Teknik Dergi, 2022 11641-11660, Paper 652

The Effects of Iraq Natural Asphalt on Mechanical Properties of Bituminous Hot Mixtures

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ABSTRACT

The increasing rate of traffic every day requires the roads to be made more stable. To improve the low and high temperature properties of the bituminous mixtures forming the coating layer of the flexible pavements, the binder in the mixture is often modified with various polymers. The most commonly used polymer in the modification is styrene-butadiene-styrene (SBS). However, SBS, which is very successful in improving the mechanical properties of the mixtures, is expensive and has brought the search for cheaper alternative additives. In this context, natural asphalts (NA) which are not subjected to any processes are used as additive. In this study, natural asphalt obtained from Zaho region of Iraq was used in 20%, 35% and 50% of bitumen modification by weight. The mechanical properties of mixtures prepared with different amount of NA modified bitumen were compared with 4% SBS modified bituminous mixtures. As a result, NA modification significantly improved the properties of bituminous mixtures. In particular, above 35% NA, the mixtures exhibited a superior performance by significantly resisting the effect of repeated loads. It was found that an average of 17.3% NA modification exhibited similar behaviour with 4% SBS modification and provided significant economic savings.

Keywords: Natural asphalt, SBS, modification, mechanical properties, mixture.

1. INTRODUCTION

Natural asphalts are solid or semi-solid materials composed of hydrocarbons and aromatic molecules. Natural asphalts generally consist carbon, hydrogen, nitrogen, oxygen, sulphur as well as a small amount of iron, nickel and vanadium [1]. Gilsonite, Trinidad Lake and rock

Note:

- This paper was received on December 24, 2019 and accepted for publication by the Editorial Board on September 28, 2020.
- Discussions on this paper will be accepted by May 31, 2022.

- https://doi.org/10.18400/tekderg.664187

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asphalt in America and Iran are the most common types of natural asphalt used as a part of original bitumen. Trinidad Lake Asphalt (TLA), mainly consists of asphalt and mineral matter, different from petroleum asphalt. Although the chemical composition of the asphalt part of TLA is similar to that of petroleum asphalt, it cannot be used as a binder alone in asphalt mixtures because it is very hard due to its high mineral and asphaltene content [2]. Xu et al. investigated the properties of Trinidad Lake Asphalt and SBS modified asphalt mixtures. In the light of experimental data, it was found that TLA and SBS increased the fracture resistance of asphalt. It was also determined that TLA and SBS improve aging resistance and service life of asphalt [3]. Gilsonite is usually located parallel to each other in the form of vertical veins in the depths. The mass gilsonite is a natural asphalt with a rather shiny, black color, notched rupture surface, similar to obsidian mineral. It can be easily crushed due to its fragile structure. The specific gravity of gilsonite is between 1.03 and 1.10. It melts between 120°C and 175°C. The penetration value of gilsonite is 0. Gilsonite is characterized by its high asphaltene properties, high solubility in organic solvents, high molecular weight and high nitrogen content. Jahanian et al. modified the mixtures by adding 0, 2, 4, 6, 8, 10% gilsonite by weight of the bitumen. It was found that Marshall stability and stiffness modulus parameters of gilsonite modified mixtures increased significantly. In addition, the increase in flow number obtained from the dynamic creep test is indicative of an increase in the rutting resistance [4]. It was determined that the penetration value of the gilsonite modified binders decreased and the softening point value increased. Gilsonite significantly increased the stability and rutting resistance of bituminous hot mixtures prepared with modified binders containing 4% and 8% gilsonite. According to indirect tensile stiffness modulus test, the rigidity of gilsonite modified hot mixtures increased at 25°C while the gilsonite did not have a significant effect at 35°C and 45°C [5]. Babagoli et al. have investigated the effects of gilsonite on the performance of stone mastic asphalt mixtures. Gilsonite was added to the binders at 5%, 10% and 15% by weight of bitumen. According to the test results, gilsonite reduced the penetration of the binders and increased the softening point. Ductility values decreased while viscosity values increased with the increasing rate of gilsonite. Marshall stability of gilsonite modified mixtures increased while creep values decreased. Mixtures containing 10% gilsonite gave the highest elastic modulus values. The tensile stress values of mixtures containing 15% gilsonite were higher than those of other mixtures. In addition, it was found that gilsonite-containing mixtures had greater resistance to moisture damage. Finally, it was observed that gilsonite modified mixtures gave a lower rutting depth [6]. It was determined that the addition of 18 wt % American gilsonite to PG 58-18 pure binder resulted in PG 76-16 and also gives lower mixing-compaction temperature compared to 5% SBS modification [7]. Rock asphalt is a type of natural asphalt that passes through the oiling process following the division of rocks from the cracks. Rock asphalt is transformed for millions of years due to heat, pressure, oxidation and mineral precipitation. Rock asphalt is environmentally friendly, does not need chemical processing and is a highly compatible building material with bitumen. When used in modified binders, it increases the high temperature strength, water resistance and durability. Li et al. have investigated the potential impact of different types of rock asphalt on the performance of asphalt composites. It was determined that rock asphalt admixture increased the rigidity but reduced the low temperature performance [8]. Yilmaz and Celoglu investigated the effect of three different natural asphalts (Trinidad Lake Asphalt, Iranian gilsonite and American gilsonite) and styrene-butadiene-styrene (SBS) additives on the performance of bituminous hot mixtures. The mixtures prepared with 10% American gilsonite, 9.5% Iranian gilsonite, 60% Trinidad

Lake Asphalt and 3.8% SBS modified binders at the same performance grade (PG-70-34) were compared with control mixtures prepared by pure bitumen (PG 58-34). Indirect tensile strength (ITS) and Marshall stability values of the mixtures prepared with TLA were found to be the highest. The mixtures prepared with 9.5% Iranian gilsonite and 3.8% SBS had the highest resistance to moisture damage. The mixtures prepared with 60% TLA had the highest hardness and the longest fatigue life [9]. It has been determined that the fatigue life, rutting resistance and high temperature performances of bituminous hot mixtures prepared with gilsonite modified binders have increased [10, 11]. Hot bituminous mixtures prepared by natural asphalt which consists of 17% asphalt fraction and 83% mineral fraction was found to have higher stiffness modulus and also resistance to permanent deformation compared to control mixtures [12]. It was concluded that the use of gilsonite is useful for constructing asphalt mixture with harder bitumen to have more rutting resistance and better load distribution within structure and as a result less stresses in pavement structure [13]. Studies showed the improvement in high temperature and temperature sensitivity performance with addition of rock asphalt [14, 15]. Li et al. reported that the America rock asphalt can increase the surface free energy of asphalt, thus results in a better moisture damage resistance [16]. It was reported that the moisture damage resistance, tensile strength and fatigue performance of petroleum mixture were enhanced as well with the addition of rock asphalt from Xinjiang, China. However, the low temperature performance was slightly sacrificed after the modification of rock asphalt [17].

Recently, SBS modified bitumen was widely used in hot bituminous mixtures. The studies showed the achievement of these additive on improving the rheological properties of bitumen [18-20] and mechanical properties of asphalt mixtures [21, 22]. The improved rheological properties result in viscoelastic behaviour over a wider temperature range. The enhanced viscoelasticity also induces longer fatigue life and less rutting potential. Some co-additives are also used besides the SBS in order to enhance the efficiency in terms of storage stability and aging properties [23, 24]. The main drawback of the SBS modification such as the limited production and high cost of the additive has motivated the researchers to explore alternative additives without sacrificing the performance.

In this study Iraq gilsonite which is a type of natural asphalt and 20% cheaper than original refinery bitumen was used as a modifier to improve the mechanical properties of mixtures. The mechanical properties of the natural asphalt modified mixtures were compared to those of the SBS modified mixtures.

2. MATERİALS AND METHOD

B 160/220 grade bitumen, which is obtained from TÜPRAŞ Batman refinery, was used as pure binder. Natural asphalt (NA) was provided from Zaho region of Iraq. The elemental analyses of the base and natural asphalt are given in Table 1. Natural asphalt was added as an additive to pure bitumen by 20%, 35% and 50% by weight of bitumen. To evaluate the performance of natural asphalt modified bituminous mixtures, the mechanical properties of the bituminous mixtures prepared by SBS (KRATON D 1101) produced by Shell Bitumen were also investigated. Kraton D-1101 is a linear triblock copolymer in powder form that consists of 31/69 styrene/rubber ratio. It has 4600 psi tensile strength and 880% elongation at break. SBS was used at 4% by weight of the binder. Bituminous mixtures produced with

20%, 35%, 50% natural asphalt modified binder are shown as 20NA, 35NA and 50NA respectively, and bituminous mixtures produced with 4% SBS modified binder are shown as 4SBS. Fig. 1 shows the natural asphalt and SBS.

Table 1 - Elemental analysis of base and natural asphalt.

	C(%)	H(%)	N(%)	S(%)	Solubility in TCE (%)
Base bitumen	82.38	8.96	0.604	7.227	99.21
Natural asphalt	81.52	10.82	0.455	5.914	97.95

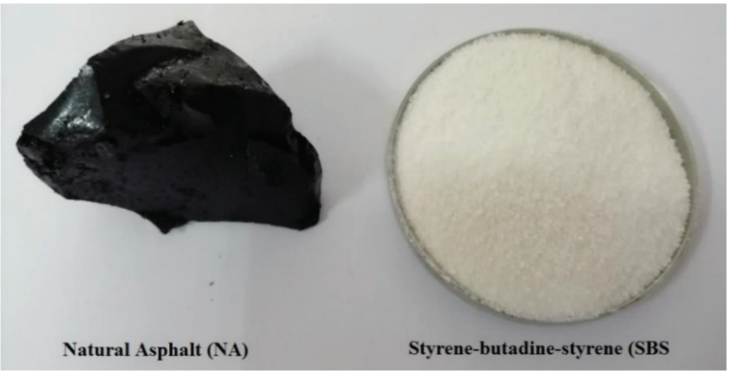

Fig. 1 - Iraq natural asphalt and SBS

Fig.2 - High shear mixer

In the bitumen modification, different contents of natural asphalt and SBS were gradually added to the pure bitumen and mixed with a four-bladed mixer at 1000 rpm for 1 hour at a constant temperature of 170ºC. The total amount of binder in the container was adjusted to be 500 g for each batch. An insulated container (Fig.2) was used during the modification. The heater plate has a thermostat which is submerged into bitumen throughout a channel on the top of the cap. The temperature was kept constant and excessive aging during the mixing was avoided thanks to insulated container with closed cap and thermostat-controlled heating plate. The pure binder, which does not contain any additives, has been subjected to the same mixing process so that the aging effect occurring during the modified bitumen preparation was eliminated. Table 2 shows the physical properties of the binders.

Table 2 - The physical properties of the binders.

Properties	Pure	20NA	35NA	50NA	4SBS
Softening point (ºC) ASTM D36	42.1	49.7	52.8	69.7	53.9
Penetration (0.1 mm) ASTM D5	206	83.2	53.6	23	101
Penetration index	1.01	-0.24	-0.12	1.01	1.86
Viscosity (cP) 135ºC /165ºC ASTM D4402	262/100	437/150	587/162	1588/325	1125/325

Mixture samples were prepared by applying 75 blows on both sides of the samples according to the Marshall Mix Design. The properties and gradation of the limestone aggregates are given in Table 3. Type-2 of the Turkey Highways Technical Specification was used as a grading. The limestone was obtained from Elazig Karayazi region. The optimum bitumen content was determined for the mixture samples prepared with pure bitumen. Modified mixtures were prepared with the same bitumen content.

The pure and modified mixtures prepared in the optimum bitumen content (5.8%), air voids (Va), voids filled with asphalt (VFA), voids in mineral aggregates (VMA), bulk specific gravity (Gmb) and the mixing-compaction temperatures are given in Table 4. The mixing-compaction temperatures of the mixtures were determined as the temperatures corresponding to the viscosity values of 170 ± 20 and 280 ± 30 cP according to the rotational viscometer test applied to the binder [25]. The modified mixtures require more mixing-compaction temperature than the pure mixture since the viscosity of the binders increases with the use of additives. However, the NA modified mixtures give lower temperatures than the 4% SBS modified mixture even at the 50% NA content. It has been found that the mixture samples comply with the specification terms of the volumetric properties.

Table 3 - Aggregate properties and gradation.

Properties	Coarse	Fine	Filler
Los Angeles abrasion (%) ASTM D131	25		
Soundness of aggregates ($MgSO_4$) ASTM C88	12		
Flat and elongate particles (%) BS 812	20		
Water absorption (%) ASTM C127	0.8		
Bulk specific gravity ASTM C127, C128	2.533	2.619	
Apparent specific gravity ASTM D854			2.732

Sieve size (mm)	12.5	9.5	4.75	2.00	0.425	0.180	0.075
% Passing	100	87	55	38	21	8	6

Table 4 - Volumetric properties of mixture samples.

Mixtures	Va (%)	VFA (%)	VMA (%)	Gmb	Gmm	Mixing temperature (ºC)	Compaction temperature (ºC)
Pure	3.79	75.08	15.20	2.315	2.406	144-152	130-136
20NA	4.08	73.62	15.45	2.308	2.406	158-165	144-150
35NA	3.92	74.38	15.32	2.311	2.406	161-167	149-154
50NA	4.15	73.25	15.52	2.306	2.406	176-182	165-170
4SBS	4.14	73.31	15.51	2.307	2.406	179-186	166-172

3. EXPERIMENTAL RESULTS

3.1. Marshall Stability and Flow Test

Marshall stability and flow test, which is a performance indicator of bituminous mixtures, were conducted according to ASTM D 6927 standard. Fig. 3 shows the Marshall stability of the mixtures while Fig. 4 shows the stability / flow rates of the mixtures. The values are the average of the four replicates. Stability values increase significantly with the use of NA as in previous studies using natural asphalt additives [4, 6, 9]. The addition of 20%, 35% and 50% natural asphalt increases the stability of the mixtures by 7%, 19% and 32%, compared to the pure mixture. The 4% SBS modified mixtures give only 6.7% higher stability than the pure mixtures. The same stability value as that of the 4SBS mixture can be obtained by 14% natural asphalt modification as seen in Fig. 5. The change in the stability / flow ratios, which is an indicator of the rigidity of the mixtures, showed a similar performance to that of the stability. The stiffness of the 50NA mixture is increased by 14% compared to the pure mixture.

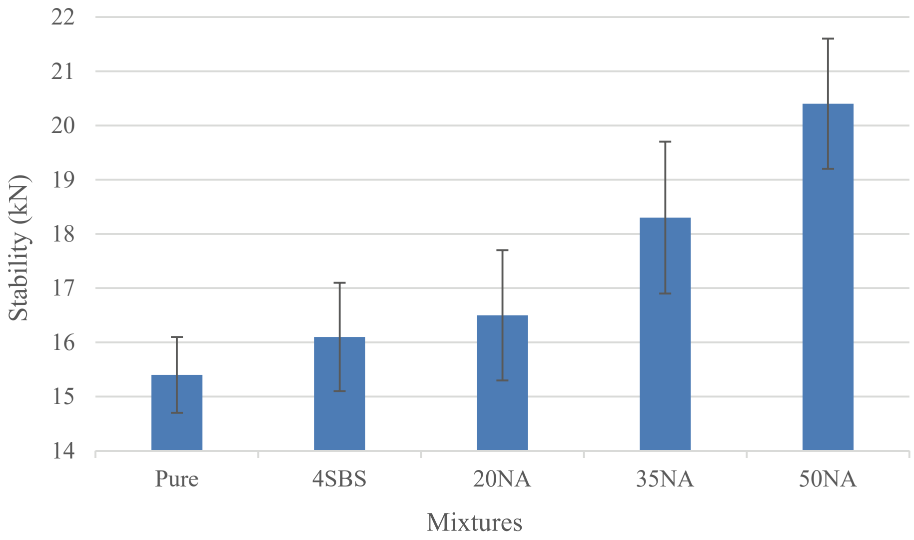

Fig. 3 - Marshall stability values of mixtures.

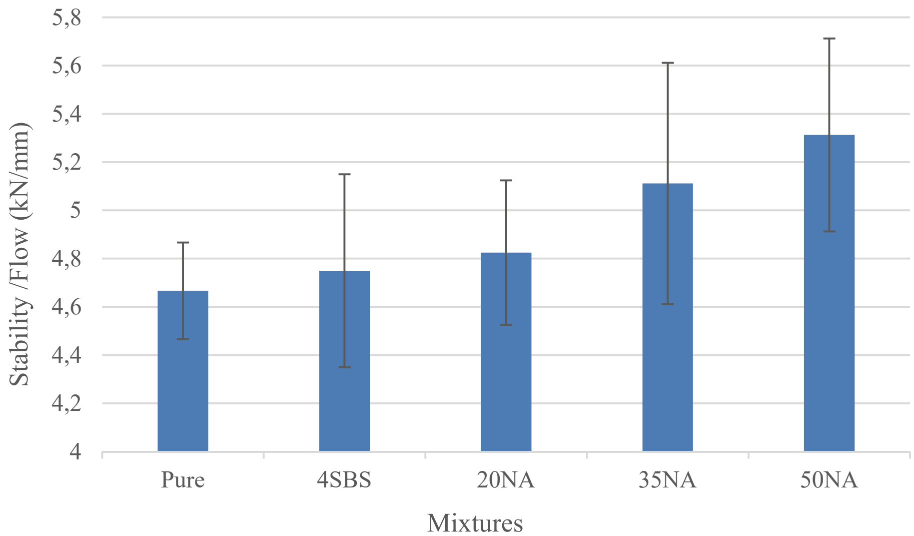

Fig. 4 - Stability / flow values of mixtures.

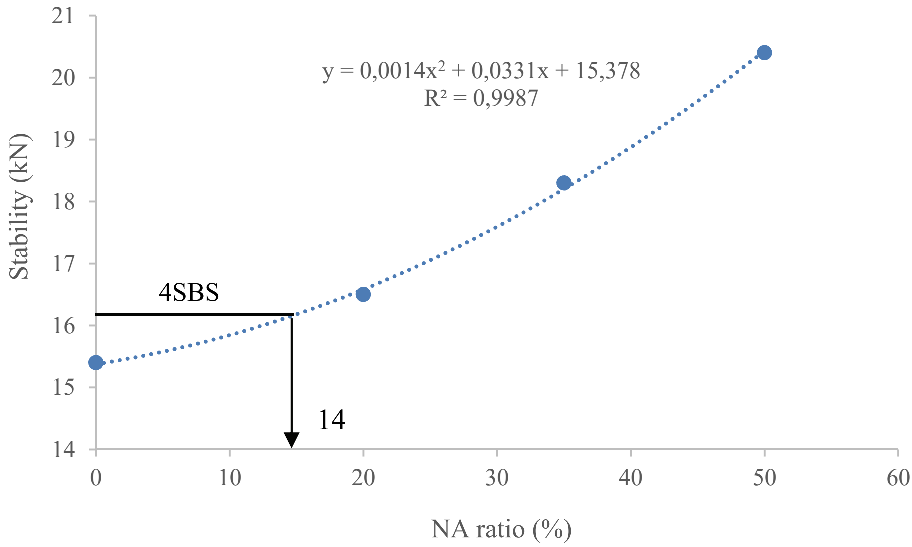

Fig. 5 - The change of the stability against NA ratio.

3.2. Indirect Tensile Strength Test

The experiment was performed using Marshall apparatus according to AASHTO T 283. The samples were wrapped in aplastic bag and placed in a 25 ºC water bath for two hours before testing. Cylindrical samples were subjected to a pressure load in the direction of the vertical diameter plane in such a way that a uniform distribution of stress was obtained. The load causing fracture was determined and ITS (kPa) values were calculated.

$$ITS = 2Pmax / \pi td \quad (1)$$

Where P is the maximum load (kN); t, the mean sample height (m); d is the sample diameter (m).

The tensile strength values of the mixtures are given in Fig. 6 sequentially. The values are the average of the four replicates. The percent increase in ITS values with natural asphalt is higher than the stability values. ITS values of 20NA, 35NA and 50NA mixtures were 64%, 97% and 180% higher than the pure mixture, respectively. It is seen that the use of natural asphalt can increase the tensile strength of the mixtures up to two times with the same trend as other studies in the literature [4, 6, 9, 12]. The 4SBS mixture has 37% higher ITS value than that of the pure mixture. The same ITS value with the 4SBS mix can be obtained by the addition of 14% NA as shown in Fig. 7. According to Marshall stability test, ITS test shows the effectiveness of additive use more clearly. The significantly higher ITS values of the NA modified mixtures compared to the pure mixture indicate that they can provide a longer service life by resisting to tensile stresses that cause crack formation.

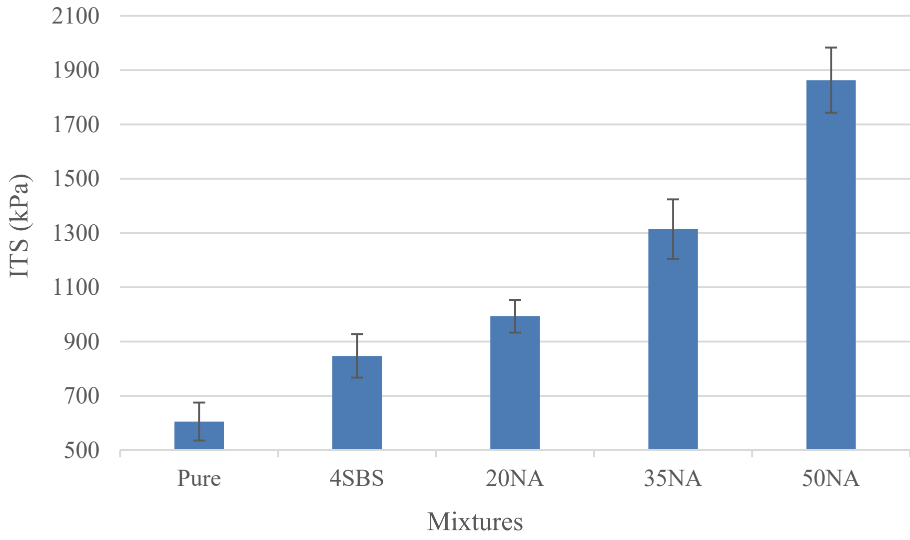

Fig. 6 - Indirect tensile strength (ITS) values of mixtures.

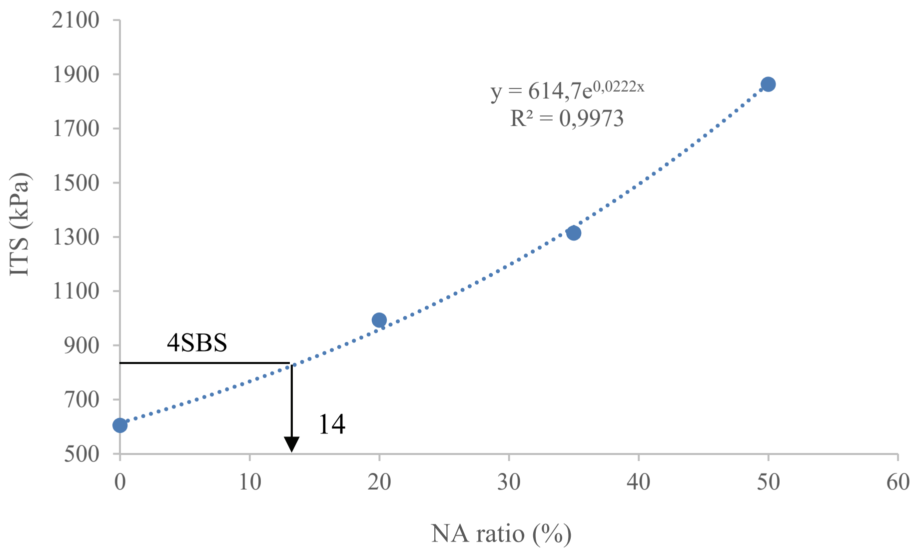

Fig. 7 - The change of ITS values against NA ratio.

3.3. Indirect Tensile Stiffness Modulus Test

The stiffness modulus, which is a measure of the load distribution capability of bituminous layers, is one of the most important performance characteristics of bituminous hot mixtures

[26]. This experiment is a non-destructive test defined by the BS DD 213 standard and the stiffness modulus (Sm, MPa) is calculated by Formula 2.

$$Sm = F(R+0.27) / LH \quad (2)$$

Where F is the maximum vertical load (N); H, mean horizontal deformation (µm) resulting from 5 repetition of loads; L, mean sample thickness (mm); R is the Poisson's ratio (0.35). The test was carried out at 25°C with deformation control. The target deformation is taken as 6 µm, the loading period is 3 seconds and the rise time is 0.124 s. Samples were stored at the test temperature for 2 hours before starting the experiment. Four samples were tested for each type of mixtures. Since the test is non-destructive, each sample was tested at three different position, hence the average of 12 value for each sample was taken into consideration.

The ITSM values of the mixtures are given in Fig. 8 with increasing order. The ITSM values of the 20NA, 35NA and 50NA mixtures were 1.80, 2.42 and 4.34 times higher than the pure mixture, respectively. Especially after 35% NA content, the increase in ITSM values of mixtures is much higher. The fact that ITSM values, which are the indicators of the load distribution capability, are significantly higher in the NA modification compared to the pure mixture means that the effect of heavy loads will be long lasting without a crack. The 4SBS mixture gave a similar performance with the 20NA mixture giving 1.7 times higher ITSM value than the pure mixture. The similar performance of the 4SBS mixture is obtained by a modification of 19% NA according to Fig. 9.

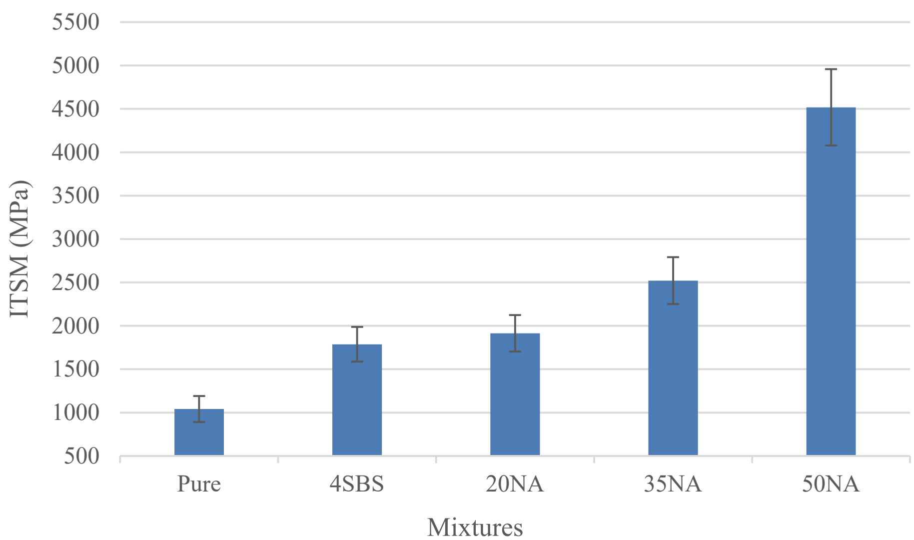

Fig. 8 - Indirect tensile strength modulus (ITSM) values of mixtures.

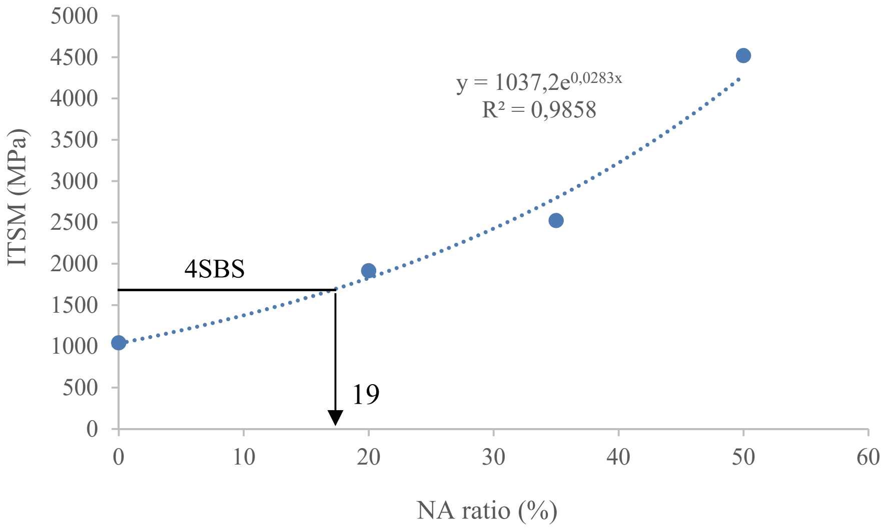

Fig. 9 - The change of ITSM values against NA ratio.

3.4. Indirect Tensile Repetitive Loading Test

Road pavements are subjected to a short-time loading on each vehicle wheel pass. This creates a very small damage that causes a decrease in the rigidity of the material. With the accumulation of these damages, the material deteriorates for a long time. Fatigue strength is the ability to resist asphalt pavement without breaking under repeated traffic loads. The test was carried out at 25°C. Constant-stress indirect tensile-fatigue test was conducted by applying a cyclic constant load of 210 kPa for 0.1 s followed by a rest period of 1.4 s.

Samples were stored at the test temperature for 3 hours before starting the experiment. At the end of this period, the sample was placed between the loading heads, the linear variable differential transformers (LVDTs) to measure the vertical deformation were set, sample height, diameter, stress level values and loading period were entered into the computer and the experiment was started (Fig.10). The test continued until all samples were completely broken except for 50NA.

All mixtures except the 50NA mixture were broken at about 4 mm deformation. However, the 50NA mixture did not break even at 32000 load repetitions. In this load repetition, the sample was deformed 0.6 mm and no crack formation was observed. Fig. 11 shows the change in the total permanent vertical deformation of the mixture by the repetition of the load. The pure, 4SBS, 20NA and 35NA mixtures was broken in 810, 2004, 3282 and 11580 load repetitions. The 50NA mixture showed a superior performance by resisting the effect of repetitive loads for a long time. The rate of deformation increase in the load-repetition curve of the mixtures initially occurred rapidly due to the compression of the air voids in the samples and then showed a linear increase. Finally, with the beginning of the crack, it shows a rapid increase again. In the 50NA mixture, the curve is still in the linear zone at 32000 load repetition and no cracks occur. According to the number of repetition loads at the 4 mm deformation level, the 20NA and 35NA mixtures have 4.1 and 14.5 times more load cycles than the pure mixture, respectively. The use of natural asphalt additive increased the number of load repetitions of the mixtures with the same trend as other studies in the literature [9]. The pure mixture at the deformation level of 0.7 mm, which is the biggest deformation seen by the 50NA mixture, has only 144 load repeats, so that according to this level of deformation, the 50NA mixture has 222 times greater load repeats than the pure mixture. In particular, the use of more than 20% natural asphalt increases the fatigue resistance of the mixtures considerably. The 4SBS mixture can withstand 2.5 times more load repetition than the pure mixture. The same performance with the 4SBS mixture can be obtained by 13% natural asphalt modification as seen from Fig. 12.

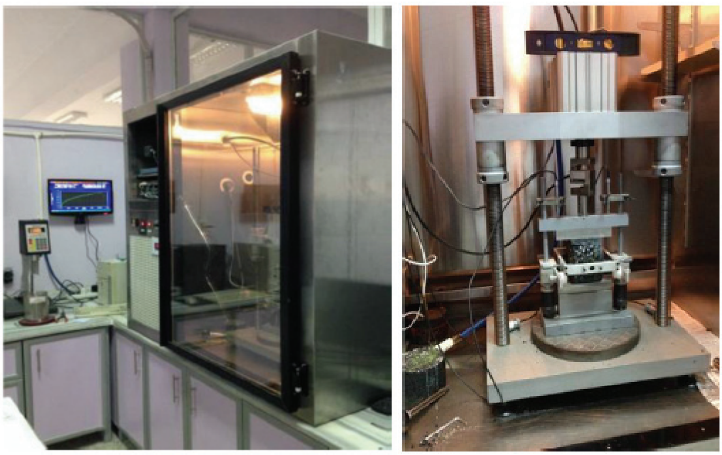

Fig.10 - Indirect tensile fatigue test equipment

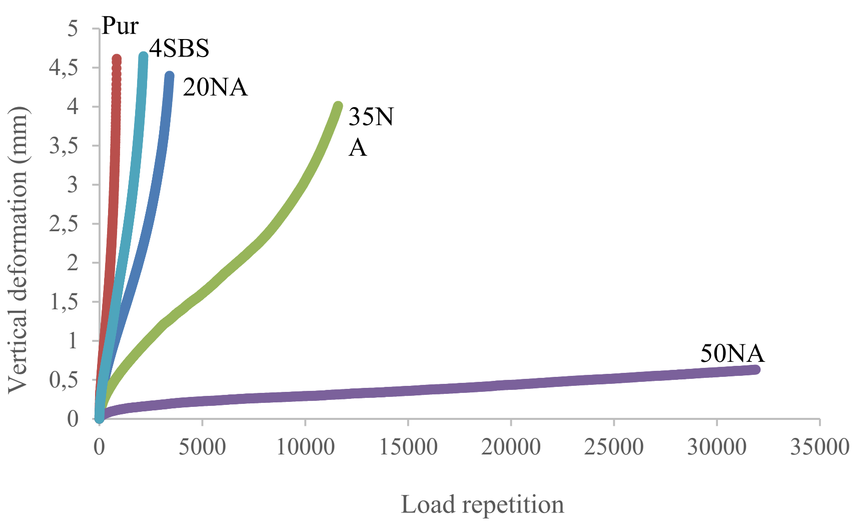

Fig. 11 - Load repetition - deformation relationship.

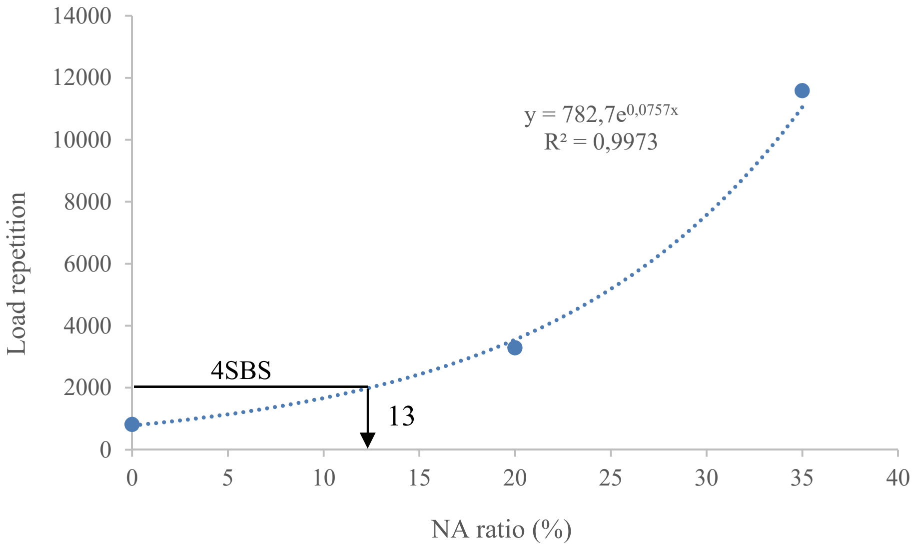

Fig. 12 - The change of load repeat against NA ratio at 4 mm deformation.

3.5. Dynamic Creep Test

The dynamic creep test is an important test used to determine the resistance of bituminous mixtures against permanent deformations and has a high correlation with the rutting resistance [27]. In the experiment, the deformations occurring together with the repetition of the load increased rapidly due to the compression of the air voids in the sample, then continued linearly in the consolidated sample and increased rapidly after the sample began to lose its integrity [28]. Creep stiffness is determined from the following formula [29].

$$E_c = \frac{\sigma}{\varepsilon_c} \tag{4}$$

Where Ec is the creep stiffness (MPa); σ is the applied dynamic stress (MPa); and ε_c is the total permanent strain. The test was carried out at a temperature of 50ºC under 0.5 MPa cycling stress. The samples were incubated at the test temperature for 3 hours before starting the experiment. In the experiment, square wave load was applied in the loading period of 1000 ms with 500 ms rest time. Samples were subjected to a conditioning static stress under 0.1 MPa for 10 minutes before starting the experiment.

In this high temperature, the resistance of the samples to the formation of permanent deformation under the influence of repeated loads was evaluated. Fig. 13 shows the variation of the total permanent strain with the repetition of loads in the mixtures. Here, as in the fatigue test, the deformation is initially linear after a rapid increase and then tends to increase rapidly again because of the loss of integrity of the mixture in the third zone. The increase in the third region is clearly seen in the pure and 20NA mixture. In the other mixtures, the test was

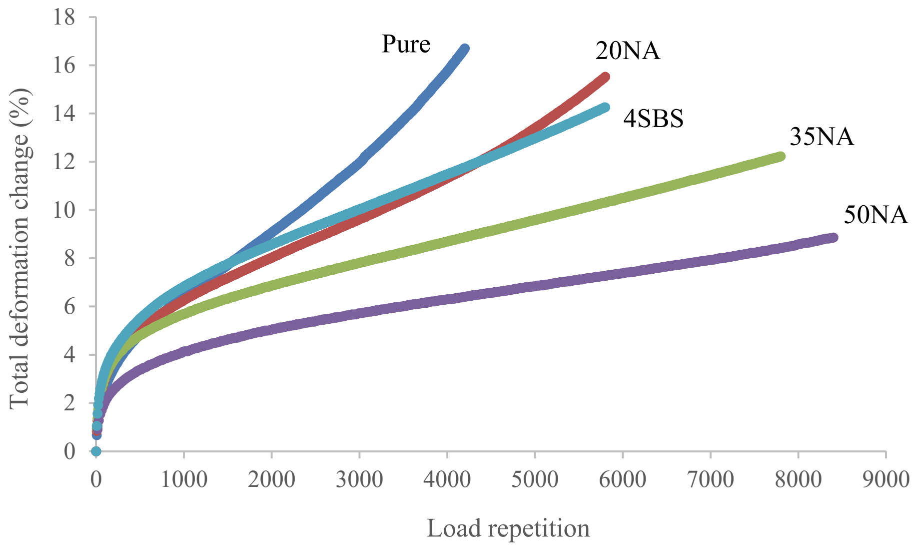

Fig. 13 - Load repetition - strain relationship.

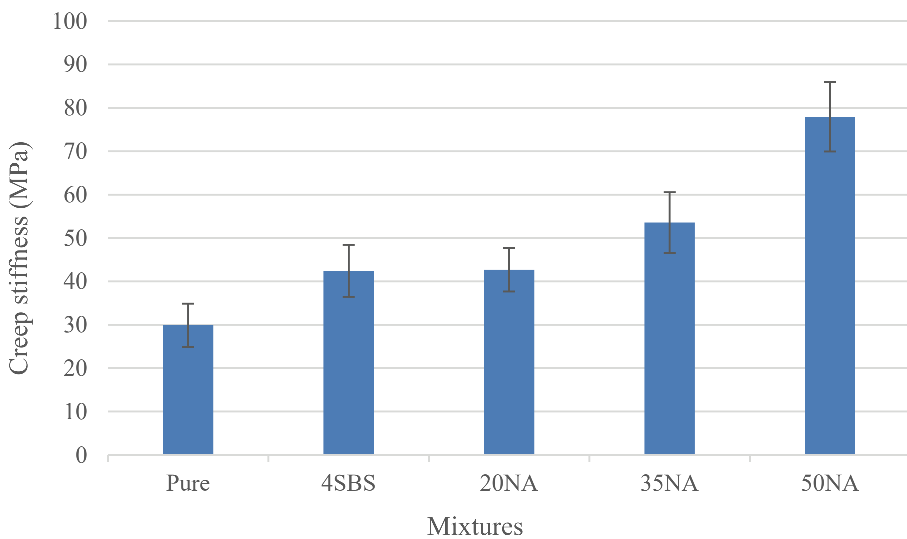

Fig. 14 - Creep stiffness values of mixtures.

terminated until the strains in the samples were passed to the third region. It is seen that 4SBS and 20NA mixtures have similar performance compared to the pure mixture until the 2000 load repetition but the pure mixture has lost its integrity after this repetition. In the pure mixture, the experiment continued until 4200 load repetitions, and the creep stiffness values at the 4200 load repeats were considered in the other mixtures. Fig. 14 shows the change of creep stiffness values. The increase in creep stiffness is evident after 20% natural asphalt content, as in other experiments. The creep stiffnesses of the 20NA, 35NA and 50NA mixtures are 1.4, 1.8 and 2.6 times higher than the pure mixture, respectively. It is clear that natural asphalt mixtures will be highly resistant to permanent deformations caused by repetitive loads at high temperature relative to the pure mixture. The 4SBS mixture gives a creep stiffness value of 1.4 times the pure mixture. The creep stiffness of the 4SBS mixture can be obtained by 22% natural asphalt modification as shown in Fig. 15. When 8% strain level at which 50NA samples reach at the end of the test is considered as a threshold value, it was determined that pure, 4SBS, 20NA, 35NA and 50NA samples have 1600, 1632, 1976, 3216 and 7136 load repetition numbers, respectively. It can be concluded that pure, 20NA and 4SBS mixtures do not behave very differently at this strain level which can be occurred at the early stage of the pavement.

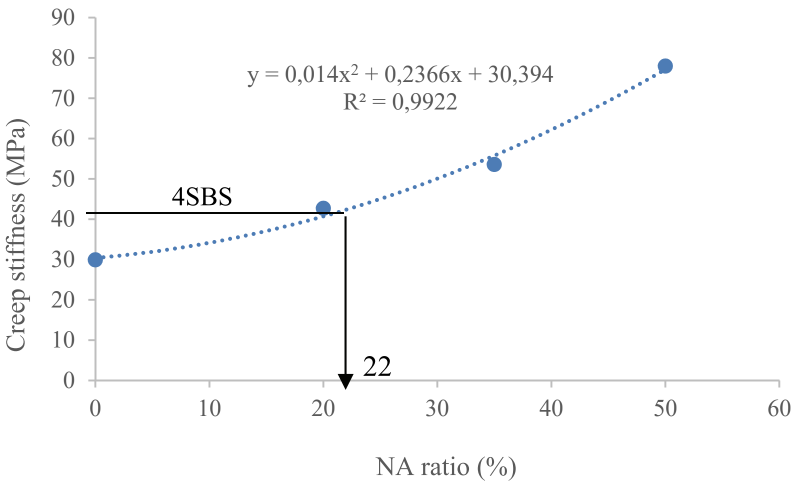

Fig. 15 - The change of creep stiffness against NA ratio at 4200 load repeats.

Table 5 - Equations used to determine the flow number of mixtures.

Mixture	**Equation**	**R^2**	**FN**
Pure	$y = -0.0098x^2 + 65.453x + 19095$	0.993	3339
20NA	$y = -0.0059x^2 + 63.401x + 19288$	0.997	5373
35NA	$y = -0.004x^2 + 68.604x + 20554$	0.998	8576
50NA	$y = -0.0044x^2 + 89.533x + 31903$	0.998	10174
4SBS	$y = -0.0047x^2 + 58.615x + 16550$	0.998	6235

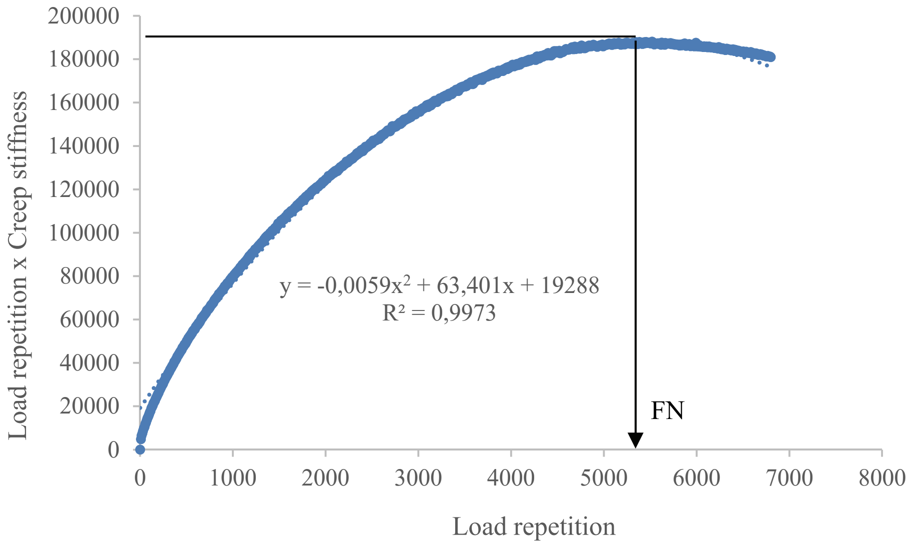

Fig. 16 - Determination of the flow number (FN).

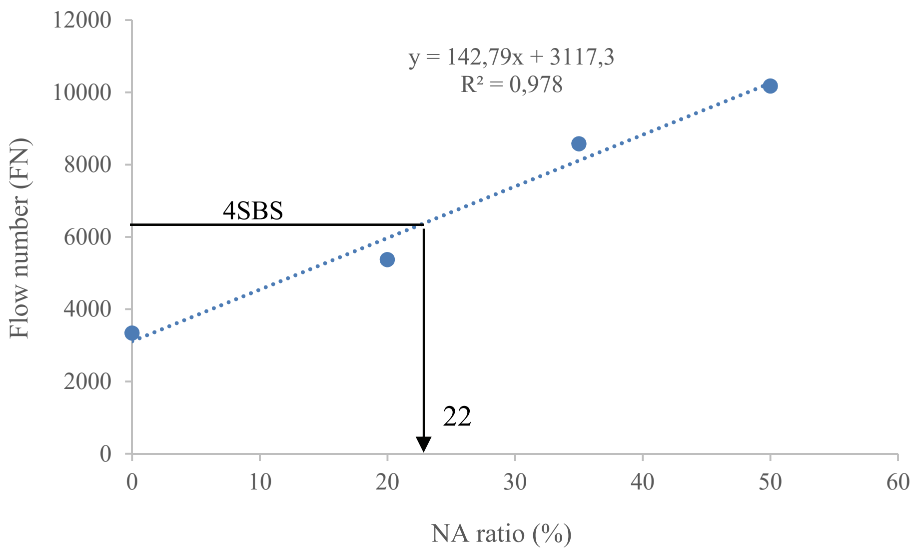

Fig. 17 - The change of the flow number against the NA ratio.

The flow number (FN), which is closely related to the rutting resistance of the mixtures, is determined as the turning point of the curve in the graph of the load repetition product creep stiffness versus load repetition [30,31]. Fig. 16 shows a graph of the 20NA mixture as an example. The second-degree parabolic equation which is adapted to the points that make up the graph was determined and given in Table 4. The change of FN and natural asphalt content is given in Fig. 17. The flow number shows a linear increase with the increase of natural asphalt content. The flow numbers of the 20NA, 35NA and 50NA mixtures were 1.6, 2.5 and 3 times higher than the pure mixture, respectively. The flow number of 4SBS mixture is 1.9 times greater than the pure mixture. The flow number of the 4SBS mixture can be achieved by 22% natural asphalt modification as shown in Fig. 17.

4. CONCLUSION

In the study, mechanical tests were applied to bituminous mixtures prepared with binders modified by 20%, 35% and 50% Iraq natural asphalt and 4% SBS by bitumen weight and the performance of the mixtures were compared. The results are given below.

The 4SBS mixture gave only 6.7% greater stability than the pure mixture, while 20NA, 35NA and 50NA mixtures gave 7%, 19% and 32% greater stability, respectively. According to the stability / flow rates, the 50NA mixture shows 14% more rigid behaviour than the pure mixture. The stability of the 4SBS mixture is achieved by 14% NA modification.

According to the indirect tensile strength test, the 50NA mixture gave 180% higher ITS value than the pure mixture. ITS experiment, which is in static mode, emphasizes the effectiveness of additive usage according to Marshall experiment. The performance of the 4SBS mixture in terms of ITS is obtained by 14% NA modification.

ITSM values, which are a measure of the load distribution capability, were determined to increase significantly in natural asphalt modified mixtures. Especially after the 35% NA content, the increase in the ITSM values of the mixtures is much more. The performance of the 4SBS modified mixture in terms of ITSM is obtained by modification of 19% NA.

In the indirect tensile repetitive loading test, 20NA and 35NA mixtures gave 4.1 and 14.5 times more repeats than the pure mixture, respectively. 50NA modified mixture was not broken even at 32000 load repetition. At 0.7 mm deformation level, the 50NA mixture has 222 times greater load repeats than the pure mixture. The performance of the 4SBS mixture may be obtained with 13% NA modification.

The creep stiffness and flow numbers of the mixtures were determined in the dynamic creep test. Accordingly, the creep stiffness of the 20NA, 35NA and 50NA mixtures were found to be 1.4, 1.8 and 2.6 times higher than the pure mixture, respectively. According to the flow numbers, these ratios are 1.6, 2.5 and 3 times respectively. The performance of the 4SBS mixture according to both creep stiffness and flow number is achieved by 22% NA modification.

Natural asphalt modification has been found to be very successful in improving mechanical properties in static and dynamic experiments. Considering all experiments, it was determined that the 17.3% NA modification gave similar characteristics with 4% SBS modification. The use of natural asphalt, which is 20% cheaper than pure bitumen, rather than SBS, which is about 5-6 times more expensive than pure bitumen [32, 33], will provide a very significant economy without adversely affecting the overall performance.

Acknowledgments

The authors would like to thank FÜBAP Coordination Unit for their support for the Performance Project with the number MF.19.17.

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