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Comparative Study on the Performance of Open Graded Friction Course using Hot and Warm Mix Technology

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ABSTRACT

Conventional pavements and parking lots are constructed as impervious structures which leads to large volumes of stormwater runoff. This increases the load of stormwater drains besides the water carries the dirt and debris present on the surface and pollutes the water bodies. Surface detention basins are usually provided to collect the runoff and slow down its rate. But this requires additional land space. So, a solution in this regard is to provide a permeable pavement system that permits the infiltration of the stormwater. Open graded friction courses are provided as the surface course of such pavements. This research aims at assessing the feasibility of using warm mix technology in the production of open graded friction course mixes. The focus was on the benefits that could be acquired by the use of WMA technology in a porous asphalt mix. In this study a chemical additive namely sasobit was used to prepare warm mixes. A comparative assessment between hot and warm porous bituminous mixes was made. The fundamental parameters evaluated includes volumetric properties of the mix, permeability, drain down, Cantabro abrasion loss, and moisture susceptibility. It was found that the warm mix additive was capable of reducing the production temperature and the maximum temperature reduction was obtained in the case of 3% sasobit. About 10^0C reduction in mixing and 13^0C reduction in compaction temperature could be achieved. The results indicate that open graded mixes prepared with warm mix technology met the performance criteria and hence it is suitable for application in porous pavements. This reduction in temperature could be translated to reduced fuel consumption for heating the binder and reduced level of emissions. Thus, it leads to better working environment for those involved in road construction.

Keywords:
Open graded friction course; warm mix; permeable pavement system

1. Introduction

Conventional pavements are impervious with dense graded configuration. They do not permit infiltration of water which leads to large volumes of storm water runoff being diverted to storm water drains and water bodies. This in turn increases the load on the storm water drains. Besides they carry a lot of dirt and debris present on the surface and pollutes the water. Detention basins are provided with the view of slowing down the rate of runoff and also for collecting the storm water. But this

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requires large areas of land. The solution to this problem could be a permeable pavement.

Permeable pavement is characterized by a surface layer of porous asphalt. Usually, open graded friction course (OGFC) is used as the surface layer. Underlying the surface layer is a granular layer which serves as a construction platform and prevents the dislocation of large sized aggregates in the stone reservoir layer beneath it. The subgrade soil below should have sufficient infiltration capability or else suitable overflow mechanism can be adopted. Open graded friction course mixes have less fines as compared to dense graded mixes. This type of gradation imparts a coarse granular skeleton with highly interconnected air voids to the mix [1]. It can be placed on top of dense graded mixes to furnish a skid resistant pavement. Alternatively, it can be placed on a stone reservoir bed underlying a granular working platform to serve as a permeable pavement. They are usually designed for onsite-runoff but may also cater to off-site runoff in certain cases.

The binder content for open graded mixes is kept higher than conventional dense graded mixes with a view of imparting durability to the mixes. This in turn leads to increased binder film thick-ness which is considered as the main reason for binder drain down. Ravelling is also attributed to the open graded configuration of porous mix which entrains more air and leads to premature ageing of bitumen. This causes the aggregates at the surface to wear away from the rest of the pavement. The problem of drain down is addressed by incorporating suitable additives in the mix [2]. Additives like polymers have found to stiffen the bitumen and fibres tend to absorb the excess bitumen. The fibres enhance the thickness of binder around the aggregate and thereby prevents its drainage. Porous mixes incorporating binder with high viscosity exhibited greater resistance to moisture damage and rutting when compared to mixes with neat binder [3]. When the content of high viscosity modifier was increased from 3 to 10 %, about 15% increase in rutting resistance was observed [4].

In order to make the construction of pavements sustainable, efforts have been made to reduce the mixing and production temperature. Warm Mix Asphalt (WMA) technology is one such technology which makes the pavement laying process more sustainable. This technology was first tried in Europe in the late nineties but it gained momentum by National Asphalt Pavement Association in USA. Lowering the production temperature can be accomplished by either increasing the volume of bitumen, which decreases its viscosity, or by reducing the surface tension at the interface between the aggregate and bitumen. WMA helps in reducing the energy consumption and there is reduction in emissions which in turn creates better working condition for the construction workers. These mixes require less time before opening the road to traffic after construction, besides they also permit greater haul distance [5].

Hence studies in this direction are essential to have a greater understanding of the behaviour of open graded warm mixes. The results from the limited field trials are quite promising on account of the fact that warm mixes can significantly reduce the premature ageing of open graded mixes which in turn could reduce the potential for ravelling. Laboratory results indicate that warm porous asphalt mix produced by foaming technology could enable its production at 105°C, even after incorporating up to 93% reclaimed materials [6]. Research in this direction has pointed towards exclusion of fibres from OGFC mixtures when using the WMA technology [7,8]. The inclusion of WMA technologies enhances the durability and performance of OGFC mixes [9]. As the demand for WMA technology and OGFC continues to grow, the synergistic amalgamation of these two advancements holds the potential to carve out a novel and thriving market opportunity.

Porous warm mixes with Advera®, a synthetic inorganic chemical additive exhibited lesser energy for compaction and no significant difference in permeability and lower dynamic modulus than control HMA [10]. Among the two varieties of warm mix additive namely bis stearic acid amide (EBS) and stearic acid amide (SA) the latter significantly improved its resistance to cracking at reduced temperature and rutting resistance of porous asphalt mix and hence it was more suited in areas with seasonal frozen climate. However, there was no effect on resilient modulus, slight reduction in water sensitivity, weak increase in permeability of WMA as compared to HMA mixes [11]. Studies with various additives in porous mixes suggest the usage of DBS polymer in high temperature areas, and hydrated lime in high rainfall areas [12].

From the literature review it is evident that the problem of stormwater runoff management can be resolved by the adoption of open graded mixes and the problem of emissions associated with hot mix technology can be alleviated with the use of warm mix technology.

This study explores the feasibility of using sasobit, a chemical additive for the preparation of porous warm mixes and also brings out a comparison between porous mixes prepared using hot and warm mix technology.

2. Methodology

The methodology used in this study is illustrated with the help of flow chart shown in Figure 1. The first step in the experimental study was the procurement of materials followed by testing its properties to assess its suitability for the preparation of the mix. After evaluating the properties of the materials, the binder was modified with varying dose of warm mix additive, sasobit from 1 to 4% by weight of bitumen, in increments of 1% and the temperature was varied from 120°C to 160°C in increments of 10°C. This was done for evaluating the temperature at which mix can be produced and compacted, to assess the extent of temperature reduction that could be possible by the use of warm mix additive. This aids in optimizing the dosage of sasobit. The drain down test is then conducted at varying binder contents from 5.0 to 7% in increments of 0.5% to determine the possibility of drainage of binder from the mix. The Marshall stability and flow as well as volumetrics of the mix like unit weight, percentage air voids, voids in the mineral aggregate and voids filled with bitumen are also evaluated. The optimum binder content is arrived at based on mix volumetrics and drain down. At the optimum binder content, both the HMA and WMA mixes are examined to see if it meets the criteria for loss due to abrasion, permeability and moisture induced damage. Finally, a comparison of hot and warm porous mixes was made.

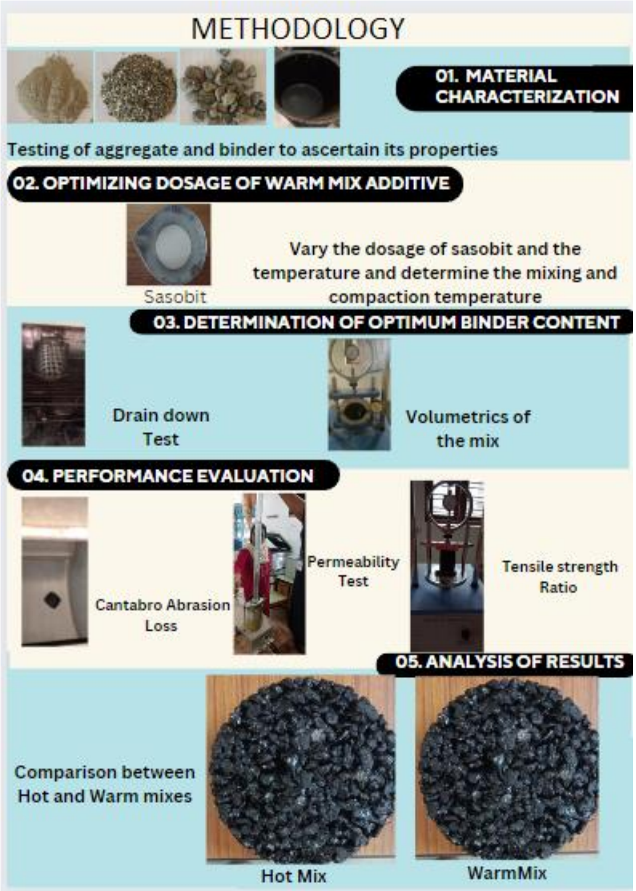

Fig. 1. Methodology adopted for the study

2.1 Laboratory Investigation

2.1.1 Material properties

The materials used in this study are shown in Figure 2. The coarse aggregate, fine aggregate and filler utilized for the study was obtained from a local quarry in Trivandrum, India. The aggregates obtained from the quarry were washed and dried and then sieved and sorted to various size fractions. The grade of binder used in this study is NRMB.


(a) (b) (c) (d)

Fig. 2. Materials used for the study; (a) coarse aggregate, (b) binder, (c) sasobit, (d) exocarp fibre

The binder was obtained from Revive Construction Company, Kerala, India. Sasobit was obtained from KPL International Limited, a chemical marketing and distribution company in India. The fibre used was exocarp of coconut with 6mm length and was manually extracted from coconut. In the present study, the fibre dosage was kept as 0.3% by weight of the total mix. The fibre was added to the dry heated aggregates and underwent dry mixing.

2.1.2 Determination of mixing and compaction temperature

The viscosity test was determined from Brookfield viscometer on NRMB and NRMB binder modified with sasobit additive. The dosage of sasobit was varied from 1 to 4% for the preparation of porous warm mixes. The temperature was varied from 120^0C to 160^0C. The mixing and com-paction temperature was selected so that viscosity of the binder lies within 170±20 cSt and 280±30 cSt respectively.

2.1.3 Drain down test

The test is done on uncompacted sample of open-graded asphalt mixes to assess the possible binder drainage during its production, transportation and placement at elevated temperatures. The test was done as per the guidelines of ASTM D6390. For each mix the test is carried out at the expected temperature of production in the plant and at 10^0C above the expected temperature of production in the plant and at each temperature duplicate samples are tested. A total of four samples are tested for a mix. In this study the HMA mixes were tested at 150^0C and 160^0C respectively and the WMA mixes were tested at 140^0C and 150^0C respectively. The amount of drain down is computed based on the mass of material drained from a wire basket suspended in a forced draft oven for one hour into a collecting tray. It is expressed as a percentage of the total mass of the asphalt mix as indicated in Eq. (1).

$$\text{Drain down (\%)} = \frac{(W_4 - W_3)}{(W_2 - W_1)} * 100 \tag{1}$$

where:
W_1 = mass of the empty wire basket (g)
W_2 = mass of the basket and sample (g)
W_3 = mass of the empty catch plate (g)
W_4 = mass of the catch plate and drained material (g)

2.1.4 Volumetrics of the mix

The samples were prepared in Marshall mould by giving 25 blows per face. The binder content was varied from 5 to 7 % in increments of 0.5%. Three samples were prepared for each combination of aggregates and binder content. The compacted specimens were allowed to cool before being extruded from the mould. The test was carried out as per the guidelines of ASTM D 1559-76.

2.1.5 Cantabro Abrasion test

This test evaluates the durability of open graded mix in terms of the loss of compacted specimen when subjected to abrasion. Five specimens each were tested at the optimum binder content as per the procedure outlined in IRC:129-2019 to calculate the abrasion loss for aged and unaged specimens respectively [13]. The specimen is placed in the rotating drum of the Los Angeles abrasion testing machine and subjected to 300 revolutions without steel balls as abrasive charge at the rate of 30-33rpm.

In case of aged specimens, the samples are placed in a heating oven maintained at 60^0C for seven days. The specimens are subsequently cooled to 25°C and left to rest for 5 hours before undergoing testing for the Cantabro Abrasion test. The percentage Cantabro abrasion loss (P) is calculated using the Eq. (2).

$$P=\frac{(P_1-P_2)}{(P_1)}*100 \tag{2}$$

where:
P_1 = Initial mass of the specimen weighed to the nearest 0.1gm
P_2 = Mass of the specimen after the test weighed to the nearest 0.1gm

2.1.6 Tensile strength ratio test

This is a measure of the resistance of compacted asphalt mixes to moisture -induced damage. The change of diametral tensile strength due to water saturation and accelerated stripping is captured in this test. The tensile strength ratio indicates the extent of indirect tensile strength retained by comparing the values of specimens subjected to conditioning with the specimens tested in the dry state, without conditioning. A total of 6 specimens viz. 3 in the dry state and 3 in the conditioned state are tested. The tensile strength of conditioned and unconditioned specimens found using Eq. (3).

$$St=\frac{2000P}{\pi\ t\ d} \tag{3}$$

where:
St = tensile strength in kPa
P = maximum load in N
t = specimen thickness in mm
d = specimen diameter in mm

The tensile strength ratio, TSR is given by Eq. (4).

$$TSR=\frac{S_2}{S_1}*100 \tag{4}$$

where:
S_2 = average indirect tensile strength of wet conditioned specimens.
S_1 = average indirect tensile strength of dry specimens.

The procedure outlined in AASHTO T283 has been adopted for conducting the test. The dry or unconditioned specimens are kept at room temperature and placed in a water bath for 2 hours at a temperature of 25^0C $\pm 0.5^0$C and then its indirect tensile strength is computed. To condition the specimens, they undergo vacuum saturation under an absolute pressure of 87.8 kPa for a duration of 10 minutes After wrapping the specimen with plastic film, the specimens are immersed in 10ml of water contained in a plastic bag and kept in a freezer for 16 hours at a temperature of 18 ± 3^0C. The specimens are placed for 24hours in water bath at 60^0C$\pm1^0$C. The specimens are then transferred to a hot water bath maintained at 25 ± 0.5^0 C for 2 hours. The indirect tensile strength of the conditioned specimen is also determined.

2.1.7 Permeability

The permeability test was carried out on HMA and WMA mixes prepared at the optimum binder content using falling head permeability test. Darcy's Law was used for computing the coefficient of permeability by recording the time taken for water to flow through a saturated asphalt sample corresponding to a known change in head. The coefficient of permeability, k is computed using Eq. (5).

$$k = \frac{aL}{At} \ln \frac{h_1}{h_2} \tag{5}$$

where:
k = coefficient of permeability, (cm/s);
a = inside cross-sectional area of the stand pipe, (cm^2);
L = average thickness of the test specimen, (cm);
A = average cross-sectional area of the test specimen, (cm^2);
t = elapsed time between h_1 and h_2, the initial and final head across the test specimen, (s).

3. Results and Discussion

3.1 Material Properties

The materials were tested as per the relevant codes and their properties are tabulated in Table 1 and Table 2. All the materials tested conformed to the relevant specifications. The aggregate gradation adopted in the study is depicted in Figure 3. The mid-gradation for open graded friction course as specified by IRC:129-2019 was adopted in the present study [13]. The nominal maximum aggregate size used was 9.5mm.

Table 1
Properties of aggregate

Property	Specifications of the test as per IS:2386 [14-16]	Test Result	Specifications as per IRC:129-2019 [13]
Cleanliness	Grain Size Analysis (Part-1)	0.9%	<2% passing 0.075mm sieve
Particle Shape	Combined Flakiness and Elongation Index (Part-1)	22%	<30%
Strength	Los Angeles Abrasion Value (Part-4)	23%	<30%
Strength	Aggregate Impact Value (Part-4)	12%	<15%
Water Absorption	Water Absorption (Part-3)	0.8%	<2%

Table 2
Properties of binder

Test Characteristic	Details of the test	NRMB 120	Specifications as per IS 15462:2004 [17]
Penetration at 25^{0}C, 100g, 5s, 0.1mm	IS1203	91	90-150
Softening Point (R&B)^{0}C	IS1205	76	Min.45
Viscosity at 150^{0}C, Poise	IS1206 (Part-1)	2.5	1-3

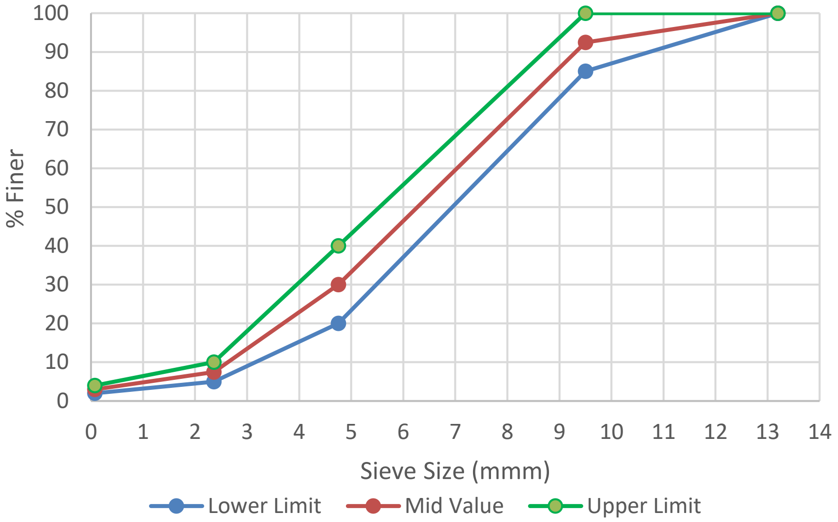

Fig. 3. Aggregate gradation adopted for the study

3.2 Mixing and Compaction Temperature

As per IS 15462:2004, at 150^{0}C the viscosity of NRMB should be between 1-3 Poise [17]. From Table 3 it can be seen that all the trial doses of sasobit met the requirement at 150^{0}C. In case of porous mixes, a high rotational viscosity will inevitably lead to poor workability [18]. Hence, these trial doses were found to have good workability.

Table 3
Variation of viscosity with temperature and dosage of sasobit

Temperature	Viscosity in cP for varying dosage of sasobit				
(^{0}C)	0%	1%	2%	3%	4%
120	533	463	398	346	365
130	380	367	324	253	315
140	250	239	195	159	212
150	158	146	131	112	145
160	145	125	103	98	110

From Figure 4, the mixing temperature for HMA is 150^{0}C and that for WMA is 140^{0}C corresponding to a binder viscosity of 170±20 cSt. Also, the compaction temperature for HMA is 139^{0}C and that for WMA is 126^{0}C, corresponding to viscosity of 280±30 cSt. From Table 4 it can be seen that the maximum temperature reduction was obtained in the case of 3% sasobit. Hence the optimum dosage of sasobit was fixed as 3%. About 10^{0}C reduction in mixing and 13^{0}C reduction in compaction temperature could be achieved.

Table 4
Determination of range of mixing and compaction temperature

Sample	Range of mixing temperature (^{0}C)	Average Mixing Temperature (^{0}C)	Range of mixing temperature (^{0}C)	Average Compaction Temperature (^{0}C)
NRMB	138-161	149.5	137-140	138.5
NRMB +1% sasobit	144-149	146.5	133-138	135.5
NRMB +2% sasobit	140-146	143	131-136	133.5
NRMB +3% sasobit	136-143	139.5	122-129	125.5
NRMB +4% sasobit	141-149	145	129-136	132.5

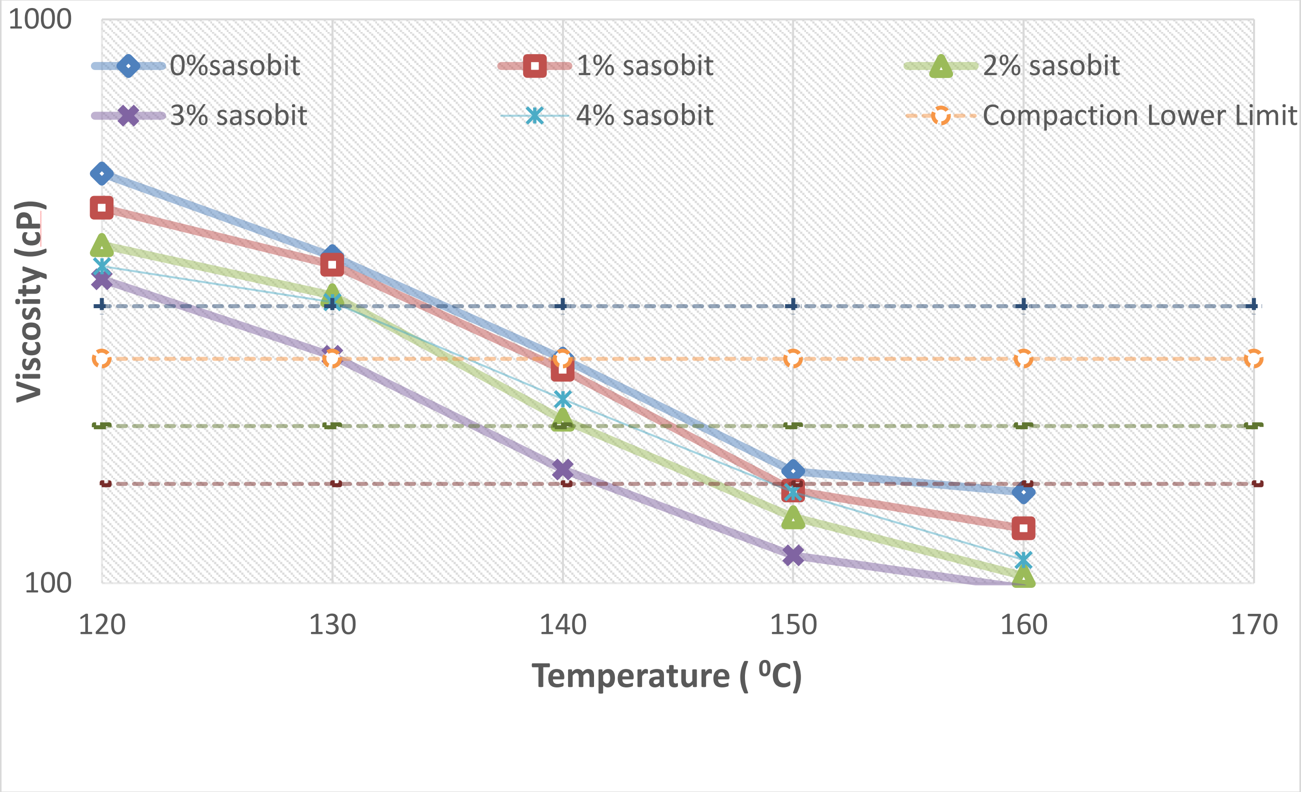

Fig. 4. Selection of mixing and compaction temperature based on viscosity

3.3 Drain Down Characteristics

The test results are shown in Table 5. It can be observed that in case of warm mixes without fibers, the drain down was within the specifications. Hence warm mix technology eliminates the need of fibers. This can be attributed to the fact that modified binders result in stiffening of the mix and thereby slows down the draining of bitumen. The drain down increases with increase in testing temperature and binder content. In order to minimize the drain down the optimum dose of binder was kept as 5.5%.

Table 5
Drain down characteristics with varying dose of binder for hot and warm mix specimens

Type of mix	Test temperature (^{0}C)	Binder Content (%)				
		5	5.5	6	6.5	7
HMA	150	0.08	0.16	0.27	0.63	1.65
	160	0.11	0.20	0.35	0.71	1.81
WMA	140	0	0.09	0.22	0.45	1.3
	150	0	0.21	0.3	0.65	1.33

3.4 Mix Volumetrics

The binder content of 5.5% satisfied the drain down criteria. At 5.5 % binder content from Figure 5 and Table 6, it can be seen that the air voids lie between 18-22% and the voids in the mineral aggregate is above the minimum value of 25% as specified by IRC:129-2019 for both warm and hot porous mixes [13]. The volumetrics properties and optimum binder content exhibited no significant differences in case of HMA and WMA mixtures. Jamshidi *et al.,* [19] also reported similar findings.

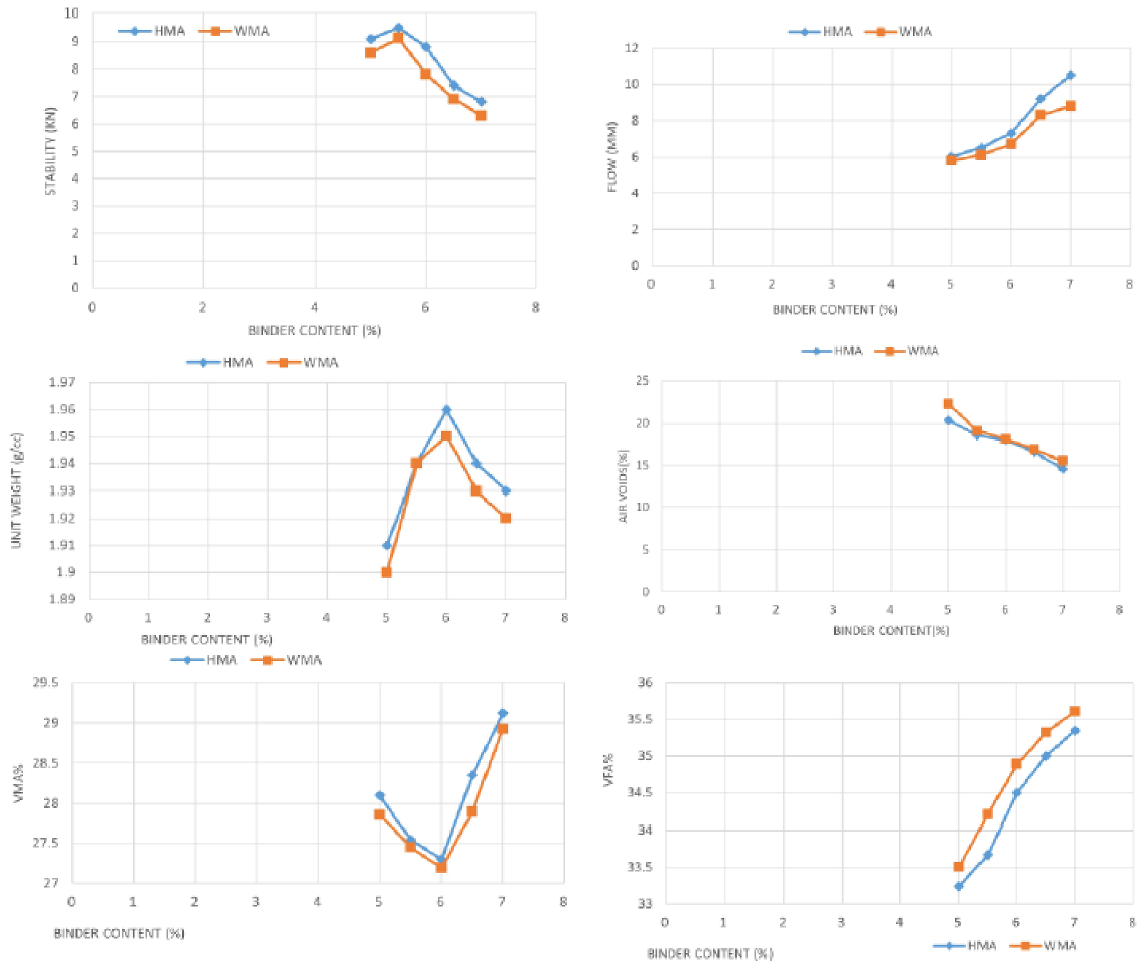

Fig. 5. Volumetric properties based on Marshall test

Table 6
Comparison of percentage air voids and voids in mineral aggregate between HMA and WMA mixes

Mix Type	Property	Binder Content (%)					Specifications as per IRC:129-2019 [13]
		5	5.5	6	6.5	7	
HMA	Va	20.36	18.55	17.98	16.54	14.56	18-22%
WMA	Va	22.29	19.11	18.12	16.85	15.47	
HMA	Vma	28.1	27.54	27.3	28.35	29.12	Min .25%
WMA	Vma	27.86	27.45	27.19	27.9	28.93	

3.5 Cantabro Abrasion Test

The specimens were tested at the optimum binder content as per the procedure outlined in IRC:129-2019 and the results are indicated in Table 4. From Table 7, it can be seen that both aged and unaged specimens of HMA and WMA satisfied the requirements specified in IRC:129-2019 [13]. It was found that both mixes had sufficient durability or resistance to abrasion.

Table 7
Cantabro Abrasion loss for HMA and WMA mixes

Sample	Cantabro Abrasion Loss (%)	Specifications as per IRC:129-2019 [13]
HMA (unaged)	18.3	20%
WMA (unaged)	17.1	
HMA (aged)	40.2	50%
WMA (aged)	38.6	

3.6 Tensile Strength Ratio Test

Tensile strength ratio is the ratio of tensile strength of water conditioned specimens to that of unconditioned specimens. The values are specified in Table 8 for hot and warm mixed porous asphalt specimens prepared at optimum binder content.

Table 8
Tensile Strength ratio for HMA and WMA mixes

Sample	Tensile Strength of unconditioned sample, S_1 (kPa)	Tensile Strength of conditioned sample, S_2 (kPa)	Tensile Strength Ratio, $\frac{S_2}{S_1}$ (%)	Specifications as per IRC:129-2019 [13]
HMA	148	128	86	Min.80%
WMA	125	105	84	

From Table 8, it can be observed that both HMA and WMA specimens offered sufficient resistance to moisture induced damage as it conforms to the minimum TSR requirement of 80%.

3.7 Permeability

The test results for HMA and WMA mixes are given in Table 9. It can be seen that both hot and warm mixed samples met the permeability requirement of 1.15mm/s.

Table 9
Permeability of HMA and WMA mixes

Sample	Permeability (mm/s)	Specifications as per IRC:129-2019 (mm/s)
HMA	1.22	Min.1.15
WMA	1.20	

4. Summary and Conclusions

The study investigated two mixes viz warm and hot mix with open graded configuration. The mid-gradation was used to prepare the mixes. Sasobit a chemical additive was used for the preparation of the warm mix. The following conclusions could be drawn from the study:

i. The optimum dosage of sasobit was 3%. At this dose about 10^0C reduction in mixing and 13^0C reduction in compaction temperature could be achieved.
ii. In order to control the binder, drain down and to have an air void content in the range of 18 to 22% and voids in the mineral aggregate, greater than 25%, the optimum binder content was kept as 5.5%.
iii. At this binder content the performance of the mix was evaluated for both HMA and WMA. It was found that both the mixes met the guidelines for Cantabro abrasion loss, permeability and tensile strength ratio.
iv. The WMA specimens had a decrease in permeability of 1.6% over HMA specimens
v. There was 2% increase in TSR for HMA specimens over WMA specimens
vi. From HMA to WMA specimens, there was a decrease in Cantabro abrasion loss of 7% and 4% respectively, for unaged and aged specimens.
vii. The open graded mixes prepared with warm mix technology met the performance criteria and hence it is suitable for application in porous pavements.

This reduction in temperature could be translated to reduced fuel consumption for heating the binder and reduced level of emissions. Thus, it leads to better working environment for the labourers involved in road construction.

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