LABORATORY EVALUATION OF STONE MASTIC ASPHALT USING CRUMB RUBBER AND MUNJIN FIBER

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A thesis submitted in partial fulfillment of
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By

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DEDICATED

TO

MY LOVING PARENTS AND UNCLE

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LIST OF ABBREVIATIONS

AASHTO	–	American Association of State Highway & Transportation Official
SMA	_	Stone Mastic Asphalt
AC	–	Asphalt Concrete
ARL	–	Attock Refinery Limited
ASTM	–	American Standard Test Method
BS	–	British Standard
Gmb	–	Bulk Specific Gravity
Gmm	–	Maximum Specific Gravity
HMA	–	Hot-Mix Asphalt
ITFT	–	Indirect Tensile fatigue Test
ITS	–	Indirect Tensile Strength
JMF	–	Job Mix Formula
OBC	–	Optimum Bitumen Content
CRM	–	Crumb Rubber
UTM	–	Universal Testing Machine
Va	–	Air Voids
VFA	–	Voids Filled with Asphalt
VMA	–	Voids in Mineral Aggregates

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ABSTRACT

In Pakistan most of the pavements are made up of hot mix asphalt as this is the most available and economical material and it is also suitable for climate here. However hot mix asphaltic pavements normally require frequent maintenance and rehabilitation because they are damaged due to intense loadings. Thus increasing the agency's estimated cost and making it uneconomical. To make the asphaltic pavement economically efficient and effective, several alternatives should be designed. One of the alternatives to minimize the damages of pavement, reduce agency cost and to prolong the service life is use of modified asphalt pavements i.e. Stone Matrix Asphalt Pavement. The Stone matrix asphalt is a gap graded mix having higher coarser content, high asphalt content and fiber as a stabilizer. In this study an attempt has been made to study the use of Munjin Fiber and Crumb rubber as a stabilizing agent in Stone matrix asphalt SMA-25. Munjin Fiber is non- conventional natural fiber. Crumb rubber is a waste material of rubber tires; wet process was opted for incorporating crumb into mix. The research was conducted to optimize crumb rubber for Volumetrics and Performance properties of mix. Crumb Rubber was incorporated at 2%, 4%, 6%, 8%, 10% and 12% by weight of optimum bitumen content. In term of performance parameters Moisture sensitivity and Fatigue life of the mix were evaluated using UTM 25. Indirect Tensile Test for moisture sensitivity was conducted on Marshal compacted samples. For Indirect Tensile Fatigue Test Gyratory compacted samples were prepared and tested for fatigue life (Cycles to failure). An average optimized crumb rubber content was determined from Marshal Test, ITS, ITFT. Study concluded that mix showed excellent behavior in terms of volumetrics at 5.8% optimum bitumen content and 4.95% Crumb Rubber content. Further it was found that on addition of 5% crumb rubber mix displayed maximum moisture resistivity. It was observed that fatigue life of the mix increased abruptly on addition of crumb rubber but to certain level after that it decreased. Average optimized crumb rubber content was found to be 4.6% and it was found that on average optimized crumb rubber content Marshal stability and Moisture resistivity was improved by 38% and fatigue life was increased 79% as compared to Control mix.

Chapter 1

INTRODUCTION

1.1 BACKGROUND

Stone Mastic Asphalt (SMA) is a gap graded mix, having better stone to stone contact thus providing excellent strength to mixture.

SMA was first introduced in Germany in the 1960s with a concept of tough surfacing to resist wear and tear caused by studded tires. After performing trials it was found that the mix enhanced the deformation resistance of pavement. Since then SMA has spread all across Europe and world, with some variations. After its introduction in 1960, first significant trials were done in 1993 in Australia, which was based on original German specifications. It was found that the mixes have high binder content (> 6.0%) due to gradation of SMA (gap graded) necessitated the use of fibers to prevent drainage of binder during mixing, placing and transport. original mixes contained some fractions of fine aggregates and a proportion of natural sand. But some work done on the SMA in Australia, resulted in mixes having field air voids more than 10%. These mixes provided good texture and better resistance to deformation but we can’t negate the fact that higher permeability results in lower durability and then there is a need to consider the permeability of underlying materials. Recent work on SMA has closely looked the interlocking properties of the aggregates, specially the void spaces in coarse aggregate. In Europe this has led to the concept of "Real SMA" based on a self-supporting stone skeleton of high quality crushed aggregates. By using single sized aggregates larger gaps in aggregate mix can be achieved, thus eliminating middle size aggregates and controlling size of fine aggregates. This report is divided into three phase.

- Environmental importance of recycling/reusing Waste tire.
- Studying the change in behavior of Bitumen by addition of Crumb rubber.
- Studying the performance parameters of Crumb rubber modified asphalt.

Rachel Louise Carson (1907-1964) said “The human race is challenged more than ever before to demonstrate our mastery - not over nature but of ourselves”, now a day’s we are challenged to find ways to produce more energy, reduce our waste production and minimizing use of limited natural resources. Wastes are generally inevitable products that are generated by living organisms. This starts from a simple unicellular organism like amoeba to the complex multi cellular organism like man. And the volume of wastes generated by these living species depends upon their size, capacity and complexity. Before this modern industrial era the production and type of waste was different, if we go back in 19th century we will find that generally waste products were ashes from burning wood, agricultural and animal waste, and in those days disposal of this simple waste was not a problem they were used to be dumped in ground and later in years this waste proves to be useful in terms of fertility of land. Now the time has changed, industry is growing bigger and bigger, world is moving towards modernization and standard of living has also improved. But have we ever thought that this modernization and living standard is equipped with different kind of wastes, and some of these waste products are also harmful to our health and environment. These wastes may be in form of solid wastes like broken glass, waste tires, spent nuclear fuels, plastics; liquid wastes like leachates, general chemical and gaseous waste such as methane emitted from landfills, carbon monoxide etc.

Waste rubber tires are those which have been used for a long term and have damaged sides, damaged corrugations, have bulges and can’t be retreaded due to excessive usage. Now a day’s amount of vehicles is rising day by day, every day you move out of your house you will find a new type of vehicle on the road. Talking of Pakistan which is under developing country, total number of registered vehicles according to survey conducted by Global Health Organization (GHO) in 2011 is 9080,437**.** So with this ongoing rise in use of motor vehicles, hundreds and millions of tires are discarded each year worldwide. The worldwide production of waste tires is about 5.0×10^6 tons per year, which is 2% of the total annual solid waste. The European Union produces more than 2.5×10^6 tons of waste tires per year. (Holíková, Jelemenský, Annus, & Markoš, 2005). Many of these discarded tires are added to existing tire dumps or landfills, and little number are gathered for recycling. This huge amount of scrap tires, rather in dumps or in recycling facilities, pose serious fire protection challenges to fire departments. Tires burn with a high amount of per-pound heat output than most of the coal, and the high heat production of tire rubber makes extinguishment very difficult. (“Special Report : Scrap and Shredded Tire Fires,” 1998) .When the tires catch fire a large amount of flammable oil is yielded, this oil is not only flammable but also environment contaminating. Chemical released during open burning of Tires. (Burned, Released, & Hazard, 2005)

As global sources of petroleum are decreasing, so their proper and appropriate utilization is required. So it is necessary to develop methods for recycling or second disposal of the waste tires.

The practice of dumping waste tires in landfills and open burning is becoming unacceptable, as the tires are non-biodegradable material. As the population of our planet is also increasing day by day and by now we have reached to seven billion, so this increasing population need some land to live and if keep filling our available land by dumping the waste where our future generations will go. Figure 1.1 shows a satellite image of Kuwait; one can see these black spots of tire dumps with naked eye from space.

Source: http://www.dailymail.co.uk/news/article-2337351

Figure 0.1: Satellite image, Sea of rubber Kuwait

This is also a fact that the tires which are dumped in landfills provide a breading nest for mosquitoes. World Health Organization (WHO) directly attributes the spread of the dengue vector to international trade in used tires. In order to prevent environment from waste rubber and in particular discarded automobile tires, it is highly recommended to recycle this material. However, the total quantity of tires currently recycled in a given year is less than 7% of the annual tire generation rate. (Integrated & Management, 1996).

Recycling tires can be done by grinding the tire and adding the waste rubber particles to rubber mixtures for manufacturing new products. However, during this process strong deterioration of the desired physical properties of the rubber occurs.

1.2 PROBLEM STATEMENT

Pakistan is a country having a road network of 260,000 km which is spread all over the country. Like other countries around the world Pakistan's road network is a life line for its development. To keep pace with developing countries we need a larger road network, much bigger than existing one. And this of course requires huge amount of money, labor and resources.

Generally there are two types of pavement in Pakistan, flexible pavement and rigid pavement. 90% of the road network in Pakistan is made of flexible pavement as Pakistan is a developing country and can't afford rigid pavements even in those areas where required.

A look at the road conditions in Pakistan reveals that there are two major types of failure faced by road network along with rutting.

- **Fatigue cracking** a major failure encountered by motorist while driving through these highways. Fatigue cracks develop under and around loading wheel, as Permanent deformation gradually develops under wheel paths due to increasing number of load applications. The Dynamic creep test provides sufficient information to determine elastic (reversible) and plastic (irreversible) deformations of asphalt. In Pakistan we may find these deformations in excess and this is due to uncontrolled loadings.
- **Stripping** is the other type of failure which is continuously found on highways. This is probably due to the fact that Pakistan is located in a region which receives heavy monsoon season and floods, due to which roads becomes moisture sensitive and eventually fail.

Although, agencies keep on maintaining these roads but this maintenance requires a lot of money and time. So to prevent these problems/failures there is a need of that type of road mix which can resist these damages.

Secondly, we know we are a country which is rich in natural resources but the quantity of natural material which is used in construction is declining day by day. The excessive crushing of mountains is destabilizing the area. As well as increasing cost of extracting good quality of natural material.

Thirdly, Pakistan is also a big contributor of Waste rubber tires. There is not enough space to dump these tires in a landfill; obviously burning them is harmful to health.

Keeping in mind the factors mentioned above, we have to look for alternate material for highway construction, by which the pollution and disposal problems may also be mitigated to some extent. Table 1.1 shows test matrix.

Table 0.1: Test Matrix for Mix

<table>
<tr><th>S/No</th><th>Test</th><th>CRM%</th><th>Bitumen Content (%)</th><th>No. of samples</th></tr>
<tr><td rowspan="9">1</td><td rowspan="15">Marshall Mix Design</td><td rowspan="9">0</td><td>3.5</td><td>3</td></tr>
<tr><td>4</td><td>3</td></tr>
<tr><td>4.5</td><td>3</td></tr>
<tr><td>5</td><td>3</td></tr>
<tr><td>5.5</td><td>3</td></tr>
<tr><td>6</td><td>3</td></tr>
<tr><td>6.5</td><td>3</td></tr>
<tr><td>7</td><td>3</td></tr>
<tr><td>7.5</td><td>3</td></tr>
<tr><td>2</td><td>2</td><td>5.8</td><td>3</td></tr>
<tr><td>3</td><td>4</td><td>5.8</td><td>3</td></tr>
<tr><td>4</td><td>6</td><td>5.8</td><td>3</td></tr>
<tr><td>5</td><td>8</td><td>5.8</td><td>3</td></tr>
<tr><td>6</td><td>10</td><td>5.8</td><td>3</td></tr>
<tr><td>7</td><td>12</td><td>5.8</td><td>3</td></tr>
<tr><td rowspan="5">9</td><td rowspan="5">Moisture Damage by UTM</td><td>0</td><td>5.8</td><td>2</td></tr>
<tr><td>2</td><td>5.8</td><td>2</td></tr>
<tr><td>4</td><td>5.8</td><td>2</td></tr>
<tr><td>6</td><td>5.8</td><td>2</td></tr>
<tr><td>8</td><td>5.8</td><td>2</td></tr>
<tr><td rowspan="5">10</td><td rowspan="5">Indirect Tensile Fatigue Test by UTM 25</td><td>0</td><td>5.8</td><td>2</td></tr>
<tr><td>2</td><td>5.8</td><td>2</td></tr>
<tr><td>4</td><td>5.8</td><td>2</td></tr>
<tr><td>6</td><td>5.8</td><td>2</td></tr>
<tr><td>8</td><td>5.8</td><td>2</td></tr>
<tr><td colspan="4">Total</td><td>68</td></tr>
</table>

1.3 RESEARCH OBJECTIVES

Objectives of this research are as follows,

1. To find the properties of Crumb rubber modified bitumen.
2. To find the volumetric properties of Crumb Modified and Munjin Fiber modified Stone Matrix Asphalt.
3. Optimization of crumb rubber for Moisture sensitivity and Fatigue life of Stone Mastic Asphalt.
4. To find average optimized crumb rubber for Marshal Stability, Moisture resistivity and fatigue life of stone mastic asphalt.

1.4 SCOPE OF THESIS

To achieve the above mentioned research objectives, a research plan were determined which is as follows.

1. Literature review on use of crumb rubber in stone matrix asphalt and in other construction projects was conducted. Different papers were studied on permanent deformation and moisture damage of stone matrix asphalt.
2. Optimum bitumen content was determined for SMA, than this optimum bitumen content was replaced with different percent of crumb rubber i.e. 2%, 4%, 6%, 8%, 10% and 12% and optimum rubber content was determined.
3. Preparation of samples for performance testing at optimum bitumen and crumb content.
4. Performance test to evaluate fatigue life of stone matrix asphalt. Superpave Gyratory Compacted samples.
5. Conditioning of samples for moisture sensitivity test according to ALDOT-361.
6. Testing of conditioned and unconditioned samples for indirect tensile strength test on UTM-25 according to ASTM D 6931-07.
7. Concluding the results obtained from performance testing.

1.5 ORGANIZATION OF THESIS

Thesis is divided in five chapters; detail of each chapter is given below.

Chapters 1 gives a brief overview of Stone Mastic Asphalt (SMA) along with fibers. It also gives information about properties and advantages of Crumb rubber. Effect of crumb rubber modification on stability, flow, volumetric and moisture sensitivity

Chapters 2 includes literature review on findings of the previous studies related to the utilization of Crumb rubber, and different fibers in asphalt mix. It also includes previous studies on SMA gradation, Crumb rubber, and bitumen.

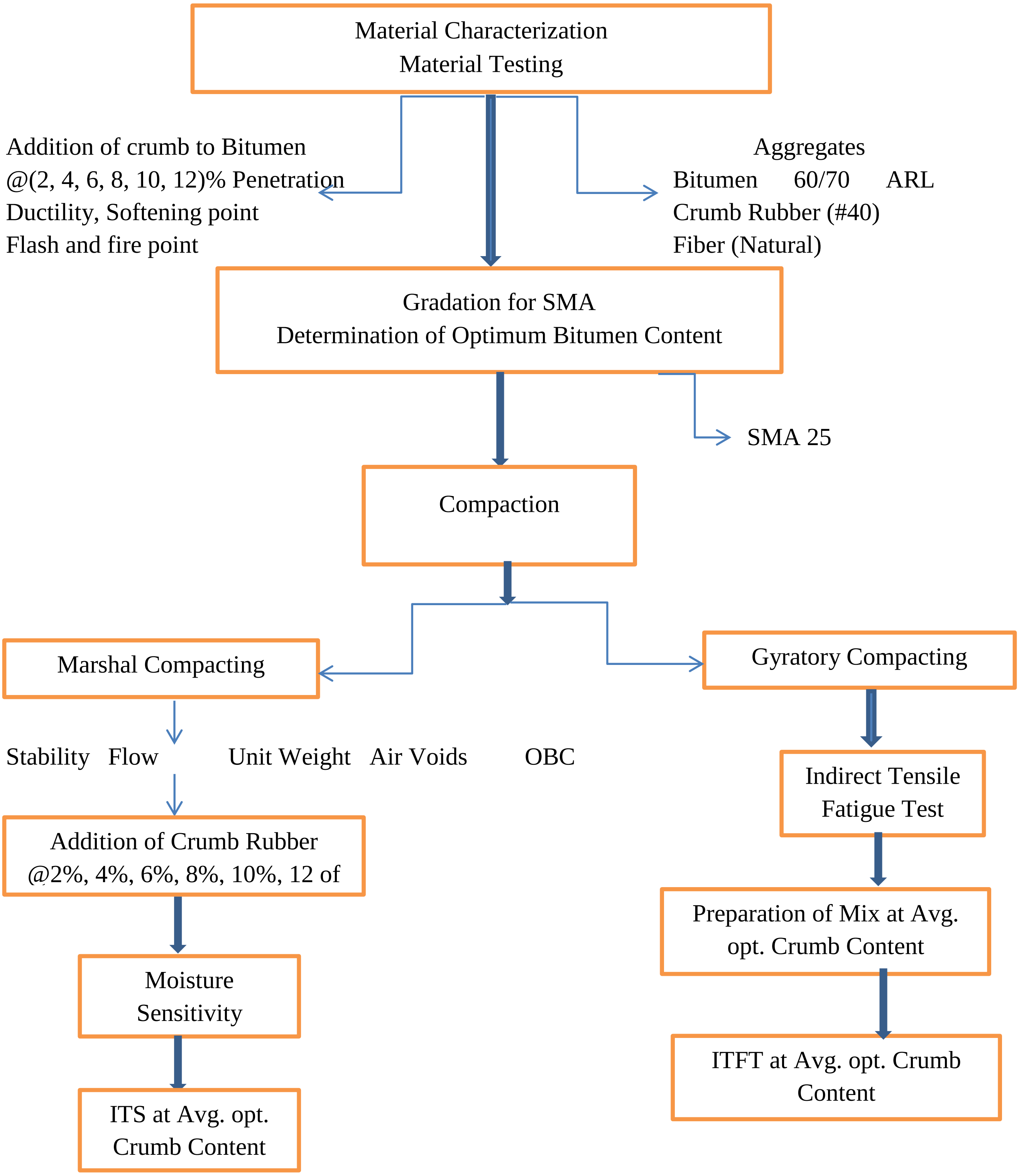
Chapters 3 gives a bird's eye view that how the work is accomplished. This also tells which type of gradation is adopted for preparing samples of SMA, from where the material was collected, which standard was adopted to perform a certain test.

Chapter 4 presents the experimental results and their analysis using the software Microsoft Excel 2016.

Chapter 5 summarizes the findings and conclusions of laboratory testing. The future work and suggestions are also discussed.

1.6 FLOW CHART

A step wise chart to carry out the planned work is shown here.



Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter gives a brief review of the literature and theory related to the response of asphalt mixes containing crumb rubber or any other fiber to different tests specially moisture sensitivity and fatigue life. This chapter deals with crumb rubber and fiber, its impact on different performance properties and researches carried out previously to predict fatigue life and moisture damage of stone mastic asphalt (SMA) mixes using ITFT test and ITS test.

2.2 BACKGROUND

Based on the stone aggregates and bitumen mixing there are three major type of asphalt surfacing which are Dense graded asphalt (DGA), Stone matrix asphalt(SMA) and open graded asphalt (OGA). These asphalt surfaces differ from one another basing on size of aggregates, binding patron , the amount of bitumen added and the presence of other additives (E-Asphalt, 2014). The paper aimed to study objectives, material composition, economy and use of waste fibers in it so that we can have a pavement which is much better than conventional asphalt pavement.

(“Summary of Georgia ’ s Experience with Stone Matrix Asphalt Mixes,” 1989) according to this report Stone matrix asphalt is a gap graded mix having high amount of coarse aggregates, due to which its stone to stone contact is increased and in result its load carrying capacity is maximized. These coarse aggregates are held together, interlocked by fine particles and fibers. SMA proved successful in Europe and American asphalt professional were introduced to Stone matrix asphalt on a tour in 1990. When they came back they started taking interest in stone matrix asphalt, Georgia department of transportation (GDOT) was first in America who used SMA on roads of Georgia. Based on the European experience and the research conducted by GDOT they found that Stone matrix asphalt has following benefits.

a) 30-40% less rutting than conventional asphalt mixes.
b) 3-5 times greater fatigue life
c) 30-40% longer service life. (Europe).
d) Less annual cost.

2.3 FINDINGS ON USING CRUMB RUBBER AND FIBER IN SMA

While talking about Stone matrix asphalt the first thing which comes in mind is fiber as this is important constituent of SMA which prevents drain down of mix, the chances of drain down in SMA are quite high as compared to conventional mixes due to high amount of bitumen. A lot of research has been carried out regarding fiber; different people used different fibers along with different additives. All the study regarding SMA focusing fiber till date was aimed to have a pavement which is much stronger than conventional pavement in terms of stability, rutting, fatigue, moisture sensitivity, etc.

(Bindu & Beena, 2014) conducted a study on different additives to be used in stone matrix asphalt. Research focuses on the influence of additives like sisal, coir, banana fibers, polypropylene and waste plastic on the drain down characteristic of stone matrix asphalt. Drain down test is conducted to check out the bleeding phenomena. After performing the test it was concluded that the optimum fiber content is 0.3% by weight of mix for all the fiber additives. For waste plastic and polypropylene the optimum contents are 5% and 7%. The study concluded that all the five additives are good to prevent drain down, but coir fiber is best suited.

(Vivek & Sowmya, 2015) investigated the use of shredded waste plastic as a modifier and fiber to prevent drain down of mix. The shredded waste was added @4%, 6%, 8% and 10% by weight of bitumen and fiber was added @0.1%, 0.2% and 0.3% by weight of mix. He found that the stability value was increased to certain extant while adding the shredded plastic and then decreased. Similarly stability increased by adding fibber content and found maximum when added 0.3% of fiber by weight of mix.

(Malarvizhi, Senthil, & Kamaraj, 2012) did a study on SMA by adding Crumb rubber and low density polyethylene (LDPE) as a dry process. In his study he used 15% crumb and 30% LDPE by weight of bitumen. No fiber was needed when this blend was used. Based on the results of indirect tensile test and unconfined compression test he found that CR+LDPE improved the engineering properties to a great extant.

(P. Kumar, Chandra, & Bose, 2017) conducted a research on use of jute fiber and Crumb rubber in SMA mainly to prevent drain down of mix. Further he conducted rutting test, moisture susceptibility, and fatigue test.

(Moghaddam, Ziaee, & Mollashahi, 2014) compared the properties of SMA by using two different fibers. In this study they compared Jute fiber with three different waste fibers (two synthetic and one cellulose fiber) in terms of drain down, Marshall Stability and tensile strength ratio.

(Issa, 2016) studied the properties of Hot mix asphalt by adding crumb rubber, in this study some important properties of asphalt mixture was studied including stability and flow. Original samples were prepared without adding bitumen, samples was prepared with bitumen percent of 4.5%, 5% and 5.5%. the optimum bitumen content was found than they replaced 5%, 10% and 20% of optimum bitumen by crumb rubber. Results indicated that properties of modified asphalt are far better than conventional asphalt. Further the study concluded that the replacement of 10% crumb with optimum bitumen content gave best results.

(Shafabakhsh, Sadeghnejad, & Sajed, 2014) the main problem in conservation and maintenance of roads are low resistance against dynamic loads and short service life due to which millions of rupees are spent over pavements to keep them in functional condition. In this paper pavement is analyzed against rutting after addition of crumb rubber. Wheel tracker test was performed for rutting; results showed crumb modified asphalt caused a great decrease in rate of rutting depth as compared to conventional mixes.

(Onyango, Wanjala, Ndege, Masu, & Binder, 2015) asphaltic pavements generally have shorter life cycle and mostly they fail due to temperature changes, loadings and ageing. But the modified asphalt produce bitumen binder with improved viscoelastic properties, which performs better over different temperature ranges and load cycles. In this study bitumen of grade 60/70 is modified by adding 2,4,6,8 and 10% by weight of bitumen following wet process, and mineral aggregates was modified by adding 1,2,3,4 and 5% of crumb rubber by volume of mineral aggregates following the dry process. Rheological properties of LDPE modified asphalt was studied, results showed the increase in viscosity, softening point and stiffness of binder. After that Marshall property of the mix was studied, samples containing 2% crumb rubber and 4%LDPE found to have 30% more stability values as compared to conventional mixes.

(Xie & Shen, 2016) did a study on “performance properties of rubberized stone matrix asphalt mixtures produced through different processes” i.e. dry process, wet process and the terminal in laboratory. For comparison the mixtures of SMA containing SBS modified binder and virgin asphalt was used. The optimum bitumen content was found according to specifications given by Georgia department of transportation. The study investigated the rutting, fatigue resistance, moisture susceptibility and dynamic modulus. Dynamic modulus test was conducted to measure the (LVE) linear viscoelastic behavior of asphalt. This test was performed under load controlled and axial compression condition using AMPT.to ensure the response of sample within linear viscoelastic limit, the strain amplitude was kept bellow 115 micro strains. Three samples were tested at three different temperatures, i.e. (4, 20 and 45 degree) at four different loading frequencies (0.01, 0.1, 1 and 10 Hz). Before the Dynamic modulus testing specimens were conditioned and conditioning temperature and time was 4, 20 and 45 degree for 18h, 3h and 3h. Similarly all the standards for above mentioned tests were followed and at the end it was found that CRM improved the Rutting resistance, fatigue resistance and high temperature dynamic modulus.

(Manosalvas-paredes, Gallego, Saiz, & José, 2016) conducted a study on “Rubber modified binders as an alternative to Cellulose fiber – SBS polymers in Stone Matrix Asphalt.” The study aimed to use two different binders modified with two elastomeric polymers, SBS and Crumb Rubber, for both the binders aggregate gradation was same SMA11 was used in the study. To determine the optimum bitumen content marshal test was conducted. And whence the binder content was determined other performance tests was conducted (Water sensitivity, binder drainage and wheel tracker test).

There are many research work done before to check the influence of fiber in SMA mix (Chui-Te Chiu and Li-Cheng Lu ,2006) used ground tire rubber to do study on SMA.

(Ibrahim M. Asi, 2003) used mineral fiber (0.3%) to use the resulting Asphalt in hot weather. (Bradley J. Putman and Serji N. Amirkhanian, 2004) done research on Utilization of waste fibers in stone matrix asphalt mixtures.

(Kumar Pawan, Chandra Satish and Bose Sunil, 2007) tried to use jute fiber and compared the results with the imported cellulose fiber using grade 60/70 bitumen. He found that when we added 0.3% fiber in the mix results were fairly good, and it was approximately same as the results of cellulose fiber.

(Gibreil & Feng, 2017) studied the effect of crumb rubber powder and high density polyethylene(HDPE) on hot mix asphalt, the properties which they investigated are penetration, softening point, ductility, flow and stability. Along with that samples were also checked against moisture sensitivity and rutting. The results indicated that the addition of modifiers changed the properties of asphalt and gave quite good results.

(Mashaan et al., 2014) investigated the fatigue life of SMA by addition of crumb rubber; he added 6%, 8%, 10% and 12% crumb by weight of bitumen. The study was aimed to check the effect of crumb rubber on stiffness and fatigue properties of SMA at optimum binder content. The tests he conducted are, dynamic stiffness (indirect tensile test), dynamic creep and fatigue test (indirect tensile fatigue test)

(Muniandy et al., 2004) used crumb rubber in stone matrix asphalt, as waste rubber tire is produced in a large amount every year, and it is too difficult to dump such big amount. In this study truck tire rubber containing 70% natural rubber was used in ground form. Than the ground rubber was blended in 80-100 bitumen. Mix was tested against stability, resilient modulus, dynamic creep and tensile strength ratio. Along with the ground tire 0.3% newly developed cellulose oil palm fiber was also used to prevent the drain down of mix. It was found that the SMA mix modified with rubber has much better performance as compare to unmodified.

(Fakhri, Hassani, & Reza, 2013) conducted fatigue test on, Styrene Butadiene Styrene (SBS) Modified asphalt, by adding 5% SBS by weight of bitumen. He concluded that SBS modified asphalt samples showed three times more fatigue life at high stress level as compared to unmodified samples. (Fakhri, Reza, & Omrani, 2013) studied the effect of warm Mix Additives WMA on Fatigue life of SBS modified and conventional samples. Aspha-min and Sasobit were used as warm mix additives, and to evaluate fatigue behavior four point flexural beam test was conducted at four different stress levels. It was concluded that fatigue life of HMA is less than Warm Mix Asphalt.

(Ebrahim & Behiry, 2012) studied the effect of axel load on fatigue and rutting life of asphaltic pavement. Study focused on behavior of strain produced in pavement when tire load was increased as in case of overloaded trucks. Results indicated that tensile and compressive strains increased as Axel load was increased and decreased with increase in Asphaltic layer modulus.

2.4 AGGREGATES

Mineral aggregate from Margalla quarry are used in combination with asphalts to prepare mixes. As the aggregates normally constitute 90 percent or more by weight of the mixes, their properties have a very important effect upon the finished product. The most commonly used mineral aggregate is crushed stone, sand and mineral filler. In asphalt pavement construction, the control of properties of mineral aggregate is just as important as the control of asphalt properties.

The test results of aggregates are commonly obtained as per AASHTO & ASTM Specifications and BS Standards, described briefly here under. Correct sampling has been exercised to obtain representative test samples of mineral aggregate. (Savitha, 2010) analyzed the results of aggregates of previous two years 2008 and 2009 the properties which was analyzed are sieve analysis, sand equivalent, water absorption and specific gravity of coarse and fine aggregates, abrasion value, impact value, crushing value, flakiness and elongation index. It was found that in last two years crushed rock was used as coarse aggregates and river run sand as fine aggregates. Here in this study also aggregates are crushed rock.

Selection of gradation for SMA is an issue of concern; it should be selected such that it is economical and best suited to conditions. (Taylor, Hafeez, Kamal, & Mirza, 2014) evaluated the effect of aggregate gradation on rutting, stiffness and fatigue performance of stone matrix asphalt with different nominal maximum aggregate size. Four SMA mixes having nominal maximum size of 4.75, 9.5, 12 and 19mm were analyzed. (Hafeez, Kamal, Mirza, & Aziz, 2012) their study was objected to investigate the influence of maximum size of aggregates on permanent deformation characteristics of Stone matrix asphalt. They used four nominal maximum sizes of aggregates, 9.5mm, 12mm, 19mm and 25.4mm. All these four mixes were investigated for wheel tracker test at 25, 40 and 60 °C. They revealed that rutting in stone matrix asphalt for any number of loading passes is a function of maximum size of aggregates and testing temperature. Further they found that rutting increased with increase in temperature and decreased with a decrease in aggregate size.

2.5 FIBER

The use of fiber in SMA is very important. It helps to increase strength and stability and decrease the drain down in SMA mixes. Different types of fiber are used in SMA, we can classify then into two main branches

a) Natural fibers

b) Synthetic fibers

Most commonly used fibers are cellulose fibers, mineral fibers and natural fibers. The uses of fibers are mainly depending on the availability and economy. Fiber helps in increasing the strength and stability by bonding between aggregates and bitumen. As we mentioned that in SMA higher content of bitumen is used than HMA. If no fiber is used in SMA pavement then there will be more drain down, rutting and flow. According to MORTH (Ministry of Road

Transport and Highways) specification of fiber content of 0.3 to 0.5% can be used. Here we have used 0.3% of fiber in SMA, which gives a value of 3.6gm.

There is a lot of research work done before to check the influence of fiber in SMA Mix. (Nascimento & Silva, 2013) the research was objected to study the use of coconut fiber as an alternative material for use of large scale construction. Study presented laboratory characterization of the fiber, superficial structure was found by SEM (scanning Electron microscope) and the dimensions were calculated by Axon vision 4.4. Cold mix asphalt mixture was prepared by mixing fiber with asphalt and it was found that the sample were good in tensile strength and resilient modulus.

(K. K. Kumar, n.d.) In their study they attempted to check the use of fibers locally available to them in stone matrix asphalt. They used sisal fiber as a stabilizer in bituminous course of SMA. Mix was prepared by varying the percentage of bitumen by 4% to 7%. They varied the fiber content from 0% to 0.5% by weight of total mix. Samples were prepared and tested for Marshal Test. The results showed that 0.3% of fiber and 5.2% of bitumen gave good results. Further different performance tests were conducted like indirect ensile test, drain down test, static creep test etc.

2.6 EFFECT ON MOISTURE AND FATIGUE LIFE OF PAVEMENTS

Water being a universal solvent can solve anything in it no matter how hard it is over the time a constant sprinkle of water can solve that thing, even an asphaltic pavement can't withstand the effect of water. Although pavements are made with great care so that water may not come in contact with it, but it is impossible to keep a pavement away from water. So a pavement should be designed such that it can bear the effect of moisture without any major damage. Generally there are two major types of failure which are caused by moisture, stripping and Raveling because the bond between bitumen and aggregates is broken due to intrusion of moisture. Asphalt is a viscoelastic material having flow characteristics due to which it tends to heave up under intense loadings or repeated cyclic loadings. To minimize this effect and enhance the serviceability different additives are used in asphalt.

(Mashaan et al., 2014) studied effect of crumb rubber at optimum bitumen content using different modification levels 6%, 8%, 10% and 12%. Samples were tested against dynamic stiffness, dynamic creep and fatigue. He observed that crumb modified samples showed higher fatigue life as compared to unmodified. Moisture damage is one of the most common causes of failure and distress in asphaltic pavements. As pavements are always prone to moisture and inspite of good drainage conditions they are always susceptible to moisture damage. Intrusion of moisture in pavement structure decreases its strength and enhance the chance of distresses like stripping, raveling, fatigue damage (Othman, Rafiq, & Rosli, 2015). Moisture conditioning of asphalt samples plays a vital role in permanent deformation (Stroup-gardiner, n.d.).

2.7 GENERAL DETAILS ON RUBBER

There is a well-known fact that economy of a country depends upon wheel; rather this wheel is of industry or of vehicle. If we look at worlds map we will find that countries having strong economy have a strong road network. As the road network spreads the quantity of vehicles on the road rises as a result the production of tires is increasing. According to a report" world Tire" published in 2016 the current production of tires is 2.5billion per year which will rise to 3.0billion units @4.1% per year in next four years. In monetary terms sales of tires will increase by 7% per year to $258 billion.

According to a report "Tire industry in Pakistan" published in "Pakistan Economist" total demand of tires in Pakistan excluding two wheelers in 2012-2013 was 8.2 million. But the tire industries in Pakistan are producing only 23% of this demand. The rest 40% are the imported tires and 37% are smuggled tires. Apart from vehicles overpopulation one of the reason for this high amount of demand is the dilapidated condition of roads in Pakistan. Tires of buses and trucks are high in demand in Pakistan which is 50% of the total consumption and this is because these two four wheelers travel maximum on the roads. To meet such a high demand there is only one major company in Pakistan "General tires" which is producing 1.6 million tires per year which is too less. Now if we compare these stats with India. Table 2.1 tells us some statistics about Indian tire industry.

Table 2.1: Tire Statistics

Consumption world rating	4^{th}
Tire Companies	36
Tire Factories	51
Total Production (2012-2013)	Rs. 110 million
Industry turnover	Rs. 3100 billion
Growth in Truck and Buses	15%

Source: Indian rubber industry statistics

Table 2.2 shows tire particle classifications.

Table 2.2: Tire Particles classification

Material	Size
Cuts	>300mm
Shred	50-300mm
Chips	10-50mm
Granulate	1-10mm
Powder	<1mm
Fine powder	<500µm
Carbon products	<500µm

Source: http:// ebooks.narotama.ac.id

Table 2.3 indicates chemical composition of rubber tires.

Table 2.3: Chemical Composition of Tire Rubber

Constituent	Percentage
Rubber (natural, synthetic)	38
Fillers (Carbon Black, Silica, Carbon Chalk)	30
Reinforcing Material (steel, Rayon, Nylon)	16
Plasticizers (oil's and Resins)	10
Chemicals for vulcanization (Sulphur, Zinc Oxide)	4
Chemical as antioxidants to counter material fatigue	1
Miscellaneous	1

Source: http:// ebooks.narotama.ac.id

Now the problem is this huge amount of tires which I being produced every year have to be dumped whence their life time is over, dumping of rubber tires is a big problem now days, because it requires a lot of space and it's also a continuous threat to environment. Accumulation of these tires is dangerous because they pose potential environmental concern, fire hazard and breeding place for mosquitoes, which causes disease like malaria and dengue. According to survey 725000 people worldwide die every year due to mosquitoes. And if these stockpiles are burned or if they catch fire they can burn for months exhausting acrid black plume which can be seen from miles thus polluting the environment. Because that plume contains toxic chemicals and air pollutant which spread in surrounding and harm the environment like other toxic chemicals released by industries. In order to prevent environment from this issue recycling of rubber tire is a good idea. Recycling of tires is a process in which the tires which are useless, whose life time is over by wear and tear on tear on roads are recycled and used again in some other form instead of burning or dumping. One of the processes of recycling is by cracker mill, which tears apart the large rubber tires and reduces their size by passing them between rotating corrugated steel drums. By this process an irregular shaped particles having a large surface area are produced and these particles are commonly called as Crumb rubber. Figure 2.1 shows ground tire rubber from a cracker mill. Source: http:// ebooks.narotama.ac.id

Figure 2.1: Crumb Rubber in Cracker Mill

2.8 OTHER USE OF CRUMB

Use of crumb is not limited to asphalt; it can be used for different purposed i.e. to produce coating of electric wires, in concrete and also in trough of ground. (Engineering & Vidyanagar-gujarat-india, 2013) used rubber crumb in concrete and found that the certain properties of concrete improved after addition of crumb rubber such as Durability, ductility and crack resistance. He found that the specific weight of concrete modified with crumb rubber reduced as level of substitution of aggregate with tire particle increased. He also found that the workability of crumb modified concrete reduced as compared to conventional concrete. He also observed that the workability of concrete made of fine rubber particles in creased as compared to the concrete mad of coarser rubber contents. (Youssf, Elgawady, & Mills, 2014) did a study on strength of crumb rubber concrete. He replaced some part of natural aggregates with crumb rubber and called it CRC. He studied that the CRC can improve ductility, damping ratio and energy dissipation which is very important in earthquakes. Whereas the compressive strength of CRC is less as compared to conventional concrete.

Here in this project I have used the crumb rubber obtained from waste rubber tires obtained from a cracker mill in Taxila, than I passed this crumb from sieve # 40 and retained on sieve # 50. Further this crumb was checked against Specific gravity which found to be 1.15.

Chapter 3

RESEARCH METHODOLOGY

3.1 GENERAL

This chapter includes the research methodology adopted to achieve the mentioned objectives. It includes Material characterization, specimen preparation, testing, results and analyzing the importance of various factors. The study was carried out to analysis the behavior of crumb rubber in stone matrix asphalt. In first part of the research properties of crumb modified bitumen was studied. The properties which were tested are penetration grading, ductility of bitumen, softening point, flash and fire point. In next step marshal mix design was conducted, for this marshal samples were prepared for stone matrix asphalt with munjin fiber and optimum bitumen content was determined. After finding OBC I added crumb rubber of waste tires @2%, 4%, 6%, 8%, 10%, 12% to OBC, and optimum rubber content was determined. Than samples for performance testing was prepared at optimum bitumen content and optimum rubber content. Performance tests which were performed are Hamburg Wheel Tracker test and Moisture sensitivity. Further results were deduced and conclusions and recommendations were presented.

3.2 MATERIAL SELECTION

Material which is used in Stone matrix asphalt is coarse aggregates, fine aggregates, Cement, Crumb Rubber, Munjin fiber and Bitumen.

Material was collected from different sources. Bitumen was taken from Attack oil refinery; it was told to supplier that bitumen should be of grade 60/70. As bitumen is a binder in asphaltic concrete, if all other things are good i.e. aggregates, admixtures etc. but the binder is weak than our mix is of no importance, so section of bitumen is as important as selection of other materials.

. Aggregates both, coarse and fine was taken from Kazmi stone crusher's Marglla hills. Care was adopted while selecting the aggregate quarry sit, because aggregates are that portion of the road which carries approximately 95% of the load and remaining 5% of the load is carried by binder. SMA which is a pure stone to stone contact skeleton greatly depends upon properties of aggregates. Figure 3.1(a), (b) and (c) is showing quarry site and collection of aggregates.

Figure 3.1: (a), (b), (c) Quarry Site Margalla hills

3.3 FIBER

The use of fiber in SMA is very important. It helps to increase strength and stability and decrease the drain down in SMA mixes. Different types of fiber are used in SMA, we can classify then into two main branches

a) Natural fibers
b) Synthetic fibers

Most commonly used fibers cellulose fibers, mineral fibers and natural fibers. The uses of fibers are mainly depending on the availability and economy. Fiber helps in increasing the strength and stability by bonding between aggregates and bitumen. As mentioned that in SMA higher content of bitumen is used than HMA.

According to MORTH (Ministry of Road Transport and Highways) specification of fiber content of 0.3 to 0.5% can be used. Here I have used 0.3% of fiber in SMA, which gives a value of 3.6gm. in this project I have used natural fiber, commonly known as MUNJIN fiber.

Munjin fiber is found in excess quantity to obtain it from North Waziristan. It is bark of Munjin Plant; Munjin fiber is off white in color, 3to 4 feet in length and 0.3 to 0.5mm in diameter. Munjin fiber is fairly smooth and flexible, having good water absorption which prevents the drain down of pavement. It is valued for use because of its strength durability to stretch affinity for certain dyestuffs and resistance to deterioration in salt water. It is economical for use because it is found in excess quantity in Pakistan.

Generally Munjin fiber is used for making ropes and carpets but it is quite different from sisal. The resultant product of sisal is soft whereas resulting product of Munjin are coarser and stronger.

3.4 EFFECT OF SIZE OF FIBER

As there is no research work done on Munjin fiber in SMA Mix. So, tests were performed to check what size of fiber gives the best results.

For this purpose I tried different sizes 1.5mm and 3mm both of same diameter. Than check samples were prepared of same gradation with different fiber size. After testing it was found that samples with fiber size 3mm were 20% in stability and rut resistance and were having 15% less flow value.

So, here I have used fiber size 3mm in length and 0.3mm in diameter. Figure 3.2 (a), (b) shows Munjin fiber directly from field in dry state.

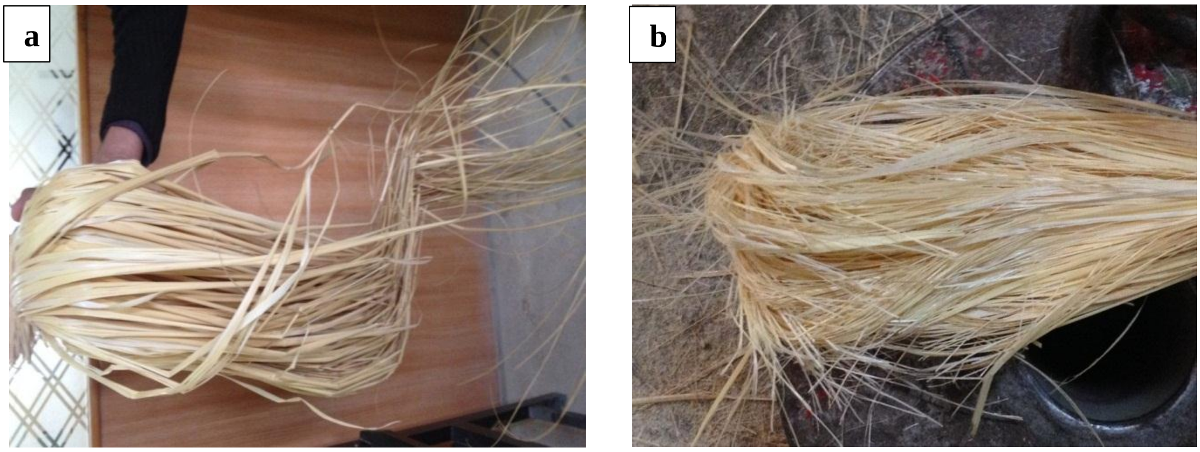


Figure 3.2: (a), (b) Munjin Fiber

Figure 3.3 shows measured quantity of the fiber which was finally used in mix.

Figure 3.3: Fiber in Proper Size

3.5 CRUMB RUBBER

Crumb Rubber is recycled rubber produced obtained from cars and truck scrap tires. Steel and tire cord (fluff) which are ingredients of tires are removed during recycling process, leaving tire rubber with a granular consistency.

Crumb rubber which is used in this project is taken from a local tire recycling industry in Taxila (Pakistan). Than this crumb rubber was sieved, in such a way that crumb pass through sieve#30 and retain on Sieve#40 as shown in Figure 3.4 (a) and (b).

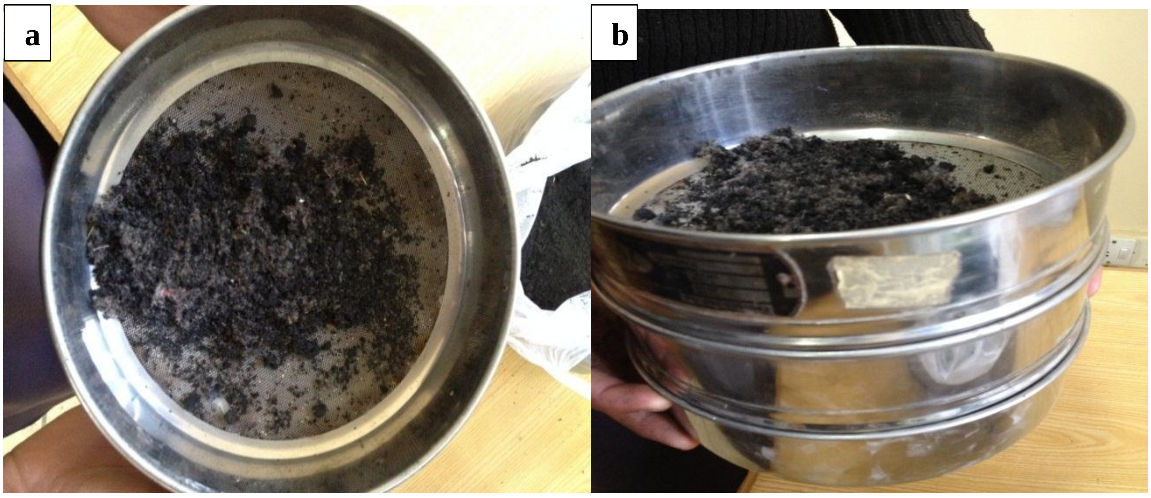


Figure 3.4: Sieving Rubber

3.6 TESTING METHODOLOGY

3.6.1 Size and Shape of Aggregates

This test was performed in accordance to ASTM D4791 to classify the aggregates on the basis of their size and shape. There are two types of aggregates.

a) Flaky material: Material whose thickness is small relative to the other two dimensions.
b) Elongated material: Granular material whose length is considerably larger than the other two dimensions.

This test also tells us about the internal friction of aggregates. Movement of aggregates around each other is restricted due to internal friction properties. And this resistance to movement is achieved by interlocking and surface friction as flaky and elongated break under load. First the sample was sieved. 200 pieces of aggregates was taken of each fraction and weighted. To separate the flaky material each fraction was passed through thickness gage. To separate the elongated material, each fraction was passed through length gage.

3.6.2 Specific Gravity

This test is performed to calculate the specific gravity and absorption of aggregates in accordance to AASHTO T85, ASTM C127 for coarse aggregates and AASHTO T84, ASTM C128 for fine aggregates. Specific gravity is the ratio of mass of a material to the mass of the same volume of water at specified temperature. Whereas, water absorption, is the increase in the mass of aggregates due to absorption of water in pores of aggregates. This test was conducted for both coarse and fine aggregates. Coarse aggregates of size 19.5mm, 12.5mm, 9.5mm and 4.75mm. And fine aggregates of size 2.46mm and 0.075mm. Further the test was also performed for filler.

3.6.3 Impact Value of Aggregates

Aggregates being used in road construction should resist crushing due to traffic load. They will resist crushing due to load only if they will be strong, to resist that impact, and the property of aggregates which resists impact is called toughness. Due to traffic, the road aggregates are subjected to impact because every part of tire behaves as cyclic impact on road when it rotates and there is possibility of stones breaking into small pieces. So the aggregates being used in road construction should have ability to resist that impact. Apparatus used in this test is Sample cup, cylindrical measure, Sieves, Balance, Oven and Tamping rod. First the aggregates was washed and dried at 100℃. sieves of the size sieve ½", 3/8" and #8 (2.36 mm) 500g of aggregates was taken and sieved through 12.5mm sieve and retained on 3/8" sieve. Than this sieved sample was poured in mold in three layers and each layer was tamped with 25 blows of tamping rod, than this mold was placed in the apparatus and 15 blows was applied from height of 38cm of the hammer having weight 13.5kg. Figure 3.5 shows crushed sample. After that the sample was passed through sieve#8 and impact value was calculated.

Figure 3.5: Hammered Sample

3.6.4 Los Angeles Abrasion Test

Aggregates should be hard and tough to resist crushing, degradation and disintegration because they go under substantial wear and tear throughout their life due to cyclic loading. They must be able to transmit load form surface layer to underlying layers. This test was performed in accordance to AASHTO T96, ASTM C131. Grading A was considered for this test. Sample of 5000g was taken and 12 numbers of charges was used. Machine was rotated at 30-33rpm for 500 revolutions. Than it was sieved through sieve #12. Than abrasion value was calculated. Gradation of class A was adopted as shown in Table 3.1.

Table 3.1: Los Angeles Gradation

Sieve (inch)	Retained on	Grading A
1 ½	1	1250
1	¾	1250
¾	½	1250
½	3/8	1250

3.6.5 Sand Equivalent Test

This test is performed to determine the relative proportion of fine dust or clay particles in soil or fine aggregates. Sand equivalent expresses the concept that most fine aggregates are mixture of coarse particles. When these fines are in excess on surface of coarse aggregates they can prevent bonding of aggregates with binder. This test is very important for Stone matrix asphalt because in SMA coarse aggregates are in excess and of course bitumen too, so if lot of fines is attached to surface there will not be a prober bonding. This test was performed in accordance to AASHTO T176, ASTM D2419.

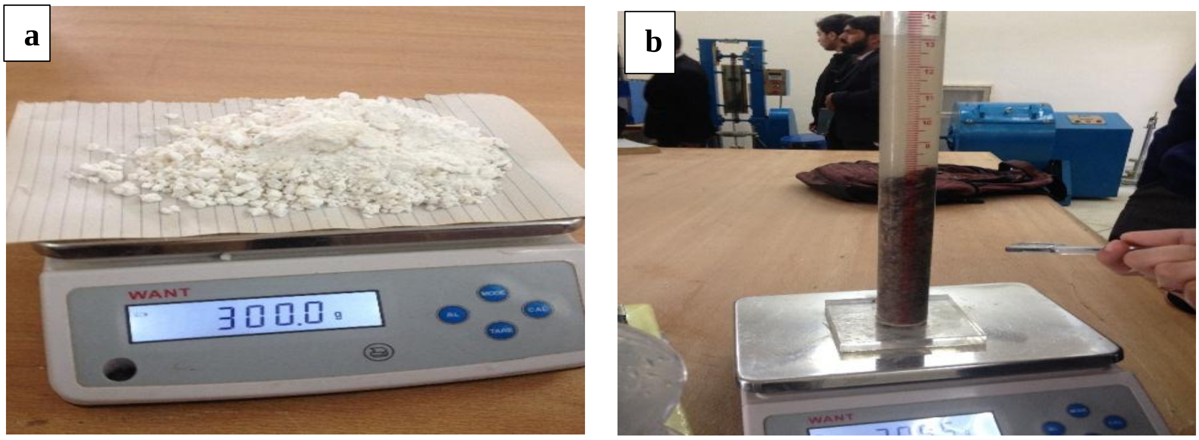


Figure 3.6: (a), (b) Sand Equivalent test

Apparatus used in this test is Graduated cylinder, Rubber stopper, Oven and Balance. Solution of calcium chloride was used in test. Aggregates passing through sieve#4 was taken and poured in graduated cylinder with calcium chloride solution and shake well. After sedimentation period height of clay and height of sand was determined. Figure 3.6 (a), (b) shows how sand equivalent test was performed.

3.7 GRADATION OF AGGREGATES

For Stone matrix Asphalt SMA there are different gradation given by different agencies according to their country environment. So to counter this problem Choice was made among three different gradations by making test samples on basis of Stability, Flow and Air Voids. SO after performing tests SMA-25 was finalized Shown in Table 3.2. SMA-25 means gradation having maximum size of 1 inch. Because it proved to be 20% more stable than other two gradations. Figure 3.7 shows gradation curve and it was observed as well suited for SMA.

Table 3.2: SMA Gradation

S.No	Sieve Size (mm)	%Passing	%Taken	Amount Taken(gm)
1	25	100	0	0
2	19.4	90-100	93	84
3	12.5	50-88	60	396
4	9.5	25-60	40	240
5	4.75	20-28	25	180
6	2.36	16-24	20	60
7	0.075	8-11	10	120
8	Pan	10	10	120

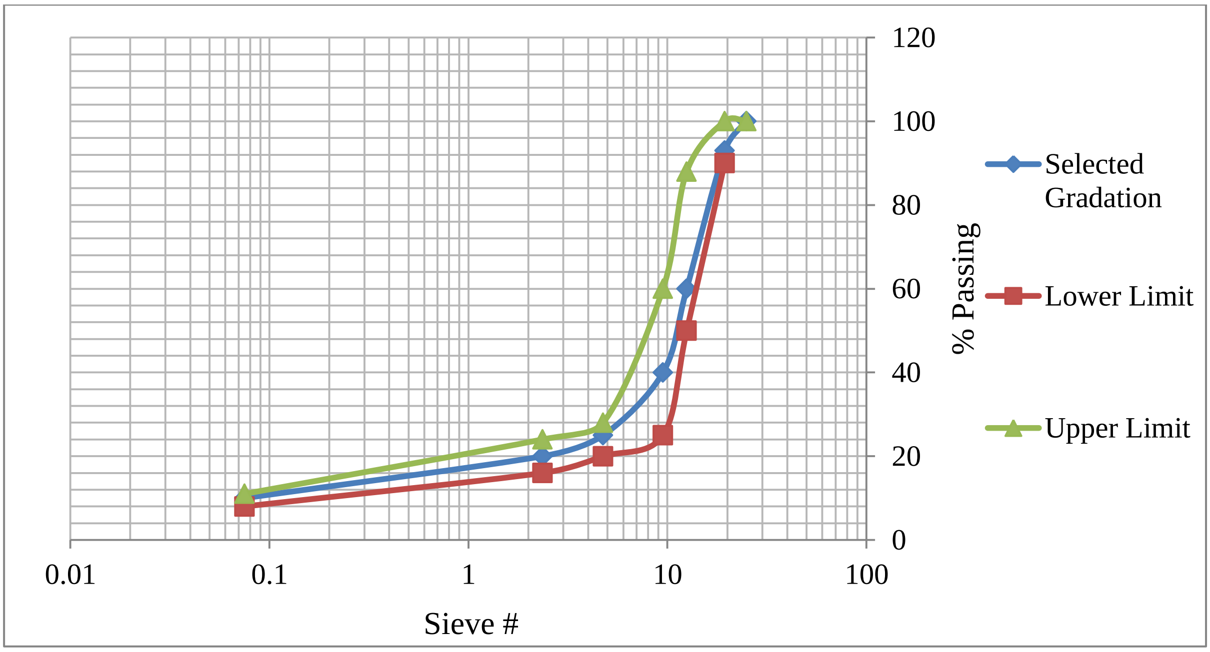


Figure 3.7: Gradation Curve

3.8 TEST ON BINDER

For construction of highway selection of binder is very important, consistency, purity and penetration are three properties of binder which should be considered while using it in construction. Bitumen should be consistent with temperature, consistency of bitumen can be found through penetration test, viscosity test or some other kind of test. Some important test of bitumen is as under.

a) Penetration grade test
b) Softening point test
c) Ductility test
d) Flash and Fire point test

3.8.1 Penetration Test

Penetration test is conducted in accordance to AASHTO T 49-03. In this test penetration of needle is measured in bitumen. Soft binder gives more penetration while hard binder gives less penetration. So in the areas where temperature is high hard bitumen should be preferred. Penetration of needle is measured in $1/10^{th}$ of mm. testing temperature for this test is 25 °C. and the weight which is used is of 100g. Test was conducted on bitumen taken from Attock oil refinery and it was found of Grade 60/70. Further test was conducted again after addition of Crumb rubber at different percent and it was found that value of penetration decreased.

3.8.2 Softening Point Test

Basic purpose to conduct this test was to find softening of bitumen, softening point is the point where bitumen attains a particular degree of softening under specified conditions. Bitumen is viscoelastic material without any specified melting temperature, so it is necessary to determine a specific melting temperature for its classification. This test was conducted in accordance with AASHTO-T-53. Experimentally softening point is the temperature at which two plates of bitumen melt to an extent that they allow two balls of steel to fall a distance of 25mm.

Apparatus includes thermometer, Glass jar, Gas Cylinder, flame, magnetic starrier. Two briquettes were filled with bitumen and after they are cooled they were placed in jar, and steel balls were placed above them. Afterwards i put the flame under glass jar, and noted the temperature at which they fall, while falling it was kept in mind that both balls fall within 1 degree of temperature.

3.8.3 Ductility Test

Ductility test of bitumen is very important because it tells us the behavior of bitumen under different climatic conditions. This test was conducted in accordance to AASHTO T 51-00. By definition ductility is extent to which a sample of bitumen can be stretched from both ends without breaking, at a speed of 5cm/min and at temperature 25 °C. For this test three samples of bitumen was taken put in briquettes shown in Figure 3.10 and pulled from both ends in ductility apparatus. Bitumen showed god results, as all the samples didn’t break even above

80cm of length. But when ductility test was conducted for Crumb modified bitumen the value of ductility decreased rapidly.

3.8.4 Flash and Fire Point Test

Flash and fire point test s also called safety test of bitumen. This test tells us the temperature of bitumen at which it flashes and then catches fire. This is very important test, as bitumen is a volatile material and while we are heating it we should know the temp at which it catches fire, as excessive heating of bitumen causes to lose its properties. This test was conducted in accordance to D3143/D3143M-13.

3.9 PREPARATION OF SAMPLES

For the preparation of surfaces of roads and airfields we use bituminous mix, often called Asphalt mix. Mix is composed of Aggregates and asphalt cement and sometimes admixtures to change or enhance the properties of the mix. There are some properties of asphalt mix which are as under,

1. Fatigue resistance: mix should not crack by repeated loads over the time.
2. Durability: it should be ensured that there is enough amount of asphalt around the aggregates so that mix can perform durably.
3. Skid resistance:
4. Resistance to deformation: mixture should be resistant to deformation in a way that it should not displace, distort under heavy loads especially under high temperature conditions.
5. Resistance to low temperature: it is important in cold regions.
6. Workability: mix should be easily placed and compacted under reasonable effort Goods drainage property.

Samples for the mix were prepared and tested according to ASTM D 6926.

This test was conducted twice. At first samples were prepared for simple Stone Matrix Asphalt. By simple SMA we mean Samples containing Aggregates, Bitumen, Fiber and cement as filler. Aggregates were sieved and weighed samples of 1200g were prepared and stored in air tight bags shown in Figure 3.8.

Figure 3.8: Weighed SMA Sample

After this, Fiber was poured and each sample was heated to 160 °C along with bitumen shown in Figure 3.9.

Figure 3.9: Addition of Fiber

3.9.1 Heating of Bitumen

ARL grade 60/70 bitumen was used in Preparation of Samples. Bitumen was heated to an extent that melts at get into liquid state so that it can be easily poured.

3.9.2 Mixing of Components

We mixed the bitumen and aggregates in a heated pan with heated mixing tools for making the sample for SMA.

3.9.3 Putting In Mold

A mold is a cylindrical of iron having diameter of 100mm, mold was heated before pouring the sample in it, so that before compaction temperature of the mix don't drop.

3.9.4 Compaction

After putting the sample in the mold, hammering was performed. Hammering was done by giving 50 blows to both side of the specimen. A mechanical compactor was used as shown in figure 3.10 (a) and compacted sample is shown in figure 3.10 (b).

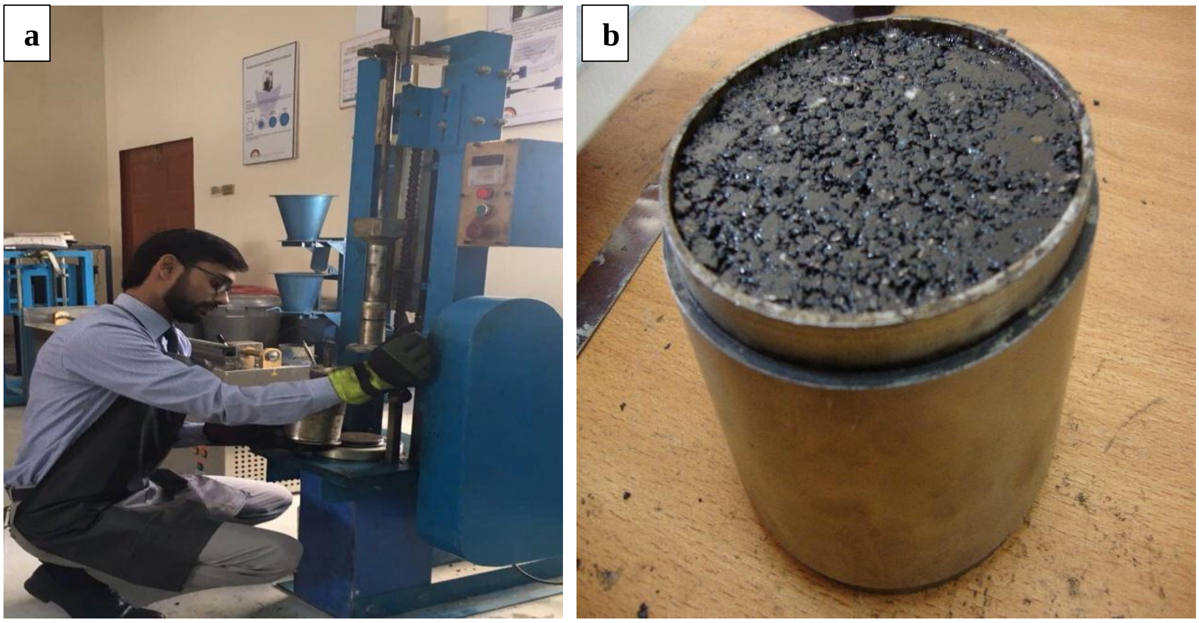


Figure 3.10: (a), (b) Sample Compacting

Specimen was left in mold for 24 hours, after that it was ejected using hydraulic ejector.
Figure 3.11 shows compacted SMA samples.

Figure 3.11: Prepared Samples SMA

After that, volumetric properties of each sample were determined by taking their weight in air and weight in water. Than these samples were check against Stability and Flow in Marshall Machine.

But before testing those in Marshall Apparatus samples were placed in Water Bath at 60 °C for 30 minutes and after removing from water bath their surface was cleaned with a cloth and immediately was tested within 30 seconds.

3.10 STABILITY AND FLOW

For stability the total number of Newton's (lb.) required to produce failure of the specimen at 60 ºC (140 F) was recorded.

For Flow value, while stability test is in process, flow gage was firmly held in position over guide rod and it was removed as the load began to decrease. This reading is the flow value for the specimen, expressed in units of 0.25mm (1/100 in.) shown in Figure 3.12

Figure 3.12: Marshal Testing

Optimum bitumen was determined for samples without Crumb rubber. Than this whole process was repeated and samples with Crumb Rubber was prepared. And optimum bitumen content was determined.

3.11 MOISTURE SENSETIVITY TEST

3.11.1 Indirect Tensile Test

One of the main causes of pavement failure is moisture damage and the failure due to moisture damage is called stripping. Indirect tensile test was used to measure tensile strength of conditioned and unconditioned samples, which in turn was used to calculate tensile strength ratio TSR. And TSR measures stripping potential of asphalt mixes (Affrin & Babu, 2017). According to ALDOT TSR value should not be less than 80%.

For moisture sensitivity Marshal Samples were prepared at optimum bitumen, Fiber and Crumb rubber content. A total of 21 samples were prepared, further they were divided in two sets. This test was conducted in accordance with ASTM D 6931-07.

Conditioning of specimen was done in accordance with to ALDOT-361. Unconditioned samples were placed in water bath at 25 °C for one hour. For conditioning samples were placed in water bath at 60 °C for 24 hours, but before placing them in water bath samples were placed in vacuum and suction of 30 in of Hg were applied for two minutes and after that we let them in water for 10 to 20 minutes. Then samples were weighed for checking the volume of water absorbed. Both unconditioned and conditioned samples were placed radially in UTM and tested as shown in Figure 3.13.

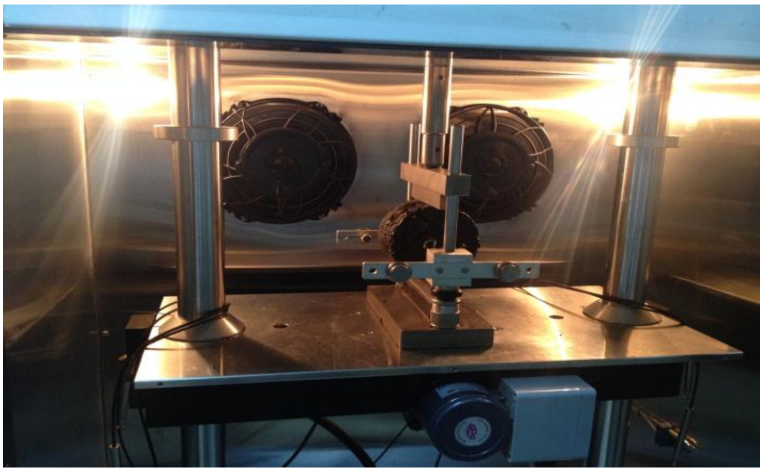


Figure 3.13: Sample in UTM for ITS

3.12 INDIRECT TENSILE FATIGUE TEST

Indirect Tensile Fatigue Test gives the fatigue life of the pavement. The test is called indirect tensile because the vertical compressive load applies uniform tensile stress in horizontal direction perpendicular to applied load. Number of cycles, at which samples fail is actually the number of passes of vehicles after which pavement will fail. In this research this test was conducted on Gyratory compacted cylindrical samples. Though this test can be performed on cored samples, but in Pakistan one can hardly find a patch of Stone mastic Asphalt. Prepared samples were subjected to compressive haversine load in vertical direction. Samples failed In the direction of applied load due to a crack produced by horizontal strain.

Stone Mastic Asphalt (SMA) samples were prepared at different percentages of crumb i.e., 0%, 2%, 4%, 6% and 8%. Crumb was incorporated by weight of bitumen. Bitumen content was kept constant (5.8%), and fiber was incorporated at 0.3 by weight of bitumen. Test was conducted at temperature 25C. Havorsine load applied on the samples includes have loading time of 0.1 second and a rest period of 0.4 second. Stress of 5000N was applied and it was kept constant for all the samples to obtain optimum crumb content.

Samples were tested in UTM 25 using the jig assembly. Sample was placed diametrically in jig assembly as shown in Figure 3.14.

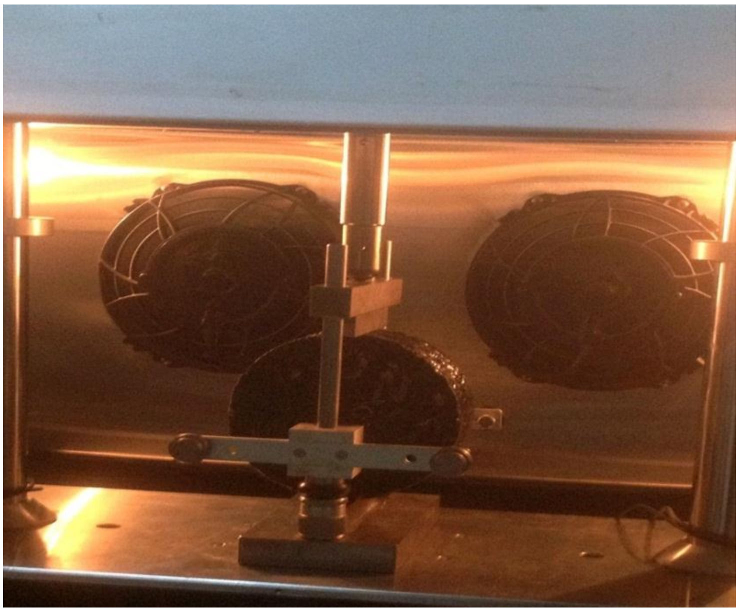


Figure 3.14: ITFT Sample in Jig Assembly

Completion of test was indicated by a crack produced due to cyclic loading.

3.12.1 Preparation of Samples

Permanent deformation is also named as Rutting test, rutting is result of accumulated stresses due to cyclic loadings. It can be identified by depressions along the length of pavement. So to test the rutting potential of Samples Hamburg Wheel tracking test was performed. For this test Gyratory Compacted samples were prepared each sample weighing 6000g. First the aggregates were sieved and specified amount of aggregates retaining on each sieve was taken, Figure 3.15 (a), (b) shows sieved sample.

Figure 3.15: (a), (b) Sieved samples for Gyratory compaction

After preparing samples they were placed in oven for heating at 120 °C for thirty to forty minutes. Along with that bitumen was also placed in the oven to melt. On the same time stove was put on and pan was heated, than measured quantity 350g of melted bitumen was poured in pan along with the aggregates. After that aggregates with bitumen was heated to 160 °C Figure 3.16. Temperature was constantly checked with temperature gun.

Figure 3.16: Uncompact mix

After preparing the mix it was poured in pan and placed in oven for four hours at 120 °C. At same time Gyratory mold was also put in the oven for heating. Than mix was poured in mold and put in machine for compaction. Machine was set at an angle of 22 for 125 cycles as shown in Figure 3.17 (a) and (b). Two types of samples were prepared a first set of samples with crumb rubber and second set without rubber.

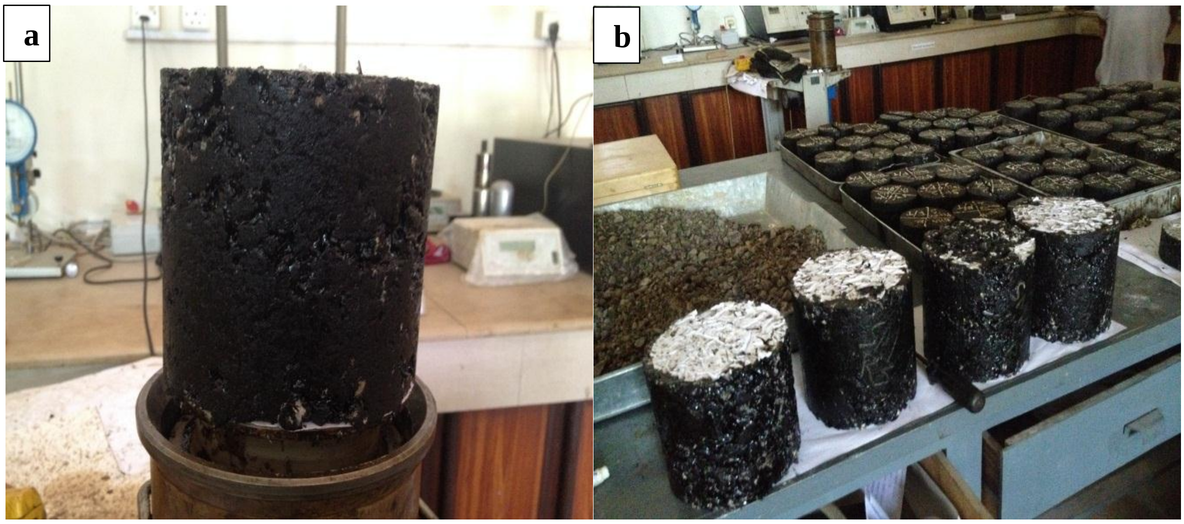


Figure 3.17: (a), (b) Gyratory Compacted

After preparing the samples they were left to dry for one day, then they was cut into two Pieces to obtain thickness of average 60mm with help of core and saw cutting machine.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter gives a brief overview of results. Chapter has been divided in three parts. In first part results of aggregates are discussed in second part results of bitumen are discussed along with tests results of modified bitumen and in in third part results of mix are presented.

4.1.1 Los Angeles Abrasion Test

Table 4.1 shows selected gradation for Los Angeles test.

Table 4.1: Selected Gradation for Los Angeles

Sieve (inch)	Retained on	Grading A	Weight
1 ½	1	1250±10	1246.8
1	¾	1250±10	1254.5
¾	½	1250±10	1252.2
½	3/8	1250±10	1252.4

	TOTAL	=	5005.9
Original weight	W1	=	5000g
Weight of aggregate retained on 1.7mm sieve	W2	=	3830.9g
Los Angeles abrasion value		=	**23.47%**

After performing the loss angles abrasion test we found the abrasion value of aggregates from Margalla query site as 23.47%. The limitations says that the aggregates having abrasion value greater than 50% are rarely allowed, and the maximum recommended abrasive value from wearing course is 40% and for base course is 50%.

As the abrasion value of the aggregates which we used in our project is 23.47% which is less than the maximum limitations of both wearing course and base course, thus we concluded that our aggregates are strong enough to be use in wearing course and off course base course too because they can resist abrasion due to heavy traffic.

4.1.2 Soundness Test

Table 4.2 shows results of soundness test.

Table 4.2: Soundness Test

Sieve no.	Initial Mass	Percentage Of Each Sample	Retained Mass	Individual Percent Loss	Percent loss On Total Sample Basis
No. 8	100	20	81.7	8.3	3.6
No. 16	100	20	79.5	20.5	4.1
No. 30	100	20	64.2	35.8	7.16
No. 50	100	20	89.8	10.2	2.04
No. 100	100	20	75.2	24.8	4.9

Weight average percent loss = 21.86

4.1.3 Sand Equivalent Test

Weight of aggregates = 205.8g

Weight of water = 295.6g

Weight of $CaCl_2$ = 90g

Conclusion:

a) Higher Sand Equivalent value means more sand.

b) Range is 26-60.

c) Our result is 41 which is good.

4.1.4 Impact Value of Aggregates

Sample passed from 1/2 in sieve and retained on 3/8in sieve

Result **= 14.56%**

4.1.5 Classification on Basis of Shape

Table 4.3 shows results of classification of aggregates.

Table 4.3: Classification on Basis of Shape

S/No	Total wt of 200 pieces W	Wt of each friction passing thickness gauge=X	Wt of each friction retain on length gauge = Y	Flakiness index FI = X/w*100	Elongation index EI = Y/W*100
Sample no.1	68550.3	15325.8	5172.4	21.85%	7.05%

4.1.6 Specific Gravity of Coarse Aggregates

Oven dried sample weight = A = 1000.3g

SSD test sample weight in air= B = 1014.3g

Weight of aggregates in water = 597.8G

Bulk specific gravity = A/B-C

= 1000.3/1014.3-597.8 = 2.4

Bulk specific gravity (SSD basis) = Ss = B/B-C

= 1014.3/1014.3-597.8

= 2.43

Apparent specific gravity = Sa = A/A-C

= 1000.3/1000.3-597.8 =2.48

4.1.7 Water Absorption

Oven dried sample weight = A = 1000.3g

SSD sample weight in air = B = 1014.3g

Water absorption in percent Aw = B-A/A *100

= 1014.3-1000.3/1000.3 *100

Aw = 1.4%

Table 4.4 shows summary of aggregates test results.

Table 4.4: Aggregates Test Result Summary

S.No	Aggregate Test	Result
1	Aggregate impact value	14.56% < 35%
2	L.A Test	23.47% < 30%
3	Sand Equivalent Test	41% (26-60%)
4	Soundness Test	21.86% > 10%
5	Flakiness Index	21.85% < 40%
6	Elongation Test	7.05% < 10%
7	Specific Gravity(Bulk, Apparent)	2.4 , 2.48
8	Water Absorption	1.4% < 2%

4.2 TESTS ON CONVENTIONAL BITUMEN

Table 4.5 Shows results of conventional bitumen tests.

Table 4.5: Results of Conventional Bitumen

S/No	Test	Result
01	Penetration Grade	69
02	Softening Point	50.1
03	Ductility	98
04	Flash Point	312 °C
05	Fire Point	326°C

4.3 TESTS ON MODIFIED BITUMEN

Figure 4.1 (a), (b), (c) shows the results of crumb modified bitumen.

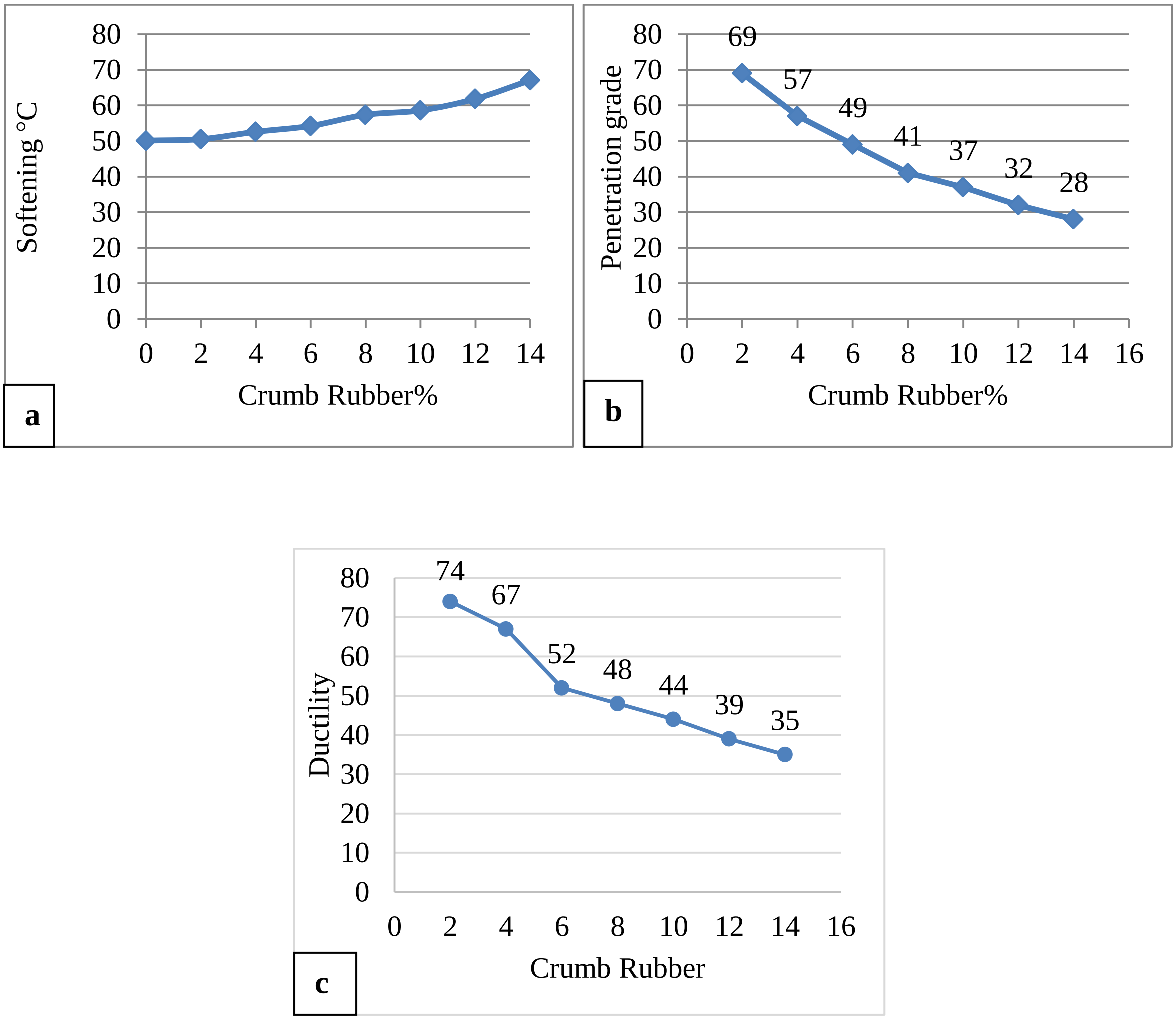


Figure 4.1: (a), (b), (c) CRM Modified Bitumen

4.3.1 Flash and Fire Point Test of Modified Bitumen

Results: flash and fire decreases with increment of rubber, and the difference between temperature of flash and fire should not exceed from 10∘C. The results shows that due to decrease in temperature of flash and fire point of the modified bitumen, it cannot be heated at high temperatures.

4.3.2 Summary of Results

Table 4.6 shows Summary of results of crumb modified bitumen.

Table 4.6: Summary of Crumb Modified Bitumen

Crumb Rubber	**0%**	**2%**	**4%**	**6%**	**8%**	**10%**	**12%**	**14%**
Penetration Grade	69	66	58	51	47	44	39	35
Softening Point °C	50	50.5	52.57	54.22	57.35	58.57	61.82	67.05
Ductility	98	74	67	52	48	44	39	35

Table summarizes the primary parameters of bitumen of grade 60/70 by addition of crumb rubber at different percentages. All the tests were carried out according to standards.

Data in Table indicates that the penetration value of grade 6/70 bitumen decreases as the percent of crumb rubber is added. The addition of 14% crumb rubber caused a major difference of 35°C which is approximately 50% decrease, which means bitumen is getting harder by addition of crumb rubber. Similarly data of softening point indicates that by addition of crumb rubber softening temperature is increasing thus causing the bitumen stiff. Ductility test values indicate that due to addition of crumb rubber bitumen is getting harder and stiffer. Which means binding ability or ability of adhesion of bitumen is decreasing.

4.4 RESULTS OF MARSHAL MIX DESIGN OF FIBER MODIFIED SMA

Samples were prepared according to Marshal Method of design. Three samples were prepared for each bitumen content (3.5%, 4%, 4.5%, 5%, 5.5%, 6%, 6.5%, 7%, and 7.5%). Stability, flow, air voids, VFB, Unit weight was determined results of which are shown in Figure 4.2 (a), (b), (c), (d), (e).

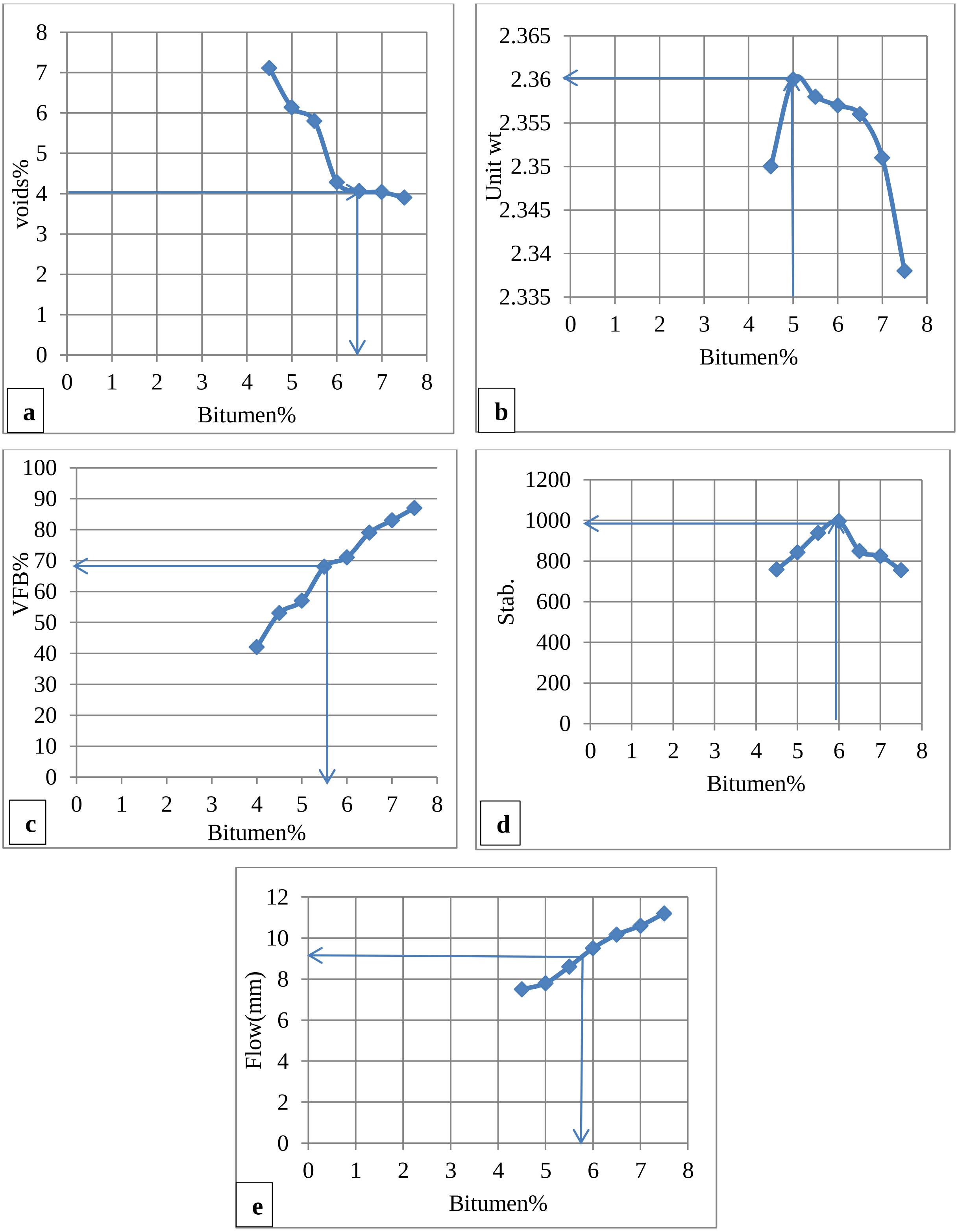


Figure 4.2: (a), (b), (c), (d), (e) Volumetric Analysis of Fiber modified SMA

4.5 BRIEF DESCRIPTION OF FIBER MODIFIED SMA RESULTS

Table 4.7 shows results of volumetric analysis of conventional SMA.

Table 4.7: Volumetric of Conventional SMA

Bitumen %	Air Voids %	Unit Weight	VFA %	Stability (Kg)	Flow (mm)
4.5	7.11	2.365	53	757.47	7.5
5	6.145	2.365	57	841.71	7.8
5.5	5.8	2.355	68	937.65	8.6
6	4.28	3.345	71	995.31	9.56
6.5	4.06	2.36	79	848.78	10.16
7	4.03	2.356	83	823.78	10.6
7.5	3.90	2.33	87	754.34	11.2

4.6 OPTIMUM BITUMEN CONTENT

Bitumen content corresponding to max stability = 6%

Bitumen content corresponding to max bulk specific gravity = 5%

Bitumen content corresponding to 4% air voids = 6.5%

Optimum bitumen content = (6 + 5 + 6.5) / 3

OBC = 5.8%

4.7 MARSHAL MIX DESIGN FOR CRUMB MODIFIED SMA

Crumb rubber was incorporated in mix by weight of optimum bitumen content (5.8 % = 69.6g) @2%, 4%, 6%, 8%, 10%&12%. Three samples against each percent of crumb rubber were prepared. Following volumetric properties was determined. Along with that optimum rubber content was also determined. Figure 4.3 (a), (b), (c), (d), (e) shows volumetrics of crumb modified Stone Mastic Asphalt.

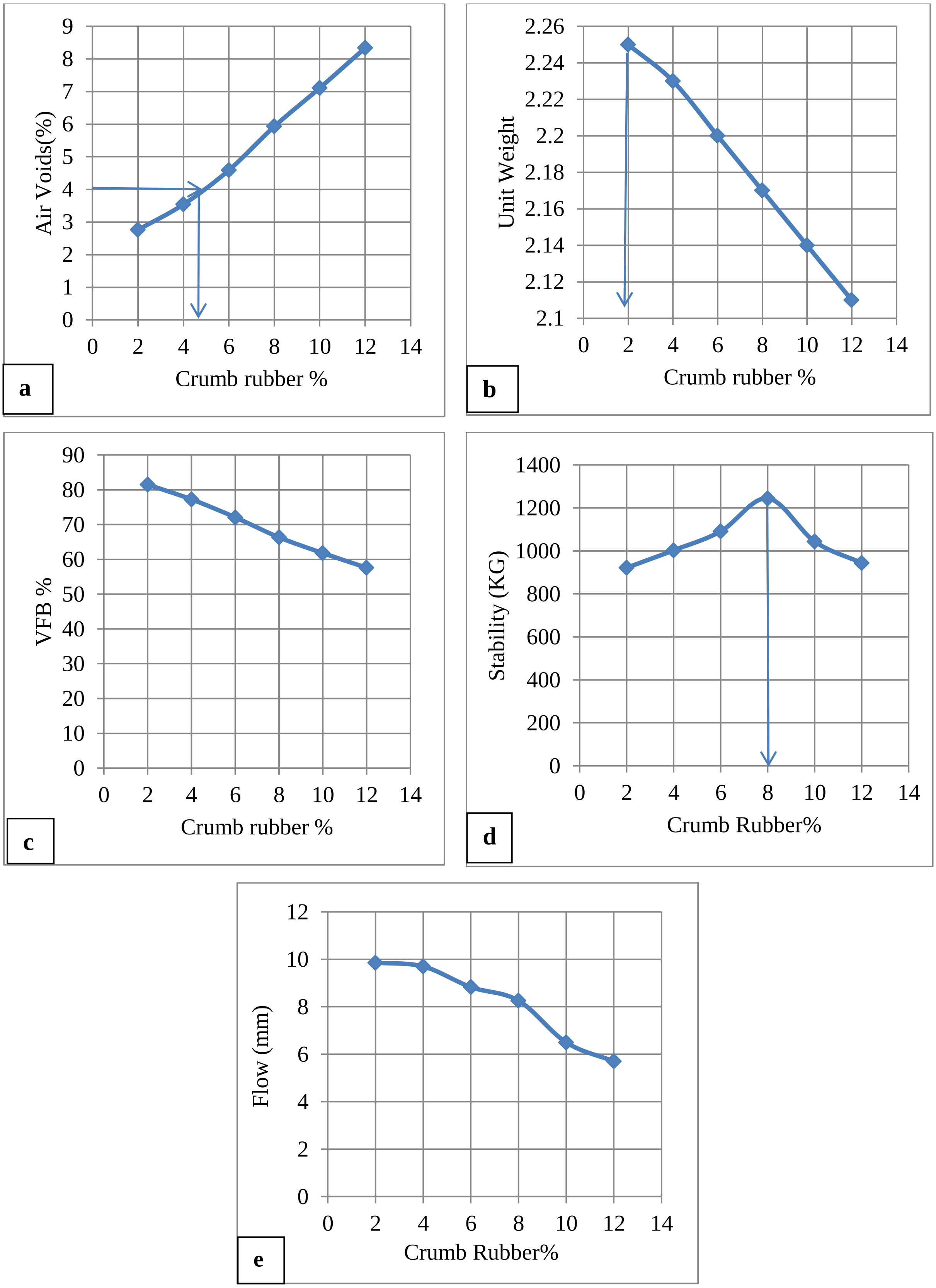


Figure 4.3: (a), (b), (c), (d), (e) Volumetric analysis of CRM Modified SMA

4.8 OPTIMUM CRUMB RUBBER CONTENT

Maximum stability = 8% ; Maximum unit weight = 2%

Air voids 4% = 5.2% ; Optimum rubber Content = (8+2+6) / 3 = 4.86%

Results show that as we add Crumb rubber in mix having optimum bitumen content (5.8%) air voids goes on increasing and voids filled with bitumen goes on decreasing,and similarly flow values also goes on decreasing. This is because of the fact that increasing cntent of Crumb rubber starts absorbing the bitumen. (Mashaan et al., 2014)

4.9 MIX DESIGN CHRACTERISTICS

Table 4.8 shows mix design characteristics of crumb modified stone mastic asphalt.

Table 4.8: Mix Design Characteristics

S/No.	Mix Characteristics	SMA
1	Binder grade	60-70
2	Binder content (%)	5.8
3	Compacting machine	Marshall Hammer
4	Aggregates gradation	Gap Graded
5	Stability at OBC	990kg
6	Air Voids at OBC	4.8% = 5%
7	Fiber	Munjin Fiber
8	Crumb Rubber	4.86%

4.10 INDIRECT TENSILE STRENGTH TEST (ITS)

This test was conducted in accordance to ALDOT-361-88. Both conditioned and unconditioned samples were radially tested in UTM-25. Samples were prepared at optimum bitumen content 5.8% and with different percentages of crumb rubber 0%, 2%, 4%, 4.5%, 5%, 6% and 8%. Munjin Fiber was incorporated by 0.3% by weight of bitumen. While performing the test it was observed that the ITS value increased till 4% of crumb rubber but then it decreased on 5% of crumb rubber, so it was obvious that maximum ITS value lies close to Optimum Crumb Rubber content 4.86% which was found in previous test. Figure 4.4

shows snapshot of computerized results. Samples were prepared for percentages of crumb rubber between 4% and 5% i.e. 4.5%. As shown in TABLE 4.9.

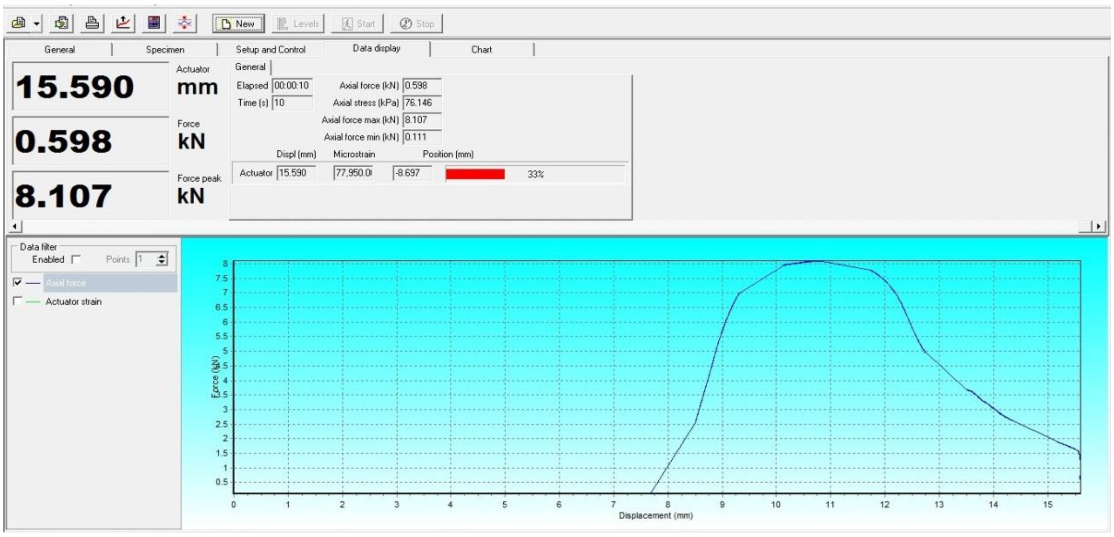


Figure 4.4: ITS Result

Table 4.9: ITS Findings

S/No	Bitumen%	Munjin Fiber %	Crumb Rubber%	Avg. Unconditioned Strength (Psi) S1	Avg. Conditioned Strength (Psi) S2	Tensile Strength Ratio (TSR %) S2/S1
1	5.8	0.3	0	113.48	60.62	53
2	5.8	0.3	2	110.25	84.48	76
3	5.8	0.3	4	111.68	86.77	77.6
4	5.8	0.3	4.5	111.86	90.38	80.7
5	5.8	0.3	5	115.09	94	82
6	5.8	0.3	6	110.82	89.12	80
7	5.8	0.3	8	109.54	84.48	77

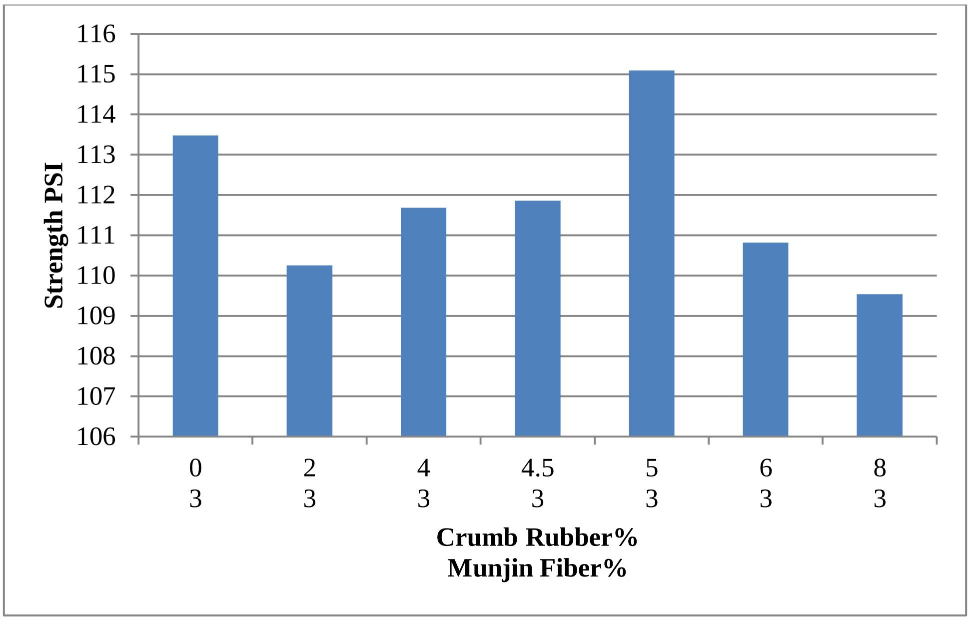


Figure 4.5: Unconditioned

It can be seen in Figure 4.5 that ITS value for controlled mix is higher in start, as we start adding Crumb rubber in the mix the ITS value first decreases and then it start increasing. At optimum rubber content value is maximum and on further addition of rubber value decreases. Similar is the case with conditioned samples shown in Figure 4.6.

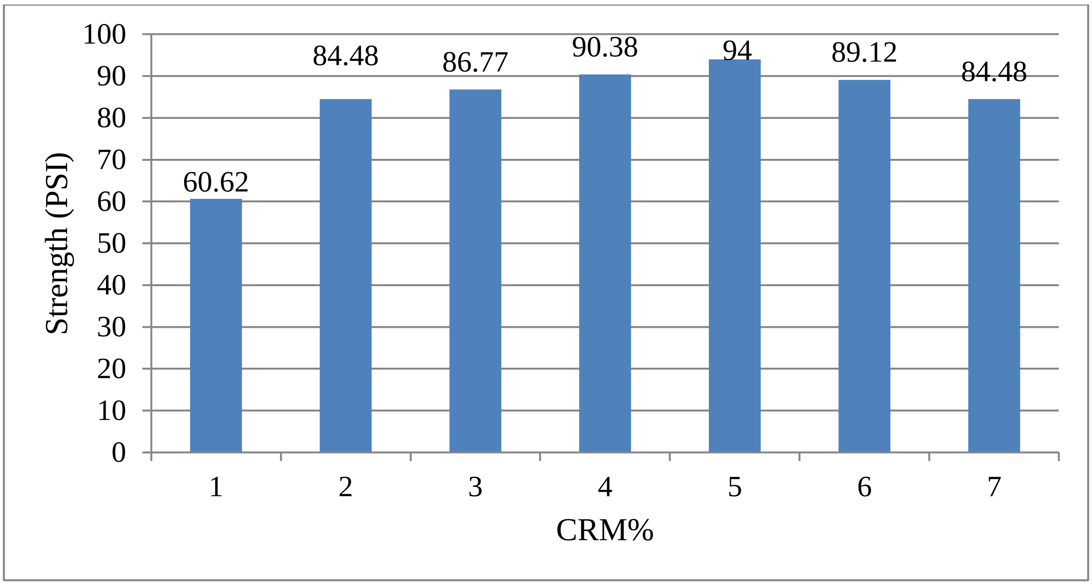


Figure 4.6: Conditioned

But in case of conditioned samples ITS value for control mix is minimum, and on addition of crumb rubber it start increasing till optimum rubber content after optimum it start decreasing as similar to unconditioned samples. Simply we can say that addition of Crumb rubber increases indirect tensile strength of Asphalt but to certain value on further addition value start decreasing (Al-shaybani, 2017) (Ghasemi & Marandi, 2013).

Figure 4.7 shows combined details of ITS values.

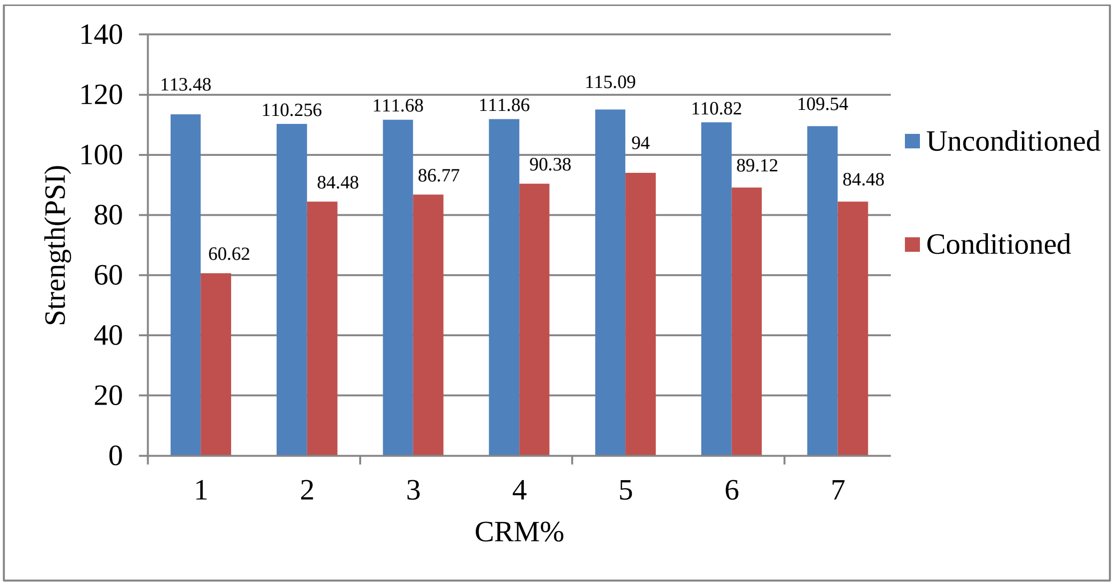


Figure 4.7: Combined Graph of ITS

Tensile strength ratio TSR is the ratio of Tensile strength value of conditioned samples and Unconditioned samples S2/S1. Results in Table 4.9 indicates that TSR value increases as the Crumb rubber content increases up till optimum content 5% after that the value start decreasing. Results indicate that TSR value is in range for 4.5%, 5% and 6% crumb rubber content. Any mix having TSR value greater than 80% is good against moisture sensitivity (Al-shaybani, 2017). Figure 4.8 shows the results of TSR.

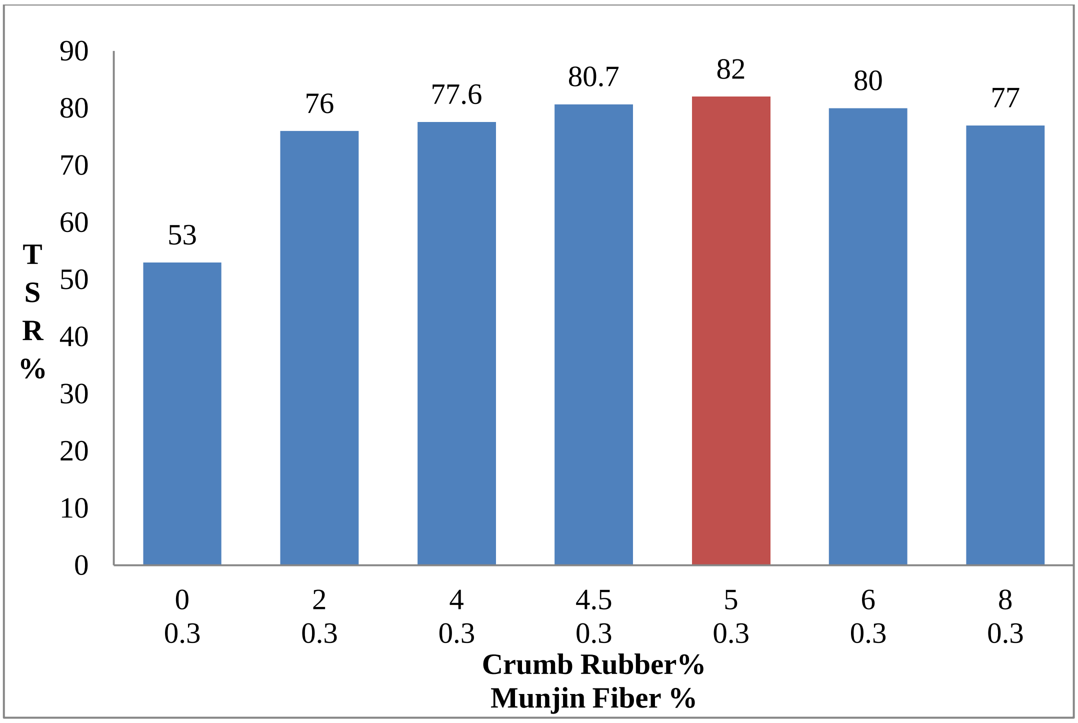


Figure 4.8: TSR Result

4.11 INDIRECT TENSILE FATIGUE TEST

In this test Optimization of Crumb Rubber for Fatigue life of Stone Mastic Asphalt was done using UTM 25P. Indirect Tensile Fatigue Test gives the fatigue life of the pavement. The test is called indirect tensile because the vertical compressive load applies uniform tensile stress in horizontal direction perpendicular to applied load. Number of cycles, at which samples fail is actually the number of passes of vehicles after which pavement will fail. In this research this test was conducted on Gyratory compacted cylindrical samples. Though this test can be performed on cored samples, but in Pakistan one can hardly find a patch of Stone mastic Asphalt. Prepared samples were subjected to compressive haversine load in vertical direction. Samples failed in the direction of applied load due to a crack produced by horizontal strain.

Stone Mastic Asphalt (SMA) samples were prepared at different percentages of crumb i.e. 0%, 2%, 4%, 6% and 8%. Crumb was incorporated by weight of bitumen. Bitumen content was kept constant (5.8%), which was determined by Marshal Method. Munjin fiber was incorporated by 0.3% by weight of bitumen. Test was conducted at temperature 25C. Havorsine load applied on the samples includes have loading time of 0.1 second and a rest period of 0.4 second. Stress of 5000N was applied and it was kept constant for all the samples to obtain optimum crumb content.

Samples were tested in UTM 25 using the jig assembly. Completion of test was indicated by a crack produced due to cyclic loading. While performing the test it was observed that the crack is too mild as compared to conventional mixes. As shown in Figure 4.9.

Figure 4.9: Tested ITFT Sample

Indirect Tensile Fatigue Test was conducted on Modified and Unmodified Stone Mastic Asphalt samples. For this purpose aggregates was obtained from Margalla, Pakistan. Gradation adopted was SMA 25. Bitumen was obtained from Attock Oil Refinery ARL. All the standardization test of bitumen and aggregates were performed before preparing the samples for fatigue testing. Test was conducted at 25°C using a stress level of 5000N and loading frequency of 2 Hz. Stress level and temperature was kept constant to obtain optimum crumb content. Figure 4.10 shows test progress of software. And Table 4.10 shows results of Indirect Tensile Fatigue Test of Crumb Modified Stone Mastic Asphalt.

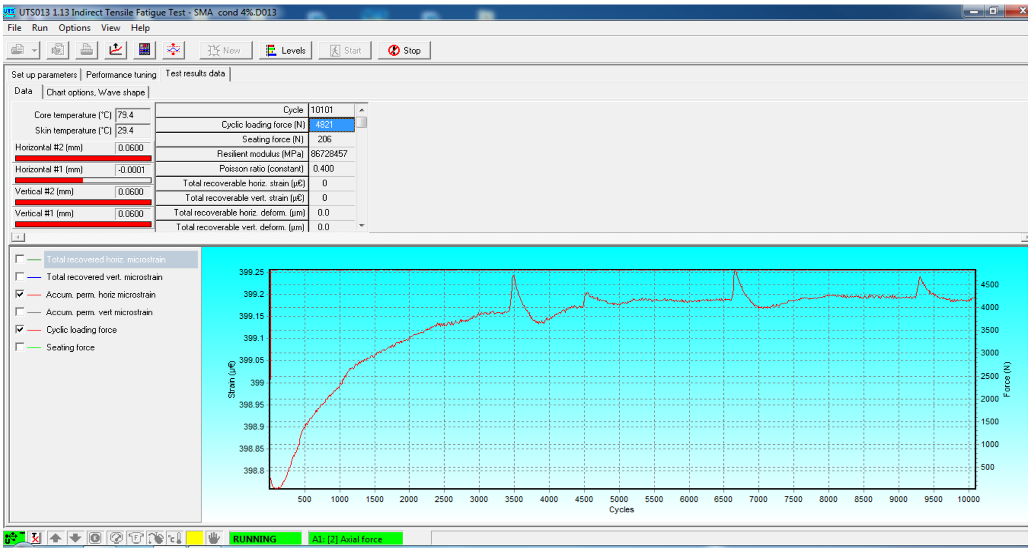


Figure 4.10: ITFT Test Progress

Figure 4.10 shows test progress of fatigue life of crumb modified stone mastic asphalt.

Table 4.10: ITFT Findings

S/No	Crumb Rubber %	Munjin Fiber	Bitumen %	Temperature °C	Stress (N)	Avg. No. of Cycles to Failure
01	0%	0.3%	5.8%	25	5000	3506
02	2%	0.3%	5.8%	25	5000	5892
03	4%	0.3%	5.8%	25	5000	18500
04	6%	0.3%	5.8%	25	5000	9551
05	8%	0.3%	5.8	25	5000	8431

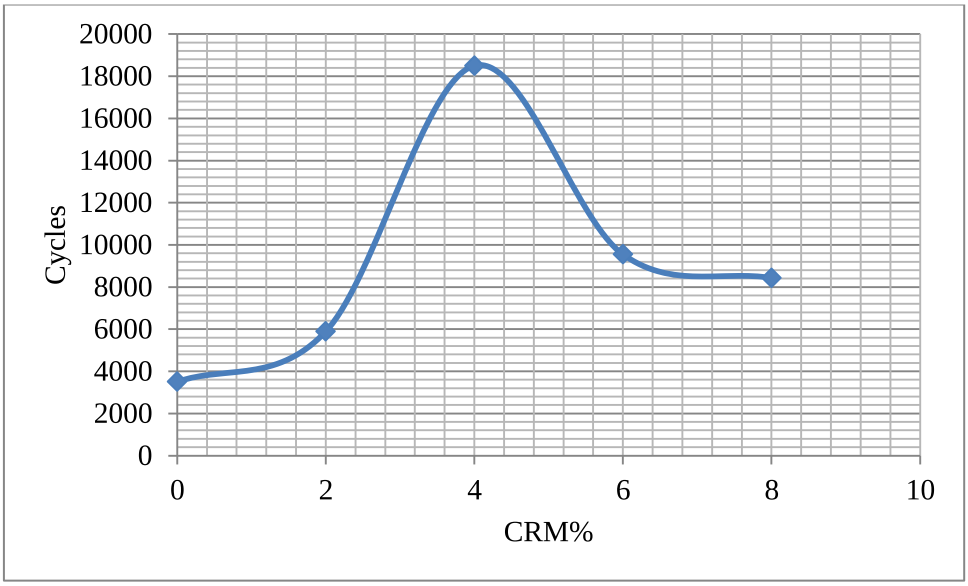


Figure 4.11: Cycles to Failure Vs Crumb Rubber

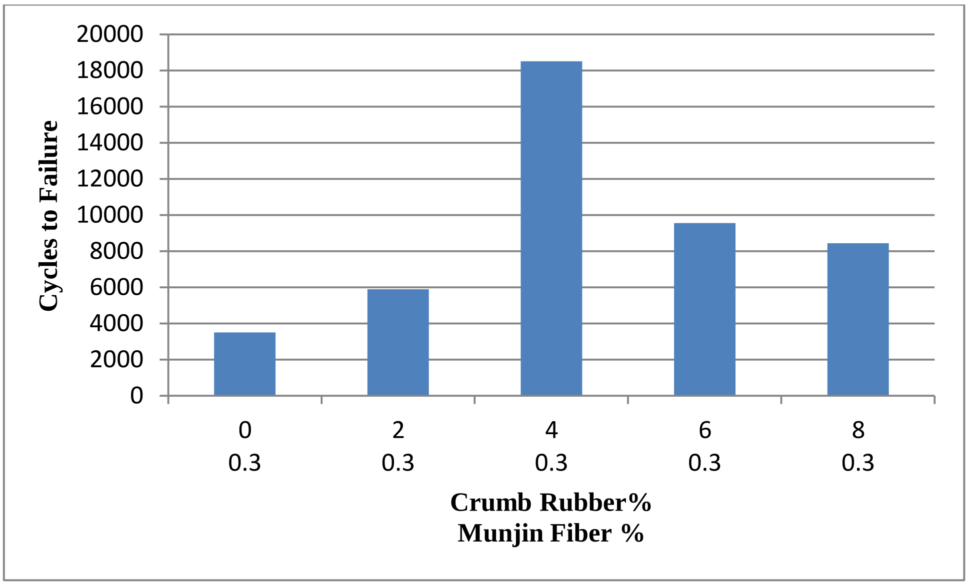


Figure 4.12: Fatigue Life Bar Chart

Test results indicated that fatigue life was minimum for unmodified samples as it has least number of cyclic loading. As the crumb rubber content was increased the fatigue life also improved which was indicated by increased number of load cycles before failure. At 4% crumb content SMA Mix showed maximum fatigue life before failure as it have maximum number of load cycles 18500 against applied stress. After 4% when further crumb was incorporated fatigue life was decreased and decreased considerably. Similarly at 8% crumb content fatigue life further decreased. Test resulted in 4% optimum crumb content to obtain maximum fatigue life shown in Figure 4.11 and 4.12.

4.12 TEST ON AVERAGE OPTIMIZED CRUMB CONTENT

After optimizing the Crumb Rubber for Marshal, Indirect tensile strength test and Indirect Tensile Fatigue test further test were conducted. Optimized Crumb content for Marshal Mix is 4.86% for Indirect Tensile Strength test is 5% and for Indirect Tensile Fatigue Test (ITFT) is 4%. Average of these three optimized crumb content was taken and again these tests were conducted and compared with Conventional SMA as shown in Figure 4.13, 4.14 and 4.15.

Average optimized crumb content was found to be 4.62%. (4.86+5+4)/3

Table 4.11: Avg. Optimized Crumb Test Results

S/No	Crumb Rubber %	Munjin Fiber %	Marshal Stability (Kg)	Indirect Tensile Test (ITS)			Indirect Tensile fatigue Test (ITFT) Cycles to Failure
				Unconditioned PSI	Conditioned PSI	TSR %	
1	0	0.3	678	113.483	60.621	53	3506
2	4.6	0.3	1090	112.913	97.131	86	16896

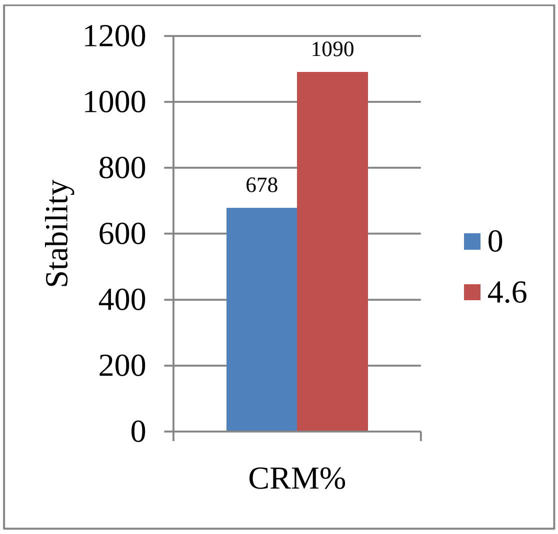


Figure 4.13: Stability vs. Opt. Crumb

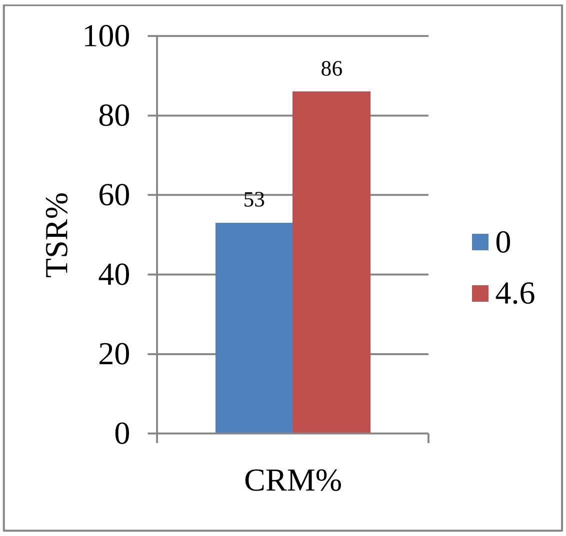


Figure 4.14: TSR vs. Opt. Crumb

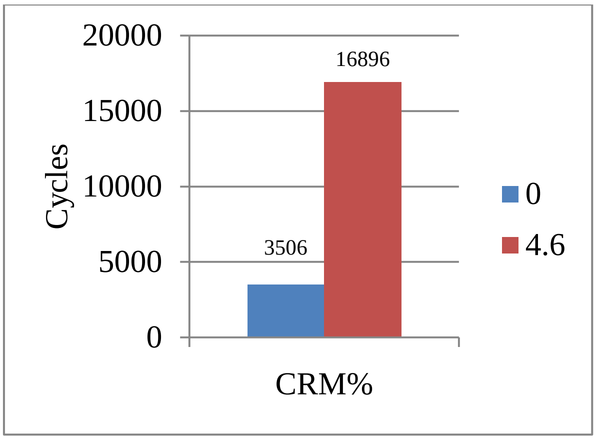


Figure 4.15: ITFT vs. Opt. Crumb

Figure 4.13 indicated the behavior of Marshal Stability at 0% crumb content and 4.6% crumb rubber content, trend shows that at 0% crumb content stability is less as compared to 4.6% crumb rubber content. Figure 4.14 indicated that tensile strength ratio at 0% crumb rubber content is less than 4.6% crumb rubber content. Figure 4.15 indicates that fatigue life of crumb modified Stone Mastic Asphalt is much better than unmodified asphalt.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

This research work determines the importance of recycling the rubber tires and using them in asphalt. Increasing number of heavy and light weight vehicles on the roads causing the production of early distresses in pavement along with production of millions of waste tires. These waste tires are serious threat to environment in terms of unavailability of useful land and production of mosquitoes which cause dengue and malaria.

Movement of heavy overloaded vehicles is major cause of early distresses in conventional pavement so there is a need of mix design which can easily accumulate these stresses and prolong the life of pavement. In this research work crumb rubber sieved through Sieve #40 is used as an admixture and optimized for Marshal Stability, moisture sensitivity and fatigue life of stone mastic asphalt. As moisture damage and fatigue distresses are major causes of failure of pavement in Pakistan.

For preparation of SMA mix SMA-25 gradation was adopted aggregates was obtained from Margalla and bitumen of Grade 60/70 was collected from Attock Oil Refinery. Crumb rubber was obtained from local vendor in Taxila. At first properties of Bitumen 60/70 was studied by adding different percentages of crumb rubber and then crumb rubber was incorporated in mix by weight of optimum bitumen content and optimized for marshal mix design. In next step crumb rubber was optimized for indirect tensile strength test and Tensile strength ratio was determined. In third stage crumb rubber was optimized for fatigue life of SMA. At final stage average of optimized crumb rubber (Marshal design, ITS and ITFT) was calculated and these three tests were conducted again on average optimized crumb rubber.

Test results are concluded as under.

5.2 CONCLUSIONS

Conclusions drawn from results mentioned in previous chapter are as under.

1. Use of crumb rubber in asphalt or another thing will reduce the environmental pollution in terms of availability of useful land.
2. Penetration grade of bitumen 60/70 decreased by addition of crumb rubber thus making it hard and stiff.
3. Softening point of bitumen 60/70 increased by addition of crumb rubber.
4. Ductility of bitumen 60/70 decreased by addition of crumb rubber.
5. Optimum bitumen content for Fiber modified SMA was found to be 5.8%.
6. It was concluded that by addition of crumb rubber use of fiber is not required as there is no such difference between the properties of these two mixes.
7. Results of Marshal Mix design showed that by addition of crumb rubber marshal stability was increased by 20%

8. Indirect Tensile Test ITS values for unconditioned samples indicate that by addition of crumb rubber ITS values first decreased than increased up to 5% crumb rubber and again decreased after 5% crumb rubber.
9. ITS values for conditioned samples, first increased and was maximum at 5% crumb rubber content, on further addition of crumb it decreased.
10. TSR values were found to be above minimum range for 4%, 4.5% and 5% crumb rubber content. TSR values was increased by 35% at optimum crumb content as compared to conventional mix
11. Values of Indirect Tensile fatigue Test (ITFT) increased gradually on addition of crumb rubber. Maximum cycles to failure were obtained at 4% crumb rubber content. On further addition fatigue life decreased. ITFT values were increased by 80% at optimum crumb content as compared to conventional mix.
12. Maximum cycles to failure at 25 C and 5000N applied stress were found to be 18500.
13. Average crumb rubber content of three tests was calculated to be 4.6%.
14. Marshal Stability, ITS and ITFT values were found to be satisfactory for average optimized crumb rubber content. On average crumb rubber content Marshal stability was increased by 38%, TSR value also increased by 38% and ITFT values was increased by 79% as compared to conventional mixes.

5.3 RECOMMENDATIONS

Based on test results and conclusions of the study following are the recommendations.

1. It is recommended that Crumb rubber content of 4.6% by weight of optimum bitumen content 5.8% can be used in production of crumb modified stone mastic asphalt but Still there are several parameters which are unknown It is recommended that the following topics be investigated to add on to the findings of this research.
2. Only two performance tests were carried out in this study i.e. Moisture sensitivity and fatigue life by using UTM 25 other performance tests like creep test dynamic modulus and rutting analysis etc. should also be carried out to completely characterize the behavior of Crumb Modified Stone Mastic Asphalt.
3. Addition of crumb rubber with different gradations of Stone Mastic Asphalt should be evaluated.
4. It is suggested to evaluate the performance of crumb modified stone mastic asphalt, trail section be constructed after extensive testing to verify that crumb modified asphalt suits the climate condition of country and to the adverse traffic loadings.
5. Moisture sensitivity test results are closer to minimum criteria of 80%, it is recommended that test should be conducted at field production temperatures, if results are not favorable and anti-stripping agent should be added to mix to increase the moisture resistivity.

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APPENDICES

APPENDIX-I: MARSHAL MIX DESIGN FOR CONVENTIONAL SMA

Stone Mastic Asphalt Project: S.H Gardezi (Thesis) Aggregate Source: Margalla Bitumen Source: ARL 60/70 Dated: 05-07-2017						
Bit%	**Binder Weight (g)**	**Sample #**	**Fiber percent**	**Weight in air (g)**	**Weight in water**	**volume**
4.5	54	1	0.3	1237.6	708.5	529.1
4.5	54	2	0.3	1244.8	721.1	523.7
4.5	54	3	0.3	1237.5	708.4	529.1
5	60	1	0.3	1239.2	723.8	515.4
5	60	2	0.3	1241.8	708.5	533.3
5	60	3	0.3	1239	723.9	515.1
5.5	66	1	0.3	1245.1	723.1	522
5.5	66	2	0.3	1254.2	716	538.2
5.5	66	3	0.3	1254	715	533
6	72	1	0.3	1262	717.2	544.8
6	72	2	0.3	1256.8	729.5	527.3
6	72	3	0.3	1256.8	728.9	527.9
6.5	78	1	0.3	1263.4	731.5	531.9
6.5	78	2	0.3	1263.4	730.9	532.5
6.5	78	3	0.3	1258.6	729.9	528.7
7	84	1	0.3	1256.9	717	539.9
7	84	2	0.3	1266.2	715.5	550.7
7	84	3	0.3	1266.1	715.3	550.8
7.5	90	1	0.3	1260.1	723.4	536.7
7.5	90	2	0.3	1271.5	729.6	541.9
7.5	90	3	0.3	1271.5	729.9	541.6

Binder percent	Wt of coarse agg	Wt of fine agg	Wt of Filler	Wt of Fiber	S.G of Coarse	S.G of Fine	S.G of Filler	S.G of Fiber	S.G of Bitumen
4.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
4.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
4.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
5.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
5.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
5.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
6	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
6	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
6	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
6.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
6.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
6.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
7	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
7	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
7	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
7.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
7.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01
7.5	900	180	120	3.6	2.75	2.52	3.12	0.756	1.01

Binder Percent	Gt	Avg Gt	Gm	Avg Gm	Vv	Avg Vv	Vb	Avg Vb	VMA	Avg VMA
4.5	2.53		2.33		7.9		0.0090		7.999	
4.5	2.53	2.53	2.37	2.35	6.32	7.11	0.1007	0.0998	6.420	7.209
4.5	2.53		2.33		7.89		0.0090		8.000	
5	2.52		2.40		4.76		0.1128		4.872	
5	2.52	2.52	2.33	2.365	7.53	6.145	0.1095	0.1111	7.639	6.259
5	2.52		2.399		4.76		0.1096		4.872	
5.5	2.50		2.38		4.8		0.1224		4.922	
5.5	2.50	2.50	2.33	2.355	6.8	5.8	0.1204	0.1214	6.920	5.921
5.5	2.50		2.38		4.79		0.1224		4.923	
6	2.45		2.31		5.71		0.1293		5.839	
6	2.45	2.45	2.31	2.345	2.85	4.28	0.1329	0.1311	2.982	4.411
6	2.45		2.38		5.71		0.1293		5.839	
6.5	2.46		2.34		4.87		0.1410		5.011	
6.5	2.46	2.46	2.38	2.36	3.25	4.06	0.1434	0.1422	3.393	4.202
6.5	2.46		2.34		4.87		0.1410		5.012	
7	2.45		2.34		4.48		0.1511		4.631	
7	2.45	2.45	2.362	2.356	3.58	4.03	0.1525	0.15183	3.732	4.181
7	2.45		2.34		4.48		0.1524		4.631	
7.5	2.43		2.336		3.70		0.1608		3.860	
7.5	2.43	2.43	2.33	2.33	3.70	3.90	0.1606	0.16074	3.860	3.860
7.5	2.43		2.336		3.70		0.1608		3.860	

Binder percent	Sample no.	Stability dial reading	Average stability	Flow dial reading	Average flow
4.5	1	300		7.5	
4.5	2	330	314	7.3	7.5
4.5	3	310		7.7	
5	1	320		7.9	
5	2	370	350	7.7	7.8
5	3	360		7.8	
5.5	1	408		8.8	
5.5	2	375	391	8.6	8.6
5.5	3	390		8.4	
6	1	417		8.8	
6	2	390	415.67	9.9	9.56
6	3	440		10	
6.5	1	345		10.1	
6.5	2	344	353	10	10.16
6.5	3	370		10.4	
7	1	330		10.6	
7	2	345	342.34	10.9	10.6
7	3	352		10.5	
7.5	1	310		11.3	
7.5	2	301	312.67	11.1	11.2
7.5	3	320		11.2	

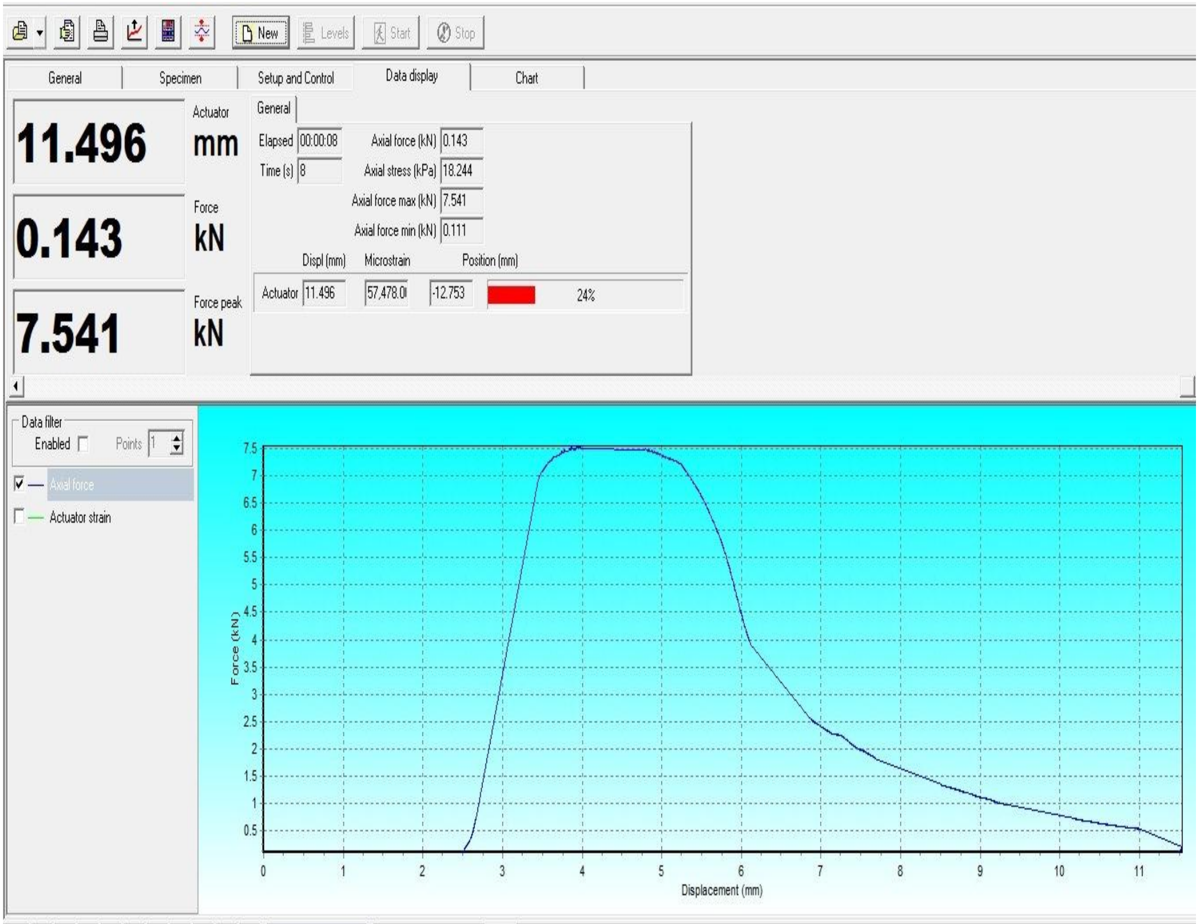
Binder Percent	Sample No.	Stability (Kg)	Average Stability (Kg)
4.5	1	724.71	757.47
4.5	2	794.91	
4.5	3	748.19	
5	1	771.51	841.71
5	2	888.51	
5	3	865.11	
5.5	1	977.43	937.65
5.5	2	900.21	
5.5	3	935.31	
6	1	998.49	995.31
6	2	935.31	
6	3	1052.31	
6.5	1	830.01	848.73
6.5	2	827.67	
6.5	3	888.51	
7	1	794.91	823.78
7	2	830.01	
7	3	846.39	
7.5	1	748.11	754.34
7.5	2	743.43	
7.5	3	771.51	

APPENDIX-II: MARSHAL MIX DESIGN FOR CRUMB MODIFIED SMA

CRM Modified SMA Project: S.H Gardezi (Thesis) Aggregates Source: Margalla Bitumen Source: ARL CRM Size: Sieve#50 retain								
S/No	**Bit. %**	**CRM %**	**Wt. in Air**	**Wt. in Water**	**The. SG (Gt)**	**Unit Weight (Gm)**	**Flow (mm)**	**Stability (Kg)**
01	5.8	2%	1244	704	2.314	2.30	9.8	1024
02	5.8	2%	1248	673	2.314	2.17	9.8	804.7
03	5.8	2%	1230	690	2.314	2.28	10	937.04
04	5.8	4%	1259	681	2.312	2.19	9.7	1069.28
05	5.8	4%	1254	689	2.312	2.22	10	937.04
06	5.8	4%	1249	701	2.312	2.28	9.4	1003.16
07	5.8	6%	1258	678	2.306	2.16	9.1	1091.32
08	5.8	6%	1261	686	2.306	2.19	8.7	1069.28
09	5.8	6%	1257	698	2.306	2.25	8.7	1113.36
10	5.8	8%	1268	690	2.307	2.19	8.3	1355.81
11	5.8	8%	1271	679	2.307	2.14	8.5	1134.25
12	5.8	8%	1270	688	2.307	2.18	8	1244.34
13	5.8	10%	1268	688	2.304	2.18	7	1080.30
14	5.8	10%	1262	652	2.304	2.06	6.6	992.14
15	5.8	10%	1273	690	2.304	2.18	5.98	1058.26
16	5.8	12%	1265	675	2.302	2.14	5.4	968.1
17	5.8	12%	1268	663	2.302	2.09	5.30	932.9
18	5.8	12%	1271	666	2.302	2.10	5.810	950.0

S/No	CRM %	Avg. Gm	Air Voids	Vb	VMA	VFB
01	2%	2.25	2.76	0.1216	0.1492	81.56
02	4%	2.23	3.54	0.1204	0.1558	77.27
03	6%	2.20	4.59	0.1186	0.1645	72.09
04	8%	2.17	5.93	0.1169	0.1762	66.34
05	10%	2.14	7.11	0.1151	0.1862	61.81
06	12%	2.11	8.34	0.1134	0.1968	57.62

APPENDIX-III: ITS TEST RESULTS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Start
Stop
General
Specimen
Setup and Control
Data display
Chart
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Actuator
mm
0.143
Force
kN
7.541
Force peak
kN
General
Elapsed 00:00:08
Time (s) 8
Axial force (kN) 0.143
Axial stress (kPa) 18.244
Axial force max (kN) 7.541
Axial force min (kN) 0.111
Displ (mm)
Microstrain
Position (mm)
Actuator 11.496
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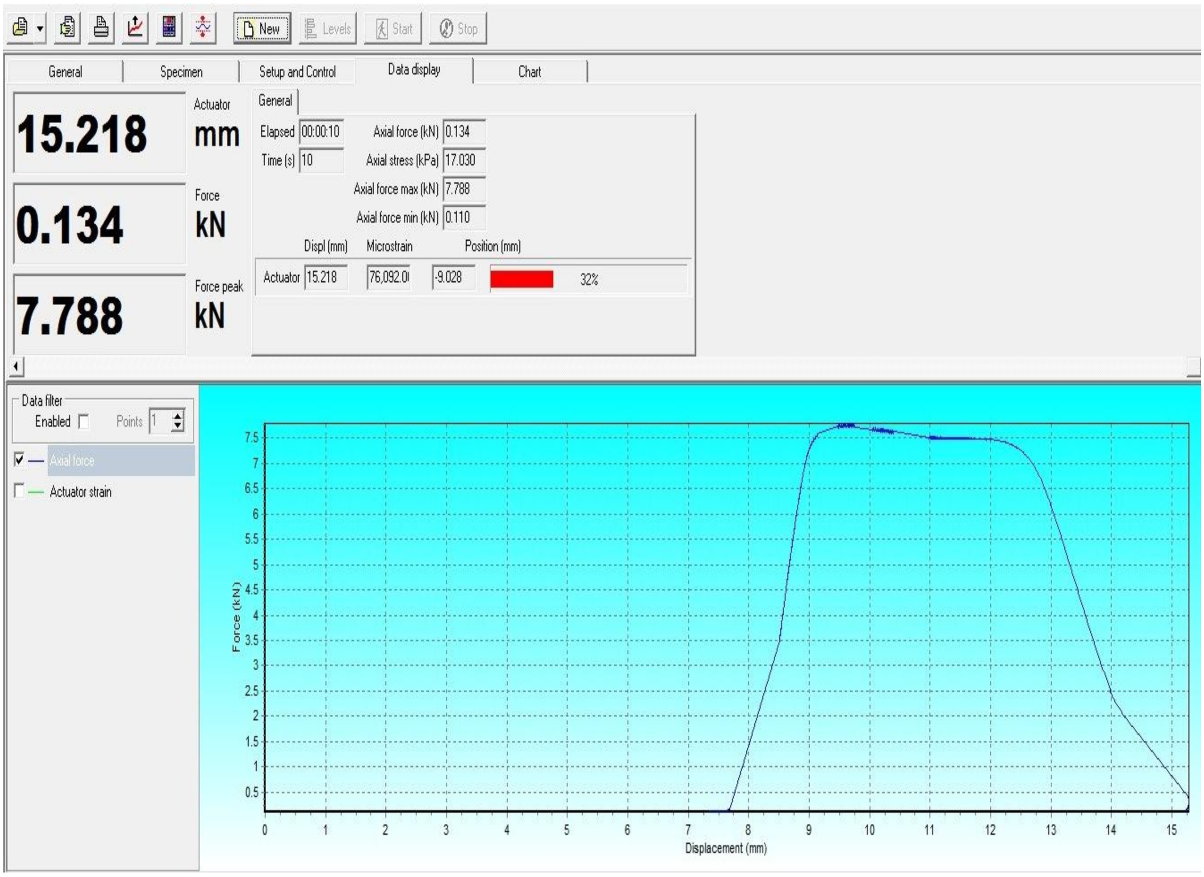
-12.753
24%
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)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Start
Stop
General
Specimen
Setup and Control
Data display
Chart
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Actuator
mm
0.134
Force
kN
7.788
Force peak
kN
General
Elapsed 00:00:10
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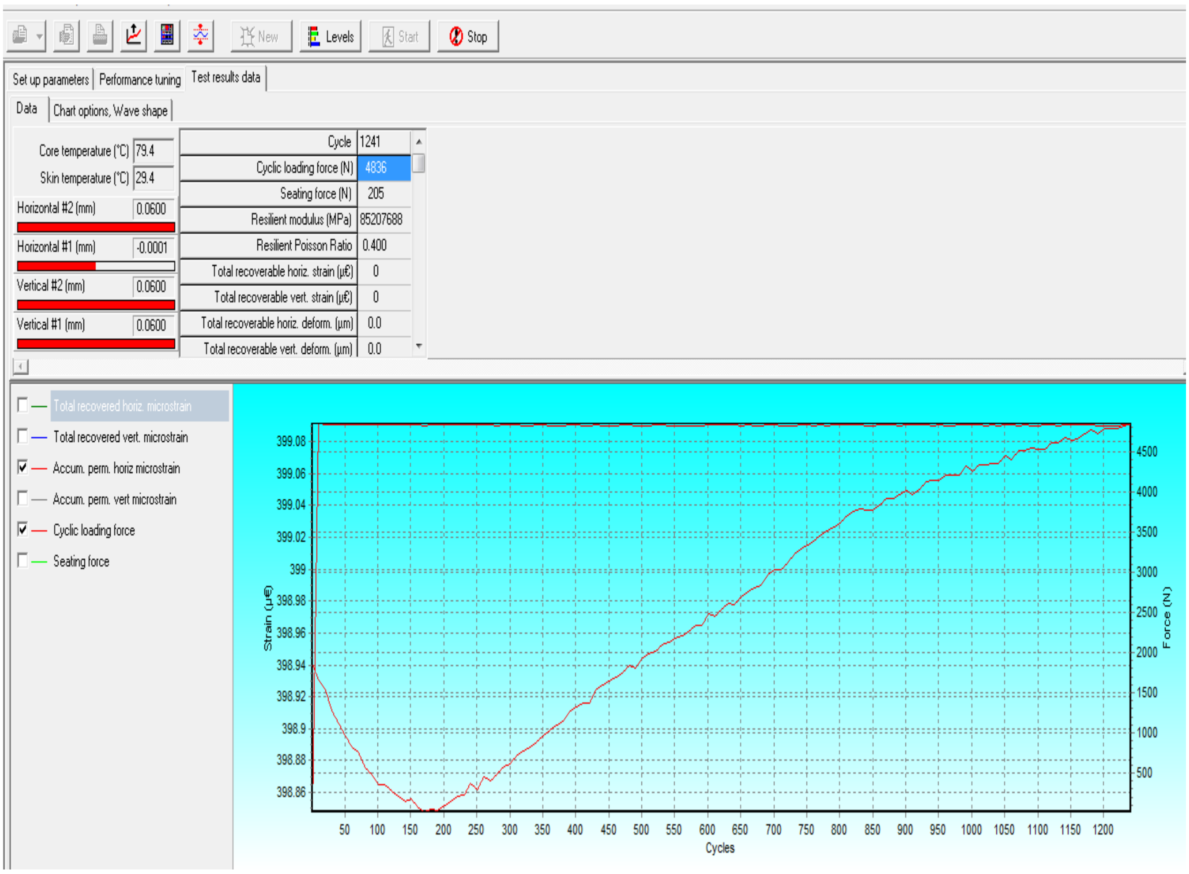
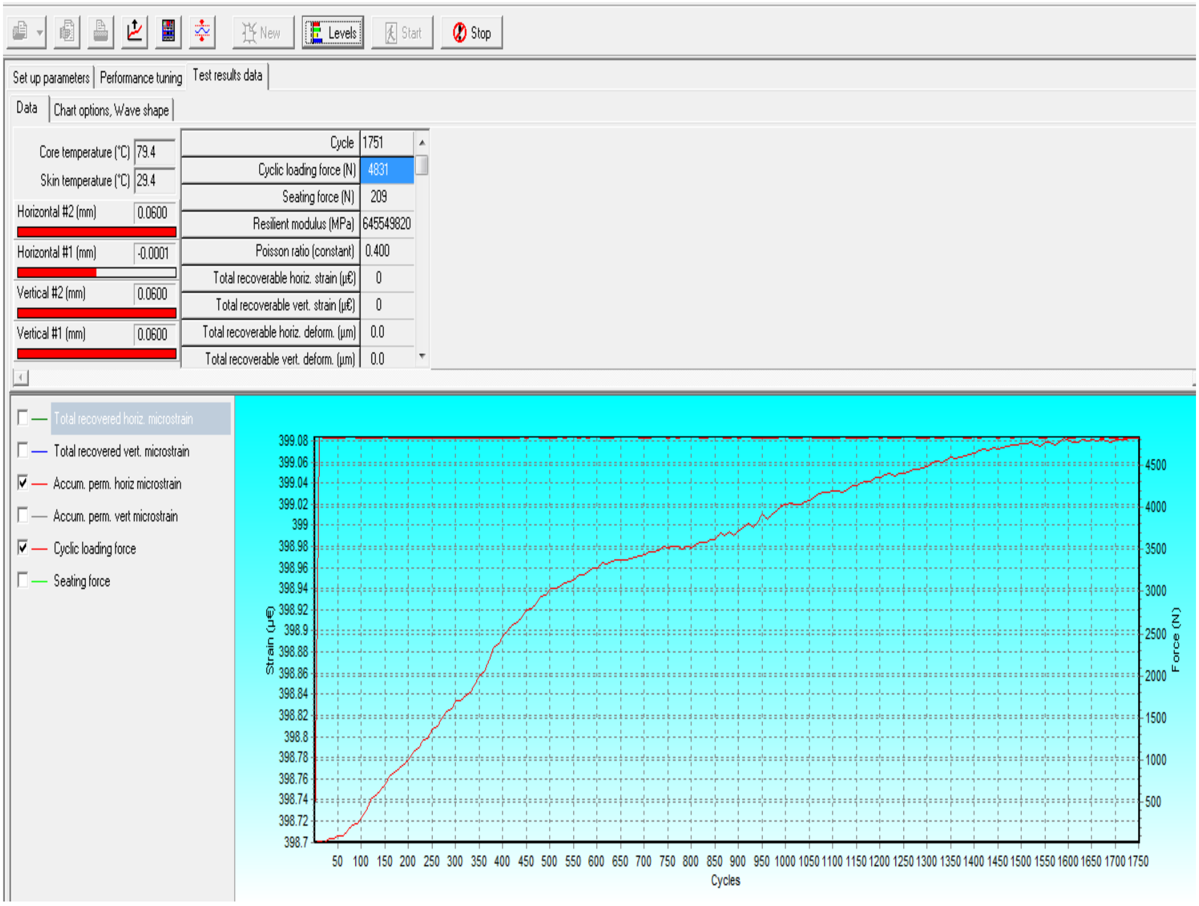
Axial force (kN) 0.134
Axial stress (kPa) 17.030
Axial force max (kN) 7.788
Axial force min (kN) 0.110
Displ (mm)
Microstrain
Position (mm)
Actuator 15.218
76,092.0
-9.028
32%
Data filter
Enabled
Points 1
Axial force
Actuator strain
Force (kN)
Displacement (mm)

APPENDIX-IV: ITFT TEST RESULTS


New
Levels
Start
Stop
Set up parameters
Performance tuning
Test results data
Data
Chart options, Wave shape
Core temperature (°C) 79.4
Skin temperature (°C) 29.4
Horizontal #2 (mm) 0.0600
Horizontal #1 (mm) -0.0001
Vertical #2 (mm) 0.0600
Vertical #1 (mm) 0.0600
Cycle 1241
Cyclic loading force (N) 4836
Seating force (N) 205
Resilient modulus (MPa) 85207688
Resilient Poisson Ratio 0.400
Total recoverable horiz. strain (µε) 0
Total recoverable vert. strain (µε) 0
Total recoverable horiz. deform. (µm) 0.0
Total recoverable vert. deform. (µm) 0.0
Total recovered horiz. microstrain
Total recovered vert. microstrain
Accum. perm. horiz microstrain
Accum. perm. vert microstrain
Cyclic loading force
Seating force
Strain (µε)
Force (N)
Cycles


New
Levels
Start
Stop
Set up parameters
Performance tuning
Test results data
Data
Chart options, Wave shape
Core temperature (°C) 79.4
Skin temperature (°C) 29.4
Horizontal #2 (mm) 0.0600
Horizontal #1 (mm) -0.0001
Vertical #2 (mm) 0.0600
Vertical #1 (mm) 0.0600
Cycle 1751
Cyclic loading force (N) 4831
Seating force (N) 209
Resilient modulus (MPa) 645549820
Poisson ratio (constant) 0.400
Total recoverable horiz. strain (µε) 0
Total recoverable vert. strain (µε) 0
Total recoverable horiz. deform. (µm) 0.0
Total recoverable vert. deform. (µm) 0.0
Total recovered horiz. microstrain
Total recovered vert. microstrain
Accum. perm. horiz microstrain
Accum. perm. vert microstrain
Cyclic loading force
Seating force
Strain (µε)
Force (N)
Cycles