Moisture Conditioning Process for Large-Sized Prismatic Straight Beam Specimens of Bituminous Concrete

Utsav Vishal, Venkaiah Chowdary

Abstract: ***This study proposesa moisture conditioning process forlarge-sizedprismatic beam specimens of bituminous concrete. Such beams are required for evaluating the fatigue characteristics of bituminous mixtures in a four-point beam bending test. The current moisture conditioning protocols are aimed at cylindrical specimen only, and no guidelines are available for prismatic beams; especially when these beams are compacted to lower air voids content. In this study, prismatic beam specimens of bituminous concrete mixed with VG-30 and CRMB-60 binderwere prepared. In addition to the control samples, warm mix asphalt and lime additive added samples were also produced. Warm mix asphalt was produced using a surfactant based warm mix additive. Lime was added to both hot mix and warm bituminous mixtures. Prismatic beams with target air voids of 4 ± 0.5% and with dimensions of 0.38 ± 0.006 m (length) × 0.050 ± 0.002 m (width) × 0.063 ± 0.002 m (height) were produced. These specimens were subjected to partial vacuum saturation by submerging completely in water. The vacuum pressures and durations were adjusted such that the desired saturation could be achieved. The saturated bituminous concrete beam specimens were mechanically weakened through the freeze-thaw conditioning. It is observed that the binder type plays a significant role in the degree of saturation whereas the influence of additives is negligible on the degree of saturation.***

Index Terms: Air Voids, Degree of Saturation, Lime, Moisture Conditioning, Prismatic Straight Beam, Vacuum Saturation, WMA Additive.

I. INTRODUCTION

Most of the bituminous roads fail prematurely due to poor drainage. Moisture accelerates the rate of distresses in bituminous pavements. Very limited information is available on how to understand and quantify the effects of moisture induced damage in bituminous mixtures. Determination of moisture sensitivity of bituminous mixtures is one of the most critical aspects to be considered for evaluating the performance of bituminous pavements as the high moisture susceptible bituminous mixtures will deteriorate at a much rapid rate. Hence, simulation of field moisture damage conditions in the laboratory is required such that bituminous mixtures that are more resistant towards the moisture damage could be identified.

Traditionally, AASHTO T283 [2] test protocol is practised to simulate the moisture damage conditions in the laboratory. This protocol is prescribed for cylindrical specimen geometries. A moisture-conditioned sample is subjected to indirect tension testing,and the ratio of the failure load with a control sample is used as a criterion to rank bituminous mixtures. In such procedures, the sample is compacted to in-place air voids after construction (≈ 6-8 %) and hence the saturation of the sample to the required level (70-80 %) is fairly straightforward and the whole process can be finished in 15 to 20 minutes. It is not clear whether such procedure could be adapted to quantify the moisture damage of beam specimen, where one is interested in characterising the influence of moisture damage on the fatigue characteristics. Such samples are compacted to 4 % air voids and hence subjecting the samples to the required degree of saturation is not straightforward.It is also not clear how to saturate prismatic beam at 4% air voids and what effect will the addition of additive will have on the degree of saturation. It is also notwell known that what effect binder type will have on the degree of saturation.

The fatigue performance of bituminous mixtures is evaluated in the laboratory using a four-point beam bending test setup under controlled conditions. This test setup utilises large-sized prismatic beam specimens. As the moisture damage accelerates the distresses in bituminous mixtures, quantification of such mechanisms requires moisture conditioning of the specimens. Post moisture conditioning, these specimens can be further evaluated for fatigue response. As there is no standard test protocol available for moisture conditioning of these specimens, this study focuses on the development of moisture conditioning process for large-sized prismatic beam specimens.

II. LITERATURE REVIEW

Moisture sensitivity tests such as boil test, immersion-compression test, retained Marshallstabilitytest and submerged wheel tracking test are practisedto assess the bituminous mixtures susceptibility tomoisture [7]. In the boil test, the loosebituminousmixtures are immersedin boiling water for 10 minutes,and the mix is visually inspected for stripping after removing the loose bitumen [3].Moisture sensitivity isalso measured as the number of freeze-thaw cycles required to induce crack on sample [9] where multiple freeze-thaw cyclesare performedwith freezing at -12

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˚C for 24 hours and thawing at 60 ˚C for 24 hours.

Immersion-compression test involves axial compression test on a 100 mm diameter cylindrical specimen at 25˚C without lateral support after the specimen is conditionedunderwater at 60˚C for 24 hours. Here, the moisture sensitivity is determined as the ratio of the wet specimen tothe dry specimen[1, 5].Marshall immersion test follows similar conditioning process as immersion compression test, where Marshal stability is used to determine the strength of the compactedbituminous mixtures. Original Lottman [10]method recommends to vacuum saturate the specimen in water for 30 minutes, freeze at -18˚C for 15 hours and thaw at 60˚C for 24 hours. Resilient modulus and tensile strength tests are conducted to evaluate the intensityof moisture damage. Modified Lottmanand Tunnicliff and Root [4] conditioning process suggests, 55 to 80% saturationforcylindrical specimen compacted to7±0.5% airvoids. Modified Lottmantest conditioning follow a freeze-thawconditioning process whereasTunnicliff and Root conditioning eliminated the freezing process [10, 12]. It is reportedthat bituminous mixtures that were known as moisture susceptible mixtures were accepted by modified Lottman and ASTM D4867 test procedures [7]. AASHTO T283 [2] test procedure recommends indirect tensile strength test on a cylindrical specimen of 100 mm or 150 mm diameter compacted to 7 ± 0.5 % air voids. The specimens are vacuum saturated between 70 to 80%, and these specimens are further considered for the freeze-thaw process. The current guideline suggests application of partial vacuum between 254-660 mm Hg continuously for 10 minutes for a cylindrical specimen [2].

IRC:111-2009 [8] recommends to vacuum saturate the specimens for 30 minutes without clearly stipulating the degree of saturation. It is important to note here that IRC:111-2009 [8] saturation may not be applicable across different bituminous mixtures prepared using different binder types as the specific time duration may not result in the desired degree of saturation. It is to note here that, one of the focus points of the current study is to identify various saturation parameters. Various conditioning processes are used to condition bituminous mixtures to quantify its moisture susceptibility depending upon the location of construction. Freeze-thaw conditioning is applicable where the pavements experience sub-zero temperatures. Similarly, bituminous mixtures can also be conditioned at 60˚C for 24 hours, neglecting the freezing process. This study reports the experimental investigation conducted to moisture condition a prismatic beam specimen.

III. EXPERIMENTAL EXPERIMENT

A. *Materials*

A total of eightcombinationsof the bituminous mixture was considered for the study. Unmodified, VG-30 and crumb rubber modified, CRMB-60 binders following guidelinesIS 73: 2013 and IS 15462: 2004 respectively were selected.The bituminous mixture specimens were prepared using locally available aggregatesselected from a single source with two types of binders. Aggregates were batched to satisfy the target bituminous concrete gradation-II [11].A surfactant based dark brown coloured warm mix additive was used to produce warm mix asphalt (WMA). Addition of warm mix additive provides improved workability during the production of the bituminous mixture at reduced temperature. WMA additive was added to the binder at 160˚C and 180˚C for VG-30 and CRMB-60 respectively at the proportion of 0.4% and 0.5% by the weight of the binder. The above dosage rates are fixed such that the desired characteristics of WMA, i.e., the desired workability could be achieved even at reduced mixing temperatures. Thorough mixing of WMA additive was achieved by mixing at 500 rpm for 15 minutes using a mechanical stirrer. Hydrated lime was introduced to the aggregate, replacing 2% of filler (passing 75-µm sieve)by the weight of total aggregate as an anti-stripping agent.The batched aggregates and binder were heated to mixing temperature and were mixed in an automated bituminous mixer.Both the unmodified and crumb rubber modified binders selected for the study were blended with aggregate to produce hot mix asphalt (HMA) and WMA bituminous mixture. Both the HMA and WMA bituminous mixture were also produced with the addition of lime to generate beam specimen. Theoreticalmaximum specific gravity (G_{mm}) was determined to be 2.604 for specimen prepared using VG-30 and 2.606 for specimen prepared using CRMB-60.

A shear box compactor, as shown in Fig. 1(a) following ASTM D7981 [6] specification was used to compact the bituminous mixtures to produce beams of size 0.45m × 0.15 m × 0.169 m. These beams were further sliced to 0.38 ± 0.006 m × 0.050 ± 0.002 m × 0.063 ± 0.002 m as shown in Fig. 1(b), using a saw cutter. Overall, 16 shear box beams were fabricated and 44 samples having air voids between 4 ± 0.5 %were selected for the study (Fig. 1b).Four fatigue beams were extracted from one shear box compacted large beam,and the entire slicing process is depicted pictorially in Fig. 2 in four steps.

B. *Moisture Conditioning Process*

The vacuum system consists of a vacuum pump, a non-return valve, a vacuum dial gauge, a vacuum controller, a moisture trap and a glass vacuum chamber (Fig. 3). The high capacity vacuum pump used in this study is capable of applying vacuum up to 760 mm Hg. The non-return valveensures that once the vacuum was created in the vacuumchamber, no leakage of air occurs from vacuum pump that in turn can affect the vacuum created in the chamber. It was also checked and ensured that there was no leakage of air from any joints and the push-in pipe. A calibrated dial gauge was installed to measure the applied vacuum accurately.A trial and error approach was adopted to determine the intensity of partial vacuum for saturating a prismatic beam specimen.It was ascertained to apply a vacuum in the range of 700 to 740 mm of Hg. The vacuum controller, directly connected to a power supply of vacuum pump was used to maintain the selected vacuum. A moisture trap was installed to filter any moisture from the air flowing from vacuum chamber towards vacuum pump during the process of saturation. A cylindrical glass vacuum chamber of 100 mm inner diameter and 550 mm height with a glass flange on top was used for moisture conditioning of the specimen.

The thickness of the wall of the glass cylinder is 5 mm.

The top flange is connected to an outlet, through which vacuum is applied. The chamber is used to submerge the sliced fatigue beam in water during the saturation process.

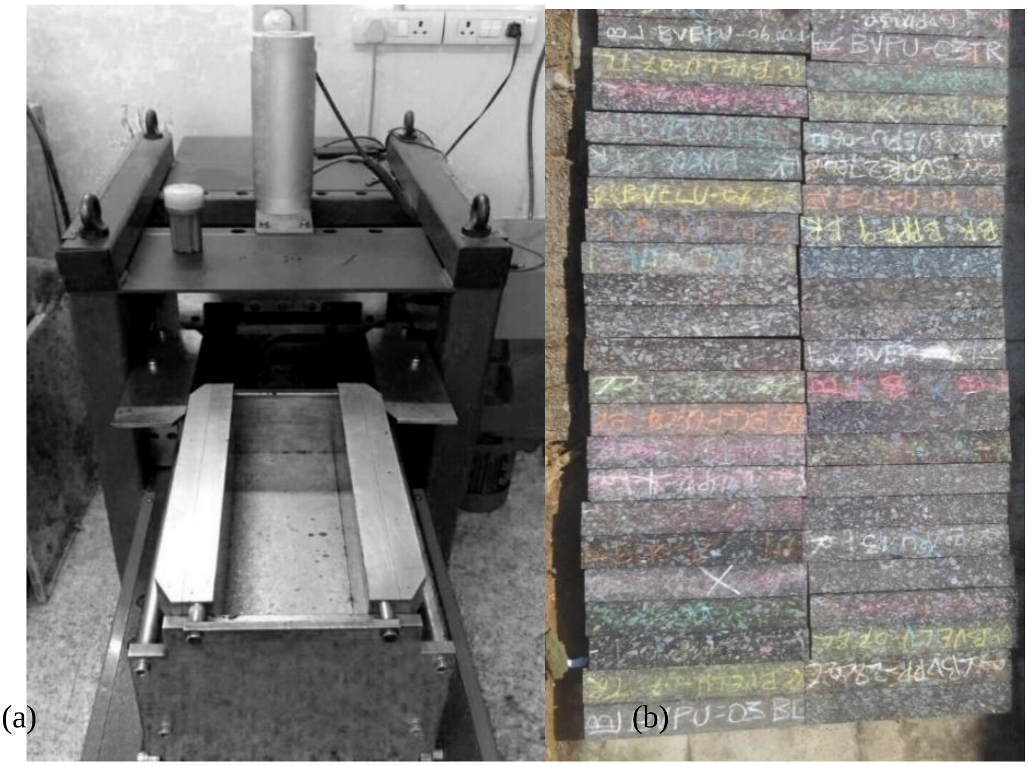

Fig.1. a) Shear-box compactor, (b) sliced beams considered for thestudy

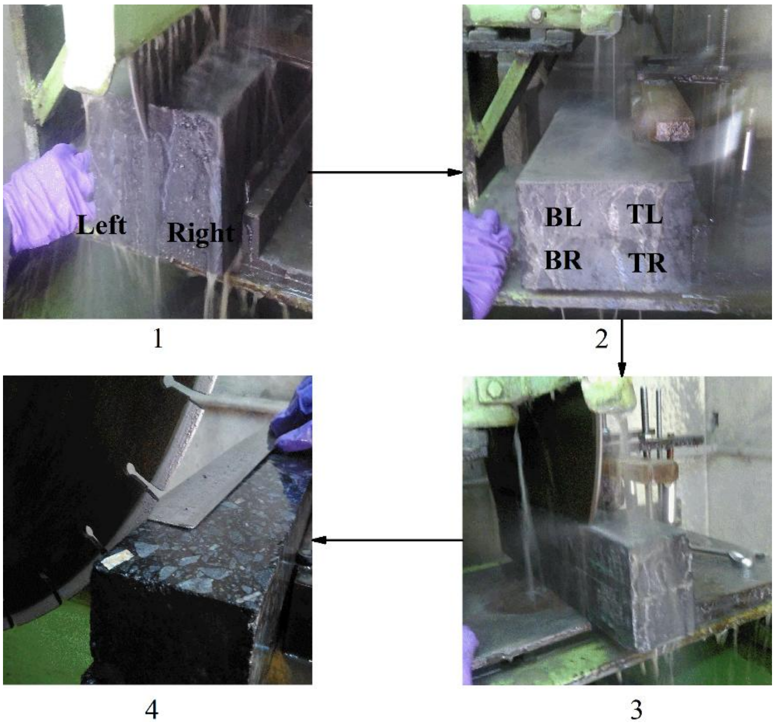

Fig.2. Slicing of the shear box beam using a saw cutter

The fatigue beam specimen was placed inside the airtight glass chamber and was submergedcompletely in water. A partial vacuum was applied, and as the vacuum reached 740 mm Hg, the controller stops the vacuum pump,and the vacuum was maintained. On the development of vacuum,the air present in the voids of the fatigue beam specimenwas subjected to pressure gradient,and the air bubbles coming out of the submerged beam specimen could be seen clearly in Fig. 4. When the vacuum reduces to 700 mm Hg, the controller triggers the pump to start and stops it again when 740 mm Hg vacuum is attained.Following partial vacuum application, the beam was then allowed to remain submerged in water after the release of vacuum, to permit the water to enter the empty voids in the beam under atmospheric pressure. Multiple trials were carried out to achieve the specified degree of saturation. To fix the time of saturation based on the preliminary trials, each specimen was allowed to saturate for 3 hours. It was perceived that specimen prepared with VG-30 saturated for 3 hours attained the degree of saturation between 70-80 %. However, beams prepared using CRMB-60 binder at equivalent air voids achieved 40-50 % degree of saturation after 5 hours at the similar application of partial vacuum. The influence of modified binder was evident on attainment of a degree of saturation when compared with unmodified bituminous mixtures. It is therefore not necessary that the degree of saturation shall be identical for unmodified and modified bituminous mixture at 4 % air voids, subject to similar partial vacuum and time. The internal microstructure is completely different for crumb rubber modified bituminous mixtures. The degree of saturation depends on the interconnectivity of the air voids, in other words, the internal structure created by the aggregate matrix and the asphalt mastic. Even though the bituminous mixtures with unmodified and modified binders were compacted to equivalent air voids of 4 %, it is hypothesized in this study that the resulting variation in degree of saturation of both these bituminous mixtures is mainly due to the difference in terms of the connectivity of the air voids. Higher the interconnectivity of the air voids, the degree of saturation is likely to be higher.

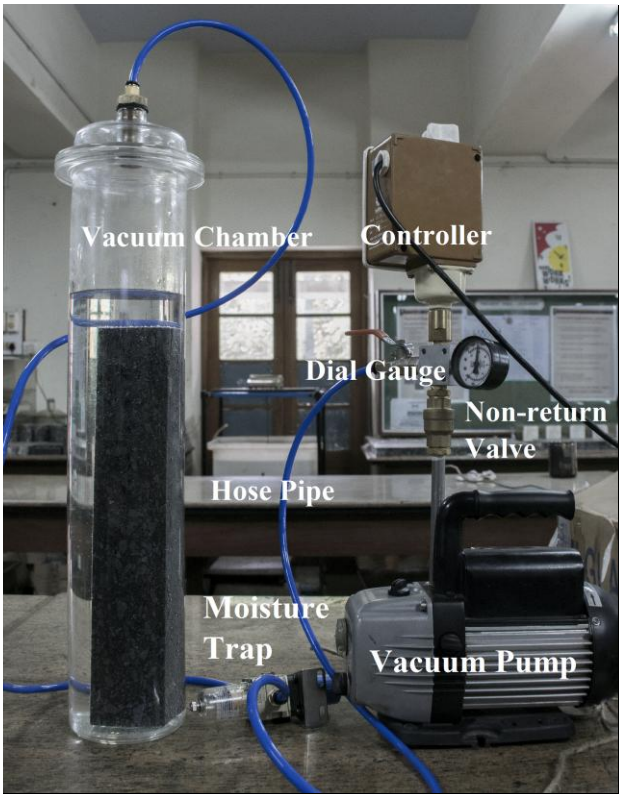

Fig.3. Vacuum system

The degree of saturation is calculated using the difference in air weight of fatigue beam before and after saturation as shown in Equation (1) and the volume of air voids is computed using Equation (2).

$$S = \frac{100 \times (\mathrm{W_{sat}} - \mathrm{W_d})}{V_{air}} \tag{1}$$

$$V_{air} = \frac{V_a \times V_{beam}}{100} \tag{2}$$

where, S – degree of saturation (%), W_{sat} – saturated surface dry weight of beam after saturation (g), W_d – weight of dry beam in air (g), V_{air} – volume of air voids (cm^3), V_a– air voids (%), and V_{beam} – volume of beam (cm^3).

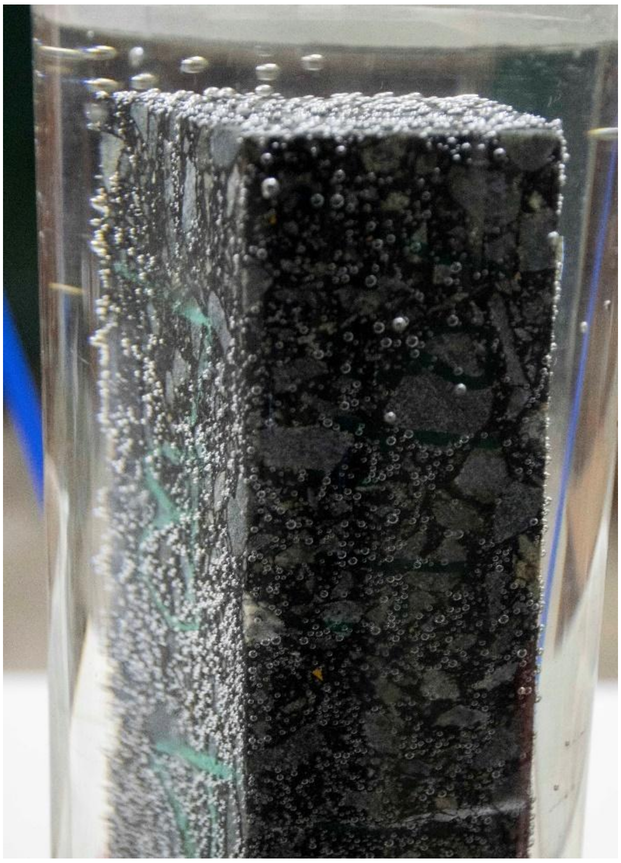

Fig.4. Saturation of fatigue beam

C. ANOVA

Analysis of Variance (ANOVA) was carried out to find the influence of various parameters on the degree of saturation.One-way ANOVAwas performed at 95% confidence interval. In the first set, within a given binder the influence of additive (WMA additive, lime, and WMA additive with lime) used was assessed. Secondly, the effect of binder type (unmodified and modified) on the degree of saturation was evaluated. The fixed variable in the first set is the type of additive used in the studyand response variable is the degree of saturation. In the second set, the fixed variablesare the types of binder used in the study. The null hypothesis for the study is no statistical difference in the means between the variables exist. Also, the alternative hypothesis states that there is a statistical difference in the means between the variables. The null hypothesis was accepted if the tabulated p-value was greater than p-critical (0.05) value, else the null hypothesis was rejected, and alternative hypothesis was accepted.

IV. RESULTS AND DISCUSSION

The optimum time required to saturate fatigue beam was found to be 3 hours for VG-30 binder and 5 hours for CRMB-60 binder.Though all eight mixtures were compacted at 4 ± 0.5 % air voids, the degree of saturation was found to be very different acrossthe binders. The difference in the degree of saturation between unmodified and modified bituminous mixtures can be hypothesised due to the change in the internal structure at comparable air voids. The air voids range, duration of saturation and degree of saturation details for the test conducted to address the study objectiveare specified in Table 1.

TABLE I. DETAILS OF THE COLLECTED DATA FOR THE STUDY

Binder	Bituminous Mix	Air Voids Range (%)	Duration (hrs)	No. of samples	Degree of saturation (%)
VG-30	HMA	4.1-4.5	3	3	68-82
	WMA	3.8-4.5		8	75-82
	HMA with Lime	3.9-4.3		4	68-74
	WMA with Lime	3.5-4.6		8	67-81
CRMB-60	HMA	4.0-4.8	5	4	51-66
	WMA	4.5-4.9		4	41-51
	HMA with Lime	3.8-4.9		10	30-65
	WMA with Lime	4.4-4.7		3	35-46

One-way ANOVA shows that there is no significant effect of the addition of additives on the degree of saturationas shown in Table 2 for a given binder. One way ANOVA was carried out with 23 samples of VG-30 and 21 samples of CRMB-60. As the p-value (Table 2) for both VG-30 and CRMB-60 is greater than 0.05 (p-critical), the null hypothesis was accepted which signifies that the means for all the four variables are equal. Thus, it can be impliedthat use of additive has a negligibleeffect on the variation of the degree of saturation for a given binder.

TABLE II. EFFECT OF ADDITIVE ON THE DEGREE OF SATURATION (%)

Binder	Additive	Control	WMA additive	Lime	WMA additive and Lime
VG-30	Mean	76	78	71	74
	SD	7.9	4	2.7	5.8
	F*	3.1			
	F	2.1			
	P	0.12			
CRMB-60	Mean	52	46	41	43
	SD	1.7	4.1	5.5	3.1
	F*	3.3			
	F	2.8			
	P	0.08			

SD- standard deviation, F* - F critical, F – F calculated, P - P value

Whereas, the degree of saturation was significantlyaffected by the type of binder as shown in Table 3. All 44 samples of VG-30 and CRMB-60 were examined for the one-way ANOVA. As p-value (Table 3) is smaller than p-critical, the null hypothesis is rejected, and alternative hypothesis was accepted. It can be said that the means of two variables are not equal. Therefore, it can be inferred that degree of saturation is binder dependent.

TABLE III. EFFECT OF BINDER ON THE DEGREE OF SATURATION

Binder	Mean	SD	F*	F	P
VG-30	75	5.5	4.1	286.8	0.000
CRMB-60	42	6.8			

V. CONCLUSION

A new process is developed in this study for moisture conditioning of the large-sized prismatic straight beam specimens of bituminous concrete. The study shows that VG-30 mixtures achieved 70 - 80 % degree of saturation in 3 hours, whereas CRMB-60 mixtures were saturated between 40 - 50 % in 5 hours, although both the mixtures were identically compacted. It was also observedthat the degree of saturation is dependent on the type of binder governing variability in the internalmicrostructure, and is independent of the addition of additiveswithin a particular binder.Specific guidelines related to the parameters to be considered during the moisture conditioning process were provided,and the relative effects of additives and binder type were quantified.Statistically, the effect of additives had no significant effect on the degree of saturation for a particular binder. It was also verifiedstatistically that the degree of saturation is very much binder dependent within the given range of air voids considered in this study.

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