INTERNATIONAL SCIENTIFIC AND VOCATIONAL JOURNAL (ISVOS JOURNAL)

Vol.: 4 Issue: 1 Date: June 2020 Received: 22.05.2020 Accepted: 18.06.2020 Final Version: 29.06.2020

ISVOS Journal, 2020, 4(1): 60-67

Effect of Active Filler Ratio on Indirect Tensile Strenght of Foam Bituminous Mixtures

Kemal Muhammet Erten [a,1], Serdal Terzi [b], Hüseyin Akbulut [c]

[a] Dazkırı Vocational School, Construction Inspection Department, Afyon Kocatepe University, Afyonkarahisar, 03950, Turkey
ORCID ID: 0000-0001-5181-4109
[b] Faculty of Enginering, Civil Engineering Department, Süleyman Demirel University, Isparta, 32200, Turkey
ORCID ID: 0000-0002-4776-824X
[c] Faculty of Enginering, Civil Engineering Department, Afyon Kocatepe University, Afyonkarahisar, 03200, Turkey
ORCID ID: 0000-0003-4504-4384

Abstract

Highway pavement consruction has been one of the most important raw material comsuming area in the construction industry, which has been cousing huge amount of environmental demages and rapid diminish of raw material resources. In order to increase the usage rates of cold recycled pavement materials in road construction works, mixing with bitumen and hydraulic binders have often been used for some time in the pavement construction. These additional materials are; with the contribution they make to the performance of the cold mixes, they increase the usage rates of the recycled materials, thereby enabling the increase of environmental and economic advantages. In this study conducted to investigate the effects of foam bitumen and three different types of active filler material (cement, hydrated lime, fly ash) on cold recycled mixtures. Productions were made for different bitumen percentages with 70 / 100-100 / 150-160 / 220 grade penetration bitumens. Different percentages of active filler materials were used in the productions. Thus, the roles of variables such as bitumen grade, bitumen percentage, active filler type and percentage were evaluated in the mixture. As evaluation criteria, ITS_{DRY} (dry indirect tensile strenght), ITS_{WET} (wet indirect tensile strenght), TSR (tensile strenght retain) and flow parameters were used. Data obtained as a result of the experimental study; the use of cement from active filler products and increasing the percentage of cement in the mixture, using bitumen with high penetration as a bitumen and reducing the percentage in the mixture showed that the mixtures had a positive effect on ITS values. However, the decrease in the bitumen percentage and the increase in the cement percentage have reduced the flow values of the material.

Keywords: “Active filler, indirect tensile strenght, foam bitumen”

1. Introduction

Due to the increasing demand for, roads and comfort expected from the roads, the road construction and the consumption of raw materials need to be used increase accordingly.

Because of use of sustainable material resources and environmental factors affecting road construction, asphalt recycling technology has been developed for road rehabilitation and construction in western countries for the last 20 years due to the advantages of less raw material and fossil fuel consumption, lower carbon footprint and increasing pavement performance [1].

Different stabilizer products are used to increase the performance of cold recycled materials, especially with their high environmental gains. The main ones are active filler materials and foam bitumen, which are widely used today.

These materials are used together in recycled asphalt to improve the mechanical properties of the mixture by closing the deficiencies caused by high void content [2, 3].

Active filler materials such as portland cement, hydrated lime and fly ash, which are frequently encountered in the literature, used to improve the mechanical properties of cold recycled mixtures. When it is considered for short term, it provides the road to be opened to traffic early, and in the long run, they increase the hardness and strength of the cold recycled material [4, 5, 6]. If active fillers are used together with bitumen; increases the adhesion of bitumen, increases the strength by increasing the tightness of the mixture, decreases the aggregate plasticity. However, the use of active fillers products is mostly limited to 1%. This is because these products cause a brittle structure in the mixture, increasing the risk of shrinkage and traffic crack [7].

[1] Corresponding author. Tel.: +0-533-294-2814
E-mail address: kmerten@aku.edu.tr

Mixing water [8], another product used in the cold recycled material mixture and whose role in production is to be workability, causes the physical structure of the cold recycled materials to develop over time (curing), which improves the mechanical properties (such as rigidity and strength) over the long term [8 , 9]. Insufficient mixing water decreases the workability and negatively affects the homogeneous dispersion of the binder, but too much water prolongs the curing time [10].

The foam bituminous mix design is largely based on empirical studies and lacks generally accepted design procedures [11]. The aim in the mix design is to optimize mix strength properties in the worst case, i.e., wet conditions [10]. In the soaked state, most moisture-sensitive bonds are lost. Therefore, the performance of foam bituminous mixtures can be better understood in a soak state [13]. ITS test is a suitable method to evaluate foam bituminous mixtures in this way [10].

The TSR (tensile strenght retain) value obtained by proportioning the ITS values after conditioning (ITS_{WET}) and pre-conditioning (ITS_{DRY}) are used to calculate the damage caused by the water effect, and it is thought to the higher the TSR value, the better moisture damage resistance in the mixture [12].

Wirtgen [7] recommends 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 and these values are generally accepted in practice. It is also stated that foam bituminous mixtures have a high void content (10-15%) [7].

In the literature; it is stated that if cement is added to the cold recycled pavement materials, prolonging the curing time will increase the strength [14], and also increase the percentage of cement in the recycled material with foam bitumen [15], and increase the percentage of foam bitumen will have a positive effect on the ITS_{WET} value [15, 16].

It was stated by Kar et al. [17] that a higher ITS value will be obtained with high viscosity bitumen, and the increase in bitumen percentage will increase the ITS value up to a point and then the value will decrease.

Iwanski and Kowalska [18] stated that adding 2.5% bitumen binder (foamed bitumen) and 2.0% hydraulic binder (portland cement) will provide the necessary physical (air void content) and mechanical parameters (ITS_{DRY}, ITS_{WET} and TSR).

Romeo et al. [19] stated that optimum filler percentages for mixtures stabilized with bitumen; cement not exceeding 1% and lime of 2% or more.

In the study, cement, hydrated lime, fly ash active filler products and foam bituminous mixtures formed with different combinations for different percentages of 70/100 - 100/150 - 160/220 bitumen grades and different combinations for different percentages were evaluated in terms of ITS and TSR parameters. In addition, the effect of prolonging the curing time on the ITS_{WET} results was observed.

2. Materials and Methods

Recycled material gradation obtained from an existing road for experimental studies is shown in Table 1. Only this material was used in the productions evaluated in the study and no new aggregate substitution was made from the outside.

Table 1. Recycled asphalt material gradation used in the study

Sieve Size (mm)	Gradation (% Passing)
25	100
19	96
12.5	87
9.5	79
4.75	58
2	33
0.425	9
0.180	4
0.075	1.6

For the productions, firstly the expansion ratio and half life values of the bitumen used in the study were determined and the ideal foaming temperature and optimum foaming water values were determined for each bitumen grades (Table 2).

Table 2. Bituminous foaming results of bitumen used in the study

Bitumen Grade	Foamed Temperature	Water Percent	Expansion Ratio	Half Life (s)

(Tüpraş)				
70/100	170°C	2,00	20,01	10,27
100/150	170°C	2,00	21,19	10,20
160/220	160°C	2,00	20,74	9,28

The procedure recommended by Wirtgen [7] was used for productions. Standard Marshall briquettes of 4 inches in diameter were prepared for each mixture. The briquettes were removed from the molds the next day of production and placed in an oven at a constant temperature of 40°C and kept for 72 hours. At the end of this period, 3 of the samples taken from the oven were broken and ITS_{DRY} values were calculated, and 3 briquettes were placed in a water bath at 25°C for a further 24 hours, and ITS_{WET} values were determined by taking it from the water bath after 24 hours (Equation 1). TSR values were calculated according to ITS_{DRY} and ITS_{WET} values (Equation 2). After the curing procedure mentioned for two of the productions given in the study, additional 3 briquettes were kept in a water bath at 25°C for a further 7 days and ITS values were obtained. Thus, moisture damage was tried to be observed in samples that waited more in water bath.

$$\text{ITS} = \frac{10^6 * 2 * P}{\pi * h * d} \tag{1}$$

$$\text{TSR} = \frac{ITSWET}{ITSDRY} * 100 \tag{2}$$

Where;

P: Maximum load (kN)

h: Briquette heigh (mm)

d: Briquette diameter (mm)

Different production combinations have been created for; 3 different bitumen, 3 bitumen grades as 70 / 100-100 / 150 and 160/220, 3 different bitumen percentages as 1.9%, 2.5% and 3.1%, 3 different active filler type as cement-hydrated lime-fly ash and non active filler, 3 different active fillers percentages as 0.5%-1% and 2%, and additionally for a production where 1% hydrated lime and 1% fly ash are used together. With these productions, it is aimed to learn about the roles of variables such as bitumen grades and percentage, active filler type and percentage in the mixture. In order to eliminate the complexities that may arise in comparisons, some variables were kept constant in each production series as determined below.

In Figure 1; For 70/100 bitumen grade and 2.5% fixed bitumen percentage, the effect of active filler type and percentage change on ITS_{DRY}, ITS_{WET} and TSR values were evaluated.

In Figure 2; The effects of 70/100 bitumen grade and fixed active filler (cement) change in bitumen percentage and cement percentage on ITS_{DRY}, ITS_{WET}, TSR values were evaluated.

In Figure 3; with the use of 70/100 bitumen grade and fixed active filler (cement), the effects of bitumen percentage and cement percentage change on flow values were evaluated.

In Figure 4; the effects of bitumen grade change and cement percentage change on ITS_{DRY}, ITS_{WET} and TSR values for constant active filler (cement) and 2.5% fixed bitumen percentage were evaluated.

In Figure 5;for 2.5% fixed bitumen percentage and fixed active filler percentage (1%), the effect of bitumen grade and active filler type change was evaluated.

Finally, in Figure 6; the change of ITS_{WET} and ITS_{WET} values at the end of 7 days were evaluated for the samples that were produced with 70/100 bitumen grades and 2.5% bitumen percentage, and kept in the water bath for 7 days after the standart curing procedure applied in the study in 2% cement and 1%hydrated lime mixtures.

Abbreviations for mixtures:

1.9-2.5-3.1: Bitumen Percentage

70 (70/100)-100 (100/150)-160 (160/220): Bitümen Grades

C: Cement, HL: Hydrated Lime, FA: Fly Ash

0.5-1-2: Active Filler Percentages

7: additional 7 days curing

Table 3. Sample codes for some productions

Sample Code	% Bitumen	Bitumen Grade	Active Filler Type	% Active Filler	Additional Curing Days
2.570C0.5	2.5	70/100	Cement	0.5	-
2.570HL2	2.5	70/100	Hydrated Lime	2	-
2.570FA1	2.5	70/100	Fly Ash	1	-
2.570-7	2.5	70/100	-	-	7

3. Results and Discussion

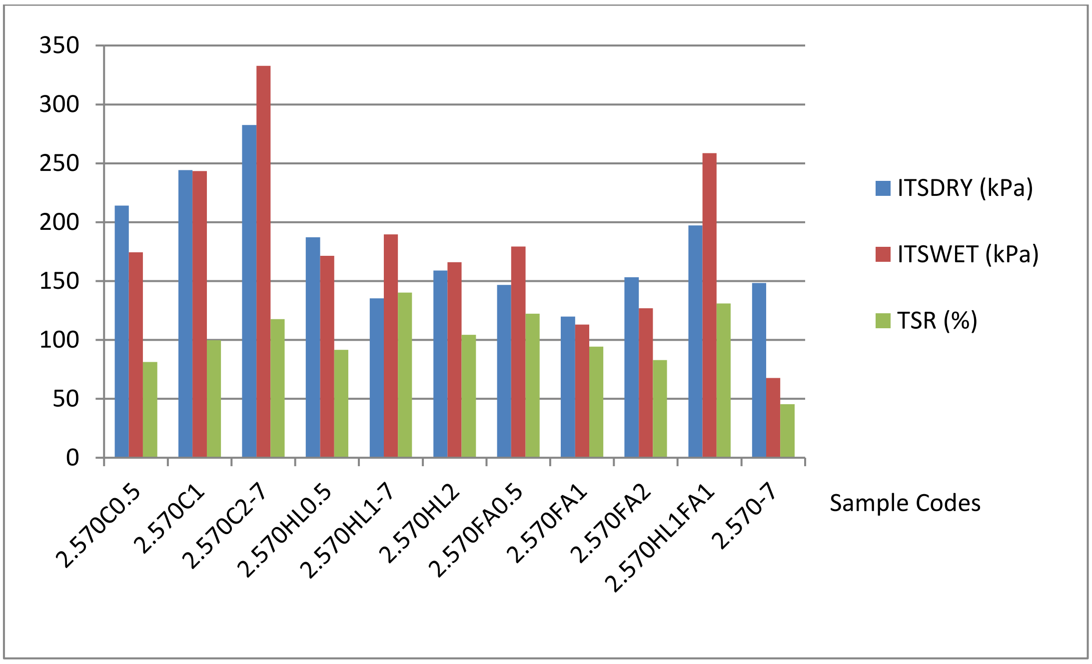

Figure 1. ITS and TSR values for variable fillers type and percentage

As can be seen from Figure 1;

As stated in Chapter 1 by [14], the percentage increase of fillers in cemented productions increased ITS_{DRY}, ITS_{WET} and TSR values.

In the hydrated lime and fly ash series, the percentage change of fillers did not show a certain decrease or increase tendency, but the values remained well below the limit values, especially in the fly ash series. However, in production where two fillers are used together, ITS values have increased significantly compared to the series with single active fillers.

While the ITS_{DRY} value in the series without active fillers has decreased very much, it is thought that the ITS_{WET} value has exceeded some production values of the fly ash and hydrated lime series and the limit values recommended by Wirtgen [7], the water entering the spaces due to the void structure of the material creates a pore water pressure and this affects the results.

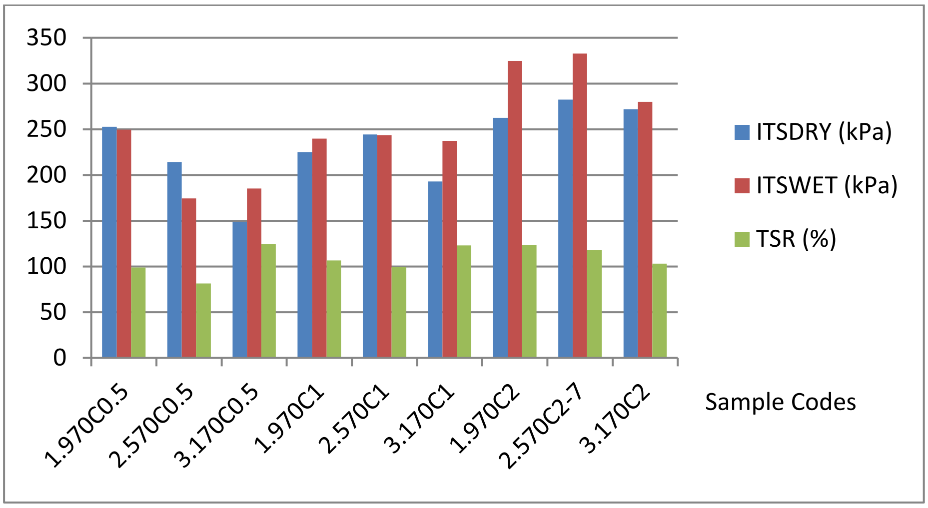

Figure 2. ITS and TSR values for variable filler percentage and bitumen percentage

As can be seen from Figure 2;

Both ITS_{DRY} and ITS_{WET} values reached a maximum of 1.9 and 2.5 bitumen percentages in all fillers percentages, with no production achieved a maximum of 3.1 bitumen percent. TSR values recommended by Wirtgen [7] provided limit values in all productions. The increase in ITS values with the percentage of cement seen for 2.5% bitumen in Figure 1 was seen for other bitumen percentages in Figure 2. Cement percentage increase reflects positively on the results regardless of the bitumen percentage. This is an indication that the distribution of the bitumen will be better with the increase of fine material in the mixture and accordingly, the moisture sensitivity will decrease.

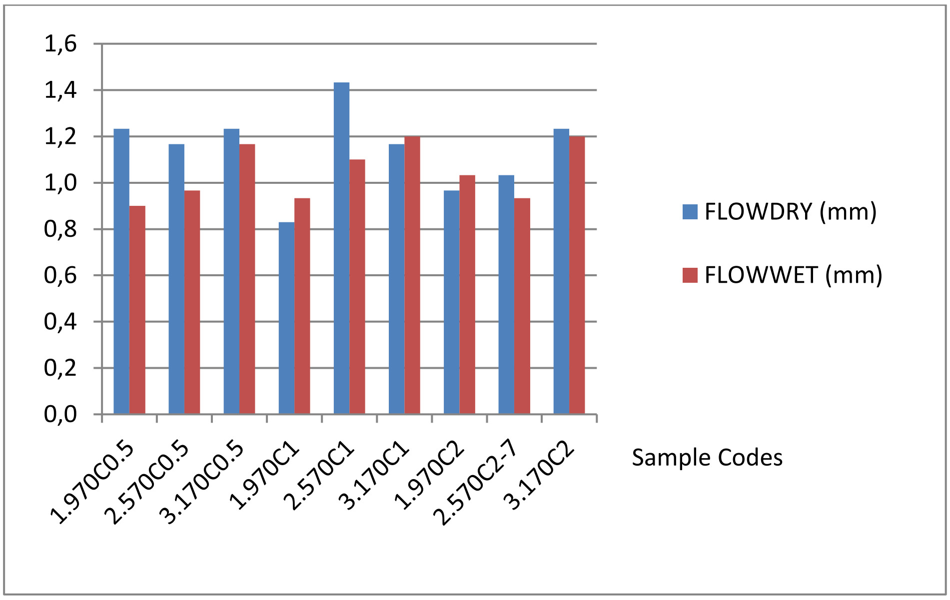

Figure 3. Flow values for variable filler percentage and bitumen percentage

As can be seen from Figure 3;

Although the bitumen percentage increase was not a clear trend in all fillers percentages, it had an effect on increasing flow values. With the increase in the percentage of fillers, the flow values of the ITS_{DRY} briquettes did not change much, but the flow values of the ITS_{WET} briquettes tended to decrease. It is thought that the long cured sample (2.570C2-7) in water in 2.5% bitumen productions is somewhat rigid due to the accelerating effect of water's to cement hydration. The fact that the flow values are very low compared to HMA (hot mix asphalt) materials is due to the active fillers' rigidity effect of the products. Low flow rates can cause deteriorations such as fatigue cracks in a short time.

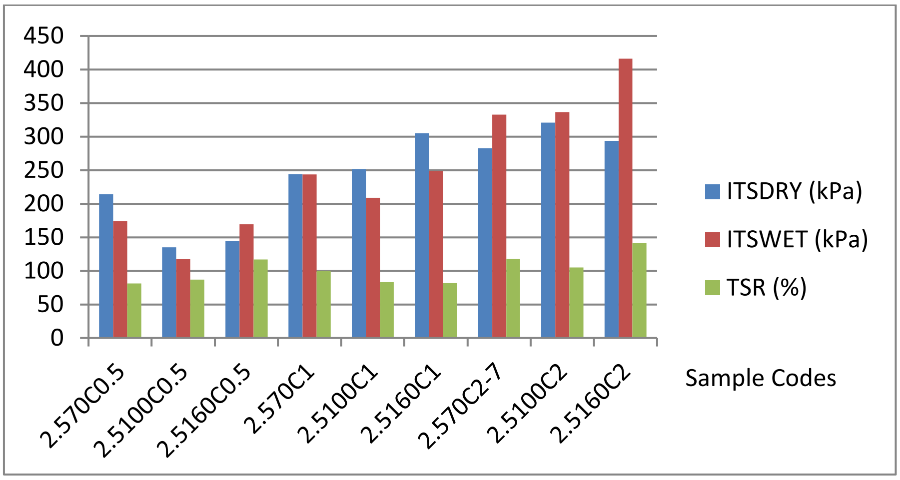

Figure 4. ITS and TSR values for variable filler percentage and bitumen grades

As can be seen from Figure 4;

TSR values were above the limit value in all productions. While the highest ITS values were obtained for 70/100 bitumen for the percentage of 0.5 fillers, the increase in the bitumen grades in parallel with the increase in the percentage of fillers had an increasing effect on the ITS values. In Figure 2, it was stated that the ITS values increased with the increase in the percentage of fillers, and in Figure 2, the highest ITS values for 70/100 bitumen were obtained in the percentage of 2.5% bitumen. In Figure 4, higher values were achieved in other bitumen grades for 2.5% bitumen. This shows that soft bitumens are better distributed during foaming and the material affects ITS values more positively.

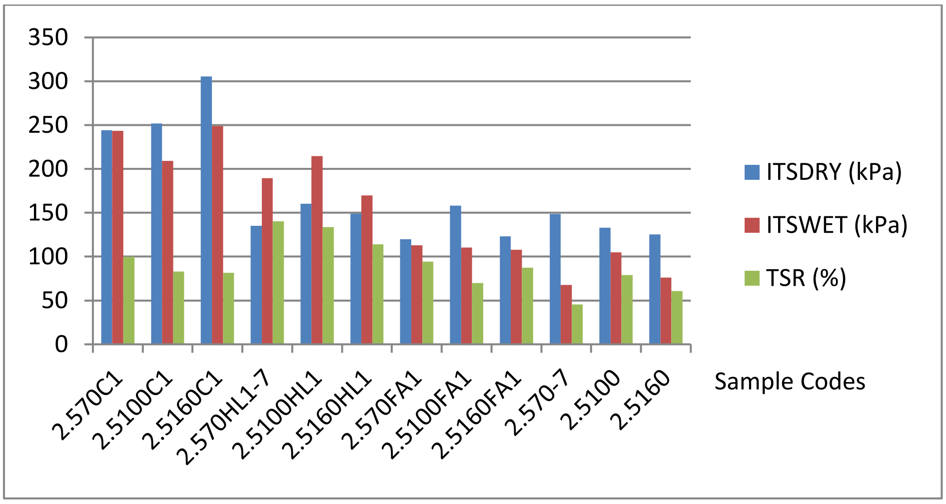

Figure 5. ITS and TSR values for variable filler type and bitumen grades

As can be seen from Figure 5;

The highest ITS values; in the cemented series are 160/220 grade bitumen, 100/150 grade bitumen in hydrated lime series, 70/100 for ITS_{DRY} in the fly ash series, 100/150 for ITS_{WET}, 70/100 for ITS_{WET} in the non-active filler series and 100/150 bitumen for ITS_{DRY} was obtained. This shows that soft bitumens are effective for cement which has rapid hydration in the early days and hydrated lime materials which has high reduction moisture sensitivity properties, and harder bitumens are effective for materials such as non active filler and as fly ash which late hydrated than cement that does not have much effect on strength in the first days of the mixture In Figure 4, the increase in ITS values in 160/220 grades bituminous mixtures with the increase in cement percentage supports this situation.

Figure 6. Effect of additional water curing on ITSwet values

As can be seen from Figure 6;

No significant change was observed in the ITS values in hydrated lime samples that were kept in water for 7 days after the standart curing procedure. Hydrated lime reduced the moisture sensitivity of the mixture immediately after production, but in this case it did not create an improvement over time. In cement production, the increase of ITSwet value is due to the increasing cement hydration with water, which develops over time, as mentioned above.

4. Conclusions

The following results have been reached in this study, which was conducted to observe what changes occurred in asphalt pavements recycled with foam bitumen with the change of bitumen, bitumen grades, active filler type, active fillers percentage and curing time, in terms of ITS-TSR and flow values.

- If cement is used in the production, ITS values increase with the increase of curing time. In addition, the use of cement creates a rigid behavior tendency in the material.
- The use of active fillers positively reflected TSR values, which are indicators of moisture damage.
- While using cement in the mixture, the increase in the percentage of fillers positively affects the results, while it is not possible to say such a thing in hydrated lime and fly ash. However, increasing the percentage of fillers using hydrated lime + fly ash increased ITS values.
- Cement is considered to be the ideal type of active filler for foam bituminous mixtures, but the use of soft bitumen with cement is recommended. In addition, although the increase in the percentage of cement increases the ITS results, the risk of cracking should be taken into account as it will stiffen the material.
- It has been observed that soft bitumens are more suitable with products that affect the performance of the mixture, especially from the first days, such as cement.
- Due to the void structure of foam bituminous cold mixes, the pore water pressure can increase the ITSwet results.
- Although increasing bitumen percentage is not a clear trend in all fillers percentages, it has had an increasing effect on flow values. However, using bitumen below 2.5% in terms of ITS for all filler percentages will increase the results.

Based on the results obtained in the study, the correct proportions of foam bitumen and active filler materials to the recycled pavement materials seem promising in terms of mixture performance and environmental benefits.

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.

References

[1] F. Xiao, S. Yao, J. Wang, X. Li and S. Amirkhanian, “A Literature Review on Cold Recycling Technology of Asphalt Pavement” Construction and Building Materials, vol. 180, pp. 579–604, 2018

[2] M. Bocci, A. Grilli, F. Cardone and A. Graziani, “A Study on the Mechanical Behaviour of Cement–Bitumen Treated Materials” Construction and Building Materials, vol. 25, no. 2, pp. 773–778, 2011

[3] C. Godenzoni, A. Graziani, E. Bocci and M. Bocci, “The evolution of the mechanical behaviour of cold recycled mixtures stabilised with cement and bitumen: field and laboratory study” Road Materials and Pavement Design, vol. 19, no. 4, pp. 856-877, 2017

[4] S.F. Brown and D. Needham, “A study of cement modified bitumen emulsion mixtures”. Proceedings of the Association of Asphalt Paving Technologists, pp. 92–121, 2000

[5] B. Dolzycki, M. Jaczewski and C. Szydlowski, “The long-term properties of mineral cement-emulsion mixtures” Construction and Building Materials, vol. 156, pp. 799–808, 2017

[6] A. Graziani, C. Iafelice, S. Raschia, D. Perraton and A. Carter, “A procedure for characterizing the curing process of cold recycled bitumen emulsion mixtures” Construction and Building Materials, vol. 173, 754–762, 2018

[7] Wirtgen (2012)– Wirtgen Cold Recycling Technology, Wirtgen Cold Recycling Manual, Germany.

[8] A. Graziani, C. Godenzoni, F. Cardone and M. Bocci, “Effect of curing on the physical and mechanical properties of cold-recycled bituminous mixtures” Materials & Design, vol. 95, pp. 358–369, 2016

[9] F. Cardone, A. Grilli, M. Bocci and A. Graziani, “Curing and temperature sensitivity of cement–bitumen treated materials” International Journal of Pavement Engineering, vol. 16, no. 10, pp. 868-880, 2014

[10] K.M. Muthen, “Foamed Asphalt Mixes Mix Design Procedure” Report. CR-98/077, Dec. 1998.

[11] G.M. Arguelles, F. Giustozzi, M. Crispino and G.W. Flintsch, “Investigating physical and rheological properties of foamed bitumen” Construction and Building Materials, vol. 72, pp. 423-433, 2014

[12] A. Diab and M. Enieb, “Investigating influence of mineral filler at asphalt mixture and mastic scales” International Journal of Pavement Research and Technology, vol. 11, 213–224, 2018

[13] S. Khosravifar, “Design and mechanical properties of foamed asphalt stabilized base material” M. S. thesis, University of Maryland, Maryland, 2012.

[14] R. Taha, A.A. Harthy, K.A. Shamsi and M.A. Zubeidi, “Cement stabilization of reclaimed asphalt pavement aggregate for road bases and subbases” Journal of Materials in Civil Engineering, vol. 14, no. 3, pp. 239-245, 2002

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

[16] P. Fu, D. Jones and J.T. Harvey, “The effects of asphalt binder and granular material characteristics on foamed asphalt mix strength” Construction and Building Materials, vol. 25, pp. 1093-1101, 2011

[17] S.S. KAR, A.K. SWAMY, D. TIWARI and P.K. JAIN, “Impact of recycled asphalt pavement on properties of foamed bituminous mixtures” The Baltic Journal of Road and Bridge Engineering, vol. 13, no. 1, pp.14–22, 2018

[18] M. Iwanski and A.C. Kowalska, “Laboratory study on mechanical parameters of foamed bitumen mixtures in the cold recycling technology” Procedia Engineering, vol. 57, pp. 433 – 442, 2013

[19] E. Romeo, G. Betti, A. Marradi and G. Tebaldi, “Effect of active fillers on cracking performance of bitumen-stabilised materials” Road Materials and Pavement Design, vol. 19, no. 7, pp. 1563-1574, 2018