Influence Of Microwave Radiation On Healing Efficiency Of Steel Fiber ModifiedAsphalt Mixture

By

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TO

MY FAMILY, MENTORS AND COLLEAGUES

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Table of Contents

LIST OF ACRONYMS

NHA – National Highway Authority

OBC – Optimum Bitumen Content

RTFO – Rolling Thin Film Oven

SCB – Semi Circular Bending test

3PB – 3 Point bending test

UTM – Universal Testing Machine

VA – Air Voids

VFA – Voids Filled with Asphalt

VMA – Voids in Mineral Aggregate

RAP – Reclaimed Asphalt Pavement

TGA – Thermogravimetric Analyis

AC – Asphalt Concrete

ASTM – American Society for Testing and Materials

HMA – Hot Mix Asphalt

ITS – indirect Tensile Strength

TSR – Tensile Strength ratio

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Self-healing ability of asphalt can help it to recover the damage incurred during service life. Due to short rest periods available between traffic, there is a need to use a high temperature method considering limited time frame to achieve better healing of asphalt pavements. Thus, it will uses of microwave radiation technology to improve the limited self-healing ability of roads and enhance its service life. The reason of this research is to find the microwave absorption properties of steel fiber and the effect on road performance of its inclusion. The surface texture and morphology of steel fiber will be studied using SEM. The mechanical tests will be performed on steel fiber modified asphalt mixtures incorporating 2%, 4%, 6%, and 8% steel fiberby total volume of bitumen. It is expected that steel fiber will and improve moisture susceptibilityof steel fiber reinforced asphalt mixture. Suitable percentage will be delineated to balance pros and cons of steel fiber incorporation in asphalt mixture. Furthermore, the healing ability of steel fiber will be quantified using a 3-Point bending test. Microwave radiated samples will be tested with multiple microwave healing cycles to establish a relationship between heating time, fiber percentage and healing efficiency. In general, the superior mechanical and microwave absorption capabilities of steel fiber may be used to enhance the sustainability of asphalt mixes including steel fiber.

Key words: Steel fiber, hot mix asphalt, asphalt materials, microwave heating, self-healing asphalt.

CHAPTER 1

INTRODUCTION

1.1 Background

Asphalt is a viscoelastic material made from petroleum refining that is commonly used topave roadways and runways *(Rece Pat Nanotec 2015)*. It forms a cohesive matrix for the asphalt mixture when it binds to graded aggregate particles. After a few years in service, however, asphalt concrete starts losingits flexibility and binder becomes brittle due to repeated traffic loads and unfavorable environmental condition. This results in brittle binder and loss of binder-aggregate adhesion and eventually leads to stripping, surface degradation and potholes. Gradual deterioration leads to fatigue crack and eventual structural failure *(Rece Pat Nanotec 2015).* As a result, asphalt pavements need be frequently preserved and mended.

Fortunately, asphalt materials have the potential to self-heal micro crack damage, restoring some performance and significantly reducing maintenance costs, thus extending their service life and ultimately reducing greenhouse gas emissions *(J Indus Eng Chem 2015).*

1.2 Problem Statement

Due to its economic efficacy, noise drop, and pleasurable driving practice, asphalt isfrequently used as a binding substantial in pavement engineering. Asphalt concrete, on the other hand, deteriorates with time as a result of cyclic vehicle stresses. Meanwhile, as a result of environmental variables such as getting old and moisture destruction, asphalt binder becomes hard over time. As a result, micro cracks form and expand into bigger level, accelerating the deterioration procedure and eventually resulting in sufferings such as raveling, potholes, and cracking.

Vehicle usage in Pakistan is rising daily, making disposal of solid waste to landfills of worn tires a critical issue for the Pakistan EPA to address. Currently, this business has several obstacles due to alack of government support for the recycling and reuse of waste tire by-products, yet a significant amount of high-strength steel fibers is removed manually from waste tires. Steel fiber inclusion intoasphalt mixtures has the potential to result in resource savings and environmental pressure reduction.

This research study expands on prior work utilizing microwave healing technology to create asphaltpavements capable of producing localized internal healing of cracks, hence minimizing the formation of macro cracks that result in premature pavement degradation. Steel fibers have greater electromagnetic characteristics than typical aggregates due to the presence of magnetic componentssuch as steel fiber. This makes the steel fiber a possible magnetic loss microwave absorber. The microwave heating method is an excellent choice owing to economic saving, simple equipment andhigher efficiency.

1.3 Research Objectives

1. Determining morphological and elemental properties of steel fiber
2. Determining the mechanical properties at different percentages of steel fiber in asphalt blend.
3. Evaluating the effect of steel fiber percentages on the healing performance of microwave radiated asphalt mixture.
4. Cost Estimation of modified asphalt mixture with normal one.

1.4 Research Methodology

Research methodology consists of following phases which are Literature review and collection of material and morphological and elemental characterization of steel fiber, Moisture susceptibility test of Marshall Samples with and without steel, Self-healing investigation of asphalt samples using 3-Point Bending test.

1.5 Scope Of Thesis

To investigate the effect of asphalt healing of microwave radiation by incorporating steel fiber as fine aggregate with 2%, 4%, 6% and 8% with conventional aggregate in mix to evaluate cyclic microwave healing properties.

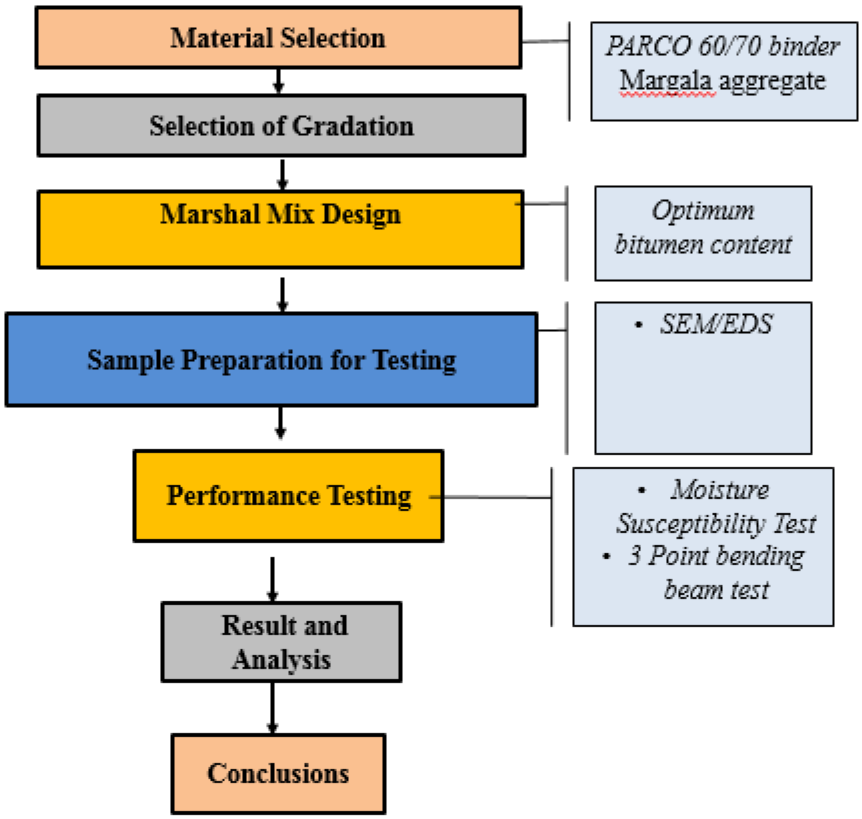

Figure 1. 1: Elements of the Research Methodology

Table 1.1: Test Matrix

Sr. No	**Material**			**Performance Tests**			
		%age of steel fiber in bitumen	**SEM**	**EDS**	**Moisture Susceptibility Test**	**TPB**	**Total**
1.	HMA	0%	3	3	3	12	21
2.	HMA + steel fiber	2%			3	12	60
		4%			3	12	
		6%			3	12	
		8%			3	12	
	Total		3	3	15	60	81

1.6 Report Outline

This thesis is divided into five chapters, which are summarized below:

Chapter-1 provides an overview and background information on current asphalt pavement maintenance techniques and self-healing asphalt. Additionally, this chapter contains the issue statement, study objectives, and research methods.

Chapter-2 discusses self-healing materials, the basic idea of self-healing pavement, and how self-healing procedures may be used to maximize healing efficiency.

Chapter-3 discusses the materials and procedures used to determine the OBC of asphalt mixtures and to prepare samples for mechanical and self-healing tests.

Chapter-4 reports the findings of steel fiber addition and asphalt mixture testing. The article discusses the effect of steel fiber on the mechanical and self-healing characteristics of asphalt mix.

Chapter-5 This chapter summarizes the major findings and makes recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter presents a scientific summary of several researches on asphalt materials' self- healing properties and their collision in sustainable construction and operation of asphalt pavement. The toughness and strength of bitumen resources reduces when bitumen materials are opened to load reiterations. The procedures of micro-cracking beginning, proliferation and macro-cracking during repeated loading were examined by many scholars. The rescue of material toughness, the increase of fatigue life and the regaining of strength were for the first time experimentally perceived in the 1960’s under a fatigue test with rest times. This was from then on well-defined as the self healing occurrence of bitumen materials, presence the regaining of material characteristics and weakening of cracking.

2.2 Self-healing

Asphalt concrete is a self-healing material capable of regaining part of its performance following damage. This is mainly owing to bitumen's ability to act like a Newtonian fluid between 30 and 70°C, depending on the kind of bitumen. Dai et al. defined asphalt healing behaviour as the capacity of asphalt materials to self-repair under specific stress and/or environmental conditions, particularly during rest period. Additionally, Xu et al. said that the essential of self-healing in asphalt pavement is the commencement of a "mobile phase" during the rest time, which leads in crack closing progressively. When not subjected to stresses, the self-healing material will restore a certain level of functioning by allowing bitumen to flow and diffuse to seal microcracks. This occurs mostly as a result of the bitumen's viscosity and gravitational force. At ambient temperatures, however, it would be impossible to halt traffic and enable sufficient self-healing and recuperation [13]. Thus, external circumstances have an effect on the healing of asphalt mixes, with additional propagation of micro-to macrocracks occurring as a result of constant loading, loading level, load repetitions, age, and moisture conditions.

2.2.1 Self Healing Phenomena

The polymer healing theory is an excellent starting point for studying the asphalt healing procedure. Nevertheless, the manner of healing might vary, then some polymers' intrinsic reversibility of matrix phase connections enhances self-healing. Numerous researchers, for example, the complexity of their compositions, microstructures, and potential interactions, the healing mechanism in asphalt materials remains unknown. Self-healing is a term that refers to the asphalt's natural reaction to minimize damage fractures and therefore allow for partial restoration of original characteristics *(J Clen Prod 2015).* Extensive research was performed on thermally reversible reactions, most notably the Diels-Alder (DA) reaction, with the goal of cross-linking linear polymers *(Leyens C, van der Zwaag S 2010).* Thus, healing is restricted to the repair of micro cracks in asphalt pavement, while macro cracks can not be wetted. Additionally, Little et al. suggested that self- healing asphalt mixes may be defined as the renovation of the inherent asphalt construction through neighboring fracture sides. Healing occurs in a broad sense as long as the material will not collapse entirely and connection between the split looks remains, since exterior force can be used to bring two broken sides into touch.

2.2.2 Self-healing Mechanism

Due to the fact that self-healing is an attribute of material, scholars in the literature have mostly utilized mechanical tests to interpret self-healing performance. Self-healing ability findings are variable and highly reliant on the mechanical testing technique and conditions, as well as thehealing index criteria. As a result, several research have highlighted the need of dissecting the asphalt healing procedure using a range of physic-chemical techniques. This segment discusses some of the self-healing characteristics that asphalt resources may possess.

2.2.3 Molecular Diffusion Healing Model

The molecular diffusion-based healing procedure is influenced by the self-healing polymer matrix and is explained by polymer sequence interactions. *(De Gennes 1971)* suggested a model of repetition in which molecules moved through a cross-linked polymeric emollient like worms. *(Wool and O'Connor 1981)* developed a self-healing mechanism for polymers based on molecular diffusion, and inter-diffusion theory implies that healing occurs in five sequentialstages: surface movement, approach, wetting, diffusion, and randomization *(Di Benedetto H, Nguyen QT 2011)*.

To conclude, healing is defined as the repair of minor bonds between molecules or microstructural parts, as well as the creation of powered force-transmitting bridges at the boundary via Rouse diffusion or repetition.

By creating a strong interfacial contact between observing sides, these activities will renovate the material's unique strength *(Kim YR, Little D, Lytton RL 2001).* Interfacial diffusion is impeded by surface rearrangement processes like as reduction, diffusive inner relocation, or organic reactivity of chains. As a result, the time needed to complete the microscopic arrangements necessary for mechanical property recovery rises. Numerous studies have demonstrated that surface rearrangement effects, namely the formation of an inhomogeneous near-surface structure, result in a decrease in cohesive bond strength *(Morenonavarro F, Solsánchez M 2015).* Partial mechanical contact occurs at the crack sides during the surface approach stage as a result of the flow of molecular segments with sufficient thermalenergy to overcome energy barriers, or as a result of driving forces such as linked chains and kept strain energy in the greater part. This phase needs link among cracked sides at a distance of about 10nm. Cohesive repair is thus enhanced by external services, electrostatic services, and hydrogen bonds as surface defects steadily reduce. Wetting eliminates possible impediments produced by heterogeneities and allows chains to flow over fracture faces, therefore increasing cohesive strength. The reintroduction of long-term striking connections (electrostatic interactions) among unbounded parts at the boundary results in absorption, which describes the consistent region with departure lengths ranging from 0.3nm to 10nm. At distances smaller than 0.3nm, short-range striking connections (acid, base or hydrogen bonds) initiate and maintain material transfer across sticking surfaces. Due to intermolecular entanglements and interpenetration, molecular chains scatter and randomize at the faces. Kim and Wool characterized escaping chain segments as minor chains, which propagate and breach the interface by assuming new random Gaussian conformations. When the originalconformations disappear, these sections entrap with low-energy chain finishes, restoring the molecular structure to its original state.

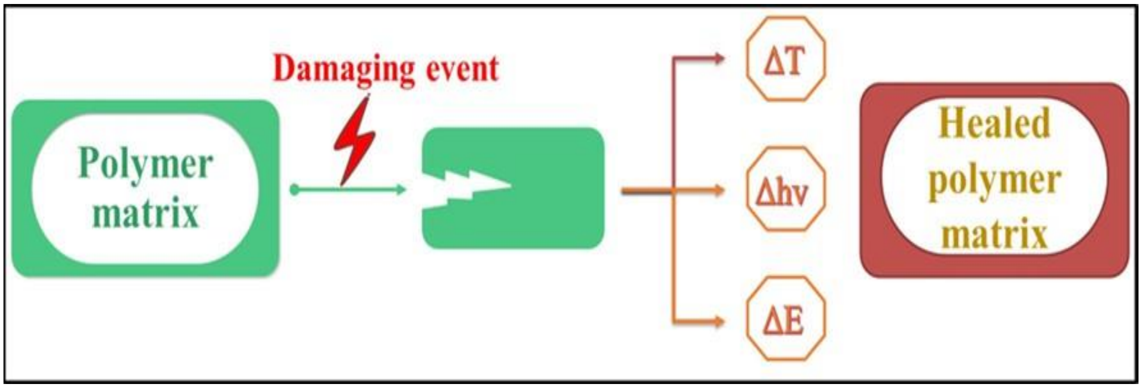

Figure 2. 1: Healed Polymer Matrix *(Zhong et al., 2015)*.

2.2.4 Self-healing Influencing Factors

Along with internal factors, external factors will have an effect on the ability of asphalt materials tomend. Some of the factors that affect the self healing process as rest time, temperature, loading rate, damage and the aging process.

(1) Rest time

Rest periods significantly benefit the mechanical development of asphalt materials during healing, regardless of whether the test is fatigue or fracture-based, *(Inter J Fati 2015).* Additionally, it is discovered that theamount of rest necessary for healing varies between a fraction of a second and several hundred days. The ideal rest interval, according to most research, would be around ten times the load period.

(2) Temperature

Temperature is additional critical element in increasing the capacity to recuperate. Healing happens fast at sufficiently high temperatures. *Bhasin et al (2008)* reported that by heating an asphalt concrete specimen to 50°C for 20 minutes, the fatigue life could be improved by around 40. Once a particular temperature is reached (which is often between 30°C and 70°C, dependent on the kind ofbitumen and its age), the asphalt binder is capable of performing adequate repair *(Kim YR 1993).* The break will not heal completely if the temperature is very short. If the heating temperature is set very high, however, the quantity of healing may be reduced as a result of the asphalt draining naturally. Additionally, asphalt binders breakdown more rapidly at higher temperatures. As a result, each typeof asphalt binder should have a healing temperature that is appropriate.

(3) Loading state

The loading situation has an influence on the healing capacities seen. Varying the control modalities (strain- or stress-controlled), loading patterns (recurrent, disturbed), loading intensities, and loading frequency results in a range of healing responses in bituminous samples. Itis well established that increasing the tensile stress/strain level reduces the comparative fatigue period addition produced by healing *(Lytton RL 1993).* It was observed that healing in absorbent asphalt mixtures was very micro strain reliant on, with a advanced micro strain level resulting in a faster rate of healing. Additionally, *(Bazin P 1967)* demonstrated that providing a little amount of compressive stress to a fracturedor tired specimen during repose may help in the development of complete contact between the fractured surfaces *(Kim YR, Little DN 2003).*

(4) Damage

When the load approaches the failure threshold, the healing capacity decreases, and healing becomes problematic during the macro cracking phase unless induction heating is used *(de Gennes 1971).* Numerous studies found that the degree of damage to asphalt mixtures or their loading history has an effect on their capacity to recover *(Wool RP, O'connor KM 1981)*. When only small damage (micro cracks) occurs, the capacity to repair is great.

(5) The ageing process

Asphalt is a material that deteriorates inexorably with time *(Bhasin A 2008).* Age tends to have a detrimental influence on asphalt materials' ability to heal. Researchers *(Bommavaram R 2009)* observed that a mortar sample aged in the laboratory displayed diametrically opposite healing capacities to one aged in the outdoors. The laboratory-aged mortar demonstrated a greater capacity for healing than the virgin mortar in a stress-controlled intermittent type test, but the field-aged mortar, which shared the laboratory-aged mortar's rheological and chemical properties, demonstrated a lower capacity for healing than the virgin mortar.

2.3 Steel Fiber

To eliminate waste Rubber tire pollution is a huge environmental concern that affects the entire planet. Presently, the removal of recycled tires is a global challenge, due to their non-degradability. During recovering, resources such as rubber and steel are improved from the recycled tires. Each year, millions of tires are buried or abandoned, posing a major threat to the environment. It is commonly known that about one billion tires have extended the end of their valuable life and that around 50% of them are wasted on a regular basis. According to the literature, discarded rubber tires contain some elements that cannot degrade under any setting, posing major environmental hazards. One alternative is to burn them, although this would have further negative consequences. As a result, the environment is gravely threatened. Tires are a type of garbage that is not easily biodegradable. As a result, it is critical to properly dispose of these tires. In recent years, advancements in the handling of polymeric wastes such as tires have resulted in the trash being a potential source of valuable raw materials. One way to address this issue is to utilize tire steel fibre as an addition in the asphalt. The usage of steel fibers, recycled from tire surplus, as a rare material to heal asphalt is an ecologically approachable and economically feasible result to achieve the remaining of tire salvaging.

Table: 2.1 Steel Fiber

Final Products	Percentage
Fuel Oil	(45%-55%)
Carbon Black	(30%-35%)
Steel Wire	(10%-15%)
Flammable Gas	(8%-10%)

The following is a list of researchers who have previously employed metallic wastes to enhance asphalt's self-healing ability.

2.4 Asphalt Healing

Healing occurs in a broad sense is extensive as the material does not collapse entirely and interaction between the split appearances remains, since exterior force can be used to bring two broken sides into touch. Investigation of the result of microwave heating performed on promotion of self-healing in asphalt concrete by using steel wool fiber. Test that performed were three point bending and scanning electron microscopy. Metallic waste (steel fiber) effectively transformed the energy of microwave radiation efficiently into thermal energy *(H.Wang 2020).* Overview of electro-magnetic induction heating technique delivers a fresh indication for road thawing. Electro-magnetic induction heating technique has various benefits like low energy depletion, less pollution, non-contact heating, and fast heating ratio. Typical thawing speed of the asphalt mix increases with the growth in steel wool fiber length and content.

The results of *(Z Liu, Y Wang 2020)* showed that as the fiber length enlarged, the heating level of the fiber and asphalt mix progressively improved, but the addition progressively reduced; as the fiber quantity improved, the induction heating level expressively improved. The induction heating level of the steel fiber was experienced. The induction heating level, upright heating and cooling guidelines, and the external temperature regularity of asphalt mixes sections with changed fiber sizes and fillings were then calculated in detail. Finally, the heating-induced fatigue-damage healing features of sections with changed fiber sizes and matters were examined by directing fatigue-healing sequences. The outcomes display that as the fiber size enlarged, the heating level of the fiber and asphalt mix progressively improved, but the increase progressively reduced; as the fiber content enlarged, the induction heating level expressively improved.

Analysis on Thawing Property of Steel Wool Fiber-Reinforced Asphalt Mix by Induction Heating was performed by *(F Yang, K Li, R Xiong, B Guan, H Zhao - 2020)* to estimate the result of steel wool fiber on thawing property of induction heating. The consequences displayed that consumption of steel slag in asphalt mixes for microwave thawing is supportive to improve the source unavailability of natural aggregates and progress the wellbeing of road traffic in winter.

Metal Shavings were recycled to investigate the result of metallic-waste aggregates on microwave self-healing presentations of asphalt mixes by *(L Baowen, S Aimin, L Yupeng, W Wentong-2020).* They establish that metallic waste efficiently transformed the energy of microwave radiation effectively into thermal energy.

Assessment of the possibility of steel wool in improving healing capability asphalt materials detected by Ajam. The healing ability of asphalt concrete can be expressively improved by Steel wool electro-magnetic field absorption properties, leading to enhancement of healing rate *(HKK Ajam – 2019).*

(MM Karimi, MK Darabi-2019) have studied the outcome of steel wool fibers on mechanical and induction heating reaction of conductive asphaltic concrete. Their results have disclosed that microwave healing capability of asphalt mastic was upgraded after the addition of steel wool.

(J Norambuena-Contreras, L Storey-2018) performed a research for self-healing properties of reused asphalt mixes comprising metal waste by using steel wool fiber to estimate the prospective of being crack-healed by microwave heating. Their outcomes revealed that the over-all influence

of the addition of metal shavings was a development in the crack-healing of asphalt mixes, while addition of steel wool to mixes with metal shavings reduced the healing.

Consequences by steel fiber asphalt healing of *(MR Garcez, AS Takimi 2018)* establish the probability to use microwave heating in the fabrication of the complex, indicating probable for future presentation as self-healing asphalt and pavement healing.

Improved heat discharge and self-healing properties of steel slag filler built asphalt materials under microwave radioactivity investigation was done by *(S Wu, Z Chen, G Tao, Y Xiao – 2018)* to find the outcomes of steel slag filler on self-healing involvement in asphalt mastic. They disclosed that steel slag filler has improved self-healing involvement in asphalt mastic. Electro-magnetic limitations of steel slag filler are advanced than lime stone filler.

(A González, J Norambuena-Contreras, L Storey-2018) used steel wool fiber to establish the consequence of RAP and fibers adding on asphalt mixes with self-healing properties extended by microwave radiation heating. Asphalt mix was rehabilitated using induction and microwave heating. At the same temperature microwave heating rehabilitated the cracks improved than induction. Air voids in mix play an significant character in asphalt self-healing by increasing the interior pressure and flexibility of bitumen during the heating procedure. It was established that the aggregate units of the mixes enclosed metals, which describes the heating of samples without fibers. Also, it was found from CT-scans that aggregates not covered by bitumen were cracked during the three point bending tests, leaving parts of the cracked side not covered with bitumen. Generally, it is established that asphalt mixes with up to 30% of RAP and metal fibers have the prospective of being crack-healed by microwave heating.

(AS Takimi, M Brykalski - Acta Scientiarum ..., 2018) performed an investigation on Production of self-healing asphalt with steel short fibres and microwave heating by prosecuting short steel fibers and outcomes display the possibility to use microwave heating in the construction of the combination, representative prospective for future submission as self-healing asphalt and pavement renovation.

(J Gao, A Sha-2017) develop the steel slag as aggregate in asphalt mix to thawing of microwave heating pavement combining with steel slag. They establish that consumption of steel slag in asphalt mixes for microwave thawing is helpful to improve the supply shortage of natural aggregates and recover the safety of road traffic in winter.

2.5 Moisture Susceptibility

The vulnerability of HMA pavements to moisture is the most common cause of pavement distress. The HMA should not be significantly degraded as a result of moisture penetration into the mix. The internal asphalt binder-to-aggregate bond in high-performance asphalt mixes may be deemed vulnerable to moisture if it diminishes in the presence of water. A significant amount of weakness might result in stripping (Figure 2.2).

Figure 2.2: HMA samples with no moisture damage (left) and moisture damage (right) (*Hicks, R.G. (1991)*

Moisture susceptibility testing may be used to determine the likelihood of HMA mixes being damaged by moisture in the environment. In some cases, the results of the moisture susceptibility test can be used to predict the likelihood of long-term stripping as well as to evaluate the efficacy of anti-stripping additives, which are substances that are added to the asphalt binder, aggregate, or HMA mixture to help prevent stripping from occurring.

It is the outcome of moisture interaction with the asphalt binder-aggregate adhesion in a hot mix asphalt (HMA) mixture that causes moisture damage. Known as stripping, this interaction between the asphalt binder and aggregate (Figures 2.2) can result in a loss of adhesion between the asphalt binder and aggregate, which can result in a variety of types of HMA pavement distress, including rutting and fatigue cracking.

Over the years, a variety of tests have been developed to determine the sensitivity of a specific HMA mixture to damage caused by moisture. These tests range from the simple (such as the boiling test) to the more complicated (such as the chromatography test) (e.g., Hamburg wheel tracking test). The modified Lottman test is the name given to the moisture susceptibility test required by the Superpave mix design specification. The details of this exam may be found in the Test Description section. Hicks (1991]) provides a thorough description of the actual moisture damage mechanism, as well as the elements that influence moisture damage, prevention strategies, and alternate testing.

As a general rule, moisture susceptibility tests do not assess individual components, but rather aim to quantify the capacity of an HMA mixture to resist moisture damage from any source. They are often only capable of producing gross data or comparative results, and they are not able to forecast the extent of moisture damage that has occurred. The following is a quick explanation of the primary tests for moisture susceptibility that are performed:

Boiling test (ASTM D 3625).

Boiling water with loose HMA is added to a measuring cup, and the percentage of the total visible area of the aggregate surface that keeps its asphalt binder covering is calculated. The test is straightforward, but it is subjective; it does not entail any judgment of strength, and it is difficult to examine the fine aggregate.

Table 2.2: Moisture Susceptibility Specification

Material	Value	Specification	HMA Distress of Concern
HMA	Tensile strength ratio	≥ 0.80	Moisture damage, stripping

2.6 Three Point Bending Test

Integrating self-healing technology into asphalt pavements results in more durable roadways while also addressing environmental and economic concerns by reducing costs and emissions throughout the maintenance and production processes. Such a combination of environmentally friendly materials can contribute in the development of asphalt pavements with self-healing technologies as well as the building of asphalt pavements as a whole.

Materials were first heated at 150°C during approximately 2h and then mixed during approximately 3.5 min. The raw materials were added into the bowl in the following order: first, bitumen and fibers; second, coarse aggregate; third, fine aggregate and finally, filler. To determine the flexural strength and strain capacity of asphalt concrete, a three-point bending test was carried out in accordance with KS F 2395. According to KS F 2395, the flexural strength and strain capacity of a material must be determined at a low temperature of less than 10 degrees Celsius. In contrast, because we typically utilize the asphalt concrete at room temperature, the bending tests were conducted at both room temperature and cold temperatures. The produced plate-type specimen was sliced into three parts with dimensions of 300 mm x 100 mm x 50 mm to assess the flexural performance. A uniaxial load was applied through a UTM with a maximum loading capacity of 250 KN under displacement control. For the low temperature circumstances, the mid-span deflection was measured using a linear variable differential transformer (LVDT) and stroke, whereas the ambient temperature conditions were measured using a linear variable differential transformer (LVDT) and stroke. As seen in figure. **,** the test setup for the three-point bending test of asphalt concrete performed at room temperature is depicted.

Figure 2.3: point Bending Beam Test performed in UTM

2.7 Chapter Summary

When a improved asphalt is developed during the early pavement installation and heated with microwave energy, it acts as a self-healing substantial, or a substance that can mend itself, resulting in extremely dependable and durable asphalt pavements. In this situation, the modified asphalt would be capable of self-healing during its life. A improved asphalt that was utilized through the first installation and heated by microwave heating would also be useful for asphalt pavement recycling. This technology may also be used to repair standard asphalt pavements quickly or even to cure cracks. A microwave device placed over the fractures warms the modified asphalt, which results in rapid crack healing. In the case of self-healing, the microwave device is installed immediately on top of the existing pavement; no changed asphalt is required prior to heating.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the technique used to accomplish the study's objectives, which include material procurement, material testing, specimen preparation, and different specimen tests. The experiment was conducted on a control sample and a sample containing steel fiber. This chapter discusses determining OBC using Marshal Mix Design. On the basis of the OBC, performance samples will be created with and without steel fiber addition. Particle loss testing, moisture susceptibility testing, and healing evaluation are all included in the performance testing. This chapter will explain the equipment used, the method for preparing samples, and the input parameters utilized during testing on the specimen obtained.

Virgin material was obtained from the Margalla highlands crush plant site, and PARCO bitumen (60/70) was purchased. A local merchant supplied steel fiber. These materials were delivered to the laboratory, where numerous experiments on aggregate and bitumen were done. Following that, Marshall specimens were created for the purpose of determining the OBC of samples. Following that, these OBCs were utilized to create samples for performance testing. The healing process was evaluated using the three-point bending beam test.

3.2 Aggregate Testing

Aggregate testing for coarse and fine aggregates was performed according to required standards. The testing includes shape test of aggregate, specific gravity test, impact value test, los angles abrasion test, crushing value of aggregates.

3.2.1 Aggregate

Aggregate was collected from Margalla hills crush site. Aggregate is critical for the strength and longevity of HMA pavements. It bears the utmost weight that the pavement can bear. The texture and form of aggregate have a significant effect on these strength-relatedcharacteristics. In general, aggregates with a greater degree of angularity and rough texture are better able to withstand stresses in pavement caused by repetitive loads. Numerous tests are conducted in accordance with ASTM and BS standards to determine the aggregate characteristicsthat impact the pavement.

Figure 3. 1: Margalla Hills Crush Plant

3.2.2 Bitumen

In Pakistan, mostly bitumen of grade 60/70 is utilized per weather conditions. Sobitumen of grade 60/70 was collected from PARCO.

3.2.3 Steel Fiber

Steel fiber was acquired from local vendor.

Figure 3. 2: Steel fiber

3.3 Aggregate Testing

The term aggregate is largely used for mineral materials such as sand, crushed stone, and gravel. They can occur naturally or be manufactured. Large rock formation from which natural aggregates are mined is called quarry. These rocks are then crushed into suitable and usable sizes. Aggregate provides the skeletal structure of the mix and is responsible for the load-bearing capacity of the pavement by transferring the moving load to the under laying layers. The basic strength properties of asphaltic mixtures are influenced by the size, the shape, the texture of the surface, and aggregate gradation for which it needs to be strong, durable, tough, hard, properly graded with low porosity. It must be clean, rough, and have hydrophobic surfaces. Many tests have been performed on the selected aggregate in the laboratory.

3.3.1 Aggregate Tests

Aggregate repels deformation in pavements, so it must have enough strength and surface to endure itsintended use in the pavement. The following tests were conducted on an aggregate basis.

Table 3. 1: Aggregate testing

S. No.	Test	Standard
1	Flakiness Index	ASTM D 4791
2	Elongated Index	ASTM D 4791
3	Los Angeles Abrasion test	ASTM C 131
4	Aggregate Impact Value Test	BS 812
5	Crushing Value Test of Aggregate	BS-812
6	Specific Gravity Test	ASTM C 127 & ASTM C 128

3.3.1.1 Shape test of Aggregate (ASTM D 4791-99)

The workability and strength of asphaltic mixtures mainly depend on the shape of the particles. It also affects the bound and unbound aggregate mix properties. The required effort for compaction is also influenced by the shape of aggregate particle which is necessary to achieve the desired density. This test provides a criterion to check the compatibility of aggregate and to find the properties and characteristics of the relative shape of the coarse aggregate. It determines the percentage of elongated and flat particles or both present in the sample of the aggregate. This examination is performed by following ASTM D 4791 which categorizes particles as flaky if their lesser dimension is smaller than 0.6 of their mean sieve size while the particles are called elongated if their length is larger than 1.8 of their mean sieve size. During the compaction practice, these flat and elongated particles can lock up more swiftly making the process more problematic. Also during the process of compaction, the aggregate particles reorient while these particles tend to break under compaction consequently making the aggregate gradation finer which helps to reduce the Voids in Mineral Aggregates (VMA). According to specifications of the ASTM, the percentage of elongated and flat particles must be fewer than or equal to 15%. Results of test performed on selected aggregates are within an acceptable range. Table shows the result of flat and elongated particles test. The percentage of flaky and elongated particles in aggregate is determined by this test. To facilitate aggregate particle interlocking, an angular form is desirable. The flakiness index must be less than 15% and the elongation index should be less than 15%.

Figure 3. 3: Shape Test Apparatus

3.3.1.2 Specific Gravity Test (ASTM C 127 & ASTM C 128)

Three weights were determined for calculating Specific gravity i.e. weight of oven dried aggregate, weight of aggregate completely submerged in water, and Saturated surface dry weight of aggregate. Specific Gravity of Fine aggregate and water absorption was determined using ASTM C 128.

Fine and coarse aggregate specific gravity is of major importance in the production of asphalt paving mixtures. It is frequently used by engineers in the design of pavement and construction too. The amount of binder absorbed and VMA is evaluated based on bulk specific gravity. Relative density is also the term used for specific gravity representing the weight volume characteristics of aggregate material. It is the mass to volume ratio of a material at a persistent temperature. The coarse aggregates are those which retain on sieve No. 4 while passing from No.4 sieve are termed as fine aggregate. Specific gravities of coarse and fine aggregate were determined separately.

ASTM standard procedure C 127 was followed to determine the specific gravity and water absorption of coarse particles of aggregate. The aggregates were first passed from sieve #4 and the aggregates that retained on sieve #4 were firstly dried in an oven and then soaked for 24hours in water. The aggregates were then rolled on a towel and its weight in the saturated state was noted. After this, the submerged weight of aggregates was determined and its specific gravity and water absorption were calculated. The oven-dried sample does not have any water in it while in the saturated surface-dry condition water fills the aggregate pores.

This test was conducted by following the C-128 standard procedure of ASTM. Aggregates passing sieve #4 were dipped in water for approximately 24 hrs. The aggregates were then dried up to the extent of the saturated surface condition by spraying it in a tray. The cone was placed on a level surface, filled with the fine aggregate, and compacted with a tamping rod by delivering twenty-five (25) blows. After removing the cone, the aggregates were observed. If they possessed the mold's shape and then the particles were not SSD. After drying the aggregate again, the same technique was performed until the aggregate slightly slumped with the cone removal. A pycnometer was weighted after filling it up with water to a specified mark. The sand was put in the flask and weighed again after saturated surface drying. The specific gravity andabsorption were calculated after oven drying of sand at a temperature of 110 ^{o}C.

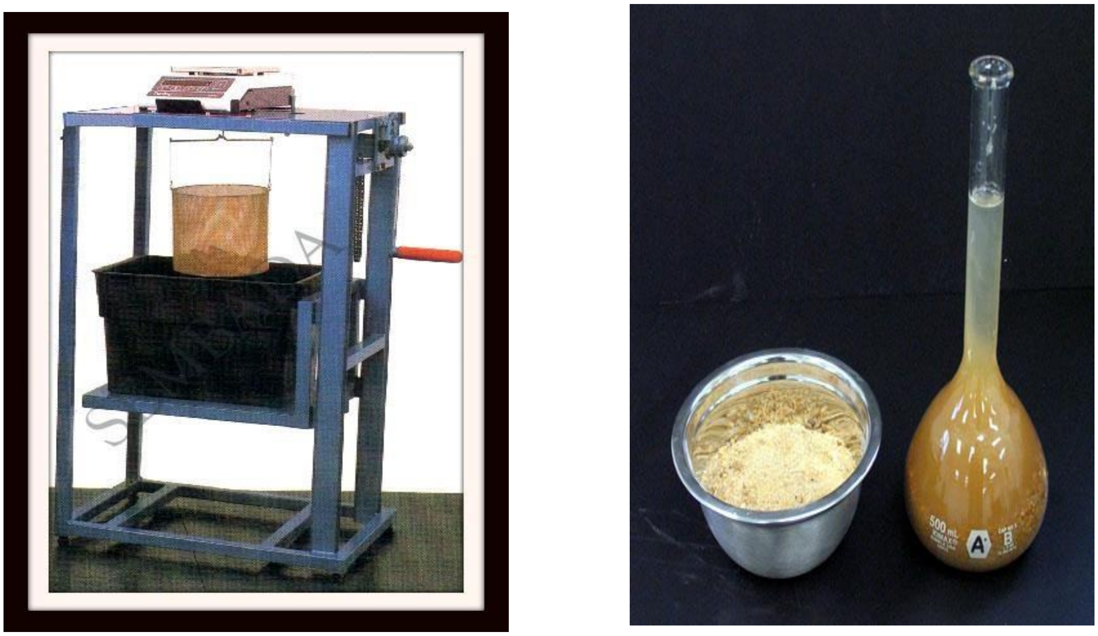

Figure 3. 4: Specific Gravity Test

3.3.1.3 Impact Value of Aggregate (BS 812)

The impact value of an aggregate indicates its resilience to a sudden shock. This method is accepted in accordance with the British Standard BS 812. The apparatus required to determine the impact value includes an impact testing machine, a cylindrical mold with a diameter of 75 mm and a depth of 50 mm, a tamping rod with a circular section of 10 mm and a length of 230 mm, and sieves in the sizes 1/2”, 3/8”, and #8. (2.36mm.) Around 350g of aggregate passing through a 1/2” sieve and retaining on a 3/8” sieve was obtained and placed in three (3) layers in the mold of the Impact Testing Machine, with each layer tamped 25 times. The sample was moved to the machine's bigger mold and 15 blows were delivered from a 38cmheight using a 13.5 to 14kg hammer. The aggregate so formed was detached and passed through filter #8. The impact value was determined by the percentage of aggregate passing through a sieve with a diameter of 2.36mm. The table below summarizes the findings.

Figure 3. 5: Impact value Test Apparatus

3.3.1.4 Los Angles Abrasion Test (ASTM C 535)

The Los Angeles (LA) Abrasion Test is frequently used to determine an aggregate's resistance to degradation. This experiment demonstrates the aggregate's toughness and abrasion resistance, i.e. its resistance to wear owing to strong traffic loads. Resistance to abrasion is critical to assess since the aggregate in the mix is subjected to high repetitive stress levels, resulting in fragmentation, deterioration, and crushing. This test is conducted using a LA Abrasion machine, a weight balance, a set of sieves, and steel balls referred to as charge. This approach used the testing methodology or grading B. 2500 g of aggregate retained on 12" and 3/8" sieves, for a total of 5000g (W1) of material, were placed in the Los Angeles abrasion instrument, together with 11 steel balls or charges. It was then rotated 500 times at a speed of 30–33 rotations per minute. The material was then sieved using a 1.7mm sieve. It was noted the weight of the sample passing through it (W2). The abrasion value was calculated using the formula = W2/W1 100. According to NHA requirements, coarse aggregates with an abrasion value of 30% or less are permitted. This test was conducted in accordance with ASTM C 131 Standard. The following table summarizes the findings of the LA Abrasion test.

Figure 3. 6: Los Angles Abrasion Machine

3.3.1.5 Crushing Value of Aggregate (BS 812)

To achieve a pavement with higher quality and strength, the aggregates must have enough strength to sustain traffic loads. The apparatus used for this test was a steel cylinder having open ends, base plate, plunger with a piston diameter of 150 mm, and a hole provided across it, so that a rod could be inserted for lifting it, cylindrical measure, balance, tamping rod, and a compressive testing machine. Aggregates were passed through a set of sieves and that passing through ½” and retaining on 3/8” were selected. The sample of aggregate was washed, oven-dried, and weighed (W1) and then added in three (3) covers into that cylindrical measure, by giving 25 number of tamping to each layer. The specimen was then shifted into the cylinder made of steel with a base plate and the plunger was inserted. Then it was placed compressing machine and tested. 4tons/minute load was applied at a uniform rate until 40tons total load was achieved. Crushed aggregate was then isolated from the steel cylinder and was passed through a sieve of 2.36mm. The passed material was collected and weighed (W2). The crushing value of aggregate was deliberated by = W2/W1 x 100. The outcomes are given in Table.

Table 3. 2 : Test results of Aggregate

Test	Specification		Result	Limits
Flakiness Index	ASTM D 4791		11.30%	≤15%
Elongation Index	ASTM D 4791		3.20%	≤15%
Aggregate Absorption	Fine	ASTM C127	2.12%	≤3%
	Coarse		0.68	≤3%
Impact Value	BS 812		18.40%	≤30%
Specific Gravity	Fine Agg	ASTM C128	2.624	-
	Coarse Agg	ASTM C127	2.631	-
LOS Angles Abrasion	ASTM C131		22.50%	≤45%

3.4 Test on Bitumen

Penetration test, softening point, ductility test, flash and fire point test, viscosity test of bitumen were performed according to their specifications.

3.4.1 Bitumen

Bitumen act as binder material in pavement and keeps aggregate in place. Bitumen is a semi-solid type material, behavior of which vary under different temperature and weather conditions. Bitumen is used as a binder in asphalt mixtures. It is blackish or dark brownish and isproduced from residues distillation of petroleum. It occurs naturally is asphalt lakes or produced in petroleum refineries from the residue of crude oil. Consistency, safety, and purity of bitumen are the properties that are necessary for engineering and construction purposes (MS-4 Manual 2003). These properties chiefly affect the asphalt mixture performance. Due to the fact that these properties fluctuate dramatically over time, the age of the binder is critical to understanding its behavior. The Strategic Highway Research Program (SHRP) has created a novel system for predicting the physical properties of bitumen in the field. This system is called the Performance Grading (PG) system. It stresses to control viscosity at low temperature but it is not a concern in our country due to the temperature of the environment. A variety of tests were performed to check the suitability of binders for HMA. Tests on binders are usually performed at 25 ^{o}C temperature to compare consistencies of asphalt binders as consistency changes withtemperature. The table below mentions tests and their standards performed on these binders. Performed tests are explained below.

Table 3.3 : Tests performed on the binder

Sr. No.	Test	Standards
1	Penetration Test	ASTM D 5
2	Flash and Fire Point	ASTM D 92
3	Softening Point	ASTM D 36
4	Ductility	ASTM D 113
5	Viscosity	ASTM D 88
6	Specific Gravity	In accordance with ASTM D 70

3.4.1.1 Penetration Test (AASHTO T 49-03)

According to AASHTO T 49-03, the temperature utilised was 25°C, the load was 100 grams, and the length of the test was 5 seconds. This is one of the earliest tests used to determine the consistency of asphalt binders. It quantifies the binder's softness and hardness in order to classify it into several standard grades. A higher penetration value shows that the binder is flexible and thin. In hot areas, binder with a low penetration value is preferable; in cold climates, binder with a high penetration value is recommended. To begin, the binder is heated to an appropriate temperature to ensure that it flows easily and does not trap air; nevertheless, the temperature should not be increased excessively, since this will damage the binder's qualities.The binder is then poured into a test container and kept at a constant temperature of 25 ^{o}C in a temperature-controlled water bath. After reaching the specified temperature, the container is removed and tested in a penetrometer by passing a 100g load through a needle for 5 seconds. Following penetration testing, five values were collected from each of two ARL 60/70 specimens. All results acquired satisfied the requirements stated for the penetration test. The penetration test result is displayed in Table 3.3.

Figure 3. 7: Penetration Test Apparatus

3.4.1.2 Softening Point (AASHTO-T-53)

ASTM D 36 is the standard that is used to conduct this test with the ring and ballapparatus. With increasing temperature, bitumen becomes softer and its viscosity decreases, despite the fact that it is a visco-elastic material. The temperature at which a sample of asphalt binder cannot withstand the weight of a 3.5g steel ball when immersed in water. Thus, it is the average of the temperatures at which two bitumen discs become sufficiently pliable to allow balls of steel to fall 25mm. To begin, the binder was heated to a temperature that allowed it to flow freely without losing its properties. Then it was pressed into horizontal discs using a mold.The balls were positioned on the discs once they were placed in the apparatus. The temperature was increased to the point where the binder permitted the balls to fall through the distances mentioned previously.

3.4.1.3 Ductility (AASHTO T 51-00)

It is done in line with ASTM D 113, which tests the binder's stretching and adhesion qualities. Bitumen's physical feature of ductility is crucial. It depicts the behaviour of bitumen as a function of temperature variations. At a standard temperature of 25 ^{o}C, this test is performed. Ductility is defined as the distance that a standard-sized specimen of binder (put in abriquette with a 1 in2 cross-sectional area) lengthens without breaking when its two ends are pulled apart at a rate of 5cm/minute at a predetermined temperature of 25 ^{o}C. To pass the ductility test, the specimen must be a minimum of 100cm in length. When exposed to repeated severe traffic loads, asphalt mixes formed from less ductile bitumen fracture. Table 3 summarizes the findings of the ductility test performed on both binders.

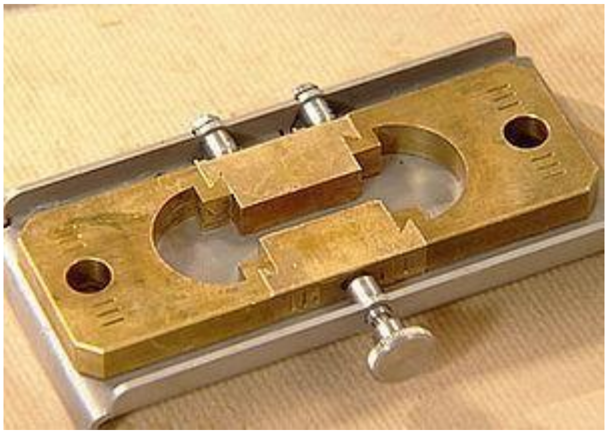

Figure 3. 8: Ductility Test of bitumen

3.5.1.4 Flash and Fire point (D3143/D3143M-13)

Flash and Fire point test was conducted as per D3143/D3143M-13 standards. A binder's flashpoint is the temperature at which the fumes of a bitumen sample in COC produce a flash in the presence of flame. The surface of the binder catches fire and produces flames for at least five seconds; this is essentially the fire point. A brass cup was filled to a specified volume with bitumen. It was then continuously heated and a test flare 30 was passed above it at predetermined intervals. When the conditions outlined above were met, the temperature at which flash and fire occurred was determined. Three separate trials were conducted to determine these temperatures for each binder.

3.5.1.5 Viscosity test (ASTM D 4402 – 06)

AASHTO procedure T-316 is used to determine the viscosity of the binder at elevated temperatures using a rotational viscometer. At elevated temperatures, viscosity is critical because it regulates pumping, workability, mixing ability, and compaction. It can be carried out at a variety of temperatures, but for Performance Grade bitumen, it is carried out between 135°C and 160°C due to the similar production temperature regardless of the environmental conditions.

As specified in ASTM D 4402 and AASHTO T 316, the Brookfield RV apparatuswas used for this purpose. To begin, we heated the sample chamber, spindle, and environmental chamber to 135 ^{o}C and 160 ^{o}C, respectively. The bitumen sample was then heated to facilitate flow and properly poured into the sample chamber after being stirred to remove any trapped air bubbles. After inserting the sample into a temperature controller unit, a spindle No. 27 was gently lowered into the sample. It was then heated to the desired temperature (135 ^{o}C or 160 ^{o}C) within thirty minutes and allowed to equilibrate for ten minutes at that temperature. Spindle should be rotated at a rate of 20 revolutions per minute to achieve a torque of between 2 and 98 percent. Take three readings after the sample has reached room temperature and equilibrated, allowing one minute between each. Viscosity is determined by averaging the three readings.

Figure 3. 9: Viscosity Test Apparatus

Table 3.4: Results of tests performed on bitumen

S No.	Tests	Standards	Results
1	Penetration test@25°C	ASTM D 5	66
2	Flash Point(°C)	ASTM D 92	264
3	Fire Point(°C)	ASTM D 92	297
4	Softening point(°C)	ASTM D 36	48
5	Viscosity Test (Pa.sec)	ASTM D 88	0.2522
6	Ductility Test(cm)	ASTM 113	113
7	Specific Gravity	ASTM D 70	1.02

3.5 Asphalt Mixture Preparation

These samples were prepared as per Marshall Mix Design method in order to determine the optimum bitumen content (OBC).

3.5.1 Preparation of Materials for Mixing/Pre-Heating

Aggregate was sieved for different sizes and oven dried. Total weight of a sample of Marshall Mix is 1200g and weight of aggregate and bitumen varied according to percentage of binder in each sample. NHA gradation B is followed for aggregate specs.

Total Sample Weight = Weight of Aggregate + Weight of Bitumen

Prior to mixing of material, Bitumen and Aggregate were pre-heated in a temperature range of 110-120 in an Electric Oven.

3.5.2 Mixing of Materials

The mixing was done at a temperature of 120-150 degrees. The aggregates and bitumen/PMB werewarmed and properly mixed before use. The mixing was carried out until all of the particles were thoroughly covered.

3.5.3 Compaction of Sample

The number of blows required is dependent on the type of road surface that needs to be prepared. Compaction blows are administered on each side of the sample .The mould waslubricated before the filter paper was placed inside of it. After that, the samples were transported to a mould and subjected to 75 blows on each side by a Marshall Compactor to accomplish compaction.

Figure 3. 10: Compaction of Sample

Figure 3. 11: Marshall Samples

3.6 Determination of Optimum Bitumen Content (OBC)

Using the Gmb and Gmm values, it is possible to calculate the volumetric characteristics of the specimen after it has been allowed to cool down to ambient temperature. ASTM D2726 AND ASTM D2041, respectively, are used to conduct gmb and gmm testing on the samples. First, the specimen's weight in air is calculated, followed by its weight in water and the SSD weight, all of which are used to estimate Gmb.

Figure 3. 12: Gmb Calculation for Marshall Sample

After the determination of G_{mb}, the specimen conditioned and then established for Marshall Stability and flow using Marshall Equipment. After placing the sample in Marshall Apparatus, it is loaded at constant deformation rate of 5mm/minute until the specimen fails. The highest load that the specimen can withstand is represented by its Stability value, and the strain that occurs when the specimen is subjected to the maximum load is represented by the flow number in millimeters. For a surface intended to withstand severe traffic loads, the Marshal Mix Design Criteria MS-2 recommends that the Stability value be not less than 8.006 KN and that the flow rate be between 2 and 3 millimeters per second.

For G_{mm} calculation weight the loose mix, then find the calibration weight ofapparatus, after that transfer the mix to apparatus and apply vacuum. After the removal of air entrapped ari in mix weigh again the apparatus containing mix also.

3.6.1 Volumetric properties of mix

The flow and stability, volumetric properties of controlled mix are shown in table.

Table 3. 5: Volumetric Properties

Asphalt%	Gmb	Gmm	Va (%)	VMA (%)	VFA (%)	Stability (KN)	Flow (mm)
3.5	2.35	2.51	6.09	13.41	54.6	11.97	2.25
4	2.37	2.49	4.86	13.40	63.8	13.27	2.55
4.5	2.39	2.48	3.76	13.09	71.3	11.879	2.74
5	2.39	2.47	2.97	13.36	77.8	8.954	3.548
5.5	2.4	2.45	1.92	13.56	85.8	8.31	4.08

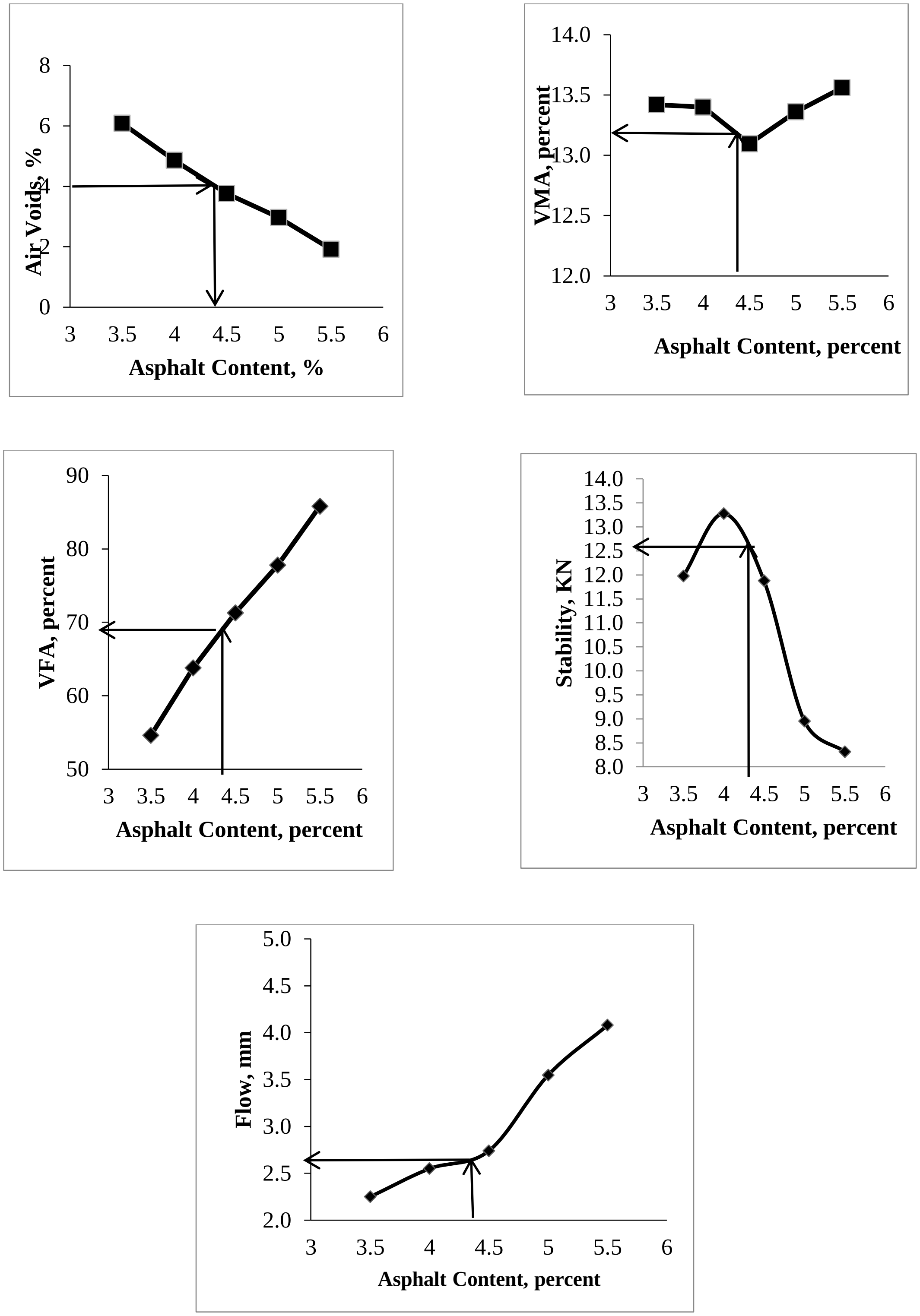

Figure 3.13: Volumetric Properties

The asphalt content at 4% air voids corresponds to OBC. The mix has an OBC of 4.37%. Other volumetric properties are checked at the OBC obtained. If all the properties are within the limits specified by MS -2 then well and good otherwise OBC will have to be adjusted.According to MS-2 Criteria, the VMA value should be greater than 13% while in this case it is 13.24% i.e. within the range. VFA should be in the range of 65 to 75 percent, however the computed result is 69.22 percent. When it comes to stability, the minimum value should be
8.006 KN, but in this situation, it is found to be 12.4 KN, and the flow rate of 2.69 mm falls within the range of 2-3.5 mm.

Table 3. 6: Job Mix Formula

Parameters	Value Measured	Limits	Remarks
OBC	4.37	-	-
VMA (%)	13.24	≥13	Pass
VFA (%)	69.22	65-75	Pass
Stability (KN)	12.4	≥8.006	Pass
Flow (mm)	2.69	2-3.5	Pass

3.7 Preparation of Sample for Performance Tests

After finding out OBC, sample for performance tests were prepared i.e. for MoistureSusceptibility and three point bending test.

3.7.1 Moisture Susceptibility

The Samples for Moisture Susceptibility were prepared according to ALDOT 361, forwhich Marshall sample having 2.5” height and 4” diameter were prepared. The samples formoisture susceptibility falls into two category normal Marshall Samples and other having fiber. Sample having steel fiber and normal samples were prepared at OBC with the different percentages of steel fiber i.e. 2%, 4% , 6% and 8%.

Table 3.7: Test Matrix for Moisture Susceptibility Test

Fiber%	Unconditioned Samples	Conditioned Samples	Sub-Total
0	2	2	4
2	2	2	4
4	2	2	4
6	2	2	4
8	2	2	4
Total			24

3.8 Three Point bending

The healing effectiveness of steel fiber integrated asphalt was determined through the useof a three-point bending test. Extensive testing was conducted to determine the link between healing time and healing temperature using the samples provided. The samples were healed at four different temperatures: 40 C, 60 C, 80 C, and 100 C. The effectiveness of healing was assessed at various resting times, including 24 hours, 48 hours, 72 hours, and 96 hours. Formula for Healing index:

$HI = Cb / Ca * 100\%$

where HI is the healing index , Ca is before healing bending strength (MPa) and Cb is thebending strength (MPa) after b cycles of healing.

Three Point Bending Test

Table 3. 8: Test Matrix for 3 Point Bending

Sr. No	Steel Fiber %	Heating Time (Sec)	Healing Time (Hrs)	No. of tests
	Control			
1	0	40	24	3
2	0	60	48	3
3	0	80	72	3
4	0	100	96	3
	Fiber			
5	6	40	24	3
6	6	60	48	3
7	6	80	72	3
8	6	100	96	3

Figure 3. 14: Sample Preparation

3.9 Chapter Summary

This chapter discusses aggregate, bitumen, and fiber testing. Following that, the material that met the criteria was utilized to produce Bituminous Mix samples. The volumetric characteristics of the mixture were estimated, as well as the OBC. The obtained OBC value was then utilized to create samples containing steel fibers for performance testing,namely the Moisture Susceptibility and 3 Point Bending Test.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

The behavior of blends including modest percentages of steel fiber is compared to that of control mixes including traditional aggregate. Parco 60/70 was utilized as a binder, while steel fiber recovered from tires was employed in the NHA-B gradation. The NHA – B gradation is somewhat coarser than that of MS-2. The objectives of this study were to characterize HMA mixes incorporating different quantities of steel fiber and to evaluate the asphalt mixes' self-healing capability.

4.2 Steel Fiber Testing

The objective of this effort was to examine the possibility of using recycled tire steel fibers to create self-healing asphalt concrete. To attain this aim, a survey of the literature was conducted to ascertain whether procedures and materials had been previously used in the fabrication of self-healing asphalt concrete samples. The purpose of this study was to determine if steel fibers combined with microwave heating might be used to increase the self- efficiency of asphalt concrete. The recovered fibers were chopped as necessary to ensure that the addition mixed uniformly into the mix.

Figure 4. 1: Steel Fiber

4.3 Scanning Electron Microscopy (SEM)

The scanning electron microscope (SEM) is the most widely used method for studying the microscopic morphology of materials. The scanning electron microscope (SEM) is a type of microscope that scans a exterior with a concentrated beam of electrons rather than light, and itmay generate images with atomic resolution. In the presence of atoms in the sample, electrons interact with them, producing in a range of signals that offer information about the exterior structure and chemical configuration of the sample (Figure 4.2).

In this study, the surface and composition of the fiber utilized in the asphalt concrete matrix are being investigated. This is the primary objective of the research. This was done by the application of scanning electron microscopy (SEM) technology. By employing a scanning electron microscope (SEM), we were able to obtain a deeper knowledge of the microstructurecharacteristics of the steel fiber and how they work in the bonding process with asphalt concrete.

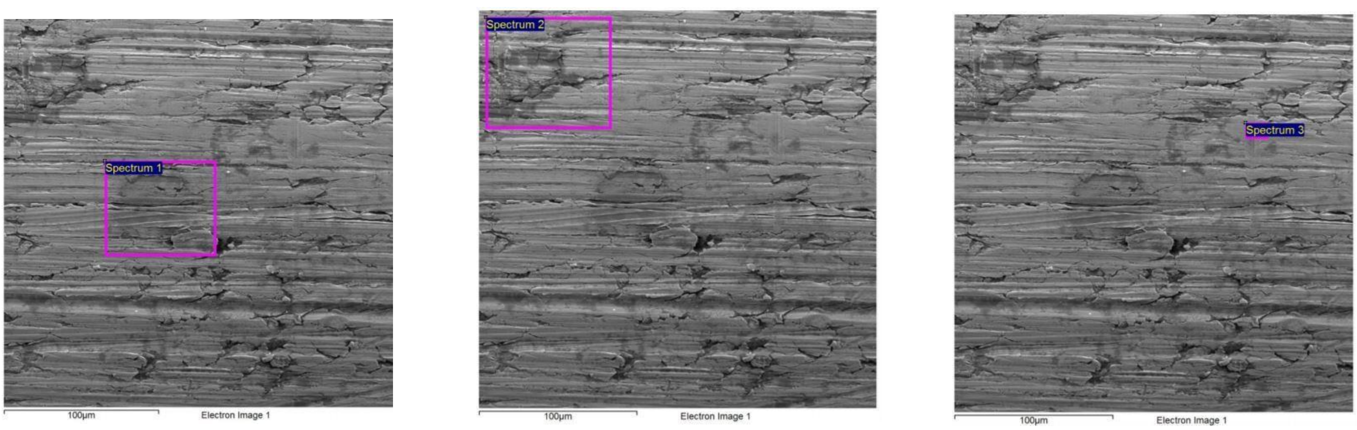

Figure 4.2: SEM of Steel Fiber

The link among the fiber and the asphalt is rather strong because of its rough surface (as seen in all the images, which are shown in Fig. 4.2. This shows that the fiber and asphalt are well weathered; a strong physical force of connection. Although the surface of the steel fiber seems smooth on a macroscopic level, the macroscopic dimension is always uneven. On top of fiber phase, an asphalt layer developed, creating a densely efficient structure and mechanical anchor effect equivalent to that of the asphalt layer on top of the fiber layer. The fact that the interface between the asphalt-fiber phases is not a single point, but rather a wide contact area demonstrates the unusually effective penetration of the asphalt phas*e* into the fiber phase. In terms of macro-performance, the steel fiber boosts the resistance of asphalt concrete toa low deformation at low temperatures. Macro performance enhancements are simultaneously introduced, such as resilience to fatigue and toughness. The force of an interfacial connection depends onthe energy of the bond from fiber to asphalt, according to the theory of chemical bonds.

4.4 Energy Dispersive Spectroscopy (EDS)

Energy Dispersive Spectroscopy was utilized to characterize the chemical composition of the steel fiber used to increase the self-healing effectiveness of an asphalt mixture (EDS). Using a spectrometer, the fundamental element composition and elemental content of metallic waste (fibers) were determined.

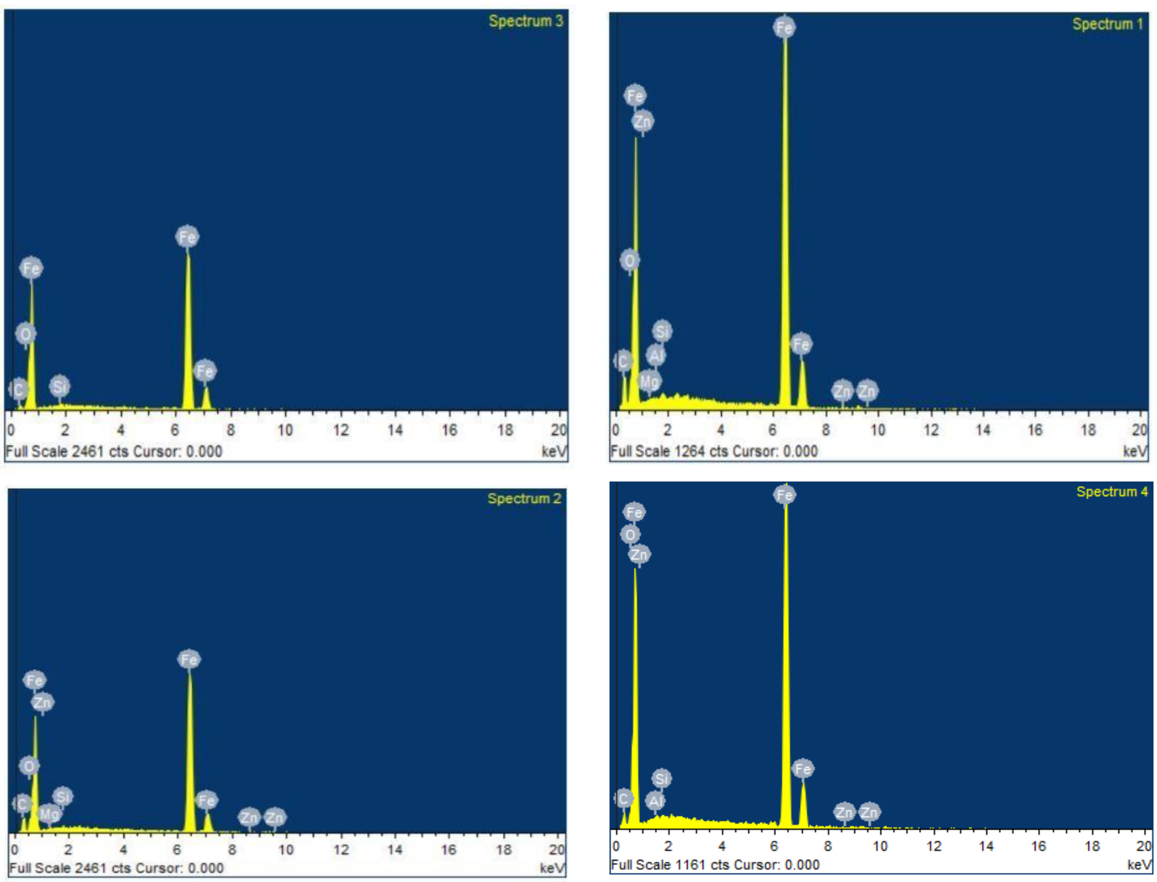

Figure 4. 3 : EDS Result

4.5 Moisture Susceptibility Test

Moisture Susceptibility testing was performed out in accordance with ALDOT 361-88. One set wasproduced for conditioned samples and the other for unconditioned samples. Unconditioned samples required just one hour of conditioning prior to testing by maintaining the sample at 25 °C (i.e. the Testing Temperature) in a temperature controlled chamber. However, for the Conditioned Sample, the sample was maintained in a water bath for 24 hours at 60°C and then for 1 hour at 25°C (i.e. the Testing Temperature). Both sets of samples were then loaded into the UTM machine at a rate of 50mm/min. Themaximum load that might cause failure was specified in kN. Tensile Strength was calculated using the provided Formula. The average Tensile Strength of the conditioned sample was compared to that of the unconditioned sample.

$$St = \frac{2000P}{\pi D t}$$

Where,

St= Tensile StrengthP= Load in N

D= Sample Dia in mm

t = Sample thickness in mm

$$TSR = \frac{S2}{S1}$$

Where,

TSR> 80%

S2 = Avg. Tensile Strength (unconditioned)   S1 = Avg. Tensile Strength (conditioned)

4.5.1 Moisture susceptibility test result

Figure shows that sample with 6 % of steel fiber have highest value of TSR.Thus, incorporation of steel fiber decreases moisture susceptibility of Asphalt sample.

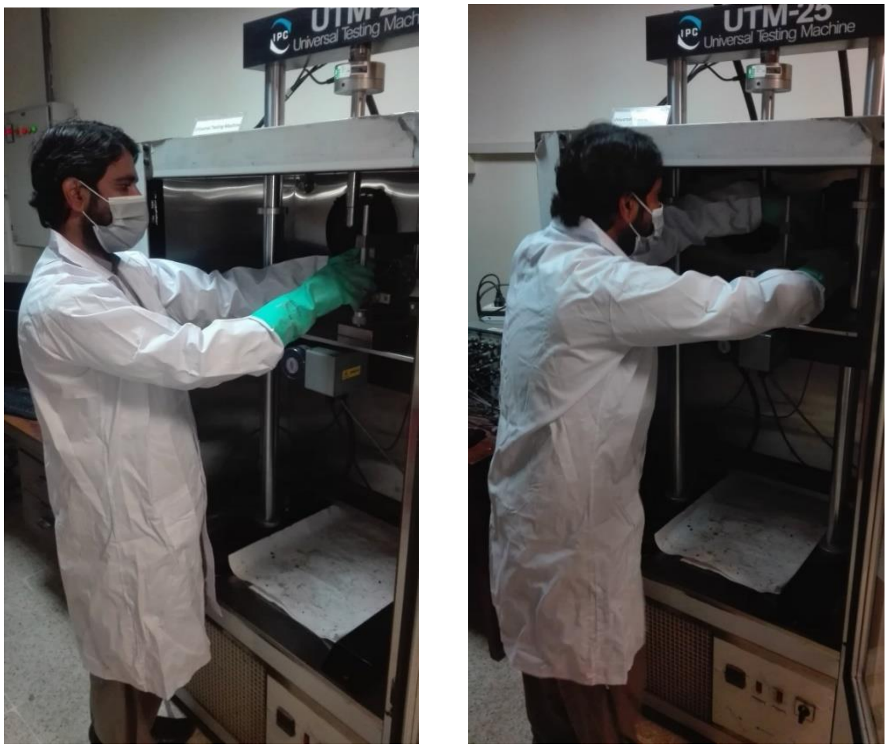

Figure 4. 4: Moisture Susceptibility test

Table 4.1: Results for Moisture Susceptibility Test

Fiber content (%)	Tensile Strength (Uncond.) (kpa)	Tensile Strength (Cond.) (kpa)	TSR (%)
0%	795.56	758.5	95.342
2%	796.5	778.5	97.74
4%	807.67	793.8	98.283
6%	**809.17**	**801.3**	**99.027**
8%	798.3	780.1	97.72

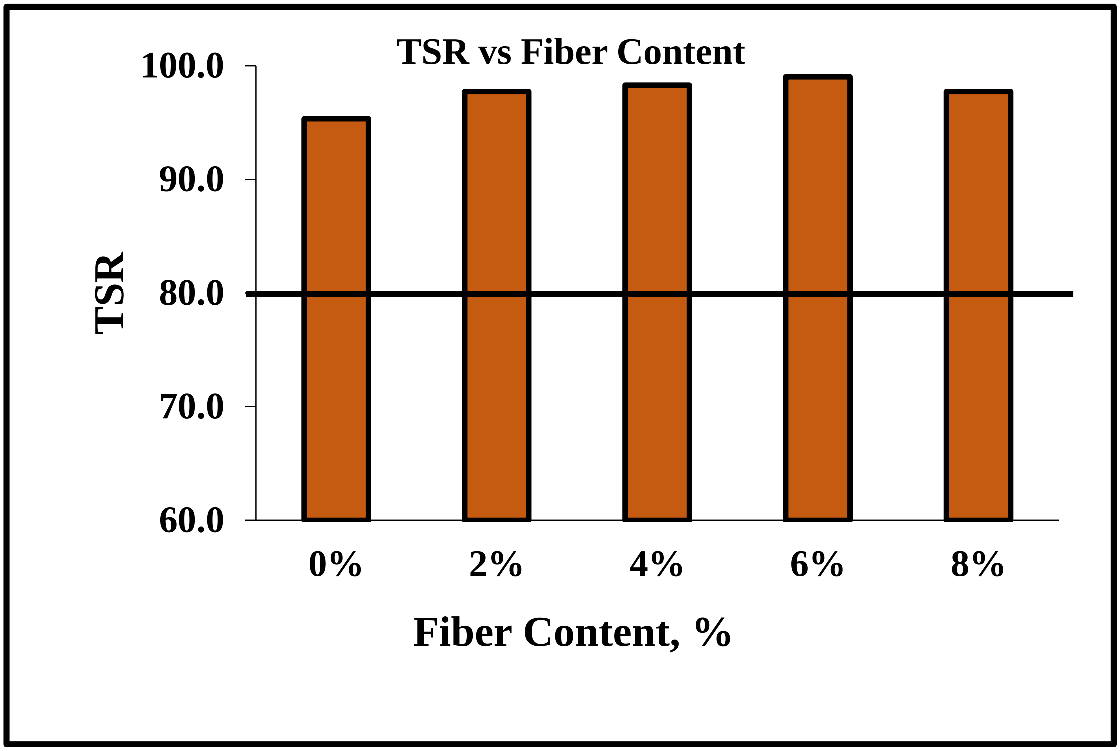

Figure 4.5: Moisture Susceptibility Test

4.6 Three Point Bending test and Healing Efficiency of Asphalt Mortar

Three Point bending test was used to find out healing efficiency of steel fiber incorporated asphalt. Samples were prepared and extensive testing was done to establish relationship between healingtime and healing temperature. Strength of beams before healing and after healing is compared to find out healing index. The samples were radiated in a microwave oven for varying amounts of time.The microwave has a power output of 700 watts and a frequency of 2.45 GHz. The selected radiation periods were 40, 60, 80, and 100. The samples were tested, microwaved and given rest period of 24 hrs, 48 hrs, 72 hrs and 96 hrs.

4.6.1 Three Point Bending Test Results

Three point bending test was performed at radiation periods were 40, 60, 80, and 100 secs and rest period of 24 hrs, 48 hrs, 72 hrs and 96 hrs. We can clearly see the healing level difference between samples without steel fiber and sample with steel fiber.

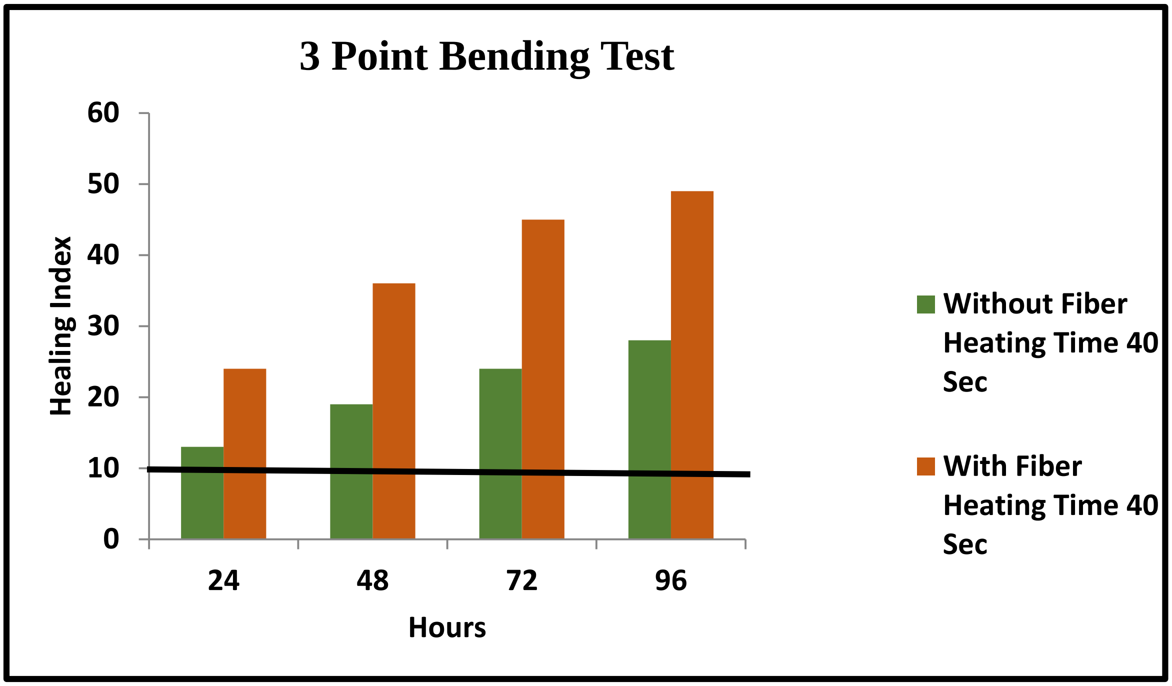

Figure 4.6 :Healing Index @40 Sec

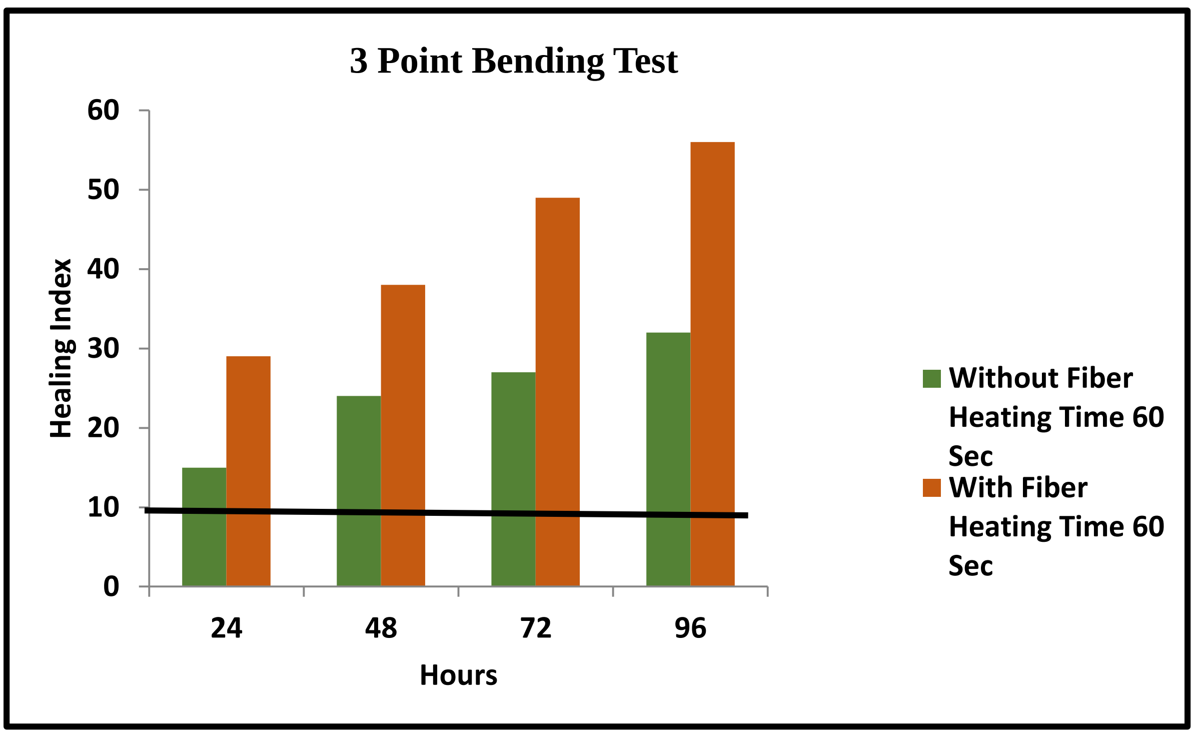

Figure 4.7: Healing Index @60 Sec

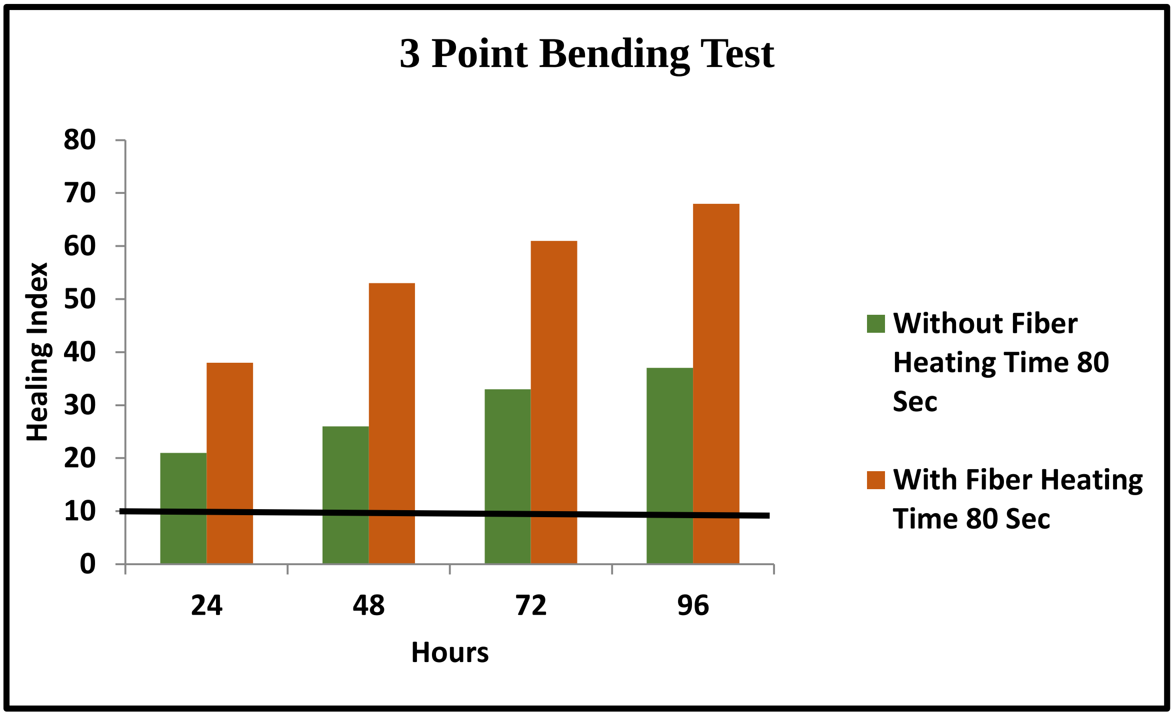

Figure 4.8: Graph for Healing Index @80 Sec

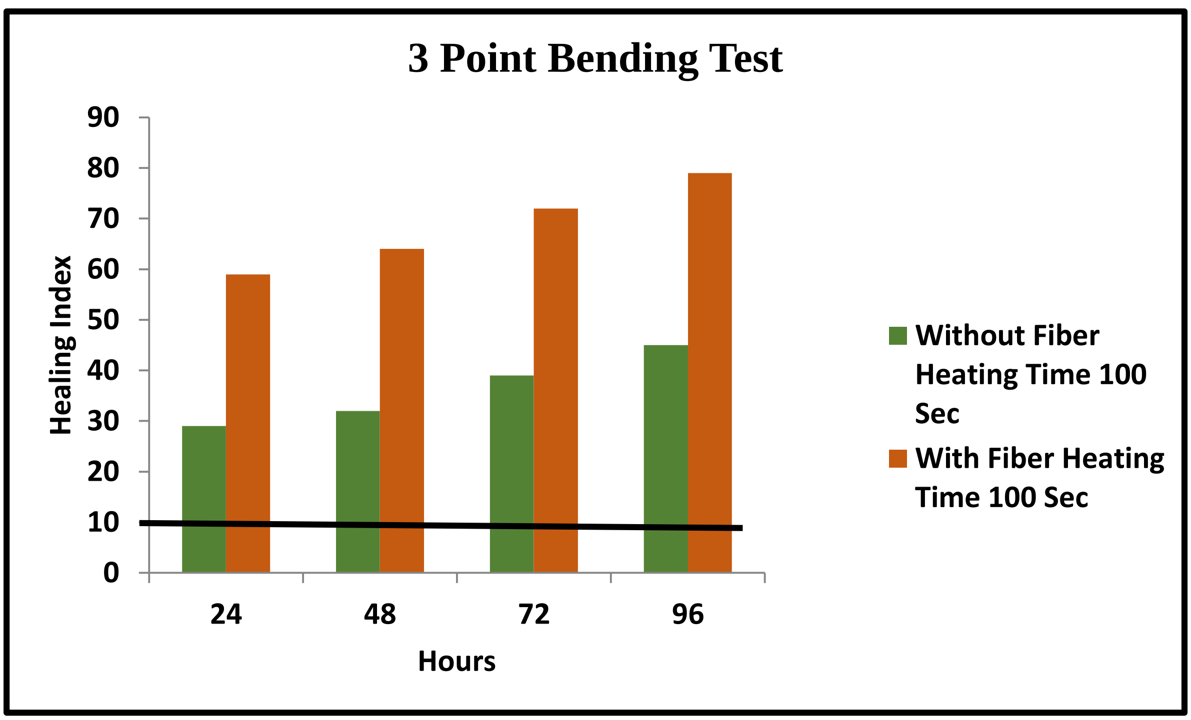

Figure 4.9:Healing Index @100 Sec

The healing index of samples increases heating time and rest time is increased. Moreover, use of steelfiber has improved healing efficiency of asphalt in comparison to control samples.

4.7 Cost Estimation

One kilometer of road segment is supposed for the cost comparison of virgin mix and modified mix containing steel fiber. Standard lane width of 3.6 meters was supposed with thickness of 63.5 mm. Cost for the lower layers base and sub-base and preparation cost of the subgrade was completely overlooked as they were supposed of related properties for both the mixes. Only cost of HMA surface course is deliberated in this comparison. For estimation of cost, NHA Composite Schedule Rates (CSR) is used. Cost comparison of virgin HMA and steel fiber modified HMA per kilometer per lane of a road segment was calculated and listed as below.

Table 4.2: Cost Comparison (with steel fiber)

Quantity and Cost Estimation										
Description: Single Lane Highway										
Description	Length	Lane Width	Layer Thickness	Volume of Material	Density of Asphalt	Asphalt Mix	Bitumen (4.37%)		Crush	Furnace Oil
	(m)	(m)	(m)	(m3)		(ton)	(ton)		(ton)	(per ton HMA)
							Virgin	6% Fiber		
Wearing Course	1000	3.6	0.0635	228.6	2.36	539.436	22.158902	1.414398	515.8627	
			Cost per Ton				110,037	30000	1000	1339.23
			Cost per Total HMA				2438299.099	42431.94	515862.7	722428.8743
		Total Cost (Pakistani Rupees)				**3719022.614**				

Table 4.3 : Cost Comparison (without steel fiber)

Quantity and Cost Estimation									
Description: Single Lane Highway									
Description	Length	Lane Width	Layer Thickness	Volume of Material	Density of Asphalt	Asphalt Mix	Bitumen (4.37%)	Crush	Furnace Oil
	(m)	(m)	(m)	(m3)		(ton)	(ton)	(ton)	(per ton HMA)
Wearing Course	1000	3.6	0.0635	228.6	2.36	539.436	23.5733	515.8627	
		Cost per Ton					110,037	1000	1339.23
			Cost per Total HMA				2593935.212	515862.7	722428.8743
		Total Cost (Pakistani Rupees)				3832226.786			

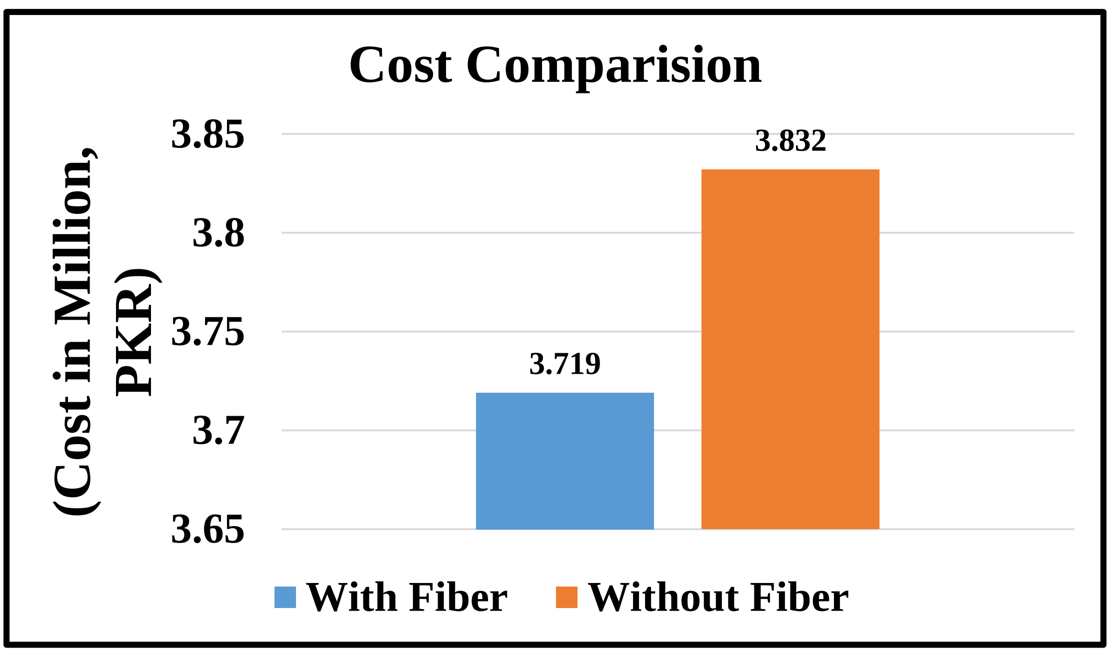

Figure 4.10: Cost Comparison with and without steel fiber

4.8 Chapter Summary

This chapter covered the comprehensive examination of performance testing results. The moisture susceptibility value obtained is addressed in relation to the increase in TSR values. Tables and graphs were used to examine the performance testing results. The results of the three-point bending test are explained in detail, complete with graphs.

CHAPTER 5

CONCLUSION

5.1 Summary

This research directed to study characteristics of asphalt mixtures containing steel fiber produced locally, by using performance tests i.e. moisture susceptibility test and three point bending tests. NHA-B gradation was adopted for this study. Limestone aggregate from the Margalla quarry was used as a conventional aggregate. Bitumen grade 60/70 was acquired of PARCO. Samples with 4 in diameter were prepared through Marshall mix design and compacted using marshal compactor. Marshal mix design was carried out for medium traffic volume. Moisture susceptibility test was accompanied to know about the behavior of asphalt with steel fiber at moisture level by using conditioned and unconditioned samples. Three point bending test was also carried out at 25 C, using 40 ^{o}C to 100 ^{o}C heating time and 24hr, 48hr, 72hr and 96hr of healing time. Loads were applied for obtaining Healing Index by the UTM machine.

5.2 Conclusion

The mechanical and self-healing capabilities of asphalt concrete reinforced with steel fiber were investigated in this work. Tests (SEM, XRF, Moisture Susceptibility and 3 Point bending test) were conducted, and the self-healing potential of fully damaged asphalt concrete was determined using an microwave technique. Steel fiber has been found to be successfullyenhancing healing capacity of bitumen used in asphalt pavement. The following conclusions are obtained from the aforementioned test findings and discussion.

5.2.1 Steel Fiber Characterization

- Steel fiber was obtained from recycled waste tire. This is an important step in reducingdisposal problem of tires that cause abundant pollution.
- SEM of steel fiber confirms rough microscopic surface of fiber that is synergistic to enhanced bonding of fiber and asphalt.
- SEM confirms rough microscopic surface that is synergistic to enhanced bonding of fiber and asphalt.

- Steel fiber has relatively smooth surface macroscopically, but small ridges, cracks and malformations can be observed on microscopic level.

5.2.2 Steel fiber effect on Asphalt performance

- Steel fiber is heated by the microwave radiation that in turn heats bitumen and makein flow in cracks. Our research confirmed that,
- First, moisture susceptibility test of asphalt proved that caps improved the watersensitivity of asphalt sample.
- 3 Point Bending test performed at different temperature and healing times showed that with increasing temperature and healing time, healing level increases. Healing level increases at 6% steel fiber at 25 °C for 48 hrs. and 120 hrs. Healing time
- Asphalt specimens tested on 3 Point Bending Test proved that sample with 6% offibers showed 40% more healing.

5.3 Recommendations

This part presents recommendations that were not included this particular study due to shortage of time and funds:

- Different materials such as silica/ limes/ rubber can be used to modify mixture composition. Steel fiber mechanical strength canbe evaluated with reference to length / Thickness ratio.

- Fiber amount broken during mixing and compaction can be quantified. The effect of environmental factors on fiber quality canalso be evaluated. For example, effect of rust on fiber.

- Fiber can be studied in combination with induction heating technique, inotropic gelation to develop a synergy betweenthese techniques.

- Economic feasibility analysis can be done to study life cycle cost assessment.

- Healing can be studied using CT scans to evaluate effect of fiber content on healing level with respect to crack width.

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APPENDIX 1

MARSHAL MIX DESIGN

Marshall Test Report																
Projec tMuhammad Nadeem (MS Thesis)																
Aggregate Source : Margala							Bitumen: Parco 60/70									
		Mass, grams of compacted					Mass, grams of loose Mix							Stability, (KN)		
% AC by wt. of mix, Spec. No.	Spec. Height in. (mm)	In Air (A)	In Water θ	Sat. Surface Dry in Air (B)	B-C	Bulk S.G. Specimen (Gmb) Gmb=A/(B-C)	Dry Weight (a)	Calibration Weight = wt: of Pycnometer+ Glass Lid+ Water (b)	wt: of Sample + Water + Pycnometer and Lid θ	Max. S.G.(loose Mix) (Gmm)=a/b-(c-a)	%Air Voids	% VMA	% VFA	Measured	Adjusted	Flow mm
3.5-A	70.99	1188.40	711.9	1219.60	507.70	2.34	1186	6779	7503.5	2.516	6.03	13.55	55.13	12.46	10.35	2.34
3.5-B	67.18	1182.40	701.2	1204.60	503.40	2.35	1192	6779	7508.5	2.523	5.98	13.25	54.48	14.36	13.35	2.27
3.5-C	69.08	1175.50	698.3	1202.20	503.90	2.33	1174	6779	7496.1	2.515	6.31	13.85	54.05	13.80	12.28	2.08
Average	69.08	1182.10	703.8	1208.80	505.00	2.34	1184	6779	7502.7	2.518	6.10	13.55	54.54	13.54	11.99	2.23
4.0-A	66.54	1164.40	688.8	1183.60	494.80	2.35	1170	6779	7489.5	2.492	4.61	13.53	65.61	13.91	12.93	2.43
4.0-B	70.35	1178.90	701.4	1203.60	502.20	2.35	1184	6779	7499	2.498	5.09	13.75	62.68	15.91	13.21	2.52
4.0-C	65.50	1184.50	704.2	1206.30	502.10	2.36	1190	6779	7504	2.506	4.90	13.32	62.90	14.32	13.75	2.64
Average	67.46	1175.93	698.13333	1197.83	499.70	2.35	1181	6779	7497.5	2.499	4.87	13.53	63.73	14.71	13.30	2.53
4.5-A	67.49	1184.40	702.3	1201.80	499.50	2.37	1195	6779	7503.5	2.487	3.70	13.32	71.99	12.46	11.09	2.75
4.5-B	66.54	1190.40	705.6	1207.60	502.00	2.37	1198	6779	7507	2.496	4.04	13.32	69.40	13.91	12.93	2.68
4.5-C	65.00	1196.00	708.5	1211.20	502.70	2.38	1201	6779	7508	2.492	3.56	13.03	72.42	12.13	11.65	2.74
Average	66.34	1190.27	705.467	1206.87	501.40	2.37	1198	6779	7506.167	2.492	3.77	13.23	71.27	12.83	11.89	2.72
5.0-A	70.67	1192.40	720.3	1221.60	501.30	2.38	1199	6779	7505	2.483	3.22	13.51	75.97	11.52	9.56	3.32
5.0-B	65.30	1191.40	708.9	1210.60	501.70	2.37	1192	6779	7499	2.473	3.01	13.65	77.78	9.14	8.78	3.63
5.0-C	64.50	1187.50	702.3	1200.30	498.00	2.38	1192	6779	7499.5	2.476	2.70	13.29	79.49	8.92	8.56	3.74
Average	66.82	1190.43	710.5	1210.83	500.33	2.38	1194	6779	7501.167	2.477	2.98	13.48	77.73	9.86	8.97	3.56
5.5-A	66.86	1184.40	702.2	1198.60	496.40	2.39	1190	6779	7495	2.459	1.97	13.69	85.53	9.47	8.81	4.22
5.5-B	64.00	1186.40	709.3	1204.60	495.30	2.40	1190	6779	7496	2.464	1.78	13.35	86.54	9.00	9.00	4.11
5.5-C	63.25	1156.20	682.8	1169.40	486.60	2.38	1152	6779	7471	2.451	2.05	14.04	85.33	7.18	7.18	3.85
Average	64.70	1175.67	698.1	1190.87	492.77	2.39	1177	6779	7487.333	2.458	1.93	13.69	85.79	8.55	8.33	4.06

APPENDIX 2

PERFORMANCE TESTING

3-Point Bending Test

Sr No	Steel Fiber %	Heating Time (Sec)	Healing Time (Hrs)	Healing Index	Remarks	No. of tests
	Control					
1	0	40	24	15	Ok	3
2	0	40	48	21	Ok	3
3	0	40	72	26	Ok	3
4	0	40	96	29	Ok	3
	Fiber					
5	6	40	24	28	Ok	3
6	6	40	48	41	Ok	3
7	6	40	72	51	Ok	3
8	6	40	96	58	Ok	3

3-Point Bending Test

Sr No	Steel Fiber %	Heating Time (Sec)	Healing Time (Hrs)	Healing Index	Remarks	No. of tests
	Control					
1	0	60	24	18	Ok	3
2	0	60	48	26	Ok	3
3	0	60	72	30	Ok	3
4	0	60	96	40	Ok	3
	Fiber					
5	6	60	24	36	Ok	3
6	6	60	48	52	Ok	3
7	6	60	72	60	Ok	3
8	6	60	96	69	Ok	3

3-Point Bending Test

Sr No	Steel Fiber %	Heating Time (Sec)	Healing Time (Hrs)	Healing Index	Remarks	No. of tests
	Control					
1	0	80	24	23	Ok	3
2	0	80	48	29	Ok	3
3	0	80	72	35	Ok	3
4	0	80	96	41	Ok	3
	Fiber					
5	6	80	24	46	Ok	3
6	6	80	48	58	Ok	3
7	6	80	72	67	Ok	3
8	6	80	96	80	Ok	3

3-Point Bending Test

Sr No	Steel Fiber %	Heating Time (Sec)	Healing Time (Hrs)	Healing Index	Remarks	No. of tests
	Control					
1	0	100	24	29	Ok	3
2	0	100	48	32	Ok	3
3	0	100	72	36	Ok	3
4	0	100	96	45	Ok	3
	Fiber					
5	6	100	24	59	Ok	3
6	6	100	48	64	Ok	3
7	6	100	72	72	Ok	3
8	6	100	96	84	Ok	3