A LABORATORY STUDY ON A WARM BITUMINOUS MIX

Prachi Tamasa

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008, ODISHA,INDIA

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By

PrachiTamasa

(Roll No. 213 CE 3095)

Under theguidance of

Prof.Mahabir panda

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008, ODISHA, INDIA

Department of Civil Engineering
National Institute of Technology, Rourkela
Rourkela-769008, Odisha, India.
www.nitrkl.ac.in

Certificate

This is to certify that the Project Report entitled "**A LABORATORY STUDY ON A WARM BITUMINOUS MIX**" submitted by **Prachi Tamasa bearing Roll No 213CE3095** in partial fulfilment of the requirements for the award of **Master of Technology** in **Department of Civil Engineering** with specialization in **Transportation Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matter embodied in this Project Report has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

Prof. Mahabir Panda
Department of Civil Engineering
National Institute of Technology
Rourkela-769008

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PrachiTamasa

Roll no213CE3095

ABSTRACT

About 80%of road network in India comprises of flexible pavement in which Hot Mix Asphalt (HMA) is used in the bituminous layer. Warm Mix Asphalt (WMA) is helpful in certain situations when the problems associated with HMA may be reduced. Warm mix asphalt lowers the mixing temperatures at which asphalt pavement materials are mixed and laid on road. The advantages of WMA are reduced emissions, improved workability and reduced energy consumption. In addition, it provides easier compaction in longer haul distances and extreme weather conditions. In this study, an experimental investigation has been carried out involving a warm mix chemical additive which can be easily available.

To decide the optimal concentration of additive for DBM mix, Warm Mix has been prepared by using additive with VG 30 at varying mixing temperatures of 110°C, 120°C, 130°C and 140°C. As per the specifications of MORTH, Marshall samples are prepared using dense bituminous macadam (DBM) grading and afterward Marshall properties were studied with optimum mixing temperature and optimum binder additive composition. It was observed that the DBM warm mix with additive provided higher indirect tensile strength (ITS) and higher Marshall stability with other reasonable satisfactory Marshall parameters. The retained stability and tensile strength ratio are also found to be reasonably satisfactory in such warm mixes. The resulting warm mixes are also observed to be quite comparable to the Control HMA.

Keywords: Additive, Marshall Properties, Tensile strength ratio, Indirect tensile strength, Retained stability

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LIST OF ABBREVIATIONS

HMA	Hot mix asphalt
DBM	Dense bound macadam
MORTH	Ministry of Road Transport & Highways
OBC	Optimum Binder Content
WMA	Warm mix asphalt
ITS	Indirect Tensile strength
TSR	Tensile Strength Test
VFB	Voids filled with bitumen
VMA	Voids with mineral aggregate
VA	Air voids

CHAPTER-1

INTRODUCTION

1.1 Background of the study

Warm mix asphalt is gaining acceptance now a days because of about 80% of the paved roads in India are comprises of flexible pavement, which consists of aggregate and asphalt binder which are heated and mixed together. Typically, the mixing temperatures of warm mix asphalt ranges from 100 to 135°C (Hurley and Prowell, 2005) compared to the mixing temperatures of 150 to 180°C (300 to 350°F) for hot mix asphalt.WMA uses chemical additives, organic additives and foaming technology to produce asphalt mix at lower temperature by decreasing the binder viscosity, which increases the workability of mixture without compromising the performance of asphalt.

Energy consumption, global warming, oxidative hardening of asphalt, and overhead total costs of the asphalt industry are reduced in warm mix asphalt and it creates a better working environment also. WMA is produced, placed and compacted at temperature10°C to 40°C lesser than the control Hot Mix Asphalt (D' Angelo et.al, 2008). However, the lower mixing temperatures have raised concerns on the performance of the mixtures. Therefore it is needed to thoroughly evaluate and characterize the WMA mixtures to ensure adequate performance.

1.1.1 Potential benefits and drawback

Warm Mix Asphalt (WMA) deals with the technology which reduces production and compaction temperatures. The benefits depend upon the particular WMA technology used.. Hence **benefits** are categorized in three groups: (Zaumanis, 2010)

- Environmental:

  Emission and fumes (lowering emissions of CO_2 and other green house gasses) are reduced because of the temperature level is comparatively low, air-pollution is less.

- Production

1. Ageing of bitumen binder during the production and paving process is controlled considerably, which improves serviceability of pavement
2. Because of reduced emissions, dust and noise, it is easier to permit for a plant site in urban areas.

- Paving

1. Compaction and workability are improved due to decreasing bitumen viscosity at paving temperature.
2. Construction season expands and also the haul distance increases.
3. Pavement cooling time is reduced because of low initial temperature
4. It convenience to public near work and production site as fume odour and emissions are reduced.

1.1.2 Benefits of warm mix as compared to hot mix

As compared to Hot Mix Asphalt WMA offers some benefits as per Button (2007) and Zaumanis (2010) mentioned below.

- Energy cost is reduced because of lower production and placement temperatures.
- During the production of WMA, ageing of binder (called short-term-ageing) is controlled considerably which improves of pavement service life.

- The construction season expands and also it increases haul distance
- Due to reduced temperature, it causes less wear on Asphalt plant.
- Because of lower temperature, it makes reduction in pavement cooling time.

1.1.3 Benefits of warm mix as compared to cold mix

The advantages of Warm mix over Cold mix mentioned below according to Soto and Blanco (2004) and Els (2004).

- Provides the full coating of aggregates which produce better mix..
- Improves compaction and handling over cold mix

1.2 Problem statement

- **Rutting**

  Due to increased moisture content and lesser production temperatures in foaming technologies, it causes premature rutting in WMA.

- **Low Temperature behaviour**

  Various types of additives are used with the binder for producing WMA. As lower mixing temperature is maintained during production, so lower temperature properties of binder should be determined to predict the potential changes of bitumen binder in WMA mixture.

- **Economical**

  Because of its cost, some fears are there for the using WMA Production technology. It is essential to prove the potential of WMA over HMA so that use of this technology will become widespread.

- **Water Presence**

  Due to the lower mixing temperature, moisture contained on the aggregate surface does not completely evaporated during the laying and mixing process which leads to distress of pavement.

Considering the concerns involving use of WMA as mentioned above, it was found necessary to develop a simply way of producing WMA by adding warm mix additive with bitumen. The effects of additive percentages and mixing temperature in warm bituminous mix have been studied with respect to Marshall properties. The performances of warm mix are also studied with respect to moisture susceptibility and tensile strength.

1.3 Objectives of study

The primary objective of the study is to develop warm mix asphalt using additive and to evaluate the effects of additive on the properties of binder and mixtures.

The specific objectives of the project include the following:

1 To investigate the viscosity and physical properties of the binders modified with additive at different temperatures.

2 To decide the optimum range of mixing temperatures for the mixtures.

3 To evaluate the warm bituminous mix prepared with additive in terms of Engineering Properties such as Marshall Characteristics and Indirect tensile strength.

4 To study performance of mix in terms of their retained stability value and tensile strength ratio.

1.4 Scope of the study

The scope of this study is to focus on the characterization of additive modified warm bituminous mix. The evaluation of rheological properties of VG-30 bitumen binder with and without modification with additive from Brookfield viscometer followed by analysis of engineering properties of additive modified warm bituminous Mix is the main aim of this study. The rheological properties, Marshall Properties, Indirect tensile strength are studied.

1.5 Organization of Thesis

Chapter 1. Introduction: A brief background about the warm mix asphalt and its advantages compare to other bituminous mix like hot mix and cold mix. The problem statement and research objectives are also included in this chapter.

Chapter 2. Review of literature: Deals with works carried out on warm mix till date and made a motivation to research on WMA.

Chapter 3. Methodology& Experimental Plan: Describes the materials used the for preparation of WMA samples, Experimental plan of binder and mixture testing.

Chapter 4. Experimental results and discussions: Deals with the analysis of results obtained from experimental work in laboratory.

Chapter5. Summary& Future scope of work: Deals with the conclusions observed from the study and recommendation for future work.

CHAPTER-2

REVIEW OF LITERATURE

2.1 Introduction

Warm Mix Asphalt (WMA) has been developed in Europe in 1990. According to their mixing temperature and energy consumed for the heating process of asphalt mixtures are divided into four types. (Vaitkus *et al*. 2009):

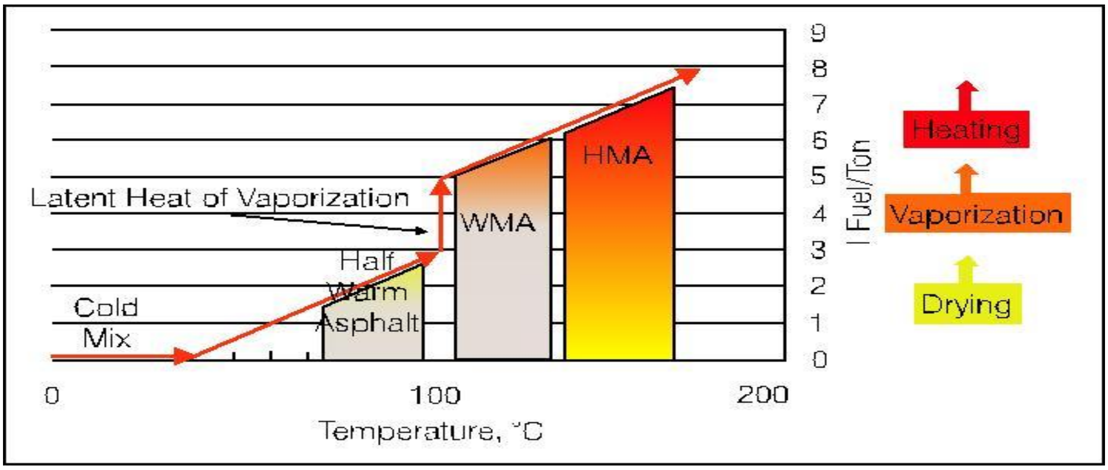

Fig 2.1 Classification by temperature range (D' Angelo et.al, 2008)

- **CMA- C**old Mix Asphalt–The asphalt mixture is produced at temperature between 10°C to 30°C by using filler, aggregate and emulsion. It is economical and environment friendly.
- HWMA- Half Warm Mix Asphalt –The bituminous mixture is developed at a temperature lower than softening point of water i.e. 65°C to 100°C.

- WMA- Warm Mix Asphalt – The bituminous mixtures are produced at a temperature in between110°C to 130°C. WMA is laid and compacted at a temperature 10^{o}C to 40^{o}C lesser than the control HMA.
- HMA-Hot Mix Asphalt–The bituminous mixture is produced at the temperature in between 150°C to180°C. The ingredients mainly aggregate and binder are heated at a high temperature.

2.2 WMA Technologies

For the production of warm mix asphalt (WMA), different types of warm mix additives and technologies are used. The basic objective is to apply several techniques to reduce the viscosity of the binder for making full coating and subsequent compactability at lower temperature.WMA technologies are of three types (Zaumanis, 2010, Erik Olesen, Erik Nielsen).

I. Organic additives
II. Chemical additives
III. Foaming Technology

2.2.1 Organic additives

Wax or Organic additives (such as Sasobit, TLA-X Warm Mix etc.) are used with bitumen in asphalt mix to reduce viscosity of binder.

Evaluation of organic additive for use in warm-mix asphalt (WMA)

Hurley and Prowell (2005) suggested that as WMA uses lower mixing temperatures so mixes reduces resistance to moisture, rutting and concluded that WMA producers should use sufficient amount of anti-stripping so that the right balance between drying of the aggregates used in the mixes and lowering the mixing temperatures can be achieved.

Wasiuddin et al. (2007) evaluated the rheological properties and rutting potential of binder. Here with Sasobit and Aspha-min, WMA mixtures additives are studied and it is being observed that with the decrease in the production temperatures, the rutting potential of the mixtures decreases.

Diefenderfer and Hearon (2008) studied Sasobit warm-mix material and concluded that HMA and WMA performance was alike in respect of fatigue resistance, rutting potential and moisture susceptibility.

Mallick et al. (2008) determined the effect of Sasobit on asphalt mixtures using high percentage of RAP materials and suggested that at higher temperature, the Sasobit lowers the viscosity of the asphalt binder.

Russell M et al. (2009) carried on field experimental study for a WMA and control HMA mixture by using Sasobit wax additive and concluded that the resilient modulus of the bituminous mixtures have not been affected by this. And the resulting mixtures have inadequate resistance towards moisture damage by conducting TSR.

Austerman et al. (2009) evaluated that when compared to the control binder, with addition of 3.0% Sasobit® and 1.5% Sasobit® improved workability and reduced viscosity of binder.

2.2.2 Chemical additives

Generally it uses a combination of anti-stripping agents, additives, polymers and surfactants to provide better coating, compaction and improve workability of mixture. REDISET WMX , CECABASE etc. are commonly used as chemical additives.

Evaluation chemical additive for producing warm-mix asphalt

NCAT (2005) evaluated the use of potential additives such as Zeolite and Evotherm produces warm asphalt mixtures (WMA) at lower temperatures which is lower than the control asphalt mixtures. During paving, thermal consistency has been monitored the by an infrared camera and reported thatat temperatures as lower than 190°F,compaction ability is achieved and resilient modulus of the asphalt mixtures has not been affected by these additives. However, the tensile strength ratio (TSR) is measured and suggested the resultant mixtures has inadequate resistance towards moisture damage.

Hurley et al. (2005 & 2006) studied on Evotherm™ and described that reduced the asphalt mixtures mixing and compaction temperatures are reduced by this technology and significantly improving the compaction of the asphalt mixture which has resulted in lower air voids. For Evotherm, the mixing and compaction temperatures were lowered so it has increased tendency towards moisture susceptibility and rutting.

2.2.3 Foaming Technologies

In Foaming technology, lesser volume of cold water has been directly injected in the asphalt-mixing chamber or put into the hot bitumen (Larsen, 2001).Technologies such as Ultra foam GX, Double Barrel Green is produced by using special technology or equipment by directly injecting cold water into hot bitumen. A large volume of foam is produced by rapidly evaporating the water. The foaming bitumen lowers the viscosity by increasing the volume of bitumen and it provides better coating of aggregate and workability of binder.

In the foaming processes, to remove the stripping problems, enough water is added to cause foaming. Producers are advised to use anti-stripping agents so that moisture resistance of an asphalt mixture can be enhanced. Foaming technologies are produced in two ways.

(A) Direct method of water based technologies

(B) Indirect method of water containing technologies

Evaluation of foaming technology for producing warm-mix asphalt

Goh et al. (2007) measured the WMA by adding Aspha- min performance based on the MEPDG after the adding of Aspha- min. From MEPDG simulations, the predicted rut depths demonstrated at which WMA decreases rutting and suggested that rutting difference can be controlled up to 44%between control HMA and WMA.

2.3 Concluding remarks

From literature, it clearly indicates that various types of aggregates, binder grades and technology have been used for preparation of warm mix. It has been observed that the procedures and techniques are used for the preparation of warm mix not only costly but also difficult to be available in the laboratory and in the field. In a simple way, warm mix additive which is not expensive and also easily available can be used for preparation of warm mix asphalt. Therefore, such an additive, which is easily available has been used in the present work to prepare warm bituminous mix and study the basic engineering characteristics and compare the same results with the conventional HMA. That is the motivation for the present work.

CHAPTER-3

METHODOLOGY & EXPERIMENTAL WORK

3.1 Introduction

This chapter describes the different materials used in this study, the experimental plan to complete proposed research and the experimental procedure employed to accomplish the objectives of research. For preparation of warm mixes, dense bituminous macadam (DBM) type of aggregate grading as per MORTH (2013 macadam (DBM) has been considered. The present study deals with the preparation of WMA in temperature range of 110°C-140^{0}C. In order to establish a best mixing, laying and compaction temperature, the viscosity of binder is determined and to determine optimum dose in mix, WMA samples are prepared in four different mixing temperatures such as 110^{0}C, 120^{0}C, 130^{0}C and 140^{0}C.

3.2 Materials used

3.2.1 Aggregates

There are various types of aggregates used for manufacturing bituminous mixes, which can be found from different natural sources such as glacial deposits or mines and can be used with or without further processing. Further these aggregates should be finished and processed to achieve adequate performance characteristics. Sometimes by- products of industry such as blast furnace slag, steel slag, fly ash etc. are used by replacing natural aggregates for enhancing the mix performance characteristics.

Fine aggregates

Fine aggregates are collected from a local crusher with fractions retained on 0.075 mm IS sieve and passing 4.75 mm IS sieve, consisting of stone crusher dusts were collected. These aggregate should be free from organic matter, clay particles, loam and clean screened quarry dusts. It fills the voids in the coarse aggregate and stiffens the binder. In this study, fine stones are used as fine aggregate whose specific gravity has been found to be 2.6.

Table 3.1 Physical properties of coarse aggregates

Property	Test Method	Test Results
Aggregate Impact Value	IS: 2386 (P IV)	14.3
Aggregate crushing Value	IS: 2386 (P IV)	13
Los Angeles Abrasion Value (%)	IS: 2386 (P IV)	18
Flakiness Index (%)	IS: 2386 (P I)	18.8
Elongation Index (%)		21.5
Water Absorption (%)	IS: 2386 (P III)	0.1

Table 3.2 Gradation for Dense Bituminous Macadam (DBM) (MORTH, 2013)

Sieve size (mm)	Percentage passing	
	Specified	**Adopted**
37.5	100	100
26.5	90-100	95
19	71-95	83
13.2	56-80	68
4.75	38-54	46
2.36	28-42	35
0.3	7-21	14
0.075	2-8	5

3.2.2 Filler

Materials passing through 0.075 mm IS sieve are treated as filler in bituminous mix. It helps to fill the voids and stiffens the binder which provides better resistance to permeability in mix. Stone dust is used as filler in this experimental work whose specific gravity found in laboratory to be 2.7.

3.2.3 Asphalt Binder

In this project, VG 30grade bitumen collected from local government depot is used to prepare the bituminous mixtures. Generally bitumen acts as a binding material in mix and treated as a visco-elastic material which shows both elastic and viscous at the normal service temperature. It acts like an elastic material at low temperature and behaves like a viscous fluid at high temperatures. The physical properties of VG 30 bitumen are presented in Table 3.3

Table 3.3 Physical properties of VG 30 bitumen

Property	Test Method	Value
Penetration at 25ºC(0.1mm)	IS: 1203:1978	67.7
Softening Point ºC	IS: 1203:1978	48.5
Specific gravity	IS: 1203:1978	1.03

3.3 Experimental plan for Binder testing

3.3.1 Binder preparation

The additive is added to the warm bituminous mix at varying rate by weight of bitumen. Binder is prepared by taking about 1.0 Kg of bitumen in a metal container and heated up to fluid condition. Detailed procedure is kept out of this report for publication purposes.

3.3.2 Viscosity measurement

At first the Rheological (viscosity) properties of additive mixed bitumen has been tested with different temperatures by Brookfield viscometer to evaluate the mixing temperature of warm bituminous mixture, It shows the changes of viscosity with temperatures. Mixing should be done at a temperature when viscosity is around 0.2Pa-s and compaction should be done when viscosity is around 5Pa-s.To evaluate the physical properties of additive mixed bitumen, test has been carried out in terms of Penetration value, softening point, ductility and elastic recovery.

3.3.2.1 Determination of Viscosity by Brookfield Viscometer

Viscosity is the resistance to flow. It is characterized in two different ways one is absolute or dynamic and other is Kinematic Viscosity. Brookfield viscometer is used to determine the absolute viscosity of bituminous binder. It is the most common method for determination of viscosity of fluid. The Brookfield rotary method shown in [Figure 3.1] is the most common method for determination of viscosity of fluid.

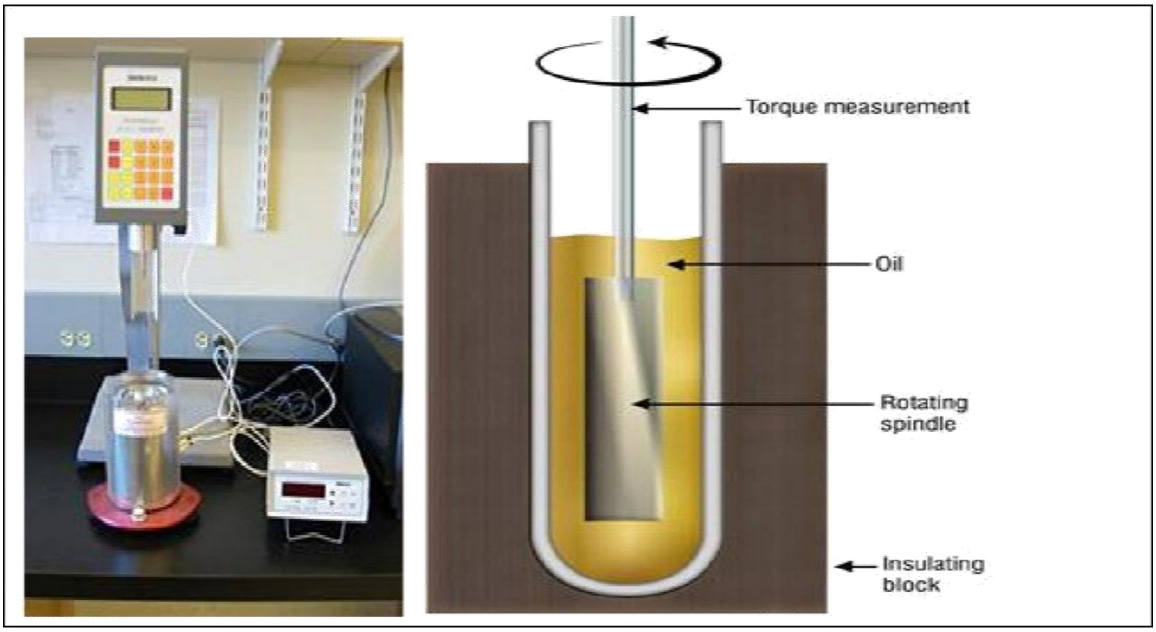

Figure 3.1: Rotational Viscometer and working principle **[** www.pavementinteractive.org**]**

3.3.2.2 Determination of Viscosity by Capillary Viscometer

Capillary viscometer can be used to determine dynamic viscosity of binder at 60^0C, according to ASTMD2170. It is also used to determine kinematic viscosity of binder at 135^0C according to ASTMD2171. The viscometer and its component parts are shown in [figure 3.2] below.

Absolute Viscosity (Pa·s) = K*t   3.1

where K = calibration factor, (Pa · s/s)
t = flow time(s)

Kinematic Viscosity (cst) = Dynamic Viscosity/ Density   3.2

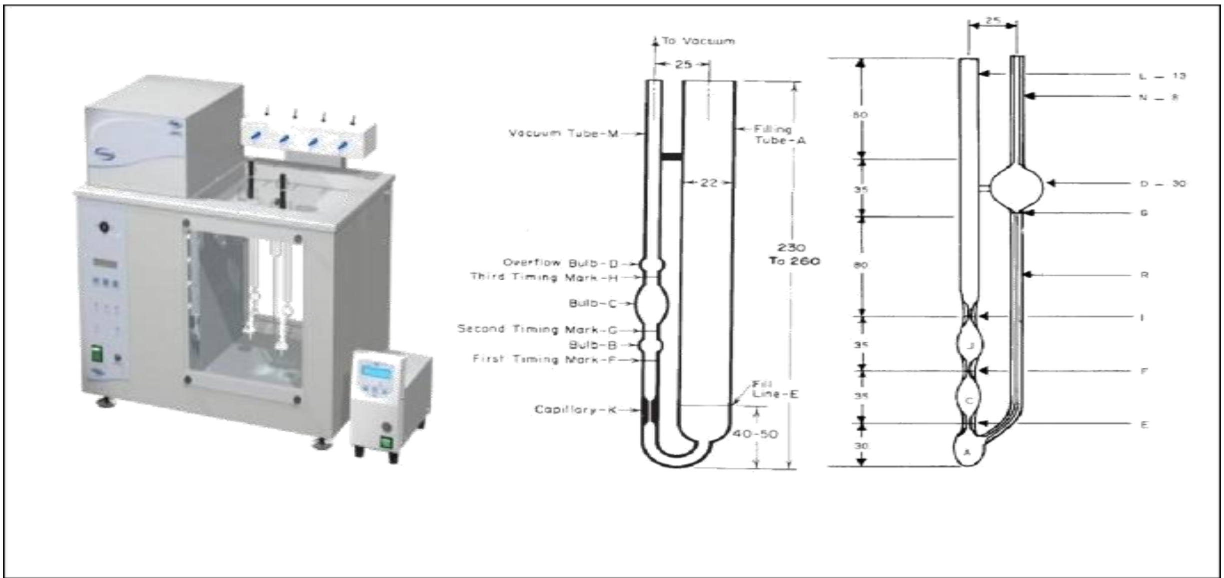

Figure 3.2: (a) Cannon Capillary Vacuum Viscometer (b) Glass tube for Absolute viscosity measurement (c) glass tube for Kinematic viscosity measurement [**ASTM D2170 & D2171]**

3.3.3 Determination of physical properties of binder

Before using this additive in road construction, it is necessary to the test the physical properties of binder, as these properties are considered really vital in India. After adding additive with VG 30, the empirical properties are studied in terms of softening point, penetration value, elastic recovery and ductility.

3.3.3.1 Penetration Test

To determine the consistency of the bitumen, penetration test is conducted under standard temperature, loading time. This test was conducted as per IS: 1203-1978.In this test, a needle penetrates into bitumen sample under a load of 100 grams for a loading time of 5 seconds at a temperature of 25 ºC. The penetration value is expressed in tenths of a millimeter (decimillimetre, dmm). The Equipment for penetration test is shown in [figure 3.13] below.

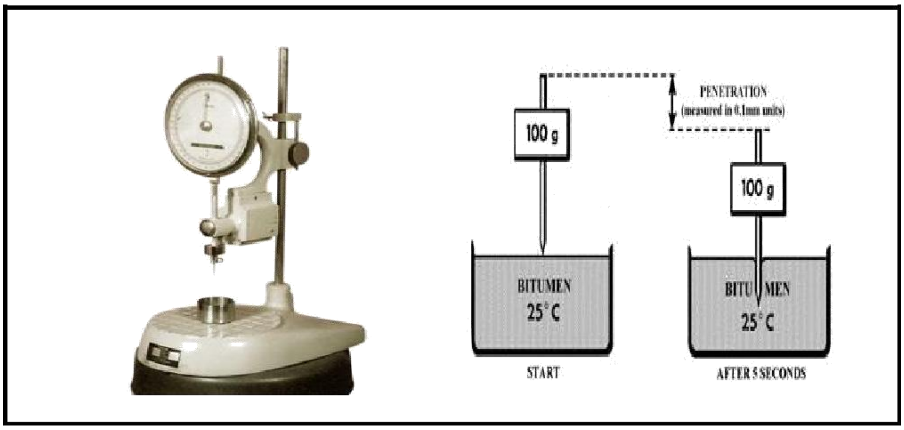

Figure 3.3: The Penetration test Apparatus [www.pavementinteractive.org]

3.3.3.2 Softening point test

Softening point is the temperature at which the binder attains a specified consistency under specified test conditions. This test is conducted as per IS: 1205-1978. In this test, fluid bitumen sample is poured in a brass ring, levelled and kept for 30 minutes at room temperature. Glass beaker containing distilled water is kept at B.O.D. incubator at 5ºC for 30 minutes. A steel ball of weight 3.5 g is laid on a bitumen sample contained in a brass ring and that is suspended inside a water bath, and then bath temperature is raised at the rate of 5ºC per minute. Temperature at which the bitumen sample touches the lower plate is reported as softening point of that sample.

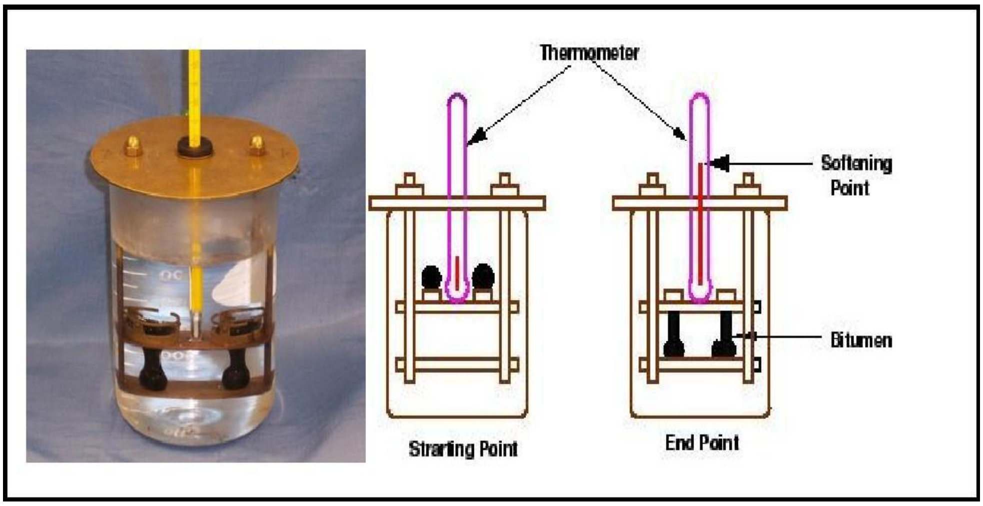

Figure3.4: Softening Point Test Apparatus [www.pavementinteractive.org]

3.3.3.3 Elastic Recovery

The elastic recovery of the bitumen is evaluated by means of the percentage recovery of the bitumen thread formed by the stretching of bitumen specimen when it is cut down by a scissor at standard conditions. The test was carried out in Ductility testing machine .Sample preparation up to attachment of mould with sample and ductility briquette in testing machine is same as ductility testing of sample. The experimental procedure is conducted as per ASTM D6084. The test was carried out in Ductility testing machine as shown in [figure 3.5].

Figure 3.5: Elastic Recovery testing apparatus **[**www.priasphalt.com**]**

3.3.3.4 Ductility Test

It gives a measure of tensile properties of bitumen.It indicates the ability of bitumento deform under load. The binder material which does not possess sufficient ductility would crack and thus provides pervious pavement surface...The experimental procedure is conducted as per ASTM D113 –07. The testing equipment is shown in [figure 3.6].

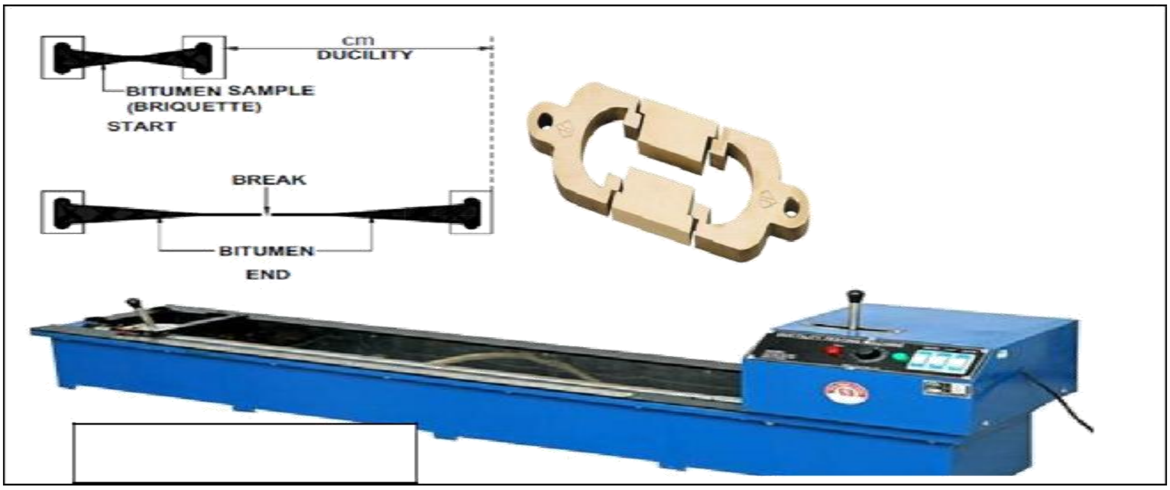

Figure 3.6: Ductility testing apparatus **[** www.pavementinteractive.org]

3.4 Experimental plan of Mixture Testing

To evaluate the effect of Additive on warm bituminous mix, Marshall samples are prepared and engineering properties such as Marshall characteristics, Indirect tensile strength, etc are carried out. The moisture susceptibility test of the modified mix was investigated in terms of retained stability values and tensile strength ratio.

3.4.1 Preparation of Marshall Samples

The modified binder was used for preparation of warm bituminous mix at a mixing temperature of 110°C -130°C. The detailed procedure has been mentioned below.

Coarse aggregates, fine aggregates and fillers of DBM aggregate gradation of required quantities are taken in an iron pan. Here stone dust is used as filler and the additive is added to the mix at a varying rate by weight of bitumen. The mix is prepared at their respective mixing temperature corresponding to the Additive concentration and then this mix is shifted to a casting mould and 75 no. of blows are given on each side of the sample.

Then each sample was marked and kept separately. Likewise Marshall samples are prepared more in number with their optimum binder contents to evaluate other engineering properties such as moisture susceptibility tests and static indirect tensile test. Marshall specimens are placed in the loading frame of a Marshall testing apparatus at temperature varying from 5°C to 40°Cto conduct static indirect tensile test as per ASTM D6913(2007) and then retained stability and tensile strength ratio tests are conducted in order to determine moisture susceptibility of the mix.

3.3.4.2 Tests on Marshall Samples

3.4.2.1 Marshall test

It is a standard laboratory method for determining the strength and flow characteristics of bituminous mix, which is adopted worldwide due to its simplicity and low of cost. It is used to determine the Optimum Binder Content (OBC) of the mix and Marshall characteristics such as Marshall stability, unit weight, flow value, air voids etc. The resistance towards plastic deformation is measured by loading the compacted cylindrical specimen of bituminous mixture diametrically at a deformation rate of 50 mm/min. Here are three major features of the Marshall method of mix design.

(i)Stability

(ii) Voids analysis

(iii) Flow tests

Marshall stability of the mix is the maximum load carrying capacity of specimen at standard test temperature of 60°Cand during loading up to the maximum load, the test specimen undergoes some deformation called flow value and then moisture susceptibility tests and static indirect tensile test are conducted for the mixes prepared at their OBC and optimum mixing temperature.

Fig. 3.7 Marshall test in progress

3.4.2.2 Retained stability test

Retained Stability (RS) test is conducted on the Marshall samples as per STP 204-22, to the measure the resistance of mix towards the moisture. The stability is determined after placing the samples in water bath at 60°C for half an hour and 24 hours. The Retained stability is calculated by using equation 3.1

$$\text{Retained Stability}=\frac{S_2 * 100}{S_1} \qquad 3.1$$

where S1= Standard stability

S2=Soaked stability (after soaking of 24 hours at 60 ℃)

3.4.2.3 Indirect tensile strength test (ITS)

In this test, a compressive load at the rate of 51 mm/minute is applied on a cylindrical Marshall specimen along a vertical diametrical plane through two curved strips made up of stainless steel, whose radius of curvature is same as that of the specimen**.** The sample is kept in the Perspex water bath maintained at the required temperature for minimum 1/2 hours before test and that same temperature is maintained during 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 and then load is applied .A relatively uniform tensile stress perpendicular to the direction of the applied load is developed in this load configuration and along the vertical diametric plane and the specimen failed by splitting along the vertical diameter. According to ASTM D 6931 (2007) from the failure load noted from dial gauge of the proving ring, the tensile strength of the specimen was calculated.

$$\mathbf{S = \frac{2 * P}{\pi * D * T}}$$

where S=Indirect Tensile Strength, kPa

P=Maximum load, kN

T=Specimen height before testing, mm

D=Specimen diameter, mm

3.4.2.4 Tensile strength ratio

The tensile strength ratio of asphalt mix is conducted to measure resistance of mix to moisture damage. As per AASHTO T283,this test are conducted on Marshall specimens with compressive load acting along the vertical diametric-loading plane at 25°C temperature and the tensile strength calculated from the load at which the specimen fails is taken as the dry tensile strength of the asphalt mix. The tensile strength ratio of asphalt mix is conducted to measure their resistance to moisture susceptibility. The specimens are placed in a water bath maintained at 60°C for 24 hours and immediately placed in an environmental chamber maintained at25°C for two hours. These conditioned specimens were then tested for their tensile strength. The ratio of the indirect tensile strength (ITS) of the water-conditioned specimens to that of dry specimens is the tensile strength ratio.

$$\textit{Tensile strength ratio} = \frac{\textit{ITS of Conditined specimen set}}{\textit{ITS of unconditioned specimen set}} * 100 \qquad 3.3$$

CHAPTER-4

RESULTS AND DISCUSSION

4.1 Introduction

According to the Methodology and Experimental work described in the 3rd chapter, test results are presented, analyzed and discussed in this chapter. This chapter consists of four sections.

First section refers Marshall Parameters used for volumetric analysis of mix.

Second section deals with selecting optimum mixing temperature used for warm mix preparation. This section also provides physical properties of bitumen with different percentages of additive.

Third Section refers the study of Marshall properties of additive modified DBM warm mix with mixing temperature of 110°C, 120°C, 130°C or 140°C and deciding the suitable mixing temperature.

Fourth Section deals with the other engineering properties of additive modified DBM mix such as resistances to thermal cracking in terms of Indirect tensile strength (ITS) and resistances to moisture damages in terms of retained stability (RS) and tensile strength ratio (TSR).

4.2 Parameters used for volumetric analysis of bituminous mix

In the volumetric analysis of warm mixture as per Das and Chakroborty (2010),The definitions and other formulae are used in calculations as follows:

Bulk Specific gravity of aggregate (G_{sb})

$$G_{sb} = \frac{\mathrm{M_{agg}}}{\text{volumeof (agg.mass +air voids in agg.+absorbed Bitumen)}} \qquad 4.1$$

where $\mathrm{M_{agg}}$ =Mass of aggregate

Effective Specific gravity of aggregate (G_{se})

$$G_{se} = \frac{M_{agg}}{Volume\ of\ (aggregate\ \ mass + air\ voids\ in\ agg)} \qquad 4.2$$

where M_{agg} =Mass of aggregate

Effective Specific gravity of aggregate (G_{se})

Theoretical Maximum Specific Gravity of Mix (G_{mm})

$$G_{mm} = \frac{M_{mix}}{Volumeof\ (mix - airvoids)} \qquad 4.3$$

$$G_{se} = \frac{M_{mix} - M_b}{\frac{M_{mix}}{G_{mm}} - \frac{M_b}{G_b}} 4.4$$

Where M_b= Mass of bitumen

G_b=Specific Gravity of bitumen

Bulk Specific Gravity of Mix (G_{mb})

$$G_{mb} = \frac{M_{mix}}{bulk\ volume\ of\ mix} \qquad 4.5$$

Air voids (VA)

$$VA= [1- \frac{G_{mb}}{G_{mm}}]\times 100 \qquad 4.6$$

Voids in mineral aggregate (VMA)

$$VMA=[1-\frac{G_{mb}}{G_{mm}} * p_s] *100 \qquad 4.7$$

P_s=Percentage of aggregate present by total mass of mix

Voids Filled with Bitumen (VFB)

$$VFB= [\frac{VMA - VA}{VMA}] * 100 \quad 4.8$$

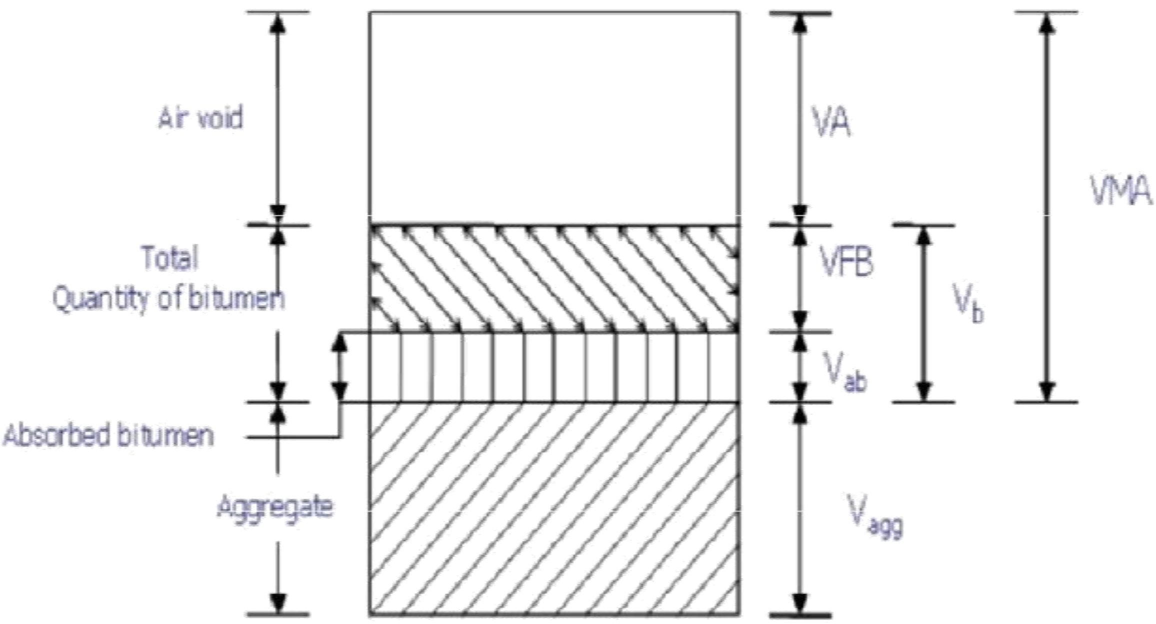

Fig. 4.1 Phase Diagram of bituminous mix (Das and Chakroborty, 2010)

4.3 Binder Test results

In this study, it is proposed to prepare warm mix with mixing temperature obtained from Brookfield viscometer by using VG 30 with different percentages of additive. As the mixing temperature plays a vital role for improving the DBM warm mix Marshall properties. Mixtures prepared with varying mixing temperatures have been studied. Mixing temperatures of110°C, 120°C, 130°C and140°C were considered for the sample preparation.

4.3.1 Determination of Mixing Temperature for Warm DBM mix

In this study, mixing temperature is determined by conducting absolute viscosity test of binder in Brookfield viscometer at different temperatures. Viscosity of VG-30 binder is measured at 110°C,120°C,130°C,140°C,150°C,160°C to produce hot mix asphalt(HMA). But viscosity of VG-30 with different percentages additive is measured at 110°C, 120°C and 130°C to produce warm mix asphalt (WMA).The results are not given here for publication purposes.

4.3.2 Determination of Physical properties of VG 30 with different percentages of additive

Before using this additive in road construction, it is necessary to the test the physical properties of binder. Thus, after adding the additive in VG 30, the physical properties are studied here in terms of softening point, penetration value, elastic recovery and ductility. The results are not given here for publication purposes.

4.4 Marshall Characteristics of warm mix

4.4.1 Effect of additive concentration on Marshall Properties for DBM warm mix

To evaluate the best combination of additive percentages in bitumen and mixing temperature, warm DBM mixes are prepared with VG-30 with different percentages of additive content at 110°C, 120°C,130°C and 140°C temperatures. The results are not given here for publication purposes.

4.4.1.1 Effect of additive content on Marshall Properties for DBM warm mix samples prepared at 110^0C, 120°C, 130°C and 140°C.

For DBM warm mix containing different doses of additives, the Marshall properties such as stability, air voids, flow value, unit weight, voids filled with bitumen (VFB) and voids filled with mineral aggregate (VMA) are obtained. It has been noticed that trend of variation in Marshall Properties with binder content are similar to normal HMA and also marked that unit weight and stability increases with binder content and there after decreases. The maximum stability and unit weight values obtained at their optimum binder content. Likewise, the air voids and flow value respectively decrease and increase with increase in binder content. It has been observed that with increase in bitumen concentration in mix VMA decrease up certain binder content and then increases sharply and also seen that VFB increases sharply with increase in binder content. The detailed results are not given here for publication purposes.

4.5 Other Engineering properties of warm mixes

4.5.1 Indirect tensile strength (ITS) of DBM mixes

Indirect tensile strength (ITS) of the mix determines the resistance against thermal cracking. These tests have been conducted for DBM mixes with modified binder at their respective mixing temperatures and binder contents having varying additive contents. The effects of temperature and additive concentrations in DBM mixes are studied. The results are not given here for publication purposes.

4.5.2 Tensile strength ratio of warm mix

Moisture susceptibility is a primary cause of distress in pavement. The evaluation of Moisture sensitivity of DBM warm mix has been widely accomplished using a standard method, AASHTO T283. The results are not given here for publication purposes.

4.5.3 Retained Stability for DBM warm mix.

Another way of evaluating the resistance to moisture damage of mix is determined by conducting retained stability test. For this additive modified DBM warm mix, retained stability has been measured at their respective optimum mixing temperatures. The results are not given here for publication purposes.

4.6 Concluding Remarks

Although DBM warm mix using certain amount additive prepared at a lower temperature shows better Marshall properties in terms of stability, unit weight, air voids and economical in consumption of warm mix additive. The detailed results are not given here for publication purposes.

CHAPTER-5

SUMMARY AND FUTURE SCOPE OF WORK

5.1 Summary

An attempt has been made in this study to prepare DBM warm mix using a chemical additive. The effect of addition of the additive concentration on DBM mix has been studied through Marshall properties.

- Satisfactory Marshall Characteristics have been observed for all DBM mixes prepared at respective mixing temperatures with their corresponding optimum binder contents.
- Tensile strength ratio and retained stability values has been observed higher with additive containing DBM warm mix prepared.

The detailed summary of results are not given here for publication purposes.

5.2 Future scope of works

In this study, Engineering properties of DBM warm mix such as Marshall properties, static tensile strength, tensile strength ratio, retained stability have been studied by using VG 30 grade bitumen with a chemical additive. There are still several aspects about this technology need to be evaluated before it is implemented particularly in respect of the engineering properties such as fatigue properties, resistance to rutting, dynamic indirect tensile strength characteristics and dynamic creep behaviour.

- ❖ The fatigue properties of Additive modified warm asphalt mixture can be evaluated.
- ❖ The performance of Additive modified warm mix binder and mixture can be evaluated and Mixture can be studied with modified grade of bitumen like SBS, CRMB.
- ❖ Various other types of aggregate grading, filler, binder and additive can also be considered for further studies.

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