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Determination of the Resistance of Hot Mix Asphalt Samples Prepared Under Different Conditions Against Wheel Tracking

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Abstract

The present study aimed to examine the resistance of pure hot mixes and those prepared with 4% of three different polymers two types of SBS (styrene-butadiene-styrene) and one type of EVA (ethylene-vinyl-acetate) against permanent deformation. Samples were prepared with application of vibration so that they would have 4% void ratio using a roller compactor and without this application. The effect of vibration application during sample preparation on the wheel track formation was also assessed in the current study. Wheel track tests demonstrated that use of additives increased the resistance of hot mixes against wheel track formation. It was also determined that the most effective additive was EVA. Furthermore, it was determined that application of vibration during sample preparation increased the resistance of specimens against permanent deformation.

Keywords: Wheel tracking, Hot mix asphalt, Styrene-butadiene-styrene, Ethylene-vinyl-acetate.

Farklı Koşullarda Hazırlanan Bitümlü Sıcak Karışım Numunelerinin Tekerlek İzi Oluşumuna Karşı Dayanımlarının Belirlenmesi

Özet

Bu çalışmada, saf ve %4 oranında üç farklı polimer (iki tür stiren-butadien-stiren ve bir tür etilen-vinil-asetat) içeren bağlayıcılarla hazırlanan karışımların kalıcı deformasyona karşı dayanımları incelenmiştir. Numuneler merdaneli sıkıştırıcı kullanılarak %4 boşluk oranına sahip olacak şekilde vibrasyon uygulanarak ve vibrasyon uygulanmadan hazırlanmıştır. Böylece numune hazırlama esnasında vibrasyon uygulamasının tekerlek izi oluşumu üzerindeki etkisi de mevcut araştırmada değerlendirilmiştir. Tekerlek izi oluşumu deneyleri, katkı maddelerinin, bitümlü sıcak karışımların tekerlek izi oluşumuna karşı direncini arttırdığını göstermiştir. Tekerlek izi oluşumuna karşı en etkin katkı maddesinin EVA olduğu tespit edilmiştir. Ayrıca numune hazırlama esnasında vibrasyon uygulanmasının numunelerin kalıcı deformasyona karşı direncini arttırdığı tespit edilmiştir.

Anahtar Kelimeler: Tekerlek izi, Bitümlü sıcak karışım, Stiren-butadien-stiren, Etilen-vinil-asetat.

1. Introduction

Two basic components of bituminous hot mixes (BHM) are aggregate and bitumen and aggregates used in BHMs consist 90-95% of the total BHM weight. 1.6 billion tons of bituminous hot mix is produced every year worldwide. For this purpose, approximately 1.5 billion tons of aggregate is used. Environmental damages caused by highway construction are those resulting from construction activities (CO_2 emissions, use of nature lands, change in current conditions and ecological balance, change in natural structure) and the damages caused by the material utilized for construction (destruction of natural lands, technological equipment causing chemical pollution, noise and vibration) [1].

One of the most encountered deformations observed with bituminous hot mixes, permanent deformations occur as a result of two basic conditions. The first occurs due to the inappropriate construction of the base course or the asphalt base course. In the second condition, while there is no deformation in lower layers, the permanent deformation (wheel tracks) form on the wearing course [2].

Wheel track formation is frequently observed on pavement courses in hot temperatures and on roads where heavy vehicle traffic is present. Deformations cause expensive rehabilitations or reconstruction, as well as new material needs, resulting in harming the environment again.

To improve the features of BHMs, postponing expensive rehabilitation and reconstructions, additive substances are utilized. Polymers used as the most common additive substances used in modification of bituminous binders are grouped in four categories of plastomers, elastomers, fibers and pavements. To improve the features of bitumen, selected polymer should form a new bond in bitumen, chemically reacting with bitumen. Obtaining a high performance polymer modified bitumen is dependent on the better distribution of the polymer in bitumen and the chemical structure of the bitumen [3]. Most frequently used bitumen additives are styrene-butadiene-styrene (SBS) from the elastomer group and ethylene-vinyl-acetate (EVA) from the plastomer group [4]. Several studies demonstrated that resistance against ageing [5], permanent deformation [6], low temperature fractures [7], and moisture damage [8] increased by the use of SBS modified bitumen. EVA especially increases resistance against permanent deformation [9] , [10].

It is possible to adjust the polybutadiene structure of SBS block copolymers using a special catalyzer. Thus, it is possible to obtain an SBS with the same molecular weight, but with a shorter polymer chain. This means low viscosity, and a better and more homogenous mixture with bitumen [11], [12].

It is of utmost significance to prepare bituminous hot mixes in laboratory environment reflecting the field conditions, for the accuracy of the design and accurate determination of the material that would be applied in the field. In the present study, bituminous hot mix samples containing pure bitumen and bitumen modified by three different additives (two types of SBS and one type of EVA) were prepared using roller compactor. The mixes were compacted with and without vibration to create the same void ratio. Afterwards, wheel track tests were conducted on these mixes. Thus, the effect of mix preparation method on permanent deformation performance of the mixes was assessed.

2. Materials and Methods

Limestone type aggregate procured from Karayazı region in Elazığ province in Turkey was used in the study. Properties of the aggregate is presented in Table 1 and the gradation selected according to Superpave method is given in Figure 1. Triangular signs depict control points, closed field shows forbidden zone, and square signs show utilized gradation points in Figure 1.

PG 58-35 bitumen procured from TÜPRAŞ refinery was used as the main binder in the present study. Two different types of SBS produced by Shell Corporation (Kraton D 1101 and Kraton MD 243) and EVA produced by Arkema Corporation (Evatane® 2805) were used as additives. A four-bladed mixing head was used in preparing modified bitumen. Pure bitumen and additives were mixed in a special mixer for 60 minutes at 180°C temperature and 1000 rpm.

To evaluate the effect of these additives on the performance of bituminous hot mixes, all additives were used at a rate of 4% (Table 2). Dynamic shear rheometer (DSR) and beam bending rheometer (BBD) test results for pure and with 4% SBS D1101 (MB_{SBS-D}), SBS MD243 (MB_{SBS-M}), and Evatane® 2805 (MB_{EVA}) bitumen are presented in Table 3. It was determined that the performance levels for MB_{SBS-D} and MB_{SBS-M} modified bitumen were similar (PG 70-34), and the low temperature value for MB_{EVA} modified bitumen was one level higher (PG70-28).

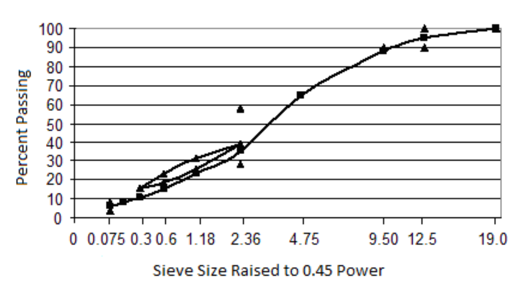

Figure 1. Used aggregate gradation.

Table 1. Physical properties of aggregate.

Properties	**Standard**	**Limit**	**Coarse**	**Fine**	**Filler**
Abrasion loss (%) (Los Angeles)	ASTM D 131	Max 30	27.8	-	-
Abrasion loss (%) (Micro Deval)	ASTM D 6928	Max 15	13.6	-	-
Frost action (%) (with Na_2SO_4)	ASTM C 88	Max 10	5.8	-	-
Specific gravity (g/cm^3)	ASTM C127		2.544	2.571	2.675

Table 2. Abbreviations used for modified bitumen.

Additive type and ratio	%4 SBS-D1101	%4 SBS-MD243	%4 EVA
Denomination	MB_{SBS-D}	MB_{SBS-M}	MB_{EVA}

Table 3. DSR and BBR test results of binders.

DSR test results				
Temperature (°C)	G*/sinδ (Pa) (Specification limit min. 1000 Pa)			
	PG 58-34	MB_{SBS-D}	MB_{SBS-M}	MB_{EVA}
58	1258	4890	4204	4534
70	-	1326	1183	1512
	G*/sin δ (Pa) RTFOT residue (Specification limit min. 2200 Pa)			
58	7862	-	-	-
70	-	5599	5171	6862
	G*.sin δ (Pa*10^6) PAV residue (Specification limit max. 5*10^6 Pa)			
16	1.83	-	-	-
22	-	1.69	1.52	-
25	-	-	-	1.34
BBR test results				
Temperature (°C)	m-value (Specification limit min. 0.300)			
	PG 58-34	MB_{SBS-D}	MB_{SBS-M}	MB_{EVA}
-18	-	-	-	0.306
-24	0.309	0.314	0.325	0.277
-30	0.266	0.221	0.291	-
	Creep stiffness (Mpa) (Specification limit max. 300 MPa)			
-18	-	-	-	131.3
-24	108.3	144.7	98.5	160.6
-30	140.9	242.6	121.9	-
	Performance Grade (PG)			
	58-34	70-34	70-34	70-28

Rotational viscometer tests were conducted on unaged pure and modified bitumen under 135°C and 185°C temperatures to determine the workability of the binders and aggregate mixing and compacting temperatures. For workability, the viscosity values for the binders should be below 3 Pa.s (3000 cP) at 135°C [13]. Furthermore, it is required that the viscosity value of bituminous binders during mixing with aggregate should be 170 ± 20 cP, and during compacting it should be 280 ± 30 cP [14]. Utilizing the viscosity-temperature graphs plotted in the study, aggregate mixing and compacting temperature for each binder was identified. Results of viscosity tests are displayed in Table 4.

Data presented in Table 4 shows that all binders met the workability criterion. Furthermore, using additives increased viscosity values and mixing and compacting temperatures rose as a result. Modification indices were obtained by division of viscosity values of modified bitumen by viscosity value of pure binder. As could be seen in Table 4, the highest modification index value was obtained with MB$_{EVA}$ modified bitumen at both 135ºC and 165ºC temperatures. This situation indicates that more energy would be required in the plant during mixing with aggregate with EVA use.

During preparation of bituminous hot mixes, aggregate and bitumen were heated to mixing temperature and mixed using a special mixer. Non-compacted samples were placed in trays 21-22 kg per square meter and aged for a short period of time for 4 hours in an incubator at 135ºC. Then, the mixtures were heated to mixing temperatures and compacted using a 1.25º angle gyratory compactor for 100 revolutions. The design was determined based on the volumetric properties of bitumen content mixtures. It was determined that design bitumen content increased with modified bitumen use. Volumetric properties of mixtures in design bitumen content and Superpave specification criteria are presented in Table 5. It was confirmed that all mixtures met Superpave specification criteria.

Table 4. Rotational viscosity test results.

Properties	**Standard**	**PG 58-34**	**MB$_{SBS-D}$**	**MB$_{SBS-M}$**	**MB$_{EVA}$**
Viscosity (cP, 135°C)	ASTM D4402	275.0	1125.0	825.0	1250.0
Viscosity (cP, 165°C)	ASTM D4402	112.5	350.0	262.5	375.0
Mixing temperature range (°C)	-	151-158	171-173	169–171	171-173
Compaction temperature range (°C)	-	129-140	167-169	163–166	167-169
Modification index (135°C)		-	4.09	3.00	4.54
Modification index (165°C)		-	3.11	2.33	3.33

Table 5. Volumetric properties of mixtures.

Mixture properties	**Specification limits**	**Binder type**			
		PG 58-34	**MB$_{SBS-D}$**	**MB$_{SBS-M}$**	**MB$_{EVA}$**
Design binder content (%)	–	4.88	5.27	5.35	5.07
Air Voids (Va, %)	4.0	4.04	4.09	4.09	3.99
Voids in mineral aggregate (VMA, %)	min. 14.0	14.61	15.39	15.50	14.86
Voids filled with bitumen (VFA, %)	65–75	72.37	73.42	73.63	73.13
Dust ratio (DP)	0.8–1.6	1.07	0.98	0.97	1.02

3. Wheel Track Tests

Wheel track formation on pavement layer was examined in the study. The tests were conducted based on EN 12697-22 standard B procedure to examine the wheel track resistance of samples that contained pure PG 58-34, 4% SBS-D, SBS-M and EVA modified binders. Since maximum aggregate grain diameter was 19 mm according to the standard, sample height was selected as 6.0 cm. Initially 30.5 * 30.5 * 6 cm plate samples were compacted using rolling compactor so that they would have 4% air void ratio. Some samples were compacted with application of vibration, and the others were compacted without. Required BHM amount for plate samples was determined using the following equation:

$$M = 10^{-6} * L * l * e * \rho_m * ((100 - v)/100) \qquad (1)$$

where M is sample weight (kg), L is inner length of the mold (mm), l is the inner width of the mold (mm), e is the final height of the sample (mm), ρ_m is the maximum density of the bituminous mixture (kg/m^3), and v is the void ratio of the sample (%).

In wheel track experiment the samples were tested at 60°C temperature. The device took 27 deformation measurements, out of which one was taken from the center of the sample, and 13were taken from the left of the center and right of the center. At the end of 10,000 wheel revolutions, wheel track depths were determined using the average of these 27 values. For each mixture sample, two samples were tested and average of the values were taken. According to EN 12697-22 standard, the test is terminated either after 10,000 load repetitions or when 20 mm wheel track depth is formed. In mixtures containing pure binder, 20 mm wheel track depth was obtained after 2,940 load repetitions and the test was ended. The tests conducted with modified bitumen were terminated after 10,000 load repetitions. The relationship between wheel track depth and number of load repetitions in mixtures prepared with vibration is presented in Figure 2, while relationship between wheel track depth and number of load repetitions in mixtures prepared without vibration is displayed in Figure 3. The load that caused 20 mm deformation in mixtures prepared with pure binder is displayed with a dashed line.

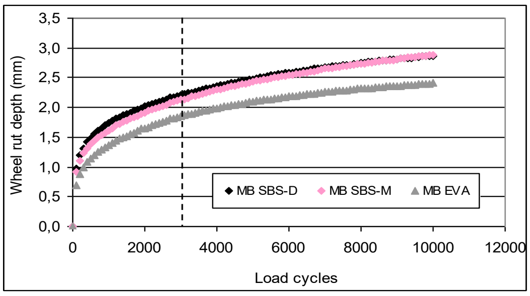

Figure 2. The wheel track depth-number of load repetition relationship in mixtures prepared with vibration.

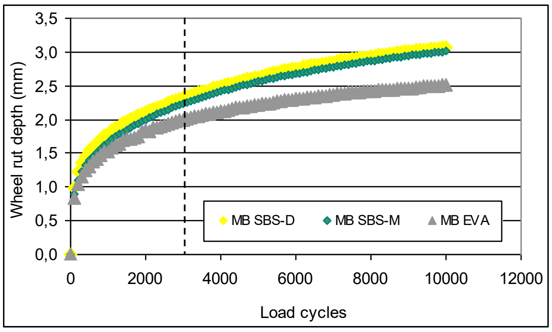

Figure 3. The wheel track depth-number of load repetition relationship in mixtures prepared without vibration

It was determined that wheel track values for mixtures prepared with MB_{SBS-D} and MB_{SBS-M} were close to each other as displayed in Figures 2 and 3. Comparison of mixtures prepared with modified bitumen showed that the lowest wheel track value was obtained with the mixture prepared with MB_{EVA}, and the highest wheel track value was obtained with the mixture prepared with MB_{SBS-D}. Deformation values for 5,000 and 10,000 load repetitions are presented in Table 6.

As could be observed in Table 6, wheel track depths for 5,000 and 10,000 load repetitions in mixtures prepared without vibration and using EVA modified bitumen were 18.5% and 22.7% lower than the mixture prepared using SBS-D modified bitumen, respectively. Furthermore, wheel track depths for 5,000 and 10,000 load repetitions in mixtures prepared using EVA modified bitumen were 15.3% and 20.3% lower than the mixture prepared without vibration using SBS-D modified bitumen, respectively.

As could be observed in Table 6, wheel track depths for 5,000 and 10,000 load repetitions in mixtures prepared with vibration and using EVA modified bitumen were 18.1% and 19.1% lower than the mixture prepared using SBS-D modified bitumen, respectively. Furthermore, wheel track depths for 5,000 and 10,000 load repetitions in mixtures prepared with vibration and using EVA modified bitumen were 15.7% and 19.9% lower than the mixture prepared using SBS-M modified bitumen, respectively.

As a result of vibration application, wheel track formation in mixes prepared using SBS-D modified bitumen decreased 5.7% after 5,000 load repetitions and 6.8% after 10,000 load repetitions. As a result of vibration application, wheel track formation in mixes prepared with SBS-M modified bitumen decreased 5.1% after 5,000 load repetitions and 4.3% after 10,000 load repetitions.

Table 6. Wheel track values for mixtures under different load repetitions.

Mixtures prepared without vibration

Deformation (mm)	Mixture type (according to used binder)			
	PG 58-34	MB_{SBS-D}	MB_{SBS-M}	MB_{EVA}
@5000 load cycles	-	2.63	2.56	2.22
@10000 load cycles	-	3.08	3.02	2.51

Mixtures prepared with vibration

Deformation (mm)	Mixture type (according to used binder)			
	PG 58-34	MB_{SBS-D}	MB_{SBS-M}	MB_{EVA}
@5000 load cycles	-	2.48	2.43	2.10
@10000 load cycles	-	2.87	2.89	2.41

As a result of vibration application, wheel track formation in mixes prepared using EVA modified bitumen decreased 5.4% after 5,000 load repetitions and 4.0% after 10,000 load repetitions.

Overall consideration of mixes showed that vibration application decreased wheel track formation. This finding demonstrated that, although the mixes had the same volume, the mix compacted better as a result of implementation of vibration. As a result of comparison of additive types, values obtained after 10,000 load repetitions showed that the mix affected by vibration the most was the one prepared with SBS-D and the mix affected by vibration the least was the one prepared with EVA based on permanent deformation. It was observed that compacting especially the SBS-D modified bitumen using vibration was more significant for wheel track formation.

4. Results

In the present study, initially the effect of three different bitumen additives (SBS-D, SBS-M and EVA) on the resistance of bituminous hot mixes against wheel track formation was examined. Later on, the effect of vibration application on the preparation of wheel track samples was attempted to be identified. Additive ratio was kept constant at 4% for all additives. Thus, the convenient comparison of all additive types was aimed. In the field, vibrating rollers are used to compact bituminous hot mixes. A roller compactor with vibration capabilities was used to obtain compatible samples with the field conditions. Samples were prepared using modified bitumen both by using and not using vibration. Wheel track tests were conducted on these samples to assess the effects of vibration.

It was determined that performance levels for modified bitumen that contained SBS-D and SBS-M equal to 4% of bitumen weight were PG 70-34, and the performance level of those that contained EVA were PG 70-28. It was identified that design bitumen content of the mixes prepared with SBS-D, SBS-M and EVA modified bitumen were 5.27%, 5.35%, and 5.07%, respectively.

Wheel track samples that contained pure and modified bitumen with 4% void ratio consistent with the field applications were prepared with roller press. Samples were prepared both using vibration and without using vibration. It was determined that mixes prepared with EVA modified bitumen had the lowest wheel track depth for both vibration applied and not vibration applied mixes. Furthermore, it was identified that wheel track values for mixes prepared with SBS-D and SBS-M modified bitumen were similar. It was also determined that vibration applied mixes displayed lower wheel track formation when compared to mixes that were not applied vibration.

It was determined that vibration was more effective especially in mixes prepared with SBS-D modified bitumen. It was considered that this condition was due to better compacting of the mixes as a result of vibration. To determine the compatibility of vibrated and non-vibrated samples with the field conditions, it would be beneficial to compare the test results for samples obtained from the field with the test results for the samples prepared at the laboratory in the future.

5. Acknowledgements

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6. References

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