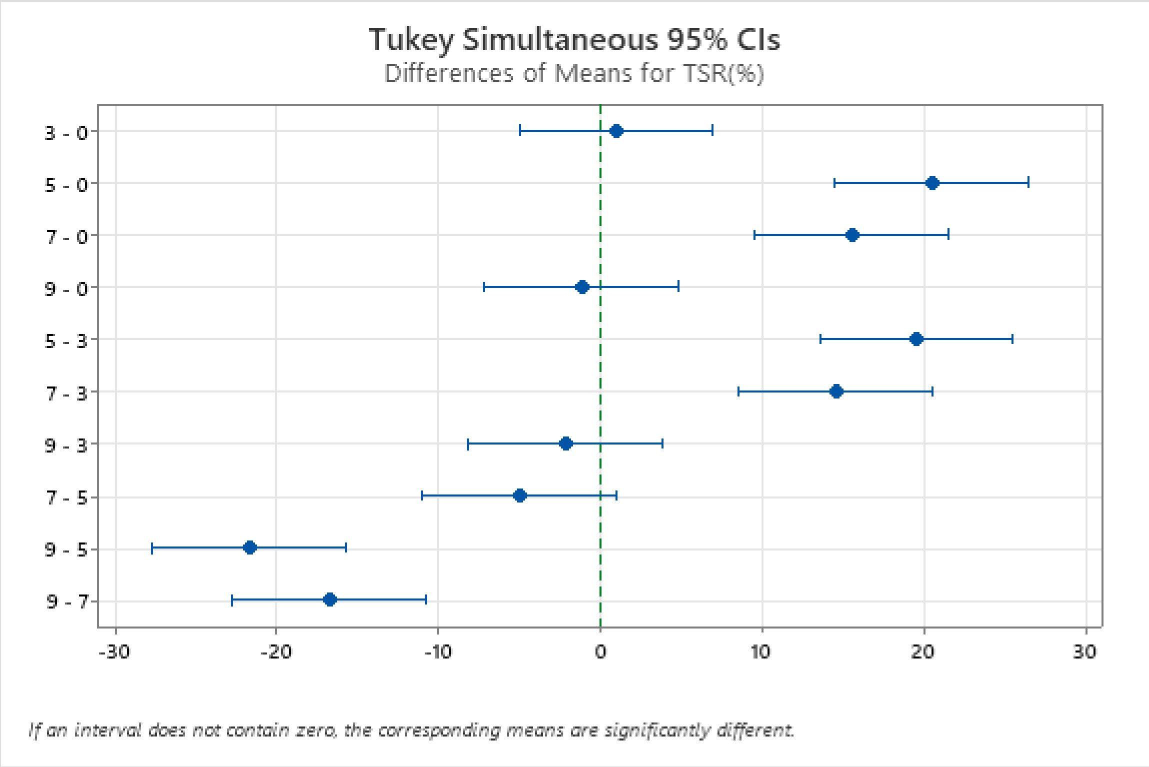

Figure 4-9:ANOVA Pairwise Tukey statistical analysis for ITS

An interval plot illustrates a confidence interval with a degree of certainty that is equal to or greater than 95% for each groups mean as shown in fig 4-10. When there are at least three observations are available for each group, interval plot functions most effectively. Generally, confidence interval was narrower and more exact when greater sample size was used for analysis.

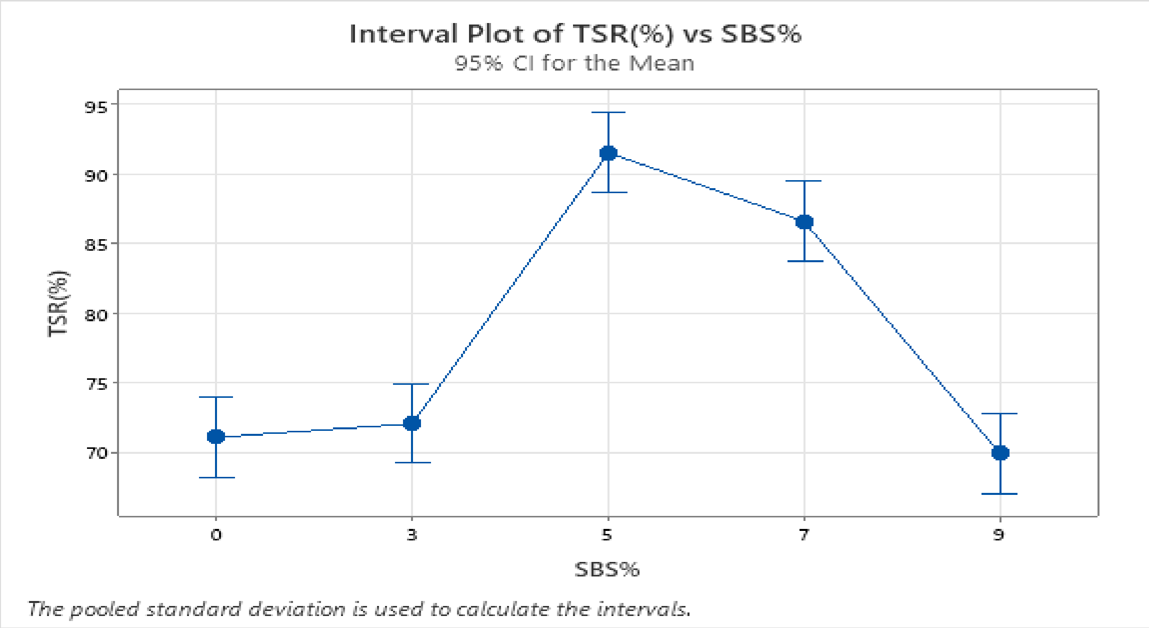

Figure 4-10:Interval plot for TSR mean values

4.4.3 Resilient Modulus (MR)

The resilient modulus values are a crucial material property input parameter for mechanistic-empirical design procedures. They can be used to analyze how the pavement structure responds to the application of traffic loads. Resilient modulus is a measure of mixture rigidity and can be defined as the ratio of load applied to the recoverable strain recorded when a specimen is exposed to cyclic stress. A non-destructive measurement can be performed in conjunction with the resilient modulus to assess the quality of the material and provide information for the design of pavement, evaluation, and analysis. Resilient modulus is reported as crucial metric used for estimating performance of the pavement and examining how the given pavement reacts to the traffic loads.

According to ASTM D 4123, 2x samples of each percentage were utilized for the robust modulus test, along with varying amounts of SBS (3%, 5%, 7%, and 9%) as a bitumen modifier. The test machine's software program determines the elasticity of each pulse of stress. Using a haversine waveform and a load applied vertically in the vertical specimen geometry plane to a cylindrical specimen with a diameter of 100 mm and thickness of 62.5 mm, the test of repetitive indirect tension test for resilient modulus is carried out.

The values of the full modulus were calculated using the applied load and the horizontal elastic deformation as shown in fig 4-11.

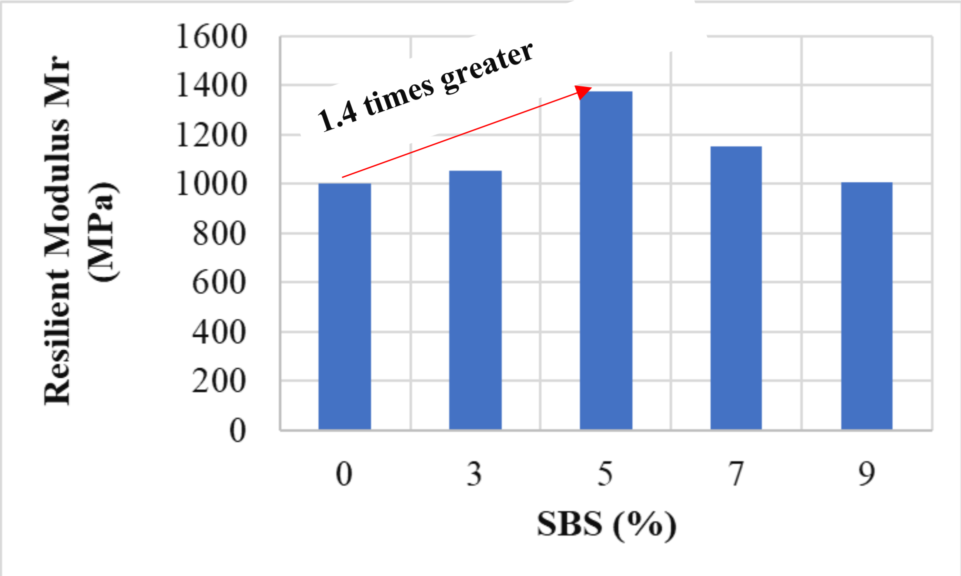

Figure 4-11:Figure: Resilient Modulus Values

4.4.4 ANNOVA

ANOVA was used to find the effect of different percentages of SBS on asphalt mixtures. The outcomes of the resilient modulus data statistical analysis are presented here. All the modified samples significantly differ from the non-additive sample, demonstrating the tremendous impact that additives have on asphalt mixtures. The result of the significant increase in this polymer mixture's modulus as opposed to comparable samples is also shown by a graph showing significant relationships between all samples and the 5% sample. Because their p-value is less than the 0.05 and their F value is larger than the 10, the variable correlations also have a big impact.

Table 4-7: Results of ANOVA analysis: SBS% VS Resilient Modulus

Source	DF	Adj SS	Adj MS	F-Value	P-Value
SBS %	4	291997	72999.3	5586.68	0.000
Error	10	131	13.1		
Total	14	292128			

For the performance of this analysis, it was assumed that variances were equal. The results are stated in the table 4-7 which are describing that modifier has a significant influence on the resilient modulus values as depicted by p value of 0.

Table 4-8: Means of samples with different percentages of SBS

SBS %	N	Mean	St Dev	95% CI
0	3	1000.00	1.00	(995.35, 1004.65)
3	3	1051.67	2.52	(1047.02, 1056.32)
5	3	1373.00	3.46	(1368.35, 1377.65)
7	3	1153.00	2.65	(1148.35, 1157.65)
9	3	1005.00	6.24	(1000.35, 1009.65)

Table 4-8 shows the mean of Resilient Modulus, Standard Deviation of all possible differences of mean by using Tukey’s pairwise analysis.

Table 4-9: Grouping Information Using the Tukey Method and 95% Confidence

SBS %	N	Mean	Grouping			
5	3	1373.00	A			
7	3	1153.00		B		
3	3	1051.67			C	
9	3	1005.00				D
0	3	1000.00				D

Means that do not share a letter are significantly different. Table 4-9 shows that all the intervals are significantly different because they are not sharing same letter.

4.4.4.1 ANOVA Pairwise Tukey statistical analysis for Mr.

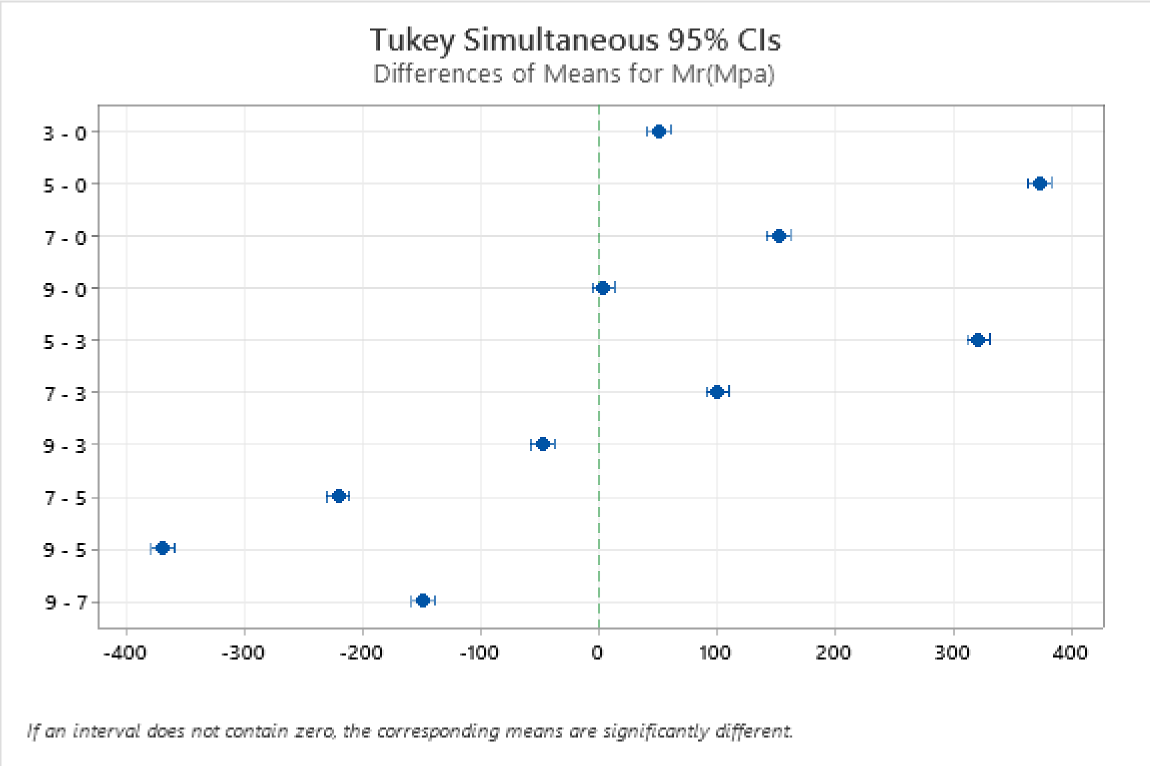

Figure 4-12:Tukey's pairwise analysis of resilient modulus

It can be seen from the figure 4-12 that there are significantly different means for all intervals. It can be summarized that resilient modulus is affected by SBS modifications

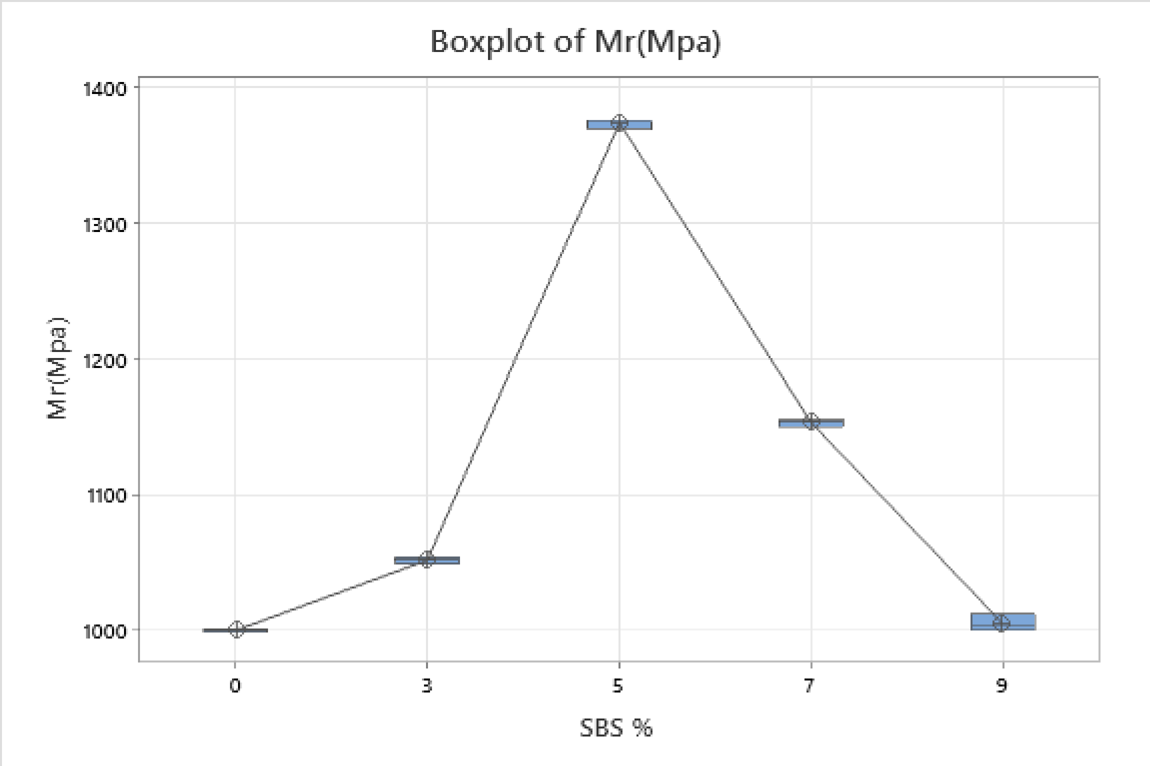

Figure 4-13:Boxplot of Mr and SBS%

Therefore, it can be concluded from the ANOVA and Tukey test that SBS as a modifier has a significant effect on asphalt samples. Fig 4-13 is also showing that 5% SBS has more significant values.

4.4.5 Wheel Tracking Test

To compare the outcomes mixtures of the asphalt with those of virgin asphalt, specimens made from SBS modified specimens and virgin asphalt mixture ARL 60/70 grade bitumen is manufactured. After these samples were being compacted by using a Superpave gyratory Compactor, samples undergo the Wheel Tracker Test.

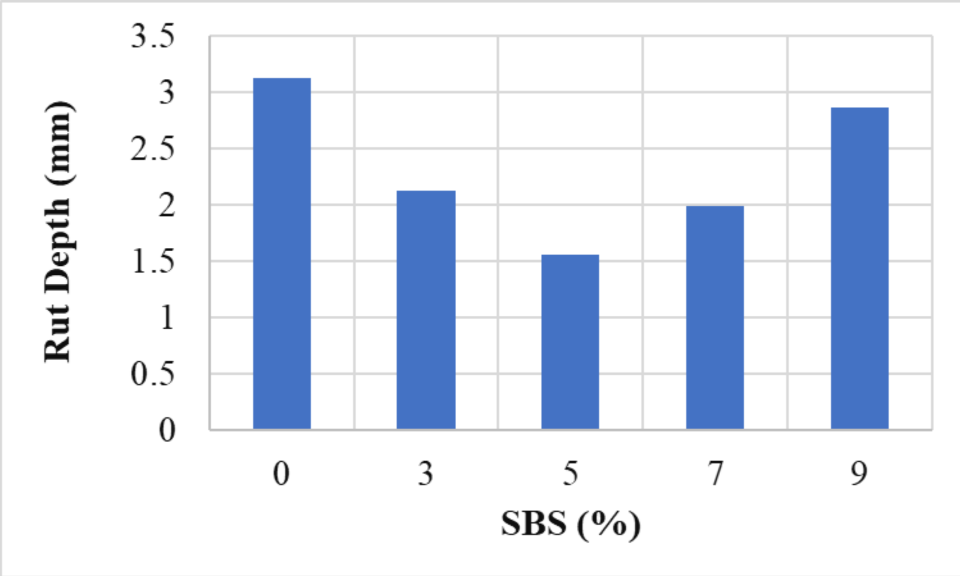

Figure 4-14:SBS % Vs RUT DEPTH (ARL 60/70)

The rut depths in mm are represented as a response to the number of passes in Fig 4-14, which shows the outcomes of the rutting test.

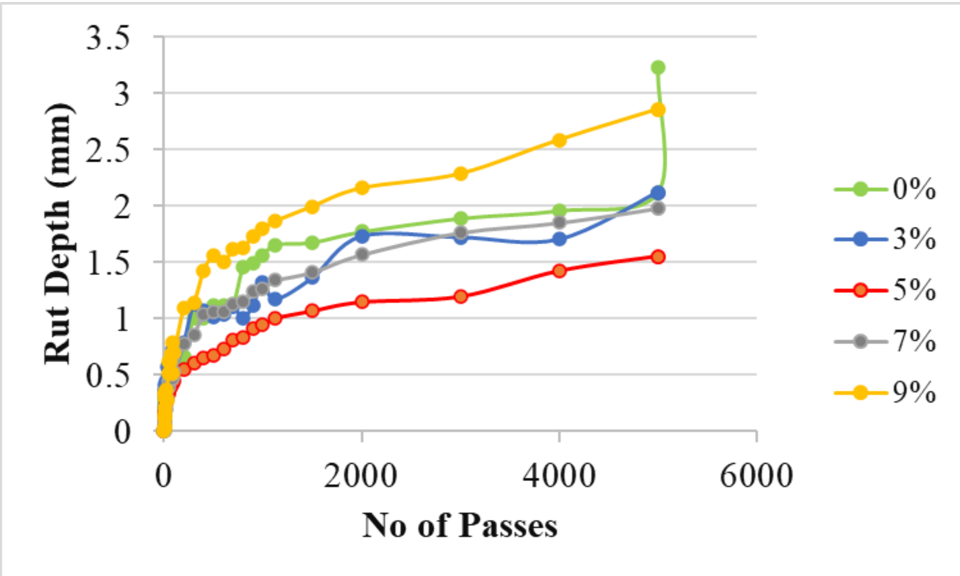

Figure 4-15:Rut Depth Vs No. of Passes

The results show that temperature and moisture have a substantial impact on the rutting properties of HMA. Rutting is shown to occur most frequently in mixes made with ARL 60/70 bitumen binder. Shoving and pushing are the principal causes of rutting in unaltered mixes by the wheels at high temperatures. When a combination is modified with SBS, the resistance of rutting of the mixture is significantly increased and decreases as the SBS % rises. SBS modifications are introduced Although the rutting resistance was improved, the increase is only slight as the percent of modifier content is raised above 5%. The fig 4-15 indicates that the inclusion of an SBS modifier results in a noticeable improvement in rutting resistance.

4.4.6 Multi Expression Programming (MEP) using Artificial Intelligence (AI)

A method of genetic programming known as MEP uses a chromosome in a linear fashion. MEPs are collections of genes that encode extremely sophisticated computer programs. Expressions encoded by MEP specialists are shown in a manner akin to how C or Pascal phrases are converted into machine code by compilers. One aspect of MEP is to store several answers to an issue in a single nucleotide. It's common to choose the best solution for a fitness assignment. when dealing with problems involving categorization or symbolic regression. The expressions stored in an MEP individual include evaluated with just one chromosomal parsing. Offspring from mutation and crossover are always MEP people with the correct syntax (computer programs). Therefore, there is no need for additional processing to repair recently acquired individuals. Modern machine learning methods and MEP must be used to estimate the rutting at various no of passes and the SBS content if the construction industry is to accelerate the usage of SBS. Several equations (chromosomes) can be contained in one program because of the MEP's special encoding property. The best of the selected chromosomes are chosen as the last recurrence of the issue. Unlike other machine learning methods, MEP does not require knowing the solution equation beforehand. The final phrase is examined for and corrected if there are any mathematical errors after the MEP has evolved. Comparing MEP comparable soft computing systems, the decoding procedure is simple. Even though MEP has several important advantages over many other algorithms, its application to civil engineering is limited.

Table 4-10: MEP hyper-parameter for SBS modified HMA

MEP hyper-parameter	SBS Modified HMA
Subpopulations Number	2
Subpopulation Size	100
Code Length	50
Cross Over Probability	0.9
Mutation Probability	0.01
Cross Over Type	Uniform
Number Generations	500
Total runs	10

MEP is helpful in material engineering situations since the uncertainty in the target equation isn't immediately obvious, as in situations where a little modification to an asphalt pavement variable could have a big impact on Hot Mix Asphalt rutting performance. A linear fashion chromosome in MEP has more solutions, letting the software try to guess with greater accuracy by taking a wider variety of potential locations into account. For the SBS Modified HMA, we used a subpopulation size of 500 to begin the MEP modeling. The chosen hyper-parameters for the MEP modeling are listed in Table 4-10.

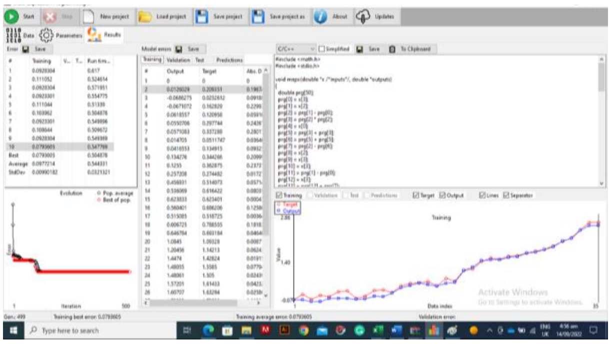

Figure 4-16:Performance of MEPX Modeling

$R = 2(S7\%) + C - (S5\%)2 + 4(S5\%)^3 + 4(S5\%) * (S7\%)^2 - 12(S5\%)^2 * (S7\%) + (S5\%) * (S7\%) - 4(S7\%)^3 + 8(S5\%) * (S7\%)^2 - S5\%$ 4.1

R= Rut Depth, C= No of wheel cycles, and S= SBS

To construct a simple equation, The fundamental operations of (multiplication, division, addition, and subtraction) were considered. Before the process is complete, the model's accuracy will depend upon the number of generations were utilized to create it. A program with more generations would produce better outcomes with fewer mistakes. Out of a variety of combinations, the one that generated the best results was chosen. On the other hand, this study postulates that 500 generations signify the point at which change stops or when the fitness function's variation starts to be less than 5%. Equation 4.1 refers to the Final MEP model for calculating the rut depth of SBS Modified HMA. MEP model validation for SBS modified HMA R^2 is 99.18 percent in Figure 4-17.

4.4.7 Limitations

It is applicable to only 5000-wheel passes and specifically mentioned SBS percentages.

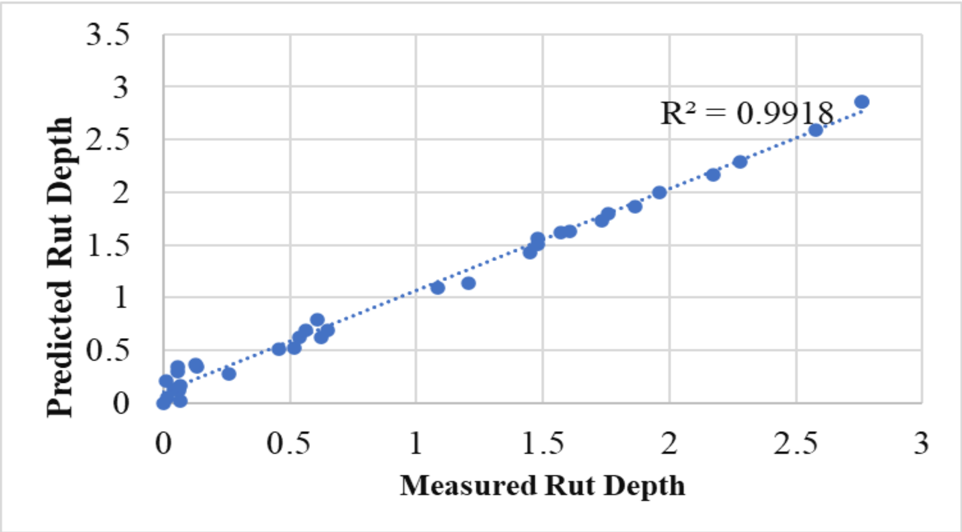

Figure 0-17:Graph Between Predicted Rut Depth and Measured Rut Depth

Chapter 5

Conclusions and Recommendations

5.1 Introduction

The principal goals of this research were to characterize the properties of the mixes of modified and unmodified asphalt. The unmodified mixtures used in this study were primarily composed of aggregate obtained from Babuzai and bitumen of the penetration grade of 60/70 are obtained from ARL. Modified mixtures were composed of Babuzai aggregate and bitumen penetration grade 60/70 obtained from ARL and SBS was imported from China's Shijiazhuang Tuya Technology Co. Bitumen was modified by the addition of SBS with varying percentages of 3%, 5%, 7%, and 9%. Following the standard sample preparation described in earlier chapters, both conventional and performance testing was carried out. The performance tests which were conducted are Indirect Tensile Strength Test for determining Moisture Susceptibility, Resilient Modulus test to determine Stiffness, and Wheel Tracking Test to measure the rutting resistance of modified and unmodified asphalt concrete mixtures. Moreover, Rotational Viscosity is conducted to determine the change in viscosity with the addition of different percentages of SBS, and a BBR (Bending Beam Rheometer) is performed to determine the stiffness of creep and low temperature cracking performance of SBS.

5.2 Conclusions

To determine viscosity, stiffness, and the low temperature cracking resistance, samples of unmodified and SBS-modified bitumen binders are examined. Strength, moisture susceptibility, stiffness, and resistance to rutting were evaluated for SBS-modified asphalt concrete mixtures. The following conclusions can be derived because of various laboratory tests:

- When bitumen was modified with SBS, we saw changes in physical properties, such as enhancement in flash & fire point of bitumen and specific gravity. This indicates that this SBS-modified bitumen can easily be used in hot areas.
- In this study, a BBR (bending beam rheometer) test was performed at the low temperatures to access the asphalt binder's stiffness properties. The stiffness property of the asphalt binder was decreased when SBS was added as a modifier.
- SBS is added to asphalt binders to decrease the creep stiffness related to low cracking. The quantity of flexural creep stiffness decreases when more SBS is added (as a modifier) to the asphalt binder. The ability of the asphalt binder to withstand flexural stresses and to relax the asphalt after the stresses have been removed allows it to resist creep failure at low temperatures. Therefore, the decreasing trend of flexural creep stiffness has been observed after the inclusion of SBS content.
- SBS is added in the following four ratios: 3%, 5%, 7%, and 9%. The test is performed at four different temperatures: (2, -10, -16, and -22) ° C.
- The incorporation of SBS content raises the binder's viscosity. All percentages between 3% and 9% show an increasing trend. Compared to the original asphalt, the viscosity was improved by the addition of SBS.
- This is due to the reason when introduced to bitumen, a suitable elastomer (for instance, SBS) absorbs the bitumen's oily component, resulting in the swelling of polymer (which is about eight times the original volume).
- Viscosities demonstrated the stiffening effects of SBS modification at high additive content. It was discovered that SBS, at up to 7% addition, attained a viscosity of 3000 cP. So, adding 5% resulted in the best outcomes.
- After testing in dry (unsaturated) mode, Samples were tested in saturated mode. the tensile strength ratio (TSR) is the strength ratio of saturated to dry (unsaturated)

samples. Based on findings of the indirect tensile strength test's, mixtures containing 5% SBS polymer had the highest ratio of indirect tensile strength and the moisture resistance.

- ❖ The results of the tests were finalized using the mean values. Results showed that SBS addition increased the mixture's resilient modulus. The resilient modulus values showed an increasing trend as the SBS content increased. According to the research, SBS has a significant favorable impact on resilient modulus in SBS modified Mixtures compared to virgin specimens, with 5% of the modifications having the highest resilient modulus.
- ❖ Rutting in the modified asphalt is reduced overall and rut resistance is improved with the addition of SBS content. The modified specimens are less sensitive to rutting than virgin samples, according to the results of the Hamburg wheel tracker test. However, the amended asphalt that included 5% SBS demonstrated significantly better resilience. This shows that the amount of SBS added to the virgin asphalt cement was revealed to affect the modified asphalt's resistance to rutting.

5.3 Recommendations

In consideration of the conclusions mentioned previously it is recommended that

5% SBS content is suggested for improved strength, stiffness, resistance, and moisture susceptibility to rutting and cracking.

- ❖ It is recommended to utilize modified bitumen because it is more favorable.
- ❖ SBS should be checked for high-temperature performance by using DSR.
- ❖ The long-term performance of pavement (after 20 years) should be checked by RTFO and PAV.

- There should be a practical application of SBS-modified asphalt concrete on a trial section.
- Life cycle cost analysis should be carried out to check the cost-effectiveness of SBS-modified asphalt.

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