Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi

Afyon Kocatepe University Journal of Science and Engineering

AKÜ FEMÜBİD **22** (2022) 065601 (1388-1399) AKU J. Sci. Eng. **22** (2022) 065601 (1388-1399)

DOI: 10.35414/akufemubid.1072221

Araştırma Makalesi / Research Article

Investigation of Cold Recycling of Bituminous Surface Treatment with Foam Bitumen

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Geliş Tarihi: 14 Şubat 2022 Kabul Tarihi: 22.11.2022

Anahtar kelimeler
Bituminous surface treatment; Foam bitumen; Indrect tensile strenght; Unconfined compressive strenght; Resilient Modulus.

Abstract

The course of turned of bituminous pavement layers into hot mix asphalt (HMA) layers has been increasing day by day all over the world. Bituminous surface treatment that contains consirable amount of aggregate and bitumen, is an important source of recycling that offers a great amount of pavement materials intead of virgin material usage on pavement consruction.In the study, it was aimed to investigate the usability of bituminous surface layer treatment in the base layers of the HMA roads by mixing with foam bitumen and active filler materials in order to eliminate the potential performance degradation that will be encountered when it is recycled due to the low bitumen percentage compared to hot mix asphalt and the wear of the aggregate due to climatic conditions and traffic loads over time. The study conducted that intends to technically evaluate the cold recycling of bituminous surface treatment of roads with foam bitumen and active filler materials; for 70/100 bitumen grade, 5 different bitumen mixes were prepared and ideal bitumen percentage was investigated for this bitumen grade. The effect of bitumen percentage on mixture performance was evaluated with 50/70-100/150-160/220 bitumen grades and mixtures were prepared in single bitumen ratio (2.5%). It was investigated that active fillers will give suitable results for foam bituminous mixtures by preparing mixtures for three different active fillers; cement, hydrated lime and fly ash. To evaluate all these productions, ITS, unconfined compressive strenght, triaxial resilient modulus and asphalt permanent deformation tests were performed. The results obtained showed that production made using 2% foam bitumen and 1% was found suitable for moisture sensitivity and structural stability. Recycling of bituminous surface treatment using foam bitumen and cement is an environmentally and economically beneficial method by reducing both waste and raw material consumption.

Sathi Kaplamalı Yolların Köpük Bitümle Soğuk Geri Kazanımının Araştırılması

Keywords
Sathi kaplama; Köpük bitüm; Dolaylı çekme dayanımı; Serbest basınç dayanımı; Esneklik Modülü.

Öz

Tüm dünyada sathi kaplamalı yolların BSK (bitümlü sıcak karışım) yollara dönüştürülme trendi günden güne artmaktadır. Ömrünü tamamlamış sathi kaplamalar barındırdığı agrega ve bitüm nedeniyle geri dönüşüm için önemli bir kaynaktır. Çalışmada, sathi kaplamaların bitümlü sıcak karışımlara göre düşük bitüm yüzdesiyle üretilmesi ve içerisinde ki agreganın zaman içerisinde iklimsel şartlar ve trafik yükleri nedeniyle yıpranması nedeniyle geri kazanıldığında karşılaşılacak muhtemel performans düşüklüğünün giderilmesi için köpük bitüm ve aktif filler ürünlerle karıştırılarak, BSK yolların temel tabakalarında kullanılabilirliği araştırılmaya çalışılmıştır. Geri kazanılmış sathi kaplamaların köpük bitüm ve aktif filler malzemelerle soğuk geri kazanımını teknik açıdan değerlendirebilmek için yapılan bu çalışmada; 70/100 bitüm sınıfı için 5 farklı bitüm yüzdesinde karışımlar hazırlanmış ve bu bitüm sınıfı için ideal bitüm yüzdesi araştırılmıştır. 50/70-100/150-160/220 bitüm sınıfları ile tek bitüm yüzdesinde (2.5%) hazırlanan karışımlarla da bitüm sınıfının karışım performansına etkisi değerlendirilmiştir. Çimento, sönmüş kireç ve uçucu kül olmak üzere üç farklı aktif filler için karışımlar hazırlanarak hangi aktif fillerin köpük bitümlü karışımlar için uygun sonuç vereceği araştırılmıştır. Tüm bu üretimleri değerlendirebilmek amacıyla dolaylı çekme modülü, serbest basınç dayanımı, üç eksenli esneklik modülü, asfalt kalıcı deformasyon testleri gerçekleştirilmiştir.

Elde edilen sonuçlar göstermiştir ki 2% civarında köpük bitüm ve 1% çimento kullanılarak yapılan üretim nem hassasiyeti açısından ve yapısal stabilite açısından uygun olduğunu göstermiştir. Sathi kaplamaların köpük bitüm ve çimento kullanılarak geri kazanılması, hem atık hem de hammadde tüketiminin azaltılması ile çevresel ve ekonomik olarak fayda sağlayacak bir yöntemdir.

1. Introduction

Due to rapidly developing industry and the expectation of more comfort and more load carrying capacity from the road, the roads with Bituminous Surface treatment, which are old type flexible pavements (seal coat), turn into hot mix asphalt (HMA) roads. In the meantime, recycling of Bituminous Surface treatment on roads has been made mandatory aplications of pavement mix design considering the storage of scraped old pavement material, the need for reconstruction, and the environmental impacts during hot mix preparation.

Asphalt industry that could make a great contribution to asphalt production, paving and sustainable transportation in many different applications (Int Kyn 1, Almeida *et al*. 2016, Zaumanis *et al*. 2016). The greatest contribution to sustainability by reducing the environmental impact of the asphalt industry will undoubtedly be achieved by recycling old asphalt pavements. In addition, it is possible to use this recycled material in all pavement layers from subbase to wearing course, even in different proportions (Int Kyn 2, Hasan *et al.* 2022). Among the different pavement recycling methods, cold recycling undoubtedly stands out due to its environmental advantages (Turk *et al*. 2016, Woszuk 2017). The in situ and cold recycling method is a very important gains achieved in terms of energy consumption (Turk *et al*. 2016, Dong *et al*. 2017).

In the foam bitumen method (Muthen 2018, Kumrawat and Deulkar 2019), in which the surface area of the bitumen is increased helps to prepare the cold mixes more homogeneously and the bitumen is foamed by injecting a small amount of water and air into an expansion chamber (Jenkins 2000, Pitawala *et al*. 2022).

The foam bituminous mixtures in which bitumen is foamed and added to the mixture are slightly different from the hot mixtures in terms of the microstructure and bituminous role in the mixture (Jenkins 2000) and consist of large aggregates partially coated with mastic droplets (Jenkins 2000, Fu *et al*. 2009). Foam bitumen is generally dispersed into fine particles in the mixture (Iwanski and Kowalska 2013). Therefore, these materials are not sensitive to temperature (Asphalt Academy 2009, Saleh and Gaspar 2021), they are sensitive to moisture due to their high void contents (Fu *et al*. 2009) for homogeneous dispersion of the foamed bitumen into the mixture.

Another product that affects the performance of foam bituminous mixtures are materials that are characterized as active fillers (Fadmoro *et al*. 2022). These products increase the density of the mixture (Wirtgen 2012), helping to increase strength (Brown and Needham 2000, Wirtgen 2012, Dolzycki *et al*. 2017, Graziani *et al*. 2018, Erten *et al*. 2020, Iwanski *et al*. 2022, Pitawala *et al*. 2022).

In addition, active fillers help homogeneous distribution of bitumen in the mixture of materials (Wirtgen 2012).

In foam bituminous mixtures, like other cold mixtures, heating is not used for workability (Mondal and Kuna, 2022); water is used instead (Graziani *et al*. 2016). The excessive use of mixing water and preserving the material after compression results in cohesion deficiency (Valentova *et al*. 2016) and loss of strength (Fu *et al*. 2010).

The development of the physical structure over time in cold mixtures is called curing. The curing event helps to develop expected strength properties (Cardone *et al*. 2014, Graziani *et al*. 2016, Graziani *et al*. 2018) (Figure 1).

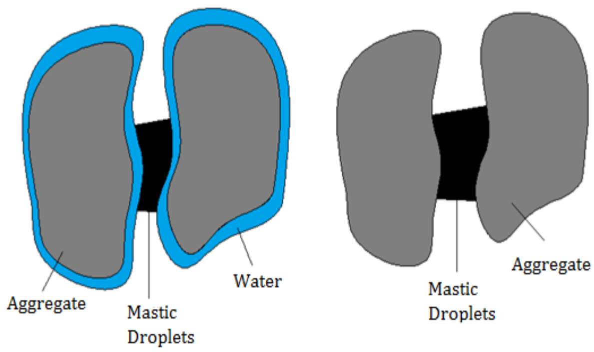

Figure 1. Foam bituminous cold mixture curing process

In order to evaluate the moisture sensitivity of foam bituminous mixtures with high void content (Fu *et al*. 2009, Iwanski and Kowalska 2013), ITSDRY (Dry Indirect Tensile Strenght) before conditioning and ITSWET (Wet Indirect Tensile Strenght) after conditioning (Wirtgen 2012, Arguelles *et al*. 2015, Diab and Enieb 2018) were used. ITSWET value of at least 100 kPa and ITSDRY value of at least 225 kPa are recommended by Wirtgen (2012). These limit values are used for optimum bitumen percentages.

The purpose of the design of foam bituminous mixtures is to optimize the mix strength properties under the worst (wetted) conditions (Muthen 1998). Khosravifar (2012) stated that most moisture-sensitive bonds disappear under wet conditions, so the performance of foam bituminous mixtures will be better understood in wetted condition.

Structural layer coefficient of the pavement layer to be formed with FBSM is estimated using the Resillience modulus value defined as the resistance of the pavement materials to flexible deformation under applied loads (Tia and Wood 1983, Fu *et al*. 2009, Schwartz and Khosravifar 2013, Romanoschi *et al*. 2013). For resilient modulus detection, in the dynamic triaxial experiment, the load is applied to the sample with a loading time of 0.1s and a rest time of 0.9s, to represent the actual wheel load (Huang 2003, AASHTO 2012).

Irreversible small deformations occurring in the material due to the applied dynamic loads cause permanent deformation over time (Sunarjono 2008). Especially in foam bituminous mixtures with a bitumen content of more than 3%, bitumen reduces the friction angle by making a lubricating effect between aggregates. The resulting permanent deformation (Wirtgen 2012, Khosravifar *et al*. 2015) is considered as main deterioration mechanism for FBSM (Asphalt Academy 2009).

According to Khosla (Khosla *et al*. 2012), the binder in RAP material is expected to increase the rutting performance of the mixture since it is aging and hard.

The active filler used in foam bituminous mixtures is used as another evaluation criterion because of the rigidity that the materials add to the mixture (Shao-Peng *et al*. 2006, Wirtgen 2012, Erten 2020).

The resilient modulus, defined as the slope of the stress-strain curve in the linear elastic region, determined during the UCS experiment (Patel *et al*. 2008), is a measure of the rigidity of the materials (Int Kyn 3).

While the experimental studies were carried out in accordance with the material percentages frequently used in the literature for foamed bituminous mixtures, it was investigated whether the reclaimed asphalt obtained from the surface treatment of roads is suitable for use in the pavement layers. The experimental methods used to evaluate the performance of foamed bituminous mixtures have been investigated how the percentage of foamed bitumen used in the mixture and the percentage of active filler affect on the structural performance of the mixture. In addition, it has been observed how important properties such as compactibility/workability and curing for foamed bituminous mixtures are affected by variables such as material used and time.

2. Materials and Method

The gradation of the material taken from a 15 cm scraping depth from a double bituminous surface treatment road is given in Table 1. This gradation has been called Type A and has been studied with this type of gradation in all productions. The percentage of bitumen in the material was determined as 3.18%. The effects of RAP (reclaimed asphalt pavement) materials with different bitumen percentage on production were investigated by producing a recycled HMA material with 4.17% bitumen percentage for the same gradation in only one production (2.5A100C1-B).

Table 1. Material gradation used in the study

Sieve Size		Gradation
mm	inch-no	
37,5	1 ½	100,0
25	1	96,0
19	¾	90,5
12,5	½	78,9
9,5	3/8	70,6
4,75	No.4	61,1
2	No.10	37,2
0,425	No.40	5,1
0,18	No.80	1,4
0,075	No.20	0,4

In the mixtures made using different materials or different ratios of the same materials, the effect of the materials on the compactibility of the mixture was tried to be determined by volume specific gravity and produced briquettes heights.

Although generally, cement is used as active filler in the productions, the effect of the active filler type was investigated in productions using hydrated lime (HL) and fly ash (FA). Similarly, mostly 70/100 bitumen grades were produced, and in order to see the effect of bitumen grade on productions, productions were made using 50/70-100/150-160/220 grade bitumen.

For the 70/100 bitumen grade, the production of 1.9-2.2-2.5-2.8-3.1 bitumen percentages was made and the effects of the bitumen percentage change were observed. For other bitumen grades, 2.5% was used as a percentage of bitumen.

In case of using the old pavement as recycled materials, as stated by Yan *et al.* (2014); the presence of aged bitumen in RAP material can reduce the stress-strain concentration in the aggregate and bitumen interface phase. Thus, it also helps to reduce the bitumen need in the mix.

In addition, CBR values of mixtures produced for all active filler types were determined and evaluated. The aim of the wet CBR experiment applied in the study is to determine the lowest bearing capacity where the voids are completely filled with water (General Directorate of Highways, 2003).

ITSDRY, ITSWET, volume specific gravity, briquette height, unconfined compressive strength, elastic modulus, resilient modulus and asphalt permanent deformation parameters were used as the evaluation criteria of productions. Especially since the ITS evaluation determines the optimum amount of bitumen, is the priority criterion for foam bituminous mixtures. In the evaluation, the bitumen percentage that meets the ITS limit values given in the first chapter is accepted as appropriate, but in case there is more than one bitumen percentage that meets these conditions, it is appropriate to make a choice considering the layer coefficient and economy. In the study, the procedure recommended by Wirtgen (2002) was used for the production of foam bituminous mix. As seen in Figure 2, sample coding was determined.

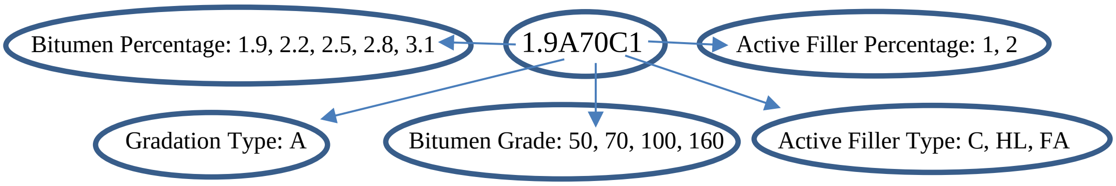

Figure 2. Sample codings related to production

2.1. Indirect Tensile Strenght

Primarily, the ideal foaming values for the bitumen grades used in the study were determined by the Wirtgen (2002) procedure, for the determination of the ITSDRY and ITSWET values of the productions. (Table 2).

Table 2. Optimum foaming temperature and optimum foaming water values determined for each bitumen

Bitumen Penetration Grade	Optimum Foamed Temp.(°C)	Optimum Water Percent (%)
50/70	170	3
70/100	170	2
100/150	170	2
160/220	160	2

The optimum amount of compaction water required for the productions was determined with the help of the modified proctor test (ASTM D1557).

9 standard Marshall briquettes (4 inch diameter) were prepared for each production. The briquettes removed from the molds after 24 hours were kept in a drying oven at 40°C for 72 hours. Necessary measurements of briquettes whose drying process was completed were taken and ITSDRY values were determined by breaking 3 briquettes for each production. After the other 6 briquettes were kept in a 25°C water bath for 24 hours, the volume specific gravity of the mixtures were determined with the help of Equation (1). ITS values are determined by Equation (2).

$$Dp = \frac{Sample\ weight\ (in\ air)}{SSSDW-SWIW} \quad (1)$$

Where;
Dp: volume specific gravity
SSSDW: sample saturated surface dry weight
SWIW: sample weight in water.

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

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

2.2. Resilient Modulus

152mm diameter and 315mm height samples were prepared with a vibrating compaction hammer. Samples were kept in a drying oven at 60°C for 24 hours and then broken. In the test carried out with the AASHTO T 307-99 method, the haversine was loaded with the help of a triaxial cell for 0.1 s loading and 0.9s rest periods. According to the method; first, 1.000 conditioning loads are made, followed by 1.500 loads. At this stage, the resilient modulus value is determined for every 100 loads (95 preload +5 resilient modulus loading) (Figure 3).

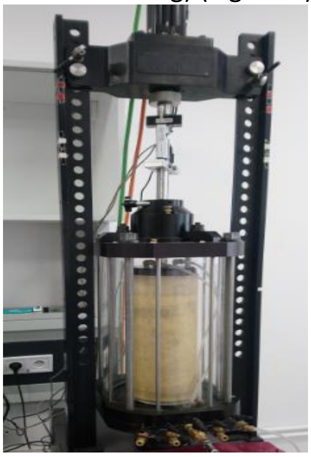

Figure 3. Resilient modulus test

Resilient modulus values for each 100 loads (sequence) are calculated by the formula (3). The confining stress and deviatoric stress values applied to the sample in each sequence and the bulk stresses according to the formula (4) are calculated. According to the relationship between the mean resilient modulus results of all sequences and the bulk stress, the k-Θ model of each production is produced. Resilient modulus is calculated with the help of the model.

$$M_R = \frac{\sigma_d}{\varepsilon_r} \qquad (3)$$

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

$$\Theta = \sigma_1+\sigma_2+\sigma_3 = \sigma_1+2\sigma_3 = 3\sigma_3+\sigma_d \qquad (4)$$

$$M_R = K_1.(\Theta)^{K2} \qquad (5)$$

Where;
Θ (bulk stress), in which K_1 and K_2 are experimentally derived constants (Huang 2003).

Layer coefficients of FBSM productions were determined by using Equation (6) according to the calculated resilient modulus (Schwartz and Khosravifar 2003, AASHTO 1993).

$$a = 0.249x\log E_{BS}-0.977 \qquad (6)$$

Where;
E_{BS}, resilient modulus value in psi.

2.3. Unconfined Compressive Strenght Test

The test was carried out in accordance with ASTM 1074-09 standard. The samples used for the unconfined compressive strength test are the same as those used in the resilient modulus test. Since the resilient modulus test is a non-destructive test, the same samples were taken into the unconfined compressive strength test after the resilient modulus test. The test was carried out uniaxially and with a constant loading of 5.08 mm/min. Maximum deformation is limited to 5mm.

Figure 4. Unconfined compressive strength samples

The unconfined compressive strength is found with the following Equation:

$$UCS = \frac{10^4 * 4 * P}{\pi * d^2} \qquad (7)$$

Where;
UCS: Unconfined compressive strenght (kPa)

P: Maximum applied load (kN)
d: Diameter of sample (cm) (Asphalt Academy, 2009).

With the help of Equation (8), Elastic modulus value of the productions was obtained for the region where the stress-strain graph in which the material behaves in accordance with the Hook law is linear.

$$E = \frac{\sigma}{\varepsilon} \tag{8}$$

Where;
σ: maximum stress at elastic region
ε: maximum strain at elastic region

2.4. Triaxial cyclic compression test

Permanent deformation control for the 2.5A70C1 sample was made according to the TS EN 12697-25 standard. With the help of Gyratory compactor, 10cm diameter and 15cm height test samples were cut in 10cm diameter and 10cm height dimensions. The test was carried out in three axial at a temperature of 40°C (Figure 5). As in the resilient modulus test, samples were applied in the waveform of the heversine. The applied axial stress is 300 kPa and the environmental stress is 100kPa. Permanent strain value was obtained by loading 10000.

Figure 5. Triaxial cyclic compression test for foam bituminous mixture

3. Results and Discussion

According to the results obtained in the experimental studies, the graphs below were prepared and interpreted.

As seen in Figure 6, along with the increase in bitumen percentage, briquette height increased and volume specific gravity values also showed a decrease trend. The increase in the bitumen percentage is an indication that the material is getting harder to compaction. Because when foam bitumen is used above its optimum value, as stated in Erten (2020), instead of coating the course aggregate, it starts to clump together and the mixture becomes inhomogeneous, which affects compaction and material strength.

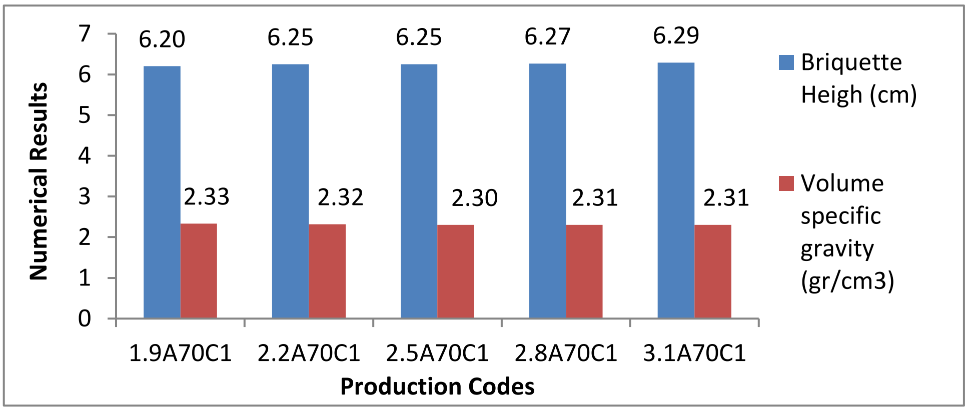

Figure 6. Comparison of briquette height and volume specific gravity values for different bitumen percentages

It was stated by Erten (2020) that the volume specific gravity of foam bituminous mixtures ranged from 2.10 to 2.20.

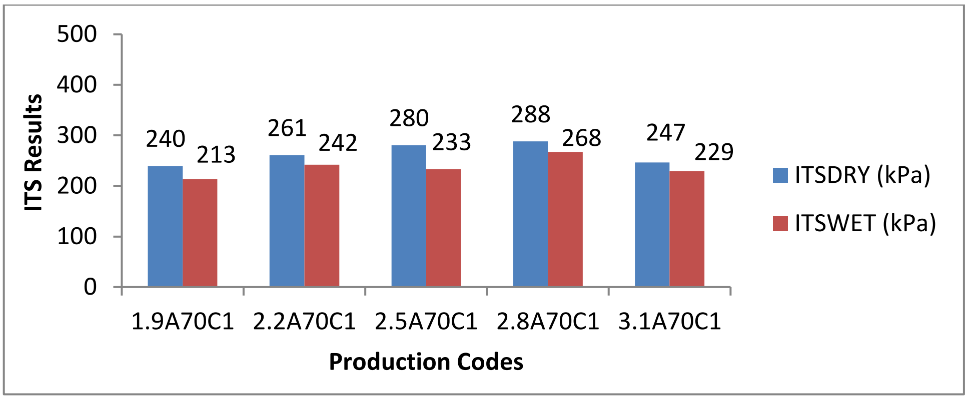

Figure 7. Comparison of ITSDRY and ITSWET values for different bitumen percentages

As seen in Figure 7, ITSDRY values for all bitumen percentages are higher than the limit values recommended in Section 1 (Introduction) and ITSWET results are quite high. This indicates that the moisture sensitivity of the mixtures is low.

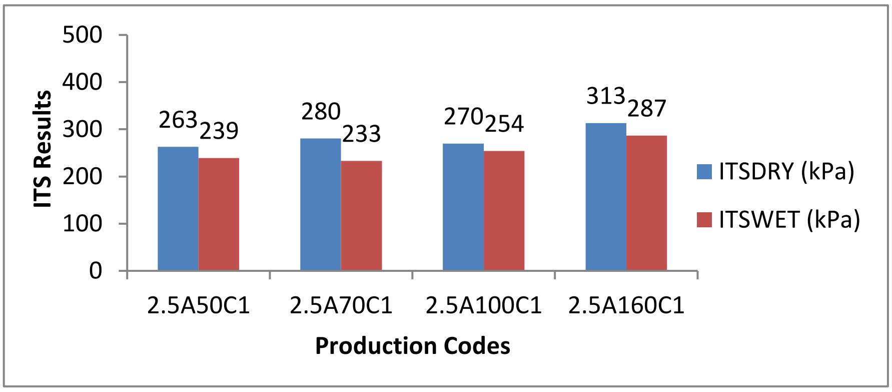

Figure 8. Comparison of ITSDRY and ITSWET values for different bitumen grades

As seen in Figure 8, the increase in bitumen penetration value show not a clear trend, but it had an increasing effect on ITSDRY and ITSWET values. ITS values for all bitumen grades exceeded the minimum criteria. Especially, the highest level of ITS values in 160/220 grade bitumen shows that soft bitumen is distributed more homogeneously in the mixture compared to viscous bitumen and affects the results.

The production of 2.5A100C1 was re-manufactured with recycled HMA material (2.5A100C1-B) using the same gradation, same cement and foam bitumen percentage, and it was tried to observe what kind of differences there might be between the recycled surface treatment and HMA.

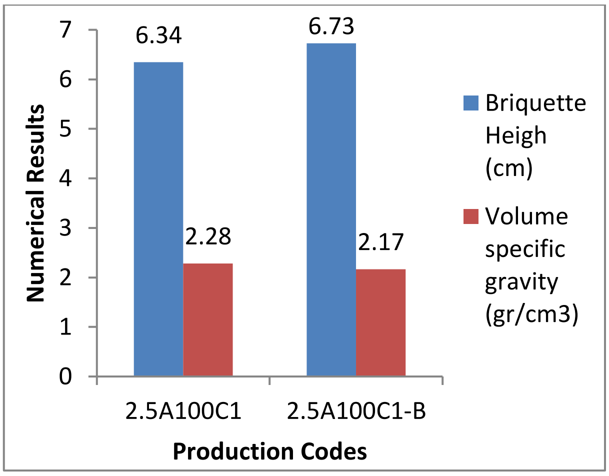

Figure 9. Comparison of briquette height and volume specific gravity values for different RAP materials

As can be seen from Figure 9, the recycled HMA material increased the briquette height and decreased the volume specific gravity value. This indicates that excessive bitumen-coated aggregate in the mixture negatively affects the compaction of the material. As seen in Figure 10, where the ITS values of the same productions are compared, the excess of the old bituminous aggregate decreased the ITSDRY value and increased the ITSWET value. The presence of old bitumen reduced the moisture sensitivity of the material.

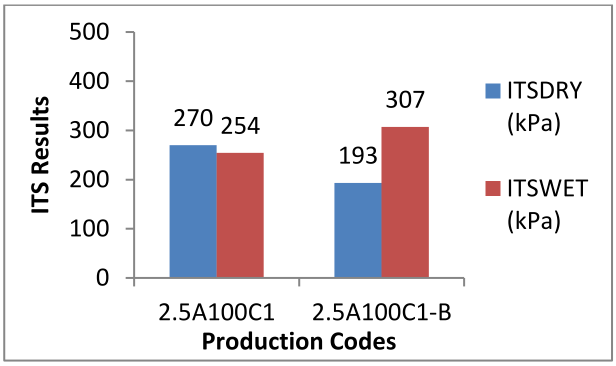

Figure 10. Comparison of ITSDRY and ITSWET values for different RAP materials

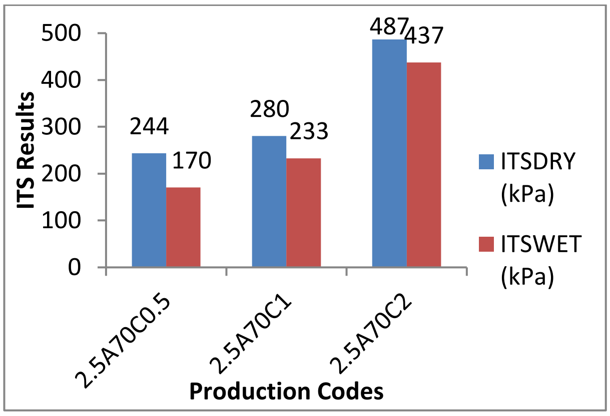

Figure 11. Comparison of ITSDRY and ITSWET values for different cement percentages

In Figure 11, where different cement percentages are compared, it is seen that the increase in cement percentage has a positive effect on both ITSDRY and ITSWET values. Similar studies are encountered in some studies in the literature (Wahhab *et al*. 2012). This situation, which is caused by the hydration effect that develops with the increase in cement percentage, increases the risk of shrinkage cracks in the material (Wirtgen 2012).

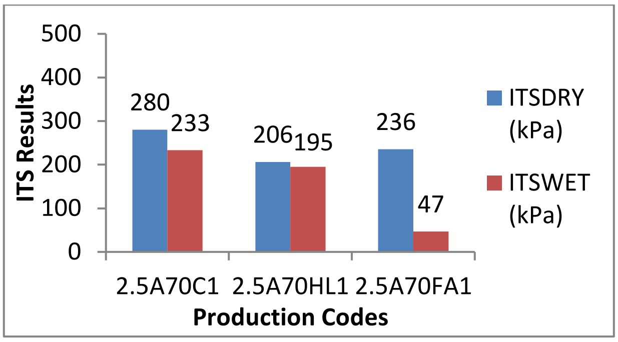

Figure 12. Comparison of ITSDRY and ITSWET values for different active fillers materials

In Figure 12, where different types of active fillers are compared, it is seen that cement is the active filler that has the most positive effect on ITS values. Hydrated lime reduced humidity sensitivity and increased ITSWET compared to fly ash. Hydrated lime is an important product that reduces moisture sensitivity (Zou *et al*. 2013).

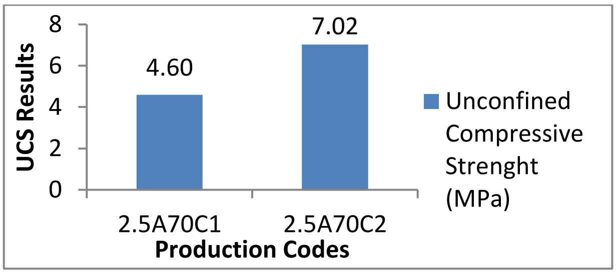

Figure 13. Comparison of unconfined compressive srength values for different cement percentages

In Figure 13, when the unconfined compressive strenght values of 1% and 2% cemented productions are compared, the increase in the percentage of cement reflected positively on the results. In the literature, Taha *et al*. (2002) and Cizkova *et al*. (2016) also mentioned the similar situation.

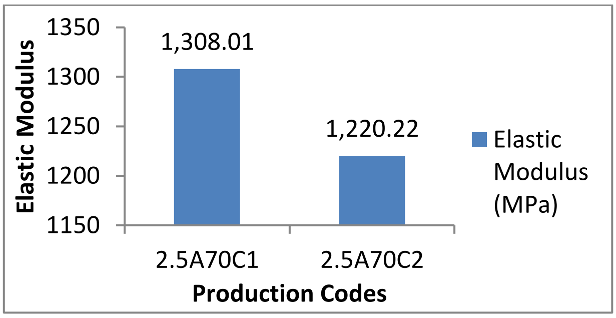

Figure 14. Comparison of elastic modulus values for different cement percentages

In Figure 14, for cement percentages %1 (2.5A70C1) and %2 (2.5A70C2), comparing the Elastic module for the among these productions, the increase in the percentage of cement in production caused a decrease in contrast to UCS results in Figure 13. It can be understood from this that while the increase in cement increases the strength in the dry sample, it indicates that the load carried in the elastic region decreases, that is, the majority of the load is carried after the elastic region.

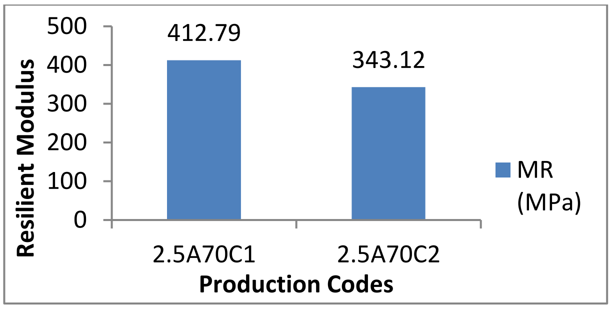

Figure 15. Comparison of resilient modulus values for different cement percentages

As with the elastic modulus value, a decrease in the percentage of cement is observed in the elastic modulus values of these productions.

Table 3. Change of CBR value according to active filler type and effect of extended curing time on ITSDRY value for different bitumen grade and active filler types

Production Code	CBR %	ITSDRY (kPa)	ITSDRY (kPa) (28 Days)
2.5A50C1		262.78	428.19
2.5A70C1	113.400	280.38	595.50
2.5A100C1		269.841	495.53
2.5A160C1		313.26	532.82
2.5A70HL1	69.200	206.39	530.56
2.5A70FA1	71.500	235.52	485.25

Table 3 shows the CBR test for some samples and the change of ITS value in the samples curing for 28 days. The ITSDRY value increased for all cured samples. This shows that active filler materials are very important for ITS. The CBR value of cemented production was quite high compared to HL and FA productions. With the calculation for Equation 6, a layer coefficient value of 0.21 was obtained for the production of 2.5A70C1 and 0.19 for the production of 2.5A70C2.
Although these values are somewhat higher than 0.18 (Romanoschi *et al*. 2003) encountered in the literature, they are lower than the values of 0.25-0.40 (Tia and Wood 1983), 0.28-0.35 (Wirtgen 2002), and 0.3-0.35 (Schwartz and Khosravifar 2003); production with 1% cement has been found to be very suitable for the base course of HMA roads in terms of structural and low risk of cracking.
Khosravifar *et al*. (2015) stated that a properly designed foam bitumen stabilized layer will be located between the granular aggregate base and hot mix asphalt, and Wirtgen (2002) can be used safely instead of bituminous base course.
As a result of asphalt permanent deformation test applied to 2.5A70C1 sample, permanent deformation value was obtained as 0.255 mm. The low level of this value indicates that the material shows a rigid behavior rather than a hot mixture.

4. Conclusions

The study that using recycled bituminous surface treatment material have been evaluated by the test methods such as ITS, unconfined compressive strength and triaxial resilient modulus tests have been performed for foam bituminous samples created with different variables such as bitumen grade, active filler material type and bitumen percentage of the results are summarized below.
It has been observed that increasing the bitumen percentage has a hardening effect on the compaction of foam bituminous mixtures.
ITSDRY and ITSWET values are suitable for all bitumen percentages. For this reason, choosing a low bitumen percentage in the application will not be a obstacle in terms of moisture sensitivity and will also be positive in terms of compaction.
Increasing bitumen penetration value increases ITS values.
In one production, instead of bituminous surface treatment material, recycled hot mix asphalt material was used in the same gradation. This change negatively affected the compaction of the material and decreased the volume specific gravity value. However, increasing the amount of old bitumen in the mixture decreased the moisture sensitivity of the mixture.
In production with cement, higher ITSDRY, ITSWET and CBR values were obtained compared to productions with hydrated lime and fly ash.
Curing the mixtures for a longer period increased the ITSDRY values.
Increasing the percentage of cement in the mixture increased ITSDRY, ITSWET and unconfined compressive srength values. However, elastic modulus and resilient modulus values decreased with increasing cement percentage.

As a result; the use of 1% cement as active filler for bituminous surface treatment materials stabilized with foam bitumen increases the performance of the mixtures. It is also appropriate to take the bitumen percentage around 2%. Although there is not much difference in mixtures for the bitumen grade, it is recommended to look at the results of the resilient modulus in the future studies as the bitumen grade evaluation for the recycled bituminous surface treatment is made only for the ITS test. Although it shows that the material behaves rigidly as a result of permanent deformation and it is recommended to investigate different production combinations.
In the light of the results obtained; the layer coefficient and ITS values of the foam bitumen stabilized bituminous surface treatment have been found suitable for the foam bituminous mixtures recommended in the literature and are considered technically feasible on the road. This application offers both economic and environmental advantages.

ACKNOWLEDGMENTS

This study was supported by SDU (Süleyman Demirel University) scientific research project 4939-D1-17 and KGM-ARGE/2017-1 KGM (General Directorate of highways) project.

5. References

AASHTO, 1993. Guide For Design Of Pavement Structures. American Association of State Highway and Transportation Officials, Washington DC.

AASHTO T 307-99, 2012. Determining the Resilient Modulus of Soils and Aggregate Materials. American Association of State Highway and Transportation Officials, Washington DC.

Almeida, M.D., Gomes, J.C., Sangiorgi, C., Zoorob, S.E., Afonso, M.L., 2016. Performance of Warm Mix Recycled Asphalt containing up to 100% RAP. *Construction and Building Materials*, **112**, 1–6.

Arguelles, G.M., Giustozzi, F., Crispino, M., Flintsch, G.W., 2015. Laboratory Investigation on Mechanical Performance of Cold Foamed Bitumen Mixes: Bitumen Source, Foaming Additive, Fiber-Reinforcement and Cement Effect. *Construction and Building Materials*, **93**, 241-248.

ARRA, 2001. Asphalt Recycling and Reclaiming Association Basic Manual, USA, 269p.

Asphalt Academy, 2009. Technical Guideline: Bitumen Stabilised Materials, TG2 Second edition, ISBN 978-0-7988-5582-2

Brown, S.F., Needham, D., 2000. A Study of Cement Modified Bitumen Emulsion Mixtures, *Asphalt Paving Technologists Proc*, **69**, 92–121.

Cardone F., Grilli A., Bocci, M., Graziani, A., 2014. Curing and Temperature Sensitivity of Cement–Bitumen Treated Materials, *International Journal of Pavement Engineering*, **16**(10), 868-880

Cizkova, Z., Sedina, J., Valentin, J., Engels, M., 2016. Laboratory Experience with the Application of Monotonic Triaxial Test on the Cold Recycled Asphalt Mixes. 6th Eurasphalt & Eurobitume Congress, 1-3 June, Prague, Czech Republic

Diab, A., Enieb, M., 2018. Investigating Influence of Mineral Filler at Asphalt Mixture and Mastic Scales.International *Journal of Pavement Research and Technology*, **11**, 213–224

Dolzycki, B., Jaczewski, M., Szydlowski, C., 2017. The Long-Term Properties of Mineral Cement-Emulsion Mixtures, *Construction and Building Materials,* **156**, 799–808.

Dong, F., Yu, X., Liang, X., Ding, G., Wei, J., 2017. Influence of Foaming Water and Aging Process on the Properties of Foamed Asphalt. *Construction and Building Materials*, **153**, 866–874.

Erten, K. M., 2020. Köpük Bitüm ile Yerinde ve Soğuk Geri Kazanılmış Bitümlü Sıcak Karışımların Karayolunda Kullanılabilirliği ve Performansının Araştırılması, Süleyman Demirel University, Ph.D. Thesis, Isparta, Turkey, 169p.

Erten, K.M., Terzi, S., Akbulut, H., 2020. Effect of Bitumen Grade, Bitumen Percentage and Mineral Binders on Mixture Properties in Foam

Bitumen Stabilized RAP Materials. *Innovations in Civil Engineering and Technology*, **2**(1), 1-11.

Fadmoro, O.F., Kar, S.S., Tiwari, D., 2022. Characterisation of Foam Bitumen Mixes with Diffrent RAP Content at Elevated Mixing Temperature Using Design of Experiment (DOE) Approach, *International Journal of Pavement Engineering*, DOI: 10.1080/10298436.2021.2020785

Fu, P., Jones, D., Harvey, J.T., Bukhari, S.A., 2009. Laboratory Test Methods for Foamed Asphalt Mix Resilient Modulus. *Road Materials and Pavement Design*, **10**(1), 188-212.

Fu, P., Jones, D., Harvey, J.T., Halles, F., 2010. An Investigation of the Curing Mechanism of Foamed Asphalt Mixes Based on Micromechanics Principles. *Journal of Materials in Civil Engineering*, **22**(1), 29-38

General Directorate of Highways, 2003. Toprak ve Stabilizasyon Laboratuvarı El Kitabı. Ankara, Turkey, pp. 77-114.

Graziani, A., Godenzoni, C., Cardone, F., Bocci, M., 2016. Effect of Curing on the Physical and Mechanical Properties of Cold-Recycled Bituminous Mixtures. *Materials & Design*, **95**, 358–369.

Graziani, A., Iafelice, C., Raschia, S., Perraton, D., Carter, A., 2018. A Procedure for Characterizing the Curing Process of Cold Recycled Bitumen Emulsion Mixtures. *Construction and Building Materials*, **173**, 754–762.

Hasan, A., Hasan, U., Whyte, A., Jassmi, H., A., 2022. Lifecycle Analysis of Recycled Asphalt Pavements: Case Study Scenario Analyses of an Urban Highway Section. *CivilEng*, **3**(2), 242-262.

Huang, Y.H., 2003. Pavement Analysis and Design 2nd Edition, Pearson Prentice Hall, United States of America, 775.

Iwanski, M., Kowalska, A.C., 2013. Laboratory Study on Mechanical Parameters of Foamed Bitumen Mixtures in the Cold Recycling Technology. *Procedia Engineering*, **57**, 433 – 442.

Iwanski, M., Mazurek, G., Buczynski, P., Iwanski, M., M., 2022. Effects of hydraulic binder composition on the rheological characteristics of recycled mixtures with foamed bitumen for full depth reclamation. *Construction and Building Materials,* **330**.

Jenkins, K.J., 2000. Mix Design Considerations for Cold and Half-cold Bituminous Mixes with Emphasis on Foamed Bitumen. Ph.D. Thesis. University of Stellenbosch, South Africa, **368**.

Khosla, N.P., Nair, H., Beth, V., Glen, M., 2012. Effect of Reclaimed Asphalt and Virgin Binder on Rheological Properties of Binder Blends. I*nternational Journal of Pavement Research and Technology*, **5**(5), 317–25.

Khosravifar, S., Schwartz, C.W., Goulias, D.G., 2015. Mechanistic Structural Properties of Foamed Asphalt Stabilised Base Materials. *International Journal of Pavement Engineering*, **16**(1), 27-38.

Khosravifar, S., Design and mechanical properties of foamed asphalt stabilized base material M. S. thesis, University of Maryland, Maryland, 2012.

Kumrawat, S., Deulkar, V., 2019. A Research on Foamed Bitumen. *International Research Journal of Engineering and Technology (IRJET)*, **6**(5) 6969-6974.

Mondal P., G., Kuna K., K., 2022. Mix design considerations for foamed bitumen stabilized materials: A review. *Construction and Building Materials*, **326**.

Muthen, K.M., 1998. Foamed Asphalt Mixes Mix Design Procedure. Report No: CR-98/077, 31p.

Patel, A., Kulkarni, M.P., Rao, K.V.K., Singh, D.N., Gumaste, S.D., 2008. A Methodology for Determination of Resilient Modulus of Asphaltic Concrete. The 12th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG), 1-6 October, Goa, India.

Pitawala, S., Sounthararajant, A., Bodin, D., Kodikara, J., 2022. Advanced characterisation of flexural fatigue performance of foamed bitumen stabilised pavement materials. *Construction and Building Materials*, **341**.

Romanoschi, S.A., Hossain, M., Heitzman, M., Gisi, A. J., 2003. Foamed Asphalt Stabilized Reclaimed Asphalt Pavement: A Promising Technology for Mid-Western Roads Mid-Continent Transportation Research Symposium, August, Ames, Iowa.

Saleh, A., Gaspar, L., 2021. Performance of Foamed Bitumen Bound Asphalt Mixtures Under Various Mixing and Compaction Temperatures. *World Wide Journal of Multidisciplinary Research and Development*, **7**(12), 15-21.

Schwartz, C.W., Khosravifar, S., 2013. Design and Evaluation of Foamed Asphalt Base Materials. Report no: SP909B4E, 86p.

Shao-peng, W., Gang, L., Lian-tong, M., Zheng, C., Qun-shan, Y., 2006. Effect of fiber types on relevant properties of porous asphalt. *Transactions of Nonferrous Metals Society of China*. Vol. **16**, pp. 791-795.

Sunarjono, S., 2008. The Influence of Foamed Bitumen Characteristics of Cold-Mix Asphalt Properties. The University of Nottingham, Nottingham Transportation Engineering Centre, School of Civil Engineering, Doctor of Philosophy, Nottingham, 311p.

Taha, R., Harthy, A.A., Shamsi, K.A. and Zubeidi, M.A., Cement stabilization of reclaimed asphalt pavement aggregate for road bases and subbases, *Journal of Materials in Civil Engineering*, **14**(3), pp. 239-245, 2002

Thompson, M.R., Garcia, L., Carpenter, S.H., 2009. Cold in Place Recycling and Full Depth Recycling with Asphalt Products (CIR&FDRWAP). Report no: FHWA-ICT-09-036, 28p.

Tia, M., Wood, L. E., 1983. Use of Asphalt Emulsion and Foamed Asphalt in Cold-Recycled Asphalt Paving Mixtures. *Transportation Research Record*, **898**, 315–321.

Turk, J., Pranjic, A.M., Mladenovic, A., Cotic, Z., Jurjavcic, P., 2016. Environmental Comparison of Two Alternative Road Pavement Rehabilitation Techniques: Cold-In-Place-Recycling Versus Traditional Reconstruction. *Journal of Cleaner Production*, **121**, 45-55.

Valentova, T., Altman, J., Valentin, J., 2016. Impact of Asphalt Ageing on the Activity of Adhesion Promoters and the Moisture Susceptibility. *Transportation Research Procedia*, **14**, 768-777.

Wahhab, H.A.A., Baig, M.G., Mahmoud I.A. and. Kattan, H.M., Study of road bases construction in Saudi Arabia using foam asphalt, *Construction and Building Materials*, **26**, pp. 113–121, 2012

Wirtgen, 2012. Cold Recycling – Wirtgen Cold Recycling Technology, Wirtgen Cold Recycling Manual, Germany, 368.

Woszuk, A., Zofka, A., Bandura, L., Franus, W., 2017. Effect of Zeolite Properties on Asphalt Foaming. *Construction and Building Materials*, **139**, 247–255.

Yan, J., Zhu, H., Zhang, Z., Gao, L., Charmot, S., 2014. The Theoretical Analysis of the RAP Aged Asphalt Influence on the Performance of Asphalt Emulsion Cold Recycled Mixes. *Construction and Building Materials*, **71**, 444–450.

Zaumanis, M., Mallick, R.B., Frank, R., 2016. 100% Hot Mix Asphalt Recycling: Challenges and Benefits. *Transportation Research Procedia*, **14**, 3493 – 3502.

Zou, J., Isola, M., Roque, R., Chun, S., Koh, C., Lopp, G., 2013. Effect of Hydrated Lime on Fracture Performance of Asphalt Mixture. *Construction and Building Materials*, **44**, 302–308.

İnternet kaynakları

1- https://eapa.org/wp-content/uploads/2018/07/EAPApaper_Asphalt_the-100-_recyclable_construction-product.pdf, (27.05.2020)

2- https://www.piarc.org/ressources/documents/actes-seminaires0102/c78-pologne02/9117,2.5-TC7-8-2002-Jacobson.pdf, (01.04.2020)

3- https://www.asphaltpavement.org/PDFs/mechdes3.pdf, (23.08.2020)