Influence of gradation on the properties of warm open graded friction course mixes

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Abstract: *The use of conventional dense graded asphalt for paving produces an impermeable surface where there are chances of water stagnation in the event of a heavy storm. A solution in this regard is to adopt open graded friction course which helps in stormwater runoff management. Also, the conventional mixes produced with hot mix technology produces a lot of fumes and consumes fuel. The inclusion of warm mixes has found to reduce emissions leading to a better working environment. This study involves an attempt to determine the influence of gradation on the properties of warm open graded friction course mixes. Warm mixes were prepared using sasobit as additive. Nine different gradations within the current specification range of open graded mixes were tried out. The properties tested includes Cantabro abrasion loss, moisture susceptibility, permeability and drain down. The gradation near to the upper bound of the current specification band (M9) was recommended. It was superior with respect to abrasion loss and moisture susceptibility compared to other gradations and it met the permeability guidelines specified in the standards.*

Keywords: *Open graded friction course, porous asphalt pavement, warm mixes, Engineering performance Environmental impacts.*

1. Introduction

Traditional pavements have a dense graded structure, rendering them impermeable to water infiltration. Consequently, substantial amounts of stormwater runoff are directed towards drains and water bodies, exacerbating the burden on drainage systems. Moreover, these pavements often accumulate surface debris, further contaminating water sources. While detention basins aim to mitigate runoff and capture stormwater, they necessitate significant land allocation. The main drawback of conventional pavement is its inability to manage large quantities of storm water runoff as the surface of these pavements are dense graded. Porous asphalt pavement is becoming increasingly popular as it has less fines than its dense graded counterpart. The benefits like less splashing and spraying under wet weather conditions, reduction in pavement tire noise and improved resistance to skidding can be achieved by laying porous pavements (Zhang et al., 2013, 2016). Permeable pavement typically features a surface layer composed of porous asphalt, commonly referred to as open graded friction course (OGFC). Below this surface layer lies a granular layer, which not only provides a stable construction platform but also prevents the displacement of larger aggregates in the stone reservoir layer beneath it. For optimal performance, the subgrade soil beneath should possess sufficient infiltration capacity; however, if lacking, appropriate overflow mechanisms can be implemented. Open graded friction course mixes are characterized by fewer fines compared to dense graded mixes, resulting in a coarse granular structure with interconnected air voids. (Alvarez, A. E., et al., 2011). This gradation imparts skid

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resistance to the pavement and can be applied either atop dense graded mixes or on a stone reservoir bed beneath a granular working platform, thus serving as a permeable pavement solution. While primarily designed to manage onsite runoff, they can also accommodate off-site runoff in specific circumstances. The presence of high percentage of air voids (typically between 18-22%) is a characteristic of open graded friction course mixes. The other benefits of open graded asphalt mix include improved drainage in the event of storm and improved road safety (Youssef, A.M. and Fahmy, E. A, 2023). In open graded mixes, the binder content is elevated compared to conventional dense graded mixes, aiming to enhance durability. Consequently, this results in thicker binder film, which is identified as the primary cause of binder drain down. Additionally, the open graded structure of porous mixes contributes to increased air entrainment, leading to premature aging of bitumen and consequent raveling. This phenomenon causes surface aggregates to wear away prematurely from the pavement. To mitigate the issue of drain down, appropriate additives are integrated into the mix (Punith, V. S., et al. 2012).

Several studies have been carried out on open graded friction course mixes. The role of fibers on the performance of OGFC mix was evaluated by (Zhang J., et al., 2020) and the study shows the potential of lignin fiber to improve the drainage characteristic, however it had little tensile strength. Polyester fiber was recommended based on its better performance, compared to lignin, basalt and polyacrylonitrile fiber. (Gu F., et al., 2018) evaluated the benefits of open graded friction courses and the findings indicate that OGFC is beneficial for rural highways with high-speed traffic. According to studies by (Chen X. et al., 2017) OGFC mixes exhibited comparable performance as its dense graded counterpart without severe deterioration. Also, the cost benefit ratio evaluated in terms of accident reduction rate found that it is suitable for improving the driving safety on roads. The seepage characteristics of OGFC pavements were evaluated based on permeability, layer thickness, underlying layer permeability, intensity of rain, and traffic volume by (H. Abohamer, et al., 2023). A new test for evaluating the skeletal strength of porous mixes was proposed by (Wang et al., 2018). The percentage passing 9.5mm sieve was found to have greatest influence on the skeleton strength while that passing 4.75mm sieve had the least impact. Various stabilizers have been used for stabilizing porous mixes. Study by (Youssef, A.M. and Fahmy, E. A, 2023) utilized human scalp hair and the findings indicate that these fibers are adequate based on their performance compared to slag wool. Polymers, for instance, have been discovered to enhance the stiffness of bitumen, while fibers have been observed to absorb surplus bitumen. These fibers augment the thickness of the binding film surrounding the aggregate, effectively preventing drain down. Porous mixtures containing binders with elevated viscosity demonstrated superior resistance to moisture-induced damage and rutting in contrast to mixtures utilizing unmodified binders. (Liu, et al. 2009). Increasing the content of high viscosity modifier from 3 to 10% resulted in approximately a 15% enhancement in rutting resistance (Chen, S., et al. 2023).

Efforts have been undertaken to enhance the sustainability of pavement construction by reducing mixing and production temperature of bituminous mixes. Warm Mix Asphalt (WMA) technology stands out as one such innovation that promotes a more sustainable pavement laying process. Originating in Europe in the late nineties, its widespread adoption gained momentum through initiatives by the National Asphalt Pavement Association in the USA. This technology achieves lower production temperatures by increasing bitumen volume, reducing bitumen viscosity, or diminishing surface tension at the aggregate-bitumen interface. The environmental benefits of warm mixes include decreased fuel costs, energy consumption and emissions, thereby fostering improved working conditions for construction workers. These mixes necessitate a shorter duration before allowing traffic on the road post-construction, and additionally, they enable longer haul distances. (Kheradmand, B., et al. 2013). Besides it becomes possible to widen the. window for paving during winter season (Hurley, G. C., and Prowell, B.D., 2005). The findings from the restricted field trials are highly encouraging, as warm mixes have demonstrated a notable capacity to substantially decrease premature aging in open-graded mixes, thereby potentially mitigating the risk of raveling. Laboratory findings suggest that employing foaming technology allows for the production of warm porous asphalt mixtures at 105°C, even when integrating up to 93% reclaimed materials (Qiu, J., et al.,2018). Research in this direction has pointed towards exclusion of fibers from OGFC mixtures when using the WMA technology (Wurst, J. E. et al., 2013, Putman, B.J. et al., 2014). There is a need to optimize the gradation of open graded mixes to maximize functionality and durability (Alvarez, A. E., et al., 2011). Incorporating WMA technologies improves the durability and performance of OGFC mixes (Abohamer, H. et al.2022). As demand for WMA and OGFC continues to increase, the combined integration of these two advancements has the potential to create a new and prosperous market opportunity. Although few researches on gradation of OGFC mixtures have been carried out, yet they are not adequate. This study makes an attempt to optimize the gradation of porous warm mixes with a view to maximize the functionality and durability.

2. Methodology

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 sasobit from 1 to 4% in increments of 1% and the temperature was varied from 120^{0}C to 160^{0}C in increments of 10^{0}C. This was done for evaluating the mixing and compaction temperature of the modified binder 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 volumetrics of the mix which includes the Marshall stability, flow, 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, nine different gradations were tried and the parameters assessed includes Cantabro abrasion loss, moisture susceptibility, drain down and permeability.

3. Preparation of Samples

3.1. Materials

The grade of binder adopted for the study was NRMB, procured from Revive Construction Company, while the coarse aggregate, fine aggregate and filler used in this study was procured from a local quarry in Trivandrum, both from Kerala, India for the preparation of asphalt mixes. The processing of aggregates included its washing, drying and sieving for separating them into various size ranges. The chemical additive used for preparation of warm mixes was Sasobit which was sourced from KPL International Limited, a chemical marketing and distribution company in India. The properties of aggregate and binder are shown in Table 1 and Table 2.

Table 1. Properties of the aggregate

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

Table 2. Properties of the binder

Test Characteristic	Details of the test	NRMB120	Specifications as per IS 15462:2004
Penetration at 25°C, 100 g, 5s, 0.1 mm	IS 1203	91	90-150
Softening point (R&B), °C	IS 1205	76	Min.45
Viscosity at 150 °C, Poise	IS 1206 (Part1)	1.5	1-3

3.2. Preparation of compacted asphalt mixture specimen

The aggregate gradation for open graded friction course mixes is shown in Table 3. In this study mid-gradation was adopted for the preparation of the specimens.

Table 3. Gradation of aggregate adopted for preparation of OGFC specimens

IS Sieve Size (mm)	Cumulative % by weight of total aggregate passing
13.2	100

9.5	85-100
4.75	20-40
2.36	5-10
0.075	2-4

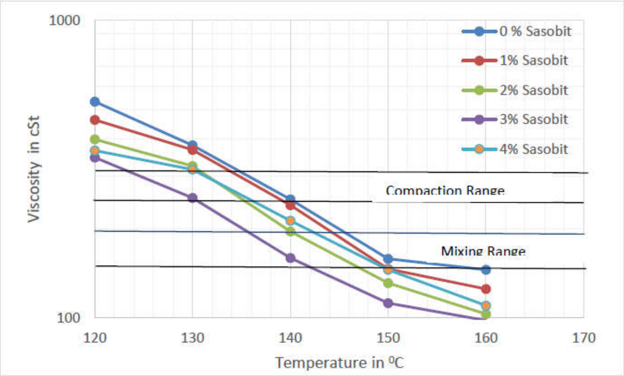

Figure 1. Mixing and compaction temperature for NRMB 120

The dosage of chemical additive, sasobit for the preparation of warm mix asphalt was optimized to achieve maximum possible temperature reduction in preparing the mix. The temperature at which the mix should be mixed and compacted was calculated so as to obtain a binder viscosity of 170±20 cSt and 280±30 cSt respectively. The selection of mixing and compaction temperature is illustrated in Fig. 1. The binder was heated and sasobit was added to it, which was then blended with the heated aggregates. The loose mix was then placed in the Marshall mould and compacted with 25 blows on either side, in order to prepare cylindrical compacted specimens. The optimum dosage of sasobit was fixed as 3%, since the maximum reduction in both mixing and compaction temperature was achieved at this dosage as shown in Table 4.

Table 4. Determination of optimum dosage of sasobit.

Sample	Range of mixing temperature (^{0}C)	Average mixing Temperature (^{0}C)	Range of compaction 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

3.3. Determination of optimum binder content

For determination of optimum binder content, the dosage of binder was varied from 5 to 7% in increments of 0.5%. The results of mix volumetrics and drain down test was utilized to arrive at optimum binder content. The volumetrics of the mix was determined in accordance with the guidelines of ASTM D 1559-76. The results are shown in are shown in Fig. 2a, 2b, 2c, 2d, 2e and2f, respectively.

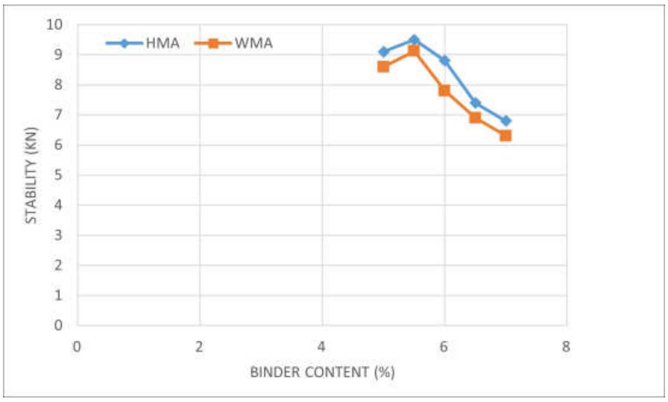

Figure 2a. Stability based on Marshall test

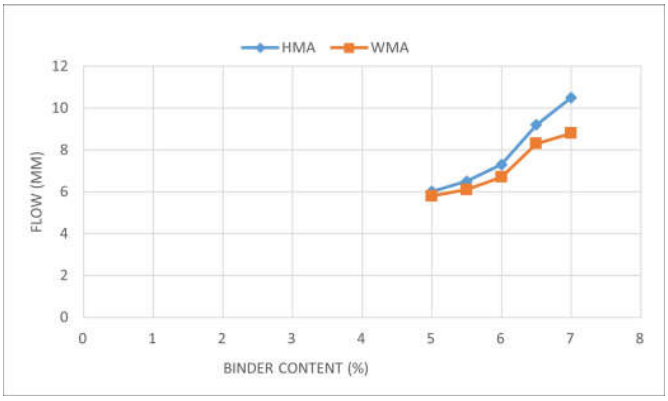

Figure 2b. Flow based on Marshall test

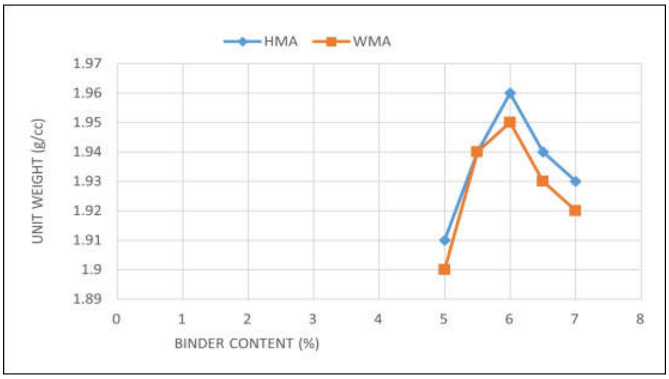

Figure 2c. Unit Weight based on Marshall test

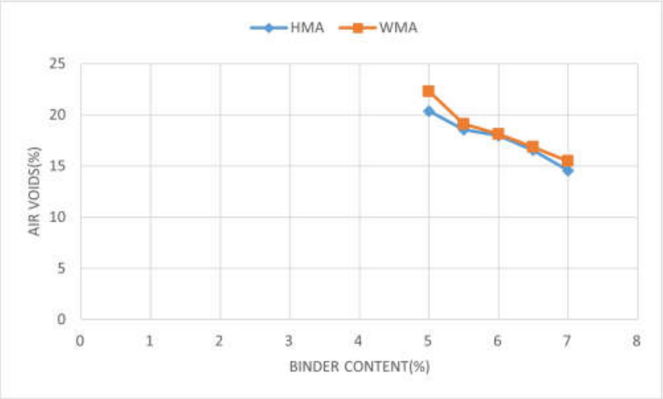

Figure 2d. Volumetric properties based on Marshall test-air voids

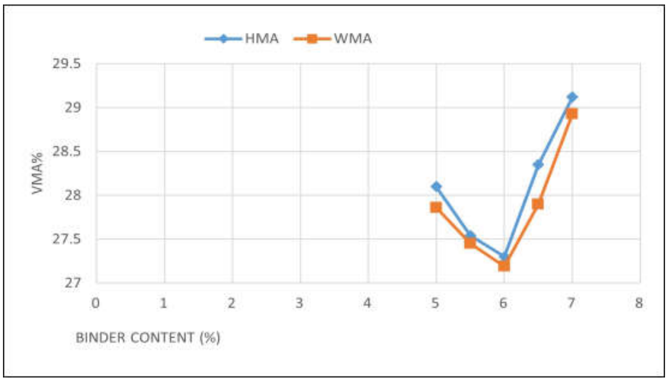

Figure 2e. Volumetric properties based on Marshall test-voids in the mineral aggregate

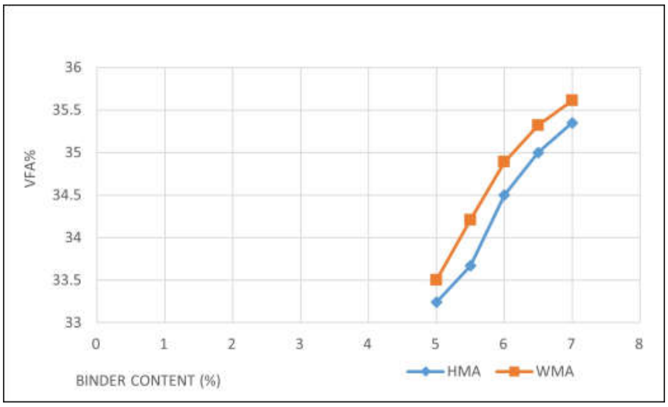

Figure. 2f. Volumetric properties based on Marshall test-voids filled with asphalt

The drain down test is indicative of potential drainage of binder during its production, transportation and placement at elevated temperatures. It is carried out on uncompacted samples as per the guidelines of ASTM D6390. The samples were tested at and ten degrees Celsius above the temperature at which it is produced. The extent of drain down is computed based on the mass of material drained from a wire basket hung in a forced draft oven for one hour into a collecting tray. The results are indicated in Table 5.

Table 5 Drain down characteristics with varying dosage of binder.

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

It is expressed as a percentage of the total mass of the asphalt mix as indicated in Eqn.1.

$$\text{Drain down } (\%) = [(W_4-W_3) / (W_2-W_1)] * 100 \qquad (1)$$

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)

From Fig. 2a, 2b, 2c, 2d, 2e and 2f, corresponding to binder content of 5.5%, the air voids lie between 18-22% and voids in the mineral aggregate exceed the minimum value of 25%, for warm mixes. This conforms to the guidelines of IRC: 129-2019. The test results from Table 6. indicate that it is possible to eliminate fibers up to 6% binder dosage. This is due to fact that modified binder yields a stiffer mix than unmodified binder, which in turn retards the bitumen drain down. Hence the binder dosage of 5.5% was kept optimum as it met the criteria for drain down and volumetrics of the mix.

4. Test and Results

In order to analyze the influence of aggregate gradation on the performance of the mix, nine different gradations were tried out on warm mixes, where M1 represented the lower limit, M5 the mid value and M9 represented the upper limit of the specification band. The percentage of material passing through and retained on each of the sieve sizes is represented in Table 6.

Table 6 Aggregate gradation adopted for the study

Passing through Retained on	13.2mm to 9.5mm	9.5mm to 4.75mm	4.75mm to 2.36mm	2.36mm to 0.075mm	0.075mm to pan
M1	15	65	15	3	2
M2	13.125	64.375	16.875	3.375	2.25
M3	11.25	63.75	18.75	3.75	2.5
M4	9.375	63.125	20.625	4.125	2.75
M5	7.5	62.5	22.5	4.5	3
M6	5.625	61.875	24.375	4.875	3.25
M7	3.75	61.25	26.25	5.25	3.5
M8	1.875	60.625	28.125	5.625	3.75
M9	0	60	30	6	4

4.1. Drain down test

For all the nine gradations, the drain down test was carried out at 140^0C and 150^0C. The dosage of binder was varied from 5 to 7% in increments of 0.5%. The results are indicated in Table 7 and 8.

Table 7 Drain down characteristics at 140^0C

Mix ID	Binder Content (%)				
	5	5.5	6	6.5	7
M1	0.15	0.23	0.32	0.62	1.41
M2	0.11	0.20	0.32	0.57	1.34
M3	0.08	0.17	0.29	0.53	1.23
M4	0.03	0.12	0.25	0.49	1.18
M5	0	0.09	0.22	0.45	1.13
M6	0	0.04	0.19	0.43	1.11
M7	0	0	0.17	0.40	0.8
M8	0	0	0.16	0.37	0.6

M9	0	0	0.16	0.34	0.6

Table 8 Drain down characteristics at 150^{0}C

Mix ID	Binder Content (%)				
	5	5.5	6	6.5	7
M1	0.19	0.28	0.39	0.76	1.63
M2	0.16	0.25	0.40	0.61	1.59
M3	0.10	0.19	0.36	0.58	1.54
M4	0.06	0.17	0.31	0.50	1.42
M5	0	0.21	0.30	0.65	1.33
M6	0	0.15	0.26	0.52	1.26
M7	0	0.08	0.25	0.47	1.15
M8	0	0.05	0.22	0.40	1.04
M9	0	0	0.20	0.38	0.7

4.2. Permeability test

` The warm mixes for all the nine gradations were prepared at the optimum binder content and tested for its permeability. The falling head permeability test, based on Darcy's Law was used for computing the coefficient of permeability. The coefficient of permeability, k is computed using Eqn.2

$$k = \frac{a\,L}{A\,t} \ln \frac{h_1}{h_2} \tag{2}$$

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, initial and final head across the test specimen, s;

The results of the permeability tests conducted on the specimens are indicated in Table 9.

Table 9 Permeability characteristics

Mix ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
Permeability (mm/s)	1.5	1.46	1.34	1.27	1.22	1.21	1.17	1.14	1.12

4.3. Cantabro Abrasion Loss

The compacted specimens were inserted into the rotating drum of the Los Angeles abrasion testing machine and exposed to 300 revolutions without steel balls as the abrasive charge, operating at a speed of 30-33 revolutions per minute (rpm) and the durability was assessed in terms of the loss of the compacted specimen which was computed using Eqn.3.

$$P= [(P_1-P_2)/ (P_1)] *100 \quad (3)$$

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

As per the procedure outlined in IRC:129-2019, for ageing the samples, they were placed in a heating oven kept at 60°C for 7 days. Afterwards, the specimens are cooled to 25°C and left to rest for 5 hours before conducting the Cantabro Abrasion test. The results are indicated in Table 10.

Table 10 Cantabro Abrasion loss for unaged and aged specimens

Mix ID	Cantabro Abrasion loss (%)								
	M1	M2	M3	M4	M5	M6	M7	M8	M9
Unaged Sample	19.1	18.6	17.8	17.5	17.1	16.8	16.7	16.7	16.5
Aged Sample	44.4	42.1	41.6	39.1	38.6	37.5	37.2	36.8	36.4

4.4. Moisture Susceptibility test

This test measures the ability of compacted asphalt mixes to resist damage caused due to moisture, by capturing the alteration in diametral tensile strength caused by water saturation and accelerated stripping. The tensile strength ratio demonstrates the level of indirect tensile strength retained by comparing the values of conditioned specimens with those tested in the dry state, without conditioning. The testing procedure outlined in AASHTO T283 has been followed, according to which six specimens were tested, of which three were in the dry state and three in the conditioned state. The indirect tensile strength of unconditioned specimens stored at room temperature is calculated after immersing them in a water bath for 2 hours at a temperature of 25°C ± 0.5°C. To condition the specimens, they are maintained under vacuum saturation pressure of 87.8 kPa pressure, for 10 minutes. The specimens wrapped in plastic film are submerged in 10ml of water within a plastic bag and placed in a freezer for 16 hours at a temperature of 18°C ± 3°C. Subsequently, the specimens are immersed in a water bath at 60°C ± 10°C for 24 hours. The specimens are subsequently moved to a hot water bath kept at 25°C ±

0.5°C for a duration of 2 hours. The tensile strength of both conditioned and unconditioned specimens was calculated using Eqn. 3.

$$S_t = 2000P/(\pi t d) \tag{3}$$

where:

S_t=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 Eqn. 4.

$$\mathrm{TSR} = [S_2/S_1] \times 100 \tag{4}$$

where:

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

The results from nine gradations are indicated in Table 11.

Table 11 Tensile Strength ratio of specimens

Mix ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
Tensile strength Ratio (%)	81	82.5	83	83	84	85	86	86	88

5. Discussion of Results

5.1. Drain down test

A comparative analysis of the drain down characteristics of lower bound of the specification range with the mid-gradation and the upper bound of specification range with the mid-gradation at 140^{0}C and 150^{0}C is shown in Fig. 3a, 3b, 3c and 3d respectively.

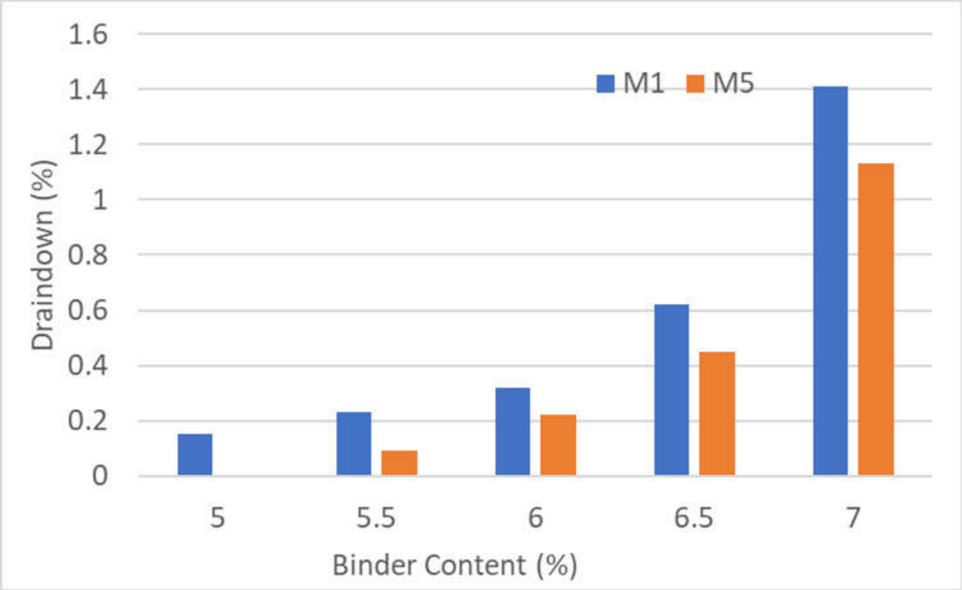

Figure. 3a. Comparison of drain down characteristics between lower bound and mid-gradation with varying binder content at 140^{0}C

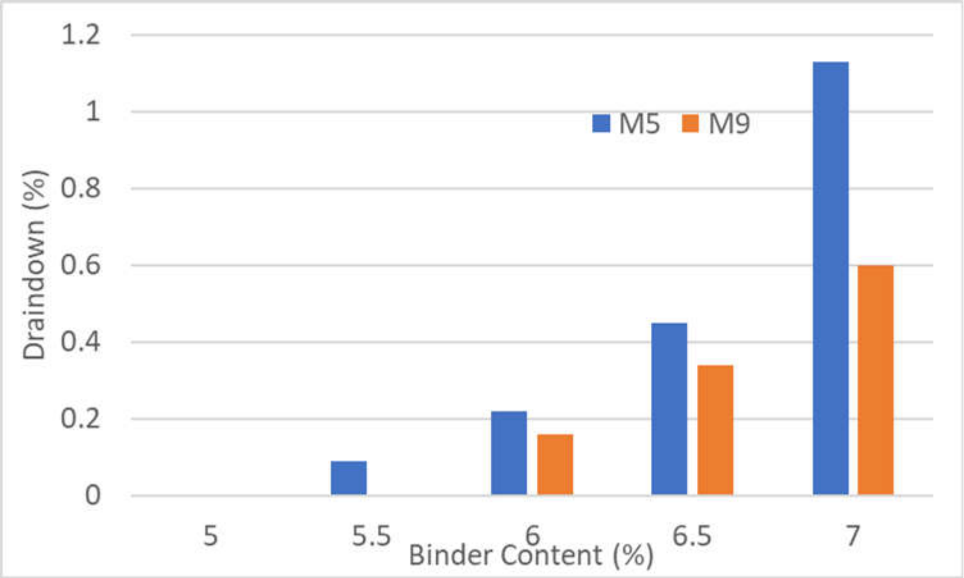

Figure. 3b. Comparison of drain down characteristics between upper bound and mid-gradation with varying binder content at 140^0C

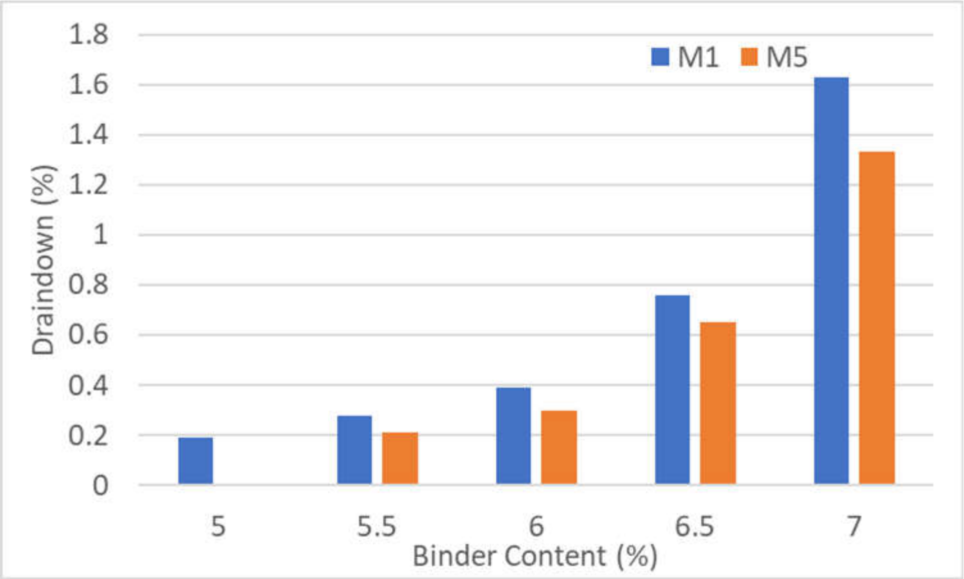

Figure. 3c. Comparison of drain down characteristics between lower bound and mid-gradation with varying binder content at 150^0C

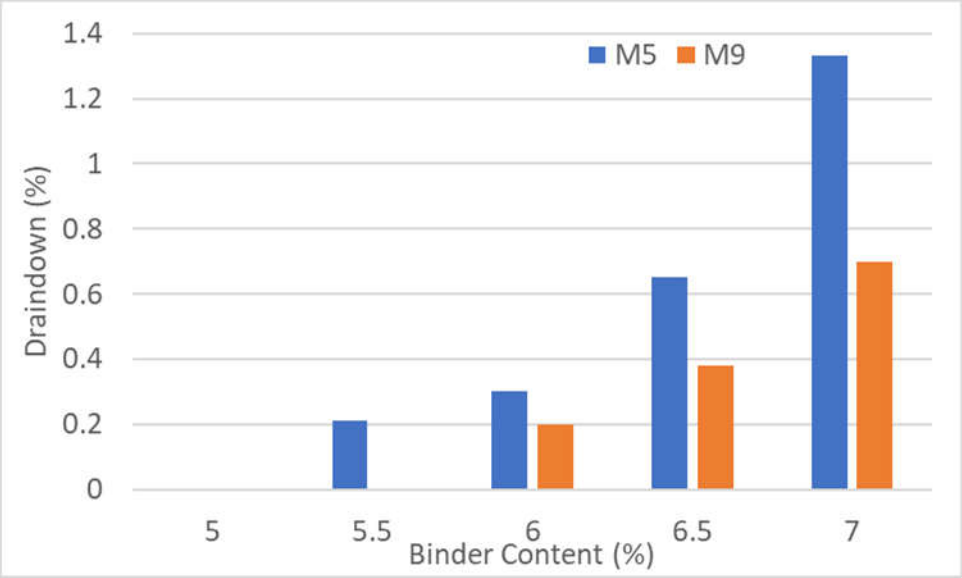

Figure. 3d. Comparison of drain down characteristics between upper bound and mid-gradation with varying binder content at 150^{0}C

From Fig. 3a, 3b, 3c and 3d it can be seen that with increase in binder content the drain down also increased. The drain down at 150^{0}C was higher than that at 140^{0}C. The drain down was found to decrease from M1 (lower bound of specification) to M5 (mid gradation) gradations. Likewise, the drain down was found to decrease from M5 (mid gradation) to M9 (upper bound of specification) gradations.

This could be attributed to the fact that as we move to the upper bound of specification, there is considerable percentage of fines which prevent the drain down of the binder.

5.2. Permeability test

The variation in the permeability values across the nine gradations is indicated in Figure4.

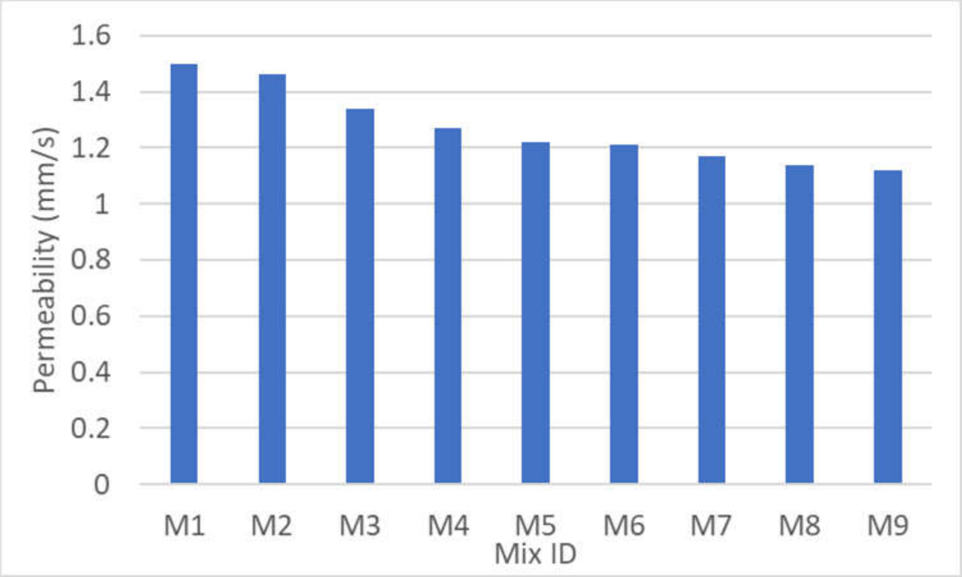

Figure. 4. Variation of permeability across the different gradations.

From Fig. 4 it is evident that all the gradations met the permeability requirement for open graded friction course mixes. However, the permeability was greatest for M1 gradation and least for M9 gradation. The percentage of fines for M1 gradation was comparatively lower than M9 gradation and owing to this, the flow of water was much easier in the former case.

5.3. Cantabro Abrasion Loss

A comparative analysis of Cantabro Abrasion loss of aged and unaged specimens across various gradations is displayed in Fig. 5. In case of unaged samples there is 11% decrease in Cantabro abrasion loss from M1 to M5 gradation and from M5 to M9 gradation there is 3.5 % decrease in Cantabro abrasion loss. Hence for unaged sample, from lower gradation to mid gradation there is a steeper decline in abrasion loss, while from mid gradation to upper gradation the decline is more gradual.

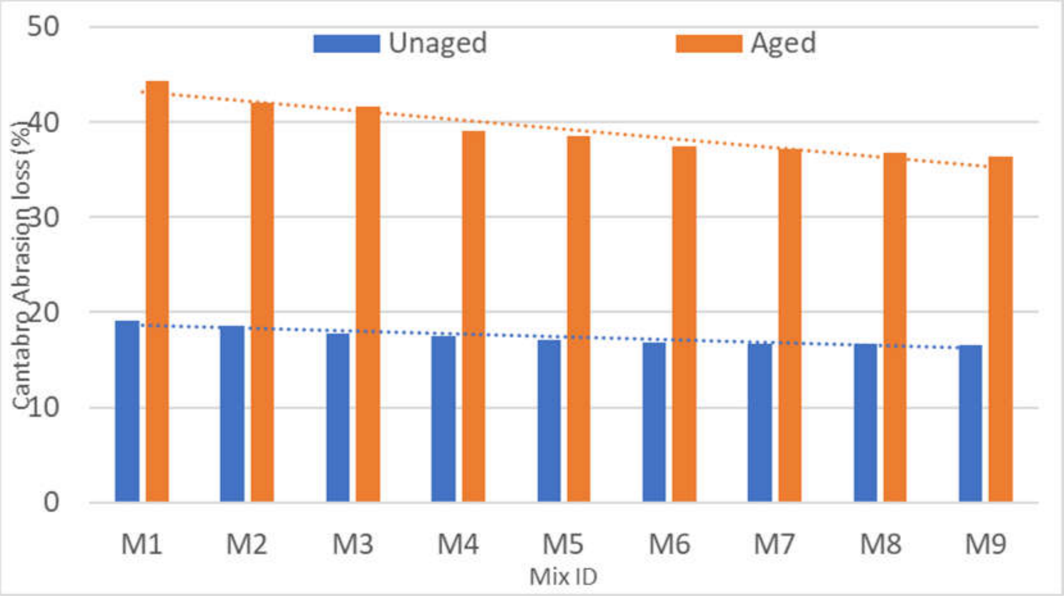

Fig. 5. Cantabro Abrasion loss of unaged and unaged samples across the different gradations

In case of aged samples there is 13% decrease in Cantabro abrasion loss from M1 to M5 gradation and from M5 to M9 gradation there is 5% decrease in Cantabro abrasion loss. Hence for aged samples from lower gradation to mid gradation there is a steeper decline in abrasion loss, while from mid gradation to upper gradation the decline is more gradual.

A comparative study of aged and unaged samples with varying gradation was also carried out as illustrated in Fig.6

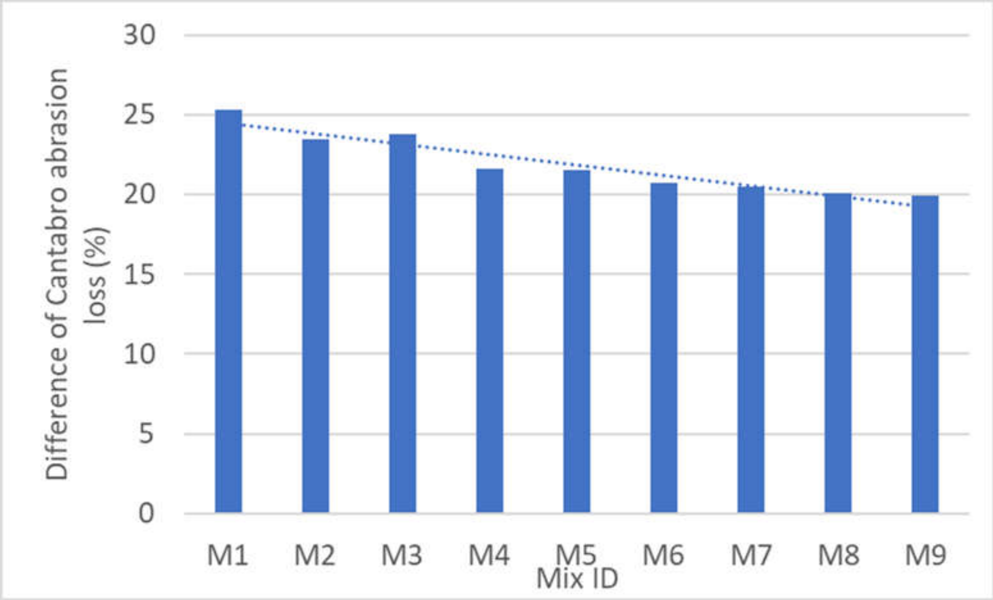

Fig. 6. Variation in Cantabro loss of aged and unaged sample across various gradation

In case of both unaged and aged samples , the Cantabro loss was greatest for M1 mixes, intermediate for M5 mixes and least for M9 mixes. In case of all gradations, the rate at which the Cantabro abrasion loss declined from unaged to aged specimen was uniform. The presence of more fines in M9 gradation resulted in imparting greater stability to the mix.

5.4. Tensile strength ratio

To analyse the influence of gradation on the tensile strength, a graph was plotted connecting the two parameters as shown in Fig. 7.

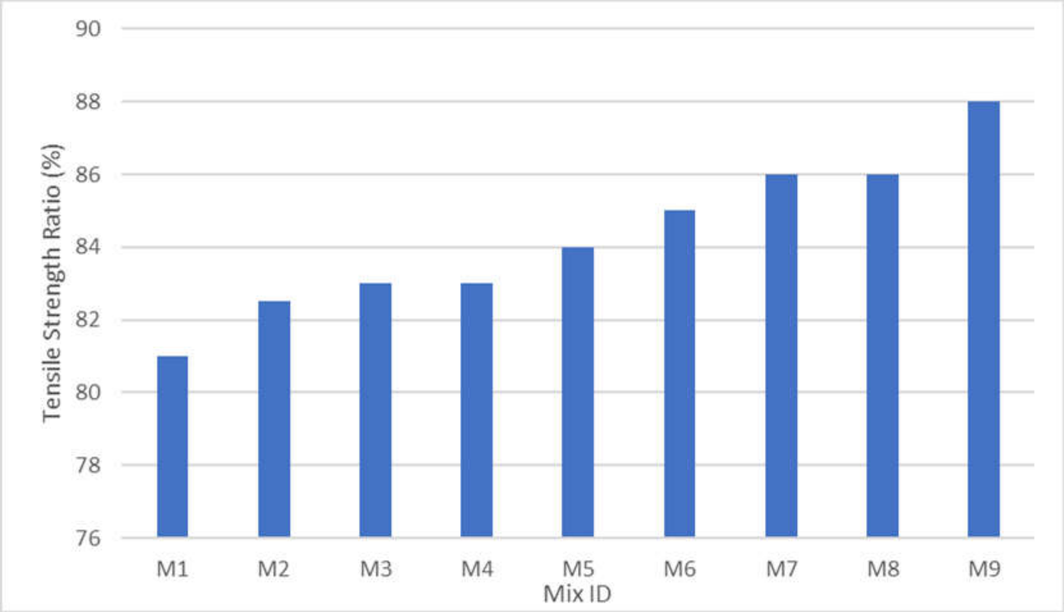

Fig. 7. Tensile strength ratio across the different gradations.

From Fig. 7, it can be seen that from M1 to M5 gradation there is an increase in tensile strength ratio. Likewise, from M5 to M9 gradation also, there is an increase in TSR. The increasing trend is more or less uniform from M1 through M5 (about 3%) to M9 gradations (about 8%). The presence of greater fines in M9 gradation as compared to M1 gradation has imparted greater strength to the mix.

6. Summary and Conclusion

This study evaluated the influence of varying gradation on the properties of warm porous asphalt mixes. Sasobit, a chemical additive was used for the preparation of warm mixes. Its dosage was optimised at 3% to obtain maximum possible reduction in temperature. The mixing and temperature relationship was arrived based on viscosity-temperature characteristics. About 10^0C reduction in mixing and 13^0C reduction in compaction temperature could be achieved. The binder content was optimised based on mix volumetrics and drain down characteristics. The optimum binder content of 5.5% satisfied the requirements of open graded friction course mixes. At this dosage there was no significant drain down, since the warm mix additive modified binder was stiffer and hence it could eliminate the need for fibres.

Nine different gradations were tried out to investigate the influence of gradation The properties evaluated includes the drain down characteristics, permeability, Cantabro abrasion loss and tensile strength ratio.

The following conclusions could be drawn from the study:

- The drain down increases with increase in temperature and binder content
- As the gradation progresses to the upper bound of the current specification, M9, the drain down decreases due to the presence of considerable number of fines which holds the mix together.
- Although all the gradations met the permeability requirement for open graded friction course mixes, M9 gradation had the least permeability as the presence of relatively more fines in this gradation retarded the smooth flow of water.
- The progress of Cantabro loss from aged to unaged samples declined uniformly in case of all gradations.
- Among the various gradations M9 gradation exhibited the least abrasion loss, owing to the presence of relatively more fines which resulted in imparting greater stability to the mix.
- For both aged and unaged samples as we move from lower gradation to mid gradation there is a steeper decline in abrasion loss, while as we progress from mid gradation to upper gradation the decline is more gradual.

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