"Influence of Air Voids and Compaction Level on Laboratory Performance of Bituminous Concrete Mixes"

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ABSTRACT

In the construction of Hot Mix Asphalt (HMA), it is important that there is adequate compaction so that initial permeability is low and there will not be any significant densification under traffic loading. Initially when the mix is laid and compacted, the air voids content should be around 8%, and later due to post compaction by vehicular traffic the air voids gets reduced (must be approximately 3%). There is a need to understand the behavior of the bituminous mixes at the approximate air voids content specified by many experts and thus an attempt is made in the present study to arrive at fixed limits of air voids required during construction and after exposure to traffic. The purpose of this work is to briefly summarize the results of the influence of air voids on fatigue behavior (performance) of BC mixes by varying initial air voids in the laboratory specimens prepared by Marshall Method by varying Compactive effort and determine the final air voids in the specimens, after simulating vehicular traffic in the laboratory using Fatigue Test. Based on this, it is aimed to fix the limits of air voids during construction and post traffic movement. It was observed that, mix with lower air void content offers longer fatigue life but it was also observed that the air voids reduced drastically which was not meeting MoRTH (V Revision) specification (3% to 5%), whereas the mix with higher air void content also met the fatigue life close to the mix with lower air void content and also air voids content post traffic simulated was within the limits specified.

Keywords: *Air voids, bituminous concrete mixes, compactive effort, fatigue behavior,marshall method*

I. INTRODUCTION

Air Voids are defined as the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture. Air voids is one of the important factors which affects fatigue cracking, resistance to permanent deformation and moisture damage of dense bituminous mixes. Pavement experts have suggested that initially when the mix is laid and compacted, the air voids content should be slightly higher than that recommended by MoRT&H, i.e., around 8%, and later due to secondary compaction by vehicular traffic the air voids get reduced. Higher voids lead to permeability of water and air resulting in water damage, oxidation, raveling, and cracking. Low voids lead to rutting and shoving of the asphalt mixture. Studies in several countries have shown that when the Voids in Mix (VIM) drop below 3%, BC mixes are very likely to fail by plastic flow. This means that 4% or 3% of air voids can bereduced during the secondary compaction caused by traffic. If, the original design was for4% or 5% air voids, the residual VIM can drop to between 0% and 2%, in which case the road will fail by the plastic flow.

II. LITERATURE REVIEW

'Veeraragavan', stated that "The voids in a bituminous mixture are directly related to density and hence it has to be ensured that the initial in-place air voids must be below approximately 8% and final in-place air voids after exposing the pavement surface to traffic movement for few years must be above approximately 3%".

Kumar and Veeraragavan (2008)[2] observed that "The air void content of the mix specimens has a significant effect on the volumetric properties, resilient modulus, tensile strength, fatigue and irrecoverable deformation behavior".

- The bulk specific gravity of BC mixes is found to increase withreduction in air void content, while the VMA is found to decrease
- BC mix with lower air void content tends to offer longer fatigue life and high resistance to permanent deformation. The results clearly indicate the benefits of a lower air void content on both fatigue life and resistance to irrecoverable deformation

E. Ray Brown (1990)[1] found that "The final voids are controlled by compacting samples (using manual hammer or equivalent) in the laboratory during the construction process"

- The voids in these samples will be representative of the final in-place voids if correct compactive effort is used. The initial in-place voids are determined by comparing the bulk density to the TMD
- The initial in-place voids should not exceed approximately 8 percent. The final in-place voids should not be below approximately 3 percent
- Typically the mix design is performed to provide 4 percent voids in the mix

Several investigations were reported on the air void content by Pell and Taylor (1969), Monismith (1969) and Bazin and Saunier (1967) and Judycki (1991). It was reported that lower the volume of air voids, higher the resultant fatigue life. Barksdale (1978) reported that the fatigue life of bituminous mixes as well as the fatigue life of the base course mixes is very inversely proportional to the air voids on log plot. Studies were conducted on indirect tensile strength of BC mixes by varying the air voids from 6% to 8%. It was observed that there is a decrease in indirect tensile strength due to increase in air voids in BC mixes[9]

III. OBJECTIVE

To fix the limits of initial and final in-place air voids during construction and post traffic movement which give rise tosuitable values for satisfactory performance of the mix throughout the life

IV. METHODOLOGY

1. Basic tests were carried out for aggregates, neat bitumen and modified bitumen whose physical requirements should meet the specifications as per MORT&H (V Revision)
2. A series of Marshall tests were conducted on a set of Bituminous concrete mix specimens using neat Bitumen and PMB made by compacting at 3 different energy levels and their Marshall properties were studied (Marshall blows were varied as 75, 50 & 35 blows)
3. The initial in-place air voids were determined by comparing the bulk density to theoretical maximum density

4. Repeated load indirect tensile fatigue test was carried out to check the fatigue life and the final air voids of the specimens at these compactive energy levels by considering fatigue testing as secondary compaction, due to the vehicular traffic

V. LABORATORY INVESTIGATIONS

5.1 Properties of Aggregates

The aggregates are subjected to laboratory investigations in accordance with specified test methods for determining the physical properties. Results of the same are given in the Table 4.1

Table 5.1 Physical Properties of Aggregates

Tests	Results	Requirements as per MoRT&H (V Revision)
Aggregate impact value, (%)	23.50	24 max
Los Angeles Abrasion value, (%)	21.10	30 max
Aggregate Crushing value, (%)	19	-----
Flakiness Index, (%)	14.4	15 max
Elongation Index, (%)	14.38	20 max
Combined Index, (%)	28.78	30 max
Aggregate specific Gravity 1.Coarse aggregates 2.Fine aggregates 3.Filler Material (Quarry Dust)	2.61 2.63 2.69	-----
Water Absorption, %	0.25	2 maximum

5.2 Properties of Bitumen

The Bitumen samples are subjected to laboratory investigations in accordance with specified test methods for determining the physical properties. Results of the same are given in the Table 5.2

Table 5.2a Physical Properties of Bitumen (VG-30)

Property	Obtained Value	Requirement as per IS: 73-2006
	VG-30	
Penetration at 25 ^{0}C 0.1mm, 100gm, 5sec	65	60-70
Softening Point (R&B) (^{0}C)	49.5°C	47 min
Ductility at 27 ^{0}C, (cm)	100$^+$	75 min
Specific Gravity	1.04	0.99 min
Elastic Recovery of half thread in Ductilometer at 15 ^{0}C, %	60	50 min
Viscosity by Rotational Viscometer i) Absolute Viscosity @ 60°C, cP ii) Kinematic Viscosity @ 135°C, Cp	i) 2500 P ii) 425cP	i) 2400 P min ii) 350cP min

Table 5.2b Physical Properties of Bitumen (PMB-40)

Property	Obtained Value PMB-40	Requirement as per IRC: SP: 53-2010
Penetration at 25 ^{0}C 0.1mm, 100gm, 5sec	31.7	30-50
Softening Point (R&B) (^{0}C)	64°C	60 min
Ductility at 27 ^{0}C, (cm)	100$^+$	75 min
Specific Gravity	1.05	0.99 min
Elastic Recovery of half thread in Ductilometer at 15 ^{0}C, %	45	30 min
Viscosity by Rotational Viscometer Viscosity at 150°C, P	1.5P	2-6

5.3 Aggregate Gradation

The gradation obtained by Job Mix Formula of aggregates used in this project is as per IRC Grade-1 as given in thefollowing table from **MoRT&H**: Specifications for Road and Bridge works (V Revision). The gradation obtained after Job Mix Formula is shown in the Table 5.3 and the gradation curve is shown in Fig.5.1

Obtained Job Mix Formula,

A : B : C = 20 : 30 : 50

Table 5.3 Specified Gradation and Obtained Gradation for BC Grade-1[15] as per MoRT&H (V Revision)

IS Sieve Size (mm)	Lower Limit	Mid Limit	Upper Limit	Adopted
26.5	100	100	100	100
19	79	89	100	93.50
13.2	59	69	79	71.56
9.5	52	62	72	51.53
4.75	35	45	55	49.40
2.36	28	36	44	42.64
1.18	20	27	34	29.53
0.6	15	21	27	22.05
0.3	10	15	20	15.51
0.15	5	9	13	8.97
0.075	2	5	8	5.16

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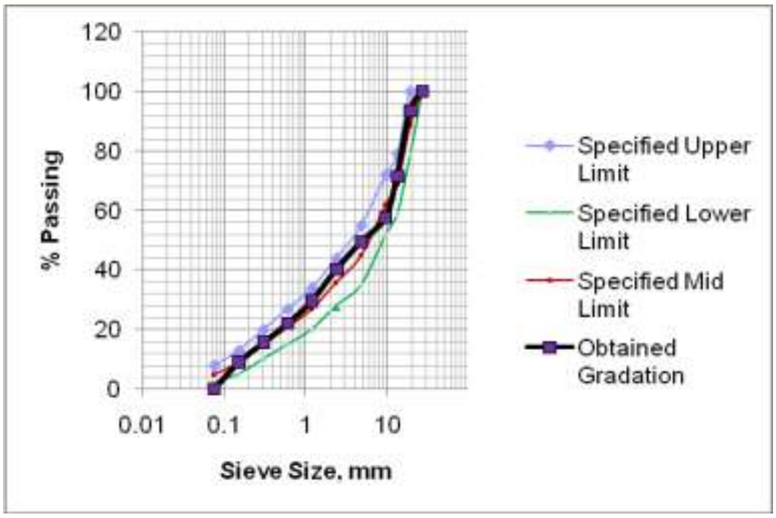

Figure 5.1 Shows the Gradation ofBC-1 mix

5.4 Marshall Properties of Varying Blows

Marshall specimens were prepared by varying the number of blows on either side of the specimen viz. 75 blows, 50 blows and 35 blows for both type of bitumen and the results are tabulated in the tables 5.4 to 5.7.

Table5.4 Marshall Properties at Optimum Binder Content for Neat Bituminous Concrete mix (75 Blows)

Marshall Properties	Result of BC mix 60/70 Grade Bitumen	Requirements as per MoRT&H (V Revision)
Compaction Level	75 blows on each face of the specimen	
Optimum Bitumen Content, %	5.3	----
Stability, kN	21.18	9 min
Flow, mm	2.50	2.0-4.0
Bulk Density, g/cc	2.37	----
Air Voids, %	3.46	3-5
VMA, %	15.51	13 min
VFB, %	77.91	65-75

Table 5.5 Marshall Properties at Optimum Binder Content for Neat Bituminous Concrete mix (50 & 35 Blows)

Marshall Properties	Result of BC mix 60/70 Grade Bitumen	Result of BC mix 60/70 Grade Bitumen
Compaction Level	50 blows on each face of the specimen	35 blows on each face of the specimen
Optimum Bitumen Content, %	5.3	5.3
Stability, kN	15.62	11.46
Flow, mm	2.80	2.97
Bulk Density, g/cc	2.32	2.28
Air Voids, %	5.13	6.83
VMA, %	16.98	18.46
VFB, %	69.77	63.02

Table5.6 Marshall Properties at Optimum Binder Content for PMBC mix (75 Blows)

Marshall Properties	Result of BC mix PMB-40 Grade Bitumen	Requirements as per MoRT&H (V Revision)
Compaction Level	75 blows on each face of the specimen	
OBC, %	5.4	----
Stability, kN	34.87	12 min(Hot) 10 min(Cold)
Flow, mm	2.10	2.5-4.0 (Hot) 3.5-5.0 (Cold)
Bulk Density, g/cc	2.38	----
Air Voids, %	3.00	3-5
VMA, %	15.22	13 min
VFB, %	80.29	65-75

Table 5.7 Marshall Properties at Optimum Binder Content for PMBC mix (50 & 35 Blows)

Marshall Properties	Result of BC mix PMB-40 Grade Bitumen	Result of BC mix PMB-40 Grade Bitumen
Compaction Level	50 blows on each face of the specimen	35 blows on each face of the specimen
OBC, %	5.4	5.4
Stability, kN	24.70	20.60
Flow, mm	2.43	2.85
Bulk Density, g/cc	2.35	2.28
Air Voids, %	4.14	6.90
VMA, %	16.34	18.75
VFB, %	74.65	63.38

5.5 Indirect Tensile Strength

Table5.8 Static Indirect Tensile Strength Test Results

Compaction Level	Indirect Tensile Strength (N/mm^2)@ 25°C	
	VG-30	PMB-40
75 Blows	1.111	1.439
50 Blows	1.052	1.284
35 Blows	0.958	1.382

5.6 Repeated Load Indirect Tensile Fatigue Test

The specimens are subjected to cyclic stresses due to repeated application of load and resulting horizontal and vertical deformation measurements at failure and also at stages of fatigue life viz. 25%, 50% and 75% of fatigue life are made. The load repetitions to failure is given in the table 5.9

Table 5.9 Fatigue life cycles at different Compaction Level

Compaction Level	Stress Level, %	No. of Cycles(VG-30)	No. of Cycles(PMB-40)
75 Blows	10%	4708	26320
	20%	822	3523
	30%	230	574
50 Blows	10%	2400	12514
	20%	496	1324
	30%	206	518
35 Blows	10%	4030	19611
	20%	519	1779
	30%	227	530

5.7 Air Voids

Using the results obtained from Repeated Load Indirect Tensile Fatigue Test, Resilient Modulus and Air Voids are found and it is shown in the Table 5.10.

Table 5.10 Abstract Sheet for Air Voids at respective Stage of Fatigue Life.

Binder Type	Compaction Level	Initial Air Voids of the Specimen, (%)	Stress Level	Resilient Modulus (MR), N/mm^2	Air Voids at respective Stage of Fatigue Life, (%)		
					25% Nf	50%Nf	75% Nf
VG-30	75 Blows	3.61	10%	5014	-	-	-
		3.15	20%	768	-	-	
		3.38	30%	2701	-	-	-
	50 Blows	5.46	10%	406	1.98	1.89	1.42
		4.49	20%	1070	1.62	-	-
		4.49	30%	1108	-	-	-
	35 Blows	6.57	10%	1085	3.36	1.80	0.84
		6.94	20%	2343	3.35	2.81	0.16
		6.56	30%	436	3.33	2.21	1.19
PMB-40	75 Blows	3.01	10%	1163	2.248	1.032	-
		3.09	20%	970	2.111	2.014	-
		3.05	30%	2863	1.921	0.361	-
	50 Blows	4.07	10%	238	3.092	0.656	-
		5.10	20%	408	2.858	1.949	0.095
		4.18	30%	1698	1.267	-	-
	35 Blows	5.70	10%	1005	5.141	4.345	1.398
		6.00	20%	1892	3.591	1.944	-
		6.57	30%	1028	5.761	3.536	3.339

VI. DISCUSSIONS AND CONCLUSIONS

Bituminous mixes were compacted at varying blows and the air voids were measured and noted as initial air voids in the specimen, and the final air voids were measured after the specimen underwent Repeated Load Indirect Tensile Fatigue Test. Based on the results obtained from the experimental studies the following conclusions were drawn:

- The Marshall Properties of Bituminous concrete grade-1 using VG-30 and PMB-40 with varying Compactive effort as 50 blows and 35 blows are shown in Tables 5.5 and 5.7 respectively and they satisfy the requirements of MoRT&H (V Revision) specifications except air voids as it is varied in the present study
- From Repeated Load Test, it shows that both VG-30 and PMB-40 mixes compacted with 35 blows takes higher number of repetitions than the mix compacted with 50blows but lesser repetitions than mix compacted with 75 blows at all varying stress levels
- For both VG-30 and PMB-40 mixes compacted with 75 blows, it is observed that the minimum required air voids was not obtained (3%-5%) at all the different stress levels during its fatigue life
- For both VG-30 and PMB-40 mixes compacted with 50 blows, though some air voids were present at 25% and 50% of the fatigue life but was not within the limits at all the different stress levels. It was observed that minimum of 3% air voids was achieved at 25% of the fatigue life for a PMB-40 mix at 10% Stress Level
- For a VG-30 mix compacted at 35 blows, it was observed that minimum of 3% air voids was achieved at 25% of the fatigue life at all Stress Levels but air voids has decreased as the specimen reached 50% of the life
- For a PMB-40 mix compacted at 35 blows, it was observed that 5% air voids was achieved at 25% of the fatigue life and the air voids has gradually decreased as the specimen reached 50% and 75% of the life and still remained at 3% which is well within the specifications limit (3% to 5%)
- For both the mix at 30% Stress Level, Resilient Modulus decreased as the air voids content increased
- It was observed that the vertical deformation during the repeated load test initially increases gradually for the specimens with lower Compactive effort (35 Blows) when compared to specimens with higher Compactive effort (75 blows, 50 blows) and it increases only after 75% of its fatigue life. This indicates that specimen prepared with lowerCompactive effort performs better after secondary compaction
- The air voids obtained after the repeated load test was within the limits (3% - 5%) for 35 blows which was not seen in the case of 50 blows as well as 75 blows (was less than 3%), hence it shows that mix compacted with 35 blows performs better with respect to air voids by keeping the required air voids content throughout the life which is not so in case of mix with 75 blows
- With this limited data it can be concluded that initial air voids must be 7% during construction of the pavements and thus after undergoing secondary compaction it reaches to 3%. Hence it helps in permeability of water in the initial stages as the air voids will be high and after few years of exposure to traffic as the minimum air voids content will still remain it helps to prevent plastic flow, whereas in

75 blows case it is not true as the air voids will be 3% during construction and later due to traffic, air voids reduces even more leading to many failures such as cracking, rutting, bleeding and so on

VII. SCOPE FOR FURTHER WORK

- To study the performance of mixes compacted with lower Compactive effort
- To study the Rutting parameters usingWheel Tracking Equipment for varying Compactive effort, whose results will help in giving a strong conclusion for the present study

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