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INVESTIGATION OF MECHANICAL PROPERTIES OF ASPHALT CONCRETE CONTAINING STYRENE BUTADIENE STYRENE

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ABSTRACT

This paper discusses the laboratory design of continuously graded asphaltic concrete mixtures containing styrene butadiene styrene (SBS). The purpose of this study is to evaluate mechanical properties of control and SBS modified asphalt mixtures. Furthermore rheological properties of conventional and modified asphalt in different SBS content were studied. AC-10 was used as binder in the study. Two different aggregate, limestone and basalt, were used in the experiments to evaluate the effect of aggregate–binder interaction. Marshall stability, indirect tensile strength, indirect tensile stiffness modulus and static creep stiffness tests were performed on mixtures. The specimens prepared with limestone showed greater mechanical properties than that of the specimens prepared with basalt. It was determined that for the resilient modulus a linear relation and for the creep stiffness a polynomial relation is exists with SBS content. The higher SBS content provides the higher properties however the increasing rate of improvement properties by adding SBS is decreased after 5 percent. So the effective and economical value of SBS content is considered as 5 percent by weight of binder.
Keywords: Asphalt concrete, SBS, mechanical properties.

STİREN-BUTADİEN-STİREN İÇEREN ASFALT BETONUNUN MEKANİK ÖZELLİKLERİNİN İNCELENMESİ

ÖZET

Bu çalışma styrene butadiene styrene (SBS) içeren sürekli gradasyona sahip asfalt betonu karışımlarını ele almaktadır. Çalışmanın amacı, normal ve SBS katkılı asfalt karışımların mekanik özelliklerinin değerlendirilmesidir. Geleneksel ve farklı SBS içeriklerindeki modifiye bitümün reolojik özellikleri ayrıca incelenmiştir. Bağlayıcı olarak AC-10 kullanılmıştır. Deneylerde, agrega ve bağlayıcı etkileşimini değerlendirmek amacıyla kalker ve bazalttan oluşan iki farklı agrega kullanılmıştır. Bitümlü karışımlar üzerinde Marshall stabilite, indirek çekme mukavemeti, rijitlik modülü ve statik sünme rijitliği deneyleri yapılmıştır. Kalker ile hazırlanan numuneler bazalt ile hazırlanan numunelere göre daha yüksek mekanik özellikler göstermiştir. Rijitlik modülü ile SBS içeriği arasında lineer, sünme rijitliği ile SBS içeriği arasında ise polinomal bir ilişki olduğu tespit edilmiştir. Yüksek SBS içeriği yüksek mekanik özellikler sergilemektedir fakat SBS ilavesiyle mekanik özelliklerde meydana gelen iyileşme artışı %5 SBS içeriğinden sonra düşmeye başlamaktadır. Dolayısıyla etkili ve ekonomik SBS oranının asfalt ağırlığınca % 5 olduğu düşünülmektedir.
Anahtar Sözcükler: Asfalt betonu, SBS, mekanik özellikler.

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1. INTRODUCTION

Quality of bitumen plays a key role in the performance related properties of asphalt mixes. The rapid increase in the number of commercial vehicles combined with overloading of trucks and substantial variation in daily and seasonal temperature of the pavement have been responsible for premature failure of the flexible pavements in all over the world. In consideration of these factors and in order to improve pavement performance, polymer-modified asphalts (PMA) have been developed during the last few decades. The quality of bitumen can be improved by adding polymers to the bitumen. Unsaturated thermoplastic elastomers like styrene–butadiene–styrene (SBS) block copolymers are probably the most commonly used polymers. They enhance asphalt's elastic recovery capacities and, therefore, its resistance to permanent deformations.

Many studies have been done on polymer-modified asphalts. Kumar et.al presented laboratory investigations on the performance of the styrene butadiene styrene (SBS) and linear low-density polyethylene (LLDPE) modified mixes. The optimum amount of modifier was determined on basis of SHRP scientific parameter G*/sin d. They concluded that the resistance to permanent deformation in wheel tracking and dynamic creep tests of polymer modified mixes was better than that of unmodified mix and also the fatigue lives of the polymer modified mixes were, respectively, 4.6 and 2.2 times higher than those of the corresponding unmodified asphalt mix [1].

Suart et al. were measured the effect of 11 asphalt binders on the moisture sensitivity of a mixture using the Hamburg Wheel-Tracking Device. The binders consisted of two unmodified asphalt binders, an air-blown asphalt binder, and eight polymer-modified asphalt binders. It was concluded that polymer-modified asphalt binders having the same G*/sinδ can provide different adhesive strengths and/or different resistances to water penetration and noted that reasons for these differences need to be determined [2].

By observing a picture of SBS-modified asphalt magnified about several hundred times by a microscope, its structure can be broadly divided into two types. One is the type in which asphalt forms a continuous phase and the other is the type in which SBS forms a continuous phase. Further, the dispersed particles of asphalt and SBS vary greatly in size from less than 0.001mm to 0.05mm [3]. The performance of SBS-modified asphalt basically improves with an increase in SBS concentration, but is not determined by this alone, i.e., it is greatly affected by the morphology of SBS.

There are several reports about the morphology of SBS-modified asphalt [4-7]. On the other hand Hanyu et.al. investigated its relation with binder properties and mixture performance. This study concluded that for a good storage stability dispersed particles of SBS should have a particle size less than 1μm and added that the mixture properties improved in proportion to the SBS concentration, and also fine dispersion level in excess of morphology has to be obtained in order to make the performance of SBS-modified asphalt fully reflect on the mixture properties. To form a homogeneous blend including polymers, a shearing speed of 4000 rpm, the shearing time of 25 min and 170 °C temperature are recommended [8].

Tayebali et al. investigated the influence of the rheological properties of modified asphalt binders on the load deformation characteristics of the mixtures. Watsonville granite and AR-2000 California Valley asphalt and the same asphalt modified with Microfil 8 and K4460 modifiers were used in this investigation. Micrpfil 8 was form of corbon-corbon black and K4460 was a blend of Kraton 1101 and extender oil. It was concluded that the accumulated plastic strain for mixtures containing modified binders was lower compared to that for the mixture containing conventional asphalt, indicating reduced potential for rutting in mixtures containing modified binders[9].

Shuler et al. were investigated the performance of asphalt concrete containing two types of styrene block copolymers and a ethylene-based polymer (Kraton D4463X, Styrelf, Elvax 150W) each at two levels of concentration in a relatively soft asphalt binder (120/150) with constructed a full-scale experimental pavement. It was concluded that Marshall stabilities and tensile strength ratio tended to increase for polymer modified mixtures. Indirect tensile resilient modulus was not reduced at low temperatures and increased at high temperatures for polymer-modified mixtures [10]. Shuler et.al also conducted indirect tensile test using AC-5 binder and SBS polymer system as one of the modifiers. They reported that, for AC-5 modified with 6 percent SBS polymer, tensile strength increased significantly over that of the straight AC-5 at –21,25, and 41^{o}C [11].

Button et.al. on the basis of stress-controlled fatigue testing and a fracture mechanics evaluation, reported that AC-5 modified with SBS polymer exhibited superior fatigue properties compared to those of straight AC-5 at 20 and 0 ^{o}C [12].

Yoon and Tarrer, determined that aggregates with approximately equal physical properties (e.g., pore volume and structure and surface area) can have very different properties depending on their basic chemistry and mineralogy, which define surface activity. They found substantially higher bonding power for limestone than for quartz gravel even though both had similar physical surface structures [13]. Huang et al. Investigated the impact of different freeze-thaw cycling on the mechanical strength of asphalt-aggregate mixtures. Two significantly different aggregates were used, a limestone and a granite. It was concluded that the mixtures prepared with limestone exhibit good adhesion than granit mixtures [14]. Thomas, indicated that increasing of $CaCO_3$ of aggregate the number of freeze-thaw cycles increases as a parabolic form [15]. Cheng et al. have demonstrated that the bond energy was far greater for the calcareous aggregates than for the siliceous when the bond was quantified as energy per unit of aggregate mass [16].

This paper presents an experimental study of asphalt and asphalt concrete containing SBS. The effect of SBS on rheological properties of binder and mechanical properties of mixtures were evaluated. The test results were compared to those obtained from control mixtures. The effect of different values of SBS on two different aggregate also investigated separately.

2. MATERIALS AND METHODS

2.1. Materials

Two different aggregate were used for the asphalt mixtures. One is the limestone second is the basalt. The basis for selection was to provide a range of performance levels in asphalt concrete. Limestone is known as an alkaline aggregate on the other hand basalt have %45-60 silica content so neither alkaline nor acidic. A crushed coarse and fine aggregate, with maximum size 19 mm, was selected for a dense-graded asphalt mixture. The physical properties of two types of aggregates and the gradation of aggregate are given on Table 1 and Table 2 respectively.

Table 1. Properties of aggregates

Physical properties / Aggregate type	Limestone	Basalt
Abrasion lost (Los Angeles) (%) (ASTM C 131)	25	18
Frost action (with Na_2SO_4) (%) (ASTM C 88)	9.100	6.160
Specific gravity of course aggregate (gr/cm^3) (ASTM C 127)	2.633	2.675
Specific gravity of fine aggregate (gr/cm^3) (ASTM C 128)	2.688	2.694
Specific gravity of filler (gr/cm^3) (ASTM D 854)	2.705	2.735

Table 2. Aggregate gradation

Sieve (mm)	25	19	12.7	9.52	4.76	2	0.425	0.18	0.075
Passing (%)	100	90	72.5	63	49	36.5	19.5	12	4.5

Asphalt cement, AC-10, the most widely used in Turkey was used as a binder for mixture preparation. The physical properties of asphalt are given in Table 3. The asphalt was modified with SBS (Kraton D 1101). The Kraton polymer is manufactured by Shell Chemical Co. The polymer is generically a triblock copolymer of styrene with a butadiene midblock resulting in the familiar SBS type block structure. Three SBS contents were used in this investigation. Values of 3 ,5 and 7 percent SBS content by weight of asphalt were used. The mixing procedures of SBS with asphalt were based on the rheological properties of the asphalt binder [17,18,19]. The asphalt binder was heated to 135 ^{o}C for 1 h and then subjected to 1,5h of mixing time with SBS at 175 ^{o}C and 500 rpm shear rate. It was expected that this processes causes aging therefore the neat asphalt also heated with same procedure before using to make good comparison.

Table 3. Properties of asphalt cements

Binder/Test	Specific gravity (g/cm^3) ASTM D-70	Penetration (0,1 mm) ASTM D-5	Ductility (cm) ASTM D-113	Softening point (^{o}C) ASTM D-36
Control asphalt AC-10	1.022	88	>100	48.4
%3 SBS modified	1.031	80	69	53.5
%5 SBS modified	1.038	59	53	71.4
%7 SBS modified	1.042	50	42	78.7

2.2. Methods

A Marshall mix design was carried out to determine the optimum binder content of each mixture for the basalt and limestone without SBS. For the mixes containing the modified asphalt binders, binder contents were adjusted according to the binder specific gravity so that the volume of asphalt in the mixture remained same. The test specimens were compacted using the standard Marshall hummer with 75 blows on each side of cylindrical samples (10.16 cm in diameter and 63.5 ±1.5 cm thick). The result of Marshall mix design is given in Table 4. Each value was obtained with three identical specimens.

Marshall stability and flow, indirect tensile stiffness modulus ITSM (S_m), creep stiffness (S) and indirect tensile strength tests were applied in order to investigate the effects of the different values of SBS on the pavement.

3. PERFORMANCE TESTS

Both control and modified mixtures containing limestone and basalt were evaluated with the Marshall stability test, indirect tension strength test, indirect tension test (resilient modulus), and static creep test. Tests were performed at optimum asphalt content for all mixtures.

Table 4. Summary of the Marshall mix design results

	Control mix	%3 SBS	%5 SBS	%7 SBS
Asphalt cement (%)	5.40 *5.20*	5.44 *5.24*	5.48 *5.28*	5.51 *5.30*
Stability (kN)	16.70 *17.10*	18.1 *18.5*	19.7 *20.2*	21.2 *21.9*
Flow (mm)	3.7 *3.7*	3.9 *3.9*	3.7 *3.6*	3.6 *3.5*
Bulk specific gravity (gr/cm^3)	2.403 *2,411*	2.406 *2,414*	2.405 *2,415*	2.405 *2,414*
Maximum specific gravity (gr/cm^3)	2.503 *2.509*	2.504 *2.511*	2.505 *2.511*	2.505 *2.512*
Void content (%)	3.969 *3.935*	3.925 *3.867*	3.972 *3.833*	4.013 *3.892*
Voids filled asphalt (%)	75.221 *74.769*	76.077 *75.749*	76.369 *76.452*	76.453 *76.444*
Voids filled mineral aggregate (%)	16.016 *15.594*	15.963 *15.524*	16.010 *15.502*	16.045 *15.553*

Note : The values written in italic form are for limestone specimens.

3.1. Marshall Stability and Flow Tests

The Marshall test is an empirical test in which cylindrical specimens100 mm diameter by approximately 63,5 mm.high are immersed in water at 60 ^oC for 30-40 min. and then loaded to failure using curved steel loadings plates along a diameter at a constant rate of compression of 51 mm/min. the ratio of stability (kN) to flow (mm) is termed the Marshall quotient (MQ) and is an indication of the stiffness of the mix [20]. It is well recognized that the MQ is a measure of the materials resistance to shear stresses, permanent deformation and hence rutting [21]. High MQ values indicating a high stiffness mix with a greater ability to spread the applied load and resist creep deformation. The MQ values of the mixtures were given in Fig.1.

Not a significant differences were obtained between %3 SBS modified mixtures and control mixtures. However by adding %7 SBS to mixtures increased the MQ about %30 and 35 for basalt and limestone mixtures respectively compared to control ones.

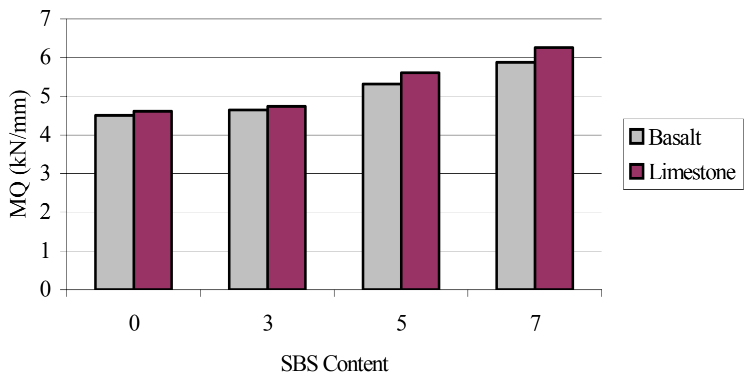

Figure 1. MQ values of the mixtures

3.2. Indirect Tensile Strength Test

In the indirect tensile strength test (ITS), cylindrical specimens are subjected to compressive loads, which act parallel to and along the vertical diametral plane using the Marshall loading equipment. This type of loading produces a relatively uniform tensile stress, which acts perpendicular to the applied load plane, and the specimen usually fails by splitting along the loaded plane [22]. Based upon the maximum load carried by a specimen at failure, the ITS in kPa is calculated from the equation 1:

$$ITS = 2F / \pi L D \tag{1}$$

Where F is the peak value of the applied vertical load (repeated load) (N), L is the mean thickness of the test specimen (mm); D is the specimen diameter (mm). This test was applied at 25 ^{o}C on briquettes both on conventional mixture and modified ones. Two types of aggregate one of which was basalt and the another was limestone were used. The average values of indirect tensile strengths of the mixtures (24 mixture) were illustrated in Fig. 2.

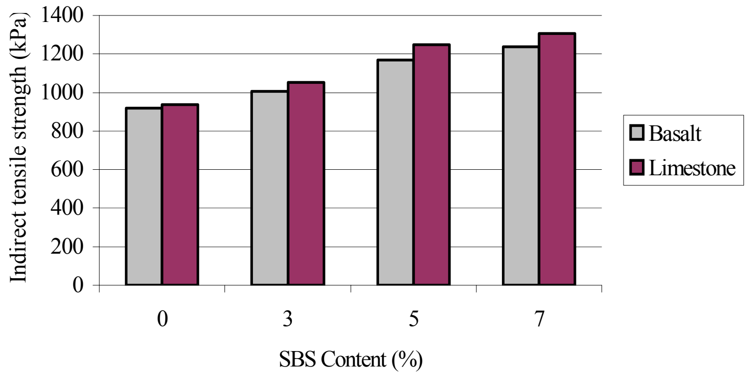

Figure 2. Indirect tensile strength of the mixtures

The typical values of the indirect tensile strength of specimens prepared with basalt ranged from 918 to 1237 kPa. As for the specimens prepared with limestone this values ranged from 937 to 1305 kPa. The limestone specimens showed greater indirect tensile strength than the basalt specimens. The indirect tensile strength values increased with increasing the SBS content for both limestone and basalt specimens. A higher tensile strength corresponds to a stronger low temperature cracking resistance [23]. In this study, the indirect tensile strengths of the modified mixtures were higher than the control mix. This indicates that the mixtures containing additives have higher values of tensile strength at failure indirect tensile strength under static loading. This would further imply that modified mixtures appear to be capable of withstanding larger tensile strains prior to cracking. The limestone specimens modified with %7 SBS gave the highest strength. However when considering the increasing rates it is obvious that the increasing rate between %3 and %5 SBS content is higher than that of the %5 and %7. So it can be concluded that the efficient SBS content is between %3 and %5 for this test method.

3.3. Indirect Tensile Stiffness Modulus Test

Stiffness (resilient) modulus of asphalt mixtures, measured in the indirect tensile mode is the most popular form of stress–strain measurement used to evaluate elastic properties and considered to be a very important performance characteristic of the pavement. It is a measure of the loadspreading ability of the bituminous layers and controls the level of traffic induced tensile strains at the underside of the roadbase, which are responsible for fatigue cracking together with the compressive strains induced in the subgrade that can lead to permanent deformation. This test also provides an important input for the structural design of a pavement system using a multi layer elastic theory for design. The indirect tensile stiffness modulus (ITSM) test defined by BS DD 213 [24] is a non-destructive test and has been identified as a potential means of measuring this property. The ITSM S_m in MPa is defined as

$$S_m = F(R + 0{,}27) / LH \quad (2)$$

Where F is the peak value of the applied vertical load (repeated load) (N), H is the mean amplitude of the horizontal deformation obtained from 5 applications of the load pulse (mm), L is the mean thickness of the test specimen (mm), and R is the Poisson's ratio (assumed 0.35). The test was done deformation controlled using Universal testing machine, which is seen in Fig.3. The magnitude of the applied force is adjusted by the system during the first five conditioning pulses such that the specified target peak transient diametral deformation is achieved. A value is chosen to ensure that sufficient signal amplitudes are obtained from the transducers in order to produce consistent and accurate results. The value was selected 7 micrometers in this test.

Figure 3. Universal testing machine

During testing, the rise time, which is measured from when the load pulse commences and is the time taken for the applied load to increase from zero to a maximum value was set at 124 ms. The load pulse, application is equated to 3.0 s. The test is normally performed at 20 ^{o}C. The average results of the resilient modulus are shown in Fig 4. Each value was obtained with 3 specimens.

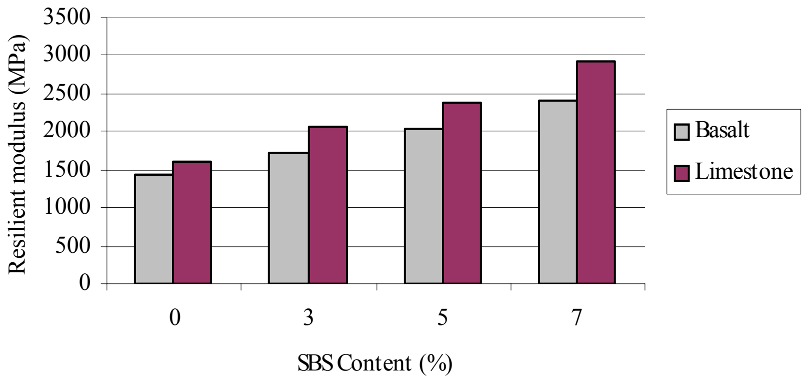

Figure 4. Resilient modulus of the mixtures

The resilient modulus values obtained from this study ranged from 1431 to 2423 MPa for basalt specimens and 1615 to 2922 for limestone specimens. The specimens prepared with limestone exhibited higher stiffness than basalt specimens. For both mixtures the resilient modulus values were increased while SBS content increased. The increasing rate of the resilient modulus values continued with the SBS increment. According to the indirect tensile test limestone mixtures prepared with %7 SBS showed greater elasticity modulus as 80% than that of the control mixtures. For the basalt specimens the resilient modulus value increased about %70 by adding %7 SBS to mixtures. The time-strain relation is given in Fig.5 and Fig.6 respectively for basalt and limestone mixtures. The curves were obtained from the fifth pulse during the test and also each curve is the average of three specimens. The time interval was given 0-400 ms in which the load pulse is efficient in the horizontal axes of the figures .

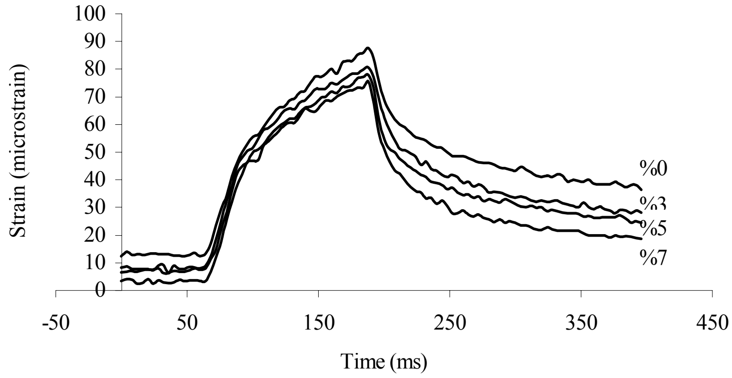

Figure 5. Time-strain relation of basalt specimens for ITS test

It is seen that from the Fig.5 and Fig.6 that the recoverable strain is increased with the SBS increment for basalt and limestone mixtures. However limestone specimens have much recoverable strain than the basalt specimens.

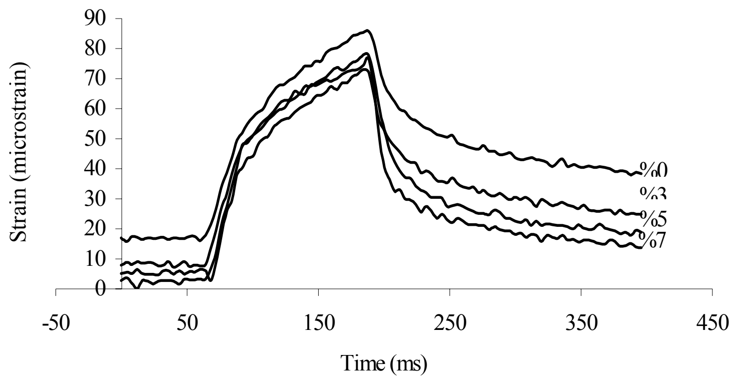

Figure 6. Time-strain relation of limestone specimens for ITS test

3.4. Static Creep Test

Test has been used to determine permanent deformation of asphalt mixtures. Creep deformation of a cylindrical specimen under a uniaxial, static load is measured as a function of time. This test gives results, which allow the characterizations of the mixes in terms of their long-term deformation behavior [25]. Creep stiffness (S) is important to shed valuable insight into asses rutting. The creep stiffness was calculated from following equations:

$$\varepsilon c_t = (L2_t - L1) / G \tag{3}$$

$$\sigma = F / A \tag{4}$$

$$S = \sigma / \varepsilon c \tag{5}$$

Where εc_t is the accumulated axial strain (creep) at time t, $L2_t$ is the displacement level of the transducers at time t, L1 is the initial zero reference displacement of the transducer before the full loading stress is applied, G is the initial specimen length, σ is the vertical stress, F is the vertical force, A is the cross-sectional area of the specimen, S is the creep stiffness at time t. The test was carried out with UTM. The test was performed at 40 ^{o}C, and the specimens preloading for 2 min. at 10 kPa as a conditioning stress and constant loading stress during the test was equal to 100 kPa in 3600 s. The values of static creep curve obtained from the test are given in Fig. 7 and Fig.8 for the basalt and limestone specimens respectively.

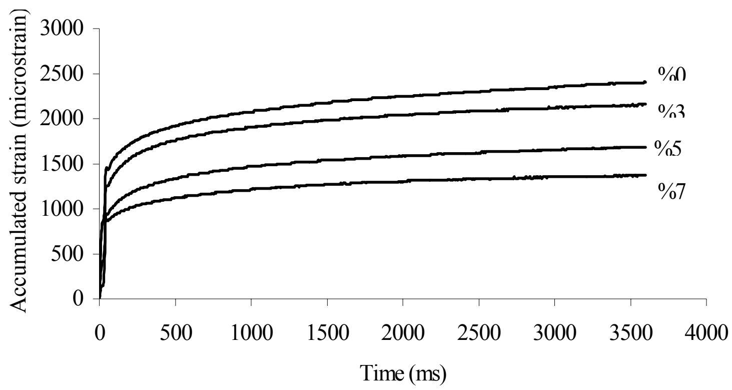

Figure 7. Time versus strain for basalt specimens in static creep test

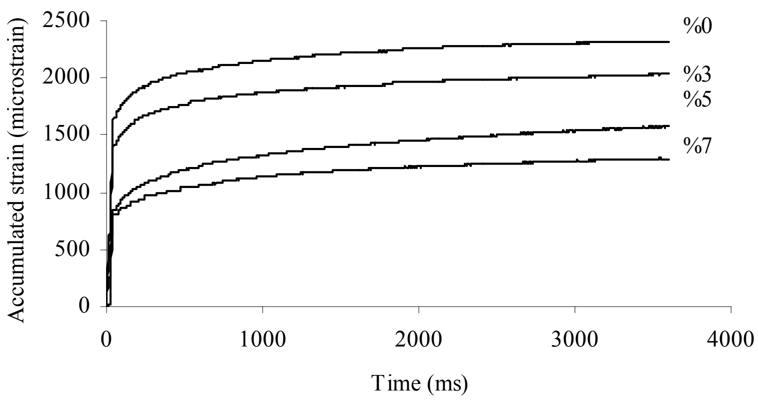

Figure 8. Time versus strain for limestone specimens in static creep test

The deformations exhibited a rapid increase in the beginning of the test due to air voids in the mixtures and the deformation rate was decreased while test was running according to air void reduction. Not a significant difference was obtained about the time-strain relation for the basalt and limestone mixtures. The creep stiffness values of mixtures were given in Fig. 9.

The creep stiffness of the mixes was increased exponential with the SBS increment according to creep test. This would further imply that SBS modified mixtures appear to be capable of withstanding to rutting. This results occurred due to binder rheological properties. The softening point of binder is increased with SBS. As the test performed at 40 ^{o}C the mixtures modified with %7 SBS of which softening point is high gave the highest creep stiffness. The creep stiffness were increased about %86 and %105 for the basalt and limestone mixtures respectively compared to control mixtures. Whether a relation between stiffness modulus and SBS content also between creep stiffness and SBS content were investigated in Fig.10 and Fig.11. It is found that a linear relation exist between stiffness modulus and SBS content however a polynomial relation is exist between creep stiffness and SBS content. Consequently the effect of SBS on creep stiffness is more significant than on stiffness modulus.

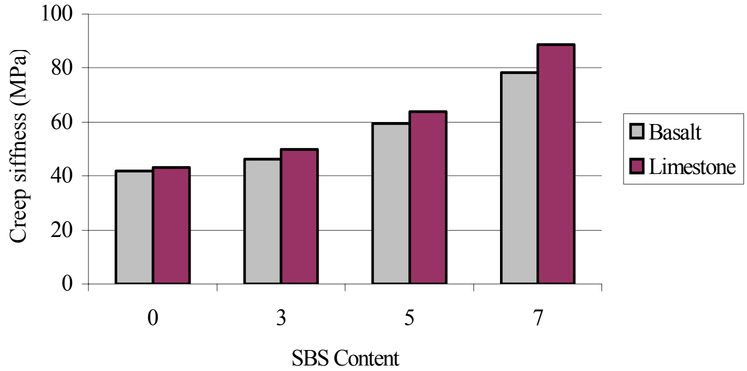

Figure 9. Creep stiffness of the mixtures

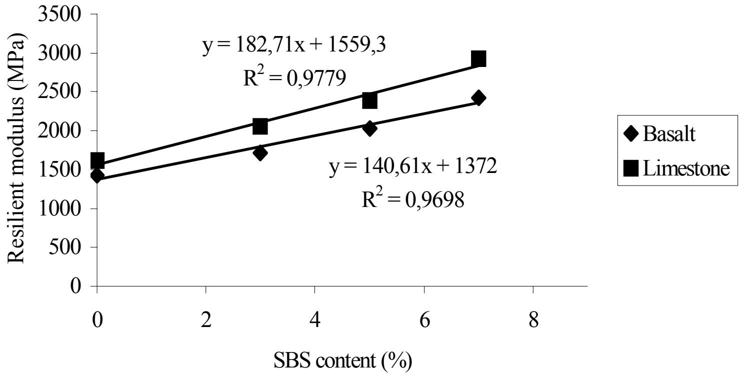

Figure 10. SBS content - Stiffness modulus relation

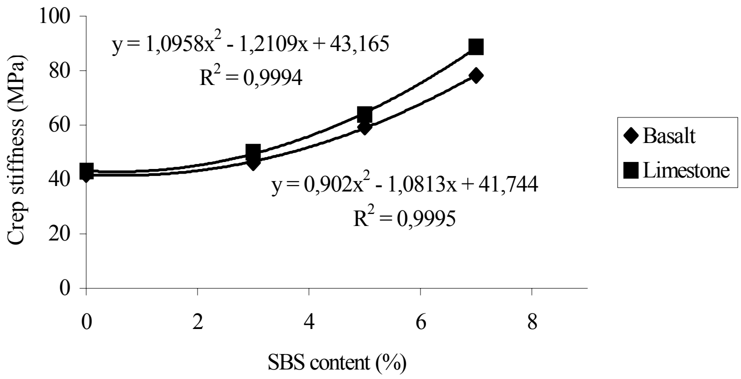

Figure 11. SBS content – Creep stiffness relation

4. CONCLUSION

For the mixtures evaluated in this study the following conclusions are derived.

According to Marshall stability test not significant differences were obtained between %3 SBS modified mixtures and control mixtures. However by adding %7 SBS to mixtures increased the MQ about %30 and 35 for basalt and limestone mixtures respectively compared to control ones.

The limestone specimens showed greater indirect tensile strength than the basalt specimens. The indirect tensile strength values increased with increasing the SBS content for both limestone and basalt specimens. Considering the increasing rates it is seen that the increasing rate between %3 and %5 SBS content is higher than that of the %5 and %7. So it can be concluded that the efficient SBS content is between %3 and %5 for indirect tensile strength test

According to the indirect tensile test limestone mixtures prepared with %7 SBS showed greater elasticity modulus as 80% than that of the controll mixtures. For the basalt specimens the resilient modulus value increased about %70 by adding %7 SBS to mixtures. Limestone specimens have much recoverable strain than the basalt specimens. A linear relation is exist between resilient modulus and SBS content

The creep stiffness of the mixes was increased with the SBS increment according to creep test and a polynomial relation exist between creep stiffness and SBS content. The creep stiffness were increased about %86 and %105 for the basalt and limestone mixtures respectively compared to control mixtures It is considered that the increasing softening point of binder play a important role on creep stiffness.

In general, the mechanical properties of SBS modified mixes are superior to those of the control mixes. Especially the limestone mixes showed the higher mechanical properties than basalt mixes. Because of limestone is calcareous aggregates it is assumed that a strong adhesion occurred between limestone and asphalt, which have acid components, than those of basalt which is a siliceous aggregate according to chemical adhesion theory and surface energy-molocular orientation theory. Increasing of adhesion improved the mechanical properties of mixtures. The higher SBS content provides the higher properties however the increasing rate of improvement properties by adding SBS is decreased after 5 percent. So the economical value of SBS content is considered as 5 percent by weight of binder.

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