A STUDY OF EFFECTS OF BINDER QUALITY AND NATURAL FIBER ON STONE MATRIX ASPHALT MIXTURES

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A STUDY OF EFFECTS OF BINDER QUALITY AND NATURAL FIBER ON STONE MATRIX ASPHALT MIXTURES

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of
Prof. Mahabir Panda

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Rourkela

CERTIFICATE

This is to certify that the thesis entitled "**A Study of Effects of Binder Quality and Natural Fiber on the Properties of Stone Matrix Asphalt Mixtures**" submitted by **Miss Arpita Suchismita** to the National Institute of Technology, Rourkela, in partial fulfillment of the requirements for the award for the award of **Master of Technology** in **Civil Engineering**, is a record of bonafide research work carried out by her under my supervision and guidance.

To the best of my knowledge, the results embodied in this thesis have not been submitted to any other University or Institute for the award of any degree or diploma.

Date:

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ABSTRACT

Stone Matrix Asphalt (SMA) is a gap graded mix, characterized by high coarse aggregates, high asphalt contents and polymer or fiber additives as stabilizers. High concentration of coarse aggregate maximizes stone-to-contact and interlocking in the mix which provides strength, and the rich mortar binder provides durability. The stabilizing additives composed of cellulose fibers, mineral fibers or polymers are added to SMA mixtures to prevent draindown from the mix. In comparison to dense graded mixtures SMA has higher proportion of coarse aggregate, lower proportion of middle size aggregate and higher proportion of mineral filler. It resists permanent deformation and has the potential for long term performance and durability.

In the present study, an attempt has been made to study the engineering properties of mixtures of stone matrix asphalt made with three types of binders namely conventional bitumen 80/100 and 60/70 and modified binder CRMB 60, with a non-conventional natural fiber, namely coconut fiber. The binders and fibers in different proportions are used for preparation of mixes with a selected aggregate grading. The role of a particular binder and fiber with respect to their concentrations in the mix is studied for various engineering properties. For this, various Marshall samples of SMA mixtures with and without fibers with varying binder type and its concentration are prepared. The optimum binder content is determined keeping the suggested air voids content in the mix. Marshall properties such as stability, flow value, unit weight, air voids are used to determine optimum binder content and optimum fiber content for each type of binder for further studies on SMA mixes. Thereafter, the draindown characteristics, both static and repeated indirect tensile strength parameters and moisture susceptibility characteristics in terms of tensile strength ratio and retained stability of different SMA mixtures values have been studied for such mixes. It is observed that only 0.3% addition of coconut fiber significantly improves the Marshall properties of SMA mixes. Addition of nominal 0.3% fiber considerably improves the draindown, indirect tensile strength and fatigue characteristics of the SMA mixes with conventional bitumen, which would otherwise have not been able to meet the prescribed criteria.

Key Words: stone matrix asphalt, coconut fiber, repeated load indirect tensile test, Marshall properties, indirect tensile strength, draindown test, moisture susceptibility.

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CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 General

Aggregates bound with bitumen are conventionally used all over the world in construction and maintenance of flexible pavements. The close, well, uniform, or dense graded aggregates bound with normal bitumen normally perform well in heavily trafficked roads if designed and executed properly and hence very common in paving industry. However, it is not always possible to arrange dense graded aggregates available at the site. In such situations a bituminous mix called stone matrix asphalt (SMA) which basically consists of gap graded aggregates, can be attempted.

SMA was developed in Germany in the 1960s by Zichner of the Straubag-Bau AG central laboratory, to resist the damage caused by studded tires. As SMA showed excellent resistance to deformation by heavy traffic at high temperatures, its use continued even after the ban of studded tires. SMA is a gap graded mixture containing 70-80% coarse aggregate of total aggregate mass, 6-7% of binder, 8-12% of filler, and about 0.3-0.5% of fiber or modifier. The high amount of coarse aggregate in the mixture forms a skeleton-type structure providing a better stone-on-stone contact between the coarse aggregate particles, which offers high resistance to rutting. Aggregate to aggregate contact is also there in dense graded mixtures but it occurs within the fine aggregate particles as the coarse aggregate floats in the fine aggregate matrix, which don’t give the same shear resistance as the coarse aggregate skeleton. Brown and Manglorkar (1993) reported that the traffic loads for SMA are carried by the coarse aggregate particles instead of the fine aggregate asphalt-mortar. The higher binder content makes the mix durable. The fibers or modifier hold the binder in the mixture at high temperature; prevent drainage during production, transportation and laying.

SMA has been proved to be more cost effective than dense graded mixes for high volume roads. Brown (1992) observed that a number of factors influence the performance of SMA mixtures, such as changes in binder source and grade, types of aggregate, environmental conditions, production and construction methods etc. Evaluation of these factors would help to determine the long term performance of SMA and provide information to make changes as needed to suit different environmental conditions. The SMA Technical Working Group of FHWA defined SMA as “A gap graded aggregate hot mix asphalt that maximizes the binder content and coarse aggregate fraction and provides a stable stone-on-stone skeleton that is held together by a rich mixture of binder, filler and stabilizing additives”.

1.2 Advantages over Conventional Bituminous Mixes

Conventional bituminous pavements lack the strength, durability and longevity of SMA. There are several factors for which SMA is better than the conventional mixes. As mentioned by Bose et al. (2006) SMA provides better resistance to rutting due to slow, heavy and high volume traffic, resistance to deformation at high pavement temperatures, improved skid resistance, noise reduction over conventional alternative pavement surfaces, improved resistance to fatigue effects and cracking at low temperatures, increased durability, reduced permeability and sensitivity to moisture. According to Brown and Manglorkar (1993) SMA has also shown good resistance to plastic deformation under heavy traffic loads with high tyre pressures as well as good low temperature properties. Further, SMA has a rough texture which provides good friction properties after surface film of the binder is removed by the traffic. Kamaraj et al. (2004) have reported that SMA has an extended life as compared to conventional dense graded mixes. They have also reported that the cost of SMA has been estimated to be about 20-25 percent more than conventional dense graded mixtures, but this can be justified by the increased life of pavement. In view of these advantages SMA has been proved to be superior over HMA mixes.

1.3 Selection of Binders

Many researchers have used different types of binders such as conventional 60/70 penetration grade bitumen and many modified binders such as Polymer Modified Binder (PMB), Crumb Rubber Modified Binder (CRMB), Natural Rubber Modified Binder (NRMB) etc. in SMA mixes. Superpave performance grade binder such as PG 76 -22 has also been used by some investigators. Reddy et al. (2006) have reported that use of CRMB in the bituminous mixes significantly improves fatigue life, temperature susceptibility and resistance to moisture damage characteristics compared to other unmodified mixes. Considering this fact, an attempt has been made in this investigation to study the SMA mixes made with locally available coarse aggregates, commonly used binders such as 60/70 penetration grade bitumen and CRMB 60. From the review of related literature, it is observed that use of 80/100 bitumen is rare in SMA mixes. An attempt has been made in this investigation to use a commonly used binder, i.e. 80/100 bitumen in SMA mixes, mainly with the objective of exploring the scope of using the same in presence of fibers.

1.4 Selection of Stabilizing Additive

SMA being a gap graded mix has more air void content and higher concentration of binder. Therefore stabilizing additives are added in the mix to prevent draindown of the binder. Many fibers such as cellulose fibers, mineral fibers etc., many polymers, plastics in pellet or powder form, waste materials such as carpet fiber, tires, polyester fiber, natural fiber such as jute fiber have been tried by various investigators in SMA mixes to solve this draindown problem. These fibers and polymers used by various investigators for evaluation of SMA mixes are either costly or not readily available. It has been reported that coconut fiber contains certain amount of cellulose, normally used in SMA mixes to prevent draindown of binder mortar. Hence, an attempt has been made in this study to utilize a naturally and abundantly available low cost material such as coconut fiber, in preparation of SMA mixes.

1.5 Objectives and Scope of the Present Investigation

The concept of stone matrix asphalt is relatively new compared to normal bituminous mixes. The stabilizing additives, such as cellulose fibers, mineral fibers and different types of synthetic polymers, which are used to prevent drain down of the binder from the mixture, are either costly or not easily available in all parts of India.

The main objectives of this investigation are:

- To compare the Marshall properties of SMA samples with binder type and its concentrations
- To compare the Marshall properties of SMA samples with varying fiber concentration using different binders
- To analyze the results of Marshall tests of SMA mixes for deciding the optimum binder content (OBC) and optimum fiber content (OFC) for further studies

- To study the draindown characteristics of the SMA mixes prepared at OBC and OFC
- To evaluate the SMA mixes with fixed fiber concentration and various binders (at OBC and OFC), in terms of engineering properties such as static indirect tensile test and repeated load indirect tensile test including fatigue characteristics at various temperatures
- To study the moisture susceptibility characteristics of SMA mixtures in terms of their tensile strength ratio and retained stability

In this study three types of binders, two unmodified penetration grade binders such as 80/100 and 60/70 bitumen, and one modified binder such as CRMB 60 have been used in SMA mixes along with coconut fiber as stabilizing additive. The SMA mixes are evaluated in terms of Marshall properties such as Marshall stability, flow value, unit weight and air voids, draindown characteristics, static and repeated load indirect tensile strength characteristics, and moisture susceptibility characteristics. The work carried out in this investigation is being described briefly in the following sections.

1.5.1 Marshall test

Marshall properties such as Marshall stability value, flow value, unit weight value and air void content of the SMA mixes have been studied. These parameters have been used to estimate the optimum binder content (OBC) and optimum fiber content (OFC) of the mixes. In general, the Marshall stability values have been found to increase with addition of fiber up to 0.5% but considering a particular mix the OBC percentage decreases when fiber is added to it. The next sets of experiments were carried out on mixes prepared at their OBC and OFC.

1.5.2 Draindown test

Draindown test is carried out on SMA mixes to evaluate the draindown percent of the binder used. It is observed from the drainage test conducted on SMA mixes with three types of binder that there is no draindown of binder in case of all the mixes with fiber. Mixes with 80/100 and 60/70 bitumen yield better results with addition of fiber.

1.5.3 Static indirect tensile test

Static indirect tensile tests have been carried out to determine tensile strength of SMA mixes with and without fibers prepared at their OBC and OFC. It is observed from the results that addition of fiber improved the tensile strength of the mix. The effect of temperature on tensile strength of SMA mixes is also being evaluated using this method as the same is time consuming in case of repeated load test. The results indicate that with increase in test temperature the tensile strength value decreases.

1.5.4 Repeated load indirect tensile test

The important parameters those are required for pavement design are elastic modulus, Poisson's ratio and fatigue characteristics of the pavement materials under dynamic condition. The repeated load indirect tensile test has been adopted to study the fatigue life characteristics of SMA mixes. A repeated load indirect tensile testing set up fabricated in the laboratory has been used for this purpose. Repeated load tests have been conducted at three different temperatures, 25˚C, 30˚C and 35˚C. The resilient modulus of elasticity, resilient Poisson's ratio, tensile stress, tensile strain etc. has been computed. It has been observed from the test results that at a particular test temperature, SMA mixes with CRMB 60 binder offers highest resilient modulus and fatigue life.

1.5.5 Moisture susceptibility tests

It is very much essential to study the resistance to moisture characteristics of bituminous mixes as moisture is a critical factor leading to failure of bituminous pavements. The loss of adhesion of bitumen from aggregates has been studied using the two methods, namely retained stability test and tensile strength ratio test. The test results show that the SMA mixes with fiber have better resistance to moisture damage than the mixes without fibers.

1.6 Organization of Thesis

The whole thesis is divided in to five chapters namely, introduction, review of literature, experimental investigation, analysis and discussion of test results and conclusion. Chapter 2 deals with the review of the investigations carried out previously by various researchers on SMA mixtures using different stabilizing additives. In Chapter 3, various experimental works conducted for this study have been described. The results obtained from the tests are presented in Chapter 4 and discussed. The last Chapter summarizes the important conclusions drawn from the experiments conducted. Scope of future work that can be further carried out is also discussed in Chapter 5.

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER – 2

REVIEW OF LITERATURE

2.1 General

A detailed review of literatures made on works related to SMA mixes is described in the following paragraphs. Majority of the roads all over the world are made up of flexible pavements. Flexible pavements consist of a bituminous layer on the surface course and sometimes in base course followed by granular layers in base and sub base courses over the subgrade. Asphalt Concrete Pavement or Hot Mix Asphalt pavement are the bound layers of a flexible pavement structure at the surface course. The most common type of flexible pavement surfacing used in India is a premix bituminous material, commonly called outside as Hot Mix Asphalt (HMA). HMA is a mixture of coarse and fine aggregates and asphalt binder. HMA, as the name suggests, is mixed, placed and compacted at higher temperature. HMA is typically applied in layers, with the lower layers supporting the top layer, which is known as surface course or friction course. The aggregates used in the lower layer are to prevent rutting and the aggregates which are used in the top layer are generally selected on the basis of their friction properties and durability. There are several types of HMA mixes. These include conventional Dense Graded Mixes (DGM), Stone Matrix asphalt (SMA) and various Open graded HMA. The HMA mixes differ from each other mainly in maximum aggregate size, aggregate gradation and binder content or type of binder used. Figures 2.1, 2.2 and 2.3, show pictures of typical dense graded HMA, SMA and open graded friction course (OGFC) mixes respectively.

Fig. 2.1 Dense graded HMA surface

Fig. 2.2 SMA surface

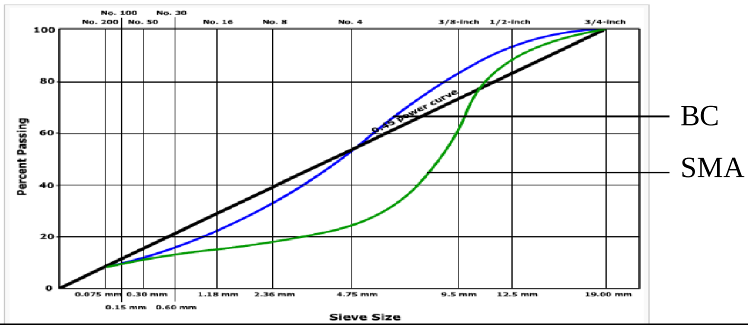
Fig. 2.3 Open graded friction course surface

The surface course in flexible pavements consists of aggregates in large volume with a suitable grading bound by a small quantity of bitumen. A dense graded HMA mix is a well – graded one which is normally used for heavily trafficked roads in the surface course.

2.2 Stone Matrix Asphalt

Washington state department of transportation (WSDOT, 2000) has mentioned in the tech notes on SMA that as per National Asphalt Paving Association (NAPA), SMA is a tough, stable, rut-resistant mixture that relies on aggregate to aggregate contact to provide strength and a rich mortar binder to provide durability. These objectives are usually achieved with a gap graded aggregate coupled with fiber or polymer modified, and high asphalt content matrix. SMA mixture is composed of mineral aggregates, mineral filler, asphalt binder and stabilizing additives. SMA is designed to maximize rutting resistance and durability. Mineral aggregates when bound with asphalt mortar forms a stone on stone contact framework to impart strength and toughness to the structure. Mineral filler plays an important role in the properties of SMA mixture in terms of air voids, voids in mineral aggregate and optimum binder content in the mix. Stabilizing additives such as polymers and fibers etc. are added to the mixture to reduce draindown of the binder material during the high temperature of production and placement. Table 2.1 summarizes the main points of differences between an SMA and a normal bituminous concrete (BC) mix.

Table 2.1 Main differences of SMA and bituminous mix (Bose et al., 2006)

<table>
<tr><th>Properties</th><th>SMA</th><th>BC</th></tr>
<tr><td>Definition</td><td>SMA is a gap graded mix which consists of high amount of coarse aggregate firmly bonded together by a strong asphalt matrix consisting of fine aggregate, filler, bitumen and stabilizing additives.</td><td>BC consists of well graded coarse and fine aggregate, filler and bitumen.</td></tr>
<tr><td>Gradation Curve</td><td colspan="2">
</td></tr>
<tr><td>Schematic Representation</td><td>
SMA Sample</td><td>
AC Sample</td></tr>
<tr><td>Mass of Coarse Aggregate Content, %</td><td>75 – 80</td><td>50 - 60</td></tr>
<tr><td>Mass of Fine and Stone Dust, %</td><td>20 – 25</td><td>40 - 50</td></tr>
<tr><td>Mass of Filler content, %</td><td>9 – 13</td><td>6 – 10</td></tr>
<tr><td>Binder Type</td><td>60/70, PMB- 40</td><td>60/70, 80/100 and modified binders</td></tr>
<tr><td>Minimum binder content by weight of mix, %</td><td>>6.5</td><td>5 - 6</td></tr>
<tr><td>Stabilizing Additives by weight of mix, %</td><td>0.3 – 0.5</td><td>----</td></tr>
<tr><td>Air Voids, %</td><td>3 – 4</td><td>3 - 6</td></tr>
<tr><td>Layer Thickness, mm</td><td>25 - 75</td><td>30 - 65</td></tr>
</table>

2.3 Material Characteristics

2.3.1 Mineral aggregates

There are various types of mineral aggregates which can be used in bituminous mixes. The aggregates used to manufacture bituminous mixes can be obtained from different natural sources such as glacial deposits or mines. These are termed as natural aggregates and can be used with or without further processing. Deori (2006) has mentioned that if these are used without processing it is termed as "back run or pit run" materials. The aggregates can be further processed and finished to achieve good performance characteristics. Industrial by products such as steel slag, blast furnace slags etc. are sometimes used as a component along with other aggregates to enhance the performance characteristics of the mix. Reclaimed bituminous pavement is also an important source of aggregate for bituminous mixes.

Aggregates play a very important role in providing strength to SMA mixtures as they contribute a greater part in the matrix. SMA contains 70-80 percent coarse aggregate of the total stone content. The higher proportion of the coarse aggregate in the mixture forms a skeleton-type structure providing a better stone-on-stone contact between the coarse aggregate particles resulting in good shear strength and high resistance to rutting. Brown and Haddock (1997) has remarked that since the strength of SMA relies heavily on the stone-on- stone aggregate skeleton, it is imperative that the mixture be designed and placed with a strong coarse aggregate skeleton. According to WSDOT (2000) the Federal Highway Administration, McLean Virginia, has suggested the following characteristics for aggregates used in SMA mixture. The aggregates must posses;

- A highly cubic shape and rough texture to resist rutting and movements,
- A hardness which can resist fracturing under heavy traffic loads,
- A high resistance to polishing, and
- A high resistance to abrasion.

2.3.2 Mineral fillers

Mineral fillers have a significant impact on the properties of SMA mixtures. Mineral fillers increase the stiffness of the asphalt mortar matrix. According to Mogawer and Stuart (1996) mineral fillers also affect workability, moisture resistance, and aging characteristics of HMA mixtures. Mineral fillers also help to reduce the draindown in the mix during construction, which improves the durability of the mix by maintaining the amount of asphalt initially used in the mix. It also helps to maintain adequate amount of voids in the mix. Different types of mineral fillers are used in the SMA mixes such as stone dust, ordinary Portland cement (OPC), slag cement, fly Ash, hydrated lime etc.

Brown and Mallick (1994) reported that draindown of binder in the mix is significantly affected by the type of filler used. Higher percentage of filler in the mix lowers the draindown of the binder.

Brown et al. (1996) evaluated the SMA mortars in terms of Superpave binder tests and studied the influence of each of the mortar components in the mix on the overall mortar performance. They used two types of mineral fillers, limestone dust and baghouse fines from a HMA plant to prepare SMA mixes. They concluded that most of the stiffening effect of the mortar comes from mineral fillers. They reported that Portland cement can also be used as a filler material in SMA mixes.

Mogawer and Stuart (1996) studied the effect of mineral fillers on properties of SMA mixtures. They chose eight mineral fillers on the basis of their performance, gradation etc. They evaluated the properties of SMA mixtures in terms of draindown of the mastic, rutting, low temperature cracking, workability, and moisture susceptibility.

Ravi Shankar et al. (2009) used stone dust and cement as the filler material in SMA mixture. They used filler content of 10% by dividing it to 8 percent stone dust and 2 percent cement.

Xue et al. (2008) utilized municipal solid waste incinerator (MSWI) fly ash as a partial replacement of fine aggregate or mineral filler in stone matrix asphalt mixtures. They made a comparative study of the performance of the design mixes using Superpave and Marshall mix design procedures. The mixes were evaluated in terms of dynamic stability, water sensitivity and fatigue life. They concluded that nearly 8-16% of MSWI ash substitution for aggregates and filler is guaranteed to meet the requirement of SMA mixtures through Marshall and Superpave mix design procedure.

2.3.3 Bitumen

Bitumen acts as a binding agent to the aggregates, fines and stabilizers in SMA mixtures. SMA mixes are rich in mortar binder which provides durability to the mix. The characteristics of bitumen which affects the bituminous mixture behaviour are temperature susceptibility, viscoelasticity and aging. The behaviour of bitumen depends on temperature as well as on the time of loading. It is stiffer at lower temperature and under shorter loading period. Bitumen must be treated as a viscoelastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. Though at low temperature it behaves like an elastic material and at high temperatures its behaviour is like a viscous fluid.

Bitumen along with different additives (fibers, polymers etc.) acts as a stabilizer for the SMA mix. Polymer modified bitumen can also be used as a stabilizer with or without additives in the mixture. Different types of bitumen have been used by various researchers to study the SMA mixture properties. Penetration grade bitumen such as 60/70, modified bitumen such as CRMB, PMB, and Superpave performance grade bitumen are used to evaluate SMA mixtures.

Brown and Mallick (1994) used viscosity grade binder AC-20 for their research on SMA properties related to mixture design. Mogawer and Stuart (1996) also used AC-20 binder. Putman et al. (2004) used a performance grade binder PG 76-22 to study the SMA properties. Neubauer and Partl (2004) used two binders one penetration grade bitumen 50/70 and polymer modified bitumen with SBS modifier. They observed that polymer modified bitumen gives better performance (in terms of deformation) than unmodified bitumen. Sharma et al. (2004) used natural rubber powder to modify 80/100 penetration grade bitumen. They termed it as Natural

Rubber Modified Bitumen (NRMB). They concluded that use of NRMB as binder in SMA mix contributes to resistance to deformation and lesser draindown of binder. They found that SMA mixes with NRMB showed improved performance under heavy wheel loads. Kamaraj et al. (2006) used 60/70 grade bitumen and SBS modified bitumen (PMB-40) in SMA mixes for their investigation. Chandra et al. (2004), Punith et al. (2004), Bose et al. (2006) and Asi (2006) used 60/70 penetration grade bitumen for their study. Kumar et al. (2007) used 60/70 grade bitumen and CRMB (Crumb Rubber Modified Binder) without stabilizing additives to study the performance of SMA mixtures. They concluded that use of CRMB without fibers in SMA mixtures (SMA-CRMB) perform similar to or better than conventional SMA although it does not follow the terminology of SMA. Chiu and Lu (2007) investigated the feasibility of using Asphalt Rubber (AR) as a binder for SMA. They produced this AR by blending ground tire rubber (GTR) with AC-20 asphalt. They termed it as AR-SMA. The performance of AR-SMA was evaluated in terms of moisture susceptibility. It was found that the AR-SMA mixtures were not significantly different from the conventional SMA mixtures in terms of moisture susceptibility. It was also observed that no fiber was needed to prevent draindown when this AR is used in the mix. Ravi Shankar et al. (2009) used conventional 80/100 bitumen in their performance study of SMA mixes using waste plastics as modifier.

It has been reported by Reddy et al. (2006) that the fatigue life, temperature susceptibility and resistance to moisture damage characteristics of the bituminous mixes can be improved by the use of CRMB as compared to other unmodified bitumen. Hence, a polymer modified binder such as CRMB 60 has been attempted in this investigation to study the properties of SMA mixes. Conventional bituminous binders such as 80/100 and 60/70 penetration grade bitumen have also been tried for comparison, though the former grade bitumen is not normally used in SMA mixes considering the draindown effects.

2.3.4 Stabilizing additives

SMA is a gap graded mix, having higher amount of voids in the mix. Therefore stabilizing additives are used in the mixture to prevent mortar draindown and to provide better binding. Initially SMA was developed using asbestos fibers. Though it was perfect from the technical point of view its use was restricted for health reasons. Fibers commonly used now-adays are polypropylene, polyester, mineral and cellulose. The main stabilizing additives used in SMA mixes can be classified in to different groups;

- Fibers (Cellulose Fibers, Mineral Fibers, Chemical Fibers)
- Polymers
- Powder and flour like materials (Silicic acid, Special Filler)
- Plastics (Polymer Powders or Pellets)

2.3.4.1 Cellulose Fiber

The most commonly adopted fibers in SMA mixtures are cellulose fibers. The main component of this fiber is cellulose, a polysaccharide $(C_6H_{10}O_5)_n$, n = 1000. This harmless organic fiber is commonly obtained from plants and is abundantly found in nature. Bose et al. (2006) have mentioned that it acts as a carrier for the bitumen binder and stabilizes the bitumen. Fig. 2.4 shows the structural unit of cellulose fiber collected from the website http://en.wikipedia.org. Fig. 2.5 shows a typical picture of appearance of cellulose fiber under scanning electron microscope. Some of the properties of cellulose fiber given by Bose et al. (2006) are presented in Table 2.2.

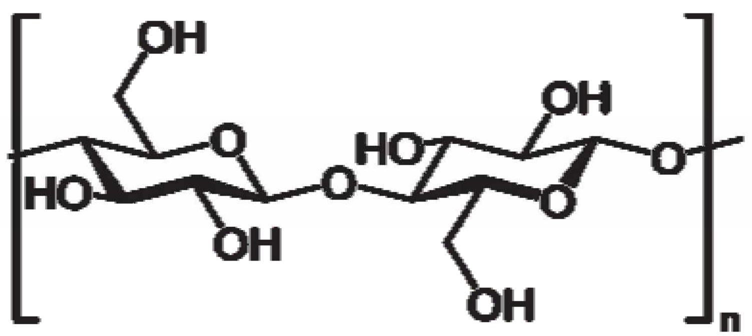


Fig.2.4 Structural unit of cellulose fiber

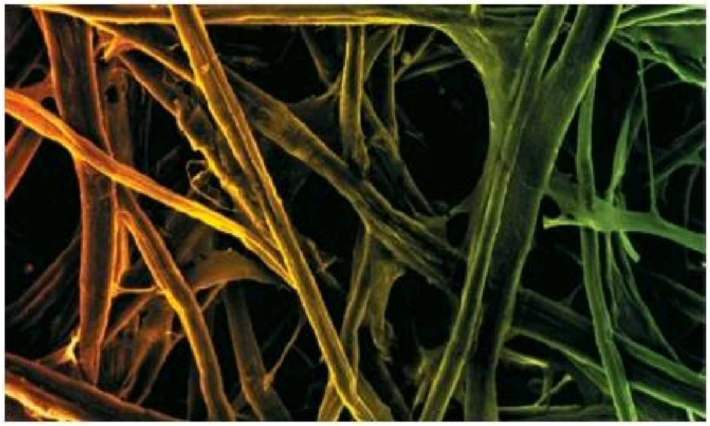


Fig.2.5 Appearance of cellulose fiber under scanning electron microscope

Table 2.2 Properties of Cellulose Fiber [Bose et al., 2006]

Property	Unit	Value
Specific Gravity	---	1.5
Bulk Density	g/cc	1600
Average fiber length	µ m	20-2500
Average fiber diameter	Ì m	25
pH value	---	3-11
Temperature Resistant	˚C	Up to 200˚C
Solubility	---	Insoluble in water and organic solvents
Resistivity	---	Resistant to dilute acids and alkalis
Humidity	---	R Low natural humidity between 10 to 15% R Humidity upon delivery up to 4 - 9%

Cellulose fibers are physiologically and toxicologically safe made out of purely natural cellulose resources. Very small amount of cellulose fiber (about 0.3%) is required to stabilize the mix. These fibers are extensively used in SMA in Europe and USA. Kumar et al. (2007) has reported that the fibers improve the service properties of the mix by forming micromesh in the asphalt mix to prevent draindown of the asphalt so as to increase the stability and durability of the mix. Brown and Haddock (1997) have studied the effect of different stabilizing additives on draindown and reported that fibers perform better job of preventing draindown than polymers. Muniandy and Huat (2006) used Cellulose Oil Palm Fiber (COPF) to study the fatigue performance of SMA mixtures. They produced COPF from empty fruit bunch by various methods of pulping. They observed that SMA mixes with cellulose oil palm fibers displayed a higher performance in terms of stability and resilient modulus.

Other than cellulose fiber, various researchers have also attempted to use different waste materials and fibers as stabilizers in SMA mixes to evaluate the performance of SMA mixtures. Brown et al. (1996) used three types of fiber in their investigation, namely cellulose, rock wool and slag wool. They concluded that fibers have a very important role at higher temperatures during production and placement of SMA mixtures. During this time the fiber works to prevent the draindown of asphalt cement. Putman et al. (2004) utilized waste fibers such as waste tire and carpet fibers in SMA mixtures. They also prepared mixes using cellulose and polyester fibers and made a comparative study. They found no significant difference in permanent deformation or moisture susceptibility in mixtures containing waste fibers compared to cellulose or polyester fibers. They concluded that tire, carpet and polyester fibers significantly improved the toughness of the mixture compared to the cellulose fibers. Kumar et al. (2007) made an attempt to use jute fibers coated with low viscosity binder as an alternative to patented fibers such as cellulose or polyester fiber. They concluded that results of strength tests on SMA mixes obtained with natural fibers are comparable to the patented fibers as indicated by Marshall stability tests, permanent deformation test and fatigue life test. They also observed that aging index of mix prepared with natural fiber is better than that of mix prepared with patented fibers. Ravi Shankar et al. (2009) used waste plastics in shredded form to study the performance of SMA mixes. They added 0, 4, 8, 12, and 16 percent of weight of bitumen of shredded waste plastics to aggregates during heating. They found that there was considerable improvement in the stripping characteristics of SMA by use of waste plastic.

The above stated fibers used by various investigators in SMA mixes, are either costly or not easily and abundantly available. The scope remains limited for use of such fibers in SMA mixes. Hence, an attempt has been made in this study to explore the scope of utilizing a naturally and abundantly available and at the same time a cheap material such as coconut fiber, for preparation of SMA mixes.

2.3.4.2 Coconut Fiber

Coconut fiber/ coir fiber is a natural fiber derived from the mesocarp tissue or husk of the coconut fruit. It is also termed as 'Golden Fiber' due to its color. The individual coconut fiber cells are narrow and hollow, with thick walls made up of cellulose. These fibers are pale when immature but later they become hardened and yellowed as a layer of lignin gets deposited on it. Brown coir fibers are stronger as they contain more lignin than cellulose, but they are less flexible. Coconut fibers are made up of small threads, each less than 1.3 mm long and 10 to 20 micrometers in diameter. This fiber is relatively water proof and is the only natural fiber resistant to damage by salt water. Tables 2.3 and 2.4 present some of the physical and chemical properties of coconut fibers as available in the websites http://coirboard.nic.in and http://www.originalmulchblock.com/propertiesofcoir respectively. The physical appearance of coconut fiber as given by http://coirboard.nic.in is shown in Fig 2.6.

Fig.2.6 Physical appearance of coconut fiber

Table 2.3 Physical properties of coconut fiber

Property		Value
Ultimate Length		0.6 mm
Diameter / Width		16 micron
Single Fiber	Length	6 to 8 inches
	Density	1.4 gm/cc
	Tenacity	10 gm/tex
Breaking Elongation		30%
Moisture regain at 65% RH		10.5%
Swelling in Water		5% in Diameter
Air Filled Porosity		Up to 70%
Water holding capacity		Up to 30%
Electrical Conductivity		< 1.5mS/cm
pH		5.8-6.4

Table 2.4 Chemical properties (Composition) of coconut fiber

Property	Value
Water soluble	5.25%
Pectin and related compounds	3.30%
Hemi - Cellulose	0.25%
Cellulose	43.44%
Lignin	45.84%
Ash	2.22%

Traditional uses of the resilient and durable coconut fiber include rope, twine, brooms, brushes, doormats etc.

2.3.4.3 Polymers

Polymer is a large molecule composed of repeating structural units known as monomers, typically connected by covalent chemical bond. Most of the polymers are organic but inorganic polymers are also there. Polymers, which are long chain molecules of very high molecular weight, are used by the binder industry. The polymers can be preblended with the bitumen to modify the bitumen and improve its properties or it can be added to the aggregates during mixing. Main purpose of using polymers in SMA mixes is to prevent draindown of the bitumen and to increase the stiffness of the mix.

Punith et al. (2004) used reclaimed polyethylene as stabilizer in SMA mixes. They cut those LDPE carry bags obtained from grocery bags in to shredded form of 3×3 mm size and used in the mix to make comparative studies on the behaviour of SMA and asphalt concrete mixtures. They concluded that reclaimed polyethylene obtained from LDPE carry bags can be effectively used as a stabilizer in SMA, to retard draindown of binder and mineral filler.

Kamaraj et al. (2006) used three types of cellulose based additives namely Technocel, Topcel and Genicel as stabilizing additives in SMA. They observed that the SMA mixes with these polymers as stabilizing additives performed very well in terms of draindown, resistance to moisture damage and permanent deformation characteristics. They concluded that these mixes are suitable for roads subjected to heavy traffic and wet weather conditions.

2.4 Mix Characteristics

2.4.1 Aggregate gradation

Strength of SMA mixtures relies mainly on the coarse aggregate skeleton of the mix. Therefore, selection of suitable aggregate gradation is a very important factor for SMA. The aggregate gradation must be so selected that the combination of aggregates will provide adequate void structure, including air voids, voids in mineral aggregate, voids filled with bitumen, and voids in the coarse aggregate of the mix. Traditionally, the SMA gradation specification has been used to help to ensure an adequate coarse aggregate skeleton. Kumar et al. (2007) has reported that the SMA gradation follows the 30-20-10 rule. The rule says that the gradation should have 30 percent passing the 4.75 mm sieve, 20 percent passing the 2.36 mm sieve and 10 percent passing the 0.075 mm sieve. From the European experience and research work done by National Center for Asphalt Technology (NCAT), Auburn University, Alabama on SMA, it has been reported that aggregate percent passing the 4.75 mm sieve and 0.075 mm sieve are critical factor in the formation of stone- on- stone contact in the mixture. Stuart (1992) stated that 4.75 mm and 2.36 mm sieves control the degree of gap and coarse aggregate content and the material passing 0.075 mm sieve control the optimum binder content (OBC) in SMA mixture. The SMA Task working group has suggested aggregate gradation guidelines to design the SMA based on stone-on- stone contact skeleton structure of aggregates.

As per Bose et al. (2006) National Cooperative Highway Research Project (NCHRP), NAPA grading and Ministry of Road Transport and Highways (MORTH, 2001, gradations I & II) gradings were investigated for design performance evaluation of SMA mixtures with nominal size of aggregate (NSA) of 19, 13, and 10 mm respectively. They have adopted two different gradings, the 19 mm NSA NCHRP grading and 13 mm NSA MORTH (2001) grading for their study. They observed that the OBC for NCHRP grading was less than that of the MORTH grading. Deori (2006) adopted the 13 mm NSA MORTH grading for his research work to evaluate the effect of different aggregate gradations foe SMA. He studied a total of twelve combinations containing 20, 30, 40 and 50 percent fine aggregates with filler content of 8, 10 and 12 percent. He concluded that the use of 13 mm NSA gradation given by MORTH is feasible to use in SMA mixtures with paving grade bitumen of 60/70 as binder without adding stabilizing additives at 5.5 percent OBC by weight of mix. He observed the draindown of this mix was almost within the limit of 0.3 percent. Sharma et al. (2004) adopted the NCHRP grading. Kamaraj et al. (2006) adopted 13 mm NSA grading specified by MORTH (2001) for their study. Kumar et al. (2007) adopted the grading specified by NAPA: Designing and Constructing of SMA mixtures- state of practice, Quality improvement programme 122, 1999 for SMA. Ravi Shankar et al. (2009) adopted the Manual for Construction and Supervision of Bituminous Works (MCSBW, 2002) gradation for their investigation.

From the above, it is observed that NCHRP grading requires less binder quantity for a satisfactory SMA mix. Considering this, the NCHRP grading has been selected throughout the investigations.

2.4.2 Mix design

Hot mix bituminous concrete pavement is a mixture of blended aggregate filled with bituminous binder. The design of a bituminous mix consists of selecting a suitable gradation of aggregates along with the necessary amount of bitumen (Optimum Binder Content) to obtain a mix that will be durable, have the stability to withstand traffic loads, and be workable for placement and compaction with the construction equipment available. The main objective of bituminous mix design is to get a mix to have;

- Sufficient bitumen to ensure a durable pavement;
- Sufficient strength to resist shear deformation under traffic at higher temperature;
- Sufficient air voids in the compacted bitumen to allow further additional compaction by traffic;
- Sufficient workability to permit easy placement without segregation;
- Sufficient flexibility to avoid premature cracking due to repeated bending by traffic; and
- Sufficient flexibility at low temperatures to prevent shrinkage cracks.

So the desirable properties of a good bituminous mix are stability, flexibility, skid resistance and workability. There are four mix design methods, Marshall, Hveem, Hubbard – Field and Smith triaxial methods, which have been used to design and construct bituminous pavements with satisfactory results. Superpave mix design method has been developed recently from the results of SHRP (Strategic Highway Research Programme). Past researches show that SMA mix design has been developed by using Marshall mix design method and Superpave mix design method. In India, Marshall Method is commonly used for characterization of bituminous mixes.

Brown and Mallick (1994) studied the SMA properties related to mix – design using Marshall Mix design method. They used the compactive effort of 50 blows of a mechanical fixed base Marshall hammer. They indicated that there would be an increase in the density of the mix if higher compactive efforts were used, but it may result in crushing of coarse aggregate due to stone to stone contact. They recommended that SMA mixtures should be designed with 50 blows rather than 75 blows. Mogawer and Stuart (1996) also designed SMA mixes using Marshall mix design method with a compactive of 50 blows per side to study the effect of mineral fillers on mix properties. They reported that SMA mixtures were designed in Europe for heavy traffic using 50 blows. Muniandy and Huat (2006) studied the Fatigue Performance of SMA with COPF using Marshall mix design procedure with 50 blows of compaction. Chiu and Lu (2006) produced AR–SMA mixes using GTR. They adjusted mix proportions based on the volumetric properties of Marshall specimens prepared using 50 blows of compactive effort. If the volumetric properties as required in the SMA specifications were not met, the compositions of the mixes were adjusted and new Marshall specimens were prepared for further research. Thus they considered Marshall Method as the main criterion and got satisfactory results. Chandra et al. (2004), Punith et al. (2004), Sharma et al. (2004), Kamaraj et al. (2006) and Kumar et al. (2007) adopted Marshall mix design at 60°C, using 50 blows of compaction per side and got satisfactory results from their research. Ravi Shankar et al. (2009) also used Marshall stability and flow analysis to determine the OBC of SMA mixes with waste plastics in shredded form as modifiers.

Brown et al. (1996) investigated the SMA mortars using Superpave system binder tests and concluded that some of the Superpave binder test equipment like BBR and DSR can be used for testing SMA mortars with slight modifications. Putman et al. (2004) followed Superpave mix design guide lines to design SMA mixtures using PG 76-22 binder and waste fibers such as waste tire and carpet fibers as additives. They compacted the specimen with 50 gyrations of Superpave Gyratory Compactor per SC DOT procedures. Neubauer and Partl (2004) investigated the behaviour of SMA mixtures with different filler/ binder combination in order to do a comparative study between Marshall and Gyratory Methods. They observed that the optimum binder content value determined using Marshall compactor were distinctively higher than those using the Gyratory compactor. They also concluded from the values of air voids, voids of mineral aggregate, and volume of voids filled with binder for all the mixes that SMA is more efficiently compacted with the Gyratory compactor than with the Marshall compactor. Xue et al. (2008) also made a comparative study of use of Marshall mix design and Superpave mix design methods in SMA mixtures with MSWI. They concluded that Superpave mixtures showed superior performance over Marshall mixtures in almost all pavement performance, such as dynamic stability, water sensitivity and fatigue life.

In this investigation, SMA mixes have been prepared using normal Marshall procedure by applying 50 blows of compaction on either face of all types of mixes.

2.4.3 Draindown study

Draindown of binder is a major problem of an SMA mix because of its gap grading. So it is essential to study the draindown properties of the SMA mixture. It evaluates the capability of the stabilizers used in the mix to hold the binder aggregate bonding in the matrix.

Brown and Mallick (1994) developed a procedure to study the draindown of binder in SMA mixes. They used wire mesh baskets having openings ¼ inch by ¼ inch. The aggregates and fibers weighed according to the required gradations were kept in an oven at 315°F (157°C) for 4 hours. Then they were mixed at 310°F (154°C) for 2 minutes and transferred to the baskets. The baskets with the mix were placed in a pre heated oven at 300°F (149°C) for 2 hours. Pre weighted papers were kept under the baskets to collect the drippings. The drippings were collected at every 30 minutes interval. The cumulative weights were calculated and presented as a percentage of the weight of the mix. This test has been adopted by FHWA.

Mogawer and Stuart (1996) adopted the NCAT draindown test to evaluate the effects of different mineral fillers on the draindown of the matrix. The sample was placed in a wire basket, positioned on a pre weighted, dry paper plate. The sample, basket and plate were placed in a forced air oven for 60 minutes at 143°C. The paper plate was then weighed. The percent loss due to draindown was calculated as:

$$Loss\ (Percent) = \frac{100\ (final\ paper\ mass - initial\ paper\ mass)}{initial\ paper\ mass} \tag{2.1}$$

Putman et al. (2004) adopted the AASHTO T 305 method to perform the draindown tests. The uncompacted mixtures were put in a basket and placed in the oven at two different temperatures; one at the mixing temperature of the binder (162°C) and another at 177°C as per AASHTO T 305. The draindown was calculated as the percentage of binder that drained out of the basket compared to the original weight of the sample.

Bose et al. (2006) adopted the test developed by Schellenberg Institute in Germany. Deori (2006) also adopted this method for the draindown study. They prepared approximately

1kg of the mixture at the mixing temperature. The mixture was then poured into an 800ml glass beaker and weighed. The beaker was then kept in an oven for 60 minutes at 170°C. Then the mixture was removed from the beaker and placed by quickly turning the beaker upside down without shaking. The final weight of the mixture was taken and the percentage draindown was calculated.

Punith et al. (2004), Sharma et al. (2004), Kamaraj et al. (2006) also adopted the test developed by Schellenberg Institute, Germany for draindown study. They used the following equation to calculate draindown percentage.

$$D_{n,}\ percent = 100 \times \frac{(Weight\ of\ initial\ sample - Weight\ of\ final\ sample)}{Weight\ of\ initial\ sample} \tag{2.2}$$

Kumar et al. (2007) adopted three test methods; Dr. Schellenberg test, an FHWA test developed at the Turner Fairbank Highway research center (TFHRC), and NCAT test for open graded friction courses (OFGC), were used to determine the efficiency of the stabilizers in preventing draindown in loose mixtures. They observed that German test was not suitable for modified asphalt binders.

Xue et al. (2008) used the AASHTO T 305 drainage test method for their research.

Ravi Shankar et al. (2009) used a wire basket made up of 6.3 mm standard sieve cloth for drainage test. They calculated the draindown percentage by the equation;

$$\text{Draindown, \%} = \frac{(D - C)}{(B - A)} \times 100 \tag{2.3}$$

where,

A = mass of empty wire basket

B = mass of wire basket plus sample

C = mass of the empty catch plate

D = mass of the catch plate plus drained material

The draindown test in this investigation has been done as per MORTH (2001) test method.

2.4.4 Fatigue performance

Fatigue of bituminous mixes is an important parameter related to structural failure of pavements. Fatigue failure of HMA surface occurs under repeated traffic loading. After repeated loading, the longitudinal cracks formed get connected with each other, resulting in failure of the pavement surface. The fatigue cracking can be of two types;

- **Bottom up Cracking:** In thin pavements, cracking initiates at the bottom of HMA layer where the tensile stress is highest and then propagates to the surface as one or more longitudinal cracks.
- **Top down Cracking:** In thick pavements, the crack initiates most likely from the top in areas of high localized tensile stresses resulting from tire pavement interaction and asphalt binder aging.

The possible cause of fatigue failure is inadequate structural support which can be due to several factors such as;

- Decrease in pavement load supporting characteristics;
    - Loss of base, sub base or subgrade support;
    - Stripping on the bottom of HMA layer;
- Increase in loading
- Inadequate structural design
- Poor construction

The fatigue failure can be a key factor for SMA pavements. From the past researches it can be observed that many researchers have highlighted that SMA mixtures have great potential in resisting permanent deformation or rutting, but have ignored any potential fatigue resistance of the SMA. Very few studies have been done to asses the fatigue characteristics of SMA mixtures till date. Muniandy and Huat (2006) studied the laboratory diameteral fatigue performance of SMA mixtures using cellulose oil palm fiber (COPF). They performed a repeated load indirect tensile test on SMA samples (AASHTO-TP8-99), using an IPC material testing apparatus

(MATTA). They observed that the initial strain of the specimens showed distinctive improvement with fiber increment at various temperatures and load. They concluded that COPF improved the fatigue performance of SMA mixes.

Asi (2006) compared the resilient modulus and fatigue characteristics of SMA mixtures with dense graded mixtures. They observed that SMA mixtures showed higher M_R value than dense graded mixes. Therefore, they conclude that SMA has improved the diameteral resilient modulus of asphalt mixtures. They also conducted diameteral fatigue test on both the mixes and observed that SMA mixtures showed lower fatigue life than dense graded mixture and concluded that this may be due to the lack of proper mechanical locking of aggregates.

Kumar et al. (2007) performed flexural fatigue test on SMA mixtures conducting beam fatigue test under controlled strain mode in beam fatigue system complying with SHRP M-009. They observed that at a given strain level, SMA with modified binder sustained higher number of load cycles as compared to other mixes and suggested that it can be used in areas with very heavy traffic with improved durability. They also compared the fatigue performance values of SMA mixes with conventional dense graded mixes and found the fatigue life of SMA mixes to be higher than that of dense graded mix.

Xue et al. (2008) studied the resilient modulus and fatigue performance of SMA mixes with MSWI. They used three- points bending fatigue test. They made a comparative study between Superpave design method and Marshall method. They found that superpave mixes perform better in both tests.

The resilient modulus characteristics of the SMA mixes and their fatigue performance have been studied in this investigation using repeated load indirect tensile test as per ASTM.

2.4.5 Moisture susceptibility

Moisture damage in the asphalt pavements is the degradation of mechanical properties of the asphalt composite due to the action of water. It is the main cause of pavement distress due to the loss of cohesive bond between aggregate and binder in the mix. Since SMA is a gap graded mix it is very much necessary to study the moisture susceptibility characteristics of the mixture. Many researchers in the past have studied this property of the SMA mixture.

Mogawer and Stuart (1996) adopted the ASTM D 4867 method to study the moisture susceptibility characteristics of the SMA mortars using different fillers. The Marshall specimens were conditioned subjecting to a freezing cycle at -18°C ± 2°C for 15 hours and then soaking in a 60°C water bath for 24hours. These wet conditioned specimens were tested at 25°C along with dry specimens. The diametral modulus retained ratio and tensile strength retained ratio were computed.

Putman et al. (2004) conducted the moisture susceptibility test by comparing the indirect tensile strength (ITS) of conditioned Marshall specimens in a 60°C ± 1°C water bath for 24 hours to the indirect tensile strength of dry conditioned specimens at 25°C ± 1°C. The tensile strength ratio (TSR) was calculated as a percentage of wet to dry ITS value.

Asi (2006) used the Lottman test (AASHTO T-283) to find out the water susceptibility of the mixture utilizing the indirect tensile strength. They also calculated the percentage loss in terms of retained Marshall Stability value. The Marshall Sample were immersed in a water bath maintained at 60°C for 35 minutes and then for 24 hours. The Marshall stability values of the samples for both the cases were determined and the percentage loss was calculated.

Bose et al. (2006) determined the resistance to moisture damage of SMA samples using the indirect tensile strength test. They immersed a set of Marshall samples in a water bath maintained at 60°C for 24 hours. Then the samples were removed and kept at a temperature of 25°C for 2 hours. The indirect tensile strengths of these conditioned samples and also of unconditioned samples kept at a temperature of 25°C for 2 hours were determined. The TSR was ratio of wet ITS to dry ITS expressed in percentage. Sharma et al. (2004) also adopted the same procedure.

Chandra et al. (2004) and Kamaraj et al. (2006) used the AASHTO: T 283 method to determine the resistance to moisture damage of SMA samples.

Kumar et al. (2007) also used the TSR of bituminous mixes to determine their moisture susceptibility. They adopted ASTM D 4123 (1995) method to determine the ITS value of conditioned and unconditioned specimens. They used the same procedure to condition the samples as adopted by Bose et al. (2006).

Chiu and Lu (2007) adopted the AASHTO T 283 procedure to obtain the moisture susceptibility characteristics of the AR-SMA mixtures.

Xue et al. (2008) evaluated the stripping resistance/ water susceptibility value of the mixtures by the decrease in the loss of the ITS value after immersion in water for 24 hours at 60°C, according to AASHTO T-283.

Ravi Shankar et al. (2009) evaluated the moisture resistance of compacted SMA mixes using the indirect tensile strength (ITS) method. The effect of water saturation was measured by subjecting the samples to a freeze-thaw cycle before testing for ITS. The TSR was obtained as a percentage of ratio of wet ITS to dry ITS.

2.5 Concluding Remarks

The review of literature gives an overview of the researches done on stone matrix asphalt mixtures. Keeping the important points of the researches in mind, the materials of SMA with its composition and the corresponding test methods for the present investigation have been chosen.

As the performance of SMA mixtures relies mostly on the stone- on- stone contact coarse aggregate skeleton, bituminous binders have less influence on the strength of the mix. However, from the past studies it has been observed that if stiffer binders are used in the mixture it improves the mix properties in terms of deformation characteristics. Hence, an attempt has been made to use CRMB 60, a rubber based modified binder commonly used in India. Two penetration grade bitumen, namely 80/100 and 60/70, also commonly used in normal paving mixes have also been used for the purpose of comparison though the former is not normally recommended. In this research work the 19 mm NSA NCHRP grading has been adopted with cement used as the filler material. Investigators mainly have focused on uses of cellulose fiber and other materials in the SMA mixes to prevent draindown of binder mortar from the mix. Use of a non conventional fiber such as coconut fiber which primarily contain cellulose on its outer part and is widely and cheaply available all over the world, is not available in literature, particularly in SMA mixes. Hence this material has been used as the stabilizing additive in the preparation of SMA mixes. This would solve to good extent the problem of solid waste management and at the same time explore the possibility of using a non conventional waste material in a typically non conventional mix like SMA. The performance of the stone matrix asphalt mix is evaluated in terms of Marshall properties, draindown characteristics, fatigue characteristics and moisture susceptibility. The draindown test for SMA mixtures suggested by MORTH has been adopted. The fatigue performance of the SMA samples with conventional and polymer modified binders with and without coconut fibers has been studied using a repeated load tensile test apparatus. The resilient modulus properties of these mixes have also been studied using the above apparatus. Like other investigators, the moisture susceptibility characteristics have been studied using retained stability and tensile strength values of the mixes.

CHAPTER 3

EXPERIMENTAL INVESTIGATIONS

CHAPTER – 3

EXPERIMENTAL INVESTIGATIONS

3.1 Introduction

This chapter describes the experimental works carried out in this present investigation. This chapter has been divided into two parts. First part deals with the experiments carried out on the materials (aggregates, bitumen, and fiber), second part deals with the tests carried out on bituminous mixes.

3.2 Tests on Materials Used

3.2.1 Aggregates

For preparation of SMA mixes, aggregates as per NCHRP grading as given in Table 3.1, a particular type of binder and fiber in required quantities were mixes as per Marshall procedure.

3.2.1.1 Coarse Aggregates

Coarse aggregates consisted of stone chips collected from a local source, up to 4.75 mm IS sieve size. Standard tests were conducted to determine their physical properties as summarized in Table 3.2.

3.2.1.2 Fine Aggregates

Fine aggregates, consisting of stone crusher dusts were collected from a local crusher with fractions passing 4.75 mm and retained on 0.075 mm IS sieve. Its specific gravity was found to be 2.65.

3.2.1.3 Filler

Portland slag cement (Grade 43) collected from local market passing 0.075 mm IS sieve was used as filler material. Its specific gravity was found to be 3.15.

Table 3.1 Adopted aggregate gradation (NCHRP)

Property	Grading
Nominal Size of Aggregate (NSA)	19 mm
Sieve size, mm	Percent Passing
25	100
19	99
12.5	61
9.5	40
4.75	22
2.36	19
1.18	18
0.6	16
0.3	14
0.075	9

Table 3.2 Physical properties of coarse aggregates

Property	Test Method	Test Result
Aggregate Impact Value (%)	IS: 2386 (P IV)	14
Aggregate Crushing Value (%)	IS: 2386 (P IV)	12
Los Angels Abrasion Value (%)	IS: 2386 (P IV)	18
Flakiness Index (%)	IS: 2386 (P I)	17.24
Elongation Index (%)		12.38
Water Absorption (%)	IS: 2386 (P III)	0.09
Specific Gravity	IS: 2386 (P III)	2.64

3.2.2 Binders

Two conventional binders, namely 80/100 and 60/70 bitumen and a polymer modified binder namely CRMB 60 were used in this investigation to study the effects of binder type on SMA mixes. These binders were collected from the local depot. Normal tests were performed to determine the important physical properties of these binders. The physical properties thus obtained are summarized in Table 3.3.

3.2.3 Fibers

The peelings of ripe coconut were collected locally, dried and neat fibers taken out manually. The lengths of such fibers were normally in the range of 75 to 200 mm and diameter varied from 0.2 to 0.6 mm. The tensile strength of these fibers was tested in a materials testing machine, Tinious Olsen, UK, Model HIOKS. The test was done in tensile mode with 10 KN load cell and the cross head speed was maintained at 0.2 mm/min. The average tensile strength of the fiber thus obtained was found to be 70.58 N/mm^2. The coconut fibers were cleaned and cut in to small pieces of 25-75 mm in length to ensure proper mixing with the aggregates and binder during the process of mixing.

Table 3.3 Physical properties of binders

Binder	Property	Test Method	Test Result
80/100 Bit.	Penetration at 25°C, 100g, 5 sec, 0.1 mm	IS : 1203-1978	92
	Softening Point (R&B), °C	IS : 1205-1978	44.5
	Viscosity (Brookfield) at 160°C, cP	ASTM D 4402	145
60/70 Bit.	Penetration at 25°C, 100g, 5 sec, 0.1 mm	IS : 1203-1978	68
	Softening Point (R&B), °C	IS : 1205-1978	48.5
	Viscosity (Brookfield) at 160°C, cP	ASTM D 4402	200
CRMB 60	Penetration at 25°C, 100g, 5 sec, 0.1 mm	IS : 1203-1978	49
	Softening Point (R&B), °C	IS : 1205-1978	62
	Viscosity (Brookfield) at 160°C, cP	ASTM D 4402	275

3.3 Preparation of Mixes

The mixes were prepared according to the Marshall procedure specified in ASTM D1559. The coarse aggregates, fine aggregates and cement were mixed according to the adopted gradation as given in Table 3.1. Three types of binders as already stated were used in different proportions in the mixes starting from 3% to 7% with an increment of 0.5% of the total mix to obtain the optimum binder requirement and also to determine the effect of binder content and binder type on the mix properties. After some initial trials for preparation of SMA samples with coconut fiber, a proper procedure could be developed. The coconut fibers after being cut in to small pieces (25-75 mm) were added directly to the aggregate sample in three different proportions, 0.3%, 0.5%, and 0.7% of the total mix to assess the optimum fiber requirement for the best possible mix. The mineral aggregates with fibers and binders were heated separately to the prescribed mixing temperature. The temperature of the mineral aggregates was maintained at a temperature 10°C higher than the temperature of the binder. Required quantity of binder was added to the pre heated aggregate-fiber mixture and thorough mixing was done manually till the colour and consistency of the mixture appeared to be uniform. The mixing time was maintained within 2-5 minutes. The mixture was then poured in to pre-heated Marshall moulds and the samples were prepared using a compactive effort of 50 blows on each side as 75 blows compaction is reported to result in significant degradation of aggregates as reported by Brown (1992). The specimens were kept over night for cooling to room temperature. Then the samples were extracted and tested at 60°C according to the standard testing procedure.

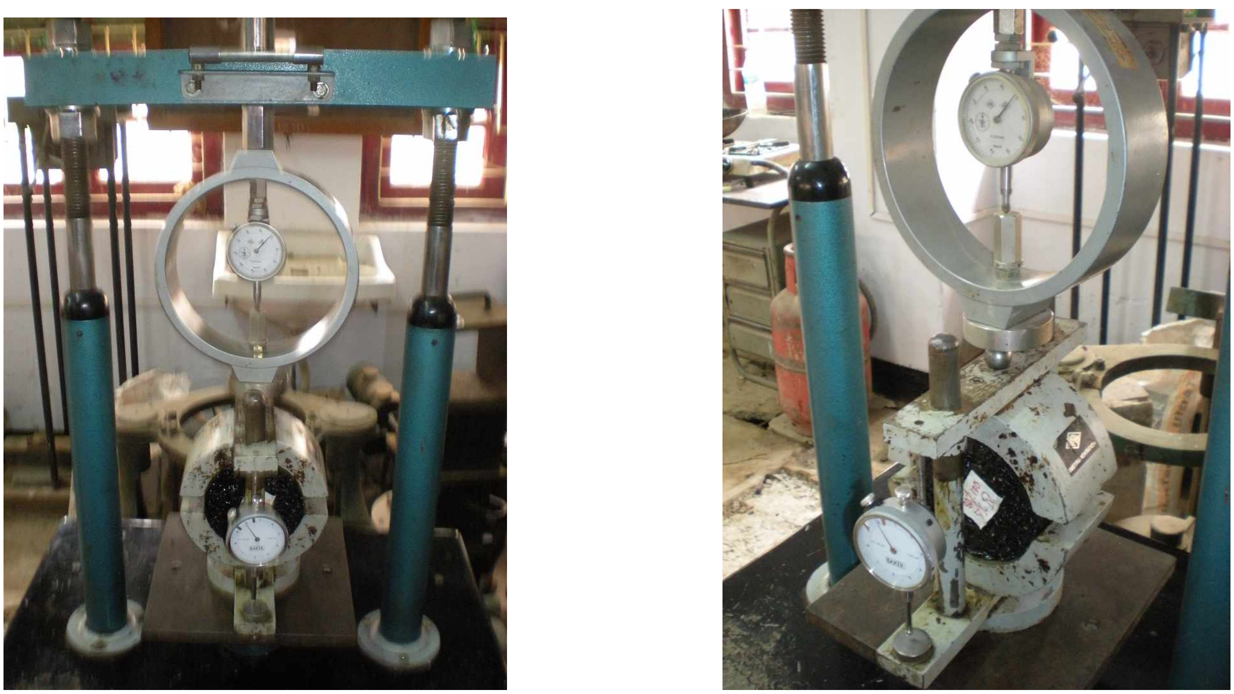
3.4 Tests on Mixes

Presented below are the different tests conducted on the bituminous mixes with variations of binder type and quantity, and fiber concentration in the mix.

3.4.1 Marshall test

Marshall mix design is a standard laboratory method, which is adopted worldwide for determining and reporting the strength and flow characteristics of bituminous paving mixes. In India, it is a very popular method of characterization of bituminous mixes. This test has also been used by many researchers to test SMA mixes. This test method is widely accepted because of its simplicity and low of cost. Considering various advantages of the Marshall method it was decided to use this method to determine the Optimum Binder Content (OBC) of the SMA mixes and also study various Marshall characteristics such as Marshall stability, flow value, unit weight, air voids etc.

Figures 3.1 (i) and (ii) show the Marshall apparatus with a loaded Marshall specimen. The Marshall properties such as stability, flow value, unit weight and air voids were studied to obtain the optimum binder contents (OBC) and optimum fiber contents (OFC). The mix volumetrics of the Marshall samples such as unit weight, air voids were calculated by using the procedure reported by Das and Chakroborty (2003). For constraint of time each and every test on all types of mixes can not be completed. Hence it was decided to carry out the next set of experiments such as draindown test, static and repeated load indirect tensile test and moisture susceptibility tests on the SMA mixes prepared at their OBC and OFC.



(i) (ii)

Fig. 3.1 Marshall test in progress

3.4.2 Draindown test

There are several methods to evaluate the draindown characteristics of SMA mixtures. The draindown method suggested by MORTH (2001) was adopted in this study. The drainage baskets fabricated locally according to the specifications given by MORTH (2001) is shown in Figure 3.2. The loose uncompacted mixes were then transferred to the drainage baskets and kept in a pre-heated oven maintained at 150°C for three hours. Pre-weighed plates were kept below the drainage baskets to collect the drained out binder drippings. From the draindown test the binder drainage has been calculated from the equation 3.1;

$$d = \frac{W_2 - W_1}{1200 + X} \tag{3.1}$$

where;

W_1 = initial mass of the plate

W_2 = final mass of the plate and drained binder

X = initial mass of fibers in the mix

For a particular binder three mixes were prepared at its optimum binder content and the draindown was reported as an average of the three. Figure 3.3 shows the drainage baskets kept in the oven at the required test temperature. Figures 3.4 to 3.6 show the drained out 80/100 and 60/70 bitumen and CRMB 60 binder samples after being kept in oven for three hours.

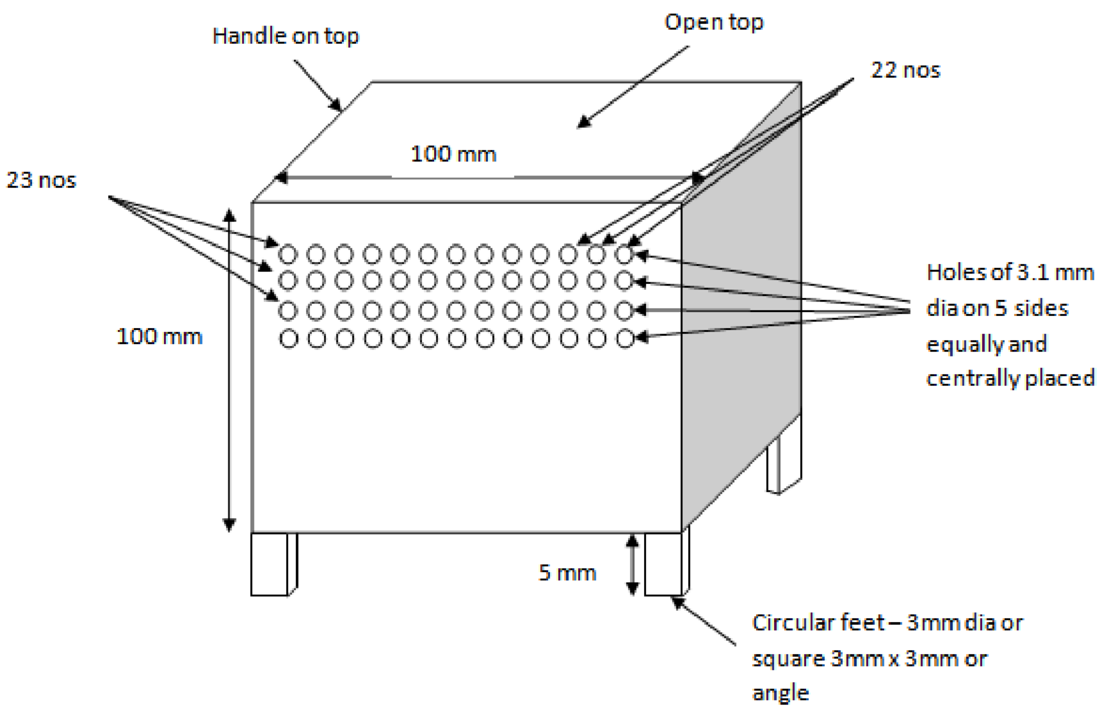


Fig. 3.2 Schematic representation of 100 mm x 100 mm x 100 mm cubical drainage basket

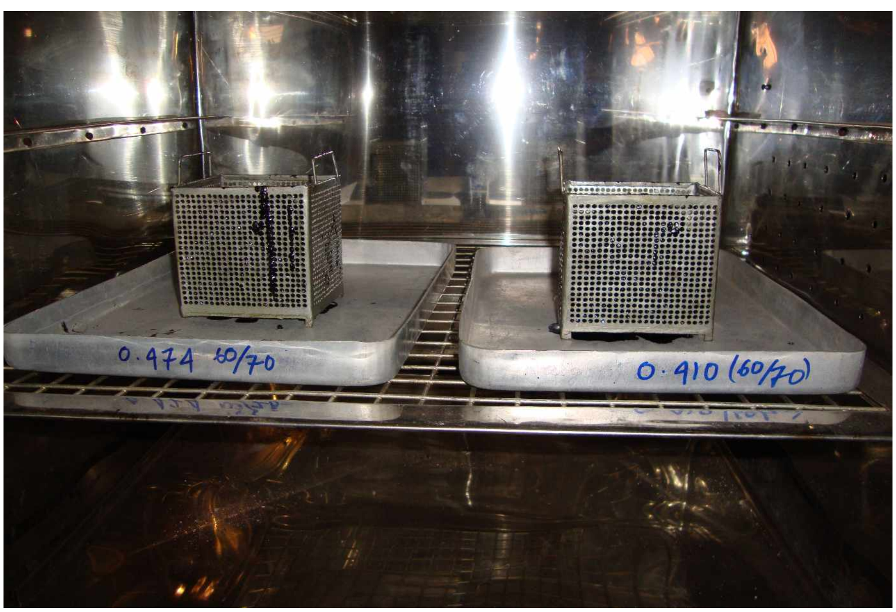


Fig. 3.3 Drainage baskets kept in oven at 150°C

Fig. 3.4 Drainage of 80/100 bitumen sample

Fig. 3.5 Drainage of 60/70 bitumen sample

Fig. 3.6 Drainage of CRMB 60 binder sample

3.4.3 Indirect tensile test

Indirect tensile test is used to determine the indirect tensile strength (ITS) of bituminous mixes. In this test, a compressive load is applied on a cylindrical specimen (Marshall Sample) along a vertical diametrical plane through two curved strips the radius of curvature of which is same as that of the specimen. A uniform tensile stress is developed perpendicular to the direction of applied load and along the same vertical plane causing the specimen to fail by splitting. This test is also otherwise known as splitting test. This test can be carried out both under static and dynamic (repeated) conditions. The static test provides information about the tensile strength, modulus of elasticity and Poisson’s ratio of bituminous mixes. The repeated load test determines the resilient Poisson’s ratio, resilient modulus of elasticity and fatigue life. The repeated load indirect tensile strength test has been used by many researchers to determine the fatigue life characteristics of bituminous mixes. The static indirect tensile strength test has been used to evaluate the effect of moisture on bituminous mixtures.

3.4.3.1 Static Indirect Tensile Test

This test was conducted using the Marshall test apparatus with a deformation rate of 51 mm per minute. A compressive load was applied along the vertical diametrical plane and a proving ring was used to measure the load. A perspex water bath (270 mm × 250 mm × 195 mm) was prepared and used to maintain constant testing temperature. Two loading strips, 13 mm (1/2″) wide, 13 mm deep and 75 mm long, made up of stainless steel were used to transfer the applied load to the specimen. The inside diameter of the strip made was same as that of a Marshall sample (102 mm). Fig. 3.7 shows the static indirect tensile test being carried out on a specimen. Fig. 3.8 shows a close view of the loaded specimen.

The sample was kept in the water bath maintained at the required temperature for minimum 2 hours before test. The perspex water bath maintained at the same test temperature was placed on the bottom plate of the Marshall apparatus. The sample was then kept inside the perspex water bath within the two loading strips. Every care was taken to place the sample centrally along its vertical diametrical plane. A loading rate of 51 mm/minute was adopted. The load was applied and the failure load was noted from the dial gauge of the proving ring. The tensile strength of the specimen was calculated by using the formula given in ASTM D 6931 (2007) and mentioned in Equation 3.2.

$$S_t = \frac{2000 \times P}{\pi \times t \times D} \tag{3.2}$$

where,

S_t = Indirect Tensile Strength, kPa

P = Maximum Load, N

t = Specimen height before testing, mm

D = Specimen Diameter, mm

The test temperature was varied from 5˚C to 40˚C at an increment of 5˚C. In this test three Marshall samples were tested at a particular temperature and the tensile strength was reported as the average of the three test results. Figures 3.9 (i) and (ii) show SMA sample with CRMB 60 binder after static indirect tensile testing at temperatures 10°C and 30°C respectively.

Fig. 3.7 Static indirect tensile test in progress

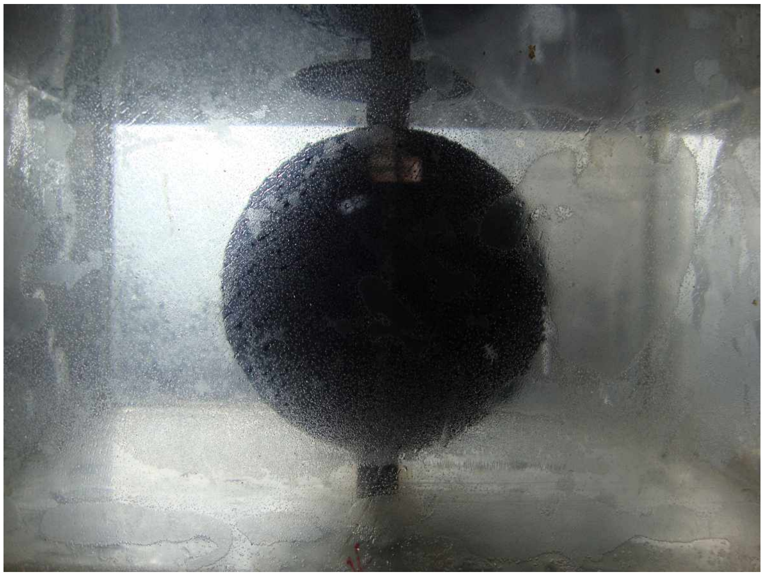


Fig. 3.8 A close view of a loaded sample

(i) Specimen tested at 10°C

(ii) Specimen tested at 30°C

Fig. 3.9 CRMB 60 sample tested in static indirect tensile test

3.4.3.2 Repeated Load Indirect Tensile Test

3.4.3.2.1 Theory of Indirect Tensile Test

This test is similar to the static indirect tensile test in principle where instead of static load a repeated load is applied with a suitable frequency, having appropriate loading time and rest period. Both horizontal and vertical deformations are accurately measured. The resilient modulus of elasticity, resilient Poisson's ratio, tensile stress, tensile strain etc. is computed by using the following equations, equations 3.3 to 3.7.

R Resilient Poisson's ratio, $\mu_R = \frac{3.59 \times H_R}{V_R} - 0.27$ (3.3)

R Resilient Modulus of Elasticity, $M_R = \frac{P(0.27 + \mu_R)}{H_R \times h}$ (3.4)

R Tensile Stress, $\sigma_t = \frac{P_{fail}}{h} \times D_1$ (3.5)

R Initial Tensile Strain, $\varepsilon_i = \frac{(1 + 3\mu_R)\sigma_t}{M_R}$ (3.6)

R Stress Difference, $\Delta\sigma = 4\sigma_t$ (3.7) where, H_R = Horizontal deformation

V_R = Vertical Deformation

P = Repeated Load

h = Height of specimen

D_1 = 0.0061 (a constant)

Fatigue life is the number of load applications to cause failure at a particular stress level for a mix at a particular temperature. Fatigue life was noted directly from the output of the computer software.

3.4.3.2.2 Equipment Description

A repeated load indirect tensile testing machine fabricated in the Highway Engineering Laboratory of National Institute of Technology, Rourkela was used for this purpose. The details of the equipment are given below. The entire set up has been shown schematically in Figure 3.10. It basically consists of the following.

A) Hydraulic system comprising

i) A power pack of 100 lit capacity.

ii) A Double ended single acting cylinder with high speed proportional valve (Four way solenoid valve) with amplifier card of solenoid valve and necessary data acquisition and software to control the cylinder movement at selectable frequency.

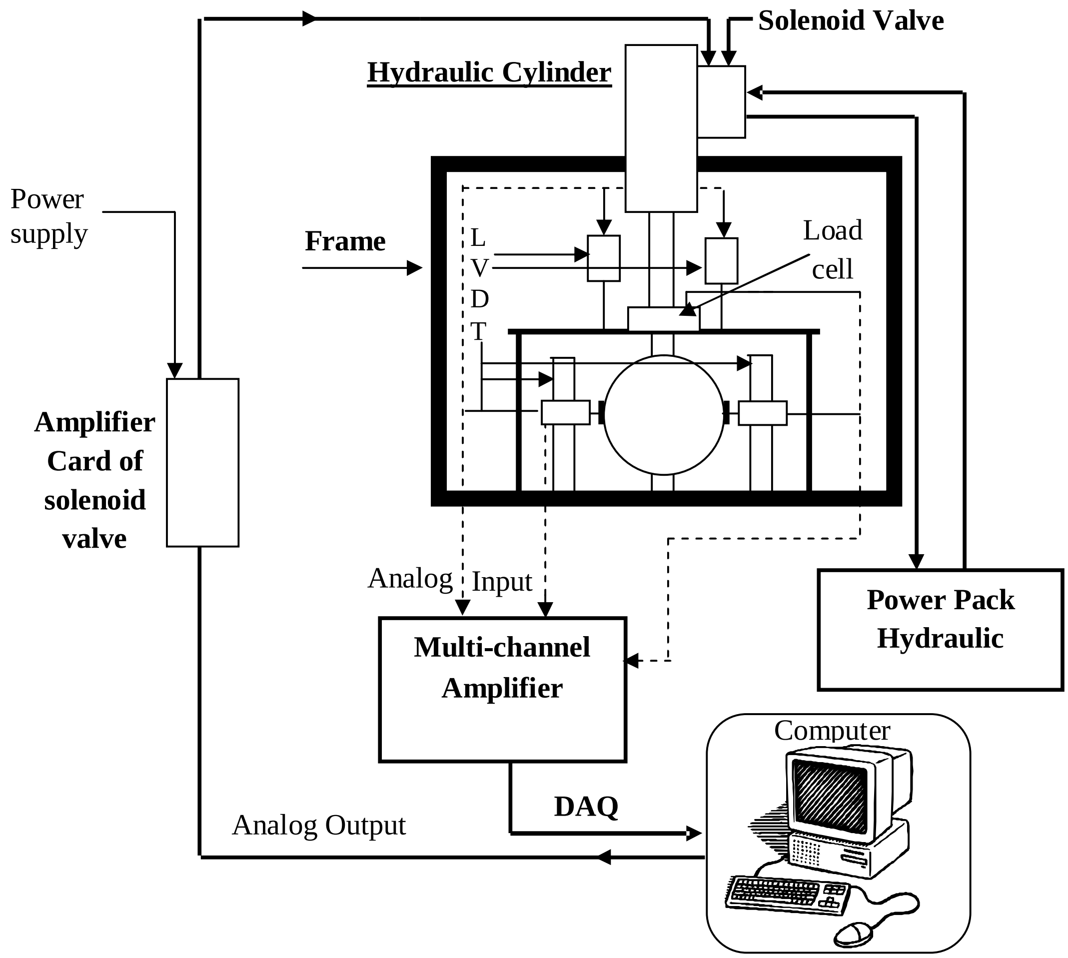


Fig. 3.10 Schematic diagram of repeated load indirect tensile test setup

B) Repeated Load Test Setup as shown in Fig. 3.11, mainly comprises of

(a) a Mechanical Frame:

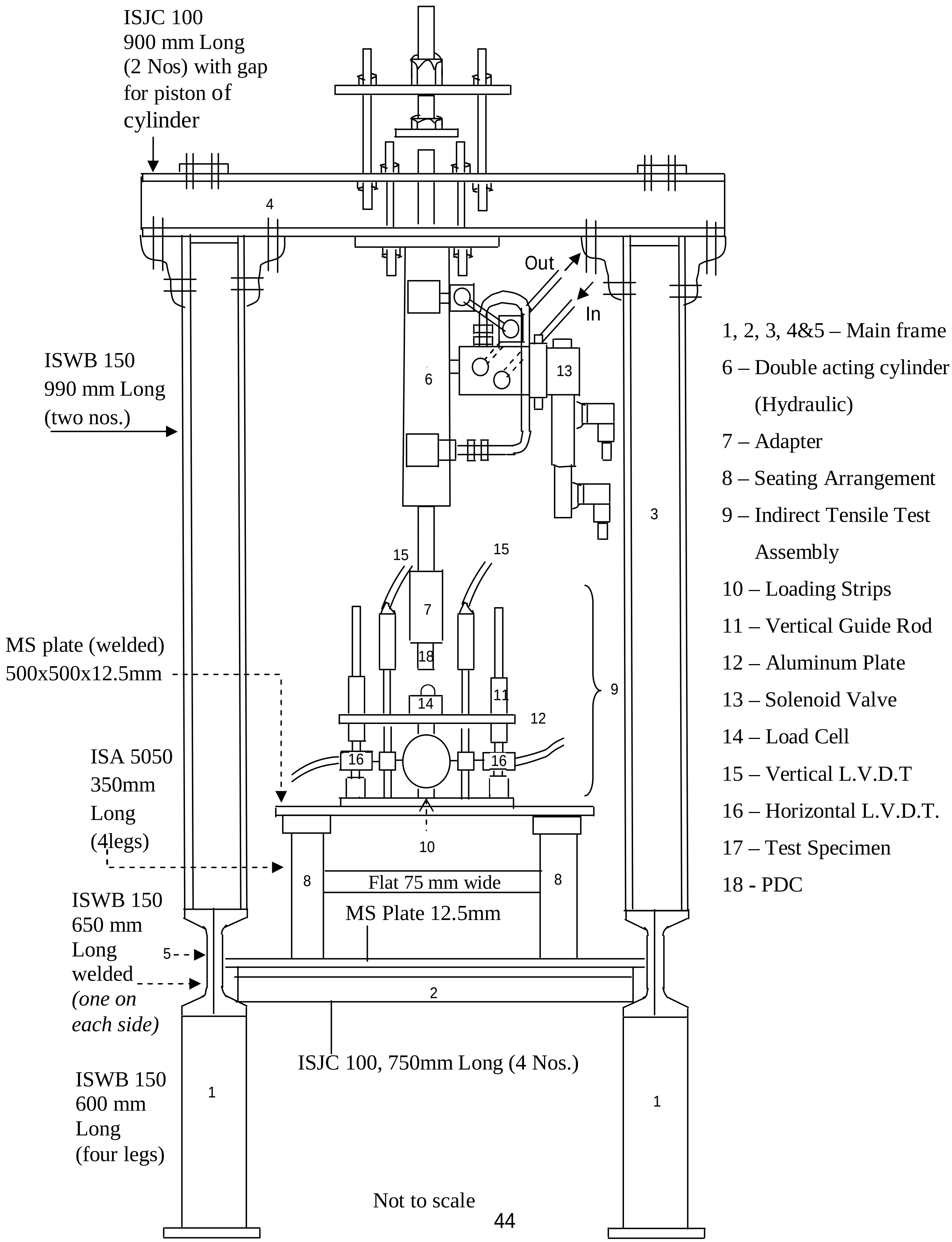


Fig. 3.11 Repeated load test set - up

(b) Seating Arrangement for Indirect Tensile Test: Consisting of an M.S. plate 12.5 mm thick welded to the four legged frame.

(c) Indirect Tensile Test Assembly: As shown in Figure 3.12 has provisions for seating Marshall specimens with appropriate grooves

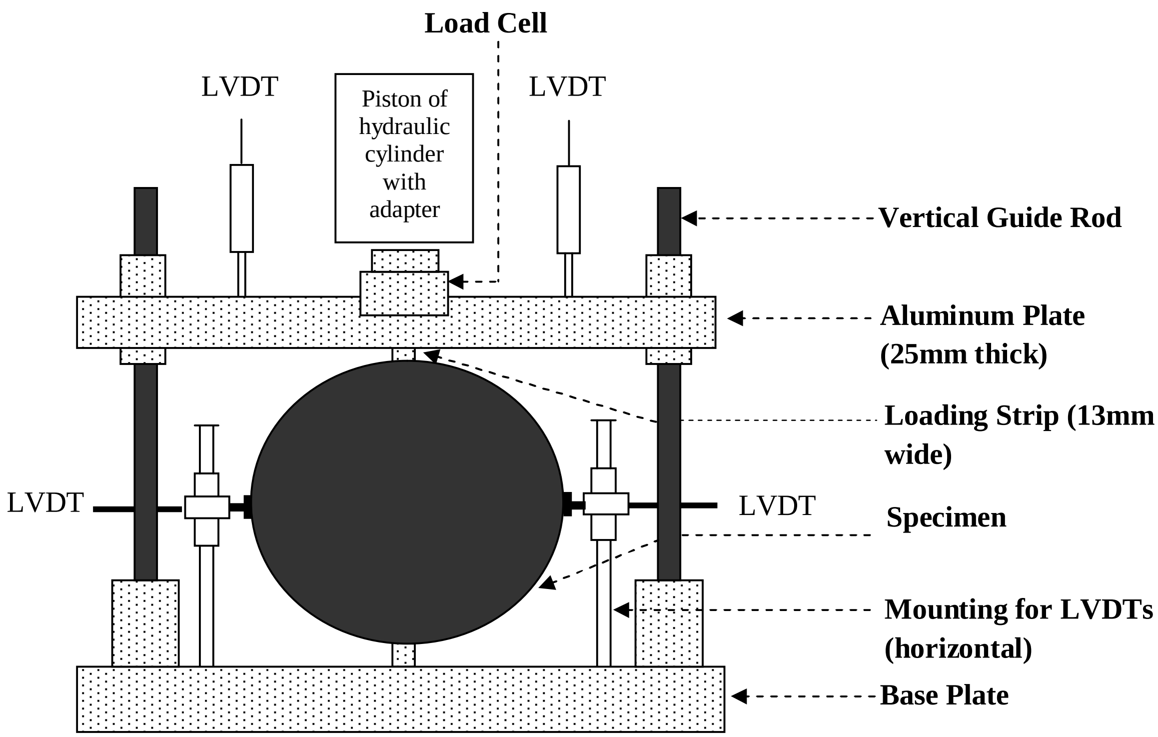


Fig. 3.12 Indirect tensile test assembly

(d) Load and Deformation Measurement Devices

(i) Load Cells: Flat Bottom 51 mm dia (compression type)

(ii) LVDTs for horizontal and vertical deformation measurement

(e) Permanent Deformation Compensator: used to keep the plunger in contact with the load cell during the test

(C) Data Acquisition System

With necessary cards and software installed with a PC to operate the cylinder under controlled stress mode and record all horizontal and vertical measurements.

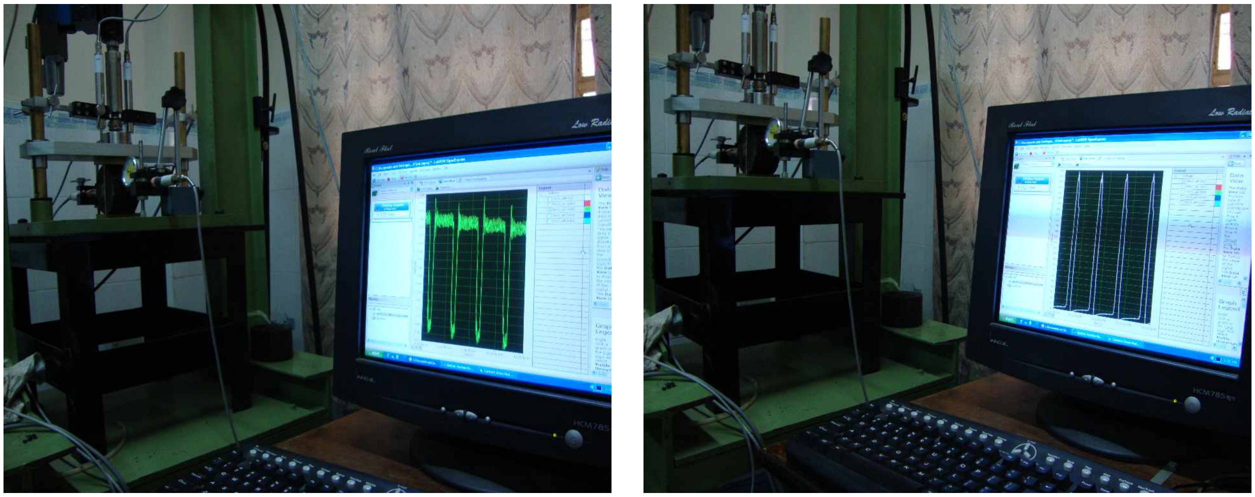
A photograph of this repeated load tensile setup is shown in Figure 3.13.

3.4.3.2.3 Test Procedure

A load cell of 1000 kg was used to measure the repeated load. Two horizontal LVDTs of the range ± 5 mm and two vertical LVDTs of the range ± 10 mm were used to measure the resilient horizontal and vertical deformations respectively. The loading time, rest period and frequency of the load repetitions were maintained using inbuilt software. The tests were conducted in controlled stress mode and the loading time and rest period was set at 0.2 sec and 0.3 sec respectively, which is available at a frequency of 2 hz. The applied repeated load, horizontal deformations and vertical deformations were measured and recorded by using appropriate Data acquisition card and corresponding software. The vertical and horizontal deformations were also at times verified by using sensitive dial gauges having least count of 0.01 mm and 0.001 mm respectively. The initial deformations were recorded during first 50-200 load repetitions. The fatigue testing was done till the specimen failed at a particular load. The testing was done at three different temperatures, 25˚C, 30˚C and 35˚C. The applied load was varied depending on the type of binder and the test temperature. For a particular repeated load, a minimum of three tests were conducted for each mix at a particular temperature. For this test, samples prepared at their OBC and OFC were used. Figure 3.14 shows the close view of the repeated load indirect tensile test set up with an SMA sample loaded in the machine with LVDTs and a load cell. Figure 3.15 shows the repeated load tensile test in progress. Some of the samples tested in indirect tensile test set up are shown in Figure 3.16. Figure 3.17 shows close view of some specimens tested in repeated load indirect tensile test.

Fig. 3.13 A photograph of repeated load indirect tensile test setup

Fig. 3.14 Close view of a loaded sample in repeated load indirect tensile test



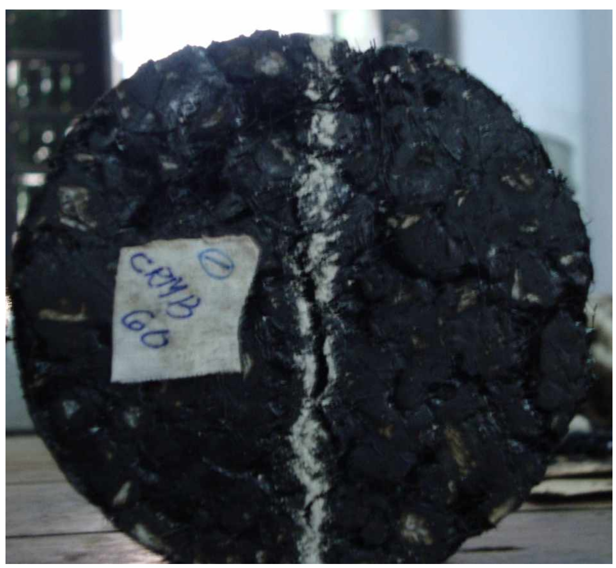
(i) (ii)

Fig. 3.15 Repeated load indirect tensile test in progress

Fig. 3.16 Some of the samples tested in repeated load indirect tensile test

(i) 80/100 bitumen sample

(ii) 60/70 bitumen sample



(iii) CRMB 60 sample

Fig. 3.17 Close view of some specimens tested in repeated load indirect tensile test

3.4.4 Moisture susceptibility test

The presence of moisture in bituminous pavement is a critical factor leading to failure of pavement. Therefore it's very much essential to study the resistance to moisture characteristics of bituminous mixes. There are several methods in which the loss of adhesion of bitumen from aggregates can be studied. However, the following two methods have been used to study the moisture susceptibility characteristics of the SMA mixtures. Both of these tests are used to evaluate the loss of strength of bituminous mixes after being subjected to moisture for a certain period of time.

3.4.4.1 Retained Stability Test

Marshall tests were carried out on SMA samples with fiber and different types of binders, prepared at their OBC and OFC. For a particular mix, a set of three samples were prepared for dry stability test, using normal Marshall procedure as described in section 3.4.1 and similarly a set of three samples were prepared for wet stability test, in which the Marshall samples were cured in water at 60°C for 24 hours before testing in Marshall test apparatus. The average wet Marshall stability value, expressed as a percentage of average dry Marshall stability value is called the retained stability value.

3.4.4.2 Tensile Strength Ratio Test

Normal static indirect tensile test was carried out on Marshall samples as described in the section 3.4.3.1. The Indirect tensile strength (ITS) test was conducted at 25°C. Tensile strength was computed by using equation 3.2 stated earlier. The similar specimens were placed in the water bath maintained at 60°C for 24 hours and then these samples were kept in a chamber maintained at a temperature 25°C for 2 hours. These conditioned samples were then subjected to indirect tensile strength test and the corresponding tensile strength was computed. For a particular mix, a set of three samples were tested each for conditioned and unconditioned cases and the average of three values was taken. The ratio of tensile strength of conditioned specimen to that of unconditioned specimen expressed as a percentage is known as tensile strength ratio (TSR).

CHAPTER 4

ANALYSIS OF TEST RESULTS AND DISCUSSION

CHAPTER – 4

ANALYSIS OF TEST RESULTS AND DISCUSSION

4.1 Introduction

It is mentioned earlier that three types of binders, namely 80/100 penetration grade bitumen, 60/70 penetration grade bitumen and CRMB 60 grade binder have been used in the SMA mixes with and without coconut fiber in this investigation. The details of the experiments carried out on these SMA mixes are given in the previous chapter. In this chapter the results and observations of the tests conducted are presented, analyzed and discussed. This chapter is divided into five sections. In first section, the results of the Marshall tests carried out on SMA mixes are presented. In second section, the draindown test results carried out on SMA mixes are discussed. The third and fourth sections deal with the results of the static and repeated load indirect tensile test respectively. The last section presents the moisture susceptibility test results.

4.2 Marshall Properties

Marshall samples were prepared using SMA mixes with different binders, varying the binder and fiber concentrations, as described in Chapter 3. In this chapter, the results of the Marshall tests carried out on these mixes are presented and discussed.

4.2.1 Effect of binder type, binder content and fiber content on Marshall properties

For each type of binder, its concentration and fiber concentration in mixes were varied to study the effects on Marshall properties. Three types of binders, namely 80/100 and 60/70 conventional penetration grade bitumen and CRMB 60 binder as well were used in varying proportions to make a comparative study. The results thus obtained are analyzed below.

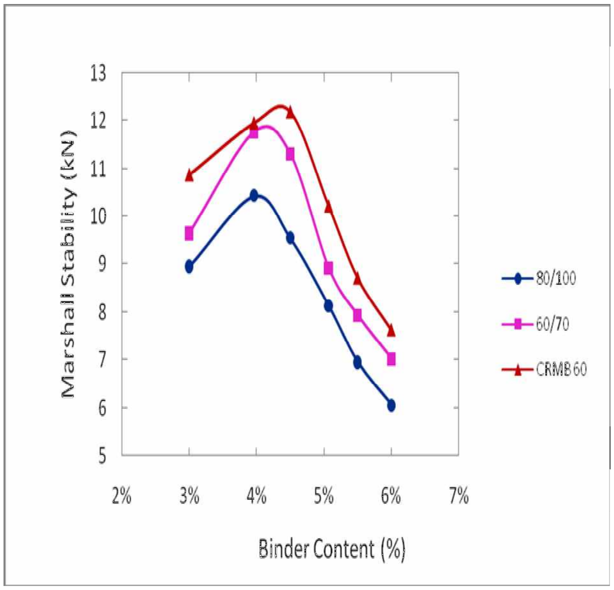
4.2.1.1 Marshall Stability

Figures 4.1 (i), (ii), (iii) and (iv) show the variation of Marshall stability value with binder content for the three binder types at fiber concentrations of 0%, 0.3%, 0.5% and 0.7% respectively. The binder content in the mix was varied from 3% to 7% by weight. It can be observed from the above figures that, with increase in binder content the stability value increases up-to a certain binder content then decreases as per the normal trend for a bituminous mix. It is observed that the stability value in general increases with the hardness (in terms of penetration value) of the binder. For example at a particular fiber content, the samples prepared with 80/100 bitumen result the least stability values and that with CRMB 60 has the highest stability value. This is because with higher viscous binders the interlocking between aggregates with thicker void packing is better retained. It can also be observed that, when a stiffer binder is used more binder content is required to attain the maximum stability value. This may be due to the fact that the higher viscosity of the binder requires more amount in its voids as its draindown effect is less.

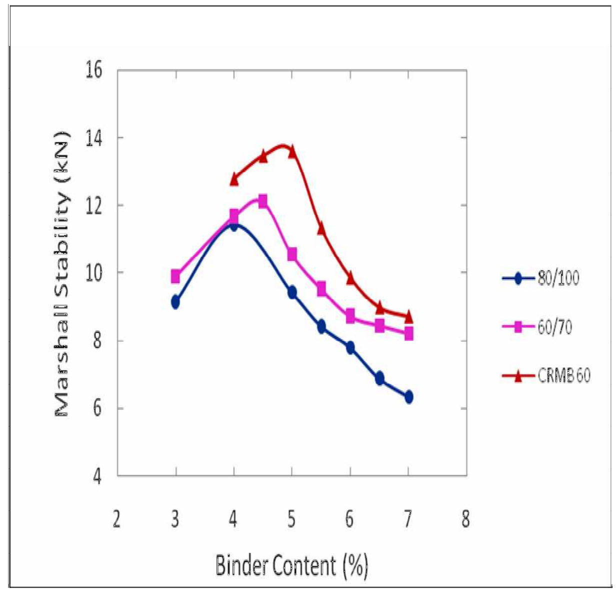
It is observed that with increase in fiber content the stability value increases up to 0.5% fiber, thereafter decreases. This is due to the fact that at higher percentage of fiber homogeneous mixing of the fiber materials is not possible and this results conglomeration of fibers. Such a heterogeneous mixture affects the aggregate-binder bonding and interlocking between the aggregates resulting in low stability value. It can be observed from these plots that the maximum stability value without fibers in the mix is even more than the stability value with 0.7% fiber in the mix. This trend is followed in case of all the three types of binders.

Table 4.1 presents the maximum stability value for different binders at different fiber percentages in the mix and their corresponding binder requirement. For example, for mixes prepared with 80/100 bitumen, without fiber and with 0.3% fiber content the maximum stability value is obtained at 4% binder content and for the mixes with 0.5% fiber and 0.7% fiber the maximum stability value is obtained at 4.5% binder content.

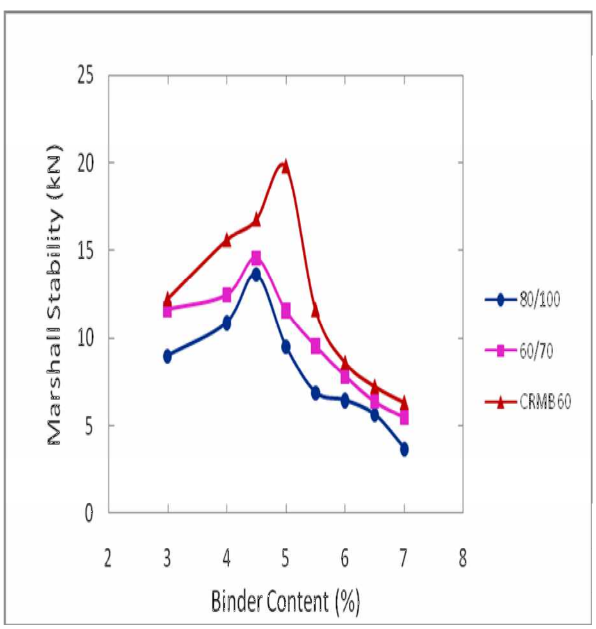
The results of the above Marshall tests have been represented in a different way in Figures 4.2 (i) to (iii).



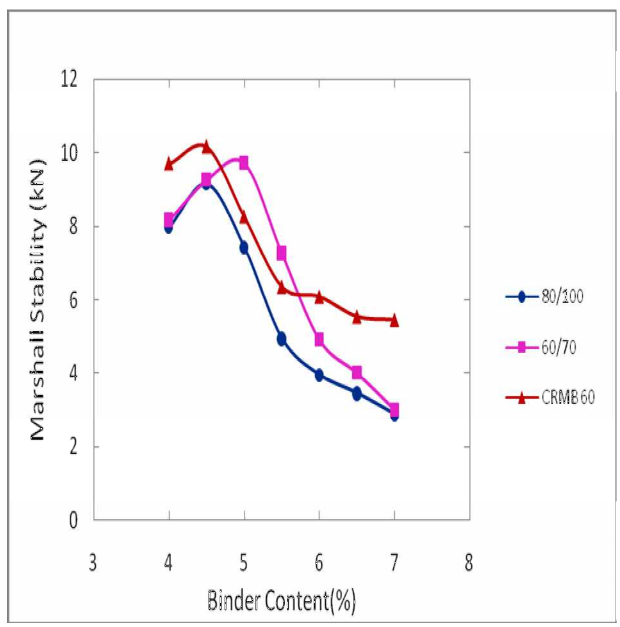
(i) 0% Fiber



(ii) 0.3% Fiber

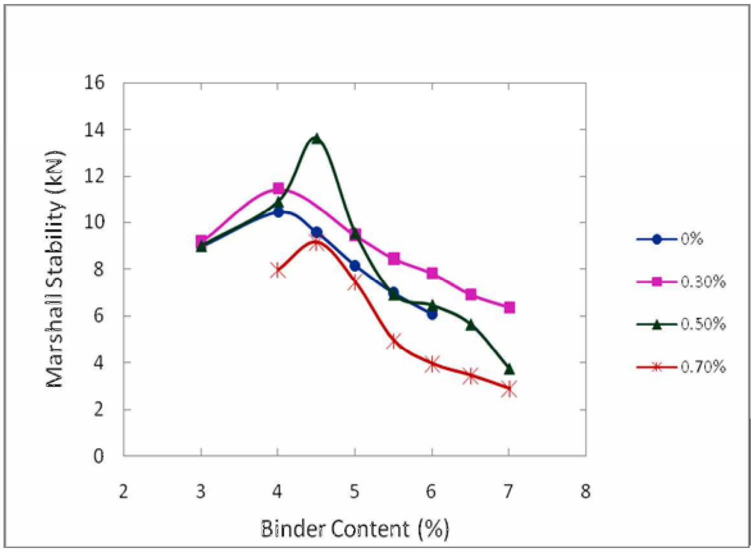


(iii) 0.5% Fiber

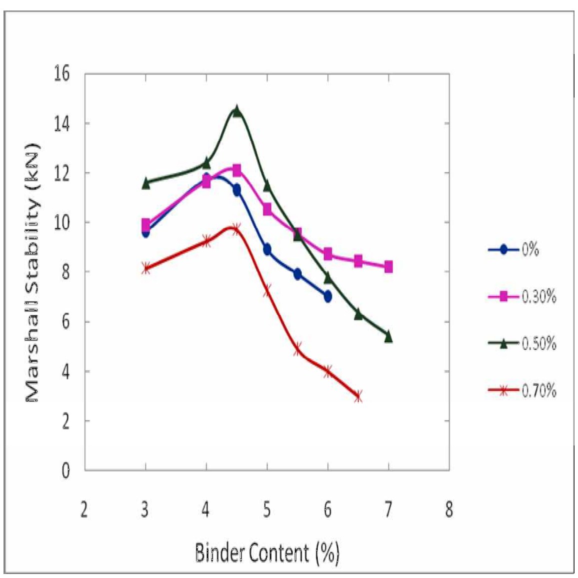


(iv) 0.7% Fiber

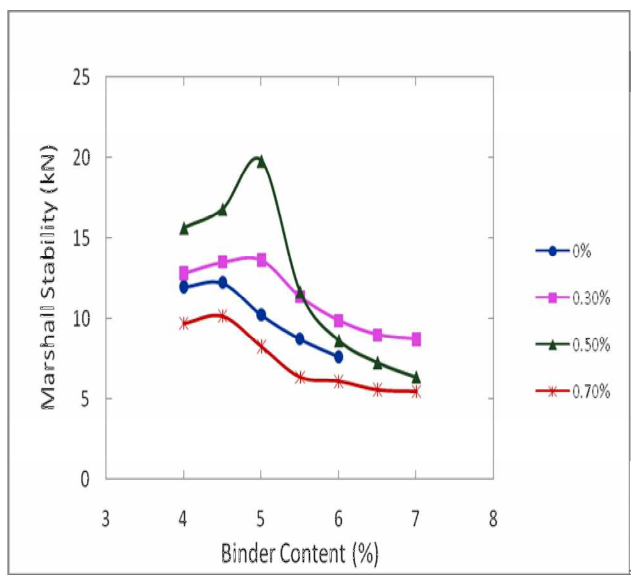
Fig. 4.1 Variation of Marshall stability value with binder content for different binders



(i) 80/100 Bitumen



(ii) 60/70 Bitumen



(iii) CRMB 60 Binder

Fig. 4.2 Variation of Marshall stability value with binder content for different fiber concentrations in the mix

Table 4.1 Maximum Marshall stability values and their corresponding binder content

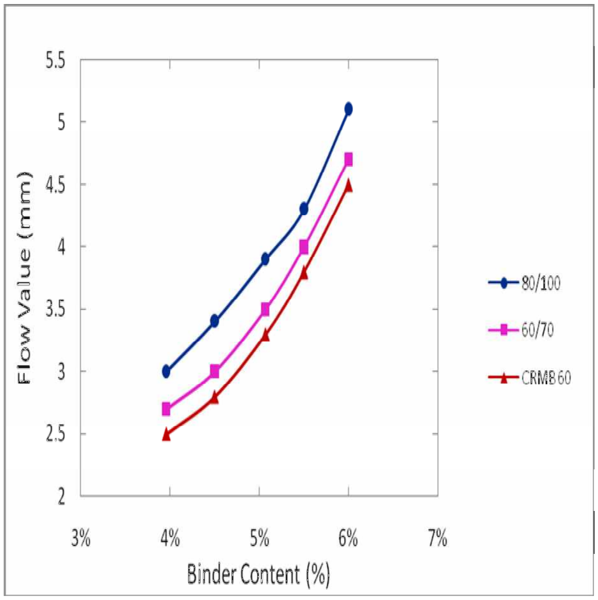
Fiber Content (%) / Binder Type	0%		0.3%		0.5%		0.7%	
	Max. Stability (kN)	Binder Content (%)	Max. Stability (kN)	Binder Content (%)	Max. Stability (kN)	Binder Content (%)	Max. Stability (kN)	Binder Content (%)
80/100 Bit.	10.42	4%	11.43	4%	13.61	4.5%	9.16	4.5%
60/70 Bit.	11.75	4%	12.09	4.5%	14.52	4.5%	9.71	5%
CRMB 60	12.19	4.5%	13.61	5%	19.78	5%	10.16	4.5%

4.2.1.2 Flow Value

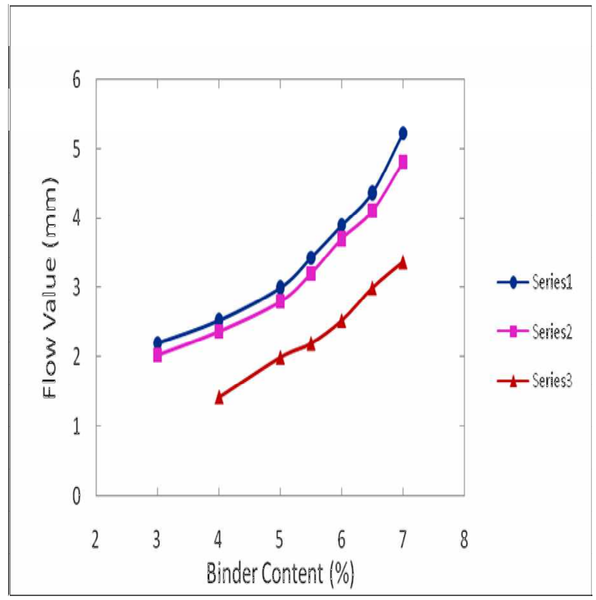
The variation of flow value with binder content for SMA mixes with different binders i.e. 80/100 and 60/70 bitumen and CRMB 60 binder at different fiber contents are shown in Figures 4.3 (i) to (iv). It can be observed that as per the normal trend, the flow value increases with increase in binder content and decreases with increase in stiffness of the binder. It can be clearly seen that for mixes without fiber the decrease in flow value with increase in stiffness of binder types is almost constant. It is observed that for 0.5% fiber content, at higher binder content mixes with 60/70 bitumen has higher flow value than that of 80/100 bitumen. Mixes with 0.7% fiber has higher flow value than that of other mixes. This may be due to result of a heterogeneous mix with fibers forming lumps and causing the increase in deformations under load. Generally a flow value of 2 mm to 4 mm is recommended for SMA mixes. Table 4.2 gives the binder content requirement of different SMA mixes for a flow value of 3 mm, the average of the recommended range.

Table 4.2 Binder Content (%) for 3 mm flow value for different mixes

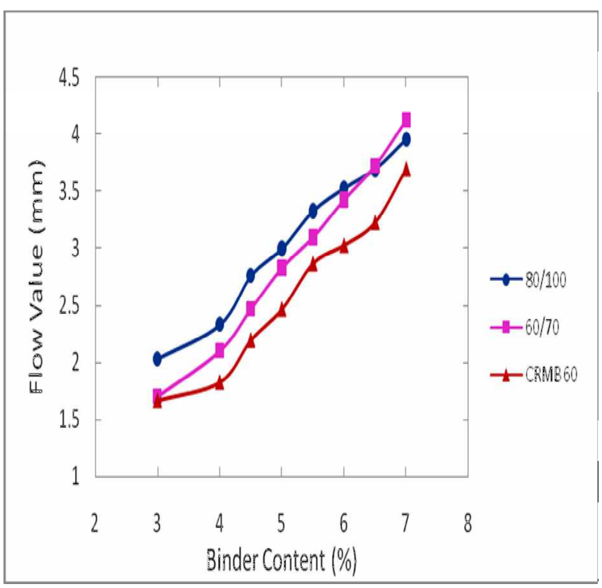
Fiber Content (%) / Type of Binder	0	0.3	0.5
80/100 Bit.	4	5	5
60/70 Bit.	4.5	5.3	5.4
CRMB 60	4.7	6.5	6



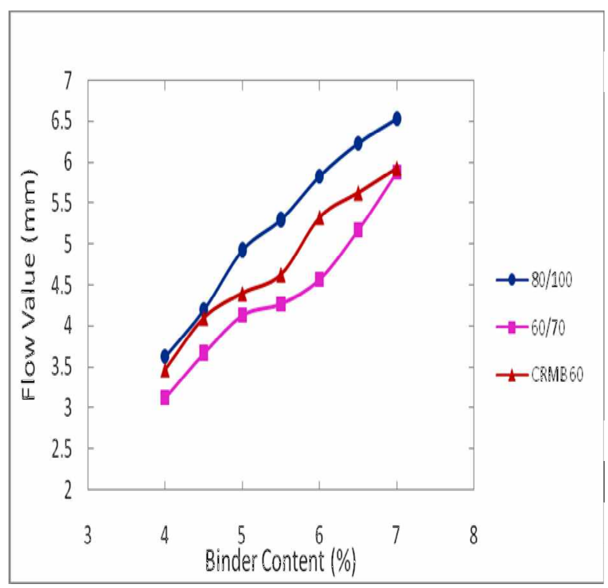
(i) 0% Fiber



(ii) 0.3% Fiber

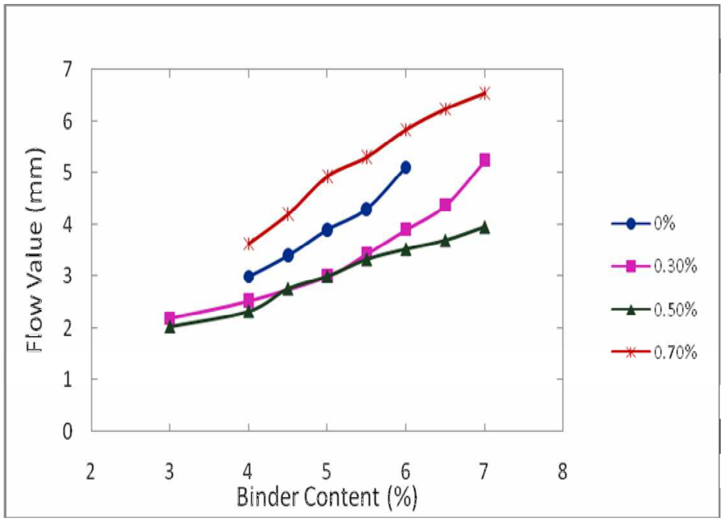


(iii) 0.5% Fiber

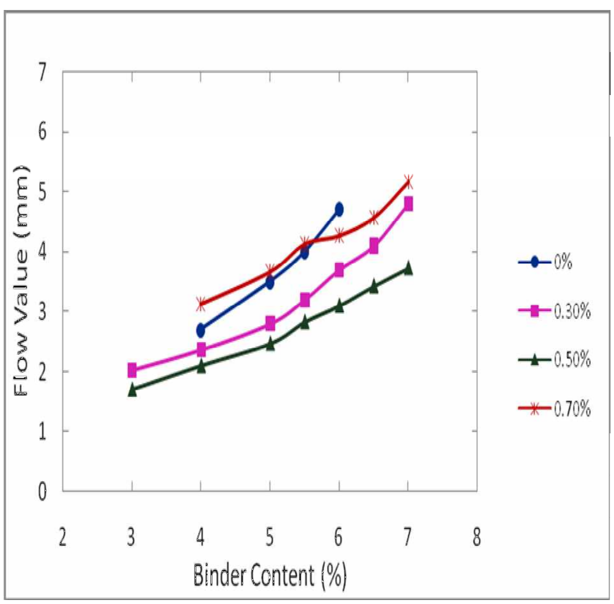


(iv) 0.7% Fiber

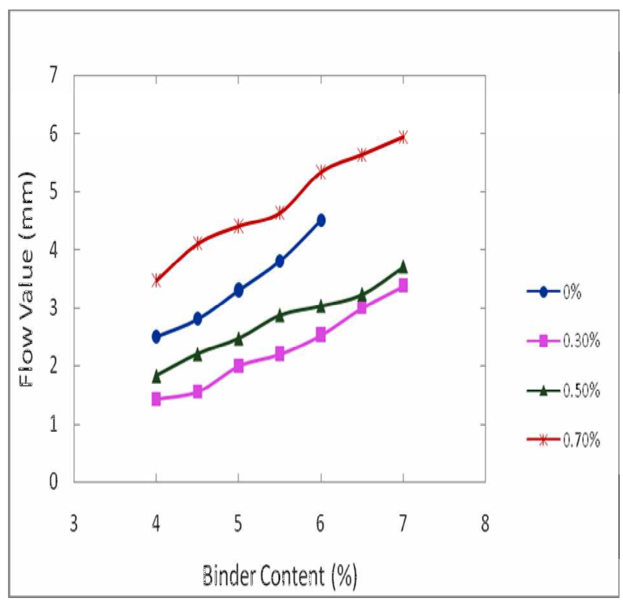
Fig. 4.3 Variation of flow value with binder content for different binders



(i) 80/100 Bitumen



(ii) 60/70 Bitumen



(iii) CRMB 60 Binder

Fig. 4.4 Variation of flow value with binder content at different fiber contents

Figures 4.4 (i), (ii) and (iii) presents the variation of flow value with binder content for variation in fiber contents of different SMA mixtures with 80/100 and 60/70 bitumen and CRMB 60 binder respectively. It is clearly observed from the above plots that the flow value decreases with increase in fiber concentration up to 0.5% but further addition of fiber in the mix increases its flow value. In case of 80/100 bitumen there is a significant decrease in flow value with increase in fiber content up-to 0.3% and thereafter the decrease is quite less with fiber content increased to 0.5%. The mixes with 0.7% fiber has flow value much higher compared to that of mixes without fiber. For 60/70 bitumen the decrease in flow value is also quite less when the fiber concentration increases. The decrease is almost constant in case of mixes with CRMB 60 binder.

4.2.1.3 Unit Weight

Figures 4.5 (i), (ii), (iii) and (iv) present the variations of unit weight with binder content for different types of binder for SMA mixes with the selected fiber content such as 0% , 0.3%, 0.5% and 0.7% respectively. The normal trend of bituminous mix for variation of unit weight is also observed for the SMA mixes, i.e. it increases up-to a certain value with increase in binder content and then decreases. The unit weight is observed to decrease with the increase in hardness of the binder, i.e. mixes with 80/100 bitumen have the highest unit weight, followed by 60/70 bitumen and CRMB 60 binder. It is also observed that for maximum unit weight the SMA mixes with stiffer binder require more binder. For example, for mixes with 0.3% fiber and with 80/100 and 60/70 bitumen the maximum unit weight is obtained at 4% binder content, whereas for CRMB 60 binder it is attained at 5% binder content. Table 4.3 summarizes the binder requirement for maximum unit weight of various SMA mixes tried.

Table 4.3 Binder Requirement (%) of mix for Maximum Unit Weight

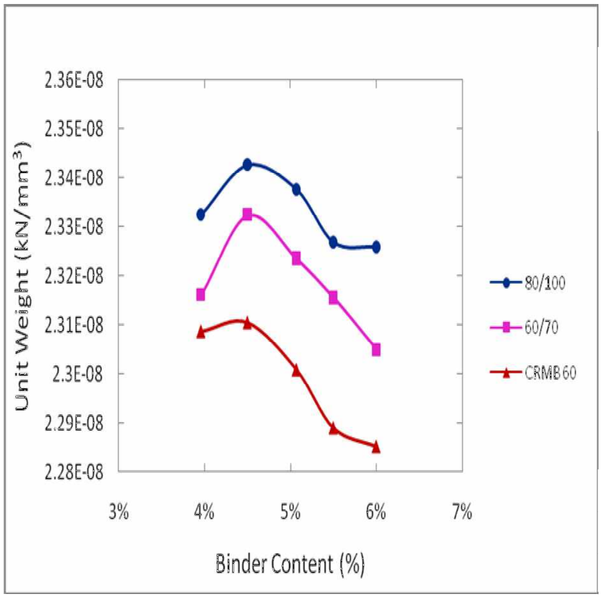
Fiber Content (%) / Binder Type	0	0.3	0.5	0.7
80/100 Bit.	4.5	4	4.5	4.5
60/70 Bit.	4.5	4.4	5	4.5
CRMB 60	4.5	5	5	5

The variation of unit weight with binder content for SMA mixes with different fiber concentrations for different binder types have been shown in Figures 4.6 (i), (ii) and (iii). It can be observerd from the graphs that when 0.3% of fiber is added to the mix its unit weight increases but further addition of fiber lowers the unit weight value of the mix. This type of behaviour may be because of the fact that at 0.3% fiber content in the mixture, the mixing can be done easily and uniformly and the voids get filled properly, but at higher fiber content there are high air voids in the mix due to improper and non-uniform mixing, so the unit weight decreases. This trend is observed in case of all three types of binders.

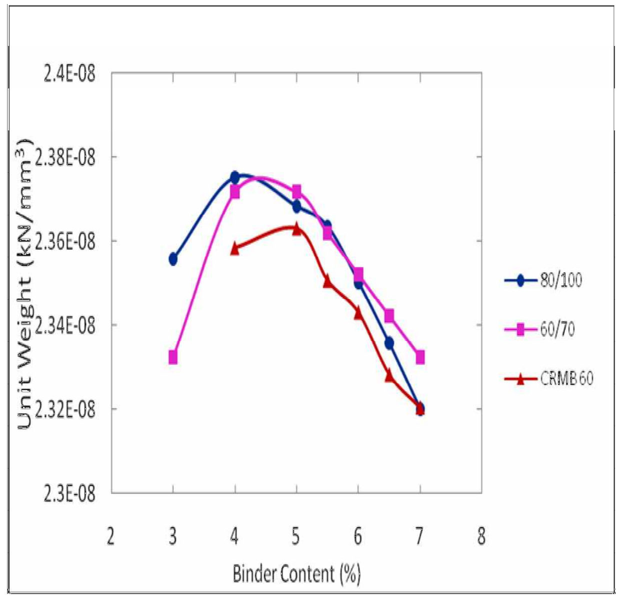
4.2.1.4 Air Voids

Figures 4.7 (i) to (iv) give the variations in air voids value with binder content for different SMA mixes with different binder types. It is observed that like other Marshall properties this variation is similar to conventional bituminous mixes, i.e. percentage air voids decrease with increase in binder content. It can also be observed that with increase in hardness of binder the air voids increase or decrease depending on the percentage of fiber content in the mix. For the mixes without fiber, 80/100 bitumen offers the lowest air voids, followed by 60/70 bitumen and CRMB 60 binder. When 0.3% fiber is added to the mix, the difference in air voids for the mix with 80/100 and 60/70 bitumen is quite less. The mixes with CRMB 60 binder result highest amount of air voids.

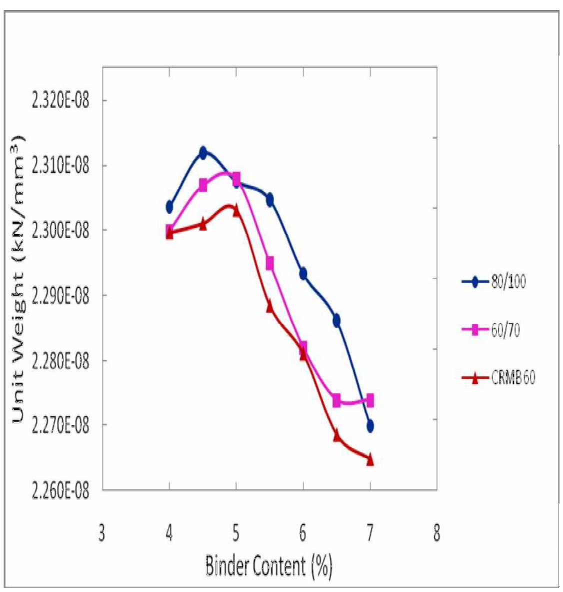
The variation of air void value with binder content at different fiber concentrations for mixes with 80/100 bitumen, 60/70 bitumen, and CRMB 60 binder are shown in Figures 4.8 (i), (ii), and (iii) respectively. Considering a particular binder, the mix has the lowest air voids at 0.3% fiber content and highest air voids at 0.7% fiber content. The amount of air voids is recommended to be 2-4% for SMA mixes (MORTH, 2001). The mixes with 0.7% fiber do not satisfy this criterion at all.



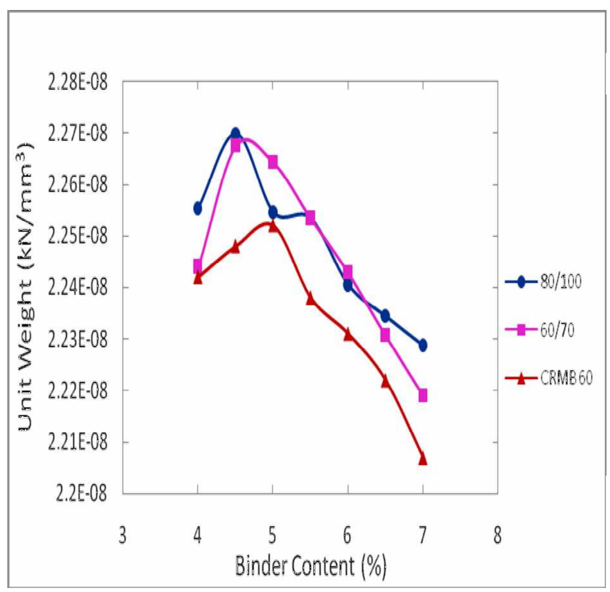
(i) 0% Fiber



(ii) 0.3% Fiber

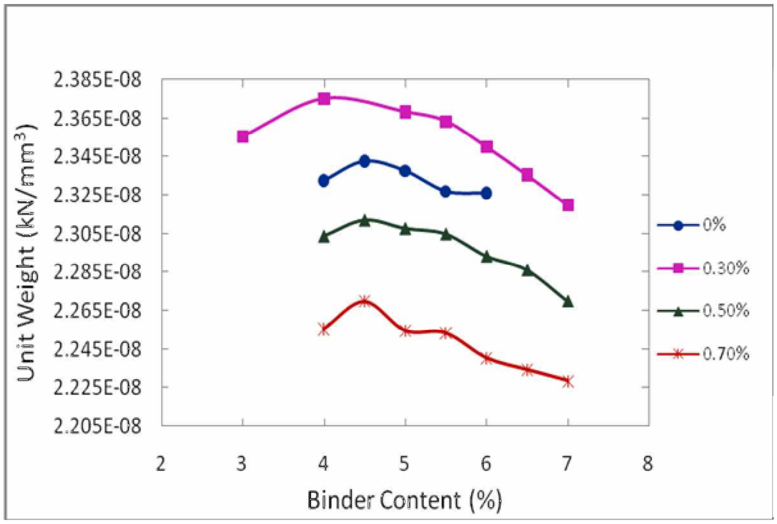


(iii) 0.5% Fiber

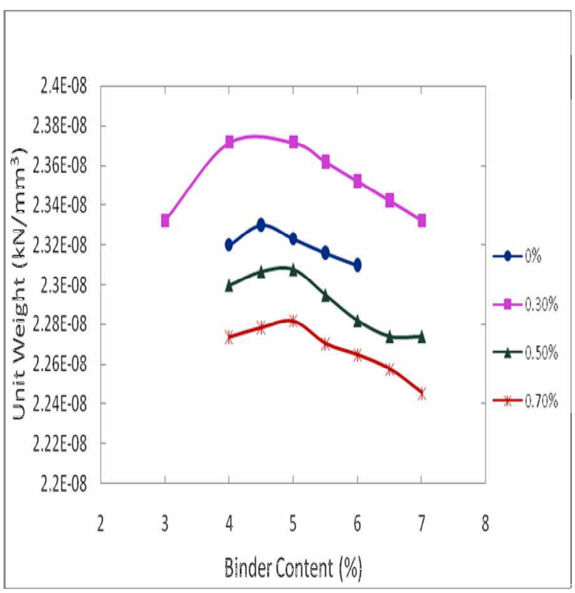


(iv) 0.7% Fiber

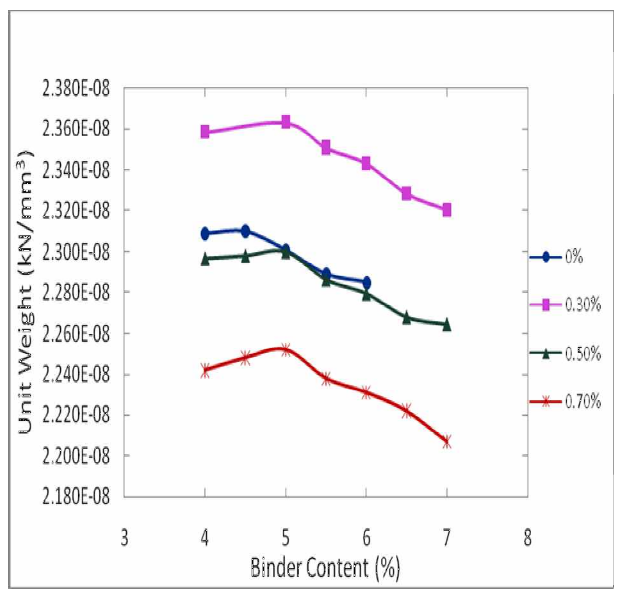
Fig. 4.5 Variation of unit weight with binder content for various binders



(i) 80/100 Bitumen

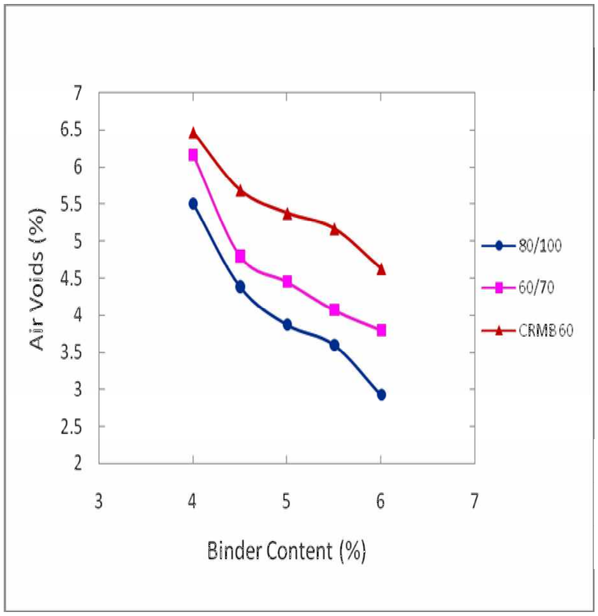


(ii) 60/70 Bitumen

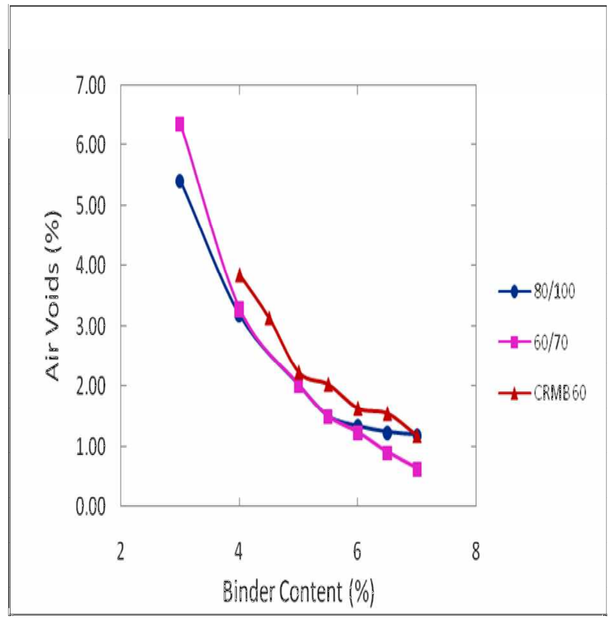


(iii) CRMB 60 Binder

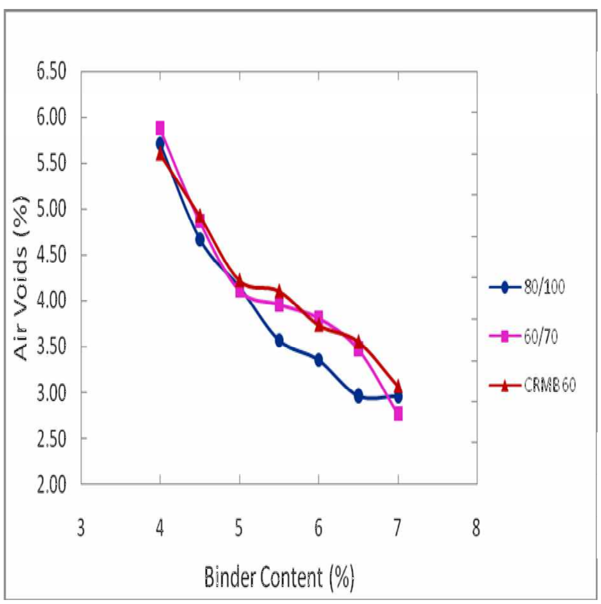
Fig. 4.6 Variation of unit weight with binder content for different fiber contents



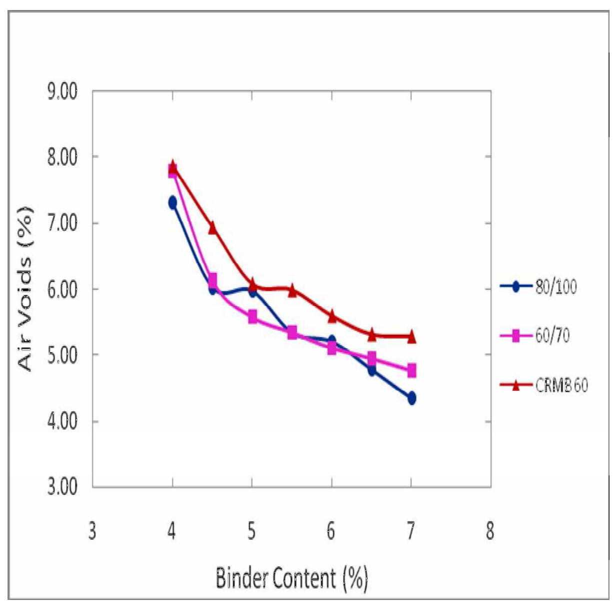
(i) 0% Fiber



(ii) 0.3% Fiber

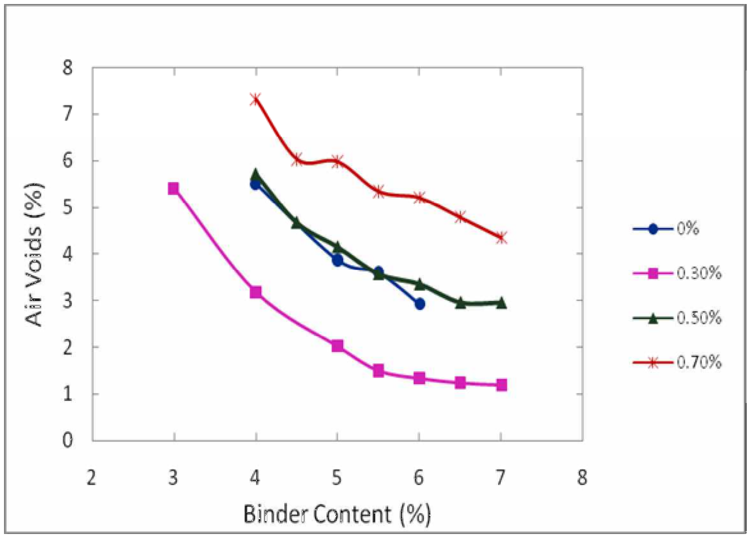


(iii) 0.5% Fiber

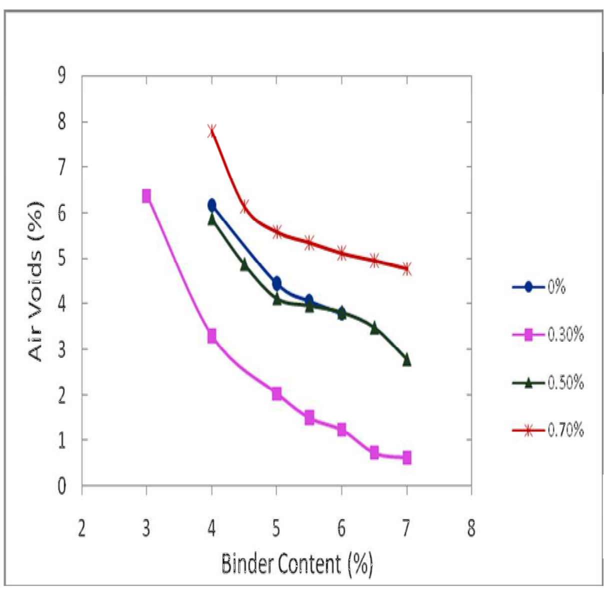


(iv) 0.7% Fiber

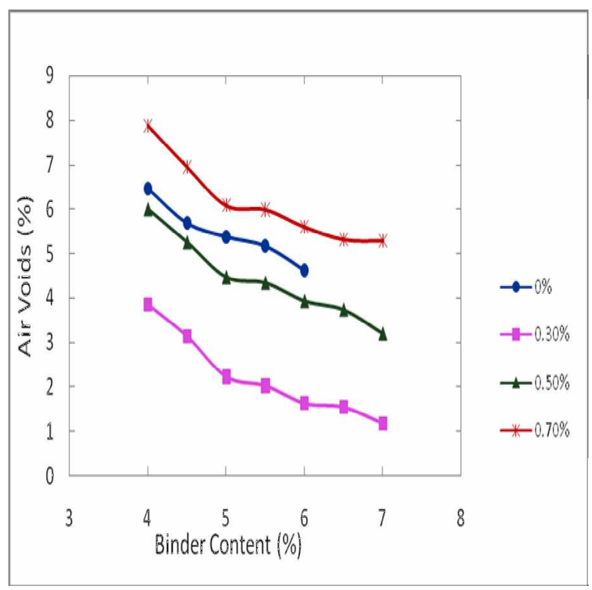
Fig. 4.7 Variation of air voids with binder content for various binders



(i) 80/100 Bitumen



(ii) 60/70 Bitumen



(iii) CRMB 60 Binder

Fig. 4.8 Variation of air voids with binder content for different fiber contents

4.2.2 Optimum binder content

In general, for bituminous concrete mixes the optimum binder content is decided on basis of three factors, i.e. maximum Marshall stability value, maximum unit weight and 4% air voids. But the SMA mixes are gap graded and the stability mainly relies on stone to stone contact in the matrix. Therefore, in this case the parameters like Marshall stability value or flow value may not be the suitable factor for deciding the optimum binder content of SMA mixes. It is suggested by the MORTH that at the target composition the air voids should be within the range 2-4%. So, the optimum binder content (OBC) of the present SMA mixes was decided to be estimated based on 3% air voids in the mix. Table 4.4 presents the binder requirement of different SMA mixes resulting 3% air voids.

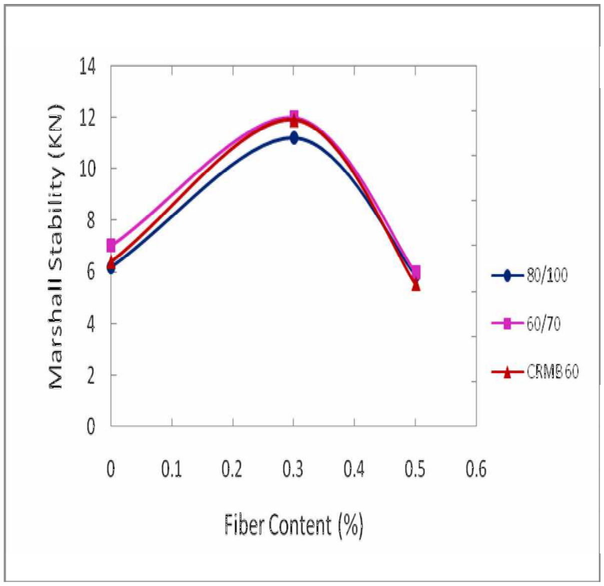
Table 4.4 Binder Requirement (%) for 3% air voids in the mix

Fiber Content (%) / Type of Binder	0	0.3	0.5	0.7
80/100 Bit.	5.9	4.2	6.4	-
60/70 Bit.	6	4.2	6.8	-
CRMB 60	6.5	4.6	7	-

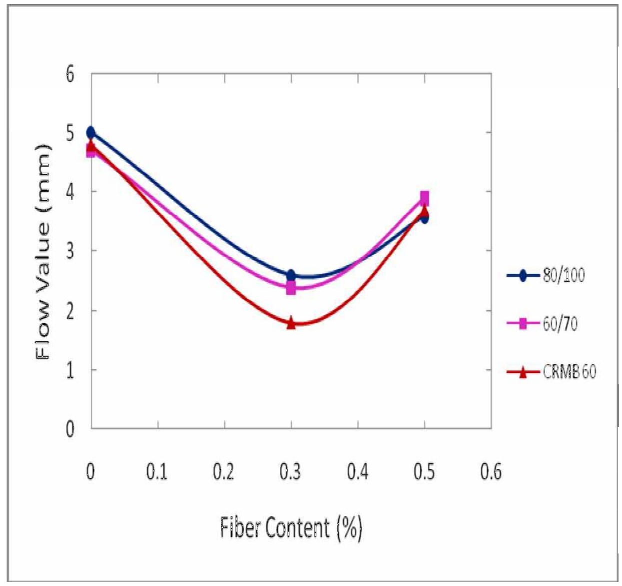
It can be seen that for all types of binders, the mixes with 0.7% fiber content do not satisfy the prescribed criteria for air voids. So, those mixes were not considered while estimating optimum fiber content. It is seen that the optimum binder content is normally higher for harder grade of binder used and higher fiber concentration in the mix for a particular binder.

4.2.3 Marshall properties at OBC

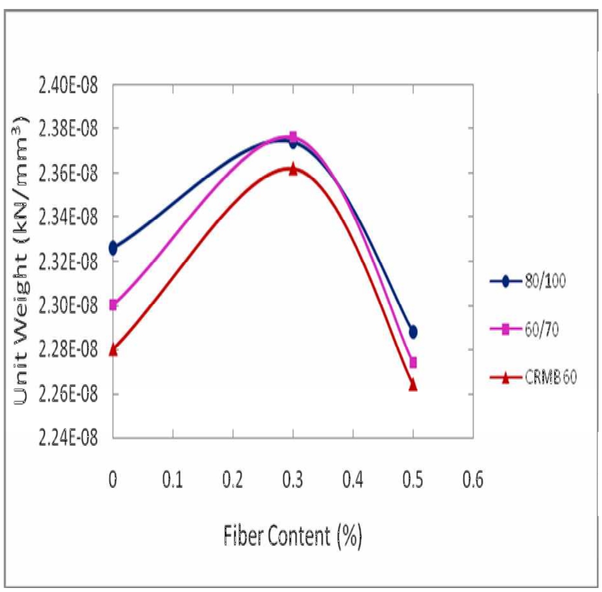
The Marshall properties such as Marshall stability, flow value and unit weight of different SMA mixes at their optimum binder contents for all types of mixes are shown in Figures 4.9 (i), (ii) and (iii) respectively. Fig. 4.9 (iv) presents the optimum binder requirement of SMA mixes at different fiber contents. It is observed that for all the mixes at their OBC the stability value and unit weight value increase with addition of 0.3% fiber, but with further addition of fiber they decrease. Similarly, mixes with 0.3% fiber concentration has the least flow value at OBC. The optimum binder content percentage is also the least in case of these mixes. Therefore, the optimum fiber content (OFC) was decided to be 0.3% for mixes with all the three types of binders. For further experiments the mixes were prepared at their OBC and OFC.



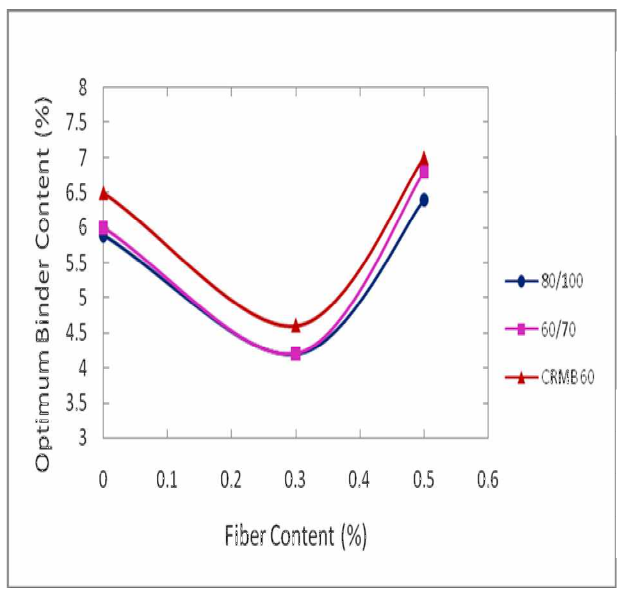
(i) Marshall Stability at OBC



(ii) Flow Value at OBC



(iii) Unit Weight at OBC



(iv) OBC at different Fiber Contents

Fig. 4.9 Marshall properties of mixes at their OBC

4.3 Draindown Characteristics

SMA mixes are rich in binder, which provides durability to the mix. A major problem that has been observed with SMA mixes is draindown of the binder resulting in bleeding and formation of fat spots. Therefore the draindown characteristics of the SMA mixes prepared at their OBC and OFC were verified using the MORTH (2001) specifications as described in chapter 3. In this part, the results of the draindown tests are discussed.

4.3.1 Draindown of mixes without fiber

Table 4.5 gives the results of the draindown tests carraied out on mixes without fiber and with three different types of binder and estimated by using Equation 3.1. It can be observed from the results that for SMA mixes with 80/100 and 60/70 bitumen the draindown is 0.01% and 0.005% respectively. For mixes with CRMB 60 binder negligible draindown was observed and hence not mentioned in this table.

Table 4.5 Draindown of mixes without fiber

Type of Binder used in the mix	Draindown (%)	Average (%)
80/100 Bit.	0.01	0.01
	0.01	
	0.011	
60/70 Bit.	0.005	0.005
	0.005	
	0.005	

4.3.2 Draindown of mixes with fiber

When SMA mixes with coconut fiber prepared at their OBC and OFC were subjected to MORTH drainage test no draindown of binder could be observed for any of the mixes. Therefore addition of the fiber improved the draindown characteristics of SMA mixtures.

4.4 Static Indirect Tensile Test

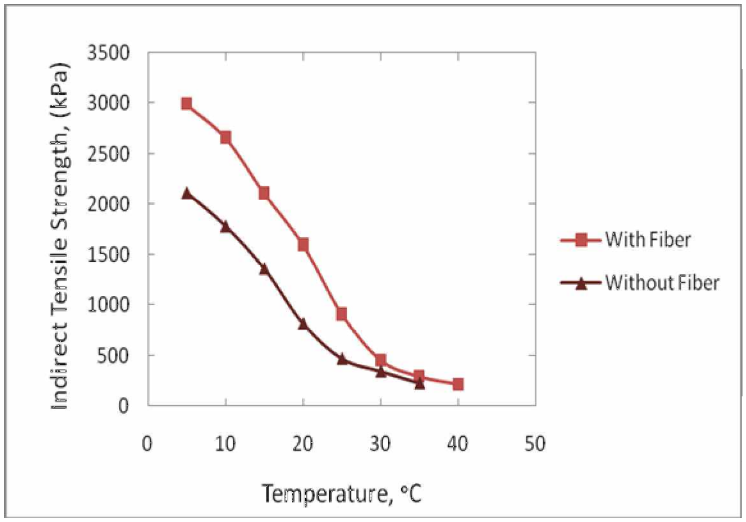
Static indirect tensile test of bituminous mixes measures the indirect tensile strength (ITS) of the mix which helps in assessing the resistance to thermal cracking of a given mix. The stress level up to which a given mix sample can be subjected to repeated load can also be assessed. The static indirect tensile tests were carried out on SMA mixes prepared at their OBC and OFC as described in chapter 3. The effect of temperature on the ITS of SMA mixes with three different types of binder, with and without fiber is also studied. The results of static indirect tensile test are presented and discussed in this section.

4.4.1 Effect of fiber on static indirect tensile strength

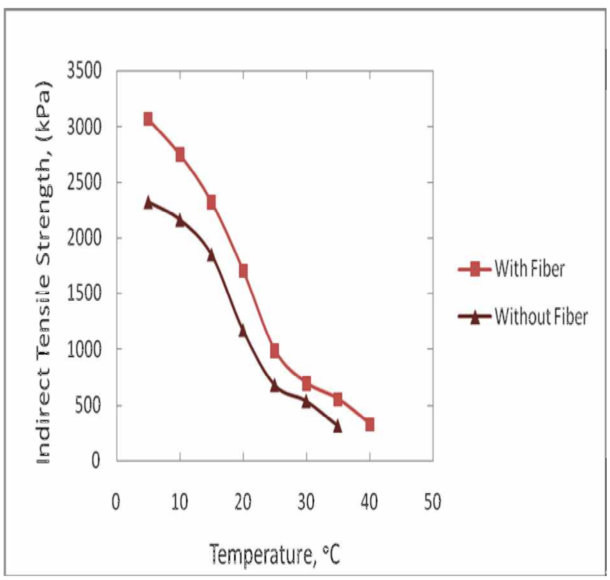
Figures 4.10 (i), (ii) and (iii), show the variations of indirect tensile strength with temperature for mixes with 80/100 and 60/70 bitumen and CRMB 60 binder respectively. It is seen that the ITS value decreases with increase in temperature and for a particular binder, when fiber is added to the mix it increases. This trend is followed in case of all the three types of binders.

4.4.2 Effect of temperature on static indirect tensile strength

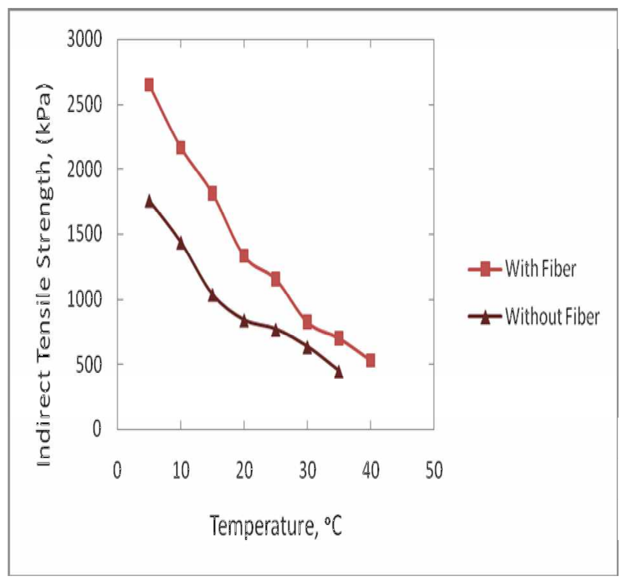
Figures 4.11 and 4.12 show the variations of ITS value with temperature for mixes with and without fiber and with different binders. It is observed that for a particular binder, the ITS value decreases with increase in temperature. At lower temperature, the mixes with 60/70 bitumen has the highest indirect tensile strength followed by the same with 80/100 bitumen and then with CRMB 60 binder. But at higher temperatures, the mixes with CRMB 60 binder have the highest tensile strength as compared to the mixes with other two binders. This is an advantage of using modified binder in bituminous paving mixes.



(i) 80/100 Bitumen



(ii) 60/70 Bitumen



(iii) CRMB 60 Binder

Fig. 4.10 Variation of ITS with temperature for mixes with different binders

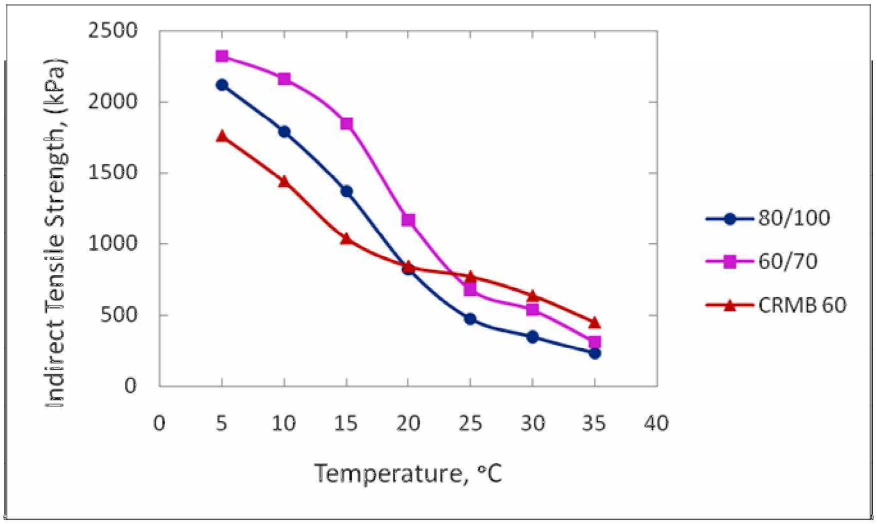


Fig. 4.11 Variation of ITS with temperature for mixes without fiber

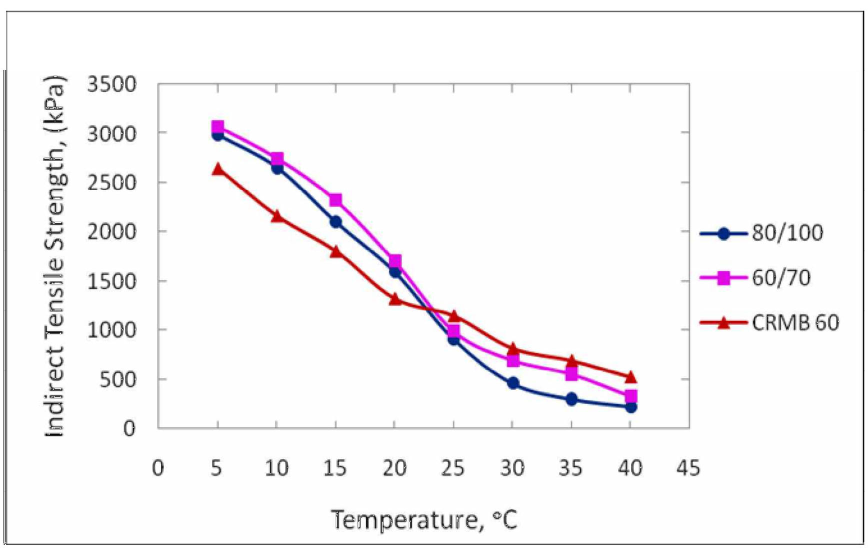


Fig. 4.12 Variation of ITS with temperature for mixes with fiber

4.5 Repeated load Indirect Tensile Test

From the results of the static load tests it is seen that SMA mixes with modified binder CRMB 60 and fiber performs better in terms of Marshall properties and tensile strength as compared to conventional ones. However, the load on pavements due to traffic is mostly repetitive in nature. Considering this fact and to know the fatigue characteristics of SMA mixes, the samples with and without fibers, prepared at their OBC and OFC were tested under repeated load conditions as described in Chapter 3. The parameters studied in this test are the resilient Poisson's ratio (μ_R), resilient modulus of elasticity (M_R) and fatigue life (N_f) at varying stress levels and at three most prevailing temperatures, namely 25°C, 30°C and 35°C. The results of the repeated load tests are presented in this section.

4.5.1 Relationship between resilient modulus and tensile stress

The results of the repeated load tensile tests for different SMA mixes with and without fiber and with three types of binder at three different test temperatures are presented in Tables 4.6 to 4.23. The symbols used in these tables are, P = Repeated Load, h = height of the specimen, H_R = resilient horizontal deformation, V_R = resilient vertical deformation, μ_R = resilient Poisson's ratio, M_R = Resilient Modulus of elasticity, σ_t = tensile stress, ε_i = initial tensile strain, N_f = Fatigue life.

Figures 4.13 (i) to (iii) show the variation of resilient modulus of elasticity with tensile stress for mixes without fibers, and Figures 4.14 (i) to (iii) show the same for mixes with fiber at three different testing temperatures and using 80/100 and 60/70 bitumen and CRMB 60 binder. It can be observed from the figures that with increase in stress level the M_R value decreases. For mixes without fiber the decrease in M_R value with stress level is more as compared to the mixes with fiber. In case of mixes with and without fiber, at a particular temperature and a particular stress level mixes with CRMB 60 binder have the highest M_R value followed by 60/70 bitumen and then 80/100 bitumen. The reason for this type of behaviour may be due to the use of modified binder in the mix, which is harder as compared to the normal penetration grade binders.

Table 4.6 Results of repeated load indirect tensile tests for mixes without fiber and with 80/100 bitumen at 25°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_I, \times 10^5$	N_f, Nos
1883.8	60.5	0.0224	0.117	0.419	957.0	0.190	44.80	1609
1881.1	60.75	0.0220	0.117	0.408	954.2	0.189	44.02	1213
1889.2	60.75	0.0224	0.117	0.420	958.3	0.190	44.73	1566
1682.5	61.25	0.0184	0.099	0.397	996.1	0.168	36.83	1952
1695.9	62.25	0.0184	0.099	0.400	991.4	0.166	36.86	2291
1673.8	60.75	0.0182	0.098	0.395	1009.3	0.168	36.38	2725
1476.4	62.25	0.0145	0.080	0.382	1064.3	0.145	29.19	3179
1482.7	62.5	0.0146	0.080	0.387	1070.4	0.145	29.20	3348
1496.5	62.75	0.0148	0.081	0.391	1063.5	0.145	29.74	3487
1200.5	62.25	0.0103	0.059	0.362	1183.5	0.118	20.74	5841
1177.0	61.75	0.0099	0.057	0.360	1211.1	0.116	19.96	5906
1178.9	61.25	0.0099	0.057	0.356	1217.6	0.117	19.95	6108

Table 4.7 Results of repeated load indirect tensile tests for mixes without fiber and with 80/100 bitumen at 30°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_I, \times 10^5$	N_f, Nos
2110.6	61.25	0.0288	0.148	0.427	833.9	0.210	57.53	385
2058.0	60.25	0.0287	0.149	0.423	825.8	0.208	57.22	412
2077.6	60.75	0.0284	0.147	0.424	835.6	0.209	56.72	459
1557.5	60.25	0.0189	0.099	0.415	939.1	0.158	37.69	1105
1568.0	61.75	0.0191	0.101	0.410	907.1	0.155	38.11	1238
1548.4	60.75	0.0189	0.098	0.426	938.5	0.155	37.73	1098
1477.7	60.5	0.0166	0.089	0.403	987.8	0.149	33.30	1484
1463.1	60.25	0.0165	0.088	0.401	990.7	0.148	32.94	1509
1481.8	61.25	0.0160	0.089	0.379	981.3	0.148	32.14	1723
1160.6	61.25	0.0118	0.064	0.391	1062.1	0.116	23.66	3352
1097.6	60	0.0113	0.061	0.387	1068.7	0.112	22.57	2745
1127.0	60.75	0.0111	0.061	0.389	1100.8	0.113	22.27	3149

Table 4.8 Results of repeated load indirect tensile tests for mixes without fiber and with 80/100 bitumen at 35°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_I, \times 10^5$	N_f, Nos
1687.7	60.5	0.0276	0.140	0.435	714.0	0.1702	54.96	244
1666.0	60	0.0274	0.140	0.431	710.5	0.1694	54.67	289
1675.8	60.25	0.0275	0.141	0.434	710.7	0.1697	54.93	278
1436.6	63.5	0.0200	0.104	0.419	780.0	0.1380	39.91	335
1421.0	63.25	0.0195	0.104	0.403	775.9	0.1370	39.04	387
1430.8	63.75	0.0200	0.104	0.418	774.0	0.1369	39.87	405
1122.4	63	0.0148	0.079	0.403	812.2	0.1087	29.57	872
1097.6	61.25	0.0151	0.081	0.401	799.2	0.1093	30.14	912
1087.8	60.75	0.0149	0.080	0.400	803.5	0.1092	29.92	998
1021.7	60.25	0.0128	0.069	0.395	880.0	0.1034	25.68	2854
999.6	60	0.0127	0.069	0.387	862.4	0.1016	25.48	1758
1009.4	60.25	0.0128	0.069	0.395	870.0	0.1022	25.66	1520

Table 4.9 Results of repeated load indirect tensile tests for mixes without fiber and with 60/70 bitumen at 25°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_I, \times 10^5$	N_f, Nos
1893.6	62	0.0214	0.113	0.411	973.7	0.186	42.71	2820
1881.6	61.25	0.0210	0.113	0.398	976.0	0.187	42.13	3124
1891.4	61.75	0.0209	0.114	0.389	968.8	0.187	41.82	2203
1685.6	61.5	0.0171	0.095	0.376	1038.1	0.167	34.26	3459
1666.0	60.75	0.0170	0.095	0.372	1036.3	0.167	34.18	3320
1674.8	61.25	0.0169	0.094	0.375	1044.3	0.167	33.96	3894
1533.8	61.5	0.0143	0.081	0.361	1099.6	0.152	28.80	5422
1519.0	60.75	0.0141	0.082	0.347	1094.7	0.153	28.45	5874
1538.6	62.25	0.0143	0.082	0.354	1082.1	0.151	28.72	6104
1183.8	62.25	0.0100	0.057	0.355	1194.6	0.116	20.05	7223
1176.0	62	0.0100	0.057	0.357	1189.4	0.116	20.15	6985
1195.6	62.75	0.0100	0.058	0.346	1179.3	0.116	20.08	7337

Table 4.10 Results of repeated load indirect tensile tests for mixes without fiber and with 60/70 bitumen at 30°C

P, N	*h*, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	ε_I, $\times 10^5$	N_f, Nos
2083.4	61.25	0.0260	0.136	0.416	896.8	0.207	52.01	479
2058.0	60.25	0.0250	0.134	0.402	918.5	0.208	50.06	512
2067.8	60.75	0.0261	0.137	0.415	893.6	0.208	52.18	401
1757.1	60.5	0.0204	0.110	0.398	951.1	0.177	40.89	653
1744.4	60.25	0.0203	0.109	0.394	949.7	0.177	40.59	857
1734.6	60	0.0205	0.112	0.390	930.8	0.176	41.11	898
1572.5	61.75	0.0162	0.091	0.370	1007.9	0.155	32.50	1827
1558.2	61	0.0161	0.090	0.369	1014.4	0.156	32.38	1509
1577.8	62.25	0.0162	0.091	0.371	1005.4	0.155	32.48	1203
1176.2	61.5	0.0114	0.064	0.363	1066.2	0.117	22.87	2983
1176.0	61.25	0.0113	0.065	0.359	1068.7	0.117	22.76	3105
1166.2	61	0.0115	0.067	0.348	1032.1	0.117	23.10	3318

Table 4.11 Results of repeated load indirect tensile tests for mixes without fiber and with 60/70 bitumen at 35°C

P, N	*h*, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	ε_I, $\times 10^5$	N_f, Nos
1750.2	63.25	0.0238	0.124	0.421	803.4	0.169	47.55	415
1734.6	62.75	0.0229	0.122	0.407	816.8	0.169	45.83	439
1744.4	63.75	0.0230	0.120	0.421	822.0	0.167	45.95	385
1447.0	60.75	0.0184	0.097	0.411	883.7	0.145	36.70	646
1430.8	60	0.0183	0.098	0.404	878.0	0.145	36.64	751
1440.6	60.25	0.0183	0.097	0.412	889.5	0.146	36.68	809
1196.5	61.5	0.0134	0.073	0.386	953.2	0.119	26.87	1203
1195.6	61.25	0.0134	0.073	0.388	961.9	0.119	26.78	1329
1176.0	60.75	0.0135	0.075	0.376	926.6	0.118	27.13	1608
1031.6	60.25	0.0108	0.061	0.369	1014.2	0.104	21.68	2234
989.8	60.25	0.0102	0.058	0.361	1016.8	0.100	20.54	2135
999.6	60.75	0.0102	0.058	0.364	1027.3	0.100	20.43	2759

Table 4.12 Results of repeated load indirect tensile tests for mixes without fiber and with CRMB 60 binder at 25°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_{I,} \times 10^5$	N_f, Nos
1817.3	62.5	0.0189	0.102	0.392	1021.2	0.1774	37.81	5658
1842.4	63.25	0.0190	0.102	0.399	1025.2	0.1777	38.06	6671
1803.2	62.25	0.0184	0.100	0.391	1039.9	0.1767	36.90	5320
1729.7	62.5	0.0161	0.090	0.370	1099.0	0.1688	32.42	7189
1715.0	61.75	0.0160	0.090	0.368	1107.8	0.1694	32.19	7055
1724.8	62.25	0.0161	0.090	0.372	1105.2	0.1690	32.37	6958
1507.7	62.5	0.0133	0.075	0.364	1152.0	0.1472	26.73	7653
1489.6	62.25	0.0135	0.076	0.366	1126.6	0.1460	27.17	8567
1479.8	62	0.0130	0.075	0.352	1142.5	0.1456	26.21	8129
1232.8	62.25	0.0096	0.056	0.341	1260.0	0.1208	19.41	9987
1225.0	62	0.0096	0.057	0.340	1255.4	0.1205	19.39	9453
1195.6	61.25	0.0091	0.054	0.336	1297.7	0.1191	18.41	9870

Table 4.13 Results of repeated load indirect tensile tests for mixes without fiber and with CRMB 60 binder at 30°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_{I,} \times 10^5$	N_f, Nos
2049.9	62.25	0.0226	0.120	0.405	984.0	0.2009	45.20	1301
2058.0	62.75	0.0228	0.120	0.412	981.2	0.2001	45.60	1505
2067.8	63	0.0233	0.123	0.413	961.9	0.2002	46.59	1419
1764.0	60.75	0.0184	0.099	0.396	1051.5	0.1771	36.85	2564
1754.2	60.75	0.0172	0.095	0.382	1097.0	0.1761	34.44	3102
1764.0	61.25	0.0177	0.096	0.390	1074.2	0.1757	35.50	2985
1467.1	61	0.0142	0.078	0.381	1104.4	0.1467	28.47	3869
1450.4	61	0.0138	0.077	0.379	1115.8	0.1450	27.76	4157
1430.8	60.25	0.0135	0.075	0.376	1136.7	0.1449	27.13	4208
1225.4	62.5	0.0104	0.059	0.366	1200.0	0.1196	20.93	5184
1225.0	62.25	0.0103	0.058	0.364	1218.0	0.1200	20.63	7235
1195.6	60.75	0.0104	0.059	0.360	1197.5	0.1201	20.85	6501

Table 4.14 Results of repeated load indirect tensile tests for mixes without fiber and with CRMB 60 binder at 35°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	ε_I, $\times10^5$	N_f, Nos
1943.3	60.75	0.0241	0.127	0.411	905.7	0.1951	48.14	564
1950.2	61.75	0.0238	0.125	0.415	910.3	0.1927	47.48	509
1940.4	61.25	0.0225	0.119	0.409	955.7	0.1932	45.02	614
1723.0	60.75	0.0194	0.104	0.398	976.9	0.1730	38.83	897
1705.2	60.5	0.0186	0.103	0.381	987.2	0.1719	37.35	918
1715.0	60.5	0.0192	0.104	0.393	978.5	0.1729	38.49	968
1543.0	61.5	0.0158	0.087	0.385	1040.8	0.1530	31.67	1934
1528.8	61.25	0.0151	0.083	0.383	1079.6	0.1523	30.31	1517
1509.2	60	0.0149	0.083	0.376	1094.6	0.1534	29.84	1760
1298.5	61.25	0.0111	0.062	0.370	1223.9	0.1293	22.30	2871
1274.0	61	0.0105	0.059	0.369	1270.8	0.1274	21.12	3210
1264.2	60.25	0.0104	0.059	0.368	1287.6	0.1280	20.92	2975

Table 4.15 Results of repeated load indirect tensile tests for mixes with 80/100 bitumen and fiber at 25°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	ε_I, $\times10^5$	N_f, Nos
2700.7	64.25	0.0147	0.074	0.438	2030.9	0.256	29.21	978
2590.2	61.75	0.0136	0.070	0.427	2152.7	0.256	27.13	1300
2570.5	61.75	0.0136	0.070	0.424	2132.2	0.254	27.06	1335
2178.9	60.75	0.0109	0.059	0.393	2175.0	0.219	21.91	2539
2223.4	61.75	0.0114	0.061	0.406	2126.4	0.220	22.90	2079
2198.4	61.25	0.0109	0.058	0.399	2209.8	0.219	21.76	2123
1979.3	63.25	0.0088	0.048	0.386	2344.8	0.191	17.56	4863
2017.5	63.5	0.0092	0.050	0.392	2284.9	0.194	18.45	4819
1982.5	63	0.0089	0.048	0.389	2334.2	0.192	17.81	4684
1785.5	63.5	0.0076	0.042	0.377	2383.8	0.172	15.33	6320
1772.2	63.25	0.0077	0.043	0.374	2357.3	0.171	15.38	7088
1800.7	63.5	0.0081	0.043	0.398	2345.6	0.173	16.17	5920
1643.1	62.75	0.0068	0.039	0.364	2433.8	0.160	13.73	14746
1556.3	60.25	0.0063	0.036	0.355	2561.3	0.158	12.70	12385
1596.4	61.75	0.0066	0.038	0.356	2471.6	0.158	13.20	15543

Table 4.16 Results of repeated load indirect tensile tests for mixes with 80/100 bitumen and fiber at 30°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_{I}, \times 10^5$	N_f, Nos
2605.3	63.5	0.02287	0.117	0.435	1264.3	0.250	45.61	280
2560.2	64	0.02146	0.112	0.421	1287.3	0.244	42.87	327
2589.4	63.25	0.02255	0.114	0.440	1288.5	0.250	44.95	310
2246.0	63.5	0.01634	0.091	0.373	1391.6	0.216	32.85	451
2312.8	64.25	0.01805	0.098	0.391	1318.7	0.220	36.20	520
2276.9	63.25	0.01689	0.093	0.382	1390.1	0.220	33.91	562
1749.6	62.25	0.01267	0.072	0.364	1405.5	0.171	25.50	1394
1756.6	61.5	0.01330	0.073	0.383	1402.9	0.174	26.70	2179
1753.9	61.25	0.01278	0.072	0.363	1418.1	0.175	25.73	2320
1566.8	63.75	0.01097	0.061	0.373	1440.0	0.150	22.05	1750
1547.6	63.25	0.01048	0.059	0.366	1483.8	0.149	21.09	2239
1555.8	62.5	0.01095	0.062	0.369	1451.9	0.152	22.03	1987
1332.8	64.75	0.00853	0.049	0.354	1506.5	0.126	17.19	4452
1293.6	62.75	0.00815	0.047	0.350	1568.7	0.126	16.44	4755
1345.8	63.75	0.00901	0.051	0.367	1493.4	0.129	18.13	4356

Table 4.17 Results of repeated load indirect tensile tests for mixes with 80/100 bitumen and fiber at 35°C

P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_{I}, \times 10^5$	N_f, Nos
2544.0	62.25	0.03160	0.154	0.467	952.7	0.249	62.80	164
2591.4	62.25	0.03658	0.176	0.475	848.2	0.254	72.63	177
2542.3	60.25	0.03600	0.177	0.462	858.3	0.257	71.58	162
2233.8	62.25	0.02396	0.119	0.456	1087.1	0.219	47.67	431
2152.8	62.5	0.02215	0.112	0.443	1108.2	0.210	44.14	290
2181.9	63.25	0.02270	0.114	0.448	1090.6	0.210	45.21	401
1790.1	61.75	0.01769	0.091	0.430	1146.8	0.177	35.30	530
1843.3	61.75	0.01864	0.095	0.436	1130.8	0.182	37.17	556
1788.7	60.25	0.01802	0.093	0.429	1152.1	0.181	35.96	607
1564.4	63.25	0.01421	0.074	0.416	1194.9	0.151	28.40	770
1537.8	64.5	0.01331	0.071	0.403	1205.9	0.145	26.65	884
1551.9	63.25	0.01370	0.073	0.405	1209.1	0.150	27.42	819
1201.7	62.25	0.01037	0.056	0.393	1234.5	0.118	20.79	1936
1201.1	62.5	0.01018	0.055	0.389	1244.2	0.117	20.42	2654
1206.5	61.75	0.01050	0.056	0.398	1243.7	0.119	21.04	2334

Table 4.18 Results of repeated load indirect tensile tests for mixes with 60/70 bitumen and fiber at 25°C

P, N	*h*, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_I, \times 10^5$	N_f, Nos
2551.5	60.25	0.0122	0.065	0.407	2355.2	0.258	24.37	1509
2479.2	63	0.0110	0.059	0.402	2409.2	0.240	21.97	1480
2458.3	62.75	0.0107	0.057	0.400	2453.4	0.239	21.43	2215
2343.5	63	0.0098	0.053	0.386	2499.4	0.227	19.59	3729
2387.2	61.25	0.0104	0.056	0.391	2485.7	0.238	20.78	3628
2374.9	60.75	0.0104	0.057	0.390	2479.5	0.238	20.88	3530
2024.4	62	0.0081	0.046	0.369	2566.2	0.199	16.35	5209
2099.6	62.25	0.0087	0.048	0.375	2503.1	0.206	17.46	5890
2043.9	62.25	0.0084	0.047	0.372	2519.1	0.200	16.83	6102
1823.1	63.75	0.0069	0.040	0.356	2587.8	0.174	13.94	9107
1709.1	63.25	0.0064	0.037	0.352	2618.5	0.165	12.94	8583
1697.4	63.25	0.0065	0.038	0.350	2558.8	0.164	13.11	9328
1512.4	63	0.0056	0.033	0.336	2622.6	0.146	11.22	19619
1538.4	62	0.0058	0.034	0.340	2591.3	0.151	11.80	17385
1506.3	62.25	0.0056	0.033	0.335	2625.0	0.148	11.28	15958

Table 4.19 Results of repeated load indirect tensile tests for mixes with 60/70 bitumen and fiber at 30°C

P, N	*h*, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_I, \times 10^5$	N_f, Nos
2584.2	61.75	0.0203	0.106	0.414	1413.9	0.255	40.49	379
2618.6	62.5	0.0213	0.110	0.424	1368.9	0.256	42.43	340
2619.0	62.25	0.0211	0.109	0.425	1385.4	0.257	42.13	388
2169.0	61.5	0.0161	0.086	0.400	1473.3	0.215	32.15	550
2349.0	62.75	0.0173	0.092	0.401	1456.0	0.228	34.55	620
2295.7	62.25	0.0172	0.092	0.400	1433.6	0.225	34.53	680
1814.4	62.5	0.0121	0.066	0.387	1573.6	0.177	24.32	2344
1764.6	63.75	0.0112	0.062	0.376	1593.4	0.169	22.55	2657
1780.1	63.25	0.0116	0.064	0.381	1579.5	0.172	23.29	2489
1556.2	63.25	0.0093	0.054	0.345	1621.3	0.150	18.85	1828
1654.1	63.5	0.0102	0.058	0.358	1608.6	0.159	20.49	2330
1656.5	62.25	0.0104	0.059	0.360	1609.7	0.162	20.97	3960
1332.8	62.5	0.0077	0.045	0.336	1684.7	0.130	15.50	8523
1293.6	64	0.0071	0.043	0.328	1701.7	0.123	14.37	9052
1313.2	63.25	0.0075	0.044	0.333	1676.6	0.127	15.11	8897

Table 4.20 Results of repeated load indirect tensile tests for mixes with 60/70 bitumen and fiber at 35°C

P, N	*h*, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_{I,} \times 10^5$	N_f, Nos
2697.3	61.5	0.0266	0.131	0.461	1203.4	0.268	52.98	183
2686.9	61.5	0.0251	0.125	0.451	1254.7	0.267	49.97	191
2698.5	62.25	0.0261	0.128	0.462	1214.9	0.264	51.92	179
2165.6	60.5	0.0191	0.098	0.426	1306.4	0.218	38.06	555
2226.9	60.75	0.0204	0.102	0.446	1286.3	0.224	40.63	361
2206.5	61.25	0.0198	0.100	0.438	1290.0	0.220	39.40	562
1701.6	63	0.0133	0.070	0.409	1382.4	0.165	26.55	747
1778.5	63.25	0.0145	0.076	0.416	1325.8	0.172	29.07	721
1782.0	62.75	0.0146	0.076	0.417	1337.1	0.173	29.18	803
1496.2	62.75	0.0106	0.058	0.387	1485.9	0.145	21.17	1271
1521.6	65	0.0103	0.056	0.395	1506.1	0.143	20.72	1154
1539.6	63.25	0.0113	0.060	0.403	1451.6	0.148	22.59	1374
1256.6	63.5	0.0078	0.044	0.364	1607.3	0.121	15.70	3133
1257.2	63.5	0.0080	0.045	0.367	1579.9	0.121	16.06	2759
1260.1	63.25	0.0079	0.044	0.368	1609.0	0.122	15.89	3565

Table 4.21 Results of repeated load indirect tensile tests for mixes with CRMB 60 binder and fiber at 25°C

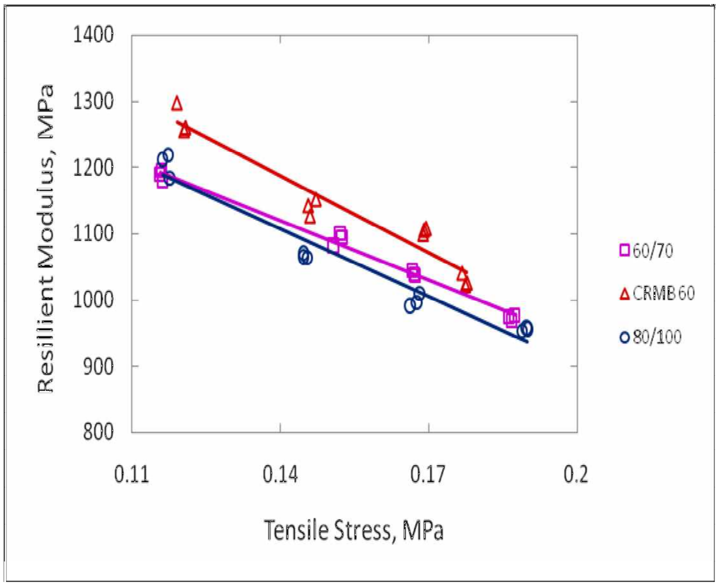
P, N	*h*, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	$\varepsilon_{I,} \times 10^5$	N_f, Nos
2531.2	60.25	0.0100	0.055	0.386	2756.0	0.256	20.07	2980
2539.9	60.25	0.0102	0.056	0.391	2721.9	0.257	20.52	2825
2528.2	60.5	0.0100	0.055	0.389	2752.7	0.255	20.06	2546
2158.6	60.25	0.0079	0.045	0.363	2863.0	0.219	15.94	5337
2264.5	62.25	0.0083	0.047	0.372	2803.7	0.222	16.75	5472
2245.4	62	0.0082	0.046	0.368	2822.6	0.221	16.46	6068
1961.9	60.25	0.0068	0.040	0.345	2947.3	0.199	13.72	8175
2063.2	63.25	0.0069	0.040	0.355	2939.6	0.199	13.99	8962
2061.1	63.25	0.0070	0.040	0.352	2907.3	0.199	14.05	9156
1766.9	63.5	0.0054	0.032	0.331	3121.3	0.170	10.84	14879
1758.8	62.75	0.0051	0.032	0.306	3152.3	0.171	10.40	17923
1762.9	62.75	0.0051	0.032	0.309	3191.2	0.171	10.35	11576
1607.3	64.25	0.0046	0.028	0.320	3245.2	0.153	9.22	37,711
1558.1	64.5	0.0042	0.026	0.303	3288.6	0.147	8.56	28288
1555.3	63.25	0.0043	0.027	0.302	3311.8	0.150	8.64	20951

Table 4.22 Results of repeated load indirect tensile tests for mixes with CRMB 60 binder and fiber at 30°C

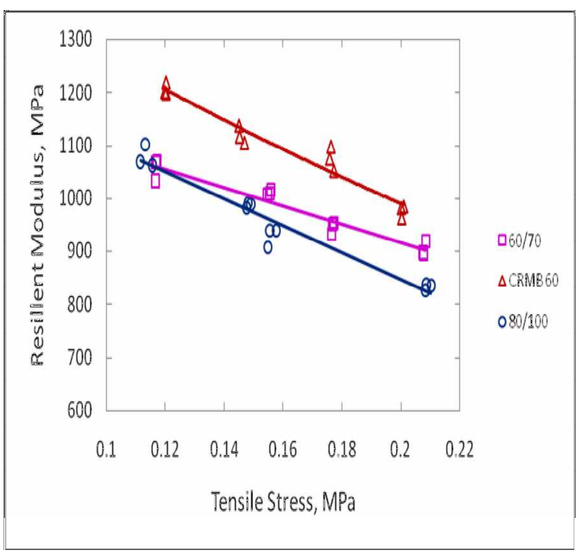
P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	ε_I, ×10^5	N_f, Nos
2516.2	63	0.0156	0.085	0.390	1686.5	0.244	31.37	464
2538.2	63.25	0.0166	0.087	0.414	1657.6	0.245	33.11	480
2526.4	62.5	0.0166	0.089	0.400	1630.5	0.247	33.25	510
2213.4	61	0.0136	0.074	0.387	1757.2	0.221	27.23	886
2179.5	62.5	0.0126	0.069	0.384	1814.9	0.213	25.23	741
2202.1	62.75	0.0126	0.069	0.386	1827.2	0.214	25.28	589
1770.4	62.75	0.0086	0.050	0.344	2012.2	0.172	17.38	4468
1775.0	64.5	0.0089	0.051	0.350	1920.5	0.168	17.93	3951
1783.6	63.25	0.0089	0.051	0.353	1985.0	0.172	17.84	2239
1532.0	63.75	0.0068	0.041	0.326	2094.1	0.147	13.85	10881
1566.3	63.5	0.0072	0.043	0.329	2061.7	0.150	14.51	7137
1522.9	62.25	0.0071	0.043	0.323	2056.9	0.149	14.28	9457
1293.6	64.5	0.0055	0.033	0.317	2155.6	0.122	11.07	24147
1265.9	62.5	0.0054	0.033	0.310	2186.5	0.124	10.90	19136
1277.9	63.25	0.0055	0.034	0.314	2165.2	0.123	11.06	20145

Table 4.23 Results of repeated load indirect tensile tests for mixes with CRMB 60 binder and fiber at 35°C

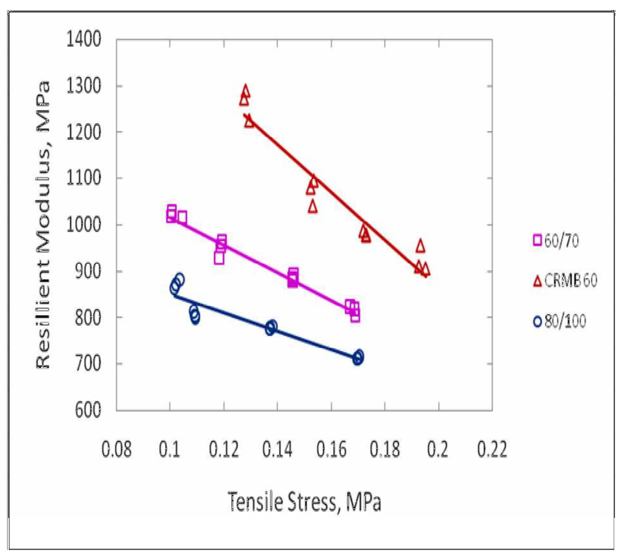
P, N	h, mm	H_R, mm	V_R, mm	μ_R	M_R, MPa	σ_t, Mpa	ε_I, ×10^5	N_f, Nos
2675.3	62.5	0.0216	0.109	0.443	1412.4	0.261	43.04	325
2685.1	62.25	0.0231	0.115	0.449	1343.6	0.263	45.94	343
2650.9	61.75	0.0216	0.111	0.432	1394.7	0.262	43.10	409
2158.1	62.5	0.0155	0.080	0.420	1541.3	0.211	30.87	460
2132.0	61.75	0.0152	0.080	0.412	1554.2	0.211	30.30	505
2127.6	62	0.0151	0.080	0.410	1544.7	0.209	30.21	649
1764.0	63	0.0108	0.061	0.366	1644.9	0.171	21.79	1159
1775.0	63	0.0116	0.063	0.396	1612.7	0.172	23.31	1521
1771.3	62.75	0.0116	0.063	0.393	1621.4	0.172	23.15	1374
1590.5	63.5	0.0087	0.052	0.337	1742.1	0.153	17.64	1947
1568.5	63.5	0.0082	0.050	0.325	1786.3	0.151	16.66	1839
1566.0	63.25	0.0083	0.049	0.333	1799.3	0.151	16.78	2285
1189.5	62.75	0.0055	0.033	0.316	2033.8	0.116	11.07	6191
1224.2	64	0.0057	0.035	0.321	1973.3	0.117	11.61	6578
1197.6	63	0.0058	0.035	0.316	1935.9	0.116	11.66	7108



(i) Resilient Modulus Vs Tensile Stress at 25°C

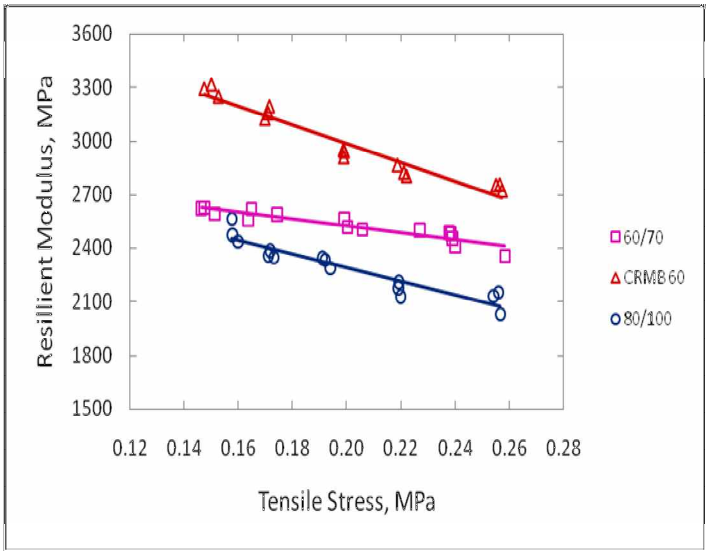


(ii) Resilient Modulus Vs Tensile Stress at 30°C

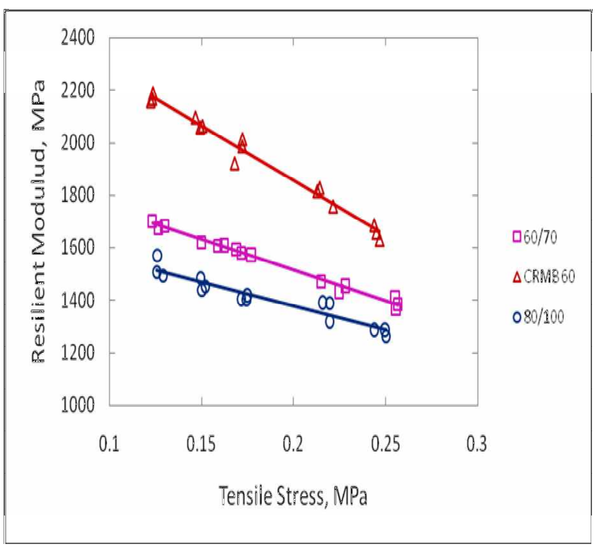


(iii) Resilient Modulus Vs Tensile Stress at 35°C

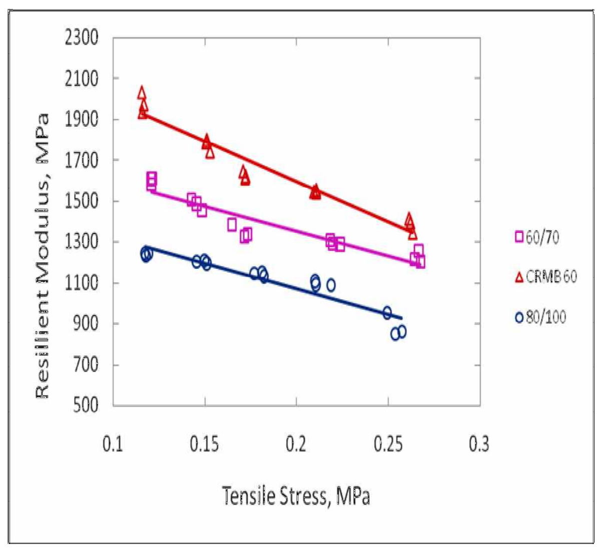
Fig. 4.13 Variation of resilient modulus with tensile stress for mixes without fiber



(i) Resilient Modulus Vs Tensile Stress at 25°C



(ii) Resilient Modulus Vs Tensile Stress at 30°C



(iii) Resilient Modulus Vs Tensile Stress at 35°C

Fig. 4.14 Variation of resilient modulus with tensile stress for mixes with fiber

4.5.2 Relationship between fatigue life (N_f) and stress difference ($\Delta\sigma$)

As reported by Kennedy (1978), there exists a linear relationship between the logarithm of tensile stress and logarithm of fatigue life for bituminous mixes, which is expressed as

$$N_f = K_2 \left(\frac{1}{\sigma_t}\right)^{n_2} \tag{4.1}$$

Where, N_f = Fatigue Life

σ_t = Applied Tensile Stress

K_2, n_2 = Regression Coefficients

Moreover, as per Kennedy (1978), to ensure the compatibility of repeated load tensile stress test with other tests the fatigue life is expressed in terms of stress difference instead of tensile stress. Stress difference, $\Delta\sigma$ is equal to $4\sigma_t$. In such cases it does not affect the value of the coefficient n_2, but the value of K_2 is changed. So the new expression can be,

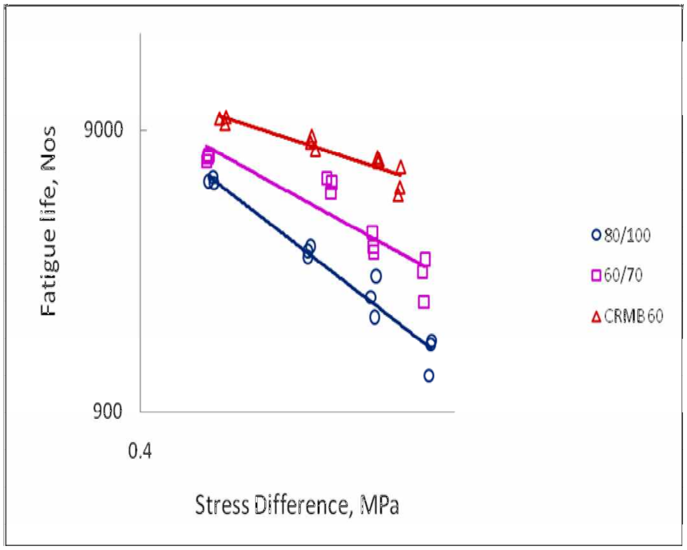
$$N_f = K_2' \left(\frac{1}{\Delta\sigma}\right)^{n_2} \tag{4.2}$$

Where, N_f = Fatigue Life

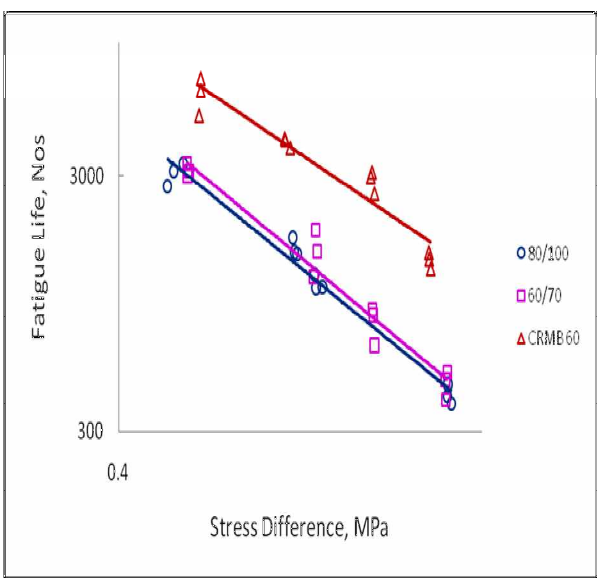
$\Delta\sigma$ = Stress Difference

K'_2, n_2 = Regression Coefficients

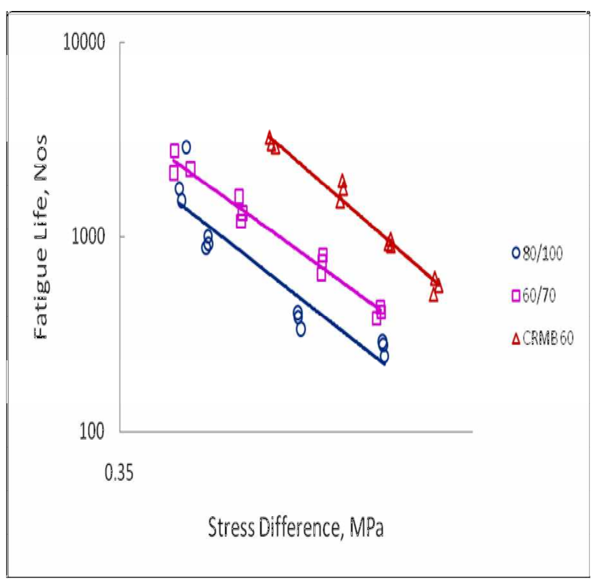
The variation of fatigue life with stress difference for SMA mixes with three types of binder at three different temperatures are shown in Figures 4.15 (i) to (iii) for mixes without fiber, and in Figures 4.16 (i) to (iii) for mixes with fiber. The values of constants obtained for all the SMA mixes without and with fiber are presented in Table 4.24 and 4.25 respectively. It is observed from the figures that addition of fiber to the mix improves its fatigue life. At a particular test temperature and for a particular stress difference value, the mixes with CRMB 60 binder have the longest fatigue life value as compared to other mixes.



(i) Fatigue life Vs Stress difference at 25°C

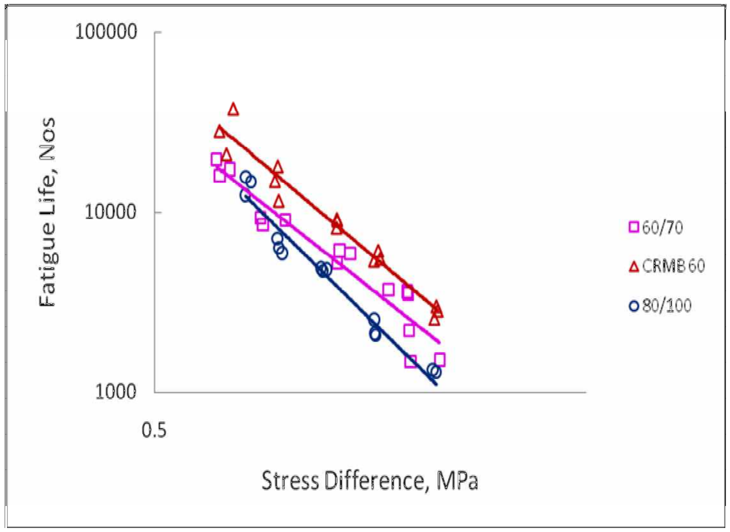


(ii) Fatigue life Vs Stress difference at 30°C

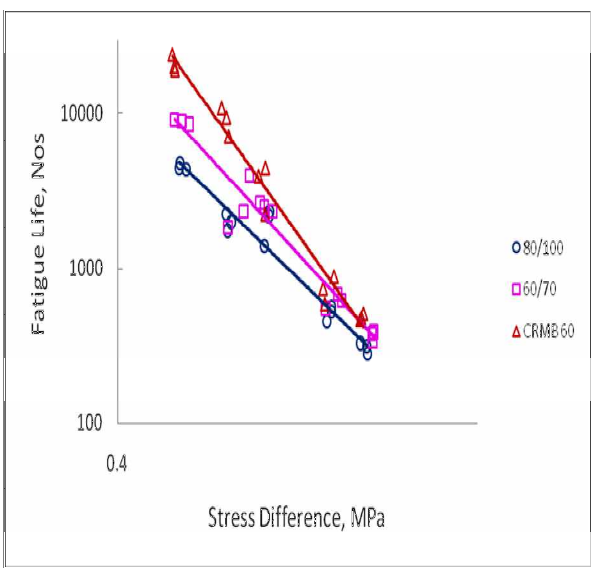


(iii) Fatigue life Vs Stress difference at 35°C

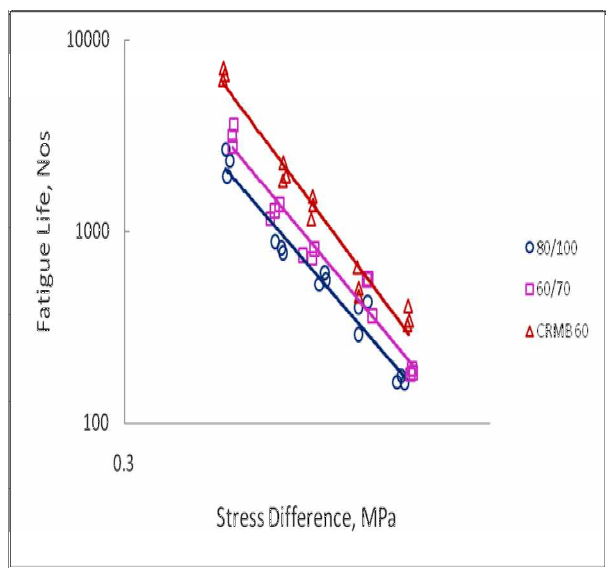
Fig. 4.15 Variation of fatigue life with stress difference for mixes without fiber



(i) Fatigue life Vs Stress difference at 25°C



(ii) Fatigue life Vs Stress difference at 30°C



(iii) Fatigue life Vs Stress difference at 35°C

Fig. 4.16 Variation of fatigue life with stress difference for mixes with fiber

Table 4.24 Constants of fatigue life-stress difference relationships for mixes without fiber

Type of binder in the mix	Test Temperature (°C)	K'_2	n_2	R^2 value
80/100 Bit.	25	686.76	2.874	0.9581
	30	245.71	3.285	0.9747
	35	53.931	3.688	0.8626
60/70 Bit.	25	1633	2.051	0.8277
	30	259.12	3.358	0.9556
	35	110.27	3.405	0.9754
CRMB 60	25	4165.5	1.191	0.8557
	30	906.84	2.721	0.9155
	35	203.48	4.127	0.9761

Table 4.25 Constants of fatigue life-stress difference relationships for mixes with fiber

Type of binder in the mix	Test Temperature (°C)	K'_2	n_2	R^2 value
80/100 Bit.	25	1245.3	4.947	0.9661
	30	317.24	3.959	0.9468
	35	190.51	3.19	0.96
60/70 Bit.	25	2153.5	3.936	0.9154
	30	401.01	4.424	0.947
	35	248.31	3.288	0.9532
CRMB 60	25	3192.3	4.193	0.9592
	30	383	5.758	0.9755
	35	348.58	3.668	0.9693

4.5.3 Relationships between fatigue life (N_f) and initial tensile strain (ε_i)

The initial tensile strain (ε_i) has been calculated by the expression suggested by Gilmore (1984) as follows

$$\varepsilon_i = \frac{(1+3\mu_R)\sigma_t}{M_R} \quad (4.3)$$

Where, ε_i = Tensile strain

σ_t = Tensile stress

μ_R = Resilient Poisson's ratio

M_R = Resilient modulus of elasticity

Figures 4.17 and 4.18 present the relationships between fatigue life and tensile strain on logarithm scale on each axis. Similarly, Figures 4.17 (i), (ii) and (iii) present the variations of fatigue life with tensile strain for mixes without fiber and with 80/100 and 60/70 bitumen and CRMB 60 binder at test temperatures 25°C, 30°C and 35°C respectively. It is observed that the fatigue life for mixes with CRMB 60 binder at lower tensile strains is higher than the other two mixes with unmodified binder. Figures 4.18 (i), (ii) and (iii), show the variation of fatigue life with tensile strain for mixes with fiber and with the three types of binder at test temperatures 25°C, 30°C and 35°C respectively. For these mixes also, the fatigue life of mixes with CRMB 60 binder is higher followed by 60/70 and 80/100 bitumen at any particular stress level. Mixes with CRMB 60 binder offer lower tensile strain at a particular stress level than the other two mixes. The equations obtained from the graphs are of the form,

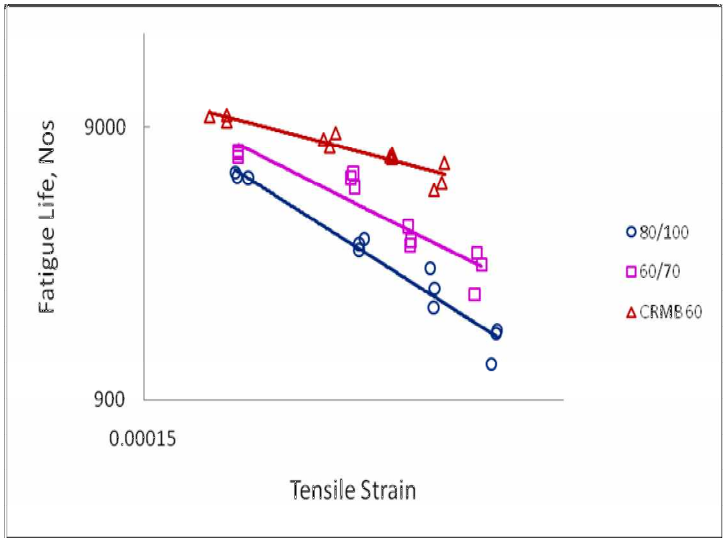
$$N_f = K_1 \left(\frac{1}{\varepsilon_i}\right)^{n_1} \quad (4.4)$$

Where, N_f = Fatigue life

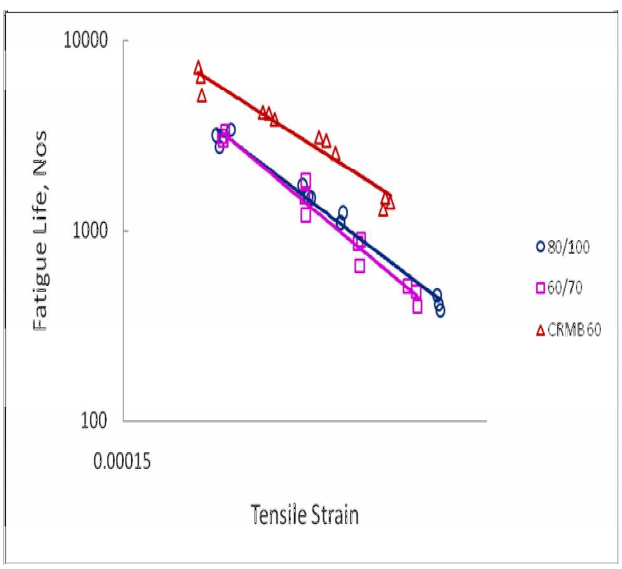
ε_i = Initial tensile strain

K_1, n_1 = Regression Coefficients

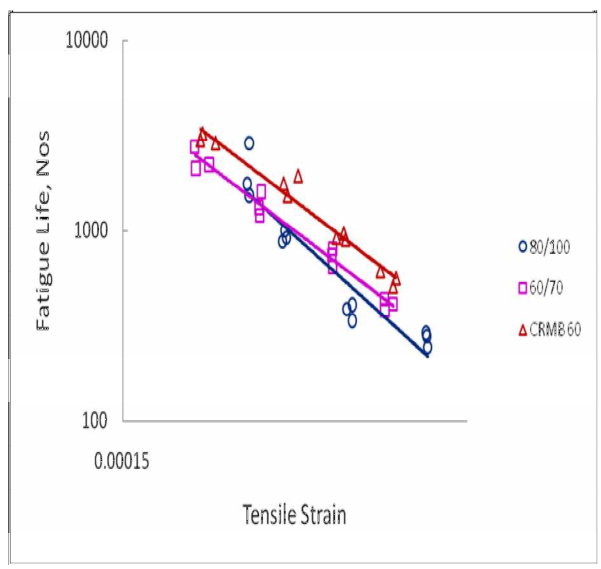
The values of K_1 and n_1 obtained from this investigation are listed in Table 4.26 and 4.27 for various SMA mixes without and with fiber respectively.



(i) Fatigue life Vs Tensile strain at 25°C

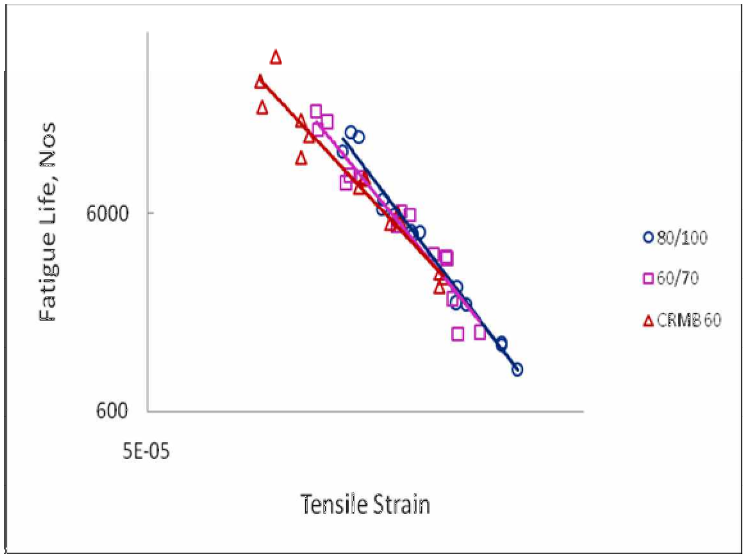


(ii) Fatigue life Vs Tensile strain at 30°C

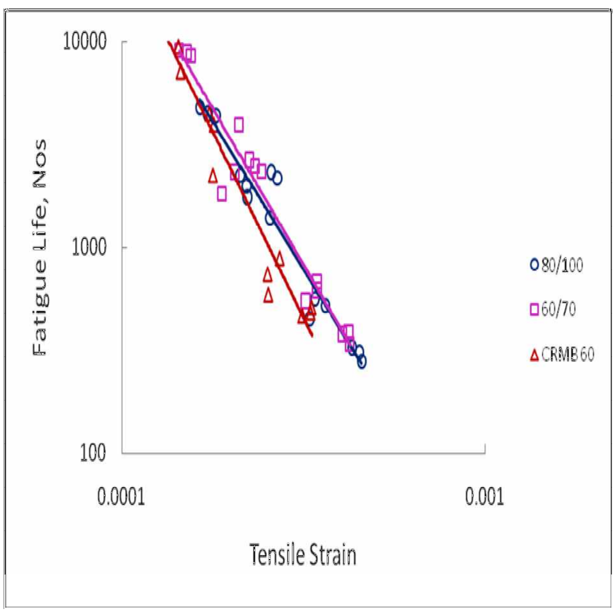


(iii) Fatigue life Vs Tensile strain at 35°C

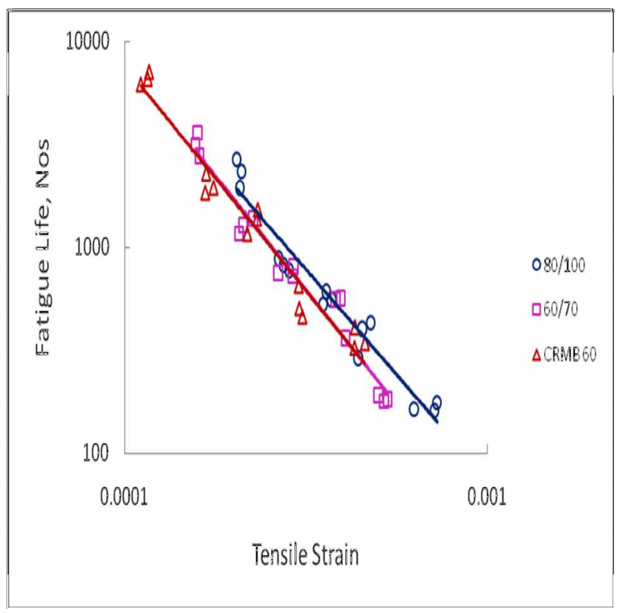
Fig. 4.17 Variation of fatigue life with tensile strain for mixes without fiber



(i) Fatigue life Vs Tensile strain at 25°C



(ii) Fatigue life Vs Tensile strain at 30°C



(iii) Fatigue life Vs Tensile strain at 35°C

Fig. 4.18 Variation of fatigue life with tensile strain for mixes with fiber

Table 4.26 Constants of fatigue life-initial tensile strain relationships for mixes without fiber

Type of binder in the mix	Test Temperature (°C)	K_2	n_2	R^2 value
80/100 Bit.	25	2.2×10^{-3}	1.747	0.9548
	30	4×10^{-5}	2.18	0.9821
	35	9×10^{-7}	2.568	0.8826
60/70 Bit.	25	6.79×10^{-2}	1.369	0.8754
	30	6×10^{-6}	2.392	0.9702
	35	3×10^{-5}	2.158	0.9759
CRMB 60	25	21.443	0.717	0.8739
	30	1.2×10^{-3}	1.836	0.9495
	35	4×10^{-5}	2.153	0.9652

Table 4.27 Constants of fatigue life-initial tensile strain relationships for mixes with fiber

Type of binder in the mix	Test Temperature (°C)	K_2	n_2	R^2 value
80/100 Bit.	25	4×10^{-9}	3.234	0.9773
	30	7×10^{-8}	2.873	0.9423
	35	5×10^{-5}	2.047	0.9465
60/70 Bit.	25	3×10^{-8}	2.995	0.9332
	30	2×10^{-8}	3.035	0.9449
	35	1×10^{-5}	2.224	0.9609
CRMB 60	25	7×10^{-7}	2.606	0.9398
	30	9×10^{-11}	3.63	0.9704
	35	1×10^{-5}	2.186	0.9594

4.5.4 Effect of Temperature

An attempt has been made to study the effect of temperature on the elastic properties of SMA mixes such as Poisson's ratio, Resilient Modulus and Fatigue life at three different test temperatures, namely 25°C, 30°C and 35°C. The variation of these parameters with temperature is discussed in the following sections.

4.5.4.1 Poisson's Ratio

Tables 4.28 and 4.29 present the Poisson's ratio values of the mixes without and with fiber respectively, at three different temperatures. It is observed that at a particular stress level for a given mix the Poisson's ratio value increases with increase in temperature, and also when stiffer binder is used in the mix the Poisson's ratio decreases.

Table 4.28 Poisson's Ratio of mixes without fiber

Temperature (°C)	Type of binder in the mix		
	80/100 Bit.	60/70 Bit.	CRMB 60
25°C	0.362	0.357	0.336
30°C	0.391	0.363	0.360
35°C	0.403	0.376	0.369

Table 4.29 Poisson's Ratio of mixes with fiber

Temperature (°C)	Type of binder in the mix		
	80/100 Bit.	60/70 Bit.	CRMB 60
25°C	0.355	0.340	0.302
30°C	0.369	0.345	0.329
35°C	0.405	0.403	0.333

4.5.4.2 Resilient Modulus

Tables 4.30 and 4.31 present the resilient modulus value of the mixes without and with fiber respectively at three different temperatures. It can be observed that addition of fiber improves the resilient modulus value and also at a particular temperature the resilient modulus is highest for the mix with CRMB 60 binder in both the cases, i.e. with and without fiber.

Table 4.30 Resilient Modulus (MPa) of mixes without fiber

Temperature (°C)	Type of binder in the mix		
	80/100 Bit.	60/70 Bit.	CRMB 60
25°C	1183.48	1189.42	1297.72
30°C	1062.07	1066.24	1197.52
35°C	812.19	926.6	1153.51

Table 4.31 Resilient Modulus (MPa) of mixes with fiber

Temperature (°C)	Type of binder in the mix		
	80/100 Bit.	60/70 Bit.	CRMB 60
25°C	2561.3	2591.31	3311.75
30°C	1451.86	1621.26	2061.71
35°C	1209.1	1451.57	1799.33

4.5.4.3 Fatigue Life

Fatigue life of the SMA mixes depends upon the test temperature and stress level. It can be seen from the Tables 4.6 to 4.23 that fatigue life of the mixes decreases with increase in temperature. It also depends on the type of binder used in the mix. Fatigue life is more for the mixes with CRMB 60 binder followed by 60/70 and 80/100 bitumen.

4.6 Moisture Susceptibility Characteristics

One of the most important and critical factors leading to premature failure of bituminous pavements is due to presence of moisture on the pavement surface and inability of aggregates to retain the coating in presence of moisture. Therefore it is very much significant to study the moisture susceptibility characteristics of the paving mixes. As described earlier in Chapter 3, two types of tests, namely, tensile strength ratio (TSR) test and retained stability test are used in this investigation to study the behaviour of SMA mixes subjected to moisture conditions. The test results thus obtained are discussed in the following sections.

4.6.1 Tensile strength ratio (TSR) test

Static indirect tensile test has been used to compute the tensile strength ratio of SMA mixes. The indirect tensile strength (ITS) of unconditioned and conditioned (at 60°C, for 24 hours) samples have been determined for this purpose. The TSR is expressed as the percentage of ratio of these two values. Table 4.32 presents the results of tensile strength ratio test of SMA mixes with and without fiber and with three types of binder. It can be seen that for mixes without fiber, the mixes with CRMB 60 binder has TSR value more than 80%, the prescribed limit (MORTH, 2001). In case of mixes with 80/100 and 60/70 bitumen the TSR is observed to be below 80%. However, addition of fiber to the mix increases this value beyond 80% and hence is acceptable in terms of moisture susceptibility characteristics.

Table 4.32 TSR test results of mixes

Type of binder in the mix	Mixes without fiber			Mixes with fiber		
	ITS of unconditioned sample, kPa	ITS of conditioned sample, kPa	TSR (%)	ITS of unconditioned sample, kPa	ITS of conditioned sample, kPa	TSR (%)
80/100 Bit.	614.55	439.08	71.45	775.38	622.19	80.24
60/70 Bit.	764.48	601.44	78.67	884.61	759.68	85.87
CRMB 60	888.85	741.97	83.47	1029.56	950.28	92.29

4.6.2 Retained stability test

Retained stability value of the SMA mixes has been computed using the Marshall stability test. Retained stability is the Marshall stability value of specimens conditioned in water at 60°C, for 24 hours, expressed as a percentage of the normal Marshall stability of the mix. Table 4.33 presents the retained stability value of different SMA samples with and without fiber. It is observed that SMA mixes with fiber show more retained stability than the mixes without fiber. Use fiber in mixes with 80/100 and 60/70 bitumen improves its retained stability, and also the use of modified binder such as CRMB 60 in the mixes has improved the retained stability value, and hence the moisture susceptibility characteristics.

Table 4.33 Retained stability test results of mixes

Type of binder in the mix	Mixes without fiber			Mixes with fiber		
	Marshall Stability of unconditioned sample, kN	Marshall Stability of conditioned sample, kN	Retained Stability (%)	Marshall Stability of unconditioned sample, kN	Marshall Stability of conditioned sample, kN	Retained Stability (%)
80/100 Bit.	6.2	4.26	68.78	11.2	8.43	75.34
60/70 Bit.	7.02	5.26	74.97	12	10.25	85.44
CRMB 60	7.32	6.44	88.01	13.6	12.61	92.7

CHAPTER 5

CONCLUSIONS

CHAPTER – 5

CONCLUSIONS

5.1 General

Based on the results and discussions of experimental investigations carried out on different SMA mixes the following conclusions are drawn.

5.2 Marshall Properties

i) Marshall Stability

It is observed that with increase in binder content the Marshall stability value increases up to a certain binder content and then decreases, like conventional bituminous mixes. It is also found from the variations that the stability value varies with the type of binder used in the mix, it increases with increase in the stiffness of the binder. In general the Marshall stability is found to be maximum for mixes with CRMB 60 binder followed by that with normal bitumen 60/70 and 80/100. However, the stiffer binder requires more binder to attain the maximum stability value. It also depends on the fiber content in the mix, i.e. an increase in fiber content increases the stability value as long as its amount is 0.5% in the mix, but further increase in fiber content (i.e. 0.7%) in the mix its value decreases.

ii) Flow Value

The flow value increases with increase in binder content and decreases with increase in stiffness of the binder. When fiber is added to the mix, the flow value further decreases as compared to normal SMA mix without fiber. However, a higher fiber concentration in the mix increases its flow value.

iii) Unit Weight

The unit weight increases with increase in binder content up to a certain binder content and thereafter decreases. After, there is a decrease in the unit weight with increase in stiffness of the binder used in the mix. The unit weight also depends on the fiber content of the mix. When 0.3% of fiber is added to the mix its unit weight increases compared to the mix with no fiber but further addition of fiber lowers the unit weight of the mix.

iv) Air Voids

The amount of air voids decreases with increase in binder content in the mix. It also increases or decreases depending on the percentage of fiber content in the mix. The mix is observed to have the lowest air voids at 0.3% fiber content in the mix.

v) Optimum Binder Content

The optimum binder content (OBC) of the SMA mixes, based on the Marshall test results taking 3% air voids as the main criterion are observed to increase with increase in stiffness of the binder i.e. mixes with CRMB 60 binder have the highest optimum binder content. It is also found that addition of coconut fiber lowers the optimum binder content of the mix.

vi) Optimum Fiber Content

It is seen from the results of Marshall tests that at 0.3% fiber content all the mixes show utmost properties at optimum binder content. So a fiber content of 0.3% in the mix is taken as the optimum fiber content (OFC) for all the SMA mixes with 80/100 and 60/70 bitumen and CRMB 60 binder.

5.3 Draindown Characteristics

Mixes with CRMB 60 modified binder are found to show the best performance in terms of draindown for the mixes either with or without fiber. In case of mixes with CRMB 60 binder and no fiber, too little drainage of binder occurs. In case of mixes with 80/100 and 60/70 bitumen small percentage of draindown is observed when there is no fiber in the mix, but when fiber is added to these mixes no draindown of the binder is observed.

5.4 Tensile Strength

The indirect tensile strength of SMA mixes is observed to decrease with increase in test temperature. At a particular test temperature mixes with 60/70 bitumen has higher tensile strength than mixes with 80/100 bitumen. At lower temperatures mixes with CRMB 60 binder have lower tensile strength than the mixes with other two unmodified binders, but at higher temperatures the same yields higher tensile strength. The mixes with fiber have higher tensile strength than the mixes without fiber.

5.5 Repeated load Indirect Tensile Test

i) Poisson's Ratio

Poisson's ratio of a paving mix depends on the type of binder used in the mix and temperature. At a particular temperature mixes with 80/100 bitumen have the highest Poisson's ratio value followed by that with 60/70 bitumen and CRMB 60 binder. For all the mixes the Poisson's ratio increases with increase in temperature.

ii) Resilient Modulus of elasticity

Resilient Modulus of Elasticity value depends on the type of binder in the mix, fiber content in the mix and the test temperature. At a particular temperature a maximum resilient modulus is obtained for mixes with CRMB 60 binder followed by the same with 60/70 and 80/100 bitumen. For a particular mix, the resilient modulus decreases with increase in temperature. The SMA mixes with fiber have much higher resilient modulus compared to the same without fiber.

iii) Fatigue Life

The fatigue life of SMA mixes also depends on the type of binder used in the mix, test temperature and fiber concentration in mix. At a particular stress level and temperature of testing, mixes with CRMB 60 binder have much higher fatigue life compared to the same with unmodified binder such as 80/100 and 60/70 bitumen. For a particular mix, the fatigue life decreases with increase in test temperature. Fatigue life of the mixes with fiber is longer as compared to mixes without fiber.

The relationship between fatigue life (N_f) and stress difference ($\Delta\sigma$) is obtained in the following form.

$$N_f = K_2' \left(\frac{1}{\Delta\sigma}\right)^{n_2}$$

where, K'_2 and n_2 are the regression coefficients.

Similarly the relationship between fatigue life (N_f) and initial tensile strain (ε_i) at any particular temperature is obtained in the following form.

$$N_f = K_1 \left(\frac{1}{\varepsilon_i}\right)^{n_1}$$

where, K_1 and n_1 are the regression coefficients.

5.6 Moisture Susceptibility Tests

(*i*) It is found that in case of mixes with unmodified binders, the tensile strength ratio (TSR) of SMA mixes without fiber is less than 80%, whereas that with CRMB 60 binder its value is more than 80%. Addition of fibers increases the TSR value of mixes with all types of binders used beyond 80%, the prescribed limit.

(*ii*) The percentage retained stability obtained from the immersion stability test is found to be more in case of mixes with CRMB 60 binder followed by that with 60/70 and 80/100 bitumen. Similarly addition of fibers increases the retained stability value of mixes.

Hence satisfactory moisture susceptibility characteristics of mixes result with addition of fiber in the mix.

5.7 Scope for Future Work

Many properties of SMA mixes such as Marshall properties, draindown characteristics, tensile strength characteristics, fatigue properties, moisture susceptibility characteristics have been studied in this investigation. Three types of binders, including one modified binder, a natural fiber have been tried in this investigation. However, some of the properties such as resistance to rutting and creep behaviour can further be investigated. Some other synthetic and natural fibers can also be tried in SMA mixes and compared. Only one gradation has been adopted here, so an attempt can be made to compare different gradations suggested by various agencies. Coconut fiber used in this study is a low cost material, therefore a cost-benefit analysis can be made to know its effect on cost of construction. Moreover, to ensure the success of this new material, experimental stretches may be constructed and periodic performances monitored.

5.8 Concluding Remarks

Three types of binders, such as conventional 80/100 and 60/70 penetration grade bitumen and a modified binder such as CRMB 60 have been tried for preparation of mixes with and without fiber. Coconut fiber, which is a low cost and abundantly available natural fiber has been used in the mixes. It has been observed that a marginal fiber concentration of 0.3% considerably improves the Marshall properties of SMA mixes even for the same with 80/100 bitumen. The optimum binder contents are found to reduce considerably by addition of fibers, which is an important advantage from economy and quality point of view. It has been observed that the draindown and moisture susceptibility characteristics have improved by using modified binder and fiber in the mix. It is also found that addition of fiber substantially increases the tensile strength of mixes with any binder type. The mixes with CRMB 60 binder result maximum tensile strength. These mixes also perform satisfactorily under repeated load test conditions and in terms of fatigue characteristics. From the overall discussion of the test results on SMA mixes with three types of binders, it can be concluded that all the mixes made at 0.3% fiber content perform satisfactorily and can be used in mixes in the wearing courses of flexible pavements. However further studies such as permanent deformation and creep properties need to be carried out, and for validation of the above test results, experimental track should be laid to study the performance of pavements with such SMA mixes.

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