# Rapid Maintenance of Asphalt Concrete using Calcium Alginate Capsules with Waste Cooking Oil as a Rejuvenator

## FINAL YEAR PROJECT UG 2018

By


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| Usama Bin Sajjad | NUST BECE2018 268545 |
| Naseeb Ullah | NUST BECE2018 -245553 |
| Hamza Ahmad | NUST BECE2018 -263108 |
| Muhammad Asad | NUST BECE2018 -261221 |

Supervisor:

**Dr. Arshad Hussain**

**NUST Institute of Civil Engineering**

**School of Civil and Environmental Engineering**

**National University of Sciences and Technology,**

**Islamabad, Pakistan**


**2018**

This is to certify that the

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| Hamza Ahmad | NUST BECE2018 -263108 |
| Muhammad Asad | NUST BECE2018 -261221 |


has been accepted towards the requirements for the undergraduate degree

in

**CIVIL ENGINEEERING**


____________________________

Dr. Arshad Hussain

Assistant Professor

NUST Institute of Civil Engineering (NICE)

School of Civil and Environmental Engineering (SCEE)

National University of Sciences and Technology, Islamabad, Pakistan (NUST)

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## DEDICATION

Dedicated to our beloved parents and honorable teachers.

## ACKNOWLEDGEMENTS

Commend be to All-powerful ALLAH, Most Thoughtful, Most Kind, for presenting us with wellbeing and information to total our proposal. We would like to thank our administrator **Dr. Arshad Hussain** for giving us the opportunity to work beneath his supervision and utilize the state-of-the-art testing offices and hardware display in National Organized of Transportation in National College of Science and Innovation. It has been an honor for us to have such qualified, rumored, and lifted up individuals to administer us all through our investigate stage, and we are incapable to precise in words our appreciation towards our tutor for contributing his valuable time and information, too for all those times when he kept pushing us forward in accomplishing the set objectives of the inquire about independent of the troublesome stages of inquire about. Completing this inquire about would never have been conceivable in the event that we never had the steady backing, back, tirelessness, offer assistance and the thrust to move forward from our boss. We are moreover thankful to the staff of transportation lab, particularly Mahmood Hussain for making a difference us out within the lab testing all through our inquire about. We moreover wish to recognize PARCO Islamabad for giving us with Bitumen with so ease and bucking us up. We would too like to recognize the positive state of mind of our classmates towards our work which always gave us trust at whatever point we were on the skirt of letting the extend go. Much appreciated everybody who continually facilitated with us and made a difference us out of our issues. At the exceptionally final we would like to thank the foremost vital individuals in our lives, our guardians, and siblings, for supporting and accepting in us all through the complete extend.

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ABSTRACT

Bitumen possesses the unique phenomena of intrinsic self-healing, given the adequate rest period is provided to it. Asphalt is more preferred material used for pavement construction due to its low-cost, noise reduction and comfortable driving experience. Microcracks appear in asphalt pavement when it is subjected to repeated traffic loading, temperature variation, weather changes and oxidation, reducing the tensile strength and increasing the viscosity of bitumen. Reducing the premature aging of asphalt through the incorporation of self-healing technology in road design process can enhance the life span of asphalt pavements with considerable reduction in maintenance cost. Self-healing asphalt will reduce the number of natural resources used to maintain the road networks, decreases the traffic disruption caused by road maintenance, decreases the $CO_2$ emission and increases the road safety. This research focuses on the use of encapsulated rejuvenator in the design process to understand the healing phenomena of asphalt pavements. Na-alginate capsules were prepared which contains the waste cooking oil as rejuvenator. Asphalt samples with different capsules content (0.5%,0.75%,1%) were prepared. In-situ crack healing method was used to improve the intrinsically limited self-healing properties of bitumen to increase the service life of road. When the initial crack appears on surface, the energy released during this crack ruptures the capsule and releases the oil contained within. The released rejuvenator reduces the viscosity of nearby cracked area through the diffusion process and helps pavement restore its original properties. Moisture sensitivity of asphalt mixture containing capsule was measured using ITS. Capsules containing samples were less prone to moisture as compared to the controlled sample. Tensile strength of capsule-induced asphalt mixture was better as compared to the controlled samples. Semi-circular bending and Three point bending test were conducted to measure the healing index. Self-healing behavior of capsule-induced asphalt was calculated using the semicircular bending and three point bending test. Results of SCB and Three-point bending were used to explain the relationship between healing time and temperature. The encapsulated rejuvenator increased the healing capability of asphalt. Cost analysis is performed for a section of particular length, to have the idea about the economic aspects of the project. Initial cost of modified samples was higher than the controlled samples, but maintenance cost was considerably low.

**Keywords**: Rejuvenator, healing index, semi-circular bending

# CHAPTER 1: INTRODUCTION

## 1.1 Background:

Road transportation is the spine of Pakistan's transportation framework bookkeeping for 90% of national traveler activity and 96% of cargo development. NHA is right now the overseer of about all of Pakistan's major inter-provincial street joins called the national thruways, counting the motorways and vital streets. Roads being one of the most prominent factors of the economy, needs to have a long service life and increased safety for the users. During its life cycle, asphalt pavement is subjected to different environmental conditions, which can lead to the premature aging, loss of viscosity, and considerably reduced life span. Repeated traffic loading, harsh weather conditions, inappropriate design, and oxidation leads to the cracking and fretting in asphalt. These cracks in long run affects the rheological properties of asphalt. Life span of typical asphalt pavement is around 15 to 20 years. Incorporation of self-healing techniques can durable the life span of pavements. Encapsulated rejuvenator techniques are used now a days which helps the asphalt recover its original properties and speed up the limited self-healing phenomena in bitumen.

Over the past few years, self-healing materials have received a lot of attention, with the majority of the research focused on their potential uses in engineering materials such as polymers, concrete, and asphalt. The majority of microcracks that are observed in asphalt pavements are self-healing, provided that the surrounding environment is suitable. This results in self-healing asphalt pavements that are capable of repairing cracks on their own. A self-healing property of asphalt was discovered in laboratory studies, meaning that it can heal itself.

The aim of self-healing technology is to enable material to recover after the damage. It reduces the viscosity of damage part and helps it recover its functionality and extend the life time of pavement. (Fisher H. 2007). Rest periods are necessary for the activation of autonomous self-healing capability of the bitumen. Self-healing is the viscosity driven phenomena dependent on both the time periods and healing temperature provided to the pavement. The higher the temperature and longer the rest period, more effective will be the self-healing of asphalt. (Qiu, j et al, 2012). Healing of the crack takes place in the following three stages,

1. After the crack formation, the rejuvenator released wets the two faces of the crack.
2. Diffusion of the bituminous molecules form one face to the other.
3. Mixing of molecules helping the asphalt pavement restore its functionality.

Road construction process involves the emission of green-house gases, even more so during the maintenance and rehabilitation process. Use of encapsulated rejuvenators can significantly lower the emission of $CO_2$, helping in having a clean and eco-friendly environment.

**1.2 Problem Statement:**

Cracks are inevitable to appear in asphalt pavement, causing the pavement to deteriorate and loss tensile strength prior to the period set during the design process. These micro-cracks can lead to the macro-cracks under repeated traffic loads, causing rutting, distress, potholes and permanent failure of the pavement. Intrinsic self-healing rate of bitumen is very slow as compared to the rate of deterioration caused by the cracks. Self-healing of bitumen without any external aid requires longer rest periods and higher temperature, causing the traffic disruptions and poses threat to the security of users. Using a low-cost rejuvenator can speed up the healing phenomena is asphalt along with reduction in maintenance and rehabilitation cost as compared to the traditional rehabilitation methods.

Pakistan being the fifth largest country according to population has to import 75% of the edible oil to meet its demand. Cooking oil is used for household purposes and all the restaurants around the country. Used cooking oil is often sold by the restaurants at a cheaper rate to some local vendors. A large portion of used cooking oil is dumped at waste sites or water bodies which ultimately makes its way to the seas and oceans contributing directly to water pollution. According to researcher's used cooking oil can be a best rejuvenating agent for encapsulation process. Waste cooking oil when released at optimum temperature can help asphalt restore its original functionality.

Our research focuses on the use of waste cooking oil as rejuvenator. Sodium alginate capsules are prepared in the laboratory. These multi-compartment capsules contain waste cooking oil as rejuvenator, while the outer shell is composed of alginate. After the formation of crack, these capsule rupture under the loading pressure and waste cooking oil is released. Rejuvenator lowers the viscosity of damage parts and bituminous molecules intermix with each other through process of diffusion. This helps in the closure of crack and pavement is restored to its original position.

### 1.3 Purpose of Research:

1. Following are the main purpose of our study,
2. Reducton in the maintenance cost of roads
3. Reduction of water pollution caused by waste cooking oil
4. Reduction in the emission of $CO_2$ and other harmful gases.
5. Increase in safety of road users.
6. Durable pavements with extended service life.

### 1.4 Research Objectives:

1. Determining the OBC of controlled samples and OBC and OCC of modified samples.
2. Determining the moisture susceptibility of controlled and un-controlled samples.
3. Determining the healing index, healing level and healing temperatures of controlled samples and capsule-induced asphalt.
4. Cost analysis of controlled section with the section containing Na-alginate capsules.

### 1.5 Thesis Outline:

This thesis consists of five chapters. A short over-view of every chapter is mentioned below.

**Chapter 1:** this chapter is about the introduction of the topics. It contains a short introduction of topic, background about self-healing technology, problem statement, purpose behind the research, objectives of our research and thesis outline.

**Chapter 2:** This chapter covers the literature review. It highlights and acknowledges the previous work done related to our research. Literature review about asphalt binder, aggregate, waste cooking oil, self-healing technology, encapsulated rejuvenator, moisture sensitivity of capsules-induced asphalt, SCB and TBT.

**Chapter 3:** Explanation about the test matrix. Collection of material, aggregate testing, bitumen testing, Marshal mix design testing, capsule formation procedure and performance testing procedures.

**Chapter 4:** Results and analysis of aggregate testing, bitumen testing and performance testing.

ITS, SCB and three point bending results and analysis.

**Chapter 5:** Discussions about the finding of results and giving suggestion for future works are presented in this chapter

# Chapter 2: LITERATURE REVIEW

## 2.1 Overview:

This chapter covers the literature review about different elements of road pavement. An extensive overview about asphalt binder, waste cooking oil, encapsulation methods, moisture sensitivity, three-point bending and semi-circular bending test is presented here. This chapter covers the intrinsic and self-healing behavior of asphalt tested and explained by the previous researchers.

## 2.2 Asphalt Binder

Asphalt binder refers to the asphalt that has been prepared to use in HMA and other paving applications such as roads, airports and flexible pavements. Black-top cover is the by-product of petroleum-refining framework that produces gasoline, diesel fuel, greasing up oil, as well as a few other major petroleum items. The black-top cover is delivered from the thick, overwhelming buildup that remains after the refining of petroleum to evacuate powers and greases. Black-top cover incorporates the black-top cement and as well as the adjusted components included to improve the properties of blend. The foremost imperative property of black-top which influences the chemical as well as physical properties of black-top is temperature. One major property of asphalt binder is the durability, as how ageing affects the physical properties of asphalt in long term. In general, the viscosity of asphalt increases as it ages and results in more stiff and hard asphalt pavement. Asphalt binder is usually solid at room temperature and as the temperature rises over $80^0$ C its converted to liquid. In factory asphalt binder is usually mixed with aggregate for 30s and the temperature ranges between $140^0$C to $160^0$C. temperature of asphalt used at site normally ranges between 130-$140^0$C. Main components of asphalt are composed of Carbon, Oxygen, Nitrogen and Hydrogen. Minor number of elements such as nickel, iron and vanadium are also found in asphalt binder. Chemically, asphalt binder structure is mixture of asphaltenes and maltenes. These two components being volatile in nature, evaporates with the passage of time, resulting in oxidation and polymerization of asphalt binder. Asphaltenes are more viscous than the maltenes (usually resins and oils) and play a major role in determining the viscosity of asphalt pavement. (Airey, G.D 2003)

## 2.3 Asphalt Self-healing

Asphalt has an intrinsic self-healing property, owing to its strong wetting and diffusion capability. Fatigue cracking due to repeated traffic loading can lead to the permanent degradation of pavements if the proper rehabilitation and maintenance is not provided. Self-healing rate of asphalt can be sufficiently increase by use of innovative techniques such as Induction heating, microwave heating and encapsulated rejuvenators. All these techniques help lower the viscosity of bitumen present at broken part. Diffusion and wetting capability of broken part is enhanced by the heat generated through these processes, helping in the closure of cracks and prevention of further deterioration of asphalt.

Surface theory of asphalt, which depends on the principles of fracture mechanics was developed by Schapery and Lytton (1989). Surface theory states that the energy is released at the surface of asphalt during the crack formation. Crack formation and the healing level are the function of the change of area at the crack interface. The relation between the crack formation and healing level at the crack interface helps in lowering the crack surface energy.

(Y. Li, P. Hao, M. Zhang, 2021) elaborated the molecular diffusion theory. Polymer self-healing mechanism results in the formation of molecular diffusion theory. This theory states that, self-healing of bitumen is combination of several factors including molecular arrangement at crack, molecular diffusion, molecular random distribution and crack interface wetting.

Induction heating phenomena of accelerating the self-healing rate of bitumen was designed and introduced by Minsk. Graphite can be added to the pavements for effectively producing the heat for the removal of snow and ice on road pavement surfaces (Minsk, L.D, 1971).

Wu. S et.al 2006 presented the concept that using conductive carbon fibers, carbon black and graphite as a conductive medium in induction heating can be more effective than the conductive fillers.

Researchers (Liu et al. 2010) investigated the effect of using long steel wool and short steel fibers for producing heat in the induction heat process. For making the porous asphalt electrically conductive, long steel fibers are more effective.

(Su, Schalnegin, Garcia, 2010) presented the process of including encapsulated rejuvenators in asphalt pavement. This research states that when crack appears, energy is released. This released energy encounters the capsules within specimen and rupture. Upon rupture, healing agent is released which lowers the viscosity of cracking interface. Lowers viscosity helps in diffusion and wetting of crack interface and assists in closure of gaps. This process saves pavements from further deterioration and extend their service life.

Capsules produced through the encapsulation technique are thermally and mechanically stable and can withstand the mixing and compaction temperature during the preparation of specimen. (Garcia, Schalngen et al. 2010)

## 2.4 Waste Cooking Oil

We can use waste cooking oil as a rejuvenator to modify its rheological properties because of having similar chemical composition as asphalt. Removing the acidic components of waste cooking oil can result in increased resistance of WCO to moisture sensitivity. Acidic molecules in WCO can have a better bonding with silicious aggregate but they can be easily replaced by water, making the bitumen more prone to water. For the use of WCO as a rejuvenator, its acidic components can be removed through the process of esterification. Oldham et.al (2021) inquired about around benefits of utilize of esterified utilized cooking oil as a rejuvenator and states that the bitumen containing esterified squander cooking oil appears higher resistance to dampness harm than the bitumen with customary squander cooking oil.

Researchers Asli and Karim (2011) inquired the effects of using used cooking oil as a restorer with recycled asphalt pavements (RAP). According to them, use of WCO as a restorer with RAP improves the rheological properties of asphalt including softening point, penetration grade and viscosity. Use of WCO reduces the environmental degradation when used as rejuvenator with RAP, because of its best suitability to be used as an alternative to recycled glass, paper, plastic and rubber. Asli and Karim et al. (2011)

Yupeng Zhang (2019) examined the impacts of sunflower oil expansion to matured and virgin bitumen. In expansion to recuperating capacity, rutting resistance and weariness resistance was too tried by the analyst. Sunflower oil essentially expanded the rheological properties of black-top. With 1% expansion of squander sunflower oil, the matured bitumen recoups 13.69% of its unique modulus. Expansion of 5% sunflower oil by weight of the bitumen noteworthy increments the rutting resistance and weariness resistance of the bitumen by impressive sum.

Cooking and broiling create expansive sum of squander cooking oil, which has the potential to be utilized as a rejuvenator since it contains light oil components that are practically equivalent to to the one display is black-top (Sun, Yi, Huang, and Feng, 2016). Due to WCO's lesser oil components, it has the potential to be an successful rejuvenator. Black-top on the other hand contains heavier oil components.

The effect of using utilized cooking oil rejuvenator on high temperature characteristics of asphalt were studies by the researchers. ( Meizhu Chen, Bradley, Bingbing Land, 2014). The use of WCO can prominently increases the rutting reluctance of asphalt. WCO contains the lighter chemical elements analogous to asphalt, which are mainly responsible for the reduction in viscosity value of aged asphalt. The reduction in viscosity value results in lower temperature during the mixing and compacting of asphalt samples preparation. Phase angle of asphalt components also increases with the use of WCO as rejuvenator.

## 2.5 Encapsulation Method

In recent times, researchers have proposed various techniques to improve the already existed intrinsic healing property of bitumen. Researchers have worked on different methods to provide the innovative, novel methods of increasing self-healing capacity of asphalt to prolong the life span of pavements.

Al-Mansoori et.al (2018) created the capsules which comprised of WCO as rejuvenator and the external center or shell is composed of Ca-Alginate. These capsules are able to resist the mixing and compaction handle within the test arrangement. Al-Mansoori expressed that Ca-alginate tends to improve the self-healing capacity of black-top in the event that the most extreme temperature was kept underneath 40 degree Celsius. Capsules included within the blend did not influence the rheological properties of the black-top.

(Norambuena-Contreras et. al 2020) developed the encapsulated capsules of bio-oil to examine the thermal stability, chemical composition of bio-oil capsules, and healing level offered by the capsules. Bio-oil was extracted from liquified bio-mass and drooping funnel and a syringe device was used to create a bio-mass encapsulation through the polymer structure of sodium-alginate.

Researchers stated that these encapsulated bio-oil capsules diffuse easily into bitumen upon cracking, resulting in lower viscosity and increased self-healing capacity.

Sunflower encapsulated capsules in porous calcium-alginate is developed by the researchers ( Alvaro Garcia, Tahseen, Grossegger, 2021). These researchers stated in detail the influence of these capsules on thermal expansion, thermal resistance and internal structure of pavement surface when oil is released upon rupture of capsules. sunflower oil encapsulated capsules can withstand the mixing and compaction process and release almost 50% of the oil upon the rupture of capsules. the strength of capsules depends upon the oil to aggregate ratio and diameter.

Biopolymeric capsules were developed by the previous researchers. Waste cooking oil is contained in the biopolymeric sodium alginate capsules extracted from the cell wall of algae. Ionic gelation process was used for the synthesis of polymeric capsules (Concha, Artega-Perez, 2021). WCO capsules provided thermal stability to the asphalt samples and presented suitable surface morphology to the asphalt.

Micaelo et al. reported in 2016 that they employed a CaCl2 coagulation solution to coagulate a saline alginate solution containing a rejuvenator, which was then rinsed and dried to get Ca-alginate capsules/fibers following the treatment. The addition of an alginate/rejuvenator solution to a CaCl2 coagulation bath and the subsequent pouring of the solution via an aperture resulted in Ca-alginate capsules with particle sizes higher than 1 mm. in order to get the ca-alginate fibers with the diameter in micrometer, the sodium alginate solution must be continuously injected into calcium chloride coagulation solution using a needle. Before the fibers can be combined with asphalt, it must be first cut into short fibers of specific length and then chopped again.

### 2.6 Moisture Susceptibility

Moisture sensitivity refers to the interaction of water with asphalt causing the weaker asphalt-aggregate bond and reducing the adhesion between the particles. Loss of adhesion between asphalt and aggregate leads to the phenomena called stripping resulting in various distresses in asphalt including rutting and fatigue.

**Figure with moisture damage**

(Al-Mansoori, Alvaro Garcia, 2017) stated that addition of capsules in asphalt samples decreases the moisture damage susceptibility by 4.3%. The reason for the lesser loss of particle is due to the fact that capsule adapts the properties of surrounding aggregate and reduces the air void content present in samples. Capsules create a strong bond of adhesion between mastic layer and asphalt eliminating the chances of water penetration in asphalt.

According to the researchers (Diab, Jorge. G Paris 2017) chemical reactivity of aggregate and presence of deleterious material can cause the degradation of asphalt allowing the moisture penetration into the pavement structure. Highly angular aggregate is not preferred to be used in pavement design as their edges are not properly coated with bitumen and often leads to the puncture of asphalt binder. Bonding strength of hydrophobic aggregate with bitumen is greater as compared to the hydrophilic aggregate.

Calcium-alginate capsules with different percentages were added in the asphalt mixture by the previous researchers (Norembuena-Contreras, Garcia. A, 2019). Capsule percentage of 0.5% proves to be more suitable for increasing the moisture resistance of asphalt pavement and improves the other rheological properties of asphalt. If the capsule percentage is increased beyond 0.5%, more oil release upon the rupture of capsules leading to a less stiff and more moisture prone pavements.

Durability of asphalt pavement is vital for its long-term service life. One major factor which adversely affects the durability of asphalt is damage caused due to moisture content. Researcher (Amelie et al.2020) states moisture damage as the most prominent factor affecting the durability of asphalt pavements. Durability loss is often in the form of stripping, where water enters the asphalt layer and causes the loss of adhesion between bitumen film and aggregate particles. This leads to the rupture of bitumen film on aggregate surfaces, causing the disintegration of particles.

(Kanta Raja Nagesh, 2018) studied the use of RAP, sand and UFS mixtures on the moisture sensitivity of asphalt pavements. Use of antistripping agent by 1% of total bitumen content can increase the moisture resistivity of asphalt considerably as compared to the pavements without the antistripping agents like RAP, sand and UFS mixture.

Use of waste cooking oil and Crumb rubber as a rejuvenator with RAP highly improves the moisture resistance capability of asphalt. Using RAP alone increases the rutting and fatigue resistance of asphalt, but reduces the moisture resistance. Addition of WCO and Crumb Rubber increases the rutting and fatigue resistance and makes the modified asphalt less prone to moisture as compared to the virgin asphalt samples (Bilema, Yusri Aman, Ali Omer, 2021)

## 2.7 Semi Circular Bending

SCB is performed on the asphalt to measure the fatigue and cracking resistance. Healing level of cracked asphalt in the presence of rejuvenators and capsules is evaluated by measuring the release energy during the cracking of asphalt samples. Healing level of asphalt through SCB mainly depends upon two factors, temperature and the rest periods.

Reyma Verma et al.2021 states the importance of temperature and rest periods required for the evaluation of self-healing capability of asphalt. Healing of samples tested immediately after the crack propagation and at a low temperature was less than the asphalt that is provided with 4 hours rest period and a temperature of 30-40 Degree Celsius. The load carrying capacity of the samples provided with rest periods and adequate temperature was increased by 30 times of the sample tested immediately after crack propagation.

(Tabavoki et al.2017) used the SCB method to calculate the healing index of the fractured asphalt samples. Asphalt samples were equipped with calcium alginate fibers of different size and variable pores distribution. Researcher concluded the result that the self-healing capacity of samples containing calcium alginate fibers is limited to the fiber size and pores available within alginate capsules.

Healing level index of asphalt containing calcium alginate capsules was determined using SCB by the researcher (Zain Ul Abadeen, Arshad Hussain, 2021). Asphalt with 0.5% of Calcium alginate capsules showed 40% of healing after first healing. Strength retained of asphalt samples depicted that capsule had a positive impact on healing index of asphalt.

### 2.8 Three Point Bending

Shi Xu, Amir Tabakovic et.al 2019 developed the testing procedure for the evaluation of calcium alginate and PEMA (polyethylene-alt-maleic-anhydride) capsule's efficiency on the healing level index of asphalt. PEMA was used a coating to prevent the diffusion of rejuvenator into the alginate shells. By using universal testing machine, three-point bending test was performed to evaluate the healing level of asphalt mortar. Notches size of 25mm was used to initiate a crack at the center of the beams that propagated throughput the cross sections. For the first healing fractured beams were given 4h rest period and were kept at a temperature of $20^0$C.

TPB was applied again to calculate the retained strength. Second healing followed the same rest period and temperature. Researcher states that initial condition of fresh bitumen plays an important role in the strength recovery of the specimen. The healing index for the beams without capsules were almost same as compared to the specimen containing capsules. virgin bitumen possesses enough healing capability and the addition of calcium alginate capsules with PEMA doesn't affect the strength recovery process to a great extent.

T.Al Mansoori et al.2018 devised the experimental setup based on the field conditions to evaluate the healing levels of asphalt containing encapsulated rejuvenator. Recovery of flexural strength of beams tested under the 3PB gives an account for the healing level of specimen. Specimen or the beams were placed at frozen temperature of $-20^0$C for the initial propagation of crack. A thin plastic sheet was inserted between the two broken faces of beams to prevent the diffusion of oil at initial stages. Broken beams were put in a controlled chamber at $20^0$C in a steel mold for 2h, and a load was applied simulating the original traffic loading in the field. Rest periods ranging from 5h to 96h were given for the determination of flexural strength recovery of beams. Healing temperature provided during the rest period was $40\text{-}50^0$C.

Results given by Al. Mansoori stated that healing level for capsules containing samples were greater than the controlled samples. Healing level increases for larger rest periods, due to fact that a large number of capsules rupture during that period under the applied loading conditions. More greater rest periods, quantity of oil released increases and results in better diffusion between two cracked faces and closure of crack. Specimen containing 0.50% of capsules provide optimum healing than the other percentages of capsules.

## 2.9 Chapter Summary

This chapter focuses on the techniques used to accelerate the existed intrinsic healing properties of bitumen. Literature review about different asphalt components along with their compatibility te used for our purpose and the works carried out by the previous researchers is discussed in detail here. Bitumen has this intrinsic property of healing the cracks caused by different distresses, but this rate is relatively slow and sometimes fails to restore the original properties of asphalt pavement, causing permanent deformation and failure of the system. There are two main methods for increasing the self-healing rate of asphalt, Encapsulated rejuvenators and Induction heating. Induction heating process of accelerating the natural healing rate of bitumen is very fast, as it creates heat inside the bitumen layer and helps reducing the viscosity of system. Main disadvantage of induction heating is that it only heals the part of pavement near the surface and induction heating equipment. Heat produced during induction heating doesn’t intrudes into deeper parts of bitumen layer system. Methods presented in this research is encapsulated rejuvenators, in which healing agent is contained within the shells made of alginate. Main advantage of these capsules is their ability to withstand the compaction and mixing temperature during the specimen preparation. Formation of crack releases the energy which penetrates into asphalt layer. Upon the contact of energy with capsules, rupture of capsules occurs releasing the healing agent stored within. This healing agent effectively diffuses between the two faces of broken part and lowers the viscosity of bitumen. Reduction in viscosity causes the bitumen to flow and helps in the closure of crack, without causing the further deterioration of pavement. Encapsulated rejuvenator technique helps to improve the asphaltenes to maltenes ratio in asphalt pavement. In encapsulated rejuvenator technique, the healing recovery of specimen depends on the temperature and rest periods provided to the specimen. Results of our research are promising and helpful for further studies.

# Chapter 3: RESEARCH AND TESTING METHODOLOGY

## 3.1 Introduction

This chapter summarizes the techniques used to achieve research objectives, including material selection, material collection, material testing, sample preparation, and large sample testing. The study included a control sample and a sample containing capsules. This Chapter describes OBC decisions using Marshall Mix Design. Based on OBC, Performance samples are created with and without capsules. Moisture sensitivity and cure rate are included in the performance check. This chapter describes the equipment to use, the method for preparing the sample, and the input parameters used during the testing of the obtained sample.

## 3.2 Methodology

This study was performed on asphalt concrete samples prepared using Margalla Quarry aggregate, and bitumen with a penetration grade of (60/70) was purchased from PAK-ARAB REFINERY LTD. (PARCO). Chemicals such as sodium alginate, calcium chloride, and deionized water were purchased from Rawalpindi, Pakistan. Waste Cooking oil was purchased from a local market including different Hotels and Restaurants. After procurement of aggregate and bitumen, these materials were brought to the laboratory and different testing was done to check the characteristics according to ASTM standards. Sodium alginate capsules were made with waste cooking oil as a rejuvenator. To check the thermal stability of capsules at high mixing temperature and compaction due to heavy loadings Thermogravimetric test was performed. Optimal binder content was determined by experimenting with different binder proportions starting from 4% to onward with an increase of 0.5%. Marshall sample from scrap material was created with an optimal binder content to detect moisture damage. The tests were performed under the control set at the temperature specified for each test. Marshall samples were made at optimum bitumen content to check the Tensile Strength Ratio (TSR) for Unconditioned and Conditioned samples and later on these samples were tested using a Universal Testing Machine. Samples were kept in a water bath for 24hrs for conditioning at 60ºC. Two different tests were performed to investigate the healing process named as Semi-circular bending test and the 3-point bending beam test. By comparing the results of these samples (With capsules) with the results of the control sample (without capsules), the efficacy of the encapsulated rejuvenating agent was determined.

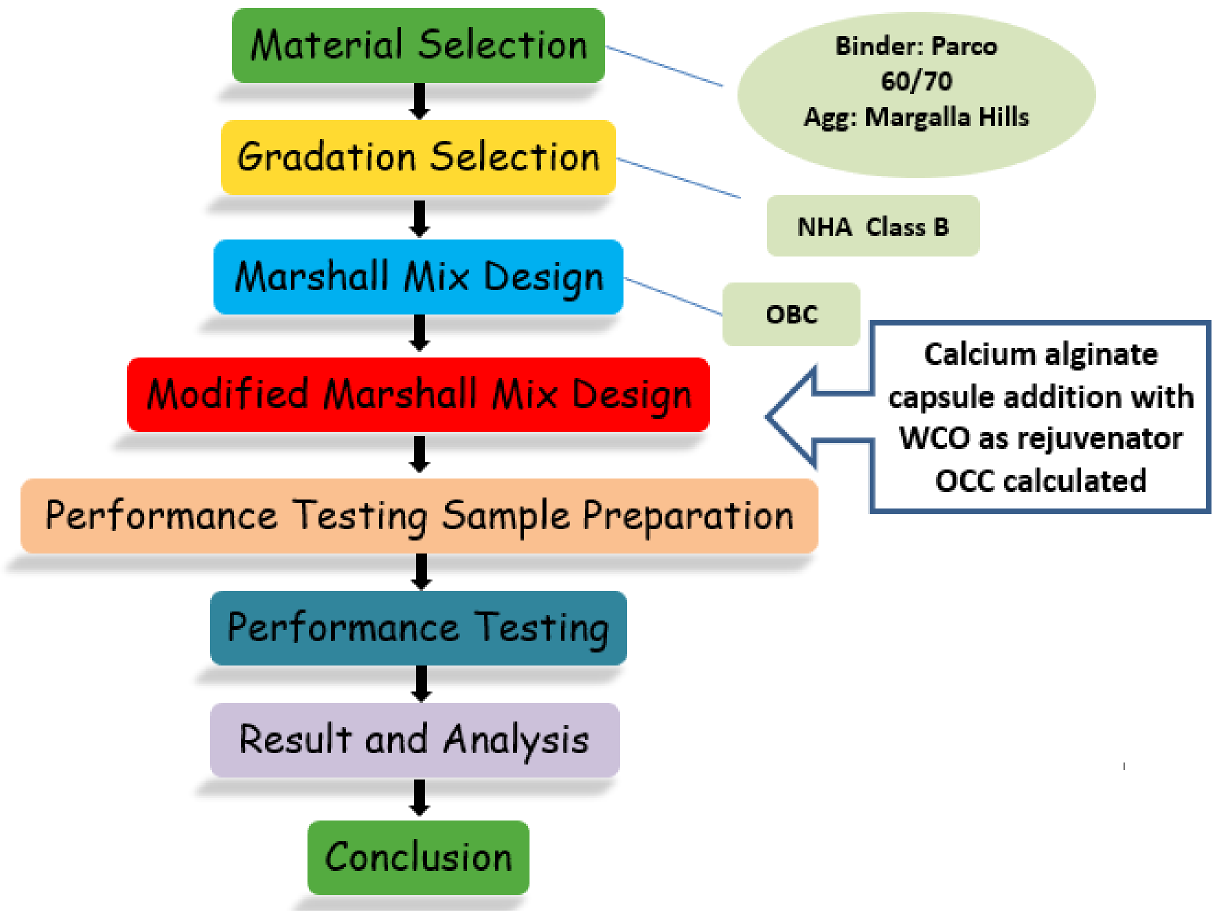



**Figure 3.1: Methodology**

### 3.3 Material Selection:

To prepare the samples fine and coarse aggregate were brought from Margalla hills Islamabad and a binder with a penetration grade of (60/70) from PAK-ARAB REFINERY LTD (PARCO). Binder 60/70 grade was selected because it is commonly used in Pakistan's asphalt mixtures during road construction practices. It is also suitable for use in moderate to cold temperature areas. Asphalt is composed of aggregate, bitumen, and air. Normally, aggregate provides maximum resistance to permanent deformation because the mixture contains 95% of aggregate by weight and 5% bitumen. Since air is weightless, it plays no role in terms of percentage but air voids are necessary to avoid flushing or bleeding phenomena. The asphalt mixture is composed of 90% aggregate,5% binder content, and 5% air. Extensive laboratory testing of aggregates and bitumen is carried out to check the asphalt mixture meets the criteria following ASTM standards.

### 3.3.1 Aggregate

Aggregate was procured from Margalla Hills crushers. Aggregate withstands most of the recycling loadings. Aggregate is important for the strength and longevity of the HMA deck. It carries the heaviest weight the pavement can support. The texture 19 and shape of the aggregate have a significant impact on these strength-related parameters. In general, large-angle, coarse-textured aggregates can withstand the stresses of the pavement caused by repeated loads. Numerous tests are performed according to ASTM and BS standards to determine the overall quality that affects the deck.

**Fig 3.2 Margalla Hills Crush Plant**

### 3.3.2 Bitumen

Bitumen is utilized as a cover in black-top blends. It is blackish or dim brownish and is produced from buildups refining petroleum. Bitumen's consistency, security, and immaculateness are required for building and building needs. In Pakistan, generally, a bitumen of review 60/70 is utilized per climate conditions. So, a bitumen of review 60/70 was collected from PAK-ARAB REFINERY LTD. (PARCO).


**Fig 3.3 Bitumen**

### 3.3.3 Preparation of Capsules

Sodium Alginate has been utilized as an emulsifying administrator with waste cooking oil while calcium chloride is provided as granular pellets gotten from the local market in Rawalpindi.

**Fig 3.4 Capsules Formation**

Sodium alginate is the main component that shapes the capsule shell. It was founded in 1881 for its unprecedented capacity to concentrate liquids and fabricate thin films. After 50 a long time, large-scale commercial creation of sodium alginate began since its cheap taken a toll and normal invitingness. It gives promising utilization in capsule formation due to its polymer nature.

Waste cooking oil was filtered first and then it was mixed with water with the help of a stirrer at room temperature. Capsules were made using a sodium alginate polymer to contain a rejuvenator which is waste cooking oil. Waste cooking was purchased from a local market at a very low cost. To form capsules, we utilize 2.5 percent of sodium alginate and mix it in water the side oil, and water. Freely, a 2 percent calcium chloride course of action in the water is made. Emulsion of sodium alginate is poured into a dropping pipe. The emulsion is put into a course of action of calcium chloride. All through the methodology, a calcium chloride course of action is disturbed. Capsules are tapped and set on a 40°C stove for 24 hours.

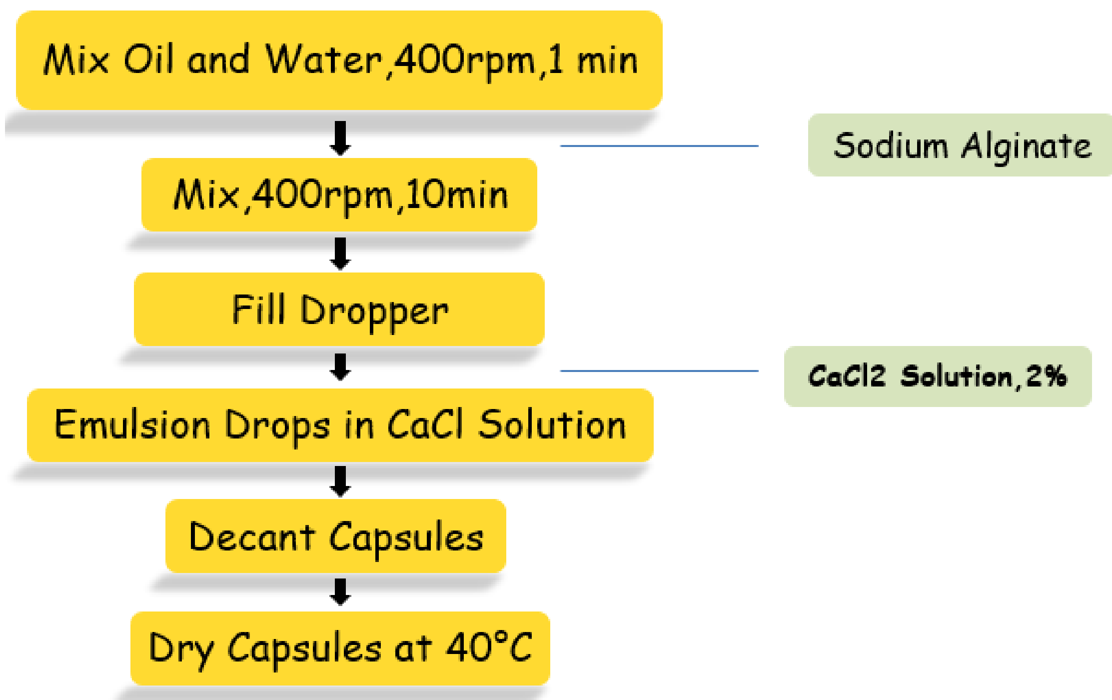



**Fig 3.5 Capsules Formation Mechanism**

### 3.3.4 Waste Cooking Oil

Waste cooking oil used in our research was purchased from the local market in Islamabad. Squander or waste cooking oil has been demonstrated to be a restoring operator that revitalizes asphalt's misplaced properties. Waste cooking oil is created in over-the-top amounts in Pakistan and can be purchased at low prices.

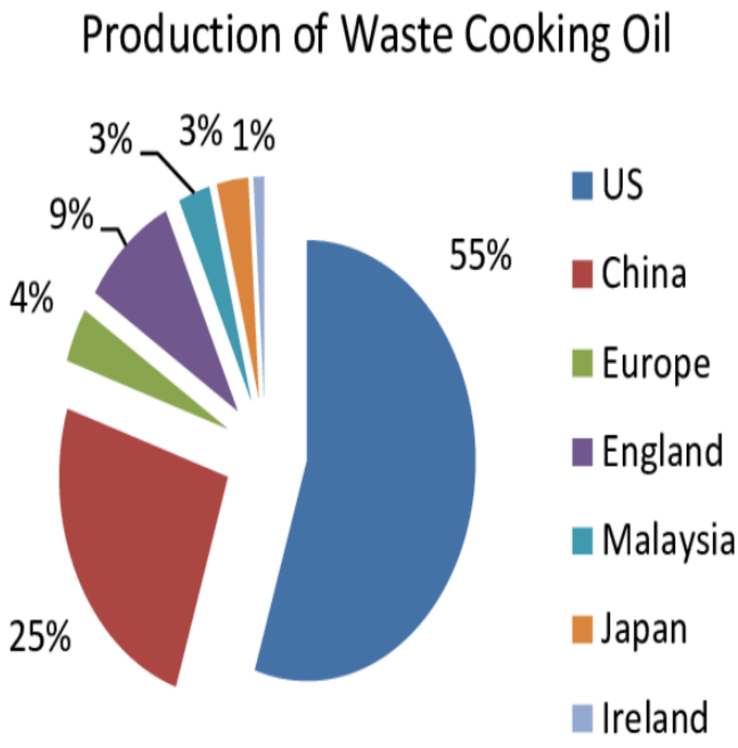



**Figure 3.6 Production of Waste Cooking Oil**

## 3.4 Material Testing

Material testing includes the testing of aggregate and bitumen that will be used for the project. There are various sorts of common aggregates that can be obtained from a quarry. Rocks are broken down into more diminutive pieces that can be utilized. Materials used for flexible pavement or rigid pavement are made up of aggregate which serves as a skeleton and is mindful of their essential perception and load-bearing capacity. Asphaltic mixtures' crucial quality characteristics are chosen by the surface's degree, shape, and surface, and add up to a degree, all of which must be strong, solid, extraordinary, troublesome, fittingly assessed, and moo in porosity. It must be free of soil, repulsiveness, and water.

### 3.4.1 Aggregate Tests

Aggregate must be free of pollution, rough, aquaphobic surfaces, and environment friendly. The basic quality properties of asphaltic blends are decided by the estimate, shape, surface, and degree of the aggregate, which must be solid, extreme, appropriately reviewed, and have low porosity.

**Table 3.1 Test Performed on Aggregate**

| Test Description | Specification Reference |
|---|---|
| Los Angles Abrasion | ASTM C 131 |
| Elongation Index | ASTM D 4791 |
| Flakiness Index | ASTM D 4791 |
| Specific Gravity | ASTM C 127 |
| Impact Value | BS 812 |

#### 3.4.1.1 Los Angles Abrasion Test

This test shows the aggregate's durability and abrasion resistance, or its capacity to resist wear caused by heavy vehicular loadings. Los Angeles (LA) Abrasion Test is broadly performed to check the strength of an aggregate against disintegration. The procedure of this test was based on gradation B. 2500 g of the aggregate was used which should be retained of sieve 12" and 3/8", a total of 5000 g (W1) of material, were stacked into the Los Angeles scraped spot instrument, together with 11 steel balls to check the loss in weight of material due to collision of material with these steel balls. Los Angles Abrasion machine was operated at 30-33 revolutions per minute for half an hour to collide the aggregate with steel balls. Abrasion value is calculated by the formula (W1-W2) *100/W1. W2 is the mass of aggregate after the abrasion test and W1 before testing. According to NHA standards, abrasion value should be less than 30% to meet the standards.

**Fig 3.7 Los Angles Abrasion Machine**

### 3.4.1.2 Impact Value of Aggregate

The procedure of the Impact value of an aggregate is recognized by British standards BS 812. An aggregate impact value illustrates its deterioration by sudden loading or shock. The impact testing equipment comprises an impact testing machine, a round and hollow cylinder with a diameter of 75 mm and 50 mm depth, and a steel tamping bar with a circular area of 10 mm, and a length of 230 mm. Around 350g of aggregate was taken by passing it from a 1/2″ sieve and layering it in the mold by tamping each layer with a tamping rod. The sample was kept in the larger mold to check the impact value by dropping a hammer of approximately 14kg from 38cm height. 15 blows were given to check the impact value of aggregate. After hammering the aggregate was sieved from a sieve #8. The impact value of aggregate was calculated by the proportion of aggregate that passed through sieve #8 having an opening of 2.36mm.


**Fig 3.8 Impact Value Test Apparatus**

### 3.4.1.3 Specific Gravity Test

Specific gravity test of aggregate was done by calculating three weights of aggregates in different conditions including the weight of oven-dried aggregate, the weight of aggregate submerged in water, and surface saturated weight. The specific gravity of aggregate is basic within the fabricate of asphalt clearing blends. Engineers typically utilize it within the plan of asphalts and buildings as well. Bulk-specific gravity is utilized to decide the sum of cover absorbed and the percentage of voids filled by mineral aggregate (VMA). The aggregate that passes from sieve no. 4 comes in the category of fine aggregates and aggregate which remains or is retained on sieve no. 4 is termed as coarse aggregate. Aggregate was first passed from sieve no.4 and the retaining aggregate on sieve no. 4 was oven-dried and was soaked in water for 24hrs. After 24hrs submerged weight of aggregate was calculated and then aggregate was gently rolled on cloth and surface saturated weight was measured to obtain the value of specific gravity. The first weight was the oven-dried weight which contains no water but the third weight is surface saturated weight in which pores are filled with water.

**Fig 3.9 Specific Gravity Test**

### 3.4.1.4 Shape Test of Aggregate

During the process of compaction, these level and prolonged particles might bolt together more rapidly, making the strategy more troublesome to the total. According to ASTM D 4791, flaky particles are classified as such if their lesser dimension is less than 0.6 of their cruel sifter measure, whereas prolonged particles are classified within the same way as flaky particles on the off chance that their length surpasses 1.8 of their cruel strainer size. When the aggregate length is bigger than its width and width is bigger than its thickness at that point it is said to be flaky and stretched aggregates. Studies reveal that the effect of elongated particles is more than flaky particles in aggregates on the characteristic compressive strength of the pavement.

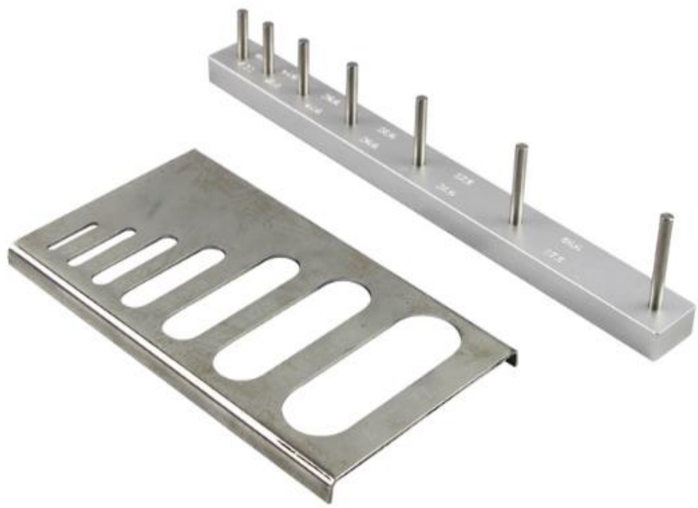


**Fig 3.10 Shape Test Apparatus**

### 3.4.2 Bitumen

Bitumen is a blackish or dark brownish and this is obtained after the distillation process of petroleum. Bitumen is a binder material mostly used in flexible pavements to position the aggregate in a place. Bitumen behavior is largely affected by temperature changes because it’s a semi-substance in nature. Its behavior is also changed by metrological conditions. Either it is obtained naturally from asphalt lakes or it can be synthesized from the leftover material of petroleum. Bitumen's consistency, security, and immaculateness are required for designing and building needs These qualities have a significant effect on the execution of black-top blends. Due to the significant vacillations in these characteristics over time, the age of the cover is significant for understanding its conduct. Due to the significant changes in these characteristics over time, the age of the cover is significant for understanding its behavior. The SHRP has created a procedure for estimating the physical characteristics of bitumen in the field. The Execution Evaluating (PG) framework is the title given to this framework. Various tests were conducted to decide the fittingness of covers for Hot Mix asphalt. Regularly, tests on bitumen are conducted at a temperature of 25ºC to compare the textures of black-top covers, as consistency shifts with temperature.

### 3.4.2.1 Penetration Test

AASHTO T 49-03 specified some standards for penetration test of bitumen which includes 25ºC temperature, a 100g needle to check penetration, and penetration time allowed for the test is 5 seconds. It measures the binder's delicate quality also known as softness and hardness in arrange to review it. This was one of the primary tests utilized to evaluate the consistency of black-top folios. Bitumen is flexible and thin binder if the needle penetration in it is high and if the penetration value is low, it will be stiff. Bitumen with a low penetration value is more suitable and desirable in hot regions due to high temperatures and bitumen with high penetration grade will be more suitable to use in a cold region.

To start with, the bitumen is warmed to a reasonable temperature to guarantee that it streams openly and does not jaw air, the temperature ought to not be expanded too much, since this will compromise the binder's properties. The bitumen is at that point set into a test holder and kept up in a temperature-controlled water shower at a steady temperature of 25ºC. When the temperature reaches 25ºC it is removed from the water and set in a penetrometer to check the value of penetration. The test is carried out by dropping a 100g needle from a specific height and the time allowed for penetration is 5 seconds. The test was carried out three times to obtain a mean value of penetration. All discoveries got met the penetration test's prerequisites.

**Fig 3.11 Penetration Test Apparatus**

### 3.4.2.2 Softening Point

ASTM D 36 is the standard that indicates how this test with the ring and ball equipment ought to be conducted. To start with, the bitumen was warmed to a temperature that allowed a free stream without compromising its characteristics. At that point, employing a shape, it was smoothed into horizontal plates. Once the plates were put within the gadget, the balls were situated on them. The temperature was raised until the cover or binder permitted the balls to drop through a specific distance. The ring and Ball method used to check the softening point is the moment most seasoned test strategy connected to bitumen, after needle infiltration. Bitumen was initially melted and then it was cool down to a temperature of 30ºC. It is the temperature at which a bitumen test in a ring has had a distortion of 25 ± 0,4 mm by a ball when it is heated. The test was conducted with the same apparatus and procedure three times to obtain the value of softening point and its value was 51ºC.


**Fig 3.12 Softening Point Test Apparatus**

### 3.4.2.3 Ductility Test

The ductility test was conducted according to the specifications of ASTM D 113 which tells about the bitumen adhesion quality and elasticity. Ductility is a physical property of bitumen that is very critical as it has a direct relationship to temperature changes. Ductility is characterized as the distance that a standard-sized example of cover (in a 1 in2 cross-sectional zone briquette) extends without breaking when its two closes are dragged separated at a rate of 5 cm/minute at an indicated temperature of 25ºC. Bitumen was heated to a temperature when it starts flowing and then it was cool down to a temperature of 30ºC. When the temperature reaches 30ºC it was kept in a water bath for 1hr. Bitumen with grade 60/70 shows an elongation of 127cm in our test. During the test, bitumen dragged length should not be less than 100cm. Pavements that are constructed with a bitumen having a ductility value less than 100cm are fractured and show a phenomenon of rutting due to heavy recycling loadings.

**Fig 3.13 Ductility Test of Bitumen**

### 3.4.2.4 Flash and Fire Point Test

Flash and Fire point is the measurement of the temperature at which bitumen starts to catch fire. Flashpoint gives the initial value of temperature when bitumen is at risk to catch fire in the presence of flame and the temperature at which bitumen catch fire is known as the fire point. Flash and fire point test for bitumen was carried out according to the specifications of ASTM D-92. Bitumen was first heated and then it was poured into a metal cup to conduct the test. It was heated continuously and at specific intervals, and a test flare was passed over it. The experiment was performed three times to obtain an average value of the temperature at which bitumen catches fire.

**Fig 3.14 Flash and Fire Test of Bitumen**

### 3.5 Asphalt Mixture Preparation

To determine the optimum bitumen content (OBC) three samples were prepared for each percentage as per Marshall Mix Design method.

The Test matrix for the OBC is shown in table 3

**Table 3.2 Test Matrix of Marshall Testing**

| Performance Test Matrix | |
|---|---|
| Marshall Testing | |
| **Bitumen Content (%)** | **No of Samples** |
| 4 | 3 |
| 4.5 | 3 |
| 5 | 3 |
| 5.5 | 3 |
| **Total** | **15** |

### 3.5.1 Preparation of Materials for Mixing/Pre-heating

Aggregate was sieved through different sieve sizes as per NHA gradation B while bitumen was pre-heated in an electric oven at a temperature range of 110-120°C. Total weight of a Marshall Mix design sample is 1200g in which weight of aggregate and bitumen varied according to binder percentage in each sample

**Fig 3.15 Sieving**

### 3.5.2 Mixing of Materials

Mixing was done at temperature range of 120-165°C. Aggregates and bitumen were heated and mixed thoroughly. Mixing was carried out until all the particles were well coated.

**Fig 3.16 Mixing of Material**

### 3.5.3 Compaction of Sample

Number of blows are determined on the basis of anticipated loading. For heavy traffic 75 blows are given on each side for compaction. Mold was oiled along with the filter paper placed at its bottom. The mix was transferred into the mold along with periodic tamping and was covered with another oiled filter paper at the top. The sample was transferred into the Marshall compactor and given 75 blows on each side.

**Fig 3.17 Marshall Test Preparation**

## 3.6 Determination of OBC

After cooling the specimen to room temperature the volumertic properties of specimen are calculated by determining $G_{mb}$ and $G_{mm}$ values. The test for $G_{mb}$ and $G_{mm}$ are performed according to ASTM D2726 and ASTM D2041 respectively. For the determination of $G_{mb}$ first weight in air of specimen is determined , after which its weight in water and SSD weight are determined. Following the determination of Gmb, the specimen was conditioned and then established utilizing Marshall Equipment for Marshall Stability and Flow. The sample is placed into the Marshall Apparatus at a continuous deformation rate of 50.8mm/minute until the load reaches its maximum value and then starts to decrease at that instant the specimen has failed. The flow value is recorded in 0.25 mm (0.01 inch) increments at the same time the maximum load is recorded. The Stability value indicates the maximum load that the specimen can withstand, and the flow number indicates the strain that occurs when the specimen is subjected to the maximum load. The Marshal Mix Design Criteria suggests that the Stability value be at least 8.006 KN and the flow rate be between

2 and 4 millimetres per second for a surface intended to sustain heavy traffic loads. To calculate the Gmm, we weighed the loose mix first, then determined the calibration weight of the apparatus, transfer the mix to the apparatus, and apply vacuum using pycnometer. After removing the air contained in the mix, re-weigh the equipment containing the mix. Equipment.

**Table 3.4 Marshall Test Results**

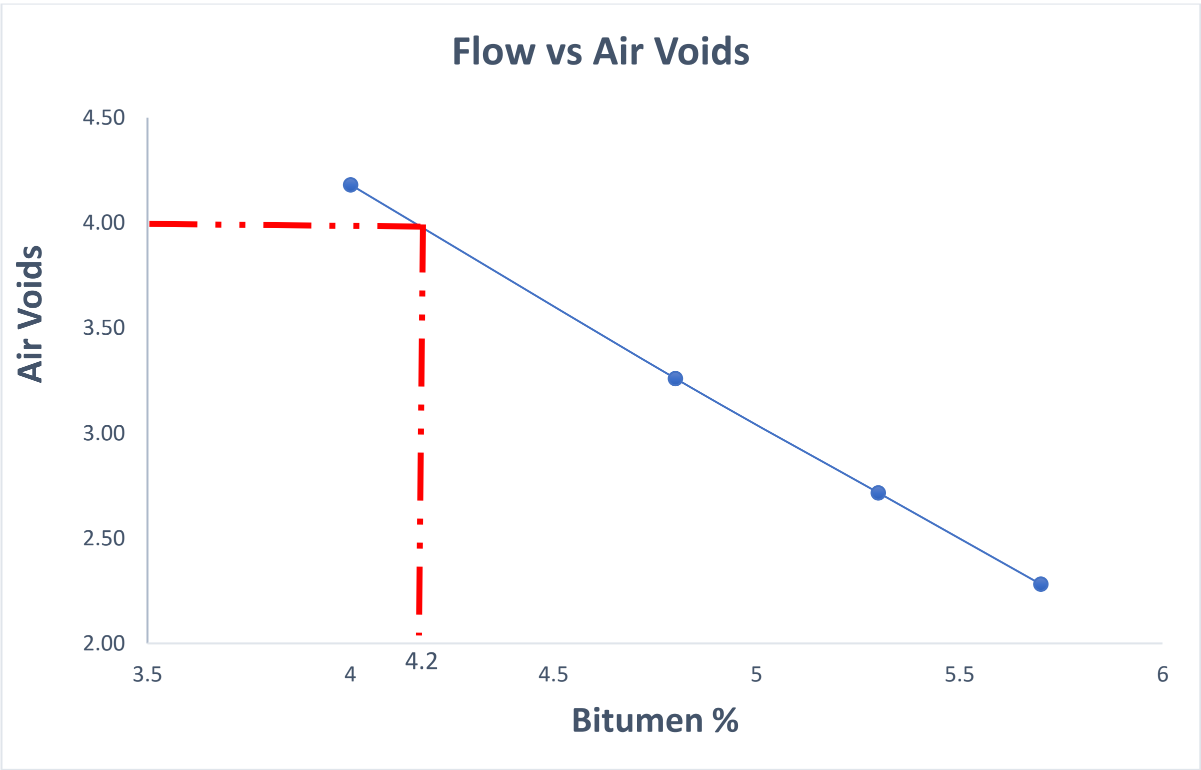
| Sr.No | Bitumen (%) | Gmb | Gmm | Air voids VA | VMA | VFA | Stability (KN) | Flow(mm) |
|---|---|---|---|---|---|---|---|---|
| 1 | 4 | 2.35 | 2.46 | 4.5 | 14.22 | 68.35 | 10.67 | 4.13 |
| 2 | 4.5 | 2.36 | 2.45 | 3.67 | 14.31 | 74.35 | 15.23 | 3.79 |
| 3 | 5 | 2.39 | 2.44 | 2.05 | 13.66 | 84.99 | 12.38 | 2.67 |
| 4 | 5.5 | 2.4 | 2.43 | 1.23 | 13.76 | 91.06 | 9.85 | 2.21 |

Graphs for bitumen content vs air void, stability, flow, VMA and VFA were plotted. OBC is the bitumen content that corresponds to 4% air void. The above values of VFA, VMA, stability and flow were checked against Marshall Mix Design Criteria and upon there satisfaction we proceeded to performance testing. The specifications corresponding OBC are given below in the tables along with their respective graphs.

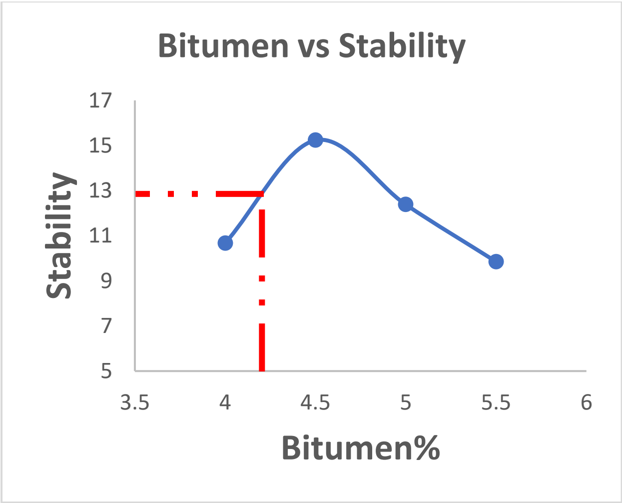
**Table 3.5 Specifications Check**

| Parameters | Value Measured | Limits |
|---|---|---|
| **OBC (%)** | **4.2** | **-** |
| **VFA (%)** | **72** | **65-75** |
| **VMA (%)** | **14.25** | **≥13** |
| **Stability (KN)** | **13.2** | **≥8.006** |
| **Flow (mm)** | **2.4** | **2-4** |

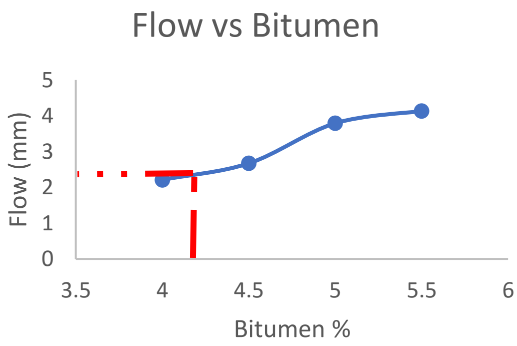
**Fig 3.18 Test Property Curves**



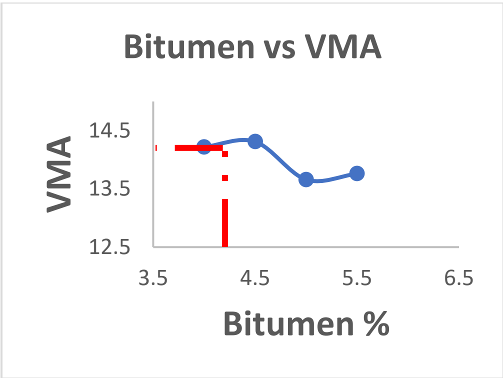

**(a) Bitumen content vs Air Voids**



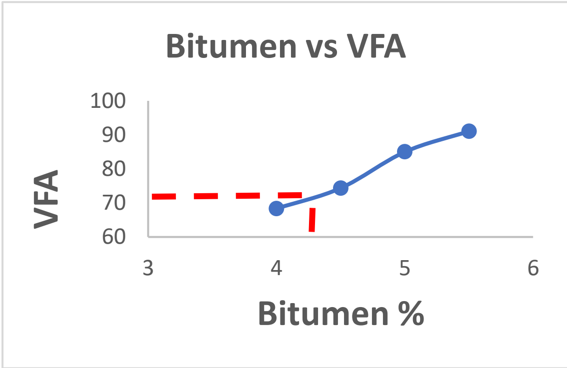

**(b) Bitumen % vs Stability**




**(c) Bitumen % vs Flow**




**(d) Bitumen % vs VMA**




**(e) Bitumen % vs VFA**


**Fig 3.19 Marshall Testing**

## 3.7 Modified Marshall Test

Modified Marshall Test is similar to that of Marshall Test but is performed to determine Optimum Capsule Content. The test was performed using three different capsule percentages that were taken from read literature. Those percentages were 0.5, 0.75 and 1. The similar procedure as of Maeshall Test was repeated and the Optimum Capsule Content came out be 0.5%.

**Fig 3.20 Modified Mix Sample**

**Fig 3.21 Calcium Alginate Capsules**

**Table 3.6 Test Matrix of Marshall Testing**

| Performance Test Matrix | | |
|---|---|---|
| **Modified Marshall Testing** | | |
| **Bitumen Content (%)** | **No of Samples** | **Capsule Content (%)** |
| **4** | **3** | **0.5<br>0.75<br>1** |
| **4.5** | **3** | **0.5<br>0.75<br>1** |
| **5** | **3** | **0.5<br>0.75<br>1** |
| **5.5** | **3** | **0.5<br>0.75<br>1** |
| **Total** | **15** | |

## 3.8 Preparation of Sample for Performance Testing

Samples were prepared in the same way as for Marshall Mix. Samples were made for each test i.e. Moisture Susceptibility Test, Three Point Bending Test and Semi-Circular Bending Test in accordance with their respective ASTM and AASHTO standards. Two different types of samples are involved in performance testing called controlled and uncontrolled sample. The one without any percentage of capsules is called controlled sample and the one with capsule content is called uncontrolled sample. Test are performed on both type of samples and compared afterwards.

**Fig 3.22 Sample being placed for conditioning**

### 3.8.1 Moisture Susceptibility Test

Six samples of diameter 6" and height 4" were prepared in accordance with AASHTO T 283, Three of which were kept in water at 60°C for 24 hours for a process called conditioning and other three unconditioned samples were kept at 25°C for 60 minutes. Both sets of samples were subjected to Indirect Tensile Strength Test. The ratio of average tensile strength of the conditioned sample over the over the average tensile strength is calculated which is called Tensile Strength Ratio (TSR) . The same procedure was repeated for the uncontrolled samples as well and its TSR was found and compared with the controlled sample.

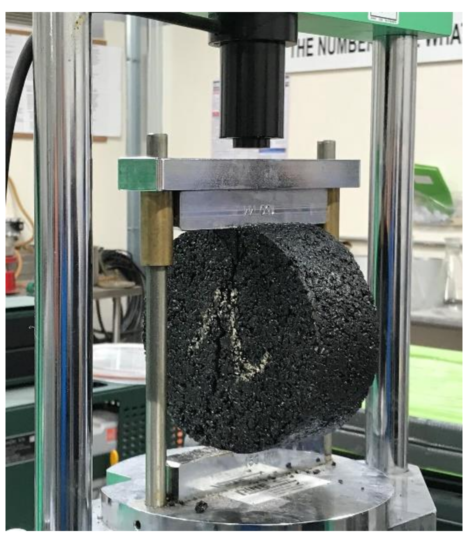


**Fig 3.23 Moisture Susceptibility Test**

### 3.8.2 Semi Circular Bending Test

The test was perfomed in accordance with ASTM D8044**.** It is used to measure the cracking resistance of asphalt mixture at long term pavement performance. Test sample is a half disk with a notch in its center. The nominal depths of the notch are 25mm, 32mm and 38mm which are cut parallel to the loading axis. The sample is loaded monotonically until fracture occurs under a constant rate of deformation. The load and deformation are recorded continuously to compute strain energy for each notch depth. The test is repeated multiple times for different notches to compute critical strain energy release rate Jc. A Jc value ranging from 0.5-0.60 $KJ/m^2$ is recommended for adequate fracture resistance. Test was performed for both controlled and uncontrolled samples and the results were compared.

$$J_c = (-1/b)(dU/da)$$

where: Jc = critical strain energy release rate (kJ/m2 )

, b = sample thickness (m),

a = notch depth (m),

U = strain energy to failure (kJ),

**Fig 3.12 Semi Circular Bending Test**

### 3.8.3 Three-Point Bending Test

Three-point bending test was performed to find the healing efficiency of asphalt mix. The test was performed at four different temperatures i.e., 20, 25, 30 and 40°C and healing level of asphalt mix was checked at different rest times. Graphs between healing level and time were plotted to check out the optimum resting time.

$$\mathbf{HI = (Cb/Ca) * 100}$$

HI = Healing Index,

Cb = binding strength after b cycles of healing,

Ca = binding strength before healing

### 3.9 Chapter Summary

This chapter covers performance testing starting from finding optimum bitumen content (OBC) using Marshall Mix design to finding optimum capsule content by Modified Marshall design. It also covers sample preparation for performance testing along with its types and finally the testing methods of the performance tests for both controlled and uncontrolled samples. The tests performed are moisture susceptibility test, semi circular bending test and three-point bending test.

# Chapter 4: RESULTS AND ANALYSIS

## 4.1 Introduction

The impact of recycling trash from many sectors such as Waste Cooking Oil on the healing properties of asphalt concrete are investigated. The comparison of the properties such as healing ability and Tensile Strength Ratio of traditional asphalt mix design and waste cooking oil modified asphalt mix design are studied. The aggregate used was achieved from Margalla hills. Bitumen was from Parco 60/70 grade. NHA-B gradation was followed but there were some modifications used in the retaining percentages of sieve#16. Waste Cooking Oil was Obtained from a fish shop in Rawalpindi. Sodium Alginate was also obtained from a local shop in Rawalpindi. The basic purpose of the study was to investigate the healing properties of Asphalt mix design.

## 4.2 Capsule Testing

Capsule Preparation process is explained earlier in this paper. There were no tests performed on capsules as advised by our project advisor.

## 4.3 Semi Circular Bending Test

The Semi-Circular Bending Test is used to calculate the healing capacity of the modified asphalt mix design. The sample is cut in half and a 3mm notch is introduced in the center of cut sample. Load is applied at the top of sample and the fracture load is observed.

### 4.3.1 Semi Circular Bending Test Result

Test results are shown in the graphs below (fig 4.1 and figure 4.2). In spite of the fact that the top loads of the second and third SCBs are lower than the primary peak load, the discoveries are much superior than those from tests without capsules. This shows that a 20-hour healing interim considerably expanded SCB test healing. The healing index is 38% for the primary healing and lowers to 16% for the secondary healing owing to capsule break caused by cracks. The discoveries indicate that SCB samples prepared with capsules were able to recapture 16% of their unique top force, but control tests were as it were able to reestablish

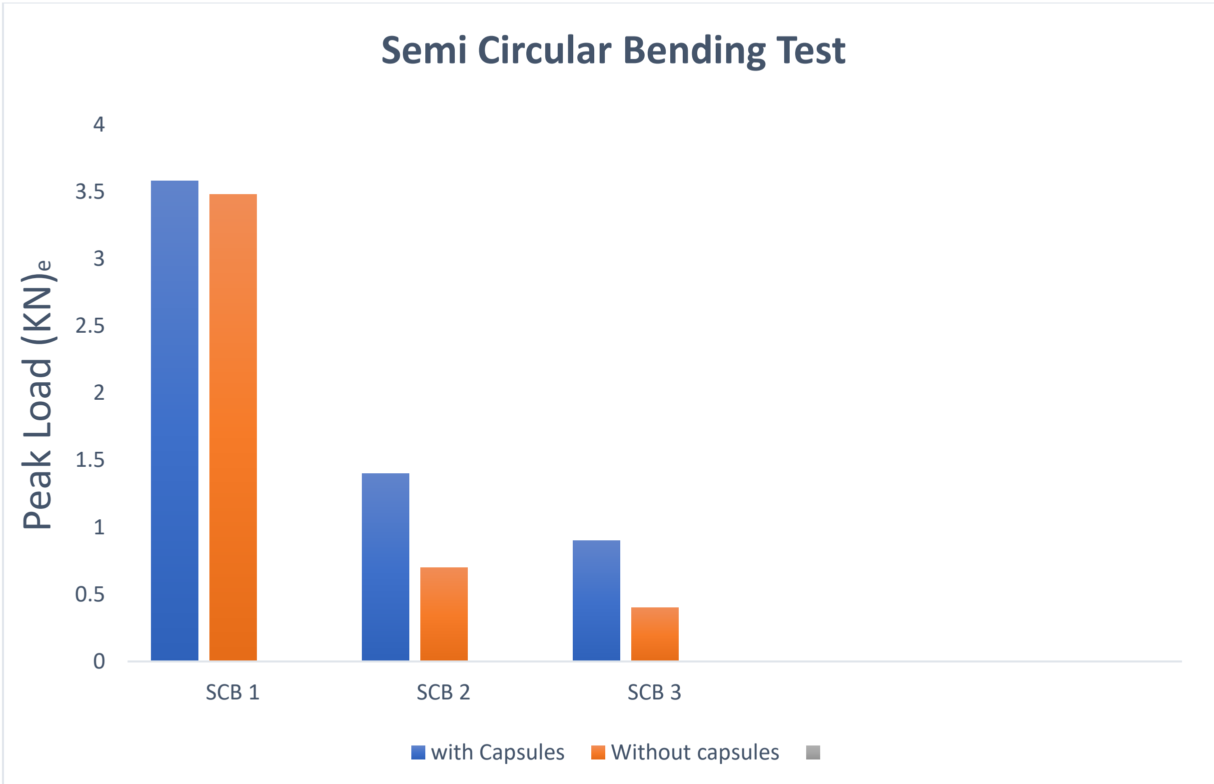

Semi Circular Bending Test
Peak Load (KN)e
4
3.5
3
2.5
2
1.5
1
0.5
0
SCB 1
SCB 2
SCB 3
with Capsules
Without capsules

Fig 4.1

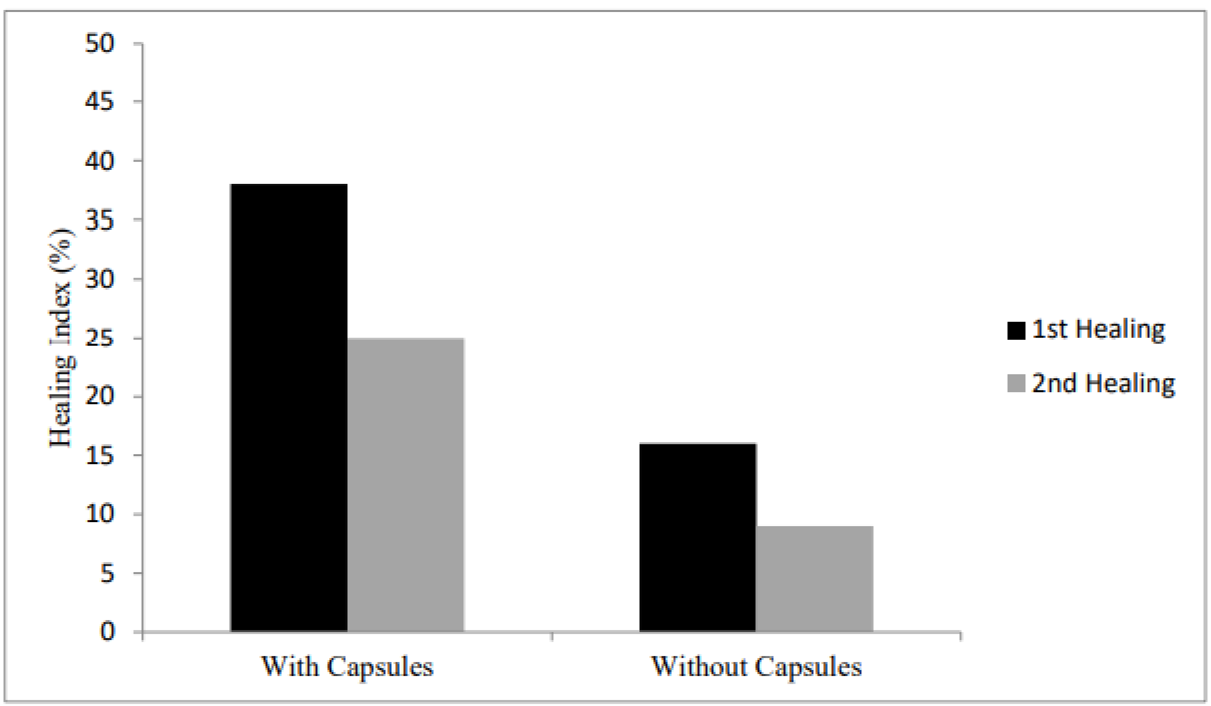

Healing Index (%)
50
45
40
35
30
25
20
15
10
5
0
With Capsules
Without Capsules
1st Healing
2nd Healing

Fig 4.2

## 4.4 Moisture Susceptibility Test

Moisture Susceptibility Test was performed according to AASHTO T 283. One sample set for conditioned the other one for unconditioned tests was arranged. Un- Conditioned test fair required 1 hr. of conditioning by keeping the sample at 25 °C (i.e., the Testing Temperature) in temperature-controlled Chamber earlier to testing. In any case, for conditioned Test, the sample was kept in water bath for 24 hrs. at a temperature of 60°C, afterward it was kept for 1 hr. at 25 °C (i.e., the Testing Temperature) in water bath. Both sets of tests were at that point put in UTM machine where the load was maintained at 50mm/min. The Highest load of failure was noted in KN. Tensile Strength was decided by the given Equation. The proportion of the tensile strength of the conditioned sample to that of un-conditioned sample was calculated as per following equation.

$$\mathbf{St = 2P / \Pi t}$$

Here,

St = Tensile Strength (kpa)

P = Rupture Load (N)

D = Sample Diameter (mm)

t = Sample Thickness (mm)

The Tensile Strength ratio for each set of samples was determined by the following equation

$$TSR = S2 / S1$$

here,

S2 = Average Tensile Strength of Conditioned sample

S1 = Average Tensile Strength of Un-Conditioned sample

### 4.4.1 Moisture Susceptibility Test Result

Figure 4.3 and 4.4 elaborates that test samples with 0.5% capsules has most elevated value of Tensile Strength Ratio. Hence, the incorporation of capsules lowers moisture sensitivity of the sample. The reason behind increment in moisture sensitivity with increment in capsule substance till 0.5 % is the increase in pressing of asphalt mix design. It is proposed that on the off chance if capsules increment past 0.5% occurs then quantity of capsules has expanded past ideal dosage and the dampness begins contrarily affecting asphalt mixture. We take 0.5 % as ideal measurements for our healing tests since higher doses might compromise other mechanical properties as well.

Asphalt experiences high temperature amid blending and compaction stage and it increases past 170 C. This high temperature is critical figure to consider amid self-healing assessment utilizing encapsulated rejuvenators. Our test resluts conclude that the ductile strength for unconditioned samples is 794.1 and 802.4 whereas ductile quality for conditioned samples is 734.2 and 779.3 for 0 % and 0.5 % capsules separately. This demonstrates that conditioning has caused decrement in the ductility of samples. TSR for 0 % capsules is 92.46 whereas for 0.5 % capsules it has expanded to 97.12 %.

| **Capsules %** | **Unconditioned (KPa)** | **Conditioned (KPa)** | **TSR (%)** | **Range** |
|---|---|---|---|---|
| **0** | 788.2 | 702.1 | 89.1 | >80 |
| **0.5** | 795.8 | 769.3 | 96.6 | >80 |
| **0.75** | 810.1 | 779.6 | 96.2 | >80 |

Table 4.1

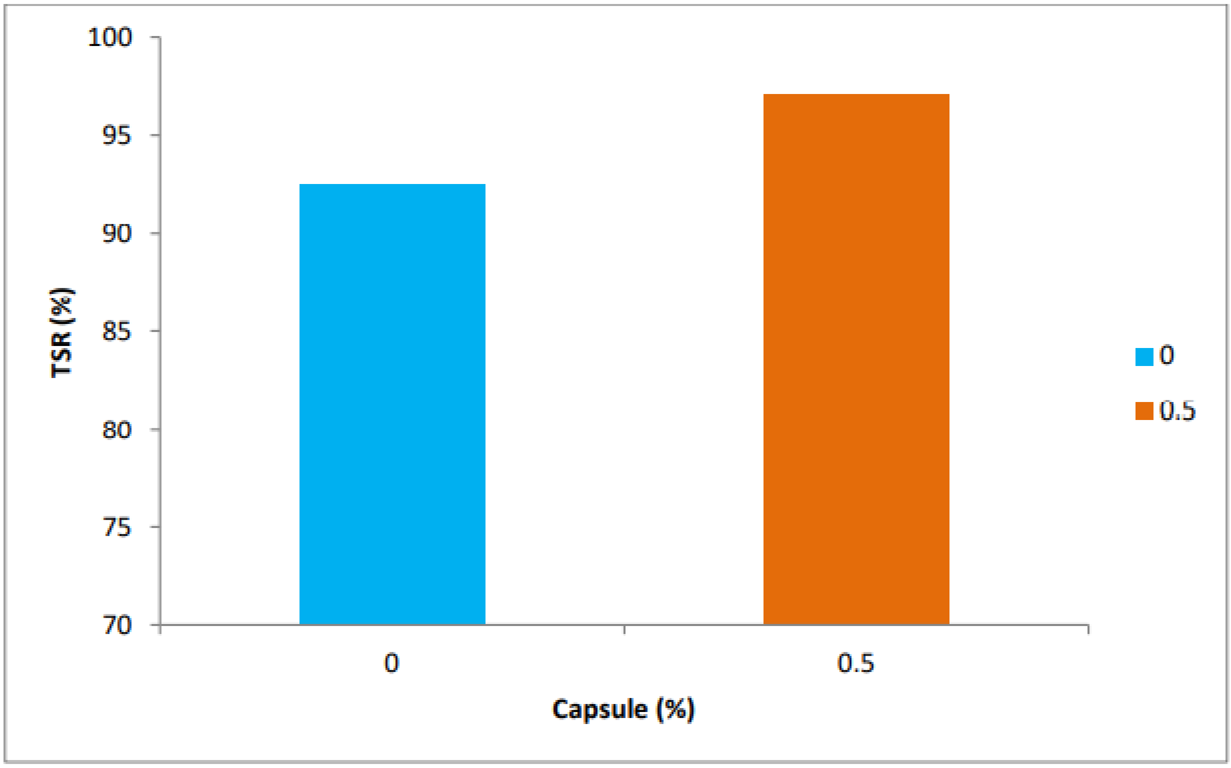



Figure 4.3

### 4.5 Three Point Bending Test

The Three Point Bending quality of the asphalt samples was measured utilizing UTM 25 KN for the starts of breaks in semicircular samples which experiences three healing cycles. The comes out of 3- point bending test on controlled and uncontrolled samples after each healing cycle appeared in following form.

Encapsulated beams showed a superior performance in terms of healing than non-encapsulated beams as already confirmed in SCB. This test further investigates the effect of increasing temperature on healing. As healing temperature increases the flowability of bitumen naturally increases and crack closure becomes easier. This results in improved healing performance with increasing temperature.

Fig 4.4 3 Point Bending Test

### 4.5.1 Healing performance

4 semicircular samples of each percentage of capsules were prepared. These samples were used to check the healing index at different healing cycles and average of thesis values was used in the graphs. After first healing cycle the controlled sample healed up to 37% while the modified sample healed up to 65%. Thus, showing that the strength regain capability of the modified samples is 28% more than that of the controlled samples.

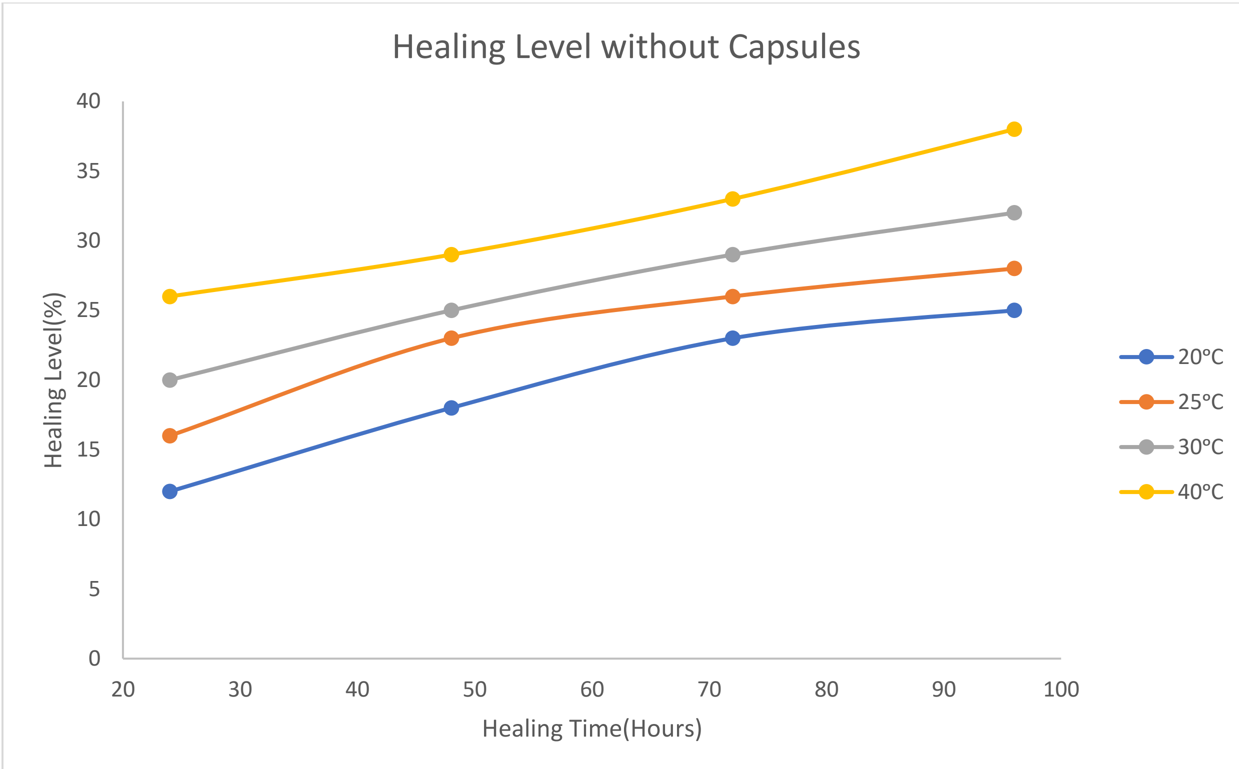

Healing Level without Capsules
Healing Level(%)
40
35
30
25
20
15
10
5
0
20
30
40
50
60
70
80
90
100
Healing Time(Hours)
20°C
25°C
30°C
40°C

Fig 4.6

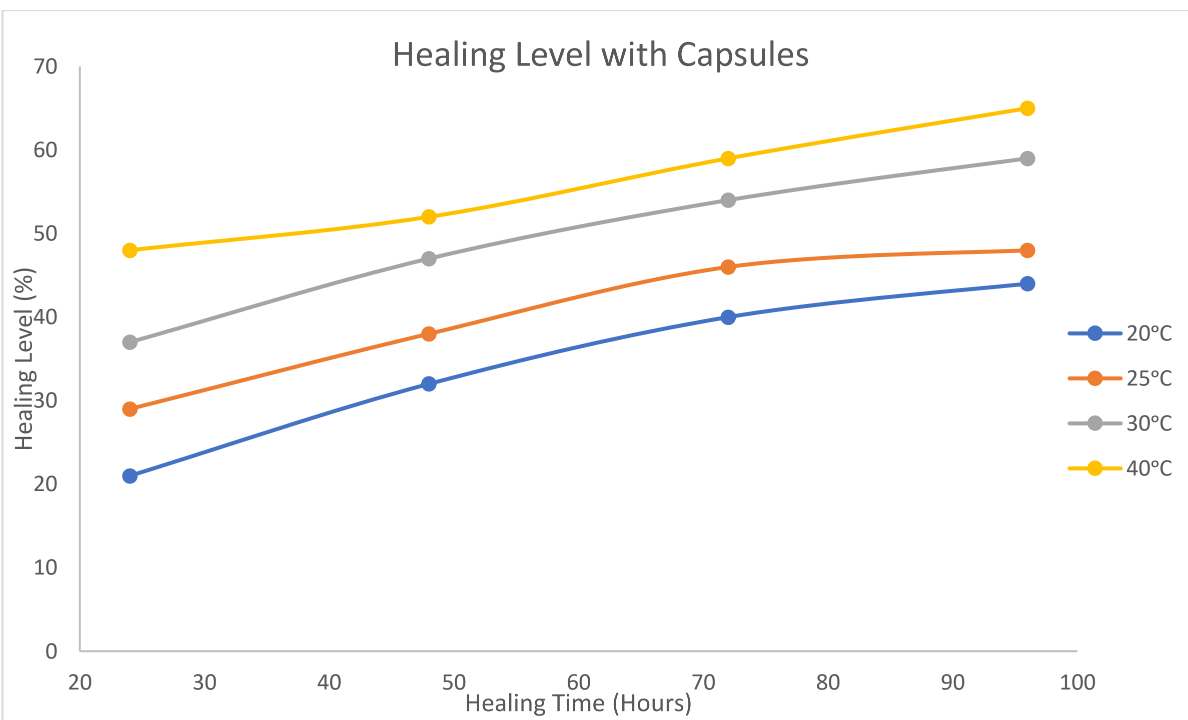

Healing Level with Capsules
Healing Level (%)
70
60
50
40
30
20
10
0
20
30
40
50
60
70
80
90
100
Healing Time (Hours)
20°C
25°C
30°C
40°C

Fig 4.7

## 4.6 Cost Analysis

For the financial evaluation of controlled and changed mixtures inclusive of Sodium Alginate Capsules, a one-kilometer road section is assumed. A trendy road width of 3.6 meters with a thickness of fifty millimeters was selected. The price of the layers beneath, which includes base and subbase, in addition to the price of subgrade preparation, have been completely left out due to assuming same characteristic for each mixture; most effective the price of the HMA floor turned into addressed on this study. The compacted density of HMA is taken as 2360 kg/m3 . The internet site of the National Highway Authority (NHA) composite scheduling rates(CSR) was used to estimate the price of HMA and the results are explained below:

**Table 4.2 Cost Without Capsules**

| Description | Length (m) | Width (m) | Layer thickness (m) | Volume of material ( $M^3$) | Asphalt density (Ton/$m^3$) | Asphalt mix (ton) | Bitumen (4.2%) (ton) | Aggregate (ton) |
|---|---|---|---|---|---|---|---|---|
| Quantity | 1000 | 3.6 | 0.0635 | 228.6 | 2.36 | 539.436 | 22.63 | 516.779 |
| Cost per ton | | | | | | | 110930.64 | 2000 |
| Total Cost per HMA | | | | | | | 2510360.38 | 1033558 |
| Total cost without capsules | | | | | | | | RS 3543918.38 |

**Table 4.3 Cost Estimation with Capsules**

| Description | Length (m) | Width (m) | Layer Thickness (m) | Volume of Material ($m^3$) | Asphalt Density (ton/$m^3$) | Asphalt Mix (ton) | Bitumen 4.2% (ton) | Aggregate (ton) | Sodium Alginate (ton) | Waste Cooking Oil (ton) |
|---|---|---|---|---|---|---|---|---|---|---|
| Quantity | 1000 | 3.6 | 0.0635 | 228.6 | 2.36 | 539.436 | 22.38 | 514.34 | 0.06544 | 0.2192661 |
| Cost per ton | | | | | | | 110930.64 | 2000 | 3000000 | 200000 |
| Cost per HMA | | | | | | | 2482627.7 | 1028700 | 196320 | 43853.22 |
| | | | | | | | 3751500.92 | | | |
| Total cost with capsules | | | | | | | | | | Rs 3751500.92 |

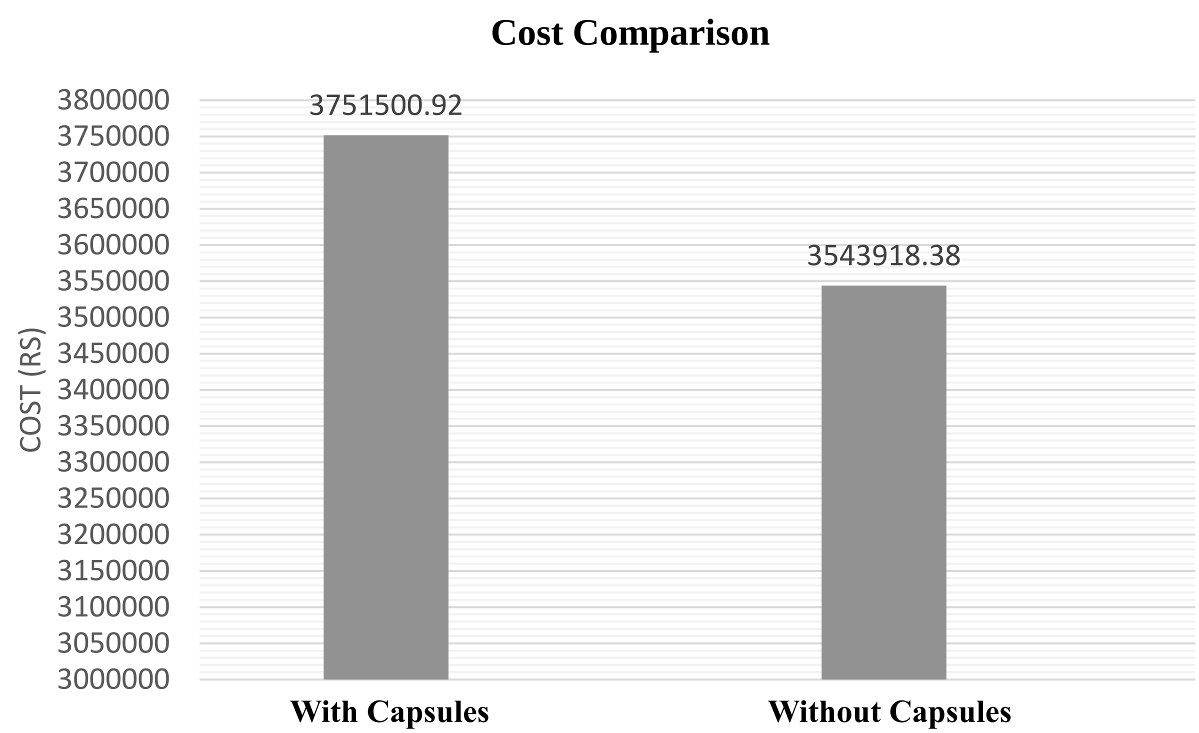



**Fig 4.8 Cost Comparison**

### 4.7 Chapter Summary

This chapter covered extensive research on performance test results. UTM results are investigated in relation to the increase in TSR value. We used tables and graphics for evaluation Performance test results.

The results of the 3-point bending test and the semi-circular bending test are displayed in detail using graphics. The increase in healing index is given as a function of Healing Time and Temperature. From the figure showing the relationship between the degree of healing and the healing temperature Repair time indicates optimal conditions for self-healing roads.

# CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

## 5.1 Introduction

Waste cooking oil as a rejuvenator increased the aromatic properties of asphalt and decrement occurs in the viscosity of asphalt. The healing ability of modified asphalt mixture i.e. when there are sodium alginate capsules inside, was investigated at various temperatures and healing durations.

## 5.2 Conclusions

Following conclusions were drawn from the results:

- At 4.2% OBC, mixed with 0.5% capsule content, the volumetric properties such as stability, flow, voids in mineral aggregate (VMA), voids filled binder (VFB) and air voids satisfy the requirement of asphalt concrete as well as the marshal design criteria.
- Cost comparison between controlled mix and modified mix containing sodium alginate capsules were made for 1km long section. The initial cost for modified samples was 5.8% of the IC of controlled samples.
- TSR% for controlled sample is 89.1% and TSR% for modified sample is 96.6%.
- At Optimum healing temperature, Healing level for modified sample is 65% and healing level for controlled sample is 37%. thus, less maintenance cost.

## 5.3 Recommendations

- The effect of the amount of present capsule oil on the degree of healing in relation to the width of the fracture can be determined by CT scans.
- You can change the composition using different materials such as silica, lime and gum Of capsules in different ways. The mechanical strength of the capsule can be measured with oil The ratio of water present in the capsule.
- It is possible to model the propagation of rejuvenating agents as well as the propagation of cracks. To deepen your knowledge about cap rupture and bitumen healing.

- FTIR can be used to analyze the amount of oil produced during mixing and Compression process. You can also investigate the impact of the environment on capsule quality. For capsules, fungi and bacteria can play a role hit.
- You can conduct an economic survey to assess the life cycle cost of a product. Carried out.
- Develop Other methods for testing the in-situ Healing level.
- Surface morphology and thermal stability studies can also be performed for capsules.

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