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A Study on Rutting Behaviour of EVA Blended Bituminous Concrete Mix

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ABSTRACT

Bitumen is mainly used to construct wearing courses of flexible pavements and runways. Due to its viscoelastic and thermoplastic properties, it plays a major role in the performance of pavements, where temperature and rate of loading have significant effects. Due to high intensity of traffic, overloading of vehicles and significant variations in climate, early development of distress indices, like rutting, cracking, undulation, potholes, … etc., has been found in flexible pavements. Conventional bitumen fails to give longer life for pavements. Hence, it is required to modify conventional bitumen for improving its properties. There are several modifiers available in the market, where polymer modifiers are the most commonly used, such as Styrene Butadiene Styrene (SBS), Styrene Butadiene Rubber (SBR), Ethylene Vinyl Acetate (EVA), … etc.

In the present study, EVA was used as a modifier in VG-30 grade bitumen to reduce rut depth for bituminous concrete (BC) mixes. Marshall stability test was performed to determine Marshall stability, flow value and volumetric properties, such as air voids (Vv), Voids in Mineral Aggregates (VMA) and Voids Filled with Bitumen (VFB). A wheel rut tester was used to study the rutting defect with varying temperature and number of repetitions.

KEYWORDS: Ethylene Vinyl Acetate (EVA), Marshall stability, Modified bitumen, pavement distress, Rutting, Temperature susceptibility.

INTRODUCTION

Bitumen is used as a binder in the construction of flexible pavements due to its viscoelastic and thermoplastic properties. It is a black-or brown-coloured viscous aromatic hydrocarbon mixture, which is obtained during the distillation of crude oil. It becomes brittle at low temperatures, which results in fatigue cracking in flexible pavements (Dehouche, Kaci and Ait, 2012). On the other hand, at higher temperatures, bitumen becomes soft, which causes rutting in flexible pavements (Santamar, Gonz and Garc, 2004). These types of failure in flexible pavements are very common in India. Factors causing these types of distress in pavements are: heavy traffic load, high tyre pressure, significant variations in daily and seasonal temperatures, inadequate compaction of the mix,…etc. The characteristic operation of bituminous mix depends on its volumetric properties and external causes, like environmental factors and traffic load. Therefore, to enhance the properties of conventional bitumen, it has been a common practice to modify conventional bitumen by some modifiers. There are different types of modifiers available for modifying bitumen, where polymer modification is very popular (Laukkanen et al., 2018; Yildirim, 2007; Munera and Ossa, 2014; Polacco et al., 2015; Zhu, Birgisson and Kringos, 2014). In this study, it is proposed to modify bitumen using EVA polymer to enhance its properties.

Rutting is a longitudinal depression which occurs in flexible pavements along the wheel path in the surface layer. It is measured in terms of rut depth. Generally, rutting development in flexible pavements happens in two stages. The first one is densification which is related with volume change of the bitumen layer and the second one is shape distortion. The main factor of rut initiation

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is shear strain in the bituminous layer. Due to rutting, service life of pavements may get reduced. In case of severe rutting depth, water may accumulate in the pavement portion, leading to vehicle hydroplaning.

There are several studies available that have investigated the potential of polymer-modified bitumen. It is revealed that both recycled polymer-modified bitumen (PMB) and virgin polymer are used for enhancing the performance of flexible pavements. With addition of polymer, both cracking of pavements at low temperatures and rutting at high temperatures decrease. Studies indicated that addition of 1% recycled EVA or virgin EVA enhances the performance of pavements (Santamar, Gonz and Garc, 2004; Dehouche, Kaci and Ait, 2012). Dynamic rheological properties at low temperatures indicated a significant reduction in stiffness with the addition of SBS (Laukkanen et al., 2018). EVA, high-density polyethylene and nano-clay together form a nanocomposite, which when blended with bitumen enhances its thermal susceptibility (Mansourian, Rezazad and Karimian, 2019; Siddig, Pei and Yi, 2018). Polymeric compound prepared by mixing LDPE and EVA showed improved performance and increase in the stiffness modulus of mixture (Celauro et al., 2019). One of the studies revealed that modified bitumen with polyphosphoric acid (PPA) increased its overall performance up to -20℃ and that below -20℃, only blended bitumen without PPA gave satisfactory results (Teltayev et al., 2019). Bitumen modified with EVA or EVA-grafted maleic anhydride copolymer showed less temperature susceptibility and reduced deformation in pavements (Luo and Chen, 2011). Bitumen (60/70 and 150/200 grade) blended with recycled EVA copolymer improved viscous property of bitumen at high temperatures (Partal et al., 2004). Low polymer content showed better polymer dispersion and with increased percentage of polymer, continuous polymer phase was observed (Sengoz and Isikyakar, 2008). Rutting increases when bitumen is blended with both EVA and gilsonite. Addition of EVA alone decreases fatigue and creep stiffness, whereas it increases the m-value. Gilsonite increases fatigue and creep stiffness, while it decreases the m-value (Ameri, Mansourian and Hossein, 2012; Ameri, Mansourian and Hossein, 2013; Laukkanen et al., 2018). Use of Adaptive Network-based Fuzzy Inference System (ANFIS) revealed that the improvement effect of EVA polymer is considerable at low frequency of intermediate temperature (Yilmaz et al., 2011). EVA-blended bitumen shows an increase in zero shear viscosity and relaxation time (Yang et al., 2019). EVA-PMBs showed less strain induced microstructural changes as compared to HDPE PMBs (González et al., 2016). Storage temperature of PMBs also affects its rheological and conventional properties at a temperature greater than 180℃ (Singh, Kumar and Ravindranath, 2018). Flakes made of rubber tyre and recycled polyethylene improve the rheological properties as compared to virgin bitumen (Leite et al., 2019). Adding 3% high-density polypropylene (HDPP) will increase rutting resistance at higher temperatures only, but 2% HDPP will increase rutting resistance at high and low temperatures (Otuoze et al., 2018). Optimum range of adding polymer in bitumen lies between 1.7% and 2%. After that, the effect of adding polymer is reduced (Javid, 2014). Crumb rubber with ethylene vinyl acetate-blended bitumen showed an increase in complex shear modulus, reduced phase angle and increased binder stiffness at high temperatures (Nare and Hlangothi, 2019). New hybrid technique to modify bitumen with combination of crumb rubber and polymer shows a good fatigue resistance and increases the life of pavements (Gibson et al., 2012).

EXPERIMENTAL PROGRAM

Materials and Methodology

Type and grade of bitumen depend upon the climatic conditions and traffic volume in the region. In this work, VG-30 grade (60/70 penetration) bitumen is taken as per IS 73-2013 (IS:73 2013). VG-30 grade bitumen is thermoplastic and used to construct extra heavy-duty flexible pavements because of ease in design. Table 1 shows the selection criteria for the bitumen grade. For modified bitumen, it shall be in accordance with MoRTH, cl 500.2.1, Table 500-5 (Indian Road Congress, 2013). Several laboratory tests were performed on bitumen as per IS specifications and the results are presented in Table 2.

Table 1. Selection criteria for viscosity graded paving bitumen based on climate conditions

Lowest Daily Mean Air Temperature,℃	Highest Daily Mean Air Temperature, ℃		
	Less than 20℃	**20℃ to 30℃**	**More than 30℃**
More than -10℃	VG-10	VG-20	VG-30
-10℃ or lower	VG-10	VG-10	VG-20

Table 2. Test results of bitumen

S. No.	Name of Test	Test Results	Specification
1	Ductility Test	77.02 cm	IS:1208-1978 (IS:1201-1220 2004)
2	Softening Point Test	46.5 ℃	IS:1205-1978 (IS:1201-1220 2004)
3	Penetration Test	66.33 mm	IS:1203-1978 (IS:1201-1220 2004)

The coarse aggregate consists of crushed rock retained on 2.36-mm sieve. Physical properties of coarse aggregate were evaluated for BC mix and are represented in Table 3. Fine aggregate consists of natural rock passing through 2.36-mm sieve and retained on 75-micron sieve. Clean, hard, durable and dry aggregates, free of dust or any other deleterious matters, were used. Filler material consists of finely divided mineral matter, free of organic matter. EVA in the form of pellets of size 4-5 mm diameter was used. It is made of two monomers, Ethylene and Vinyl acetate. In EVA pellets, weight percent of Vinyl acetate varies from 10% to 40% with the remaining percentage being Ethylene. Its specific gravity ranges from 0.93 to 0.95.

Table 3. Test results of aggregate

S. No.	Test	Results (%)	(MoRTH Limits)	Indian standards
1	Aggregate Impact Value	12.92	Max. 27	IS:2386 Part IV (IS:2386 - Part IV 2011)
2	Water Absorption Value	0.65	Max. 2	IS:2386 Part III (IS:2386 - Part III 2002)
3	Specific Gravity	2.67	Min. 2.65	IS:2386 Part III (IS:2386 - Part III 2002)
4	Combined Flakiness and Elongation Test	32	Max. 35	IS:2386 Part 1 (IS:2386 - Part I 1963)
5	Aggregate Abrasion Test	22.49	Max. 30	IS:2386 Part IV (IS:2386 - Part IV 2011)
6	Aggregate Crushing Test	13.46	Max. 30	IS:2386 Part IV (IS:2386 - Part IV 2011)

Gradation of aggregate is done as per MoRTH (Table 500-19) (Indian Road Congress, 2013) guidelines for BC. Grade I is obtained by mixing 32% 20-mm aggregate, 20% 10-mm aggregate, 15% 6-mm aggregate, 28% dust and 5% cement by weight of the total mix. Obtained gradation and desired gradation for BC mix grade I are given in Table 4. Similarly, grade II is obtained by 36%, 20%, 34% and 10% of 10-mm aggregate, 6-mm aggregate, dust and cement, respectively, as shown in Table 5. Graphs for grade I and grade II are shown in Figures 1 and 2, respectively.

Table 4. Aggregate gradation for BC mix grade I

Sieve size, mm	% passing by weight of total aggregate					Obtained gradation	Desired gradation
	20 mm	**10 mm**	**6 mm**	**Dust**	**Cement**		
26.5	100	100	100	100	100	100	100
19	76.25	100	100	100	100	92.40	79-100
13.2	21.60	100	100	100	100	74.91	59-79
9.5	0	62	100	100	100	60.40	52-72
4.75	0	9.40	76.90	100	100	46.42	35-55
2.36	0	2.60	21.30	88.30	100	33.44	28-44
1.18	0	1.30	6.10	67.30	100	25.02	20-34
0.6	0	0	1.26	48.50	98	18.67	15-27
0.3	0	0	0	28.80	96.40	12.88	10-20
0.15	0	0	0	11.80	92.90	7.95	5-13
0.075	0	0	0	6.60	76.40	5.67	2-8

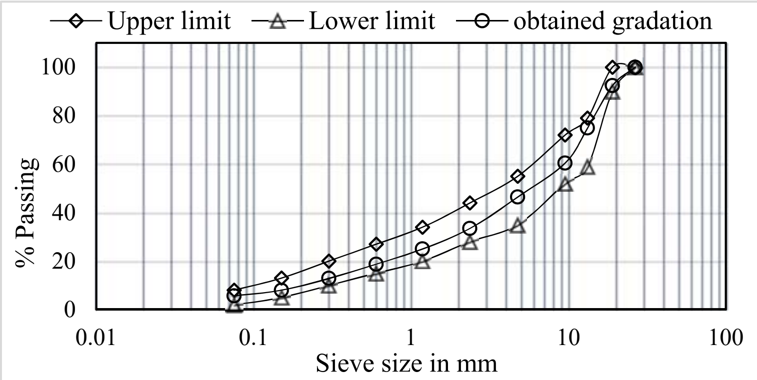

Figure (1): Aggregate gradation for BC mix grade I

Table 5. Aggregate gradation for BC mix grade II

Sieve size, mm	% passing by weight of total aggregate				Obtained gradation	Desired gradation
	10 mm	6 mm	Dust	Cement		
19	100	100	100	100	100	100
13.2	100	100	100	100	100	79-100
9.5	62	100	100	100	86.32	70-88
4.75	9.4	76.9	100	100	62.76	53-71
2.36	2.6	21.3	88.30	100	45.22	42-58
1.18	1.3	6.1	67.30	100	34.57	34-48
0.6	0	1.26	48.50	98	26.54	26-38
0.3	0	0	28.80	96.40	19.43	18-28
0.15	0	0	11.80	92.90	13.30	12-20
0.075	0	0	6.60	76.40	9.88	4-10

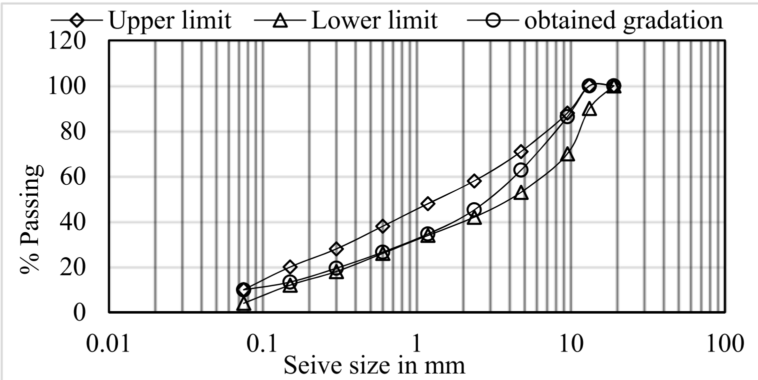

Figure (2): Aggregate gradation for BC mix grade II

Test Methods

Marshall Stability Test

Marshall stability test (MS-2, 7th edition) (Asphalt Institution, 2014) is performed to find the stability, flow value and Optimum Binder Content (OBC) of bituminous mix. In the current study, a 50-ton capacity machine with a rate of loading of 50 mm/min was used. Aggregate, dust and filler weighing 1200 gm were taken and heated to a temperature ranging from 175℃ to 190℃. Bitumen was heated to a temperature of (121℃-145℃), added to the aggregate and thoroughly mixed at a temperature of (154℃-160℃). The prepared mix was compacted by 75 blows on each face at a temperature of (138-149℃). The specimens were then allowed to cool at room temperature by keeping them in air for 24 hrs. These are extruded from the mould as shown in Figure 3. The weight, height and diameter of specimens were noted and correction was applied if required. Specimens were kept in a water bath maintained at a temperature of 60℃ for half an hour and thereafter subjected to Marshall stability machine for testing their volumetric properties and stability. The optimum binder content for the mix was determined by taking the average of the three bitumen contents; i.e., maximum stability, maximum unit weight and corresponding to the 4 % air voids from the graph.

Figure (3): Marshall stability test sample

Wheel Rut Test

Size of specimen for rutting test is 300×300×50 mm. Specimens were prepared for both conventional and modified bituminous mixes. Quantities of aggregate, dust and filler were taken according to desired grade as shown in Tables 4 and 5. All the materials were mixed and heated to a temperature of (175℃-190℃). Bitumen was heated to a temperature of (121℃-145 ℃) and optimum binder content by weight of total aggregate (for both conventional and modified mixes) was added to the aggregates. These are then mixed at a temperature of (154℃- 160℃). This mix was filled in the rutting mould and compacted by a rut shaper (Figure 4) to achieve a 50-mm thickness and the desired density. The specimen is kept in air for 24 hrs. After that, the specimen shown in Figure 5 is tested in the wheel rut tester at different temperatures and numbers of passes (Fig. 6).

Figure (4): Wheel rut shaper

Figure (5): Rutting samples

Figure (6): Wheel rut tester

RESULTS AND OBSERVATIONS

Marshall Test Observations

Marshall test was performed on conventional and modified BC mixes at both grades I and II. Modified Marshall mixes were prepared by replacing bitumen by 3%, 6%, 9% and 12% EVA by weight of bitumen binder. Results obtained for conventional BC mix and modified BC mix at grade I and grade II are presented in Figures (7-11).

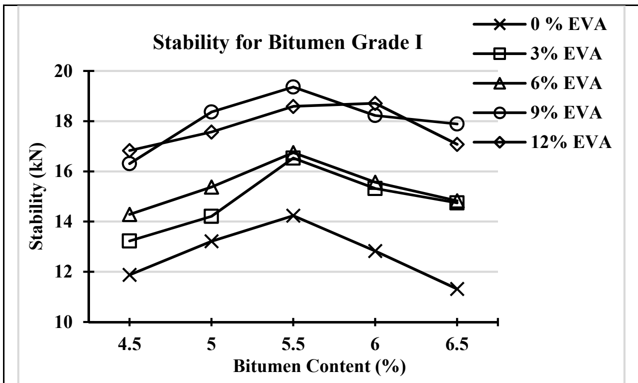

Figure (7): (a) Stability for bitumen grade I

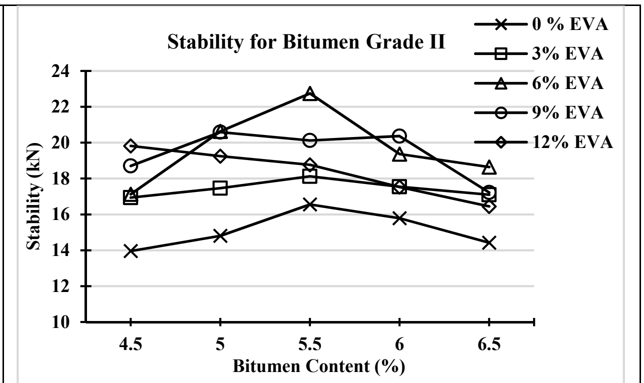

Figure (7): (b) Stability for bitumen grade II

Increase in stability can be characterized as an improvement in adhesion between aggregate and bitumen (Moses, 2016; Ahmadinia et al., 2011; Chen et al., 2009; Sabina et al., 2009). Stability of conventional bituminous mix increases when % of EVA increases up to 9% for grade I (Fig. 7 (a)) and up to 6% for grade II (Fig. 7 (b)). After this, stability decreases on further addition of EVA. Also, increase in Marshall stability enhances the rutting resistance (Nkanga et al., 2017; Ebrahim and Behiry, 2013).

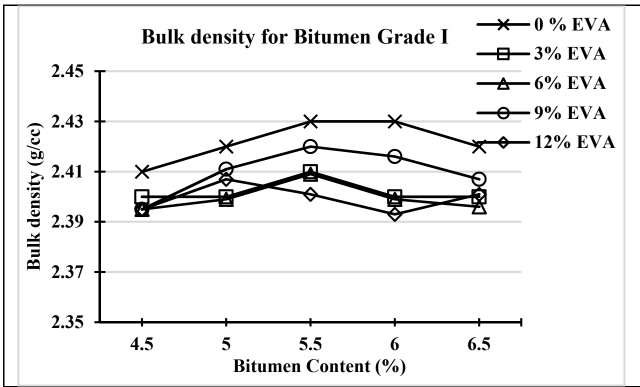

Figure (8): (a) Bulk density for bitumen grade I

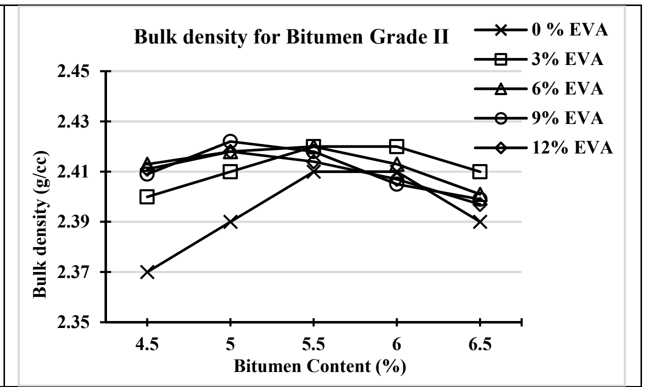

Figure (8): (b) Bulk density for bitumen grade II

As the percentage of bitumen increases, bulk density also increases, reaches its maximum level and then decreases at a diminishing rate (Fig. 8 (a) and Fig. 8 (b)). Increase in density indicates more compact packing and reduction in voids between the aggregates (Awwad and Shbeeb, 2007; Sabina et al., 2009). It is also observed that after addition of EVA, the density of the mix reduces as compared to conventional mix, because EVA has a lower density as compared to bitumen (Ahmadinia et al., 2011).

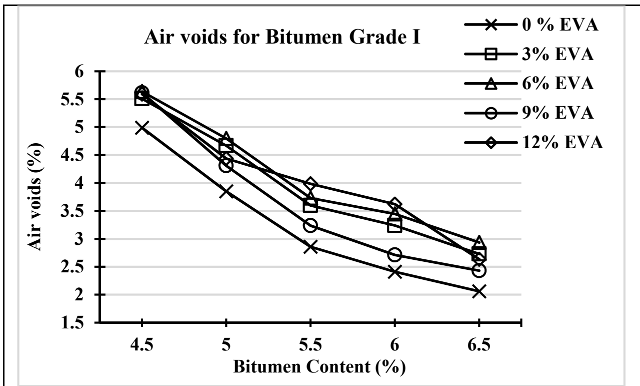

Figure (9): (a) Air voids for bitumen grade I

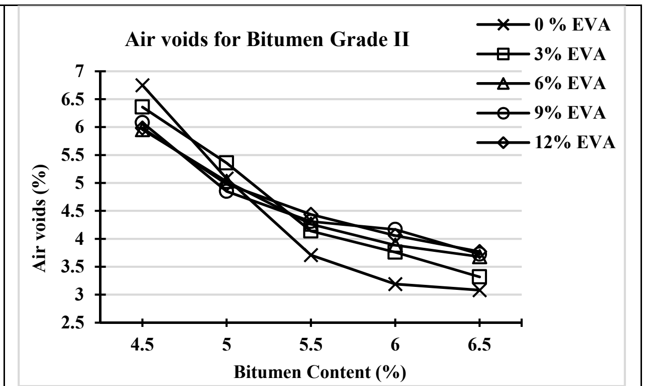

Figure (9): (b) Air voids for bitumen grade II

From Fig. 9 (a) and Fig. 9 (b), it is observed that on increasing bitumen percentage, air voids reduce. At the same time, increasing bitumen after OBC decreases the stability and increases the flow value (Moses, 2016). Also, 4% air void is required to make the mix flexible (Saltan, Terzi and Karahancer, 2017).

Voids in mineral aggregate (VMA) represent the volume of intergranular void space between the aggregate particles of a compacted mixture, including the air voids and the volume of bitumen not absorbed into the aggregate (Sadeeq et al., 2014). VMA graphs are shown in Figure 10 (a) and Figure 10 (b). From the graphs, it is observed that for grade I, 9% EVA shows lowest VMA at optimum binder content while in grade II, 12% shows lowest VMA.

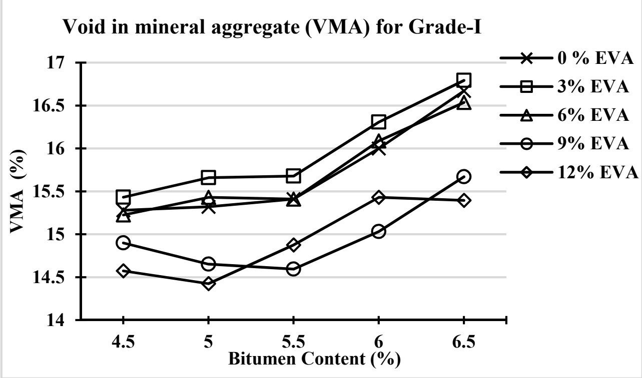

Figure (10): (a) Voids in mineral aggregate (VMA) for grade I

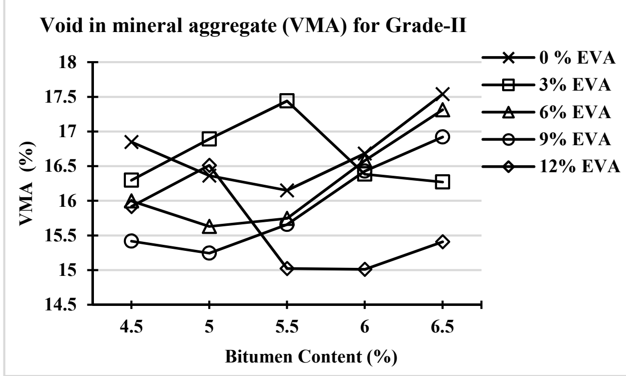

Figure (10): (b) Voids in mineral aggregate (VMA) for grade II

Voids filled with bitumen (VFB) graphs are shown in Figure 11 (a) and Figure 11 (b). From the graphs, it is observed that the values of VFB for all mixes containing EVA are lower than those of the control mix (0% EVA), implying that the addition of EVA reduces VFB values (Sadeeq et al., 2014).

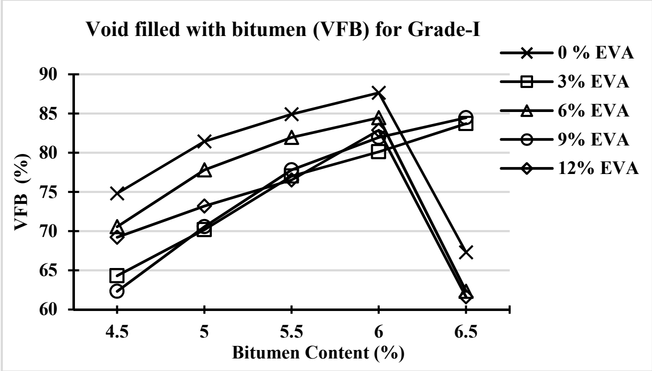

Figure (11): (a) Voids filled with bitumen (VFB) for grade I

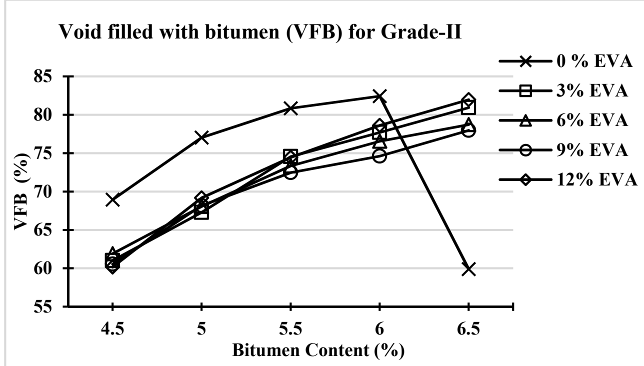

Figure (11): (b): Voids filled with bitumen (VFB) for grade II

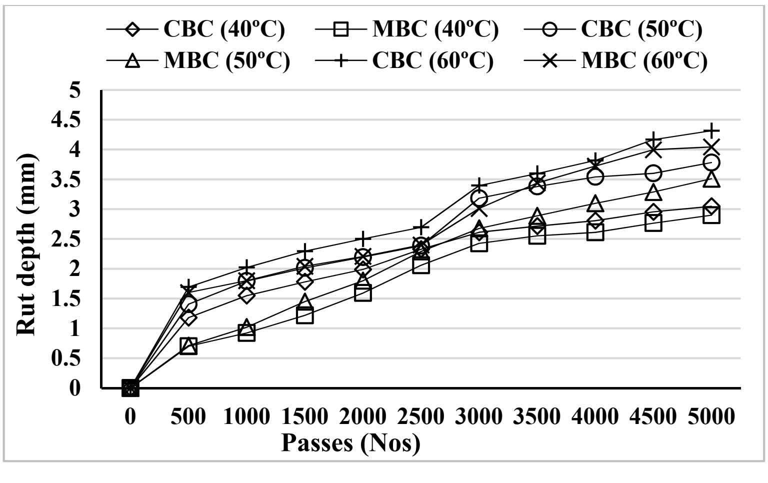

Figure (12): Graphs of rutting for grade I at 40℃, 50℃ and 60℃

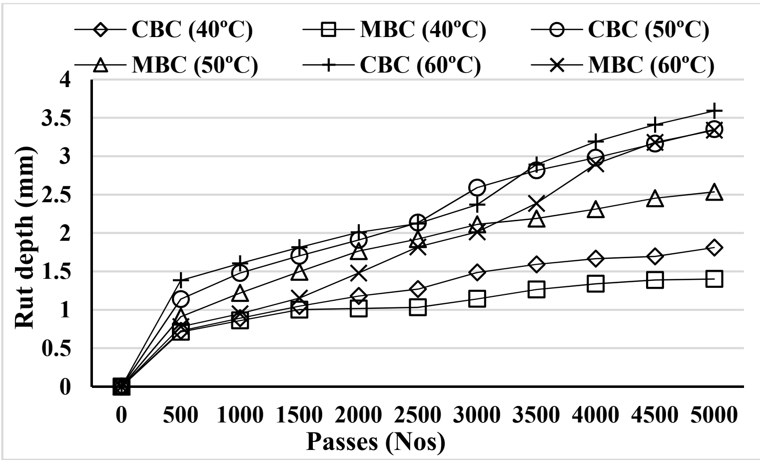

Figure (13): Graphs of rutting for grade II at 40℃, 50℃ and 60℃

From the Marshall stability test results shown in Figures (7-11), OBC is calculated as the average of bitumen contents of maximum stability, maximum density and 4% design air voids (Asphalt Institution, 2014; Sadeeq et al., 2014). Optimum binder content for BC grade I and grade II was found to be 5.3 % and 5.52%, respectively. Modified bituminous mix shows maximum stability when blended with 9% EVA for grade I and 6% EVA for grade II, as shown in Figure 8. The optimum binder content for BC grade I modified with 9% EVA is found to be 5.42% and for BC grade II modified with 6% EVA is found to be 5.56%. The stability values for conventional and modified mixes of grade I and grade II were found to be 14.24 kN, 16.56 kN, 19.36 kN and 22.75 kN, respectively.

Rut Test

Rut test was performed on conventional and modified BC mixes at 40℃, 50℃ and 60℃ for various numbers of passes at grade I and grade II. The results are shown in Figures 12 and 13.

Table 6. Rut depth (in mm) for conventional and modified BC mix at OBC

	Grade I		Grade II	
	Conventional bitumen	**Grade I (9% EVA)**	**Conventional bitumen**	**Grade II (6% EVA)**
40℃	3.047	2.898	1.812	1.402
50℃	3.781	3.511	3.352	2.537
60℃	4.315	4.043	3.592	3.340

The rut depth values for BC grade I and BC grade II for both conventional and modified bitumen mixes are shown in Table 6. These observations are taken at 40℃, 50℃ and 60℃ for 5000 passes.

CONCLUSION

Volumetric and Marshall properties of BC mixtures for grade I & grade II are satisfying MoRTH specifications. On comparing the Marshall parameters, such as flow value, density and air voids for different contents of EVA, improved results have been shown. The stability value for BC grade I and grade II modified with EVA is found to improve when compared with that of conventional BC mix. The stability value for BC mix grade I modified with 9% EVA is found to be maximum, which is 35.95% greater than the stability value of conventional BC mix with the same grade. The optimum stability value for BC mix grade II is obtained at 6% EVA addition, which is 37.37% greater than the stability value of conventional BC mix of grade II. EVA-modified BC mix shows greater resistance to rutting at

40^0C, 50^0C and 60^0C for 5000 passes as compared to conventional BC mix. On increasing the temperature from 40^0C to 60^0C, the rut depth increases. Also, a considerable decrease in bitumen content was observed after blending it with EVA.

Future Scope

Rut test can be conducted at a greater number of passes. Regression analysis by considering various factors affecting the rutting behaviour can be used for developing rutting models. The properties of bituminous mixes can be further improved by using more advanced techniques with more than one modifier. There is a need to carry out more research work to reduce defects in flexible pavements and increase the of pavement life.

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