Crumb Rubber and Epoxy Modified Bitumen For Flexible Pavement

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LIST OF ACRONYMS

CRMA	-	Crumb Rubber Modified Asphalt
CR	-	Crumb Rubber
M_R	-	Resilient Modulus
TSR	-	Tensile Strength Ratio
UTM	-	Universal Testing Machine
HMA	-	Hot Mix Asphalt
VMA	-	Voids in Mineral Aggregate
VFA	-	Voids Filled with Aggregate
BS	-	British Standards
OBC	-	Optimum Bitumen Content
AASHTO	-	American Association of State Highway and Transportation
ASTM	-	American Standard Test Method
JMF	-	Job Mix Formula
PG	-	Performance Grade
AC	-	Asphalt Concrete
ITS	-	Indirect Tensile Strength
NHA	-	National Highway Authority

ABSTRACT

The Crumb Rubber Modified Asphalt (CRMA) presents several advantages, such as improved resistance to rutting and reflective cracking. However, its broader application is limited due to various significant concerns. These include the poor solubility of Crumb Rubber (CR) in asphalt, heightened viscosity with increased incorporation, and inadequate storage stability. To address these challenges, a hybrid methodology was embraced in this investigation, integrating Epoxy into CRMA. This approach aimed to strike a balance between stiffness and fluidity while optimizing the utilization of Epoxy and CR to diminish the reliance on base bitumen by maximizing waste material integration. Through laboratory-based experimentation, the modified asphalt mixtures' resilient modulus (M_R) and Tensile Strength Ratio (TSR) were assessed. Adding epoxy to asphalt along with crumb rubber can enhance its effectiveness. Epoxy's adhesive properties are well-known for improving bonding between materials. When introduced to asphalt, it can facilitate better binding of crumb rubber particles, resulting in overall performance enhancement of the modified asphalt mixture. Furthermore, the consolidation of Epoxy and Crumb Rubber resulted in a significant increase in resilient modulus and an enhancement in moisture resistance compared to control mixtures. However, excessive modifier dosages led to decreased resilient modulus and moisture resistance.

Keywords: *Crumb Rubber Modified Asphalt (CRMA), Crumb Rubber (CR), Resilient modulus (M_R), Tensile Strength Ratio (TSR).*

CHAPTER 1: INTRODUCTION

1.1 Background Study

Pakistan is undergoing rapid urbanization, with a considerable proportion of its population relocating to urban areas. Currently, approximately 35% of Pakistanis reside in urban areas, and this trend mirrors similar patterns across South Asia. Meanwhile, the United States is also witnessing a surge in urban living, with projections indicating that nearly half of its population will be urbanized by 2025.

However, despite this urban shift, Pakistan faces challenges in maintaining and expanding its roadway infrastructure due to budgetary constraints. The government allocates only about 2% of its GDP for road development, leading to concerns about meeting the nation's infrastructure needs. This deficit could jeopardize Pakistan's ambitious plans to invest $125 billion in road construction between 2016 and 2040, exceeding the country's outstanding foreign debts.

To address these challenges, it is essential to adopt sustainable and cost-effective approaches to road construction and maintenance. Asphalt reclamation and recycling have emerged as viable solutions, offering both economic and environmental benefits. Over the past 25 years, advancements in asphalt recycling technology have made significant strides, making it an increasingly preferred method for repairing aging pavements.

By reclaiming and recycling asphalt, governments can not only reduce costs but also minimize energy consumption and environmental impact compared to traditional pavement restoration methods. However, it's crucial to exercise caution and select suitable roads for recycling, as not all pavements are suitable candidates.

Moreover, as urbanization intensifies, the demand for efficient transportation networks becomes paramount. Highways play a crucial role in facilitating passenger and freight movement, comprising a significant portion of the transportation infrastructure in Pakistan. Therefore, it's imperative to employ effective preservation techniques to prolong the lifespan of roads, reduce maintenance costs, and ensure reliable transportation for the public.

Asphalt concrete remains the most commonly used paving material globally, and enhancing its durability is vital for long-term road performance. Various modifiers, such as crumb rubber, have been explored to improve asphalt properties, including rutting resistance and flexibility, while mitigating environmental concerns. Integrating crumb rubber into asphalt mixes not only enhances performance but also offers a sustainable solution for managing discarded tires.

In conclusion, Pakistan must prioritize investment in sustainable infrastructure development to meet the challenges of urbanization and economic growth. Asphalt reclamation, recycling, and innovative pavement preservation techniques offer promising avenues to achieve efficient and cost-effective roadway systems while minimizing environmental impact.

1.2 Problem Statement

The problem with regular roads is that they can get messed up from lots of cars driving on them, bad weather, and other things like that. This causes things like potholes, cracks, and bumps, which can be dangerous and make the road hard to use. Plus, fixing and keeping these roads nice can cost a lot of money and take a long time, especially in places with tough terrain or harsh weather.

Because of this, some places might not have good roads, making it hard for people to get around and for businesses to grow. Also, the materials used to make regular roads, like asphalt and concrete, aren't always good for the environment. Making them takes a lot of energy and resources and transporting them to where they're needed adds even more pollution.

With concerns growing about climate change and protecting the environment, there's a need for new, eco-friendly ways to build and maintain roads. This problem is complicated, and fixing it requires a plan that looks at everything from making roads strong and safe to keeping costs down and being kind to the environment.

To make bitumen better, people have been mixing it with different kinds of waste, like crumb rubber from old tires. When you add crumb rubber to bitumen, it makes the bitumen harder to melt and thicker. This means it won't get soft as easily in hot weather or spread out too much. Also, when you mix rubber into asphalt, it can make the roads stronger and better at resisting bumps and cracks, especially when it's cold.

But, using crumb rubber in asphalt might mean you need to use more bitumen. Research shows that when you mix rubber with bitumen, the rubber doesn't completely melt into it. This can cause some issues, like the rubber separating from the bitumen over time. Some studies also suggest that epoxy, a type of glue, could be added to bitumen to make it better.

To tackle these challenges, one idea is to use crumb rubber and epoxy in asphalt. Crumb rubber is made from recycled tires, so it helps reduce waste, and epoxy makes the asphalt stronger. This could be a new and better way to make roads that are safer, last longer, and are better for the planet.

1.3 Scope

To accomplish the objectives of this study, a detailed plan was formulated, centering on critical research areas. A thorough examination of literature was undertaken regarding the treatment of Crumb Rubber and its incorporation, alongside epoxy, into base bitumen. A comprehensive research strategy was devised to fulfill the study's goals, outlined as follows:

- ❖ A thorough examination of asphalt mix design, incorporating previous studies on Crumb rubber and epoxy as modifiers for asphalt mixtures from scientific journals and technical literature.
- ❖ The utilization of consistency tests such as Penetration tests and softening point tests are employed to characterize the binder intended for use in this research.
- ❖ Performing Resilient Modulus tests and Tensile Strength Ratio (TSR) assessments to evaluate the strength, stiffness, and susceptibility to moisture of unmodified asphalt and asphalt modified with crumb rubber and epoxy, utilizing Superpave gyratory compacted HMA samples.

1.4 Objectives of The Research

The research project aims to achieve the following objectives:

I. To Evaluate the moisture susceptibility of Crumb rubber-epoxy-modified asphalt by analyzing the Tensile Strength Ratio (TSR).

II. To Assess the impact of Crumb rubber-epoxy as a modifier on stiffness by examining the Resilient Modulus (M_R) using a Universal Testing Machine (UTM).

1.5 Organization of Thesis

This thesis is structured into five separate sections:

Chapter 1 Includes an introduction, an exposition of the issue at hand, an investigation into research objectives, and an outline of the study's extent.

Chapter 2 Conducts an extensive literature review, exploring the diverse attributes of CR-Epoxy in pavement applications. This section underscores the significance of previous studies on CR-Epoxy in the realm of pavement engineering. Moreover, Chapter 2 provides a comprehensive analysis of the literature review conducted for the research.

Chapter 3 outlines the materials utilized, and the testing procedures employed, and provides background information on these tests. It elucidates the significance of the findings obtained from performance tests conducted during the research.

Chapter 4 The experimental findings are thoroughly detailed in this section, providing a comprehensive compilation of results that includes graphs, charts, tables, and all pertinent data from the experimental program. Moreover, Chapter 4 delves into the results and their interpretations.

Chapter 5 this section presents the findings and suggestions stemming from the study. While the preceding chapter discussed future research directions and how researchers could apply the findings, this chapter further investigates potential avenues for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter offers an overview of the research and theoretical aspects concerning the characteristics of asphalt binders incorporating Epoxy Resin and Crumb Rubber (CR). It discusses the impacts observed in previous studies regarding the addition of epoxy resin and CR on rheological properties and various performance parameters.

2.2 Background

The well-being of a nation's society and economy is greatly influenced by the state of its road infrastructure and the effectiveness of its maintenance. The extent of paved roads within a country is frequently considered an indicator of its level of development. Thus, investing in the upkeep and enhancement of road infrastructure is crucial. Bitumen, a key component of asphalt, has long been a staple in construction. As the world's population grows, more people are using roads for transportation. This increased usage puts strain on roads, leading to more congestion and wear. To accommodate growing populations, new roads must be built and existing ones expanded. Maintaining and improving roads becomes crucial to ensure safe and efficient travel for everyone. Additionally, population growth can worsen environmental issues like pollution, highlighting the need for sustainable transportation solutions. However, traditional road surfaces struggle to meet the demands of both current and future traffic loads. There's a pressing need for road materials that are of higher quality, safer, more reliable, and eco-friendly. Asphalt binder, affected by aging, temperature fluctuations, and elasticity, plays a vital role in road performance. With rising traffic density and heavier loads, roads have deteriorated faster in recent years due to decreased maintenance. Enhancements are needed in the properties of conventional bitumen to resist deformations, cracks, and rutting, thus prolonging the life of roads. The incorporation of epoxy can mitigate rutting and reduce pavement distress. Various modifications to bitumen can lead to improved pavement performance, ensuring safer and longer-lasting roads.

2.3 Modification of Pavement Binders

Adjustments are applied to the binder to achieve improvements in any of the following areas:

1. During the summer months, a higher viscosity or stiffness is required to prevent the formation of ruts or pushing.
2. To Prevent thermal cracking necessitates the material possessing lower stiffness and greater relaxation properties at colder temperatures.
3. To Expand the range of temperatures at which asphalt can effectively operate.
4. To adjust blends to stiffen when subjected to elevated temperatures.
5. To enhance resistance against oxidation and aging in the material.
6. Polymer modifiers enhance resistance to thermal cracking, offer resilience against permanent deformation, improve resilience to moisture damage, reduce the susceptibility of HMA to temperature changes, and bolster the tensile strength of asphalt.

2.4 Asphalt Modification Using Crumb Rubber

Crumb Rubber Modified Asphalt (CRMA) is often produced using recycled tire rubber, which is finely shredded to particles smaller than 1 mm through mechanical processes like shredding and grinding. CRMA has demonstrated effectiveness in enhancing resistance to rutting, increasing flexibility in asphalt mixes, slowing down asphalt binder aging, and reducing reflective cracking. Utilizing thinner layers of modified binder in asphalt mixes can significantly extend the lifespan of roads.

Figure 2.1: Asphalt Modification crumb rubber

2.5 Common Practices for Producing Crumb Rubber

The utilization of crumb tire rubber spans numerous applications, owing to its graded particles available in diverse sizes and shapes. The recognition and measurement of crumb rubber are determined by the meshing screen or sieve size employed throughout its manufacturing process, which comprises two distinct processes.

2.5.1 Shredding

The manufacturing process for granulated scrap tire rubber commences at a particular stage. Whether tires are sliced or left whole, they are transported to shredding plants for processing, resulting in a reduction of particle size to meet specifications. Magnets and separators are employed to eliminate steel belts and fiber reinforcement from tires in this procedure. The size of crumb rubber particles may impact the physical characteristics of a bitumen-rubber mixture, although minor discrepancies in size typically have minimal effects on the performance of the blend.

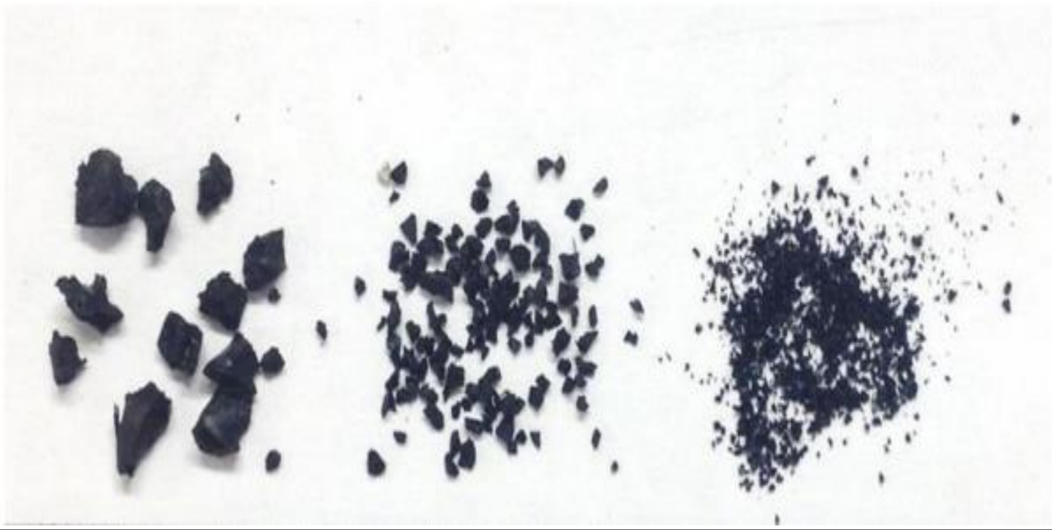

Figure 2.2: Different sizes of crumb rubber(Gheni et al., 2017)

2.5.2 Grinding and Granulation

Following the shredding of scrap tires, crumb rubber can be produced through three distinct methods. The granulator process yields a Granulated Crumb rubber modifier, characterized by uniformly shaped cubic particles. The Cracker-mill process, renowned for its flexibility, produces irregularly shaped and torn particles ranging from 4.75 mm (No. 4 sieve) to 11.42 mm (No. 40 sieve), referred to as crushed Crumb rubber modifier. Alternatively, the micro-milling technique generates an ultra-fine powdered Crumb rubber modifier.

2.6 Performance Parameters of Crumb Rubber Modified Asphalt

The addition of Crumb Rubber to asphalt brings about changes in its properties, yielding advantages such as cost reduction and enhanced pavement performance. Nevertheless, challenges like susceptibility to disintegration and high molecular weight necessitate the mechanical processing of rubber compounds. Despite the difficulty in degrading tire rubber, its utilization in asphalt has surged due to its performance benefits and environmental advantages. The research underscores the positive influence of rubber-bitumen interaction on asphalt aging, resulting in improved stiffness and rutting resistance. The use of rubberized binders shows promise in preserving asphalt quality over time. Furthermore, studies indicate that incorporating crumb rubber enhances asphalt resistance to rutting and cracking, fostering sustainable pavement development.

2.7 Problems with Crumb Rubber Modified Asphalt

Previous studies indicate crumb rubber cannot completely degrade or melt into a binder. The rate at which undissolved rubber moves through a binder depends on the rubber's radius and density difference compared to the binder. Carbon black, the primary component of undissolved rubber, has a density 1.8 to 2.1 times that of asphalt binder. De-polymerization and de-vulcanization processes release rubber components into the binder, altering its viscosity. Larger, less degraded rubber particles with higher density differences may lead to phase separation. To optimize compatibility, rubber components can form a dispersed network within the binder. Uniform dispersion of rubber across asphalt enhances its appearance and performance stability. Agglomerated rubber particles can adversely affect asphalt performance, despite potential benefits like reduced reflection cracks and noise, increased skid resistance, and prolonged pavement life. However, uneven distribution and agglomeration of rubber particles in asphalt may compromise performance reliability.

2.8 Summary of literature review

LITERATURE REVIEW

Author / Year	Test Matrix	Performance Test	Research Findings
Paravita Sri Wulandari, Daniel Tjandra, (2016) **Procedia Engineering**	1% and 2% by weight of bitumen Addition of Crum rubber to asphalt binder, no. 40 (0.42mm) and no. 80(0.177mm) size of crumb rubber used, Coarse and fine aggregates used, 60/70 grade bitumen	Marshall Stability	The additive of crumb rubber tends to increase the strength and quality of asphalt mixture, Increase stability and decrease in flow. With crumb rubber less asphalt content is needed
Luis G. Picado-Santos, Silvino D. Capitao, (2020) **Construction and Building Materials**	**CR** used with 50/70 penetration grade **12%**	Marshall Stability Test	Load stability Increases Moisture Resistant
Panos Apostolidis, Xueyan Liu, (2020) **Construction and Building Materials**	Bitumen, 70/100 penetration grade 20% and 40% epoxy used	Four-point bending stiffness and fatigue tests Indirect tensile tests	Epoxy modification level in asphalt lead to stronger and stiffer materials of improved fatigue resistance
TianlingWang, Chenguang Shi, Yunhong Yu, (2022) **Construction and Building Materials**	0%,3%,6%	Uni-axial compression test under repeated test Mix design gradation selection Dynamic creep test	DCT results reveal that addition of 6% crumb rubber will lead to excessive accumulation and increase temp. sensitivity of permanent deformation at high temp.

CHAPTER 3: METHODOLOGY

3.1 Introduction

This chapter provides an in-depth examination of the Research Methodology utilized to achieve the research objectives. Initially, essential materials for the research were gathered. The optimal bitumen content was determined through Marshall mix design, involving an analysis of volumetric attributes such as Va, VMA, VFA, Flow, and stability. Samples for performance testing were prepared using a Superpave Gyratory Compactor, and subsequently, saw cutting was conducted to facilitate tests for resilient modulus, IDT, TSR, and moisture susceptibility. Moreover, this chapter delineates the methodology for blending CR-Epoxy Resin with bitumen and evaluating the performance of the resultant mixture, as outlined in Chapter 1. The assessment of laboratory-produced samples' performance was conducted in four stages. Initially, conventional binder testing, including penetration and softening point tests, was conducted. Subsequently, IDT and MR tests were performed on Superpave Gyratory Compacted samples. Finally, unmodified Superpave gyratory samples were assessed. The aggregates originated from Kandar and Risalpur, while 60/70 bitumen was sourced from the Nowshera batching plant, and Epoxy resin was procured from China. Gyratory-compacted samples were employed to assess the performance of modified asphalt mixes. Marshall samples were created to establish the Optimum Bitumen Content (OBC), while Superpave Gyratory-compacted samples were prepared to ascertain the resilient modulus and Tensile Strength Ratio (TSR) of CR-Epoxy Resin modified samples.

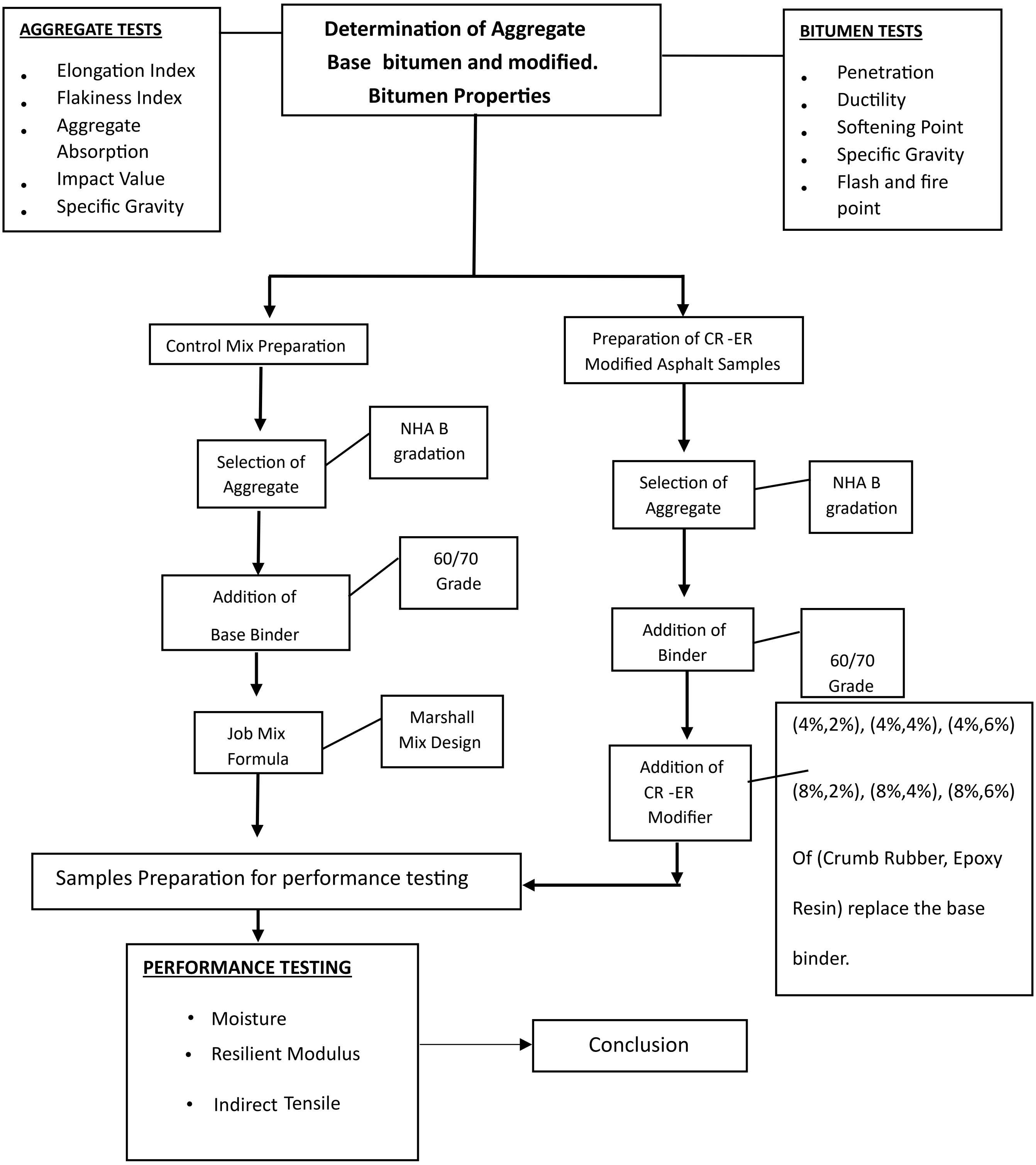

Figure 3.1: Research methodology

3.2 Aggregate Testing

The strength of asphalt mixtures is intimately linked to the characteristics of aggregates, including their strength and durability. Thus, aggregate testing forms a crucial component of determining the job mix formula. A sequence of experiments was carried out on the aggregates, including sieve analysis, aggregate gradation, the Los Angeles abrasion test, the aggregate impact value test, and specific gravity measurements for both coarse and fine aggregates. These tests were conducted to comprehensively assess the engineering properties of the aggregate samples. Key characteristics such as water absorption, specific gravity, strength, and durability were thoroughly investigated. It's worth noting that aggregate shape and texture not only influence aggregate strength but also impact various technical characteristics. Moreover, the gradation of aggregates significantly influences the characteristics of Hot Mix Asphalt (HMA).

3.2.1 Sieve Analysis and Gradation

The size, shape, texture, and grade of aggregates all play vital roles in determining the strength of asphalt mixtures. Aggregates need to possess low porosity and exhibit strength and durability. Aggregates from Kander Risalpur underwent sieving in the laboratory. Each portion retained by the sieves was carefully collected and placed into individual bags. The table below provides specifics of the gradation chosen for this study.

Table 3.1: Description of Aggregate Gradation

Sieve Designation		NHA Class-B Specification Range(% Passing)	Upper Limit	Lower Point	Our Selection (% Passing)
in	**mm**				
25	1				
19	3/4.	100	100	100	100
12.5	1/2.	75-90	75	90	82.5
9.5	3/8.	60-80	60	80	70
4.75	No.04	40-60	40	60	50
2.38	No.08	20-40	20	40	30
1.18	No.16	5-15.	5	15	10
0.075	No.200	3-8.	3	8	5.5
Pan	Pan	NIL	NIL	NIL	Pan

3.2.2 Aggregate Impact Value Test

The impact load and repetitive pounding action from traffic can cause aggregates to fracture into smaller pieces. Therefore, aggregates must possess sufficient hardness and toughness to resist fractures resulting from traffic impact loads. This test, conducted by BS 812 and IS 383 standards, aims to assess aggregate toughness. Approximately 350 grams of aggregate, passing through a 14mm screen and retained on a 10mm sieve, were selected for this test. Three layers of aggregate were arranged within the cup of the Impact testing machine, with each layer subjected to 25 tamps using a tamping rod. After compaction, the aggregates underwent impact by a 14 kg standard hammer dropped from a height of 38 cm. They were then sieved through a 2.36mm sieve to extract them from the cup. The aggregate impact value is determined by the percentage of particles passing through the 2.36mm sieve, while the percentage retained on this sieve indicates aggregate toughness.

3.2.3 Los Angeles Abrasion Test

Because heavy traffic loads can lead to disintegration, deterioration, and crushing, asphalt mixes must withstand such damage. To assess their ability to do so, aggregates undergo an LA abrasion test to gauge their toughness and durability. This test is conducted following the guidelines of AASHTO T 96-92. After subjecting the aggregate to abrasion as per the standard procedure using a specified quantity of balls, the resulting material is sieved using a number 12 sieve. The weight loss due to abrasion is then calculated, with the value required to be below 40 according to standards. The apparatus used for determining the Los Angeles abrasion value is depicted in Figure 3.2.

Figure 3.2: Los Angeles Abrasion Test Machine

3.2.4 Specific Gravity of Aggregates

The specific gravity of aggregates is determined by comparing the weight of a certain volume of aggregates to that of water at 24°C. According to ASTM C127 (2004) and American Society for Testing and Materials (2015) standards, specific gravity tests were conducted on both coarse and fine aggregates. These tests included weighing aggregates that had been oven-dried, fully submerged in water, and in a saturated surface dry condition. Likewise, tests were carried out to ascertain the specific gravity of fine aggregates and their water absorption, adhering to ASTM C 128 guidelines.

The specific gravities of coarse aggregate particles are crucial in asphalt paving mixture preparation and are utilized by engineers in planning both paved and unpaved areas. Bulk-specific gravity aids in determining both binder absorption and Voids in Mineral Aggregate (VMA). Specific gravity, also referred to as "relative density," indicates the weight-volume properties of aggregate material.

Coarse aggregates are particles that are retained on sieve No. 4 after sieving. The specific gravity and water absorption of coarse aggregate particles were determined using ASTM C127.

After passing through sieve #4, the retained aggregates were oven-dried and then submerged in water for twenty-four hours. Subsequently, the aggregates were placed on a fabric to determine their saturated weight. The aggregates' submerged weight, specific gravity, and water absorption were then determined. It's noteworthy that the oven-dried sample contains no water, whereas water may be present in the aggregate pores during the saturated surface-dry stage.

3.2.5 Aggregate Crushing Value

The apparatus used for the crushing value test comprised a steel cylinder with open ends, a base plate, a plunger equipped with a piston having a diameter of 150 mm and a hole across it for lifting through a rod, a cylindrical measure, a balance, a tamping rod, and a 28 compressive testing machine. Aggregates that passed through a 1/2-inch sieve but were retained on a 3/8-inch sieve were chosen for further processing. After thorough cleaning, oven drying, and weighing (W1), a sample of the aggregate was gradually added in three stages to a cylindrical measure, with 25 tamping actions performed on each layer. Subsequently, the sample was placed in the cylinder in three separate layers, and the plunger was inserted. The cylinder was then placed in a compression testing machine, and a load was incrementally applied at a rate of 4 tons per minute until the total load reached 40 tons. Afterward, the crushed aggregate was extracted from the steel cylinder and sifted through a 2.36mm mesh.

3.2.6 Shape Test Of Aggregate

The shape test of aggregates serves to determine the proportions of flaky and elongated particles within aggregate stockpiles. Flaky particles, in the context of aggregates, are those whose smallest diameter is less than 0.6 times the average dimension of the sample aggregates. Elongated particles, on the other hand, are aggregates with a size exceeding 1.8 times the average dimension of the sample aggregates. The flakiness and elongation indices were determined by the respective ASTM standards.

The outcomes of the aggregate tests are displayed at Table 3.2.

Table 3.2: Laboratory Test Results of Aggregate

Type of Description		Standards	Results	Specification
Fractured Particles Test		ASTM D 5821	1	90% (Min)
Aggregate impact value		BS 812	16.09%	30% (Max.)
Aggregate crushing value		BS 812	15.67%	30% (Max.)
Los Angeles Abrasion test		ASTM C 131	25.89%	45% (Max)
Flakiness Index		ASTM D 4791	7.09%	15% (Max)
Elongation Index		ASTM D 4791	2.37%	15% (Max.)
Deleterious Material Test	Coarse Aggregate	ASTM C 142	0.21%	_
	Fine Aggregate	ASTM C 142	1.30%	_
	Coarse Aggregate	ASTM C 127	2.65	_
Specific gravity	Fine Aggregate	ASTM C 128	2.56	_
	Mineral Filler	ASTM C 128	2.43	_
Aggregate water absorption	Coarse Aggregate	ASTM C 127	0.82%	3% (Max.)
	Fine Aggregate	ASTM C 128	1.76%	3% (Max.)

3.3 Bitumen characterization

To ensure the effectiveness of a binder, it must exhibit consistency, safety, and purity. Temperature fluctuations can impact the consistency of asphalt binder, thus it's essential to compare binder consistency at a constant temperature. The penetration test is commonly employed to assess bitumen consistency. Consequently, various laboratory experiments were conducted to further characterize asphalt binders.

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

3.3.1 Softening Point Test

First, Prepare the sample for the test. Such that the specific amount of the bitumen is taken and heated to a temperature of about 130–140-degree temperature. Now add the specific amount of crumb rubber and epoxy in the bitumen and mix with a spatula for a couple of minutes. Then heat the sample to about 130–140-degree temperature. Now place the ring & pour the bitumen carefully into the ring & allow it to cool for up to 60 minutes in a room atmosphere. Then put the sample in the water bath for about 60 minutes temperature (25 ^{o}C). Place the apparatus in a beaker filled with the water, also place the thermometer in the. Begin the operation of the magnetic stirrer and record the temperature at which the ball comes into contact with the base plate.

3.3.2 Penetration Test

The penetration test is a historically significant empirical test used for bitumen. In this test, a standard needle is vertically inserted into the bitumen sample under specific loading, duration, and temperature conditions. The depth of penetration is measured in tenths of a millimeter. This test allows bitumen to be categorized into various distinct groups, serving as a method of classification rather than a quality evaluation standard. A higher penetration number indicates a more fluid consistency of the sample. Bitumen with higher penetration rates is often preferred for use in cooler climates, while those with lower penetration rates are recommended for warmer regions. The standard operating temperature for the penetration test is 25 degrees Celsius, although it can be performed at different temperatures, such as 0 degrees Celsius, 4 degrees Celsius, and 46 degrees Celsius, by adjusting the needle load and penetration. These tests were conducted following the ASTM D5 and AASHTO T 49-93 standards. Base bitumen samples were conditioned with various percentages of CR-ER in a temperature-controlled water bath set at 25°C. A needle load of 100 grams and a testing duration of 5 seconds were utilized to determine the penetration values of the bitumen samples after conditioning.

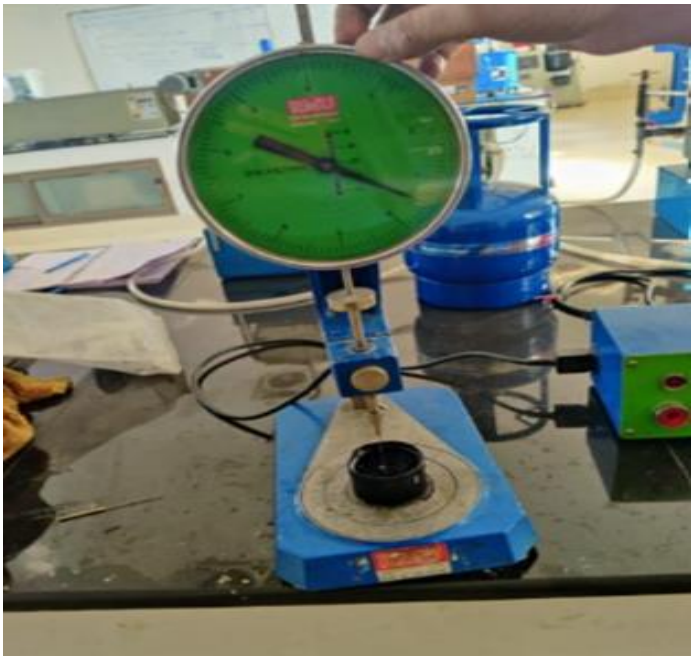

Figure 3.3: Penetration Test

3.3.3 Flash and Fire Point Test

The Flash and Fire point test assesses the maximum temperature asphalt can attain without igniting in proximity to an open flame. Samples were poured into open containers and gradually heated under controlled conditions to determine both the flash point and fire point. The flash point denotes the temperature at which a small flame ignites at the surface, whereas the fire point indicates the temperature at which the sample catches fire.

3.4 Preparation of CR-ER Modified Bitumen

The CR-Epoxy resin modifier was formulated according to prior research findings, which involved blending 2 percent Epoxy Resin and 4 percent Crumb Rubber. This blend underwent pretreatment by being placed in an oven at 100°C for 2 hours to treat the crumb rubber. Different proportions of the CR-Epoxy Resin modifier were utilized to partially substitute the base bitumen. Following this, various performance tests will be conducted to evaluate the characteristics of the modified bitumen and assess the performance of the resulting asphalt mixes.

3.5 Preparation of CR-ER Modified Asphalt Mixtures

To ensure proper mixing of CR-ER in bitumen, a high-shear mixer is typically required. However, due to the unavailability of high-shear mixers in the laboratory, a drill machine operating at 1000 rpm was used for the manual mixing of the two substances. To maximize the surface area of contact with bitumen, the front portion of the drill machine's shaft was welded and reshaped to resemble a propeller. Table 3.3 outlines the composition of various CR-ER-modified asphalt samples.

Table 3.3: Composition of Different CR-ER Modified Samples

TYPE OF SAMPLE	ABBREVIATION	BITUMEN USAGE (%)	PERCENTAGE OF CR-ER (%)
Virgin binder	Control Binder	100	0
Virgin binder+(4-2)% CR-ER	6% CR-ER	94	6
Virgin binder+(4-4)% CR-ER	8% CR-ER	92	8
Virgin binder+(4-6)% CR-ER	10% CR-ER	90	10
Virgin binder+(8-2)% CR-ER	10% CR-ER	90	10
Virgin binder+(8-4)% CR-ER	12% CR-ER	88	12
Virgin binder+(8-6)% CR-ER	14% CR-ER	86	14

The mixing procedure entailed blending CR-ER and bitumen in a drilling machine running at a speed of 1000 rpm. A temperature exceeding 180 degrees Celsius was sustained for 15 minutes. Throughout the mixing process, it was crucial to sustain a temperature above 180 degrees Celsius and a speed of at least 1000 revolutions per minute. Temperature, mixing duration, and mixing speed are the three most significant factors in CR-ER mixing. Commonly, temperatures typically vary between 180°C and 200°C, durations range from 10 to 30 minutes, and speeds range from 1000 rpm to 250 rpm are utilized.. These parameters were derived from various global studies and research projects. Adjustments in both time and speed are often necessary, as increasing speed can reduce mixing time.

3.6 Marshall Mix Design

Marshall Stability denotes the highest load a mixed specimen can endure at a standardized temperature of 60°C. With increasing applied force, the specimen experiences deformation, commonly referred to as flow. Marshall Mixes required for determining the Optimum Bitumen Content (OBC) are created using the Marshall Apparatus following standard protocols. Criteria are used to ensure that all volumetric properties, including stability and flow, meet the required standards, ultimately leading to the determination of the OBC.

Figure 3.4: Marshall Mix Design

After sieve analysis, aggregates are heated to 110 degrees Celsius in an oven until dry. To create a compacted sample with a diameter of four inches using the Marshall Mix design technique (ASTM D6926), 1200 grams of aggregates are necessary. Calculations are performed to determine the quantity of bitumen required for each sample, resulting in varying ranges from 3.5 percent to 5.5 percent.

The following procedures are carried out to prepare the samples:

Aggregates are selected from Kandar Risalpur, and their basic properties are determined to develop a suitable mixture that is properly graded, hard, sound, and rough in texture.

Asphalt binder is chosen based on rheological assessments like the penetration test and softening point test.

Warmed binder and aggregate are combined in significant amounts to create standard-sized specimens using molds. Various proportions of binder, spanning from 3.5 percent to 5.5 percent, are utilized in the preparation of Marshal Specimens.

Each side of the specimen is compacted with 75 blows, with a falling height of 18 inches according to ASTM D 1559. After preparation, samples are allowed to cool before being extracted from molds using a hydraulic jack system. Once sample preparations are complete, volumetric properties are calculated using the Marshal method.

3.7 Formulation of Job Mix Formula with Marshall Test

The determination of Optimum Bitumen Content (OBC) is crucial for preparing samples for performance testing. To accomplish this, comprehensive testing was conducted on all samples to evaluate stability, flow, density, Gmb, Gmm, air voids, VMA, and VFA. The outcomes of these tests were analyzed, and graphical plots and curves were generated utilizing this data. The primary function of the binder is to effectively cover the aggregate's surface area, thereby protecting it against water damage.

Figure 3.5: Formulation of job mix formula with marshal test

If the mixture contains insufficient bitumen content, the uncoated aggregate may be visible, leading to potential issues such as raveling or stripping due to reduced strength and durability. Conversely, an excessive amount of bitumen content can result in bleeding, reduced skid resistance, and pavement rutting. Therefore, the performance of the pavement is directly linked to the quantity of asphalt binder in the mixture.

Furthermore, the mixture must meet specified gradation criteria, ensuring that the aggregates form a well-interlocked structure. Additionally, the aggregates must meet specified properties, along with source aggregate properties, to be deemed suitable for use. A well-designed mix will result in an approved combination of aggregate and asphalt binder, often referred to as the "job mix formula" (JMF), which considers aggregate gradation and the type of asphalt binder.

The selection and assessment of asphalt binders in the Marshall test do not follow a standardized procedure. Instead, a predetermined method or local expertise may be used for binder evaluation. The Superpave PG binder system is frequently utilized for this purpose, which involves preliminary experiments to establish the temperature-viscosity relationship of the asphalt binder.

Table 3.4: Determination of Optimum Bitumen Content

%age of bitumen content	Bulk Specific gravity (Gmb)	Specific gravity (Gmm)	%age Air voids in agg. (Va)	%age voids in bitumen (Vb)	Voids in mineral agg. VMA	Voids filled with Asphalt VFA	Stability (KN)	Flow (mm)
3.5	2.34	2.499	6.22	7.93	14.32	55.54	14.28	1.83
4	2.362	2.48	4.53	9.16	13.95	65.86	15.34	2.53
4.5	2.363	2.438	3.1	10.37	13.42	77.06	15.06	2.94
5	2.352	2.41	2.37	11.45	13.81	82.57	14.05	3.35
5.5	2.348	2.399	2.15	12.53	14.64	85.51	13.15	3.93

Graphs were plotted against various parameters of Marshall Mix Design, and the values were assessed to determine the regulated Bitumen Content (OBC). Figure 3.8 illustrates the graphs plotted for stability, flow, VFA, VMA, and unit weight against bitumen content to ascertain the OBC.

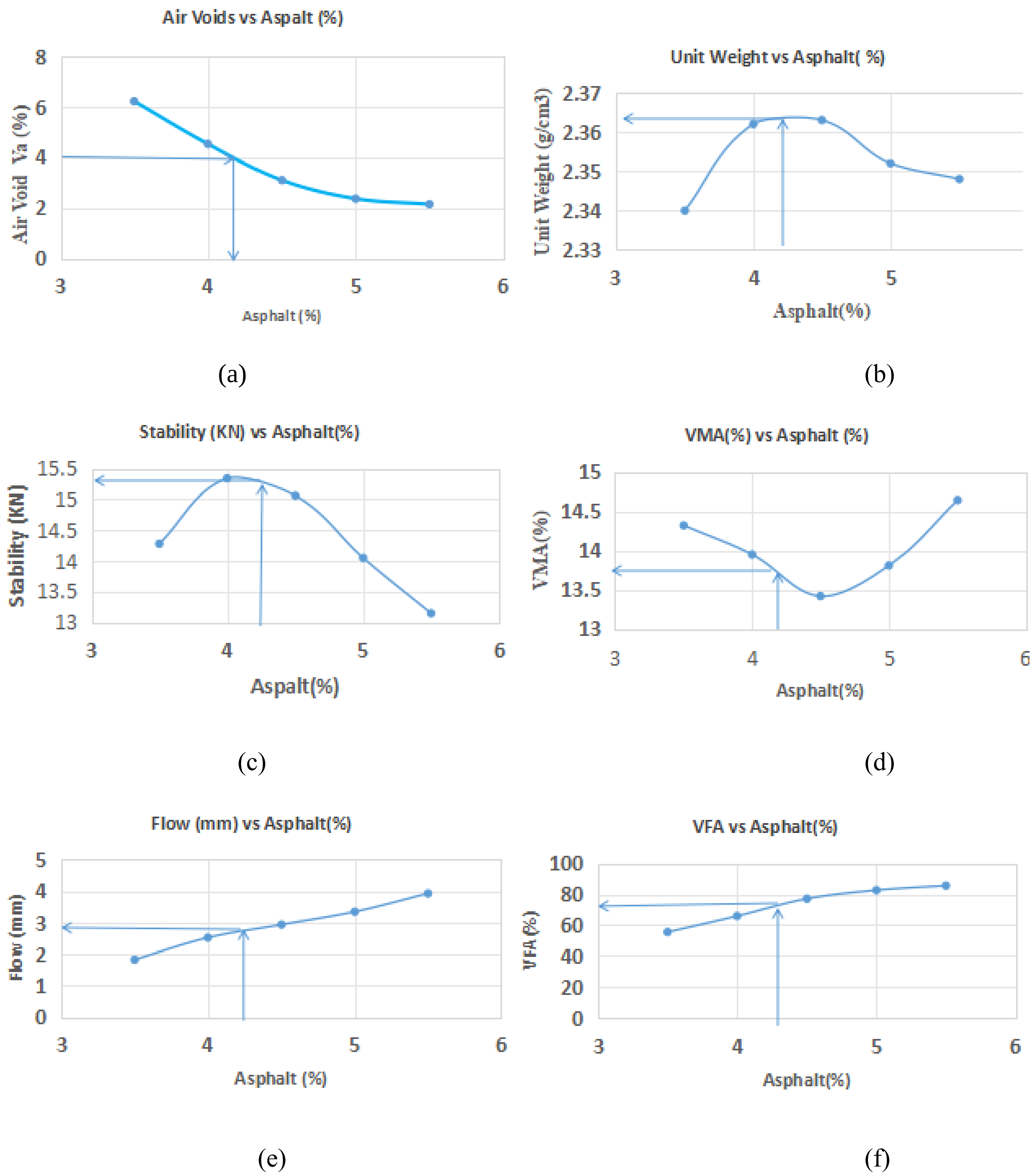

Figure 3.6:Marshall parameters for determination of OBC

Figure 3.6 illustrates the correlation among different parameters of Marshall Mix Design, with a specific emphasis on determining the Optimum Bitumen Content (OBC). The OBC was found to be 4.18% at 4% air voids. Table 3.6 presents an overview of the Marshall parameters used to confirm the OBC, indicating that other factors such as Unit weight, VMA, VFA, Stability, and flow also satisfied the designated criteria.

In detail, Figure 3.6(a) illustrates the correlation between air voids and different asphalt content, revealing the OBC at 4% air voids to be 4.18%. Figure 3.6(b) presents the relationship between unit weight and asphalt content. Additionally, Figure 3.6(c) displays the association between stability and asphalt content, indicating a stability of 15.4 at 4.18% asphalt content. Furthermore, Figure 3.6(d) shows the correlation between VMA and various asphalt content, with a VMA of 13.8% at 4.18 percent air voids. The plot in Figure 3.6(e) depicts the relationship between flow and different asphalt content, revealing a flow of 2.79mm at 4.18% air voids. Lastly, Figure 3.6(f) presents the relationship between VFA and asphalt content, indicating a VFA of 70% at 4.18%.

Table 3.5: Marshall Parameters for Determination of Optimum Bitumen Content

Marshall Parameters	Measured Value	Criteria	Remarks
OBC (%)	4.2	At 4 % air void	------
Unit Weight (g/cm3)	2.363	NA	------
VMA (%)	13.7	13 (min)	pass
VFA (%)	73	65-75	pass
Stability (KN)	15.45	8.006 (min)	pass
Flow (mm)	3	2.0-3.5	pass

Table 3.5 presents the outcomes of the Marshall test performed on samples containing various proportions of CR-ER. It was observed that the sample containing 8% CR and 4% ER exhibited the highest stability, with a Marshall stability value of 16.3 KN. However, higher percentages of CR-ER led to a decrease in stability values. Thus, it can be inferred that the asphalt mix containing 8% CR and 4% modifier achieves a balance between stiffness and fluidity, as evidenced by its enhanced stability compared to the control mix.

Table 3.6: Volumetric Parameters of CR-ER Modified Asphalt

Binder	CR-ER (%)	Voids (%)			Stability (KN)	Flow (mm) Air
		Air voids	VMA	VFA		
60/70	0	6.78	13.87	66.19	14.1	1.72
	6	5.84	13.76	58.11	15.13	1.87
	8	4.42	13.61	68.11	15.34	2.39
	10	3.97	14.12	73.62	15.7	2.87
	10	3.13	14.71	78.06	15.9	3.31
	12	2.94	15.44	81.64	16.3	3.83
	14	2.79	15.23	85.21	13.1	4.29

3.8 Sample Preparation for Asphalt Mix

The aggregates were heated to temperatures between 105 and 110 degrees Celsius to precondition the aggregates for making the asphalt mixtures. For HMA mix, a mixing temperature of 160 degrees Celsius and a compacting temperature of 135 degrees Celsius are utilized. It used 7200gm of aggregate and a gyratory compactor to produce gyratory compacted specimens with a diameter of six inches. To compact the specimens, 125 revolutions were conducted on them while the gyratory angle was set at 1.16 degrees and 600 kPa of pressure was applied. To produce a standard sample,
each specimen was cut with a saw cutter into the required dimensions.

3.9 Indirect Tensile Strength Test

The standard test for assessing asphalt mixture characteristics, conducted typically at UTM following ASTM D6391 standards, reveals two crucial aspects. Firstly, it evaluates the asphalt's susceptibility to moisture by comparing its indirect tensile strength before and after water immersion, as per a standardized procedure. Secondly, it gauges the potential for cracking in Hot Mix Asphalt (HMA) by determining its tensile strain at failure. A higher tensile strain till failure indicates greater resistance to cracking. The test involves compressing a cylindrical sample along its vertical diametric plane, utilizing loading strips of 0.5 inches width for 4-inch diameter samples with 2.5-inch heights to ensure uniform load distribution perpendicular to the load direction. At a temperature of 25°C, a deformation rate of 50 mm/min is specified for samples with a diameter of 4 inches, whereas for samples with a diameter of 6 inches, the rate is set at 76.2 mm/min. This method assesses the tensile strength of HMA mixtures, which has a substantial impact on their susceptibility to cracking.

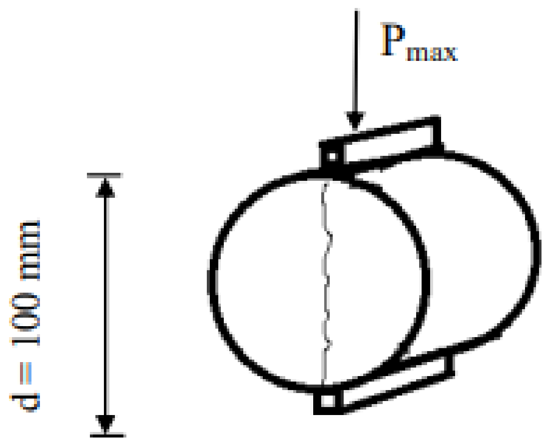

Figure 3.7: Tensile Strength Ratio Schematic Diagram

3.10 Moisture Susceptibility Test

Tests were carried out by the protocols outlined in ASTM D 6931-07 to assess the material's susceptibility to moisture. Unconditioned tests were conducted on three samples for each percentage of CR-ER. Before testing, the unconditioned specimens were subjected to conditioning in a water bath at 25.1 degrees Celsius (77.18 degrees Fahrenheit) for one hour.

Moreover, three samples of each mixture underwent examination after conditioning. The conditioning process for the samples adhered to the requirements outlined in ALDOT-361, which entailed immersing the specimens in water before placing them in a water bath heated to 60°C (140°F) for 24 hours, followed by another water bath heated to 25°C (77°F) for one hour.

Every specimen was placed in the Universal Testing Machine (UTM) to ensure that load transfer occurred across the sample's diameter at a consistent rate of fifty millimeters per minute, irrespective of whether the specimen had been conditioned or not. Subsequently, the tensile strength was assessed by measuring both the specimens and the loads at which they failed.

To determine the tensile strength ratios, the average conditioned tensile strength was divided by the average unconditioned tensile strength. According to Superpave standards, a tensile strength ratio of 80% is necessary. The tensile strength ratio (TSR) is utilized to compare the tensile strength of a conditioned sample with that of an unconditioned sample.

$$st = 2000P/\pi \mathrm{Dt} \qquad (1)$$

St = Tensile strength of sample (Kpa)

P = Maximum load applied on the sample (N)

t = Specimen height before tensile test (mm)

D = Specimen diameter of sample (mm)

3.11 Resilient Modulus Test (M_R)

After determining the sample's Indirect Tensile Strength (ITS) via the Indirect Tensile Strength test (ITS), the resilient modulus test is conducted. In this test, a peak loading force equivalent to 5 to 20% of the sample's ITS is applied, ensuring nearly recoverable deformation. This information is crucial for mechanistic-empirical pavement design procedures. In cyclic loading conditions, the resilient modulus indicates the connection between applied stress and recovered strain throughout the loading cycle. This preliminary test offers insights into material quality, aiding pavement design, evaluation, and analysis, among other applications. Variations in material stiffness due to polymer content and temperature must be compared to ascertain the resilient modulus. Experts emphasize the importance of resilient modulus in predicting pavement performance and evaluating pavement response to traffic stress. Pavements with higher resilient modulus (M_R), signifying greater stiffness, demonstrate increased resistance to permanent deformation relative to temporary deformation, particularly at lower temperatures. To conduct the resilient modulus test effectively, test samples are placed in a temperature-controlled cabinet and equilibrated to the desired testing temperature. Subsequently, they are transferred to an environmental room for a minimum of twelve hours. Samples are introduced into the loading assembly at either 25 degrees Celsius or 40 degrees Celsius, depending on the intended application, to ensure rapid attainment of the required test temperature.

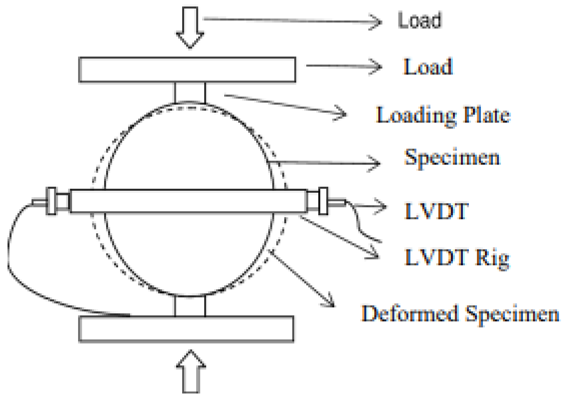

Figure 3.8: Schematic of Resilient Modulus Test

A haversine waveform is vertically applied in the vertical diametric plane of the specimen. Horizontal elastic deformation is employed to determine the load application and the resilient modulus value. Preconditioning the specimen involves subjecting it to a minimum of 50 to 200 stress cycles. The modulus of the testing machine is determined by the software program running during each load stroke. Results include average test findings, expressed as the specimen's resilient modulus at the specified temperature. Resilient modulus is determined by equations that require the calculation of the actual load, horizontal deformation, and recovered horizontal deformation for each load pulse. These values are then multiplied together.

3.12 Summary

This chapter delves into the laboratory characterization of aggregates and asphalt binders essential for preparing asphalt mixes. Only materials meeting standard criteria and specifications were utilized in creating the asphalt mix. Volumetric characteristics of the asphalt mix samples were computed, resulting in the identification of the Optimum Bitumen Content

(OBC). The chapter wraps up with an examination of sample preparation for performance assessments, which encompasses tests for moisture susceptibility, resilient modulus, and resistance to rutting.

Furthermore, the chapter provides a detailed explanation of the methodology employed throughout the experimental investigation's various stages. Both aggregate and bitumen underwent evaluation to ensure suitability for the investigation. Tests on bitumen following the mixing of CR-ER are presented along with their corresponding ASTM standards, aiming to provide a comprehensive understanding of the material properties. Additionally, the chapter elaborates on the utilization of NHA Class B gradation standards to establish a Job Mix Formula (JMF). A concise overview of the Marshall Test technique is provided, alongside the delineation of volumetric characteristics of Marshall testing specimens with reference to relevant standards and specifications.

Chapter 4: RESULTS AND ANALYSIS

4.1 Introduction

Assessing moisture-induced damage through the Universal Testing Machine (UTM) is a widely adopted and uncomplicated method, as moisture trapped within the pavement can negatively impact Hot Mix Asphalt (HMA) pavements, potentially causing premature failure.

This study focuses on incorporating Crumb Rubbe-Epoxy Resin (CR-RE) as a substitute for asphalt binder in HMA mixtures and assessing its impact on moisture susceptibility and resilient modulus. After determining the Optimum Binder Content (OBC) and adding the optimal additive content, samples were prepared for performance testing, following the specifications of NHA Class B.

In this chapter, we extensively discuss the results of various experiments, including moisture susceptibility (Indirect Tensile Strength - ITS) and Resilient Modulus (M_R). Furthermore, we conduct an analysis and comparison of test data between conventional samples and those modified with CR-RE. Utilizing Microsoft Excel, we perform a detailed analysis of the findings obtained from various laboratory trials of HMA mixtures.

4.2 Consistency Tests

To assess rheological properties such as penetrability and softening point, six varying proportions of CR-RE were employed. The consistency of asphalt binder fluctuates with temperature variations. Typically, a penetration or viscosity test is conducted to gauge its consistency. The penetration test was carried out at 25 degrees Celsius with a 100-gram load over a 5-second duration.

Bitumen displays viscoelastic properties, but as temperature increases, it tends to soften, resulting in a reduction in viscosity. The consistency tests demonstrated that the virgin 60/70 grade bitumen met all specified criteria according to respective standards. The findings of the consistency tests performed on the base bitumen are summarized in Table 4.1, showing a penetration of 69 at 25°C and a softening point of 50°C.

Table 4.1: Consistency Test Results

Test Description	Result	Standards	Specifications
Penetration Test @ 25°C	50	ASTM 5	60/70
Flash Point (°C)	270	ASTM D 92	232 minimum
Fire Point (°C)	294	ASTM D 92	232 minimum
Softening Point (°C)	50	ASTM D36-06	49-56
Ductility Test (cm)	116	ASTM D 113-99	100 minimum

The study examined the softening point and penetration of both the base binder and CR-ER-modified asphalt. It was noted that as the percentage of CR-ER increased up to 6%, there was a minor decrease in penetration values, coupled with a slight rise in softening values. However, when the percentage of CR-ER exceeded 6%, penetration values showed a significant increase, while softening point values decreased, reaching a minimum at the sample containing 18% CR-RE. This indicates that ER exerts a more dominant influence on consistency values compared to crumb rubber. In contrast, the softening point of CR-modified asphalt rose as the CR content increased. Figure 4.1 presents the findings of penetration and softening point tests for CR-ER-modified asphalt and base bitumen.

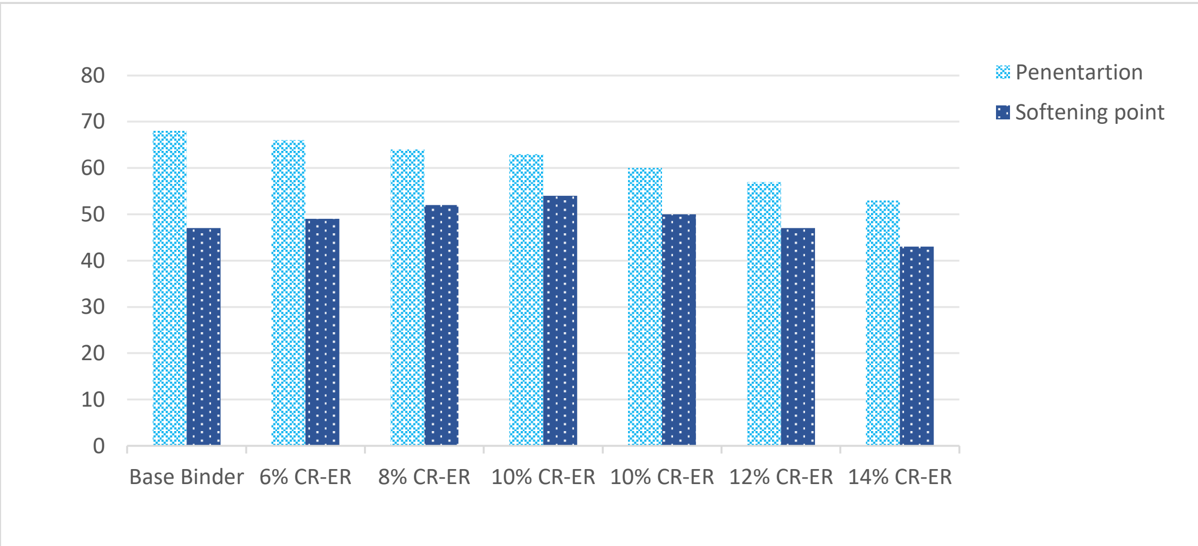

Figure 4.1: Results of consistency tests for CR-ER modified binder

4.3 HMA Performance Testing

To evaluate the effectiveness of asphalt mixes containing both virgin binder and binder modified with various ratios of CR-RE, we conducted assessments using moisture susceptibility and Resilient Modulus tests on samples of asphalt mix.

4.3.1 Moisture Susceptibility

To assess moisture susceptibility, experimentation and testing were carried out in accordance with the ASTM D6931-07 standard. Three samples were created from saw cuts of cored HMA samples, each with a diameter of 4 inches and a thickness of 2.36 inches, for both unconditioned and conditioned indirect tensile strength tests. These tests were performed on hot-mix asphalt (HMA) mixtures containing virgin asphalt binder, and the samples were conditioned following the specifications outlined in ALDOT 361.

Using a Universal Testing Machine (UTM), the maximum load that each sample could endure before fracturing was documented. Then, the tensile strength of each sample was computed using the formula provided in Chapter 3. This calculation enabled the determination of tensile strength for all samples, regardless of whether they were conditioned or unconditioned. The resulting tensile strength ratio was subsequently utilized to evaluate whether samples formulated with CR-ER modified binder complied with the prescribed tensile strength ratio criterion, typically set above 70-80 percent, as per the standard.

Moisture-induced damage led to lower Indirect Tensile Strength (ITS) values in conditioned samples compared to unconditioned ones. Furthermore, there was a significant decrease in the Tensile Strength Ratio (TSR) value as the proportion of CR-ER in the HMA mixture increased. Table 4.2 illustrates the Indirect Tensile Strength (IDT) values of both conditioned and unconditioned samples of CR-ER modified asphalt mixtures, confirming that the IDT values of conditioned samples are diminished due to moisture-induced damage endured during conditioning.

Table 4.2: Tensile Strength Values of Different CR-ER Modified Mixtures

Base and Modified Binders	Average Unconditioned (KN)	Average Conditioned (KN)	Tensile Strength Ratio (%)
Base Binder	5.64	4.1	72.7
6% CR-ER	6.1	4.4	72.13
8% CR-ER	6.0001	4.6	76.65
10% CR-ER	5.924	4.7	79.34
10% CR-ER	6.19	5.1	82.39
12% CR-ER	6.268	5.80	92.53
14% CR-ER	5.98	2.90	48.49

Figure 4.2 illustrates that with an increase in CR-ER content up to 12%, the TSR value reaches a peak of 75% before gradually declining. Consequently, the sample containing 12% CR-ER exhibited the most favorable moisture susceptibility. However, as the CR-ER content increases further, the stability of the overall mix diminishes, negatively affecting TSR values.

Despite the decrease in stability with higher CR-ER content, it's noteworthy that all samples met the Superpave criteria of a minimum TSR value of 70-80 percent, ensuring compliance with industry standards.

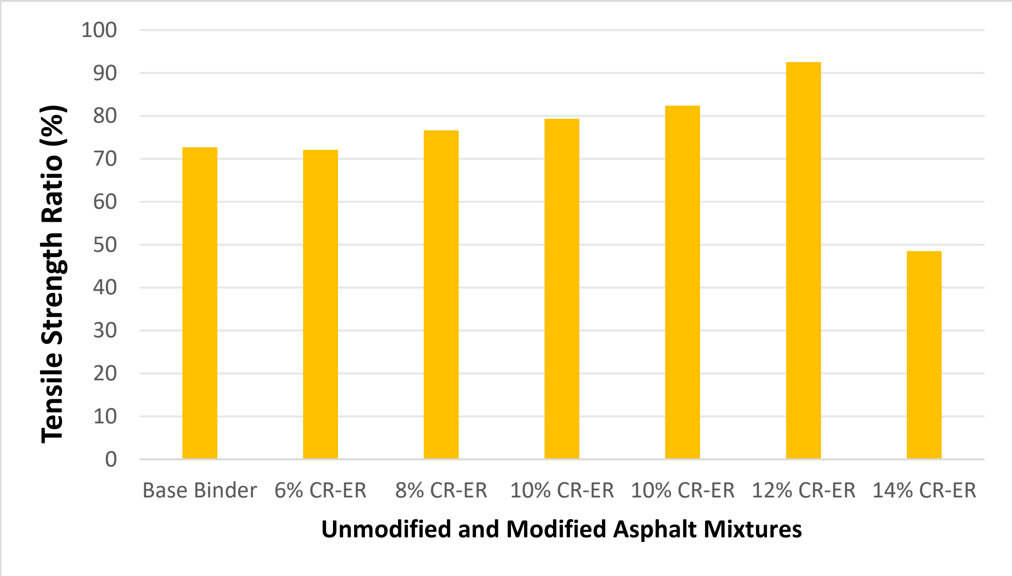

Figure 4.2: Results of the TSR Test

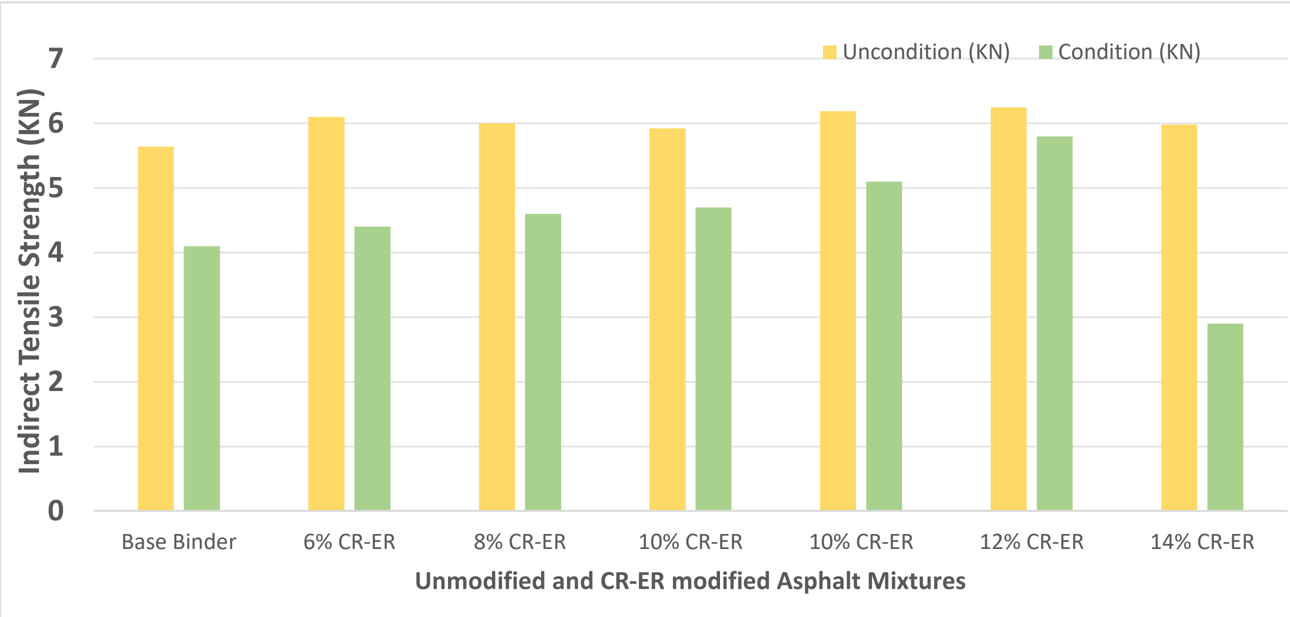

Figure 4.3: IDT values of conditioned and unconditioned asphalt samples

Figure 4.3 illustrates the Indirect Tensile Strength (IDT) values of both conditioned and unconditioned samples. Notably, the sample containing 12% CR-ER exhibits the highest IDT values among all samples. However, when the percentage of CR-ER exceeds 12%, there is a significant decrease in IDT values, indicating that higher amounts of ER have a detrimental impact on IDT values.

Based on the IDT results, it can be inferred that employing a 12% modifier content yields optimal outcomes. Beyond this threshold, the excessive presence of ER adversely affects the IDT values. Therefore, to achieve the best performance, a CR-ER content of 12% should be considered.

4.3.2 Resilient Modulus Test

Resilient modulus is an essential parameter utilized to assess how a material reacts to cyclic loading. It signifies the relationship between the stress applied and the strain that can be recovered. This ratio serves as an indicator of the material's stiffness under various conditions. Utilizing performance tests, such as resilient modulus testing, enables the assessment of material quality and provides valuable data for pavement design.

Resilient modulus is particularly crucial in estimating pavement performance and understanding how pavements respond to traffic loads. During the resilient modulus testing, a contact peak loading equivalent to 20 percent of the Indirect Tensile Strength (IDT) was applied to samples obtained by cutting cored samples. The experiments were carried out at a temperature of 25°C.

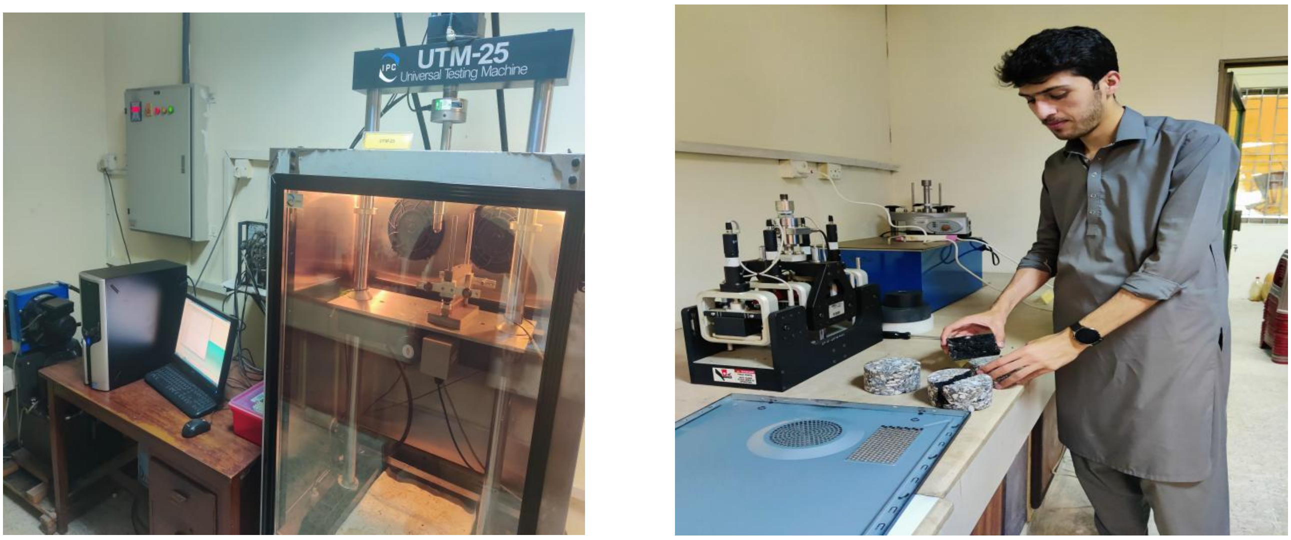

Figure 4.4:Resilient Modulus Test

Table 4.3 displays the resilient modulus values of modified asphalt mixtures. Remarkably, the sample with 12% CR-ER exhibits the highest resilient modulus values among all tested samples, suggesting its superior stiffness attributes.

Table 4.3: Resilient Modulus Values of Different CR-ER Modified Mixtures

PERCENT	Mega pascals
BASE BINDER	3108
6% CR-ER	3413
8% CR-ER	3688
10% CR-ER	3344
10% CR-ER	4305
12% CR-ER	5685
14% CR-ER	3392

In Figure 4.5, the resilient modulus of CR-ER-modified asphalt mixtures is depicted. It was noted that increasing dosages of CR-ER resulted in a decrease in resilient modulus values, particularly when the modifier content exceeded 12 percent. This trend suggests that asphalt mixtures containing 12 percent CR-ER strike the optimal balance between stiffness and fluidity.

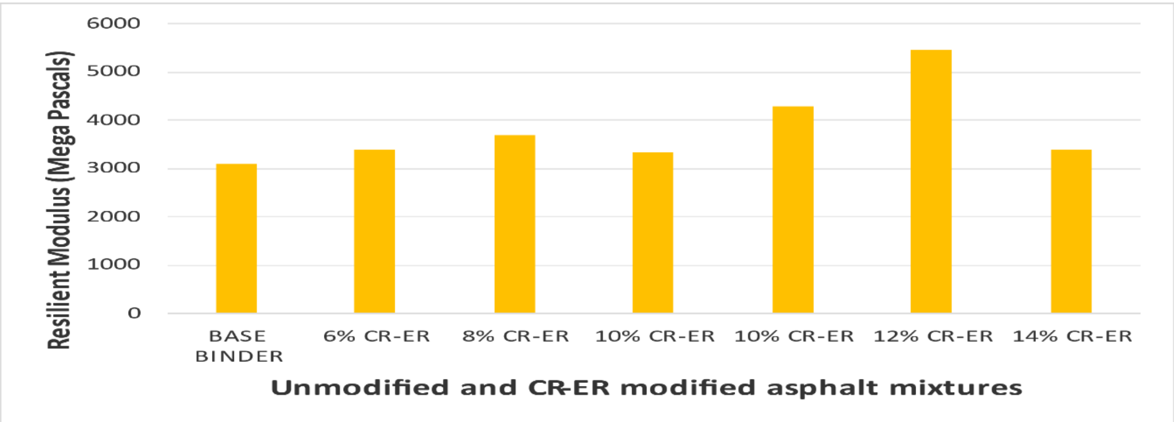

Figure 4.5: Resilient modulus values of different asphalt mixtures

The results indicate that incorporating 12 percent CR-ER has led to a significant enhancement in the resilient modulus, increasing it by 1.79 times. However, as the percentage of CR-ER exceeds 12 percent, the resilient modulus values begin to decline. Therefore, based on these findings, it is evident that the modified sample containing 12 percent CR-ER yields the most favorable results.

4.4 Summary

This chapter is based on the results of tests and analyses performed to evaluate the performance of CR-ER-modified and unmodified HMA samples. Statistical analysis was conducted using Microsoft Excel. The initial stage involved IDT and resilient modulus tests.

Throughout the experimentation process, the influence of augmenting CR-ER content to higher proportions was examined. It was noted that both IDT and MR values escalated with elevated CR-ER percentages, reaching up to 12%, at a temperature of 25 degrees Celsius.

The resilient modulus of samples incorporating 12 percent CR-ER was determined to be 1.79 times greater than that of the unmodified asphalt mix. Additionally, the inclusion of 12 percent CR-ER resulted in a TSR (Tensile Strength Ratio) enhancement of up to 1.28 times in comparison to the TSR value of the unmodified asphalt mix.

According to these results, it can be inferred that the asphalt mixture comprising 12% CR-ER exhibits the most favorable performance.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

In this study, CR-ER was incorporated as a modifier in the base bitumen to assess its influence on the physical and performance attributes of the modified asphalt mixture. Improving these factors helps prolong the lifespan of roads. The laboratory analysis aimed to recognize alterations in bitumen properties and their implications on the road structure.

The procedure commenced with the selection of materials from Kandar Risalpur, which included bitumen grade 60/70, crumb rubber, and epoxy resin. These materials were then subjected to testing according to established criteria. Afterward, CR-ER was integrated into both grades of binder using a manual high-shear mixing technique. Consistency tests, which evaluated rheological properties like penetration, softening point, and flash point, were carried out on the modified mixtures during the initial testing phase.

In the subsequent phase, Marshal Testing was executed to determine an Optimum Binder Content (OBC) by NHA Class B Specifications. This aimed to assess the strength and volumetric properties of modified HMA samples. Standard specimens, measuring four inches in diameter and two and a half inches in width, were employed for this purpose. Moreover, an Indirect Tensile Strength (IDT) test using a Universal Testing Machine (UTM) was carried out at a temperature of 25 degrees Celsius to evaluate the cracking potential and resilient modulus of HMA mixes on Superpave gyratory compacted samples.

The results of the HMA performance tests indicated that for grade 60/70 modified HMA samples, those containing 12 percent CR-ER exhibited the highest values for both IDT and MR, suggesting superior performance characteristics.

5.2 Conclusions

The experimental endeavor sought to evaluate how different proportions of CR-ER affect the properties of asphalt mixtures, with a particular emphasis on resilient modulus and moisture susceptibility. Following thorough investigation and analysis, several significant findings have been uncovered.:

- The HMA mix containing 12 percent CR-ER demonstrated superior resilient modulus values and moisture susceptibility characteristics.
- Both the aggregates and the bitumen met the respective basic testing standards, indicating their suitability for use in asphalt mixtures.
- The addition of 12 percent CR-ER led to significant improvement in the asphalt mix, notably increasing the TSR (Tensile Strength Ratio) value.
- The research findings provide compelling evidence that the use of CR-ER enhances key characteristics of modified asphalt concrete, including resilient modulus and resistance to moisture damage.
- Effective utilization of both crumb rubber and epoxy resin in asphalt pavements is supported by the findings of this research.

Overall, the study underscores the potential of CR-ER as a beneficial additive in asphalt mixtures, offering enhancements in performance indicators such as resilient modulus and moisture damage resistance.

5.3 Recommendations

According to the conducted study and its findings, the following recommendations are suggested for our local industry.

5.3.1 Promote the Development of Crumb Rubber

Given that a significant portion of scrap tires in our nation are either incinerated or exported, there is a pressing need to encourage the utilization of crumb rubber in our industry. By incorporating crumb rubber into road construction, we can effectively repurpose old tires and enhance the sustainability of road-building practices.

5.3.2 Embrace Modernization in Asphalt Construction

To mitigate initial building costs and prevent costly rehabilitation operations in the future, our local industry must move away from outdated construction methods and traditional bitumen in Hot Mix Asphalt (HMA). It's imperative to embrace modernization and adopt innovative approaches such as CR-ER-modified binders.

5.3.3 Implement CR-ER Modified Binders

The adoption of CR-ER-modified binders in our local industry holds the potential to significantly improve road performance while reducing expenses associated with road repair.

By enhancing the properties of asphalt mixtures, CR-ER modification can contribute to longer-lasting and more durable roads.

5.3.4 Optimal CR-ER Modification Percentage

Based on the results of the HMA performance tests, it was observed that samples modified with 12 percent CR-ER exhibited the best values for Indirect Tensile Strength (IDT) and Resilient Modulus (MR) compared to those modified with grade 60/70. Consequently, it is advised to use asphalt binders modified with 12 percent CR-ER to attain the ideal properties of asphalt mixtures.

Implementing these recommendations can lead to improved road quality, enhanced sustainability, and cost savings in our regional road construction industry.

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