Technical Investigation of the Usability for Foamed Bitumen Stabilized Materials in Asphalt Pavements

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ABSTRACT

Asphalt recycling efforts are increasing in order to reduce the effects of high energy and raw material consumption in the asphalt sector. One of the most common methods for using old asphalt material, which still retains some value, is recycling with foam bitumen.

In practice, for the preparation and evaluation of cold mixes produced using foam bitumen, ITS (Indirect Tensile Strength) and MR (Resilient Modulus) methods are generally used. Among these methods, ITS is mostly applied for the evaluation of the materials optimum percentages values and MR test is also used for the evaluation of mixture performance.

In the experimental study, firstly for the cold mixes prepared with foam bitumen, optimum foam bitumen values of the production series were determined by ITS test. Then, reproductions were made for these optimum values and resilient modulus values were determined. It was found that the ITS and MR values were significantly affected by the material gradation and this showed the opposite tendency for the materials with the same gradation. The type of active filler was effective the same as the values of the mixtures on ITS and MR. Especially, the MR results were affected by the bitumen grade. As a result of the study, evaluation limit values; 225 kPa for ITS_{DRY} value, 150 kPa for ITS_{WET} value and 70% for TSR, 400 MPa resilient modulus value and 0.21 layer coefficient value are recommended for FBSM (Foam Bitumen Stabilized Material).

Keywords: Foam Bitumen Stabilized Material (FBSM); Layer Coefficient; Recycled Asphalt; Resilient Modulus (MR)

INTRODUCTION

Rapidly developing industry creates energy consumption and environmental problems (Xiao et al., 2018). It is known that, Agricultural product waste (Agwa et al., 2022; Azevedo et al., 2022), plastic (Fonseca et.al, 2022), glass (Kadhim et al., 2022; Hasani et al., 2022) etc. using of many different waste materials provides technical, environmental and economic advantages in construction sector. Also in recycled asphalt pavements, for reduces aggregate consumption and the need for binders (Zaumanis et al., 2016; Kushwaha and Swami, 2019) products with binding properties such as cement, fly ash, lime and cut back bitumen are frequently used (Wang et al., 2018). Recycled asphalt, which can be used in all layers from wearing course to subbase course in the pavement, can retain its value as asphalt despite its reuse and recycle processes (McDaniel and Anderson, 2001; Hasan et al 2022). Especially with the on-site and cold recycle method, very important gains are achieved in terms of energy consumption, acidification, abiotic depletion of fossil fuels and global warming (Turk et al., 2016).

In the foam bitumen recycle process, which is one of the asphalt cold recycle methods by adding to the RAP (Reclaimed Asphalt Pavement) material, by increasing the surface area of the bitumen and reducing its viscosity (Zhang et al., 2018), it is mixed with cold and moist aggregates (Muthen, 1998). When water at ambient temperature is added to the hot bitumen, the water is trapped in the form of small bubbles in the bitumen so the bitumen volume increases (Muthen, 1998; Hasan et al., 2017; Kumrawat and Deulkar, 2019). Sprayed foam bitumen is often dispersed into fine particles (Iwanski and Kowalska, 2019). A structure consisting of large aggregates formed partially coated with mastic droplets is obtained (Jenkins, 2000; Fu et al., 2009). Therefore, material gradation is very important for foamed bituminous cold mixes.

Indirect Tensile Strenght is commonly used to evaluate the potential for fracture properties and the moisture sensitivity of asphalt mixtures. Pre-conditioning ITS_{DRY} (Dry Indirect Tensile Strength) and post-conditioning ITS_{WET} (Wet Indirect Tensile Strength) values (Wirtgen, 2012; Diab and Enieb, 2018) and the TSR (Tensile Strength Retain) parameter found by the ratio of these two parameters are used to calculate the damage caused by the moisture effect (Iwanski and Kowalska, 2019). For roads with Equivalent Standard Axle Load > 6 million, ITS_{WET} value of at least 100 kPa, ITS_{DRY} value of at least 225 kPa and TSR value of at least 50, limit values have been proposed by Wirtgen (2012). The higher TSR is the better the asphalt mixture resists the moisture damage (Diab and Enieb, 2018; Kushwaha and Swami, 2019).

Another evaluation criterion, Resilient modulus; known as the elastic module based on recoverable strain under repeated loading (Witczak, 2003), also defines the resistance of pavement materials as flexible deformation under applied loads (Fu et al., 2009), it was stated by Austroads (2011) that there are different approaches for resilient modulus that are accepted between 500 MPa and 4,000 MPa. According to Khosravifar et al. (2015), the structural capacity of the FBSM (Foam Bitumen Stabilized Material) will be located between the granular aggregate base and the hot mix asphalt when appropriate design and application is made.

In the light of the literature, in this study; productions were made with different penetration bitumen and different active filler products in different gradation materials. The ITS values of the productions and the optimum bitumen percentages of the production series were determined and the resilient modulus values were determined for these optimum bitumen percentages. In addition, the ideal gradation range has been proposed for FBSM.

MATERIALS AND EXPERIMENTAL METHODS

The gradation of the RAP material used in the study, which has a bitumen content of 3,54% and has served approximately 15 years is the Type-A gradation given in Table 1 (Erten, 2020).

Table 1. Material gradations prepared for productions

Sieve Size		**Gradation Type/Passing (%)**				
mm	inch/no	Type-A	Type-B	Type-C	Type-D	Type-E
25	1	100	100	100	100	100
19	3/4	96	97	98	96	84
12,5	1/2	87	89	90	87	75
9,5	3/8	79	81	83	79	70
4,75	No.4	58	62	67	58	58
2	No.10	33	41	50	33	45
0,425	No.40	9	18	32	11	28
0,18	No.80	4	12	20	7	20
0,075	No.200	1,6	6	12	4	12

The physical properties of the bitumens used in the study are given in Table 2 (Erten, 2020).

Table 2. Basic properties of four bitumens and RAP binders

Experimental Results of Bitumens						**Limit Values**			
Properties	**Penetration Grade**								
	50/70	70/100	100/150	160/220	RAP Residue Bitumen	50/70	70/100	100/150	160/220
Penetration. (25°C) 0.1mm	53.6	85.2	102.1	172	32.4	50-70	70-100	100-150	160-220
Softening Point. °C	49.4	46.8	43.2	37.1	60.6	46-54	43-51	39-47	35-43
Specific Gravity(g/cm^3)	1.036	1.033	1.024	1.021	1.06	1.01-1.06	1.01-1.06	1.01-1.06	1.01-1.06

For the materials recycled in practice; depending on the depth of scraping and the construction purpose of the road during the first construction, different gradations are encountered. To represent these different situations, Table 1 shows 5 different types of gradations. Black values in the table are 100% RAP material and red values are created with Type A gradation + new aggregate. In order to ensure the homogeneous distribution of foam bitumen in the mixture, fine material substitution has been made in general. Type E gradation was created using 10% RAP and 90% virgin material for the representation of material scraping from a Bituminous Surface Treatment. Type D gradation, commonly used Wirtgen proposed, is similar to the Type A gradation, but material passing through 0.425 mm is more. This difference between the two gradations is important only to see the effect of fine material increase on ITS value.

For experimental studies, penetration bitumen in 50/70-70/100-100/150-160/220 grades were used and to produce bitumen foaming and mixes, and the foam bitumen laboratory plant (WLB 10S and WLM 30) developed by Wirtgen was used.

For productions; optimum bitumen percentage control was made with ITS and TSR parameters from the series produced for each gradation type. For Type A gradation, mixtures in all bitumen grades were prepared in 5 different bitumen percentages (1.9-2.2-2.5-2.8 and 3.1).

If the bitumen percentage is high, the bitumen forms lumps of bitumen, as stated by Thompson et.al, (2009), instead of uniformly dispersing or coating the coarse aggregate (Figure 1- areas within the red square). The structure seen in the other parts in Figure 1 (Erten, 2020), as stated in Jones et al. (2008), corresponds to the more homogeneous bitumen distribution definition.

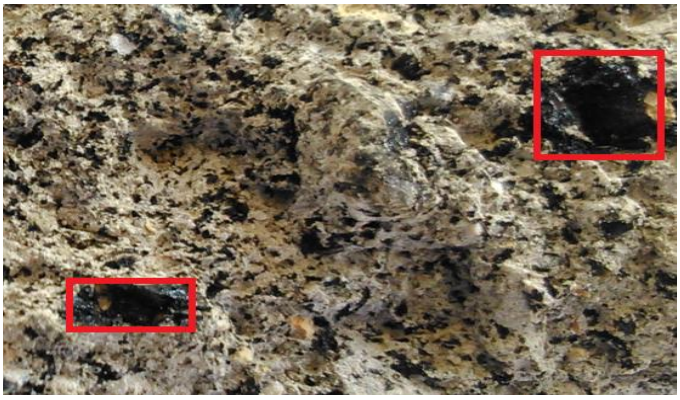

Figure 1. Different distribution regions of bitumen in the briquette internal structure

Because of, especially Cement is often used as active filler in foamed bituminous mixtures (Asphalt Academy, 2009; Jain and Singh, 2021; Fadmoro et al., 2022) only portland cement was used as the active filler all percentages. For 70/100 bitumen grade, lime and fly ash mixtures were also prepared for 2.5% bitumen. Active filler ratio was chosen as 1% to prevent shrinkage cracking (Asphalt Academy, 2009).

Indirect Tensile Strength

Marshall briquettes of 4 inches in diameter were prepared. The briquettes were removed from the molds on the next day of production and left to stand in a drying oven at 40°C for 72 hours. At the end of this period, 3 of the briquettes were broken to find ITS_{DRY} value. 3 briquettes were additionally kept in a 25°C water bath for 24 hours for ITS_{WET} value.

ITS and TSR values were calculated with the help of equality (2.1) and (2.2) (Wirtgen, 2012).

$$ITS = \frac{10^6 * 2 * P}{\pi * h * d} \quad (2.1)$$

Where; P: Maximum load (kN), h: Briquette height (mm), d: Briquette diameter (mm)

$$TSR = \frac{ITSWET}{ITSDRY} * 100 \quad (2.2)$$

Samples were prepared for the resilient modulus at the optimum bitumen values. If there is more than one bitumen percentage that provides the limit values (ITS_{DRY} > 225 kPa and ITS_{WET} > 100 kPa), lower bitumen percentage is preferred in order to increase the benefit of recycling.

Resilient Modulus

AASHTO T 307-99 (2012) procedure was used to determine the resilient modulus of samples prepared with a vibrating compaction hammer at a optimum water content of 152 mm diameter and 315 mm height. According to the procedure; The test is carried out in a triaxial chamber with half sine wave loading with 0.1 s loading and 0.9 s resting. 995 pre-conditioning loads are performed and the following 5 loads have an average resilient modulus, then the same process is repeated for every 100 loads.

Resilient modulus values of productions are calculated with equation (2.3) (Witczak, 2003) in each sequence. Then, using the confining stress and deviatoric stress applied to the sample in each sequence, the bulk stresses are calculated according to the equation (2.4) and the k-Θ model is calculated (equation 2.5)

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad (2.3)$$

Where; M_R : Resilient modulus, σ_d : Deviatoric stress, ε_r : Resilient strain (axial)

$$\Theta = \sigma_1+\sigma_2+\sigma_3 = \sigma_1+2\sigma_3 = 3\sigma_3+\sigma_d \quad (2.4)$$

$$M_R = K_1.(\Theta)^{K2} \quad (2.5)$$

Where; Θ (bulk stress), in which K_1 and K_2 are experimentally derived constants (Huang, 2003). By using Equation (2.6) (AASHTO, 1993; Schwartz and Khosravifar, 2013) layer coefficients of FBSM productions were determined. Where; E_{BS}, resilient modulus value in psi.

$$a = 0{,}249x\log E_{BS}-0{,}977 \quad (2.6)$$

RESULT AND DISCUSSION

Numerical values of ITS and resilient modulus for optimum bitumen percentages of production series are presented in Table 3 (Erten, 2020).

Table 3. Test results for productions

Specimen Code	Mean ITS$_{DRY}$ (kPa)	Mean ITS$_{WET}$ (kPa)	TSR %	MR (MPa)	Layer Coefficient (a)
2.5A70C1	244.26	243.52	99.696	399.266	0.21
2.2A50C1	270.2	256.38	94.885	539.735	0.24
1.9A100C1	264.82	214.04	80.826	403.582	0.21
1.9A160C1	251.05	232.64	92.668	334.901	0.19
2.2B70C1	264.55	224.88	85.004	197.908	0.13
1.9C70C1	272.97	257.42	94.303	150.538	0.10
1.9D70C1	253.46	223.5	88.181	440.875	0.22
1.9E70C1	345.66	282.16	81.629	209.411	0.14
2.5A70HL1FA1	197.34	258.51	131.001	351.439	0.20
2.5A70HL1	135.28	189.62	140.164		
2.5A70FA1	119.9	113	94.25		

As the ITS values are very low in productions where hydrated lime (HL) and fly ash (FA) are used as active fillers, the resilient modulus test has not been performed in these productions.

Sample coding for productions:

A: Gradation Type

2.5: Bitumen Percentage

2.5A70C1

C: Active Filler Type (Cement)

Bitümen Grade (70/100)

1: Active Filler Percentage

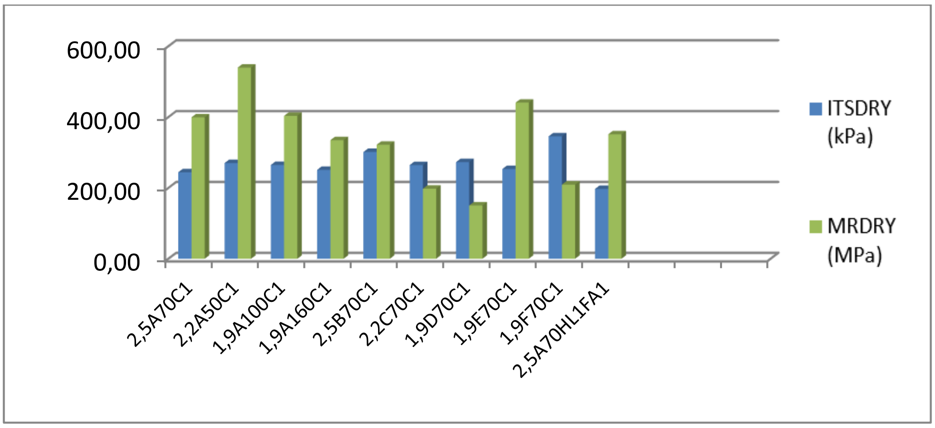

Figure 2. Comparison of MR and ITS values for productions

As can be seen from Table 3 and Figure 2 (Erten, 2020);

In some productions, the TSR value has reached close to or above 100%. These results, which are higher than the TSR values recommended in Chapter 1, can be explained because the water cure accelerates the hydration process.

Regardless of the bitumen grade and percentage, cemented productions performed better in terms of both ITS and MR compared to other active fillers.

While the ITS values of 160 penetration production for Type A gradation were similar to other bitumen grades, the lower resilient modulus value indicates that the decrease in bitumen viscosity negatively affects the material stability. Due to the fact that bitumen is more viscous than other bitumen grades in production with 50/70 grade bitumen, the deformation resistance of the samples has increased.

Using more fines of the No.4 sieve material in the mixture increased the ITS value slightly, but caused a decrease in the resilient modulus and consequently on the coefficient layer.

In Type E gradation, it is seen that the 90% of the material is formed with the new aggregate and also affects the resilient modulus negatively. This situation, although the old bitumen in RAP material is aging, can add flexibility to the mixture and Yan et al. (2014) as stated in, the aged bitumen in RAP material shows that there is still some active. Similarly Alam et al. (2010) and Hasan et al. (2018) stated that as the RAP content in the base course materials increases, the value of the resilient modulus will increase.

Although there is no cement in the production with 2,5A70HL1FA1 code and the ITS_{DRY} value is lower than the cemented productions, the resilient modulus value has been high. This result reveals that the combination of different active filler gives positive results in terms of stability of the mixture.

Increasing the percentage of fine material performed well only in terms of moisture damage (ITS). When considered in terms of resilient modulus, the opposite situation was encountered. For this reason, which is the opposite of the requirement of at least 5% of the No.200 sieve percentage that is generally encountered in the literatüre, An ideal gradation range is proposed in Table 4 (Erten, 2020) according to the resilient modulus values.

Table 4. Material gradation recommended for FBSM according to experimental results

Sieve Size (mm)	Passing (%)
37,5	100
25	98-100
19	90-97
12,5	78-89
9,5	70-81
4,75	50-60
2	28-36
0,425	8-16
0,18	4-10
0,075	1-6

The gradation recommended for FBSM was compared with the PMBC (Plant mix Base Course) and BBC (Bituminous Base Course) gradations given in Turkey highway technical specifications (2013), Figure 3 (Erten, 2020).

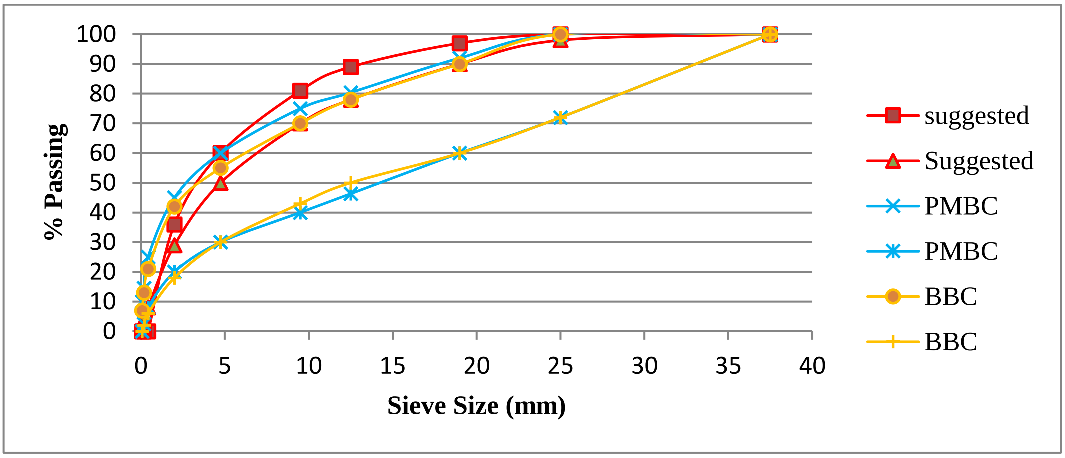

Figure 3. Comparison of gradation recommended for FBSM with PMBC and BBC gradations

This gradation also has some practical advantages. It is among these advantages that FBSM has a fine gradation, due to breaking the scraping material during the recycle process of existing pavements and RAP material has binder and wearing course materials. In addition, it will be easy to apply the fine material deficit, which is likely to be encountered only under No.40 sieve, and to be complemented with a new aggregate from outside.

CONCLUSIONS AND RECOMMANDATIONS

In the study; variables such as gradation, bitumen grades and percentage, active filler type that affect the Indirect Tensile Strength (ITS) and Resilient Modulus (MR) parameters for foam bitumen stabilized materials (FBSM), were investigated experimentally. The conclusions reached are summarized below:

- ITS results quite high when cement used as an active filler in production and it is considered appropriate to use cement for the application.
- In the light of the results obtained, minimum limit values of 225 kPa for ITS_{DRY} value, 150 kPa for ITS_{WET} value and 70% for TSR value are considered appropriate.
- For 160/220 bitumen grade, resilient modulus value were lower than other bitumen grades. For this reason, other bitumen grades have been found more suitable for FBSM production.
- Layer coefficient results given in Table 3, give the impression of a stabilized granular layer rather than bituminous mixtures for FBSM.
- If the ITS_{DRY} value exceeds 500 kPa, it is an indicator of asphaltic behavior (Wirtgen, 2012) and in the study, any production could not reach 500 kPa ITS_{DRY} value.
- Material gradation had a great effect on the resilient modulus results rather than ITS values. It has been observed that more fines of the over parts of No.4 sieve and the coarse of the under part of No.4 sieve are positive in terms of resilient modulus results.
- According to the results, the pavement section in Figure 4 (Erten, 2020) seems to be applicable for the FBSM, according to the traffic load to be encountered in the application area. However, the risk of shrinkage cracks should be controlled for these materials with hydraulic binders.

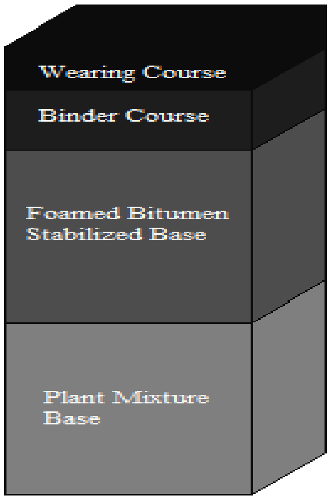

Figure 4. Recommended pavement cross section for cold in-place recycling with foam bitumen

- As a result of the production in which fly ash and lime were used together, the results was found close to cement. Therefore, the expansion of such combinations is recommended for future studies. But, it is not recommended to use active fillers other than cement alone.
- It is recommended that it will be sufficient to perform ITS control for 1.8% - 2% and 2.2% bitumen percentages.
- According to the results, 400 MPa MR and 0.21 layer coefficient values are recommended.
- In order to keep the resilient modulus and layer coefficient above the recommended limit values, the values given in Table 4 for FBSM are considered as the ideal gradation.

With this study, FBSM has been evaluated technically and it has been concluded that it will be an effective method that will contribute to sustainable transportation.

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