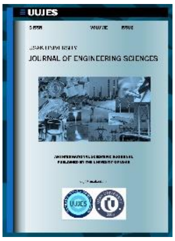

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Research article

DETERMINATION OF OPTIMUM BITUMEN CONTENT IN POROUS ASPHALT PAVEMENT USING DIFFERENT METHODS

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Abstract

In recent years, studies on porous asphalt have gained more importance and countries are conducting various studies in order to improve the engineering properties of this type of pavement. As a result of these studies, each country developed its own standard and therefore different optimum bitumen content (OBC) determination methods emerged. This paper investigates the determination of the optimum bitumen content of porous asphalt samples prepared by using different aggregate types and polymers by the methods implemented in Turkey and in other countries. The results have shown that the application of each method yielded different bitumen content.

Keywords: *Porous asphalt; optimum bitumen content; modified porous asphalt; porous asphalt design; polymers.*

1. Introduction

The primary concept of porous asphalt is to create a substantial amount of air voids which enables the removal of water from the road surface. Unlike dense asphalt mix design, the design bitumen content of porous asphalt could not be specified based on stability and flow from the Marshall Test. The selection of optimum bitumen content (OBC) must fulfill the upper and lower bitumen limits to manufacture a well permeable mixture, not susceptible to bitumen drainage during storage and transportation [1], as well as ensures sufficient resistance to break up, aging, and moisture damage. The porous asphalt mixture design greatly relies on the OBC which depicts whether the mixture has adequate adhesion

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between the aggregate particles and the bitumen [1-7]. The porous asphalt does not follow a specific procedure to estimate the OBC and there are several methods proposed in the specifications around the world. In Europe, Ruiz [8] indicated that the porous asphalt mixture design changes by the employed mechanical test. A European agreement was never achieved, and numerous methods were implemented. In some countries, particle loss, water sensitivity, and drainage tests were applied to specify the required bitumen content.

In general, European design procedures for porous asphalt verify the OBC through determination of the maximum bitumen content that yields a minimum specified air voids content. Usually, this air voids content is between 20 to 26 % (i.e., in Denmark) [9]. The draindown test is also carried out to prevent draindown related problems during manufacturing and placement. Moreover, the determination of the minimum bitumen content that provides sufficient resistance against disintegration is utilized to a certain extent in Europe. This disintegration is estimated by performing Cantabro test. Several European countries at present involve not only assessing the loss of weight in Cantabro test utilizing dry specimens but also moisture conditioned specimens. The tensile strength ratio is applied only for porous asphalt design in Switzerland [9]. Various Departments and Agencies in USA applied the mix design method suggested by the National Center for Asphalt Technology (NCAT) in 2002 [12] and edited in 2004 [13, 14]. The general aspect of these mix design methods depended on the assessment of volumetric characteristics, such as average air voids content as the primary factor to specify the design bitumen content. An evaluation of mixture durability through the Cantabro test, drainage, moisture susceptibility, and stone-on-stone contact was as well incorporated in the mix design process [15]**.** Thus, in this study, a comparison of different methods suggested by different specifications such as Turkish Specification, ASTM 7064, Chinese, Indonesian, Malesian Specification and Empirical Method has been conducted. For this purpose, different aggregate types (limestone and basalt) with different polymers (Elastomeric type polymers– Styrene Butadiene Styrene (SBS), and Reactive Elastomeric Terpolymer type – Elvaloy) were used to determine OBC for porous asphalt pavements based on the above-mentioned methods.

2. Methods and Materials

In this section, firstly the OBC determination specifications adopted by different countries and agencies will be presented followed by the presentation of the properties of the bitumen, polymers as well the type of the aggregates.

2.1. Methods of determining Optimum Bitumen Content (OBC)

For dense-graded mixtures, the OBC is determined as the bitumen content corresponding to the median of designed limits of percent air voids in the total mix (i.e., 4 %). While for porous asphalt design, the OBC determination has no specific standard and each agency or department specifies the OBC considering different parameters such as the air void content, Cantabro abrasion, stability, permeability, bitumen draindown, and Indirect Tensile Strength. The different methods suggested by the literature are summarized below:

2.1.1 Turkish Specification

Regarding Turkish Specification, the OBC is defined by taking into account the air void content, Cantabro abrasion value, stability value. These values must be within the specified limits as; the air voids range is between 18% to 22%, the maximum accepted particle loss is 20%, and the minimum stability value is 300 kg (Table 1). Following the determination of OBS, the permeability, indirect tensile strength test, draindown test are performed in order to verify whether the obtained bitumen content is applicable.

Table 1 Porous asphalt design criteria based on the Turkish Standard

Properties	Specification Limits
Number of Blows	50
Air Voids, (%)	18-22
Particle Loss (Cantabro), (%), max.	20
Stability, (kg), min.	300
Permeability Value, (m/sn), x10-3 Vertical-Horizontal	0.5 – 3.5
Schellenberger Bitumen Drain down, (%), max.	0.3
Indirect Tensile Strength (ITS) Ratio, (%), min.	80

2.1.2 ASTM D7064

In this method, the OBC is defined based on the air void ratio (min. 18%), bitumen draindown (max. 0.3), and the un-aged abrasion value (max. 20%) standardized limits as shown in Table 2.

Table 2 Porous asphalt design criteria based on ASTM D7064

Properties	Specification Limits
Air Voids, (%), min.	18
Particle Loss (Cantabro), (%), max.	20
Bitumen Drain down, (%), max.	0.3

2.1.3 Chinese Specification

The determination of OBC in Chinese specification is different compared to other mentioned methods. In this method, instead of calculating a single value, a minimum and maximum optimum bitumen contents are determined. The minimum OBC is verified as the content corresponding to the inflection point of the Cantabro loss curve. The maximum OBC on the other hand is determined as the content corresponding to the inflection point of the bitumen drain down as depicted in Fig. 1.

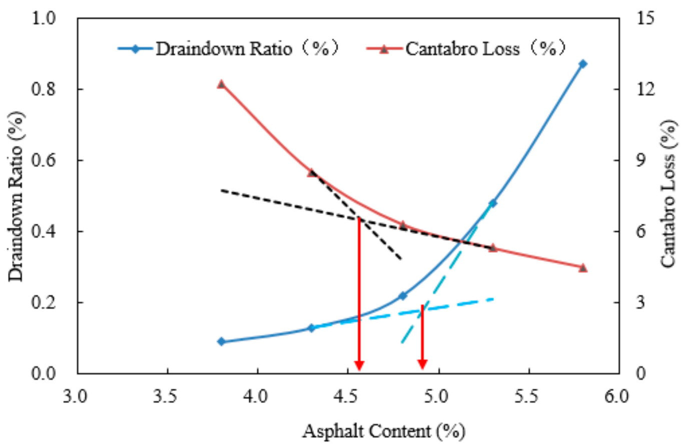

Fig. 1 Asphalt content range determination based on draindown ratio and Cantabro loss [11]

2.1.4 Malaysian Specification

Regarding Malaysian Specification, the OBC is determined using the bitumen draindown and Cantabro tests. The rate of mass loss in the Cantabro test is suggested to be less than 15% and the bitumen drain-down shall be not more than 0.3%. Also, the obtained OBC must provide between 18 and 25% air voids. The standardized limits are depicted in Table 3.

Table 3 Porous asphalt design criteria based on Malaysian Specification

Properties	Specification Limits
Air Voids, (%)	18-25
Particle Loss (Cantabro), (%), max.	15
Bitumen Draindown, (%), max.	0.3

2.1.5 Indonesian Specification

According to the Indonesian specification, the OBC for porous asphalt is determined by performing several tests such as the bitumen draindown test, Cantabro Loss test, Marshall Stability test, as well as the average air voids in the mixtures. In order to select the most suitable values for the design, the mentioned test results must be within the limit values of the specification as; the air void is between 17% - 23%, maximum particle loss is 20%, minimum stability value is 350 kg, maximum bitumen draindown is 0.3%. (Table 4).

Table 4 Porous Asphalt Design Criteria Based on Indonesian Standard

Properties	Specification Limits
Air Voids, (%)	17-23
Particle Loss (Cantabro), (%), max.	20
Stability, (kg), min.	350
Bitumen Drain down, (%), max.	0.3

2.1.6 Empirical Method

Theoretically, the OBC for porous asphalt mixtures can be estimated by implementing an empirical equation developed by Roffee (Roffee 1989) (Eq 1-3). In this method, the determination of OBC is conducted based on the aggregate properties such as apparent specific gravity, specific surface area, and percentage of coarse and fine aggregate particles. The OBC can be obtained by following equations:

$$OBC = 3.25\,(\propto)\textstyle\sum^{0,2} \tag{1}$$

$$\propto = 2.65/SG_{agg} \tag{2}$$

$$\textstyle\sum = 0.21C + 5.4S + 7.2s\ + 135f \tag{3}$$

where:
OBC = optimum bitumen content, %
SG_{agg} = apparent specific gravity of aggregate blend,
Σ =specific surface area,
C = percentage of material retained on 4.75mm sieve,
S = percentage of material passing 4.75mm sieve and retained on 0.6mm sieve,
s = percentage of material passing 0.6mm sieve and retained on 0.075mm sieve,
f = percentage of material passing 0.075mm sieve.

2.2. Materials

The unmodified bitumen utilized in this study is a 50/70 penetration grade. The physical characteristics of the unmodified bitumen considering some of the conventional tests are given in Table 5.

Table 5 Physical properties of the base bitumen

Test	Specification	Results	Specification limits
Penetration (25 ºC; 0.1 mm)	ASTM D5 EN 14264	65	50-70
Softening point (ºC)	ASTM D36 EN 1427	51	46-54
Ductility (25 ºC; cm)	ASTM D113	100	-
Specific gravity	ASTM D70	1.030	-
Flash point (ºC)	ASTM D92	260+	230 (min)
Penetration index (PI)	-	0.35	-
Rolling thin film oven test (RTFOT)	ASTM D2872-12		
Change of mass (%)	-	0.160	0.5 (max.)
Penetration after RTFOT (25 ºC; 0.1 mm)	ASTM D5 EN 1426	53	50 (min.)
Retained penetration after RTFOT (%)	ASTM D36 EN 1427	82	50 (min.)
Softening point after RTFOT (ºC)	ASTM D36 EN 1427	58	48 (min.)

The polymer-modified bitumen samples were produced using two additives: Elastomeric type – Styrene Butadiene Styrene (SBS), and Reactive Elastomeric Terpolymer type – Elvaloy. SBS and Elvaloy contents were selected as 5% and 1.5% of bitumen weight, respectively. The polymer contents were determined based on past research [16-19]. Table 6 illustrates the physical properties of the SBS and Elvaloy and the production conditions of PMB samples are given in Table 7.

Table 6 The physical characteristics of SBS and Elvaloy® polymers

Physical properties	Specification	SBS Kraton D 1101	Elvaloy® 4170
Molecular structure	-	Linear	Linear
Specific gravity	ASTM D792	0.94	-
Tensile strength at break (MPa)	ASTM D 412	31.8	31.8
Shore hardness (A)	ASTM D 2240	71	-
Physical form	-	Powder, pellet	Powder, pellet
Melt flow rate	ASTM D-1238	<1	8
Processing temperature (°C)	-	150–170	-
Elongation at break (%)	ASTM D 412	875	-
Density	-	-	0.557

Table 7 Production detailed regarding the additives and modifications

Modifier Type		Percentage (%)	Production Conditions		
			Mixing Temperature (ºC)	**Mixing Duration(min)**	**Shearing Rate (rpm)**
Polymer	SBS Kraton® D1101	5	180±5	120	2000
	Elvaloy® 4170	1.5	190	120	200

The porous asphalt samples were prepared using two different aggregate types (limestone and basalt), which were collected from the Dere Beton/Izmir quarry. Some of the physical properties of the aggregates are presented in Table 8. Two aggregate series were utilized to manufacture the porous asphalt samples. The #1 series was formed by using only limestone aggregate while the #2 series was formed by mixing the coarse particles of the basalt with the fine particles of the limestone. The gradation of the two series was selected according to Turkish standards (Fig. 2).

Table 8 The physical properties of limestone and basalt aggregates

Test	**Specification Limits**	**Test Standard**	**Limestone**	**Basalt**
Resistance to fragmentation(Los Angeles), %	≤25	TS EN 1097-2	22.3	13.7
Resistance to abrasion (Micro-Deval), %	≤20	TS EN 1097-1	18	15
Fastness weathering (With $MgSO_4$ loss), %	≤10	TS EN 1367-2	9.2	7.7
Flakiness Index %	≤15	TS EN 933-3	6.6	4.8
Water Absorption %	≤2	TS EN 1097-6	1.05	0.6

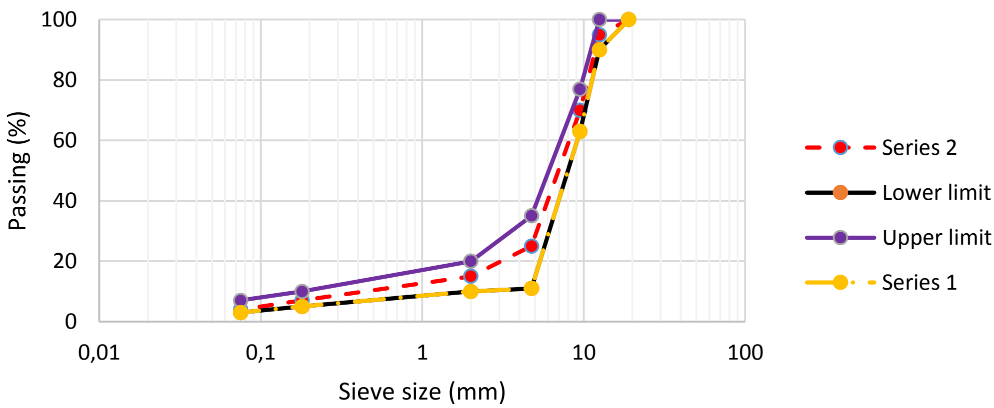

Fig. 2 Utilized Aggregate Gradation

4. Results and Discussion

4.1. Optimum Bitumen Content (OBC) determination

4.1.1 The determined OBC for Turkish Standard

The OBC of the samples prepared according to the Turkish specification was determined by evaluating the stability, Cantabro loss, and air void ratio of the samples. Concerned values are shown in Table 9 and the highlighted cells in the table are representing the values which did not meet the specification limits. The mixture prepared with SBS modified bitumen for Series#1 provides the limit values of the specification at 4.0% and 4.5% bitumen contents. In this case, a value of 4.0% was chosen as the optimum bitumen content, which gives maximum stability. The mixture prepared with Elvaloy modified bitumen met the specification limits at only at 4.5% bitumen content. Therefore, 4.5% was determined as the optimum content.

For Series#2, the mixture prepared with SBS modified bitumen met the specification limits at only 4.0% bitumen content, and this value was defined as the OBC. Regarding to Elvaloy modified samples, the optimum bitumen content was obtained as 4.5% since this is the only bitumen content which met the specification limits. The OBC results are depicted in Fig. 3.

Table 9 OBC results based on Turkish Specification

Properties	Bitumen Type	Series#1					Series#2				
		Bitumen Ratio, %					Bitumen Ratio, %				
		3	3.5	4	4.5	5	3	3.5	4	4.5	5
Stability, kg	SBS Modified	358	402	430	378	357	427	463	483	480	459
	Elvaloy Modified	369	393	416	404	352	481	510	536	463	437
Air Void Ratio, %	SBS Modified	21.37	20.09	19.01	18.44	17.02	20.78	19.41	18.92	17.49	16.27
	Elvaloy Modified	22.07	19.96	18.97	18.25	15.17	21.35	19.46	18.44	18.31	16.22
Particle (Cantabro) loss, %	SBS Modified	36.1	28.1	18.7	14.1	12.1	52.4	27.3	18	16.5	14.8
	Elvaloy Modified	39.5	32.1	26.8	19.3	16.3	52.9	33.3	25.4	19.4	17.9

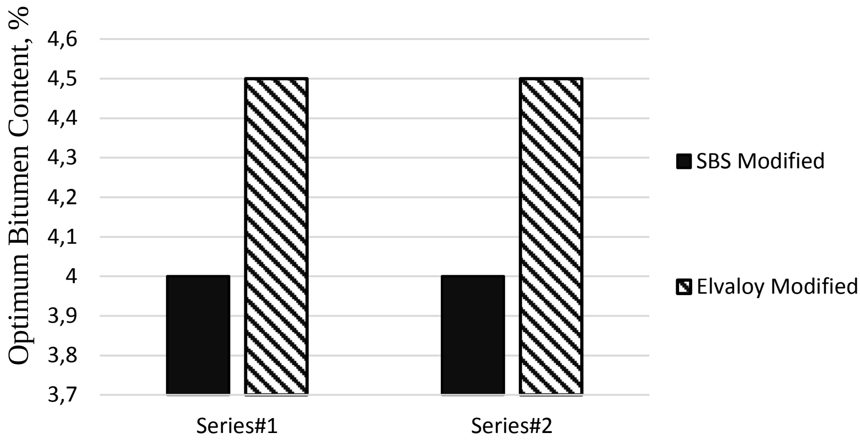

Fig. 3 OBC for Turkish specification

4.1.2 The determined OBC for ASTM 7064 Standard

The choice of OBC according to the ASTM 7064 specification is based on the values of air voids, Cantabro loss, and bitumen draindown of the samples. Related values are shown in Table 10 and the highlighted cells in the table are representing the values which did not meet the specification limits. For Series #1, 4% and 4.5% bitumen contents of the mixture prepared with SBS modified bitumen can be selected as the OBC according to the specification. Series #1 meets the lower and upper specification limits only at a bitumen content of 4.5%for the mixture prepared with Elvaloy modified bitumen. Therefore, the OBC of the Elvaloy modified mixture was determined as 4.5%.
For Series#2, the mixture prepared with SBS modified bitumen meets the lower and upper limits of the specification only at a bitumen content of 4.0%. Therefore, 4.0% was defined as the OBC of the SBS modified mixture. Regarding to Elvaloy modified samples, only 4.5% bitumen content met the specification limits, which yielded the OBC as 4.5%. The OBC results are shown in Fig. 4.

Table 10 OBC Results based on ASTM 7064 Specification

Properties	Bitumen Type	Series#1					Series#2				
		Bitumen Ratio, %					Bitumen Ratio, %				
		3	3..5	4	4.5	5	3	3.5	4	4.5	5
Air Void Ratio, %	SBS Modified	21.37	20.09	19.01	18.44	17.02	20.78	19.41	18.92	17.49	16.27
	Elvaloy Modified	22.07	19.96	18.97	18.25	15.17	21.35	19.46	18.44	18.31	16.22
Particle (Cantabro) loss, %	SBS Modified	36.1	28.1	18.7	14.1	12.1	52.4	27.3	18	16.5	14.8
	Elvaloy Modified	39.5	32.1	26.8	19.3	16.3	52.9	33.3	25.4	19.4	17.9
Draindown, %	SBS Modified	0.01	0.03	0.07	0.1	0.16	0.02	0.06	0.1	0.18	0.24
	Elvaloy Modified	0.02	0.03	0.06	0.11	0.19	0.04	0.08	0.1	0.12	0.23

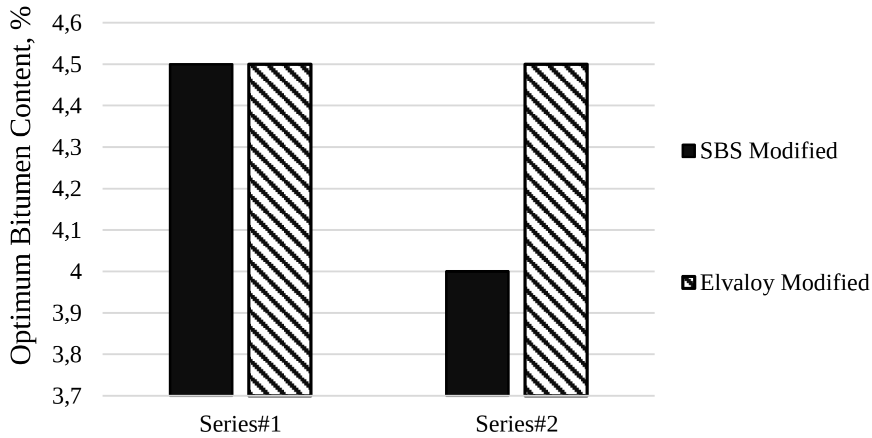

Fig. 4 OBC for ASTM 7064 specification

4.1.3 The determined OBC for Chinese Standard

The OBC of the samples prepared according to the Chinese specification is determined by calculating the average of the lower and upper limit bitumen values. For Series#1, the OBC of the mixture prepared with SBS modified bitumen was determined as 4.05%, while it was determined as 4.1%for the samples prepared with Elvaloy modified bitumen.
For Series#2, the OBC of the samples were determined as 4.15% and 4.1% for SBS and Elvaloy modified mixtures, respectively. The lower and upper bitumen content limits of the samples prepared with different polymers and aggregate series are shown in Figs. 5-8. and the OBC results are presented in Fig. 9.

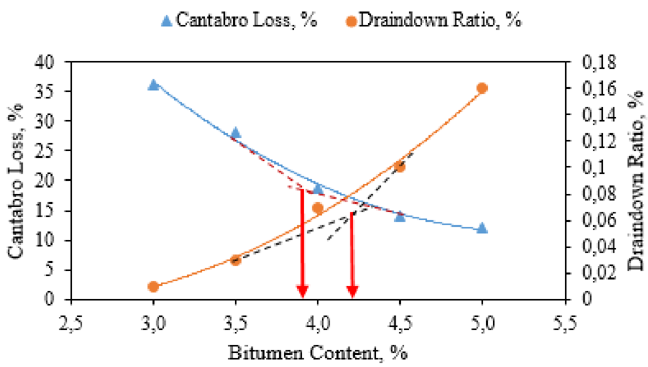

Fig. 5 Bitumen content range determination based on draindown ratio and Cantabro loss

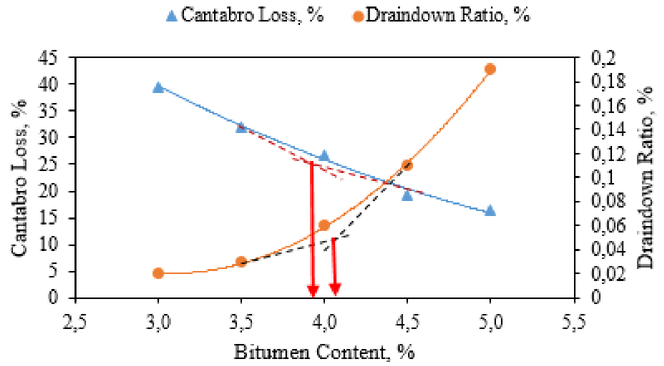

Fig. 6 Bitumen content range determination based on draindown ratio and Cantabro loss

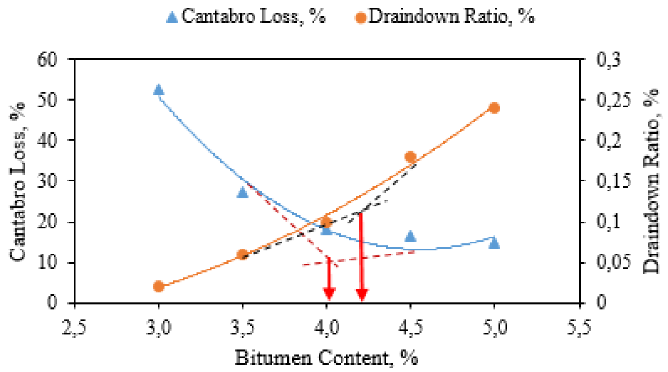

Fig. 7 Bitumen content range determination based on draindown ratio and Cantabro loss

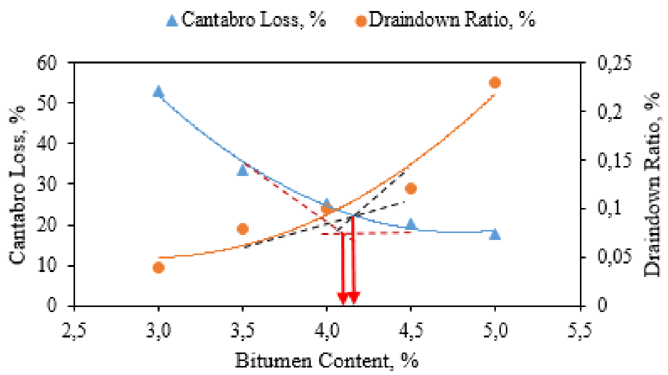

Fig. 8 Bitumen content range determination based on draindown ratio and Cantabro loss

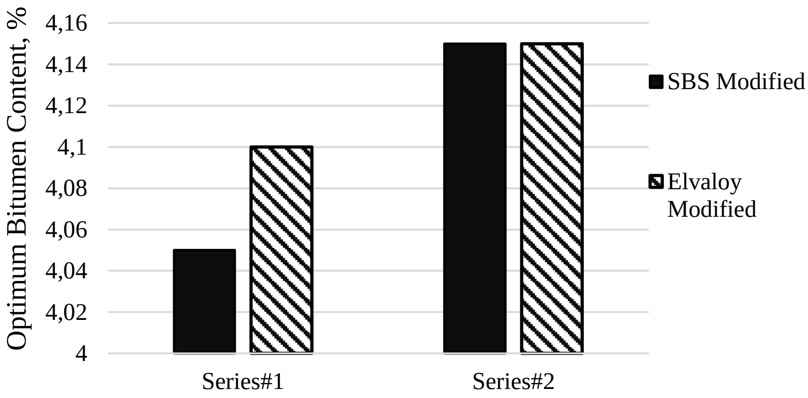

Fig. 9 OBC for Chinese specification

4.1.4 The determined OBC for Malaysian Standard

The OBC of the samples obtained according to the Malaysian specification was determined by evaluating the Cantabro loss and bitumen draindown properties of the samples. Cantabro loss and draindown test results of the samples are shown in Table 11 and the highlighted cells in the table are representing the values which did not meet the specification limits. As the mixtures prepared with SBS modified bitumen for Series#1 meet the lower and upper limits of the specification at 4.5% and 5.0% bitumen content, these percentages can be selected as the OBC range. Because the Cantabro loss values of the samples prepared with Elvaloy modified bitumen did not meet the specification limits for any bitumen content, the OBC could not be calculated for the samples prepared with this additive. The samples produced with Elvaloy did not exhibit good results for Cantabro loss compared to the SBS modified samples which may attributed to the inadequate adhesion between the aggregate and the bitumen.
Given that the mixture prepared with SBS modified bitumen for Series#2 meets the lower and upper limits of the specification at only 5% bitumen content, this value was determined as the OBC. Similar with the Series #1, the Cantabro loss value of the samples prepared with Elvaloy modified bitumen did not meet the specification limit, when the aggregate set was chosen as the combination of limestone and basalt (Series#2). Therefore, the OBC could not be calculated for these samples. The OBC results are shown in Fig. 10.

Table 11 OBC results based on Malaysian Specification

Properties	Bitumen Type	Series#1					Series#2				
		Bitumen Ratio, %					Bitumen Ratio, %				
		3	3,5	4	4,5	5	3	3,5	4	4,5	5
Particle (Cantabro) loss, %	SBS Modified	36.1	28.1	18.7	14.1	12.1	52.4	27.3	18	16.5	14.8
	Elvaloy Modified	39.5	32.1	26.8	19.3	16.3	52.9	33.3	25.4	19.4	17.9
Draindown, %	SBS Modified	0.01	0.03	0.07	0.1	0.16	0.02	0.06	0.1	0.18	0.24
	Elvaloy Modified	0.02	0.03	0.06	0.11	0.19	0.04	0.08	0.1	0.12	0.23

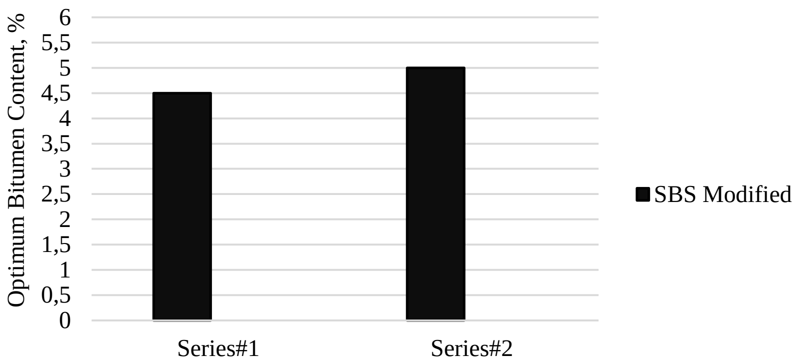

Fig. 10 OBC for Malaysian specification

4.1.5 The determined OBC for Indonesian Standard

The OBC of the samples prepared according to the Indonesian specification was determined as the content that meets the specified limits of stability, Cantabro loss, air void, and bitumen draindown values of the samples. Concerned values are shown in Table 12 and the highlighted cells are representing the values which did not meet the specification limits. The mixture prepared with SBS modified bitumen for Series#1 provides the lower and upper limits of the specification at 4.0%, 4.5%, and 5.0% bitumen contents. In this case, 4% bitumen content, which corresponds to the maximum stability, was determined as the optimum bitumen. Since the samples prepared with Series#1 and Elvaloy modified bitumen remained within the specification limits at only 4.5% bitumen, this value was determined as the OBC.
For Series#2, the mixture prepared with SBS modified bitumen met the specification limits at 4.0% and 4.5% bitumen contents. Regarding to that, the OBC was chosen as 4.0%, which provides the maximum stability. Elvaloy modified bitumen only met the lower and upper specification limits at 4.5% bitumen content, which was selected as the OBC. The OBC results are shown in Fig. 11.

Table 12 OBC results based on Indonesian Specification

Properties	Bitumen Type	Series#1					Series#2				
		Bitumen Ratio, %					Bitumen Ratio, %				
		3	3.5	4	4.5	5	3	3.5	4	4.5	5
Stability, kg	SBS Modified	358	402	430	378	357	427	463	483	480	459
	Elvaloy Modified	369	393	416	404	352	481	510	536	463	437
Air Void Ratio, %	SBS Modified	21.37	20.09	19.01	18.44	17.02	20.78	19.41	18.92	17.49	16.27
	Elvaloy Modified	22.07	19.96	18.97	18.25	15.17	21.35	19.46	18.44	18.31	16.22
Particle (Cantabro) loss, %	SBS Modified	36.1	28.1	18.7	14.1	12.1	52.4	27.3	18	16.5	14.8
	Elvaloy Modified	39.5	32.1	26.8	19.3	16.3	52.9	33.3	25.4	19.4	17.9
Draindown, %	SBS Modified	0.01	0.03	0.07	0.1	0.16	0.02	0.06	0.1	0.18	0.24
	Elvaloy Modified	0.02	0.03	0.06	0.11	0.19	0.04	0.08	0.1	0.12	0.23

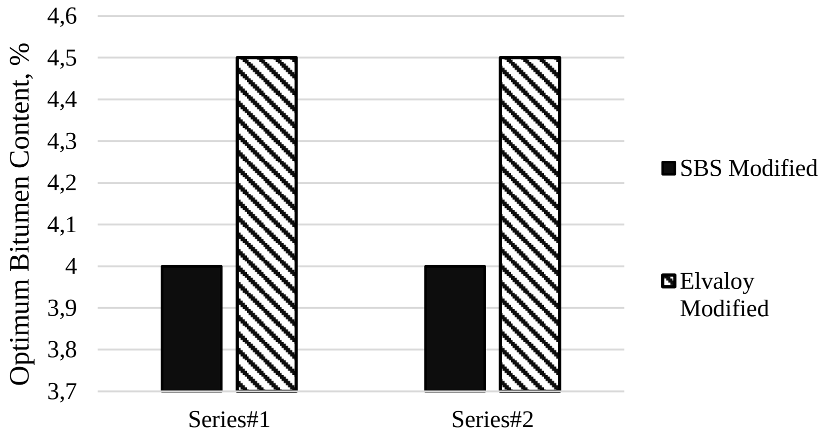

Fig. 11 OBC for Indonesian Specification

4.1.6 The determined OBC for Empirical Method

The application of the empirical method only considers the aggregate particles and does not include the bitumen behavior on the OBC determination. Thus, the results for aggregate utilized in Series#1 yielded an optimum value of 4.32 % and 4.76 for Series#2. The OBC results are shown in Fig. 12.

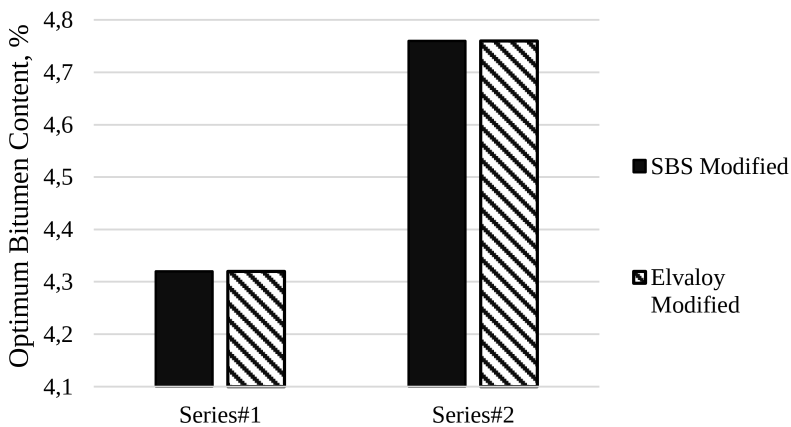

Fig. 12 OBC for Empirical Method

5. Conclusion and Recommendation

The research aims to compare the methods on determining the OBC of porous asphalt mixtures in various specifications which are used in different countries. For this purpose, the mixtures were prepared using two different aggregate sets (only limestone and basalt-limestone combination) and two different polymer types (Styrene Butadiene Styrene (SBS) for Elastomeric type and Elvaloy for Reactive Elastomeric Terpolymer type) ––. The OBCs of prepared samples were determined within the lower and upper specification limits. OBC could not be obtained from the mixtures prepared with Elvaloy modified bitumen only in the Malaysian specification since it did not meet the lower and upper limits of the Cantabro loss in the specification. Since the OBC determined by the empirical method is estimated only depending on the gradation, it is thought that it will not be an effective method in determining the optimum bitumen value of the porous asphalt due to the neglecting of bitumen role in the mixture.

When the obtained results are examined, there is no significant difference between the specifications in terms of optimum bitumen content. In general, bitumen content was determined as the lowest 4% and the highest 4.5%. However, the optimum bitumen content determined by the empirical method was found to be 4.76%, higher than the other specifications. Generally, a high air void ratio reduces the density of the mixture. This is a desirable situation for porous asphalt pavements. However, if the density of the asphalt pavement is too low, various damage mechanisms may develop. In addition, performance problems related to high density are also encountered. For porous asphalt, in mixtures prepared by using more bitumen than the optimum bitumen content, the bitumen would drain from the aggregate surface and causes the pores to be closed. A decrease in permeability occurs when the air voids in the pavement are blocked by excessive bitumen. Based on the findings of this study as well as the OBC results from the literature review, it has been seen that the inclusion of different test methods such as the Cantabro test, permeability test, and indirect tensile test to find the OBC of porous asphalt pavements is essential as it results in bitumen content that simulates the field condition. In addition, in some cases, the lowest bitumen value determined in the range was chosen as the optimum bitumen content. However, this situation causes a decrease in the long-term durability of the mixture and an increase in the part loss values. Therefore, it is recommended that the acceptable bitumen content be based on the results of the Cantabro test, especially when designing the mixture. Thus, in order for the mixtures to better represent the field conditions, the abrasion and permeability results of the mixtures, which are divided into two separate groups as un-aged and aged, should be examined and the results should be compared. This should involve an evaluation of the susceptibility of the mixture to moisture-induced damage (or freeze-thaw resistance where necessary) and permeability.

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