Chapter 7
PERFORMANCE EVALUATION OF ASPHALT MIXTURES

7.1 Prologue

The current chapter is focused on the fatigue performance evaluation of asphalt mixtures using various fillers. The details about the type of aggregate used in this research are provided, along with a brief explanation of conventional test procedures. The Marshall Mix design approach to prepare the mixes is detailed next, followed by calculating the OBC at each filler content. In addition, the significance of aging is discussed, and the procedure for conditioning, short term aging, and long term aging is described next.

The second half of the chapter is dedicated to the fatigue testing of asphalt mixtures using a semi-circular bending test. The procedure for sample fabrication is explained step by step, including the notching process. The variables of testing, such as loading rate, data acquisition, and output parameters, are also outlined, followed by an explanation of the calculation process. Finally, the results and observations are discussed in detail with primary inferences.

7.2 Preparation of Asphalt Mixtures

7.2.1 Aggregates

The aggregates of dolomite origin were used in the study to prepare asphalt mixtures. The compatibility of the aggregates was determined by conducting various physical tests which are stated in Table 7.1.

Table 7.1 Physical properties of aggregates

Test	Value	Max. Limit (MoRTH-2013)	Reference
Los Angeles Abrasion	21%	35%	IS: 2386 (IV)
Aggregate Impact Value	16%	27%	IS: 2386 (IV)
Combined flakiness and elongation	18%	35%	IS: 2386 (I)
Specific Gravity (Coarse Aggregate)	2.615	-	IS: 2386 (III)
Specific Gravity (Fine Aggregate)	2.678	-	IS: 2386 (III)
Water Absorption	0.15%	2%	IS: 2386 (III)

7.2.2 Gradation of Aggregates

The Dense Bituminous Macadam (DBM-2) gradation as per MoRT&H guidelines, with a nominal maximum aggregate size (NMAS) of 26.5 mm, was adopted in this study (Figure 7.1). DBM is the most common binder course mix used in India. Being a binder course material, the fatigue life of the bituminous layer is primarily influenced by the properties of DBM. Since this study is directed towards understanding the role of fillers on the fatigue life of HMA, DBM was considered as a suitable gradation. Three filler contents, 3%, 5%, and 7%, from within the range of the standard gradation limits (2%-8%), were adopted. These filler contents correspond to low, mid, and high filler fractions in the mix. Hence, the effect of varying filler content on the fatigue behavior of asphalt mixtures can be effectively captured. The aggregate gradation plays an important role in the fatigue performance of asphalt mixtures, due to which it is a very vital parameter in the mix design [332]. The carefully selected gradation provides a sufficient amount of air voids in the mixture to accommodate the thermal expansion of the binder, secondary compaction, and proper asphalt film thickness on the aggregate particles (MS2-2014).

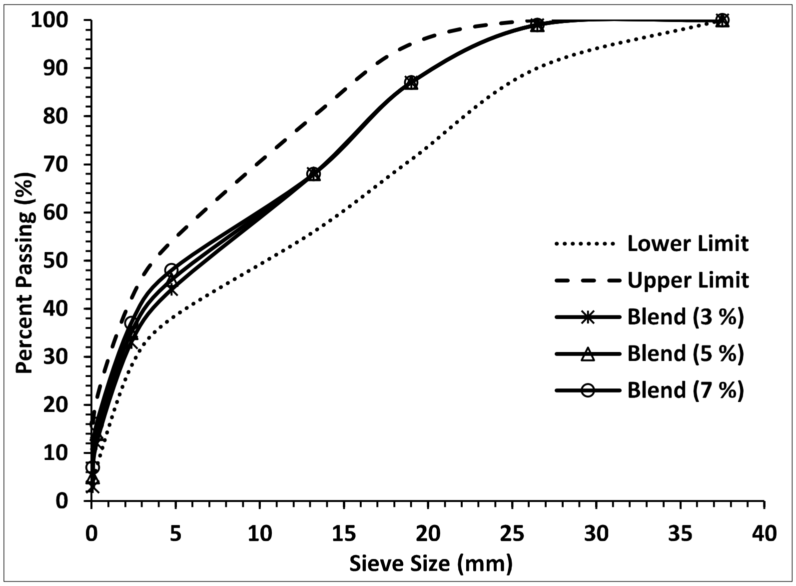


Figure 7.1 Gradation at different filler contents

7.2.3 Batching

The batching of aggregates was done by fractionating the aggregates on each sieve size, followed by the individual batching of each aggregate fraction for every specimen in accordance with the method 3 (total fractionation of all aggregate materials) of aggregate batching specified in asphalt Institute MS-2 manual. It is evident from Figure 7.1 that almost all the aggregates (99%) passed through the 26.5 mm sieve and it is a common consensus that if significant portion of aggregates is not retained on 26.5 mm sieve, 100 mm samples are adequate. However, the SCB testing was used for the fatigue testing of asphalt mixtures. As per standard specifications (ASTM D8044), the specimen diameter of 150 mm is required for the testing, therefore the same has been used in the study.The aggregates samples were oven dried for 24 hours at 105-110°C before batching to remove the entrapped moisture accumulated at the quarry or during the transportation to the laboratory. The presence of moisture increases the weight of aggregate, causing errors in the material proportioning.

7.2.4 Mixing

The mixing and compaction temperatures were obtained as 162°C and 148°C for virgin binder whereas they were found to be 171°C and 157°C for polymer modified binder. The rotational viscometer and DSR were used for the estimation of mixing and compaction temperatures for virgin and polymer modified binder respectively, prior to the mixture fabrication. The aggregates were heated in a draft oven at the mixing temperature for a time period of two hours. The asphalt binder was also heated at the same temperature but only for a time period that was enough to facilitate the mixing. This was done to avoid the aging caused by the longer exposure of the binder to higher temperatures. The aggregates and binders were then mixed in a pan at the respective mixing temperature of the binder. The mixing was done until the aggregates were fully coated with the binder, as evident from visual observation.

7.2.5 Conditioning

The mixture conditioning is necessary to account for the absorption of binder by the aggregates caused during the mixing procedure in the plant and the transportation of the mix to the site. If not taken into account, the absorption of binders by aggregates may alter the volumetric calculations and cause errors in laboratory results. AASHTO T 245, the current standard for preparing asphalt mixes using the Marshall method, lacks provision for conditioning before compaction. However, Superpave compaction specifications, as per AASHTO T 312, mentioned the provision for conditioning following the AASHTO R 30 protocols. A similar method was used in this study: spreading the loose mix in a tray and placed in the oven for 2 hours at the corresponding compaction temperature. The mixture was stirred after every hour to maintain uniform conditioning. It is to be noted that the procedure for short term aging is similar to that of conditioning, except the time duration is 4 hrs in place of 2 hrs.

7.2.6 Compaction

Lab compaction aims to simulate the finally compacted pavement after several years of service life. MS-2 specifies compaction level resulting in 4% air voids to achieve long term pavement performance. There are three major compaction methods for the design of asphalt mixtures and quality control testing, i.e., gyratory, impact, and kneading compaction. This study utilized the impact hammer as a part of a modified Marshall mix design for the compaction of asphalt mixes. It is a 10.2 kg mechanically operated hammer with a drop height of 467 mm. The hammer imparts loading to the asphalt mixture contained in a 152.4 mm diameter mold assembly. The height of the finally compacted specimen is approximately 95.2 mm. The compaction requirement for a modified Marshall mix design is 1.5 times the standard specimen, i.e., 112 blows.

After conditioning, the loose mixture was poured into the hot collar and the mold assembly. The filter paper was placed before filling the mold to avoid sticking of material to the base. The assembly was put in the compactor and subjected to 112 blows on each side of the specimen (Figure 7.2). After compaction, the samples in the mold were marked and allowed to cool overnight, followed by specimen extraction.

(a) **(b)**

(c) **(d)**

Figure 7.2 Compaction procedure

7.2.7 Mix Design Parameters

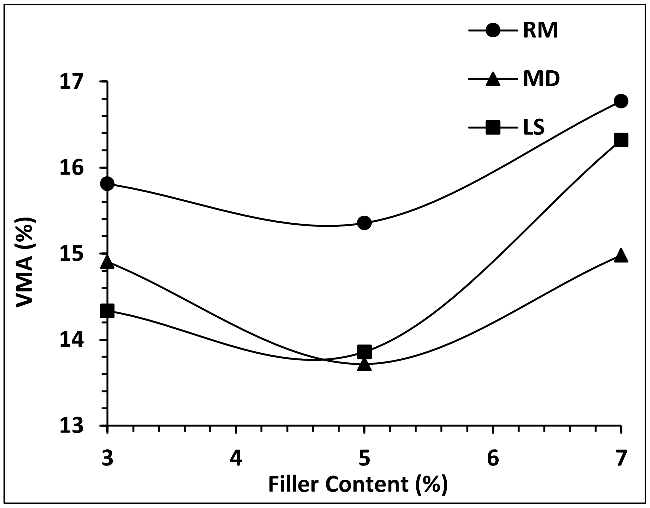
Table 7.2 presents the Marshall mix design parameters obtained in accordance with MoRT&H guidelines:

Table 7.2 Marshall mix design and volumetric parameters

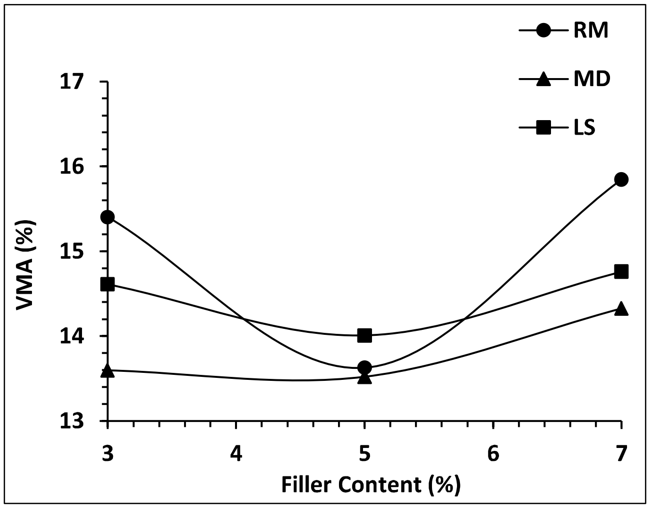
Binder	Filler	Filler Content (%)	G_{sb}	G_{se}	OBC (%)	G_{mb}	G_{mm}	A_v	VMA (%)	VFB (%)	Stability (kN)	Flow (mm)
VG-30	**MD**	3	2.6368	2.682	5.251	2.368	2.468	4.03	14.9	73	20.52	5.6
		5	2.6212	2.664	4.711	2.373	2.473	4.04	13.7	70.5	21.57	5.3
		7	2.6336	2.68	5.314	2.365	2.464	4.01	15	73.2	23.91	4.8
	LS	3	2.6402	2.675	4.806	2.376	2.474	4.04	14.3	71.8	21.85	5.3
		5	2.6336	2.663	4.675	2.38	2.479	3.97	13.9	71.3	23.30	5.2
		7	2.637	2.627	5.189	2.327	2.425	4.04	16.3	75.2	25.34	4.7
	RM	3	2.6397	2.682	5.645	2.355	2.453	3.98	15.8	74.8	24.04	5.1
		5	2.6495	2.664	5.057	2.362	2.46	4	15.4	74	26.09	5.0
		7	2.6593	2.68	5.76	2.349	2.447	4.02	16.8	76	27.11	4.1
PMB-40	**MD**	3	2.6368	2.734	5.358	2.407	2.508	4.01	13.6	70.5	27.89	6.0
		5	2.6212	2.705	5.201	2.391	2.491	4.02	13.5	70.3	28.89	5.7
		7	2.6336	2.737	5.786	2.395	2.494	3.99	14.3	72.1	30.58	5.6
	LS	3	2.6402	2.715	5.521	2.386	2.487	4.04	14.6	72.3	29.70	5.8
		5	2.6336	2.703	5.227	2.39	2.488	3.97	14	71.7	30.03	5.6
		7	2.637	2.725	5.789	2.386	2.484	3.96	14.8	73.2	32.92	5.4
	RM	3	2.6397	2.741	6.222	2.381	2.481	4.01	15.4	74	32.91	5.3
		5	2.6495	2.739	5.265	2.416	2.516	3.99	13.6	70.7	34.69	5.1
		7	2.6593	2.756	6.312	2.389	2.489	4.03	15.8	74.6	40.38	4.6

G_{sb}- Bulk Specific Gravity of Total Aggregates, **G_{se}-** Effective Specific Gravity of Aggregates **G_{mb}-** Bulk Specific Gravity of Mix, **G_{mm}-** Theoretical Maximum Specific Gravity of Mix, **A_v-** Percent Air Voids in Compacted Mix, **VMA**- Voids in Mineral Aggregate, **VFB**- Voids Filled with Binder

Figure 7.3 presents the variation in VMA with the change in filler content in the mixes prepared with neat and polymer modified binder at the corresponding optimum binder content. It is observed that the VMA exhibited a flattened U shaped curve showing a decreasing trend on increasing the filler content from 3% to 5%, followed by the increment at 7% filler content. This dependency on filler content contradicts the definition where one might expect consistent decrement in VMA with adding filler. Actually, the total volume change across the range of fillers depends on the resistance to compaction; hence, the constant volume postulation is inaccurate. The increment in filler content to 5% makes the distribution of different aggregate particles and fillers more uniform, facilitating compaction, and hence lesser voids are obtained. However, further increasing the filler (bottom of curve) starts pushing the aggregates apart, resulting in higher VMA.

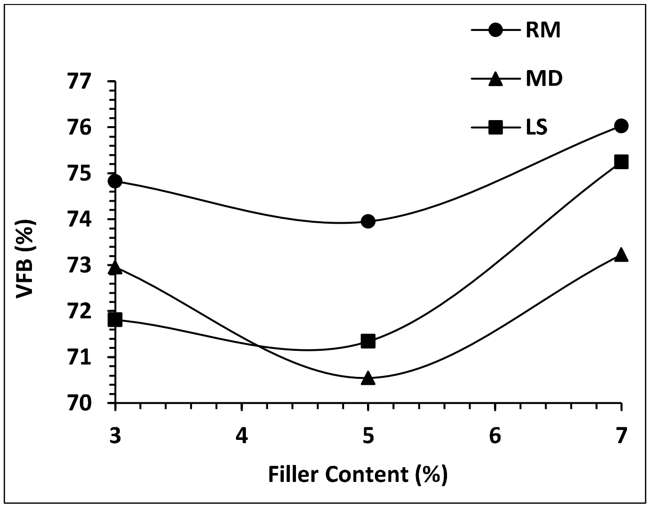


(a)

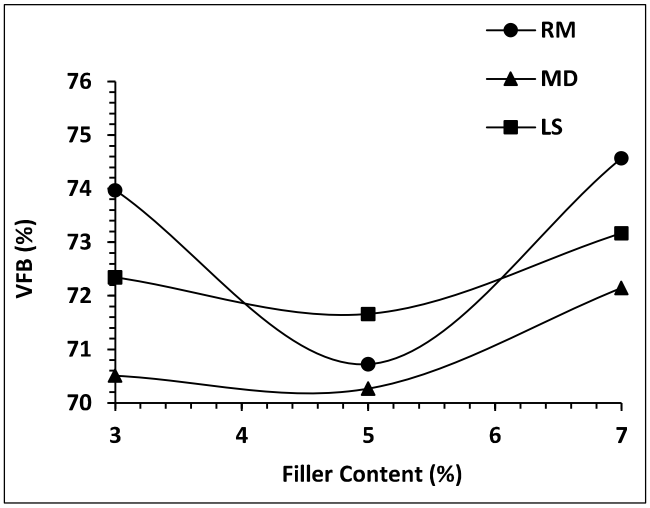


(b)

Figure 7.3 Variation in VMA as a function of filler content in the (a) neat and (b) polymer modified mixes



(a)



(b)

Figure 7.4 Variation in VFB as a function of filler content in the (a) neat and (b) polymer modified mixes

The variation in VFB as a function of filler content for mixes with unmodified and polymer modified binder is shown in Figure 7.4. It is clear that the VFB displayed a similar behavior as observed from the VMA curves, i.e., decreasing first on increasing the filler content from 3%

to 5%, followed by the consistent increment up to 7% filler content. Actually, the VMA comprises both the air voids as well as the voids occupied by the binder, and the OBC was calculated at 4% air voids (constant) for all the mixes. Hence, the VFB was the effective function of VMA only, due to which the effect of filler content was similar in both cases.

7.2.8 Determination of Number of Blows to Achieve Target Air Void Content

The OBC is the amount of binder that is added to the mix and compacted with 112 blows to get 4% air voids. But ASTM D 8044 recommends the preparation of asphalt mix samples at 7% air voids for the SCB testing. Therefore, to achieve the required voids at OBC, the compaction effort was altered by reducing the number of blows. The trial samples for performance testing were cast at different blows, and the corresponding air void content was determined. The blows with respect to 7% air voids were determined with interpolation, and the remaining samples were prepared at the same number of blows.

7.2.9 Long Term Aging of the Samples

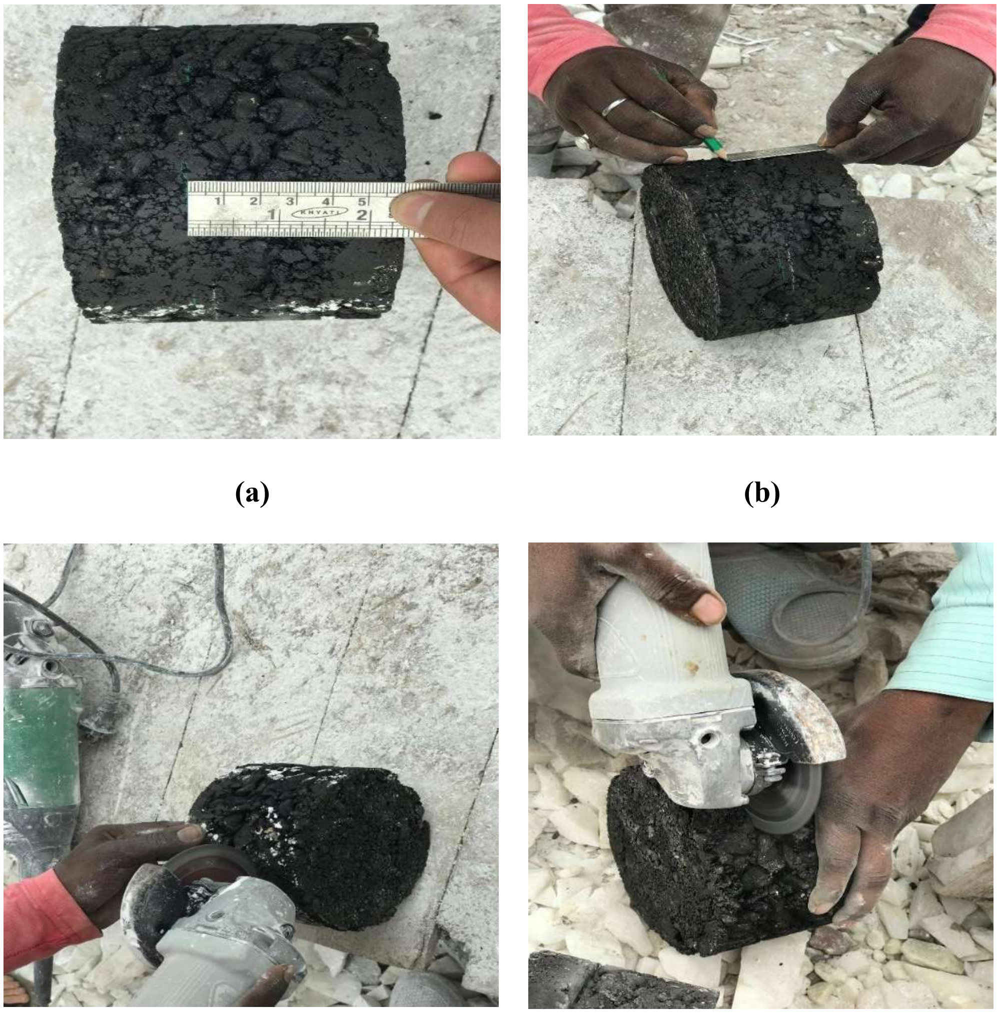
The prepared modified Marshall samples were long term aged following the AASHTO R 30 protocols. The LTA was done on the compacted samples prepared with the short term aged loose mix, whose procedure is already described in section 7.2.5. The LTA procedure consists of keeping the samples in the draft oven for 120 hours at a temperature of 85°C (Figure 7.5). Previous articles have used the same method for LTA of unmodified [333–337] and modified mixtures [338–342]. After this period, the doors of the oven were opened to allow the specimen to cool to room temperature, which generally takes approximately 16 hours. The samples were then taken out from the oven and subjected to SCB testing after the cutting and notching operations discussed in the next section.

(a) **(b)**

Figure 7.5 Extracted specimens and LTA

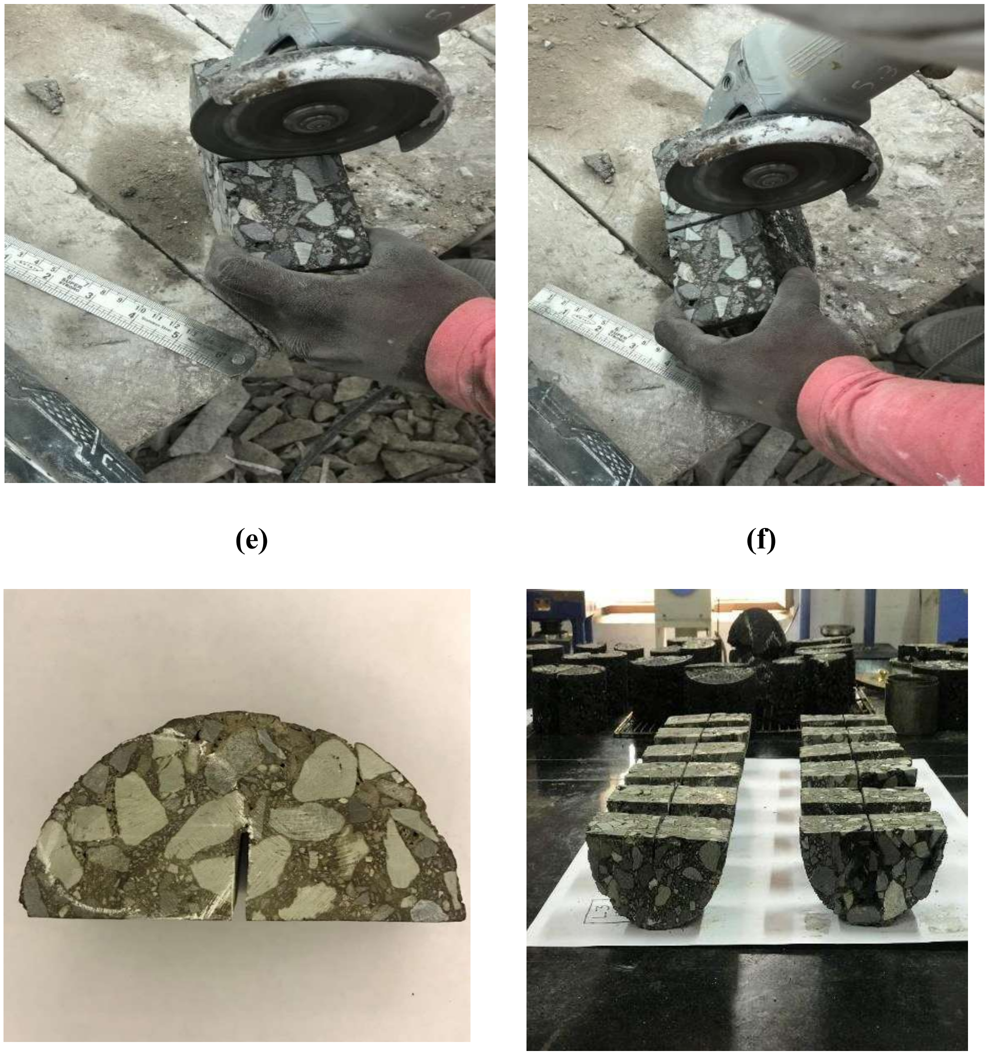
7.3 Performance Analysis via SCB Testing

The SCB test has been used to determine the fatigue resistance of the asphalt mixtures prepared using different fillers. The SCB test specimen is a half disk sample with a notch present parallel to the vertical or loading axis. The samples for SCB testing were cast at 7% air voids as recommended by ASTM D8044. It is followed by long term aging in a draft oven at a temperature of 85°C for 120 hours as per AASHTO R 30 protocols. The LTA samples were subjected to cutting and notching operations to mold them in the required shape, as shown in Figure 7.6. The samples were trimmed to a thickness of 57 mm using an electric stone cutter and divided into two equal halves in the form of semi-circular specimens. Elseifi et al. [343] stated that a minimum of two notch depths are required to determine the critical value of J-integral. The notching operation involved marking a fine notch in the middle of the specimens with 15 mm and 30 mm depths. Three replicates at each notch depth were prepared for testing, and the average values were reported. The prepared specimens were conditioned in the water bath for 2 hours at a corresponding testing temperature of 15°C.



(a) **(b)**

(c) **(d)**



(e) **(f)**

(g) **(h)**

Figure 7.6 Preparation of SCB specimens

The SCB testing involves applying a monotonic loading under a constant rate of 0.5 mm/minute in a three-point bending load configuration until fracture, as shown in Figure 7.7. The test automatically stops when the load drops to 75% of the peak magnitude. The test output consists of load and deformation in the sample at the time interval of 0.05 s which are utilized to calculate the strain energy (SE), which is nothing but the area under the curve up to the peak load measured for each notch length. The SE was calculated using the quadrangle rule given below:

$$U = \sum_{i=1}^{n} (\delta_{i+1} - \delta_i) * P_i + 0.5 * (\delta_{i+1} - \delta_i) * (P_{i+1} - P_i) \tag{7.12}$$

Where P_i is the loading (kN) at the i^{th} load step application

P_{i+1} is the loading (kN) at the $(i+1)^{th}$ load step application

δ_i is the displacement (m) at the i^{th} load step

δ_{i+1} is the displacement (m) at the $(i+1)^{th}$ load step

The cracking resistance of the asphalt mixtures was quantified by the critical strain energy release rate, which is calculated as the change of strain energy with respect to different notch lengths per unit sample thickness as expressed below:

$$J_c = \frac{-1}{b}\left(\frac{dU}{da}\right) \tag{7.13}$$

Where,

J_c is the critical strain energy release rate in kJ/m^2

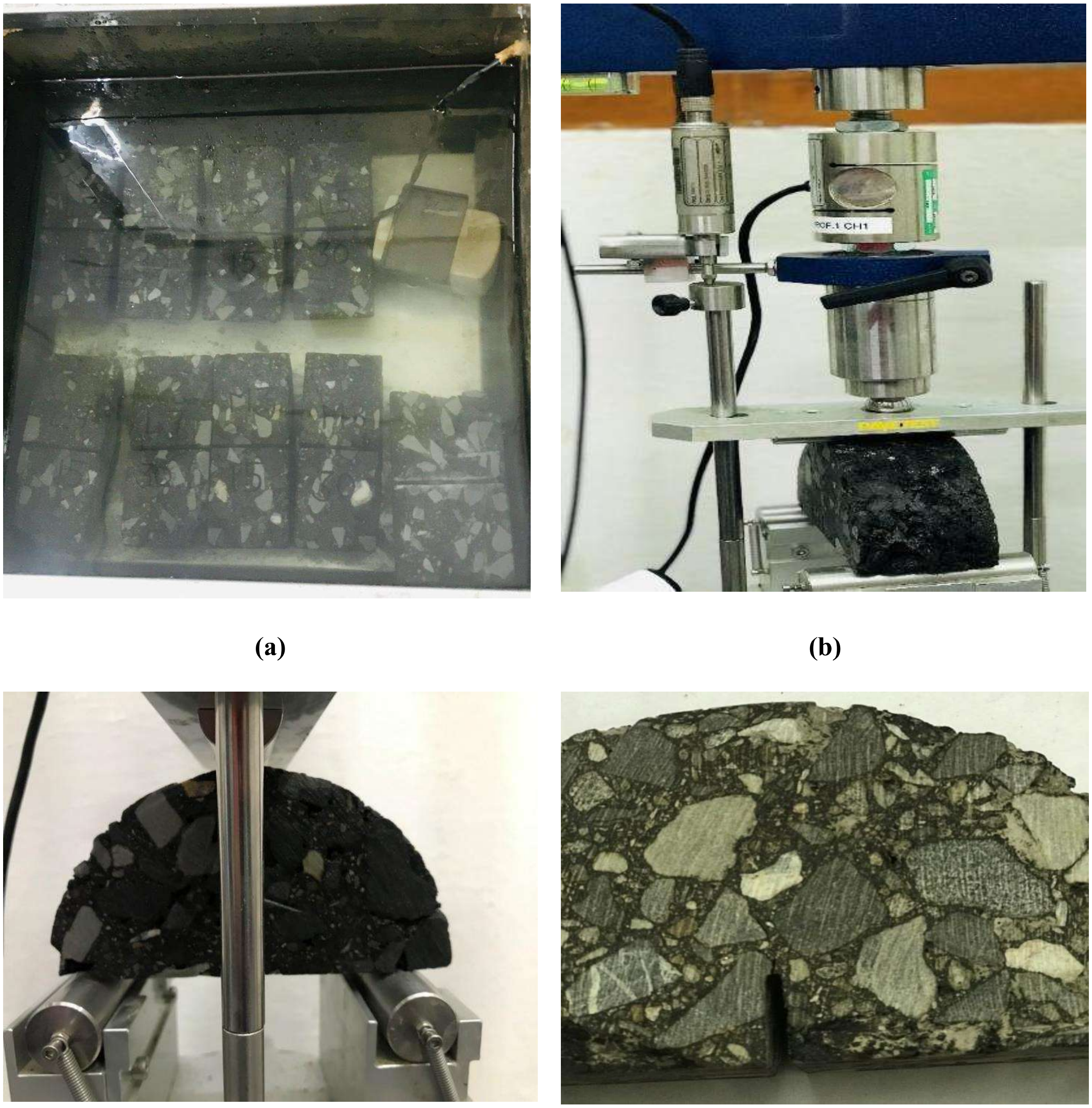
b is the thickness of the sample in m

a is the notch depth, in m

U is the strain energy up to the failure for each notch depth in kJ

dU/da is the change in strain energy with the notch depth in kJ/m

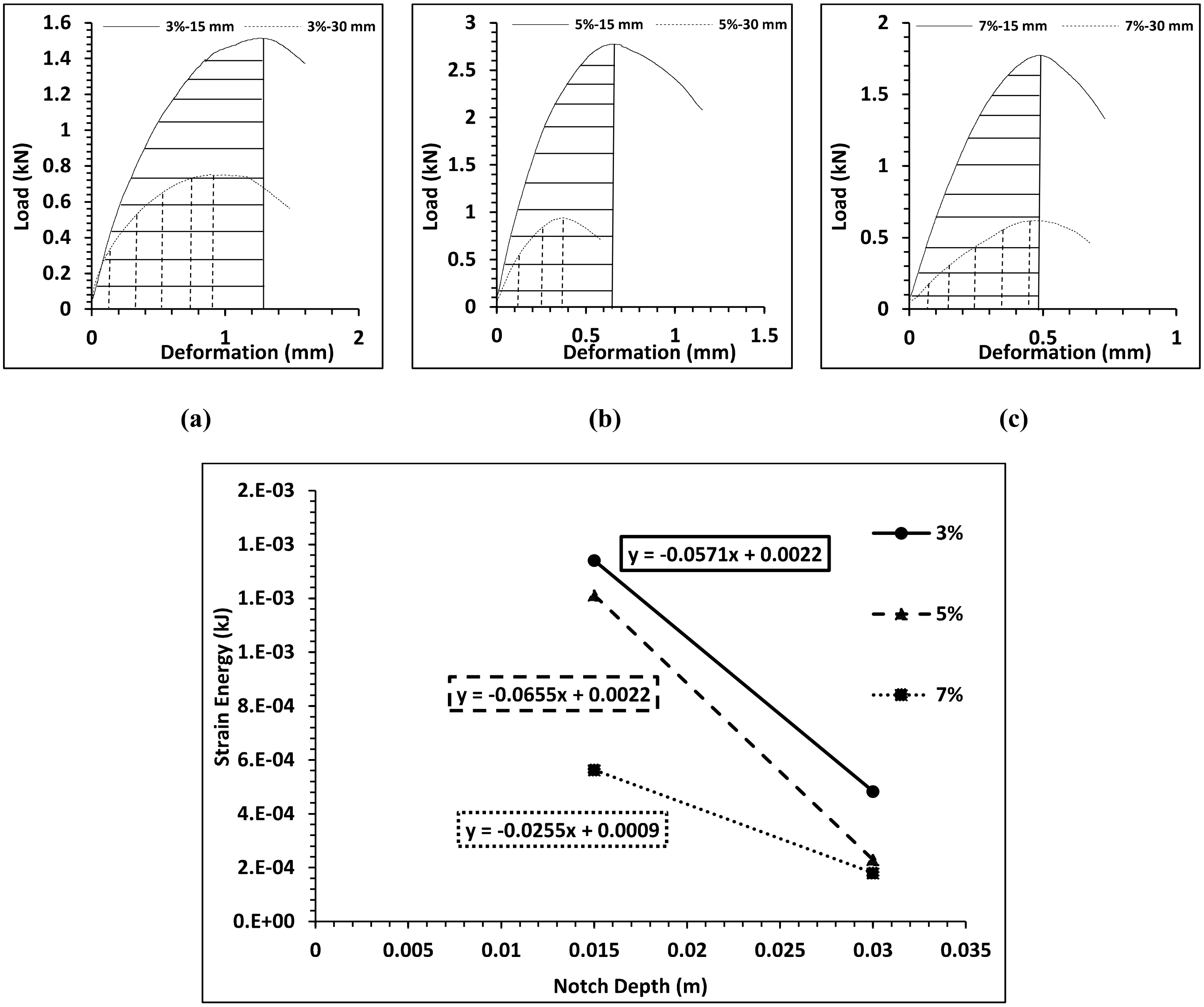
Figure 7.8 (a)-(c) shows the sample data for load versus deformation curves corresponding to 15 mm and 30 mm notch depths at varying filler content. The area under the curve upto the failure is shown by horizontal lines for 15 mm notch depth and vertical split lines for 30 mm notch. The variation of strain energy with notch depth was further modeled using a linear equation (Figure 7.8). The slope of the regression line represents the change in strain energy with notch depth (dU/da).



(a) **(b)**

(c) **(d)**

Figure 7.7 SCB testing

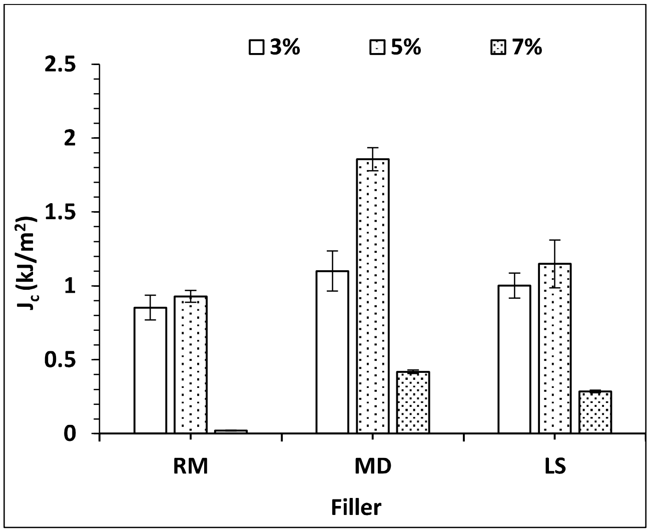


(a) **(b)** **(c)**

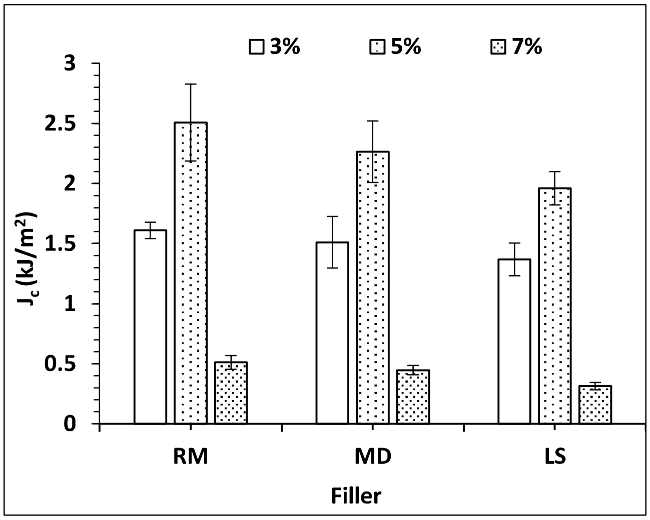
(d)

Figure 7.8 Load vs Deformation curves at (a) 3% (b) 5% (c) 7% filler content (d) Relationship between strain energy and notch depth.

Figure 7.9 shows the variation of critical strain energy release rate (J_c) with the change in filler content for different combinations of binder and filler. It was observed that the magnitude of J_c increased from 3% to 5% filler content, followed by a reduction in the value up to 7% filler content, where it reached the minimum. This behavior was independent of the type of filler and binder. However, the rate of reduction in J_c from 5% to 7% varied for different mixes, owing to difference in filler characteristics and binder properties. For the unmodified binder, J_c reduced at a higher rate in the case of RM, whereas the rate of fall was relatively lower for MD and LS. On the other hand, the relative variation in J_c was almost similar for all the fillers in the case of polymer modified mixes. This implies that the effect of binder was more dominant in the case of PMB based mixtures as compared to the unmodified mixtures. These observations align well with the results obtained from the fatigue analysis of asphalt mastics, where the effect of filler was similar in PMB based mastics and the behavior of VG-30 based mastics different fillers behave differently during the LAS test.



(a)

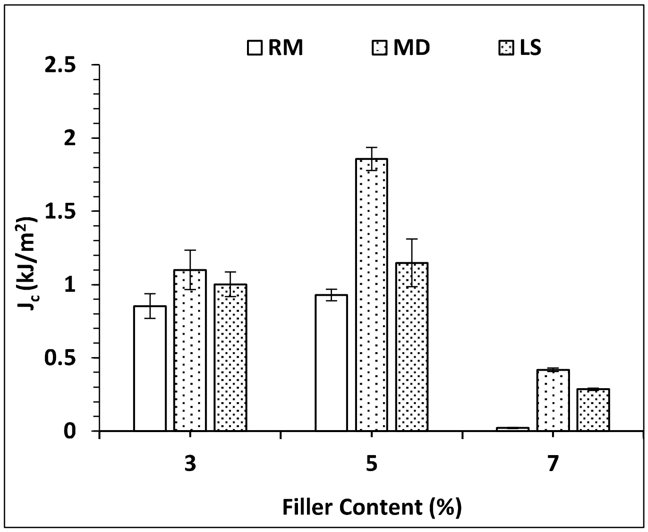


(b)

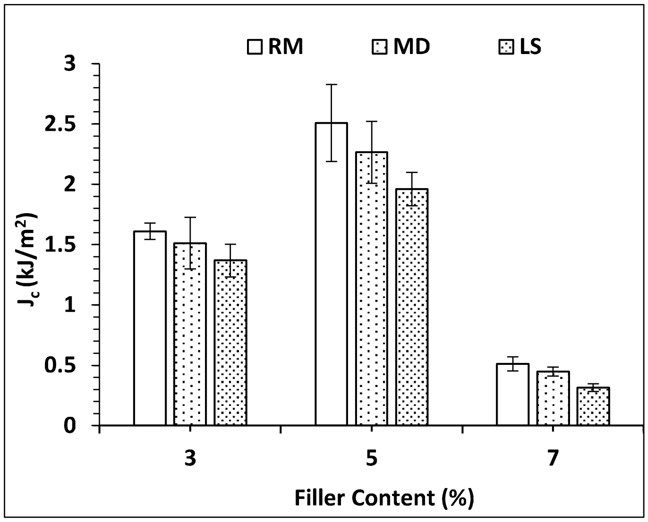
Figure 7.9 Variation in J_c as a function of filler content in the (a) neat and (b) polymer modified mixes

It is observed that the asphalt mixtures prepared with MD as filler showed the best fatigue performance followed by LS, whereas RM based mixes yield the worst fatigue performance, as evident from the J_c parameter (Figure 7.10(a)) irrespective of the filler content. These observations were valid only for the neat binder since the behavior of the fillers changed considerably with the change in the base binder from VG-30 to PMB-40. The performance of the RM based mixes was better than the other mixes in the polymer modified binder, irrespective of the quantity of the filler. Hence, RM was the worst performing filler with VG - 30 binder, but its performance was highest with PMB-40. This can be attributed to the nature of asphalt mastics within the mixture. The mastics prepared with RM filler were very stiff owing to its lower FM and SSA and higher RV due to which the corresponding mixtures yield inferior fatigue performance. However, the stiffening provided by the RM filler was compensated by the polymer modified binder in case of PMB based mastics and it resulted in the enhanced performance of the corresponding mixture. On the other hand, the relative ranking of MD and LS fillers remained more or less the same with both the binders. This shows that the stiffer mix can be used for the improved fatigue performance with polymer modified binder.

The ranking of the fillers follows the order MD>LS>RM with VG-30 based mixes and RM>MD>LS in the mixes prepared with polymer modified binder. A similar ranking was observed in the performance of asphalt mastics with VG-30 and PMB-40 binder respectively. The aforementioned observations justifies the hypothesis that the nature of asphalt mastics dictates the performance of the corresponding asphalt mixtures. In addition, it can also be concluded that the relative fatigue performance of the asphalt mixtures prepared with different fillers can be predicted with the LAS testing on asphalt mastics using the hyperbolic geometry.



(a)



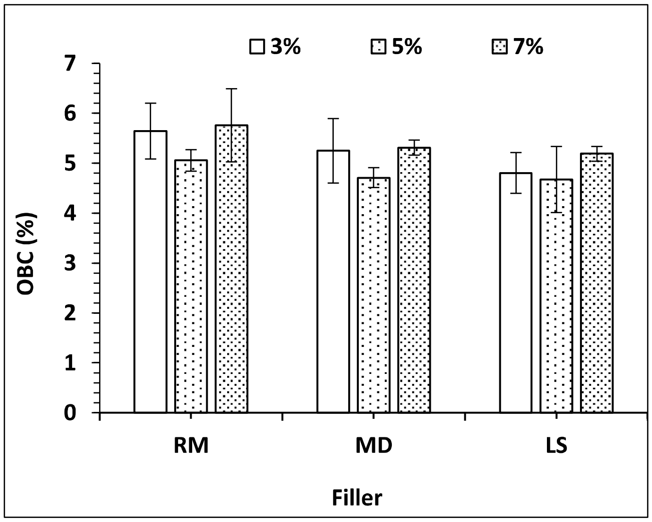
(b)

Figure 7.10 Comparative fatigue performance of fillers for (a) neat and (b) polymer modified mixes

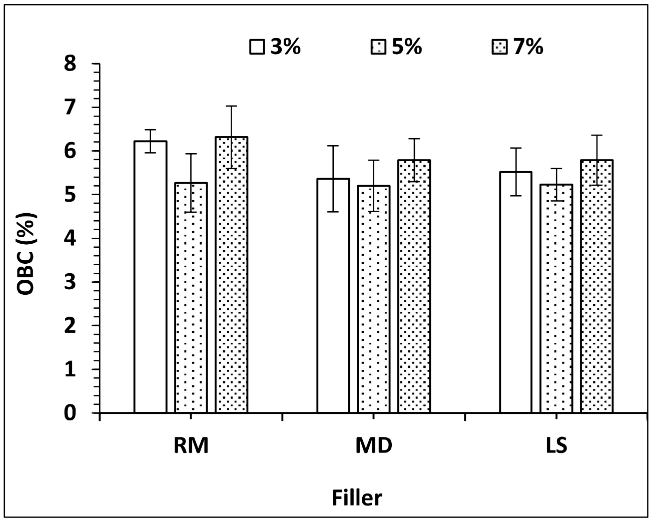
7.4 Optimum Binder Content (OBC)

Figure 7.11 shows the variation of OBC with the filler content for different combinations of filler type and asphalt binder. As can be seen, with an increase in the filler content, the OBC first decreases and then increases, irrespective of the type of filler and asphalt binder. At 3% filler content, the amount of filler is too low to fill the voids created by coarser and medium sized particles. Therefore, to satisfy the need of target air-void content (4%), more binder is required to balance the volumetrics. As more filler is added, it starts to occupy the voids and therefore requires less binder to meet the desired criteria of 4% air voids. On the contrary, an increase in filler also increases the specific surface area of the mix and, therefore, should require more binder to coat the filler particles. Hence, it can be concluded that the balance between the filler and binder is a function of the specific surface area of the mineral aggregates and the requirement to occupy the available air voids. At 5% filler content, the filler occupies the voids created in the aggregate skeleton, wherein even a lower binder content is sufficient to coat the filler particles. When more filler is added, it occupies additional space than that required to fill the voids. Therefore, at this point, the requirement of additional binder contributes towards coating of the filler particles, which has a high specific surface area. It is to be noted that the 7% filler content tends towards the upper threshold of the specified gradation, and being the finest proportion of the aggregate, the binder requirement for coating such a high quantity of filler also became higher. Hence, the OBC was highest at 7% filler content irrespective of the type of filler and the filler content, which may also be unsuitable from the economic point of view. The worst cracking resistance and highest OBC requirement make the 7% filler content undesirable irrespective of the filler and the binder used.

The above findings showed that the 7% filler content was very high for all the fillers and should be kept lower than that for satisfactory fatigue performance and lower binder demand, irrespective of the binder type. This also showed that the designer should not choose any random filler content within the specified limits just to satisfy the gradation, but a range of optimum filler content should be selected considering the output in terms of fatigue performance and lower binder requirement.

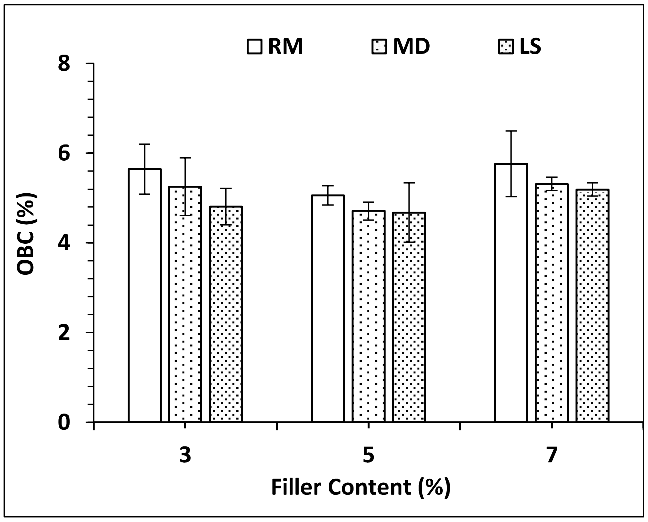


(a)

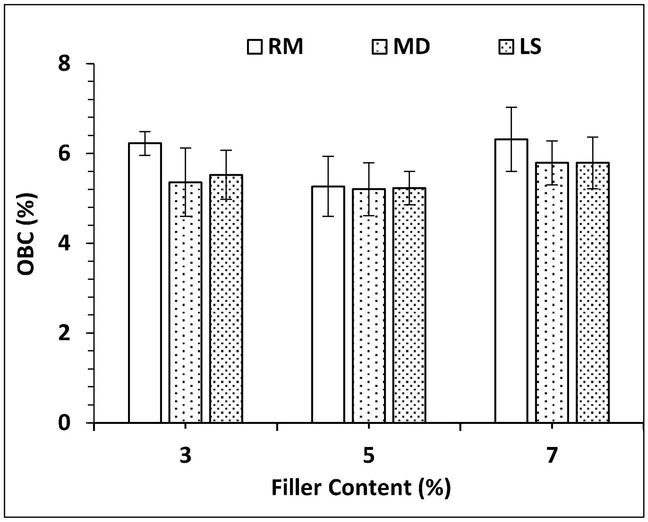


(b)

Figure 7.11 Variation in OBC as a function of filler content in the (a) neat and (b) polymer modified mixes



(a)



(b)

Figure 7.12 Comparative OBC requirement of (a) neat and (b) polymer modified mixes prepared using different fillers

While comparing the effect of filler type on the OBC, it was found that the mix with RM had higher OBC in comparison to MD and LSD based mixtures (Figure 7.12). This was true for the unmodified as well as modified mixtures. The highest OBC with RM filler can be attributed to its lower FSR value. The presence of a larger proportion of finer particles, along with the higher specific surface area, results in the high value of RV. Due to this, the amount of fixed asphalt required to fill the voids between the fillers was very high; hence, the highest optimum binder content was obtained. This also confirmed the hypothesis of higher binder requirement described in section 4.3.2. Statistical analysis was also performed to assess the effect of filler dosage and type on the OBC. For each binder type, two-way analysis of variance (ANOVA) was performed and F-statistics was used to analyse the results. At 95% confidence level, the effect of filler amount and type was found to be insignificant (Fstatistic<Fcritical), irrespective of the type of binder. However, at 85% confidence level, their effects were found to be statistically significant for mixtures prepared with VG30. For PMB-40, though the effect of amount of filler was found to be significant (85% confidence level), the effect of filler type had

no significant effect. This indicate that in PMB mixtures the role of filler properties is dominated by the presence of polymeric binder.

Figure 7.13 shows the ratio of J_c (denoted by J_{cr}) determined by the SCB testing of the asphalt mixtures incorporating PMB-40 and VG-30 binder, respectively. The J_{cr} value of 1 is shown by the line of unity in the same figure, which signifies identical performance for both binders. The values of J_{cr} lying above the line of unity denote the better performance of the asphalt mixtures prepared using PMB as compared to those with VG-30 binder. Firstly, the value of J_{cr} was always higher than 1 at all filler contents irrespective of the type of filler which shows that the fatigue resistance of the asphalt mixture increases by replacing virgin binder with PMB. These results are in agreement with the asphalt mastics, where the fatigue life of PMB based mastics was always higher than the VG binder based mastics. Also, the value of J_{cr} was considerably higher in RM as compared to other fillers, which showed that the effect of the binder was more distinguished in the case of RM as compared to MD and LS, where the value of J_{cr} varies from 1.07 to 1.71 only. This trend was also in accordance with the mastic results in section 6.4. As mentioned previously, in VG-30 mixtures the performance is significantly affected by the filler characteristics in comparison to PMB-40 mixtures, where the effect of binder is more dominant. Due to very high SSA of RM, at 7% filler content, the VG-30 mix became excessively stiff and the fatigue resistance was poor. On the contrary, in PMB-40 mixture, at the similar filler content, the resistance to fatigue damage was controlled by the binder, and therefore showed relatively better performance.

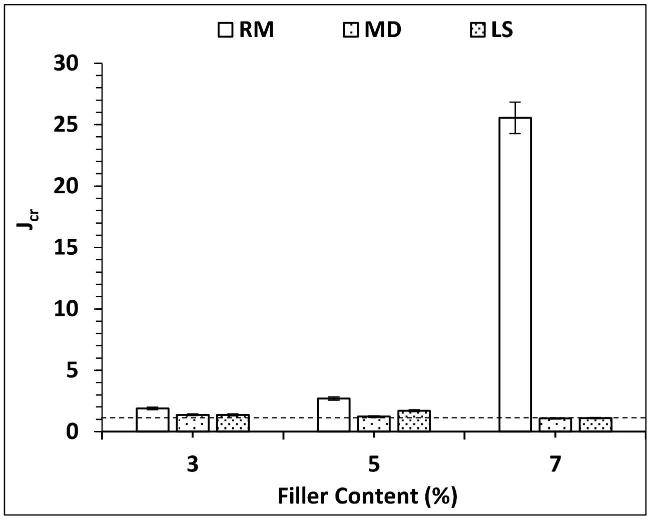


Figure 7.13 Variation of J_{cr} with the change in filler content

This shows that the relative performance of the fillers in the asphalt mixtures can be well estimated by the rheological testing of asphalt mastics. However, the effect of filler addition was not identical. For example, the fatigue performance of the mastics consistently decreased with high filler content in mastics, whereas a threshold was observed from the fatigue testing of mixtures. Actually, asphalt mastic is a combination of filler and binder, due to which only a few factors, such as type of fillers, binder, their relative proportion, and the interaction between them, affect the fatigue behavior of asphalt mastics. On the other hand, the asphalt mixture is a heterogeneous system in which numerous factors act simultaneously and dictates the performances of the resulting asphalt mixtures. These factors include the type of aggregate, filler, binder, volumetrics, compaction level, and many more, owing to which the effect of increasing filler content is different in mastics and mixes.

7.5 Determination of Optimum Filler Dosage

Asphalt pavements are constructed with the primary motive of long lasting performance. However, the economy is also an important factor that is considered in conjunction with the performance criteria while designing the asphalt mix. Ideally, the performance of the pavement can be increased to a very high extent, but it may result in expenditure which is not practical keeping in mind the other needs of the developing economy too. Hence, an ideal pavement design aims to provide well-functioning durable pavement for the anticipated design life while keeping the construction cost well within the defined budget. Many studies provide enhanced design suggestions based on laboratory performance only without considering the economic aspect. Due to this, the scope remains limited to laboratory study only, and the field application cannot be executed.

This study considered both performance and economic criteria for selecting the optimum filler dosage. The performance aspect is related to the fatigue performance of the asphalt mixtures quantified by the critical strain energy release rate obtained from the SCB test. Regarding the economic side, the inclusion of waste fillers will result in expenditure reduction related to the cost of fillers. In addition to that, the asphalt binder is a very costly ingredient of the asphalt mixture. In a study by Choudhary et al. [344], the cost of the surface course for a single km of 2-lane pavement composed of the conventional asphalt mix (stone dust as filler) was found to be ₹ 21, 43,901 out of which the cost of binder was ₹ 17, 77,089 which is approximately 83% of the total cost. This shows that the primary cost of the asphalt mixture used in the asphalt pavement construction is owed to the binder content in the mix and hence should be kept low without compromising the performance of the mix. Therefore, the study emphasized determining the optimum filler content based on higher J_c and lower OBC.

The weight of the filler is fixed at each filler content, but the respective OBCs are different, corresponding to the types of filler and the binder. The filler-binder ratio was determined as the weight of the filler divided by the weight of the binder corresponding to OBC. This filler content was directly obtained with respect to weight and converted to volume by using the specific gravity as follows:

$$(F - B)_v = \frac{V_F}{V_B} \tag{7.14}$$

$$(F - B)_v = \frac{\frac{W_F}{G_F}}{\frac{W_B}{G_B}} \tag{7.15}$$

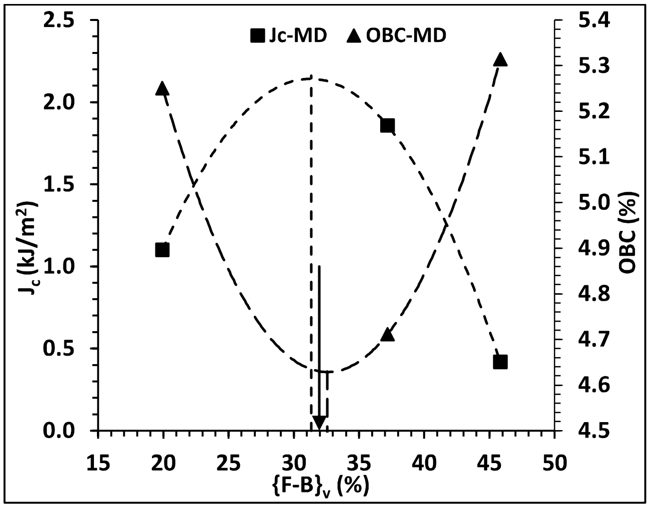
$$(F - B)_v = \left(\frac{W_F}{W_B}\right) . \left(\frac{G_B}{G_F}\right) \tag{7.16}$$

$$(F - B)_v = (F - B)_w . \left(\frac{G_B}{G_F}\right) \tag{7.17}$$

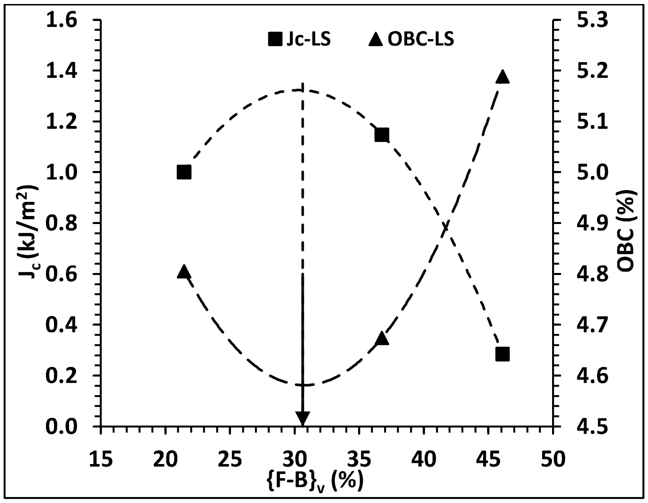
Where,

$(F\text{-}B)_v$ is the filler-binder ratio by volume, $(F\text{-}B)_w$ is the filler-binder ratio by weight, V_F and V_B are the volumes of filler and binder, W_F and W_B are the weight of filler and binder, G_F and G_B is the specific gravity of filler and binder respectively.

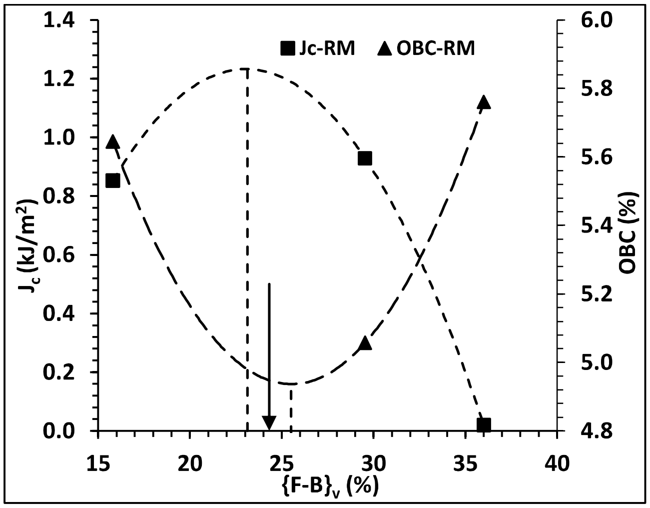
Figure 7.14 shows the variation of J_c and OBC with the change in filler content modelled with polynomial regression in the case of unmodified mixes. Firstly, the filler-binder ratio was determined corresponding to both the highest Jc and lowest OBC, respectively, and the average of both values was reported as optimum filler-binder ratio, $(F\text{-}B)_v$ (shown by downward arrow) for each filler. Similarly, the $(F\text{-}B)_v$ was also obtained for polymer modified mixes corresponding to each filler (Figure 7.15). Hence, the obtained optimum filler contents consider the performance as well as the economic aspects of the asphalt mixtures.


■ Jc-MD ▲ OBC-MD
J_c (kJ/m^2)
OBC (%)
{F-B}$_v$ (%)
0.0
0.5
1.0
1.5
2.0
2.5
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
15
20
25
30
35
40
45
50

(a)

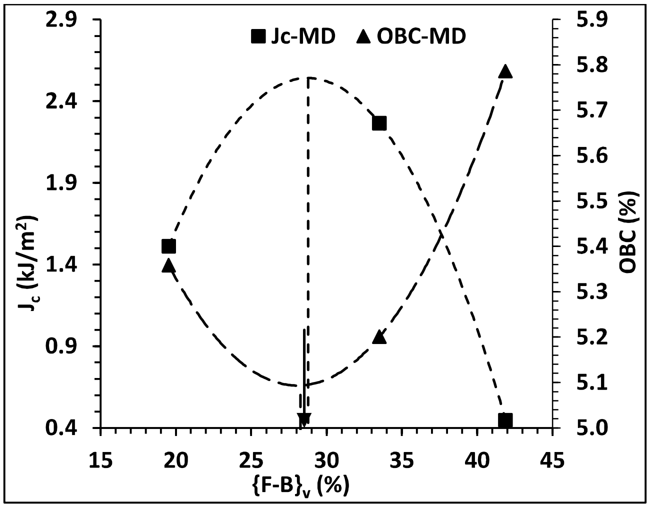

■ Jc-LS ▲ OBC-LS
J_c (kJ/m^2)
OBC (%)
{F-B}$_v$ (%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
15
20
25
30
35
40
45
50

(b)

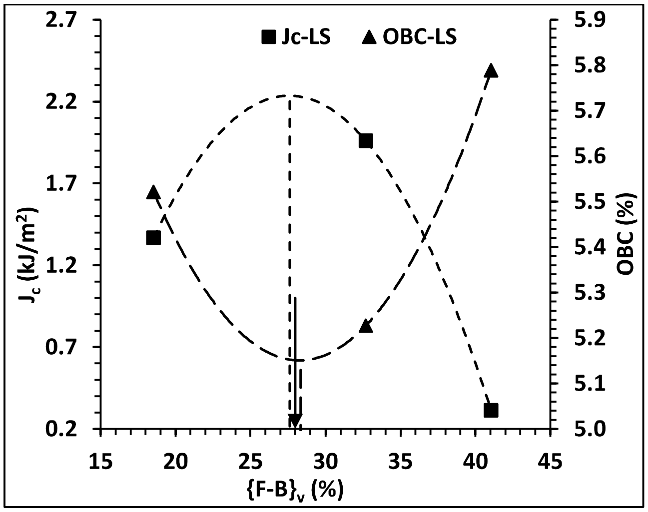

■ Jc-RM ▲ OBC-RM
J_c (kJ/m^2)
OBC (%)
{F-B}$_v$ (%)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
4.8
5.0
5.2
5.4
5.6
5.8
6.0
15
20
25
30
35
40

(c)

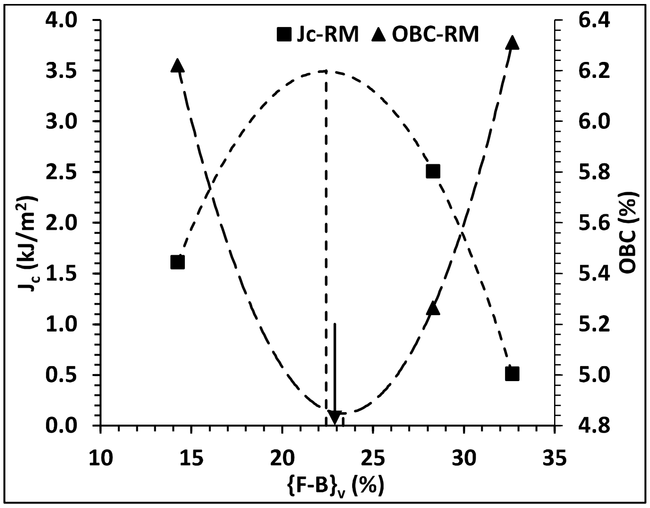
Figure 7.14 Variation in Jc and OBC with the change in filler content for the mixtures prepared with (a) MD (b) LS (c) RM filler and VG-30 binder



(a)



(b)



(c)

Figure 7.15 Variation in J_c and OBC with the change in filler content for the mixtures prepared with (a) MD (b) LS (c) RM filler and PMB-40 binder

After that, a correlation was determined between this optimum filler content and a new parameter: the ratio of FSR of the filler and $|G^*|.\sin\delta$ of the binder. The idea was to determine the optimum filler dosage in the asphalt mix from the properties of both fillers and binders. The FSR parameter obtained from the FM, SSA, and RV tests on fillers, which were proven earlier to be the primary factors affecting the performance of asphalt mastics and the mixes, were chosen as the filler parameter. On the other hand, the $|G^*|.\sin\delta$ in the undamaged or LVE state corresponding to the 20th cycle was taken as the binder property. It represents the energy dissipated with the onset of damage as a result of repeated cyclic loading and has hence been used as a common damage indicator in many studies. Therefore, the combined effect of both filler and binder was considered in selecting optimum filler content. Figure 7.16 shows the relation between the optimum F-B ratio and the parameter $FSR/|G^*|.\sin\delta$. It is found that a strong correlation (R^2) was observed between both quantities following the linear regression model. Also, the observed inter-relationship was independent of the type of binder; hence, the proposed methodology can be adapted for any type of binder. The proposed methodology can add a new dimension to the existing criteria for selecting the optimum filler dosage irrespective of the type of binder. It is to be noted that the optimum filler dosage will yield high performance as well as a low binder requirement.

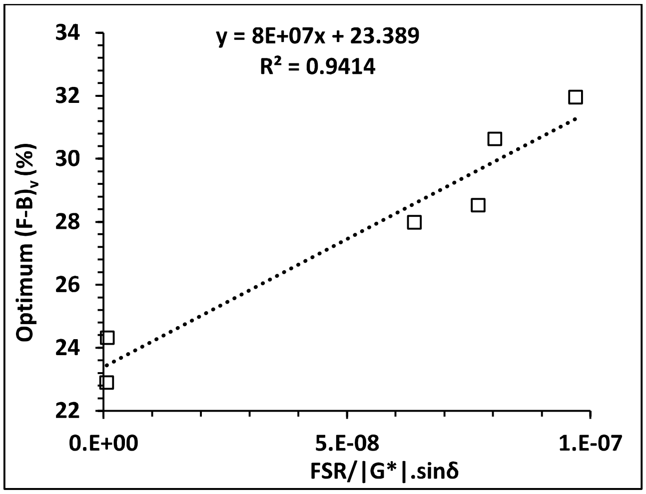


Figure 7.16 Correlation between optimum F-B ratio and FSR/|G*|.sinδ

The current procedure for the asphalt mix design is based on volumetrics only. It is generally expected that the pavement will perform satisfactorily against the distresses if the volumetrics are satisfied, which is very empirical, and hence the certainty about the future performance of pavements is very low. The solution for the aforementioned drawback has been attempted by the balanced mix design or performance based mix design approach in recent studies [345,346] which focuses on the performance parameters with or without considering the volumetric parameters depending on the approach used. However, this is a new concept and has not been explored enough, especially in the Indian context. Therefore, considering the performance aspect in the current mix design method can be an effective way to achieve long lasting pavements. The filler-binder ratio is one of the most crucial parameters influencing the behavior of asphalt mixtures. So, optimizing the filler dosage with respect to fatigue performance along with the current volumetric considerations can guarantee superior fatigue performance.

By adopting this methodology, the user just has to determine three filler properties and one rheological property of the binder, and it will provide the filler content at which the mixes should be prepared following the Marshall Mix Design process exhibiting superior fatigue performance and with lower binder requirement. Previous research articles have explored the performance of various fillers in the asphalt mastics as well as mixes and generally reported the better performing filler against fatigue. However, this study postulates that any filler which does not violate the standard specifications can be used in the mix for superior fatigue performance if the filler content is decided judicially as suggested in the proposed methodology. Moreover, this also confirms the need to redefine the existing filler-binder ratio range based on the mix constituents rather than using the current universal range of 0.6 to 1.2.

The optimum filler-binder ratio was selected as the average of the filler contents corresponding to the highest J_c and lowest OBC. For any particular gradation, the range of filler has already been specified as per Indian standards. The binder is also decided based on climatic conditions, traffic count, and other parameters. The shown ordinate values are obtained by considering both J_c and OBC, calculated at 4% air voids. Hence, both volumetrics and performance aspects are considered in this study. Also, the primary filler properties obtained from mastics and verified by mixes test results (FM, SSA, and RV) are considered along with the rheological property of the binder in terms of $|G^*|.\sin\delta$.

7.6 Summary

The asphalt mastics are a combination of filler and binder blended together at a filler-binder ratio, due to which the performance of mastics is dependent on the filler type, binder type, and filler content. On the other hand, the level of heterogeneity is very high in the asphalt mixtures owing to numerous factors acting together, which affect the behavior of the mix. Hence, the results of asphalt mastics need to be validated with the results of mixtures which were done using a semi-circular bending test. Several researchers have used it to evaluate the cracking resistance of asphalt mixtures. It consists of a half disk shaped specimen with a predefined notch at the center, due to which the path of crack propagation is pre-decided, and hence the uniform comparison between the samples can be made.

The fatigue performance of the mixtures was found to be the highest, whereas OBC was lowest at 5% filler content for all the fillers and the binders. Among fillers, MD performed best with a neat binder, with RM being the highest performing filler with polymer modified binder. Also, the relative ranking of fillers in terms of fatigue performance was similar in the mixes as well as the mastics. This shows that the LAS testing of asphalt mastics using hyperbolic geometry can be employed to rank the relative fatigue performance of the asphalt mixtures with different fillers.

A high correlation between the optimum filler dosage and the parameter FSR/$|G^*|$.sinδ was obtained based on the higher J_c and lower OBC so that the optimum filler content can be determined from the properties of fillers and the binders, which will result in higher fatigue performance and lower binder requirement in the asphalt mixture.