Investigation of Emulsion Based Warm Mixes Asphalt For Sustainable Paving Solutions

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Abstract

Due to the increase in energy costs and emission problems associated with hot mix asphalt (HMA), there has been significant interest in developing warm mix asphalt (WMA) technology for pavement construction. This method in bituminous paving technology allows for the production and placement of bituminous mixes at lower temperatures than HMA, utilizing an environmentally friendly production process with organic additives, chemical additives, and water-based technologies. This study investigates the preparation of warm mixes by pre-coating stone chips with medium setting bitumen emulsion (MS) and then mixing the coated aggregates with VG 30 bitumen at reduced temperatures. The two binders are used in equal proportions to form the binder.

Three mixing temperatures were examined: 110°C, 120°C, and 130°C. Marshall samples were prepared using dense bituminous macadam (DBM) and bituminous concrete (BC) grading according to MORTH specifications. The main objectives were to determine the optimal type of filler, emulsion setting time, mix preparation temperature, and bitumen-emulsion binder composition. The study found that mixes prepared at 120°C with an 80:20 bitumen-emulsion composition for DBM and a 70:30 composition for BC exhibited the highest Marshall Stability and indirect tensile strength (ITS), while also meeting other Marshall parameters.

The optimum binder contents for warm mixes were identified as 5.1% with an 80:20 bitumen-emulsion composition for DBM and 4.9% with a 70:30 bitumen-emulsion composition for BC, both prepared at 120°C. The tensile strength ratio and retained stability parameters were also found to be satisfactory in these warm mixes. The performance of the warm mixes was comparable to that of traditional HMA, demonstrating their potential as sustainable paving solutions.

Keywords: Warm Mix Asphalt (WMA), Hot Mix Asphalt (HMA), Medium Setting Emulsion, Marshall Properties, Indirect Tensile Strength, Tensile Strength Ratio, Retained Stability.

1. Introduction

1.1 General

Warm Mix Asphalt (WMA) is a fast emerging technology, now accepted worldwide. The idea of use of lower temperatures to produce asphalt mixes is not new.WMA is defined as the asphalt mixture whose mixing temperature is from 100C to 135C (Hurley and Prowell,2005). In this technology organic additives, chemical additives and foaming technology are used to manufacture and spread asphalt mixes at lower temperature than conventional Hot Mix Asphalt (HMA) by decreasing the asphalt viscosity.WMA is produced, placed and compacted at temperature10°C to 40°C lower than the conventional Hot Mix Asphalt (D' Angelo et.al, 2008). It is a technology that allows lowering of the production and paving temperature of Hot Mix Asphalt (HMA) by reducing the viscosity of binder which helps in increasing the workability of mixture without compromising the performance of asphalt. It reduces energy consumption, carbon dioxide emission, oxidative hardening of Asphalt, overhead and total costs of the Asphalt industry by lowering the production temperature thereby creating a better working environment. However, the lower mixing temperatures have raised concerns on the performance of the mixtures. So there is need to thoroughly evaluate and characterize the WMA mixtures to ensure adequate performance.

1.2 Objective and Present Study

The main objectives of the present study are:

- To develop a procedure for warm mix asphalt using medium setting emulsion (MS).

- To investigate and study the effects of varying temperatures on mix preparation and emulsion concentration in terms of Marshall Properties for both the types of mixes (BC and DBM mixes).
- To decide the best mix parameters such as temperature for the preparation of warm mix, emulsion concentration in binder and optimum binder content.
- To study the effects of Indirect Tensile Strength Test (ITS) of warm mixes at different temperatures.
- To study the moisture susceptibility characteristics of mixtures in terms of their tensile strength ratio and retained stability values.

2. Literature Review

2.1 Introduction

Warm Mix Asphalt (WMA) developed in Europe in the mid 1990's. This technology is known as warm asphalt mixes in areas throughout Europe, generally been referred as Warm Mix Asphalt in the United States. Warm Mix Asphalt has not only been successful in its intended purpose of lowering asphalt fumes and emissions through lowering mixing and compaction temperatures, but has also been found to possess numerous other benefits for the asphalt paving industry. Warm Mix Asphalt may also act as a compaction aid for stiffer mixes that are more difficult to compact, such as Stone Matrix Asphalt, when used at typical compaction temperatures. Enormous research and development have been done on warm mix asphalt by number of researchers. After review of literatures on the subjects some of the important research contributions are presented below. The Review of literature is divided into two parts. The first part gives detail idea about the various technologies involved in the formation of WMA along with the contribution of various researchers under that particular technology who have used wide varieties of additives for making warm mixes, which is sub categorized into three parts basing on organic additive, chemical additive, and foaming technology. Finally, the second part consists of various literatures on mix design process of warm mixes.

Maccarone et al. (1994) Studied about Warm-Mixed asphalt-based foamed bitumen with very high binder content emulsions and concluded that the use of mixes for use on roads was gaining acceptance worldwide due to energy efficiency and lower emissions.

Jenkins et al. (1999) introduced a new process involving half-warm foamed bitumen. He explored the concepts and possible benefits of heating wide variety of aggregates to temperatures below 212°F before the application of foamed bitumen. Preheating aggregates enhanced particle coating, mix cohesion, tensile strength, and compaction. This is particularly beneficial for mixes containing reclaimed asphalt pavement (RAP) or densely graded crushed aggregates.

Harrison and Christodulaki, (2000) observed that by adding Aspha-min to the mix at the same time as the binder, a very fine water vapour is created. This release of water creates a volume expansion of the binder that results in the formation of asphalt foam, allowing increased workability and aggregate coating at lower temperatures.

Koenders (2002) introduced foamed WMA technologies to produce asphalt mixtures at lower temperatures.

Hurley and Prowell (2005) stated that the addition of Aspha-min lowered the air voids measured in the gyratory compactor. It improves the compaction ability of both the superpose and vibratory compactor. Statistical analysis of test results indicated an average reduction in air voids of 0.65% using the vibratory compactor.

Goh et al. (2007) evaluated the performance of wma after the addition of Aspha- min, based on the MEPDG. The predicted rut depths from the MEPDG simulations demonstrated that WMA could decrease rutting, and the greatest difference of rutting between wma and its control HMA could be up to 44%.

2.2 Scope of the Work

Based on review of literature the following scopes have been identified for the present study.

- Selection of all materials used normally used in Indian context, for preparation of warm mixes including aggregate grading.
- Conduct of several trials starting with principle of partial coating of aggregates with the help of bitumen emulsion followed by mixing with bitumen at warm temperatures, with the objective of development of a procedure for preparation of warm mixes.
- Selection of filler type, setting time of emulsion, bitumen-emulsion composition for the preparation of specified warm mixes.

- Evaluation of warm mixes produced in terms of Marshall Properties with several variables such as temperature of mix preparation and bitumen-emulsion composition.
- Deciding the best mix parameters such as temperature of mix preparation, emulsion concentration in binder, optimum binder content for the preparation of warm mixes.
- Evaluation of warm mixes in terms of Marshall Properties, Indirect Tensile Strength and moisture susceptibility characteristics.

3. Experimental Investigation

3.1 Materials Used

3.1.1 Aggregates

The coarse aggregates and fine aggregates (retained on 0.075 mm IS sieve) inclusive of dust, were collected from a local crusher. For preparation of two types of bituminous mixes (DBM, BC) aggregates gradations were considered as per MORTH (2013), given in Table 3.1 and Table 3.2 respectively. The physical properties of coarse aggregates are given in Table 3.3 and the specific gravity of coarse and fine aggregates are 2.75 and 2.6 respectively.

Table 3.1 Gradation for Bituminous Concrete (BC) (MORTH, 2013)

Sieve Size (Mm)	Percentage Passing
19	100
13.2	79-100
9.5	70-88
4.75	53-71
2.36	42-58
1.18	34-38
0.6	26-38
0.3	18-28
0.15	12-20
0.075	4-10

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

Sieve Size (Mm)	Percentage Passing
37.5	100
26.5	90-100
19	71-95
13.2	56-80
4.75	38-54
2.36	28-42
0.3	7-21
0.075	2-8

Table 3.3 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)	13.0
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

3.2.2 Filler

The materials passing through 0.075 mm ARE sieve is filler. It fills the voids, stiffens the binder and offers better impermeability. In this experimental WMA work, stone dust and cement were used as filler whose specific gravity found in laboratory to be 2.7 and 3.0 respectively.

3.2.3 Binder

Generally bitumen acts as a binding agent to the aggregates, fines and stabilizers the bituminous mixtures. Bitumen must be treated as a visco-elastic material as it exhibits both viscous as well as elastic properties at the normal pavement temperature. At low temperature it behaves like an elastic material and at high temperatures its behaviour is like a viscous fluid. Conventional VG30 grade bitumen, collected from local government depot has been used in this research study to prepare the two types of bituminous mixtures. The physical properties of VG 30 bitumen is presented in table 3.4.

Table 3.4 Physical Properties of VG 30 Bitumen

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

3.2.4 Bituminous Emulsion

An Emulsion can be defined as the dispersion of small droplets of one liquid in another. Bituminous emulsions generally belong to oil - in -water type where bitumen is dispersed in water with small quantity of emulsifying agent. Chemically stabilized bituminous emulsion has three necessary components bitumen, water and emulsifying agent. The asphalt cement is used for cementing or bonding of aggregates and standing up to traffic, environmental conditions and climate temperature. The emulsifying agent is called surfactant which is chemically composed of large molecules. Some of the benefits of bituminous emulsions are reduce energy needs and fume production, water based emulsions mix easily with aggregates, Emulsion mixes can be mixed on site, in portable plant or at central mixing plant and Emulsion mix overlays improves structural capacity of roads.

According to the setting of emulsion these can be categorized as Rapid Setting Emulsion (RS), Medium Setting Emulsion (MS), and Slow Setting Emulsion (SS).

- Rapid Setting Emulsion (RS) are the least stable emulsion and break rapidly when come in contact with aggregates. This has no ability to mix the aggregates. These aregenerally used for spray applications.
- Medium Setting Emulsion (MS) are designed to mix with aggregates. Depending on the design medium setting emulsion remain workable from few minutes to several months.
- Slow Setting Emulsion (SS) are designed to work with the fine aggregates to allow for the maximum mixing time and extended workability. These are the most stable emulsion. These can be used in dense graded aggregate bases, soil stabilization and for some slurry seals.

The physical properties of Medium setting emulsion, also collected from local government depot are presented in table 3.5.

Table 3.5 Physical Properties of Bituminous Emulsion (MS)

Property	Test method	Test result
Viscosity by Saybolt Furol Viscometer at 50° C (Sec)	IS : 8887-2004	120
Residue by evaporation (%)	IS : 8887-2004	65.4
Residue Penetration at 25° C (0.1 mm)	IS : 8887-2004	84
Residue Ductility at 27° C (cm)	IS : 8887-2004	95

4. Results and Discussion

4.1 Parameters Used

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

Bulk Specific Gravity of Aggregate (□)

$$G_{sb} = \frac{M_{agg}}{\text{volume of (agg.mass+airvoid in agg.+absorb bitumen)}} \quad (4.1)$$

Where M_{agg} = mass of aggregate

Effective Specific Gravity of Aggregate (□)

$$G_{se} = \frac{M_{agg}}{\text{volume of (agg.mass+air void in aggregate)}} \quad (4.2)$$

Where M_{agg} = mass of aggregate

$$G_{se} = (M_{mix} - M_b) / \left(\frac{M_{mix}}{G_{mm}} - \frac{M_b}{G_b}\right) \quad (4.3)$$

Where M_b = mass of bitumen used in mix

G_b = specific gravity of bitumen

Apparent Specific Gravity (Ga)

$$G_a = \frac{M_{agg}}{\text{volume of aggregate mass}} \quad (4.4)$$

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

$$G_{mm} = \frac{M_{mix}}{\text{volume of (mix} - \text{air voids)}} \quad (4.5)$$

Bulk Specific Gravity of Mix (G_{mb})

$$G_{mb} = \frac{M_{mix}}{\text{bulk volume of mix}} \quad (4.6)$$

Air Voids (VA)

$$VA = \left[1 - \frac{G_{mb}}{G_{mm}}\right] * 100 \quad (4.7)$$

Voids in Mineral Aggregates (VMA)

$$VMA = \left[1 - \frac{G_{mb}}{G_{mm}} * P_S\right] *100 \quad (4.8)$$

Where P_S = percentage of aggregate present by total mass of mix

Voids Filled With Bitumen (VFB)

$$VFB = \left[\frac{VMA-VA}{VMA}\right] *100 \quad (4.9)$$

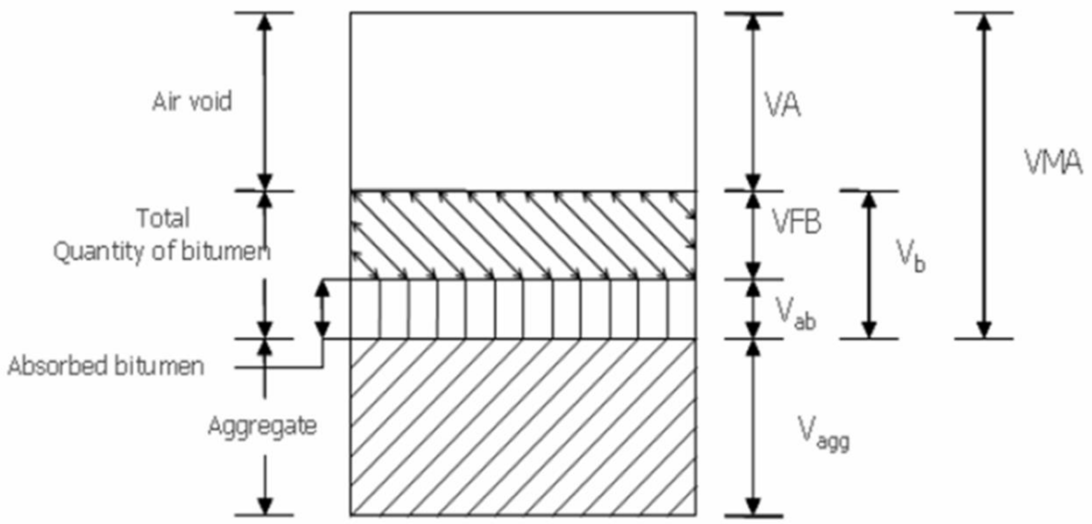

Fig. 4.1 Phase Diagram of bituminous mix (Das and Chakroborty 2010)

4.4.3 Comparison of Marshall Properties of DBM and BC Warm Mixes Prepared At Optimum Binder Content and Composition

The optimum binder content for DBM and BC warm mixes at each temperature of 110°C, 120°C and130°C is obtained by taking average value of following three binder content foundfrom above graphs i.e.

- Bitumen content correspond to maximum stability
- Bitumen content correspond to maximum unit weigh
- Bitumen content corresponding to the median of designed limits of percentage air voidsin total mix

Table 4.1 Maximum Marshall Values for DBM and BC at their OBC

Mixing Temperature(°C)	Unit Weight (Kn/M³)	Stability(Kn)	Air Voids(%)	Flow Value (Mm)	OBC(%)
DBM 110°C 70B:30E	24.06	11	4.6	2.5	5
DBM 120°C 80B:20E	24.25	11.8	3.08	2.4	5.1
DBM 130°C 90B:10E	24	10.5	4.08	2.6	5.4

BC 110°C 60B:40E	24	10.3	4.5	2.6	5
BC 120°C 70B:30E	24.16	11.5	4.4	2.4	4.9
BC 130°C 80B:20E	24.1	10.9	4.7	2.7	5.1

The test results as shown above are also presented in the form of a bar chart shown below in fig 4.50 and fig 4.51. It is seen that the DBM warm mix prepared at 120°C taking 80B:20E binder content shows better Marshall Properties having the highest stability and unit weight and less air voids as compared to samples with other mixing temperatures. Similarly for BC warm mix the mixes prepared at 120°C taking 70B:30E binder content shows better Marshall Properties.

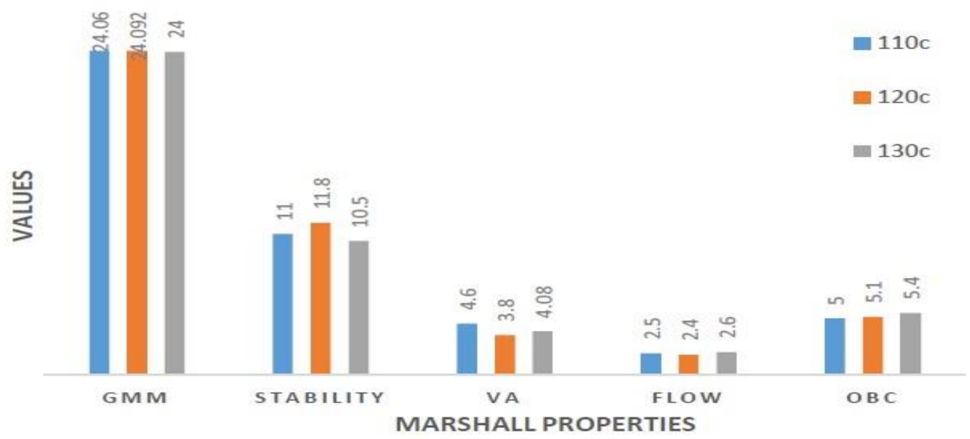

Fig.4.1 Bar Chart for DBM Warm Mix Showing Marshall Properties Values at OBC

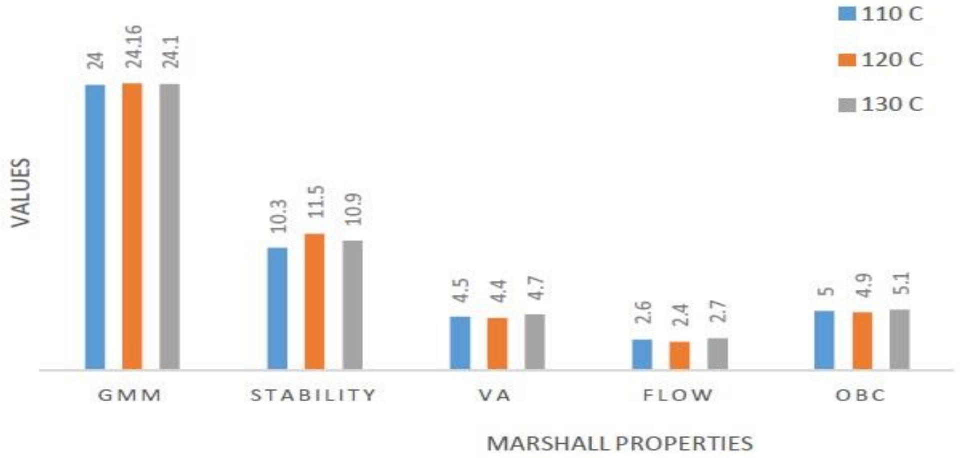

Fig.4.2 Bar Graph for BC Warm Mix Showing Marshall Properties Values at OBC

4.5 Other Engineering Properties of Warm Mixes

4.5.1 Indirect Tensile Strength (ITS) For DBM and BC Mixes at Various MixingTemperatures

Static indirect tensile test is used to determine the direct tensile strength (ITS) of the mix which helps to find out the resistance to thermal cracking. The static indirect tensile tests are carried out on DBM and BC mixes prepared at their optimum bitumen emulsion content at each mixing temperatures of 110°C, 120°C, 130°C.The effects of emulsion bitumen binder aswell as temperature on both the mixes are studied.

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Below Fig 4.52 and Fig 4.53 show the variations of indirect tensile strength with respect to temperature for both mixes of BC and DBM. It is seen that the ITS value decreases with increase in temperature. The BC warm mix prepared at 120°C by taking its 70B:30E as optimum emulsion binder content shows higher ITS value followed by mixes prepared at 110°C and 130°C. Similarly DBM mix prepared at 80B:20E binder content shows higher ITS value as compared to other DBM warm mixes. The ITS value of BC and DBM HMA mixes shows highest ITS values as compared to its respective wma mixes.

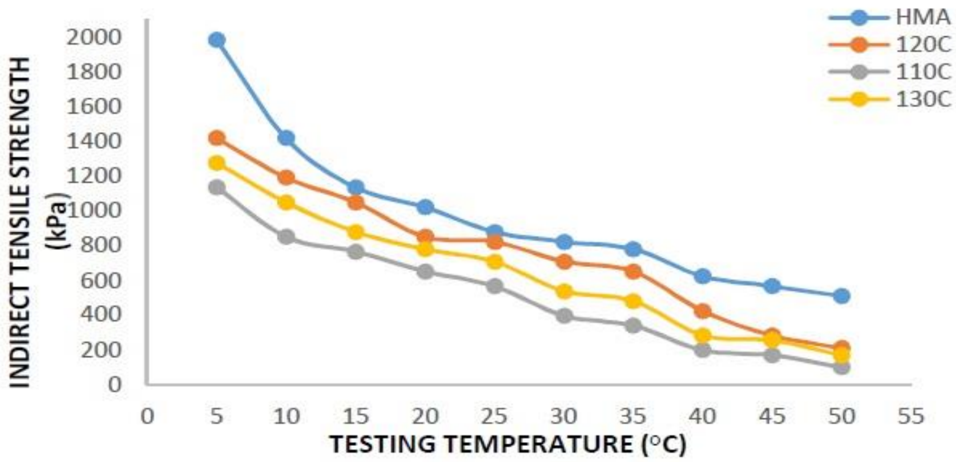

Fig 4.3 Indirect Tensile Strength for BC Mixes At Various Mixing Temperatures

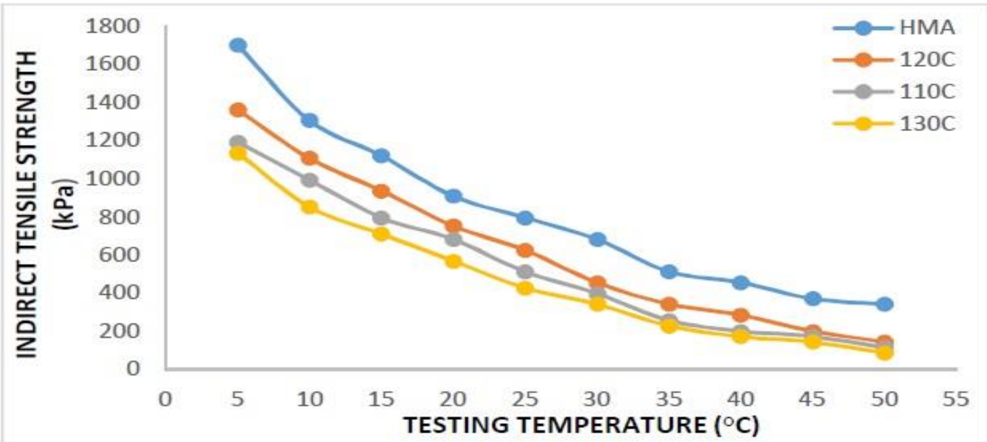

Fig.4.4 Indirect Tensile Strength for DBM Mixes At Various Mixing Temperatures

4.5.2 Tensile Strength Ratio of DBM and BC mixes

The tensile strength ratio (TSR) measures the resistance of a paving mix to moisture-induced damage. Table 4.2 presents the TSR of Dense Bituminous Macadam (DBM) and Bituminous Concrete (BC) mixes, calculated at various mixing temperatures using the optimum binder content for each mix. The BC mix prepared at 120°C with a 70B:30E emulsion binder content shows a higher TSR value compared to other temperatures. Similarly, the DBM mix prepared at 120°C with an 80B:20E binder content also exhibits a higher TSR value than other DBM warm mixes. Both BC and DBM Hot Mix Asphalt (HMA) demonstrate higher TSR values.

Bitumen viscosity, indicating resistance to flow, affects the workability and deformation resistance of the mixture. In this study, bitumen is used in two stages: emulsion in the initial stage and heated bitumen in the final stage. While higher temperatures typically benefit bituminous mixes, at 130°C, the residual bitumen from pre-coating can flow and interact with additional conventional bitumen. However, the resulting binder lacks the necessary viscosity to coat aggregate particles adequately, leading to inferior engineering properties in the warm mixes.

Table 4.2 Tensile Strength Ratio Values of Different Mixes

Tensile Strength Ratio Of DBM Mixes At Various Mixing Temperatures		
HMA	83 %	Minimum 80%(as per MORTHTable 500-17)
110 °C	78.8 %	
120 °C	80%	
130 °C	78.3%	
Tensile Strength Ratio Of BC Mixes At Various Mixing Temperatures		
HMA	83.6%	Minimum 80% (as per MORTH Table 500-17)
110°C	78%	
120°C	80.7%	
130°C	79%	

4.5.3 Retained Stability for DBM and BC mixes

Another way of assessing the moisture induced damage to a paving mix is by determining the retained stability of the concerned mix. This has been calculated for both DBM and BC mixes at mixing temperatures of 110°C, 120°C, 130°C at their respective optimum binder contents. The results of this study are presented in Table 4.3. It is seen that the retained stability of DBM shows better results as compared to BC mixes. DBM and BC warm mixes prepared at 120°C taking Optimum Emulsion Binder of 80B:20E and 70B:30E respectively shows higherretained stability values.

Table 4.3 Retained Stability for DBM and BC Mixes at Various Mixing Temperatures

Types of Mixwith temperature	Avg. stabilityafter half an hour in waterat 60 °c (kN)	Avg. stabilityafter 24 hours in water at 60 °c (kN)	Avg. retained Stability, in %	Design Requirement
DBM HMA	13	10.3	79	Minimum 75%(as per MORTHTable 500-17)
DBM 110 °C	11	7.8	70.9	
DBM 120 °C	11.8	9	76.27	
DBM 130 °C	10.5	7.1	67.61	
BC HMA	14.4	11.5	79.86	
BC 110 °C	10.3	7	67.96	
BC120 °C	11.5	8.8	75.52	
BC130° C	10.9	7.8	71.55	

4.6 Concluding Remarks

The laboratory study on warm mixes prepared on DBM and BC aggregate gradation at three different mixing temperature of 110°C, 120°C, and 130°C using medium setting emulsion (MS) and VG30 binder in various Binder Emulsion ratio of 50B:50E, 60B:40E, 70B:30E, 80B:20E, 90B:10E, 100B:0E and cement as filler. DBM and BC mixes prepared using three different mixing temperatures and six different Emulsion Binder proportion for each mixing temperature finally evaluates, that DBM and BC warm mixes prepared at 120°C using 80B:20E and 70B:30E Binder Emulsion proportion shows better Marshall properties as compared to other DBM and BC warm mixes prepared using other binder emulsion contents and mixing temperatures. The Indirect Tensile Strength Test (ITS), Tensile Strength Ratio (TSR), and Retained Stability results of DBM, BC warm mixes prepared at 120°C using 80B:20E, 70B:30E shows better results as compared to other warm mixes of both gradations.

Hence for the preparation of warm mixes of DBM and BC 120°C temperature and bitumen- emulsion composition of 80B:20E, 70B:30E respectively can be considered for better warm mix design.

4.6.1 Comparison of DBM and BC Warm Mix at 120 °C with Normal HMA

The overall study of the research work reveals that warm mixes of DBM and BC using 80B:20E, 70B:30E binder emulsion content respectively at 120°C shows better Marshall Properties in terms of stability, Unit weight, Air Voids. Hence warm mixes of DBM and BC prepared at 120°C is compared with normal HMA of both the mixes for Marshall Properties comparative study .The graphs shows comparison of DBM and BC warm mixes prepared at 120°C using bitumen Emulsion content of 80B:20E and 70B:30E respectively with normal HMA. Marshall Properties like Stability, Unit Weight, and Air Void, Flow values of both DBM and BC warm mixes are compared with normal HMA.

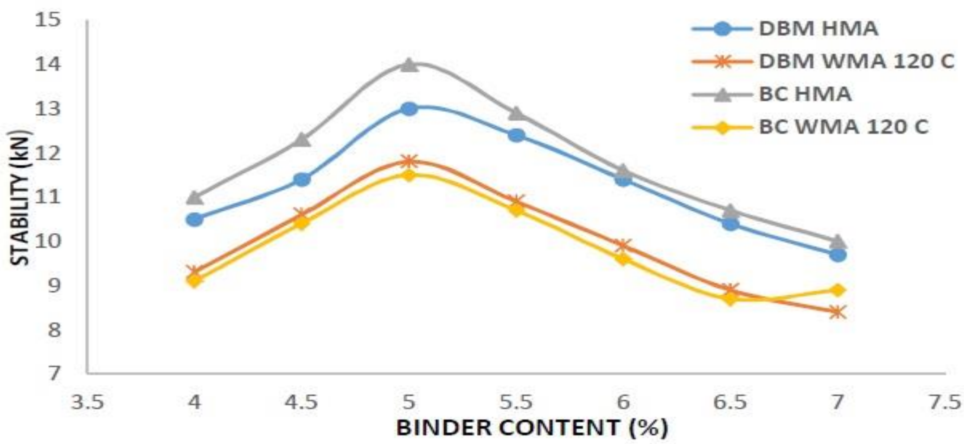

Fig4.5 Stability Vs Binder Content of HMA and WMA Mixes

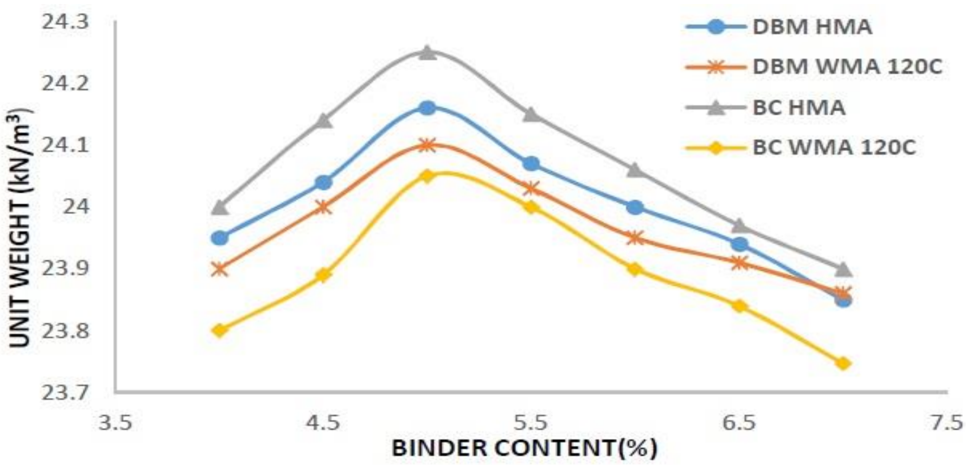

Fig. 4.55 Unit Weight Vs Binder Content for HMA and WMA Mixes

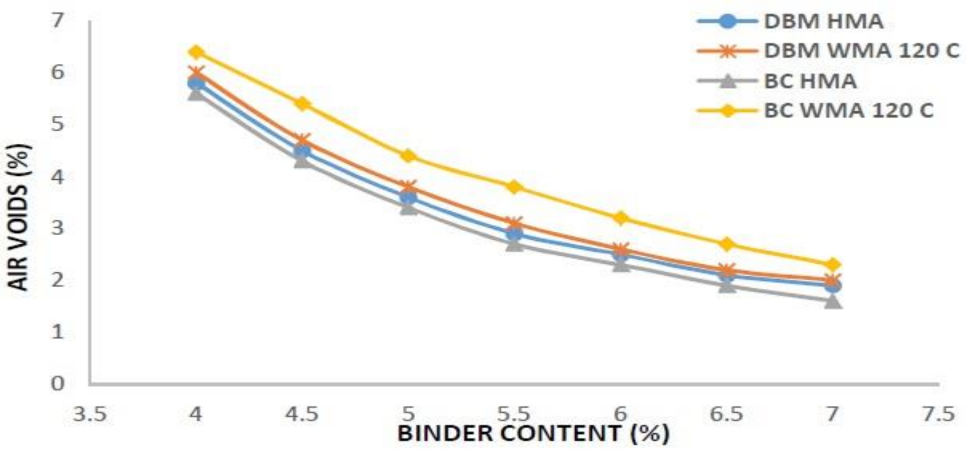

Fig 4.7 Air Void Vs Binder Content for HMA and WMA Mixes

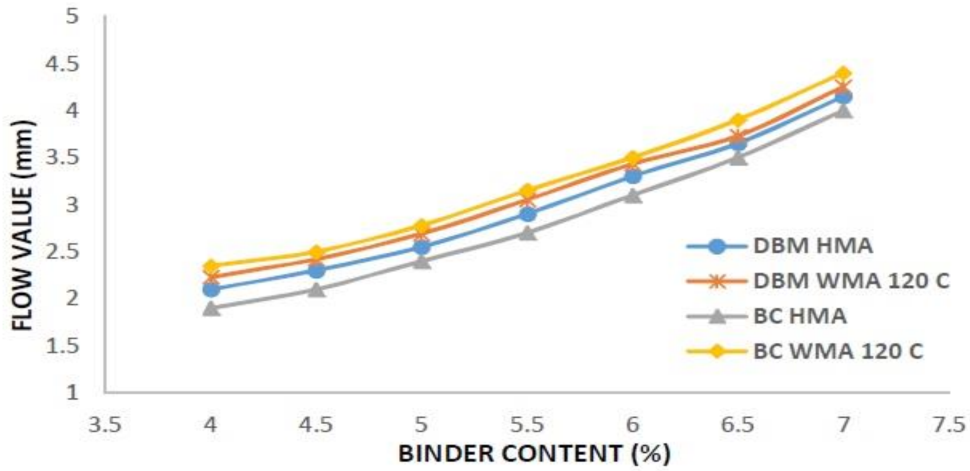

Fig 4.8 Flow Value Vs Binder Content for HMA and WMA Mixes

5. Conclusion and Future Scope

5.1 Introduction

In this study, an attempt has been made to prepare warm mixes with medium setting (MS) emulsion as initial coating of stone chips followed by application of conventional VG 30 bitumen. As a result of extensive laboratory tests conducted on Marshall warm mix specimens with DBM and BC gradation to study various parameters, the following conclusions are drawn.

5.2 DBM Mixes

Based on Marshall Properties of mixes with DBM gradation, the optimum setting time of emulsion and type of filler were found to be 9 hours and cement respectively. These parameters have been considered in subsequent studies.

- Based on Marshall Tests, for warm mixes prepared at 110°C for DBM warm mixes optimum binder composition i.e. bitumen emulsion ratio in binder is found to be 70:30 and optimum binder content is observed to be 5%. Similarly for mixes prepared at 120°C and 130°C, for DBM warm mixes the optimum binder content and optimum binder composition are found to be 5.1%, 80:20; and 5.5%, 90:10 respectively.
- Satisfactory Marshall Characteristics are observed for mixes prepared at all three temperatures at their optimum binder contents and binder compositions.
- The maximum indirect tensile strength value is observed for warm mixes prepared at 120^{0}C.
- The tensile strength ratio and retained stability values for DBM warm mix at 120 °C is observed to be higher as compared to other DBM warm mixes prepared at 110°C, 130°C.

- Out of the three temperatures tried in this study, it is observed that the mixes prepared at 120^0C for DBM warm mix offer highest stability and indirect tensile values satisfying other Marshall parameters. Hence the specific mix i.e. mix prepared at 5.1% binder content and 80:20 bitumen emulsion composition considered to be the most suitable warm mix which is normally comparable with normal HMA.

5.3 BC Mixes

Based on Marshall Properties of mixes with BC gradation, the optimum setting time of emulsion and type of filler were found to be 9 hours and cement respectively. These parameters have been considered in subsequent studies.

- Based on Marshall Tests, for warm mixes prepared at 110°C for BC warm mixes optimum binder composition i.e. bitumen emulsion ratio in binder is found to be 60:40 and optimum binder content is observed to be 5%. Similarly for mixes prepared at 120°C and 130°C,for BC warm mixes the optimum binder content and optimum binder composition are found to be 4.9%, 70:30; and 5.1%, 80:20 respectively.
- Satisfactory Marshall Characteristics are observed for mixes prepared at all three temperatures at their optimum binder contents and binder compositions.
- The maximum indirect tensile strength value is observed for warm mixes prepared at 120^0C.
- The Tensile Strength Ratio and Retained Stability value for BC warm mix at 120°C is observed to be higher as compared to other BC warm mixes prepared at 110°C, 130°C.
- Out of the three temperatures tried in this study, it is observed that the mixes prepared at 120^0C for BC warm mixes offer highest stability and indirect tensile values satisfying other Marshall parameters. Hence the specific mix i.e. mix prepared at 4.9% binder content and 70:30 bitumen emulsion composition considered to be the most suitable warm mix which is normally comparable with normal HMA.

Hence it can be concluded in general that for preparation of bituminous emulsion based warm mixes of DBM and BC gradation the optimum temperature for the preparation in both types of mixes is 120°C. The optimum bitumen-emulsion composition for warm mixes with DBM and BC gradations are found to be 80:20 and 70:30 respectively.

5.4 Future Scope of Works

1. Many properties of BC and DBM mixes such as Marshall Properties, static tensile strength, tensile strength ratio, retained stability have been studied in this investigation by using VG 30 penetration grade bitumen and medium setting emulsion (MS). However, some of the properties such as fatigue properties, resistance to rutting, dynamic indirect tensile strength characteristics and dynamic creep behaviour needed to be investigated.
2. In present Study Medium Setting Emulsion and VG 30 binder have been used. The research can further be enhanced by varying proportions of the Emulsion Bitumen content.
3. Variation of temperatures can be considered for the warm mix preparation so lower temperatures can also be studied for mix preparation.
4. Various other types of aggregate grading, Filler, Binder, Emulsion and Additive can be considered for further studies.

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