Investigating the Effects of Temperature and Loading Frequency on the Resilient Modulus of SBS Polymer Modified Asphalt Concrete in Dry and Saturated Conditions

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Abstract

Resilient modulus of pavement materials is a key property required for the pavement thickness design. This paper describes the results of an experimental study on the effects of temperature and loading frequency on the resilient modulus of a SBS polymer modified asphalt concrete under dry and saturated conditions. Dynamic creep tests were conducted on dry and saturated specimens of the mixture over a range of temperatures (-5, 5, 20 and 40˚C) and loading frequencies of 0.5, 1, 5 and 10Hz, and the variation of resilient modulus with the number of loading cycles has been evaluated. The results show that, in dry condition, the resilient modulus increases with increasing loading frequency, while, in saturated condition, a slight increase of resilient modulus with loading frequency was observed only at 40˚C. It is also found that, in both the dry and saturated conditions, the effect of loading frequency on the resilient modulus decreases with decreasing temperature. Therefore, the temperature of 40˚C was recommended for investigating the effect of loading frequency on the resilient modulus. In addition, a three-stage model was used for the resilient modulus. It is found that the logarithmic function is more appropriate for prediction of resilient modulus in stage 1.

Keywords: SBS polymer, resilient modulus, asphalt concrete, moisture damage

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1. Introduction

In recent years, the empirical pavement design methods have been replaced by mechanistic-empirical design methods [Huang, 2004]. The mechanistic-empirical design methods are commonly based on elastic theory, in which, the elastic properties of the materials are used as input data [Tayfur et al. 2007]. The resilient modulus is identical to the elastic modulus in the theory of elasticity and used for determination of the pavement responses under traffic loading in multilayer elastic method of analysis [AUSTROADS, 2010]. In the mechanistic-empirical (M-E) design methods, the pavement responses are related to the pavement performance through transfer functions and used for determination of the new pavement thickness or the remaining life of an existing pavement [AASHTO 1996, ASTM 2011].

Most of the pavement materials behave as an elasto-plastic material, for which a plastic deformation is experienced after each loading cycle. However, at the stress levels sufficiently lower than the material strength, and after a number of loading cycles, the total deformation is recoverable and they can be considered as elastic material [Mohamed et al. 2003]. Figure 1 shows the behavior of a pavement material under repeated loading cycles. As can be seen, significant plastic strain occurs at the initial loading cycles. However, the plastic strain decreases with increasing loading cycles, and, after a 100 to 200 loading cycles, all of the strain occurred under a load pulse is recoverable. Equation (1) can be used for determination of the resilient modulus (M_R) under repeated dynamic loading [Huang 2004].

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad (1)$$

Where, σ_d is the deviator stress, and ε_r is the recoverable strain.

The resilient modulus test is a non-destructive test method which can be used for evaluation of the materials quality. The moisture damage of asphaltic mixtures may be evaluated using the resilient modulus (under repeated loadings), the indirect tensile strength and the failure strain (at a constant rate of loading) (NCHRP 465). Resilient modulus of asphaltic mixtures is a general form of the relation between stress and strain for evaluation of elastic parameters [Moghadas Nejad et al. 2012]. It is directly affected by the reduction of the adhesion and cohesion, and, it is generally believed that the resilient modulus is more sensitive to the changes in the properties of asphaltic binder [Ameri et al. 2013].

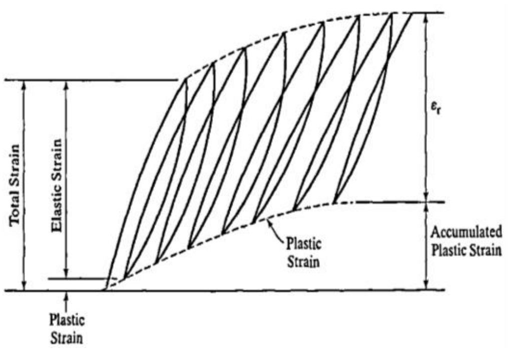

Figure 1. Strain under cyclic loading [Huang, 2004]

Moisture damage is defined as the loss of strength and durability of asphaltic mixtures due to the effect of moisture, which leads to the distress of stripping [Mehrara and Khodaii 2013, Mohammadzadeh Moghadam et al. 2014]. Moisture damage can be classified into two basic processes of, losing cohesion and losing adhesion [Shah, 2003; Kim and Coree, 2005]. Performance of hot mix asphaltic mixtures against the moisture damage is a complex issue and has been investigated over the last six decades. During this period, in an effort to reach a reliable test method to be consistent with the field performance, many test methods have been developed by researchers. The majority of these test methods are based on the interaction of the bitumen, aggregate particles and water. The dynamic creep test under different moisture conditions can well simulate the realistic field conditions. Therefore, this test method is quite appropriate for evaluation of the long term moisture damage of asphaltic mixtures [Khodaii and

Mehrara 2009; Mehrara and Khodaii 2011; Khodaii et al. 2014].

2. Literature Review

In the recent years many researchers have focused on investigating the resilient modulus because of its importance in old and new AASHTO pavement thickness design, and being as an appropriate index for describing the unbound aggregate and asphalt mixtures behavior. Depending on the type of test, material properties and environmental conditions, many factors are effective on the resilient modulus of asphalt mixtures (NCHRP 285). In the following paragraphs, some of the recent studies in this field are presented.

The shape of loading pulse and loading duration are among the effective factors in determination of the resilient modulus in laboratory [Huang 2004]. Therefore, Fakhri and Ghanizadeh investigated these factors on the resilient modulus of SBS modified asphalt concrete and showed that the beneficial effect of the modifier on the resilient modulus of the mixture is highly dependent on the temperature, loading pulse shape and loading frequency. In addition, they found that, for the ratio of the rest time to the loading time equal or greater than 9, more reliable resilient modulus can be obtained [Fakhri and Ghanizadeh, 2014; Ghanizadeh and Fakhri, 2013]

Jahromi and Khodaii investigated the effects of the maximum nominal size of aggregate particles, diameter and thickness of specimen, loading time and pulse shape on the resilient modulus of asphalt concrete. They found that, the maximum nominal size of aggregate particles is the most effective factor on the resilient modulus followed by the loading time, diameter and thickness of the specimen, in order [Jahromi and Khodaii, 2009].

Behiry conducted an experimental work for evaluation of the stripping of asphalt concrete mixtures containing cement and lime at the air voids content of 1.5, 4 and 6%, and different cycles of saturation and degrees of saturation. He found that, the resilient modulus decreases with increasing air voids content and cycles of saturation. In addition, it was found that, the mixtures containing cement and lime had a higher resilient modulus than the control mixture without the additives [Behiry, 2012].

Chen and Huang investigated the resilient modulus of a dense graded mixture under four different conditions of, one and two cycles of freeze-thaw, and 500 and 1000 cycles of pore pressure using the moisture induced stress tester (MIST). A reduction of the resilient modulus of the mixture was observed under all of the four conditions [Chen and Haung, 2008].

Erol Iskender et al. investigated the effects of SBS polymer and anti-stripping additive of fatty Amine on the asphaltic mixtures under different moisture conditions of, submerging in water, freeze-thaw cycles and a combination of submerging in water and freeze-thaw cycles. The results showed that the resilient modulus of all modified mixtures decreases under the moisture conditions [Erol Iskender et al. 2012, Ameri et al. 2013] investigated the efficiency of Zycosoil and hydrated lime on the improvement of the resistance of asphalt concrete against moisture damage under cycles of freeze-thaw, and found that, the ratio of the resilient modulus increases for both additives. They also compared the performance of asphalt concrete made by siliceous and limestone aggregate against moisture damage and found that, in dry condition, the resilient modulus of the mixtures made with siliceous aggregates is higher than that made of limestone aggregates. However, under the cycles of freeze-thaw, more damage was observed in the mixture made of siliceous aggregate than that made of limestone.

Gokhale et al. [2005] and Khodaii and Mehrara [2009] found that, the ratio of the creep modulus to the resilient modulus can be used as an index for the rate of plastic deformation to the densification of asphaltic mixtures. Dehnad et al. [2013] used this ratio as an index for evaluation of the moisture damage at high temperatures.

Wang et al. [2009] found that the modulus of graded aggregate materials increases with increasing dynamic load repeating time and is confined to an asymptote when dynamic load level is constant. Moreover, although the power and logarithmic function can be well fitted to the plot of resilient modulus, however, hyperbolic function is more appropriate.

The effects of different factors such as aggregate and bitumen properties, on the resilient modulus of asphaltic mixtures have been investigated in previous studies. The main objective of this study was to investigate the effects of loading frequency and temperature (keeping the other parameters, i.e., aggregate and bitumen characteristics, constant) on the resilient modulus of SBS-modified asphalt mixtures using the dynamic creep tests. It is also attempted to develop a model for describing the variation of resilient modulus with loading cycles at different loading frequencies and temperatures.

3. Materials and Methods

The materials used in this research include the aggregates, bitumen and SBS polymer. Crushed siliceous aggregates were obtained from a local asphalt plant. Based on the Iranian specifications for pavement materials, the gradation with the maximum nominal size of 19mm was used for the aggregates of the mixtures. Figure 2 shows the limits of the gradation defined by specification and the gradation of the mixture used in this research.

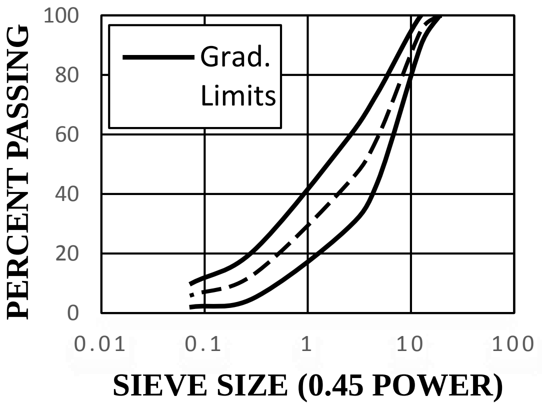

Figure 2. Aggregate gradation used and the gradation limits

Tables 1 and 2 show the physical and mechanical properties of the aggregates. 85/100 penetration grade bitumen, modified with 4.5% of SBS polymer has been used as the binder for making the asphalt concrete mixtures. Marshall Mix design method was used for determination of the optimum binder content of the mixtures. 96 specimens were fabricated with the optimum binder content, using Marshall Compactor which were compacted by applying 55 blows on each end (specimens fabricated using 55 blows had an air voids content between 6 to 8%). Dynamic creep tests were conducted at 4 different frequencies and temperatures on dry and saturated specimens. One set of three replicates were tested in each condition (Table 3).

Table 1. Mechanical Properties of Aggregates

Property	Value (%)	Standard
Los Angeles abrasion loss	25	ASTM C131 (ASTM 2006)
Particles fractured in 1 face	87	ASTM D5821 (ASTM 2013a)
Particles fractured in 2 face	93	ASTM D5821 (ASTM 2013a)
Aggregate coating	95	AASHTO T182 (AASHTO 1984)
Flakiness	10	BS EN 933-3 (BS 2012)
Sand equivalent	85	ASTM D2419 (ASTM 2009)
Sodium sulphate soundness	0.4	ASTM C88 (ASTM 2013b)

Table 2. Physical Properties of Aggregates

Property	Value	Standard
Coarse aggregates (retained on sieve #8)		
Bulk specific gravity (g/cm^3)	2.325	ASTM C127-04 (ASTM 2004a)
Apparent specific gravity (g/cm^3)	2.502	ASTM C127-04 (ASTM 2004a)
Water absorption (%)	1.60	ASTM C127-04 (ASTM 2004a)
Fine aggregates (passing sieve #8 and retained on sieve #200)		
Bulk specific gravity (g/cm^3)	2.316	ASTM C128-04 (ASTM 2004b)
Apparent specific gravity (g/cm^3)	2.498	ASTM C128-04 (ASTM 2004b)
Water absorption (%)	1.60	ASTM C128-04 (ASTM 2004b)
Filler (passing sieve #200)		
Bulk specific gravity (g/cm^3)	2.312	AASHTO-T100 (AASHTO 2006)
Apparent specific gravity (g/cm^3)	2.425	ASTM C128-04 (ASTM 2004b)

Table 3. Experimental Design

Experimental variables	Number of levels	Variable levels
Loading frequency	4	0.5, 1, 5, 10 Hz
Temperature	4	40, 20, 5, -5 ˚C
Moisture condition	2	Dry and wet
Replication	3	Dynamic creep tests

Figure 3. Saturated specimen inside the water container during the dynamic creep tests

Dynamic creep tests were conducted using UTM-25 machine with the capability of applying up to 25kN. All the creep tests were set to be continued for 10000 loading cycles. As it was expected that the SBS modified mixtures sustain much more loading cycles before failure than the control mixture without modifiers, none of the SBS modified mixtures experienced the failure. The tests were conducted by applying triangular load pulse with the stress amplitude of 200kPa, after applying the static 20kPa stress for 5 minutes as preloading as specified in NCHRP project 9-19 (NCHRP 465). The same loading condition was utilized for the creep tests in different frequencies and temperatures in wet and saturated conditions. The testing on saturated specimens at -5˚C was disregarded as the water in the specimen voids freeze at this temperature and changes to the ice which results in overestimation of resilient modulus of the mixtures. The loading times of 0.5, 0.1, 0.05 and 0.01sec at each loading cycle and resting time of 1.5, 0.9, 0.15 and 0.09sec between the load pulses were applied for the tests conducted at the frequencies of 0.5, 1, 5 and 10Hz, respectively. Before conducting the creep tests at saturated condition, the specimens were saturated according to ASTM-D4867. The specimens with a saturation level of 55 to 80% were directly used in testing. The specimens with a saturation level of less than 55% or higher than 80% were discarded and replaced with newly made specimens saturated at the desired range of saturation. The creep tests on saturated condition were conducted by placing the specimen in a water container throughout the testing period such as to the water in the container can freely enter the voids in the specimen or exit. Figure 3 shows the specimen in the water container during the creep test conducted on the saturated specimen.

Two thermometers, one inside a perforated dummy specimen and one in the chamber of test set up were used to precisely control the test temperature. Detailed description of the dynamic creep tests on SBS modified asphalt mixtures can be found elsewhere [Khodaii et al. 2014].

Two Linear Variable Differential Transducers (LVDTs), symmetrically positioned on the loading platen, were used for measuring the vertical deformation of the specimen during the testing. The loading cell of the testing equipment was used for measuring the load level during the testing. The measured deformations and loads were monitored by the software on the computer connected to the equipment. The software has the capability to measure the resilient strain after removing the load in each cycle. Using the resilient strain ε_r and the applied stress of 200kPa, the resilient modulus of the specimens at different loading cycles was calculated using Equation (1).

4. Results and Discussion

Using the calculated resilient modulus at different cycles of the dynamic creep tests conducted on the specimens in dry and saturated conditions, at different loading frequencies and temperatures, the variation of the resilient modulus against loading cycles were plotted for further analysis. It is worthy to note that the data for the cycles beyond the 200th loading cycle have been used for producing the plots in this section.

Figures 4, 5, 6 and 7 show, for examples, the variation of the resilient modulus with loading cycles of the dry and saturated specimens at different frequencies and temperatures. As can be seen, at all temperatures and loading frequencies, the resilient modulus of dry specimens are higher than those of the saturated specimens, which is attributed to the existence of water in the voids of saturated specimens. Creation of vacuum in conditioned specimens may induce micro cracks in the specimen, resulting in the reduction of resilient modulus and increase of permanent deformation of those specimens under load application [Azari, 2010]. This is the reason for being the resilient modulus of the conditioned specimens lower than those of dry specimens.

During the application of load pulse, a part of the load is sustained by the pore water, which, is consequently transferred to the mixture leading to the softening of the mixture by reducing the adhesion between the binder and aggregate particles. The pore water pressure generated under rectangular loading pulse is expected to be lower than that under triangular or haversine loading pulse [Khodaii and Mehrara, 2009; Mehrara and Khodaii, 2011; Khodaii et al., 2014; Dehnad et al., 2013]. Due to the placing of specimen in water container, the water expelled under pressure tends to return into the voids of specimen at the beginning of rest time. This phenomenon results in an increase of the resilient property of the saturated specimens compared with that of the dry specimens, leading to a lower resilient modulus of the saturated specimens compared with that of dry specimens.

As can be seen in Figure 4, after a slight increase of the resilient modulus after the 200th loading cycle, it decreases with increasing loading cycles. The permanent deformation of the mixture is composed of densification, which mostly occurs at the initial stages of loading, and shear deformation, which is dominant after the completion of the densification [Khodaii and Mehrara, 2009; Gokhale et al., 2005]. The increase of the resilient modulus occurring before the 200th loading cycle is due to the densification, and its reduction after that is attributed to the shear deformation.

The similar trend is observed at the other loading frequencies, as shown in Figure 8 and 9. However, it occurs at higher loading cycles. Loading time is one of the main factors affecting the variation of resilient modulus of asphaltic mixtures [Fakhri and Ghanizadeh, 2014; Ghanizadeh and Fakhri, 2013; Jahromi and Khodaii, 2009].

As can be seen in Figure 8, the number of loading cycles, up to which the resilient modulus has an increasing trend, are 200, 1000, 2000 and 10000, respectively, for the tests conducted at the frequencies of 0.5, 1, 5 and 10Hz. After those loading cycles, the resilient modulus levels off to approximately a constant value or decreases with increasing loading cycles. In the aforementioned numbers of loading cycle, according to the rest time corresponding to the frequencies, the accumulated loading time is 100sec.

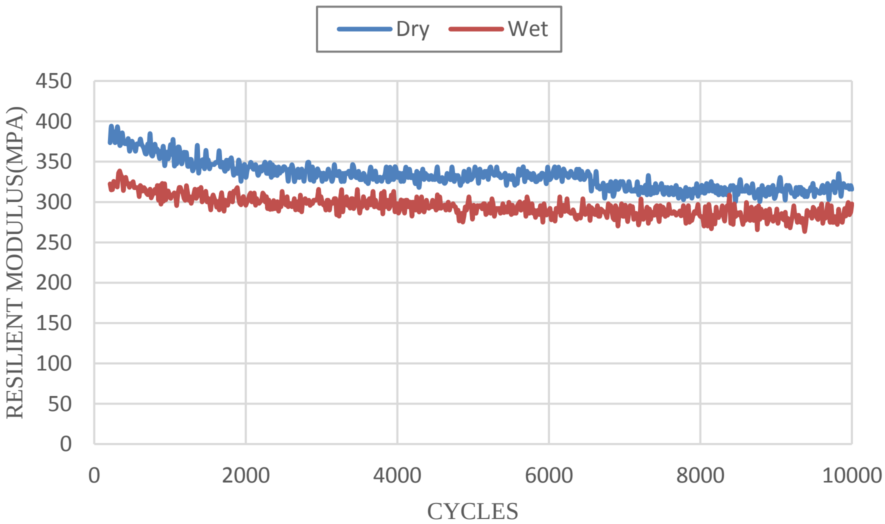

Figure 4. Variation of the resilient modulus with loading cycles for the dry and saturated specimens at 40˚C and loading frequency of 0.5Hz

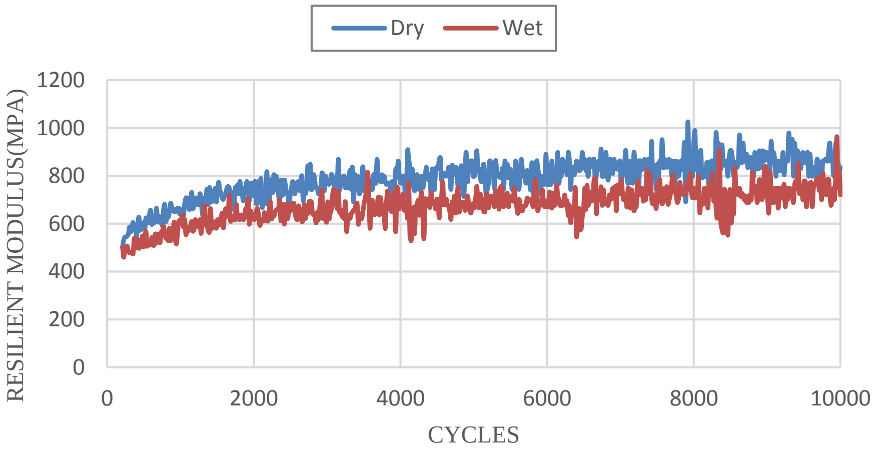

Figure 5. Variation of the resilient modulus with loading cycles for the dry and saturated specimens at 20˚C and loading frequency of 1Hz

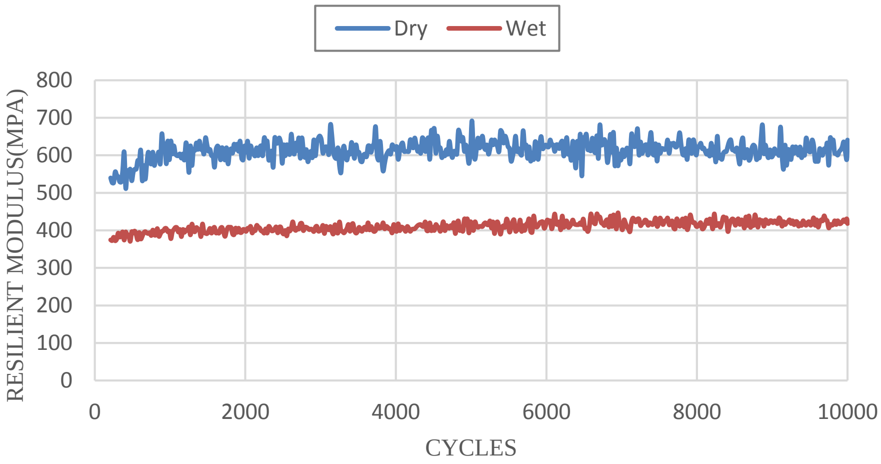

Figure 6. Variation of the resilient modulus with loading cycles for the dry and saturated specimens at 40˚C and loading frequency of 5Hz

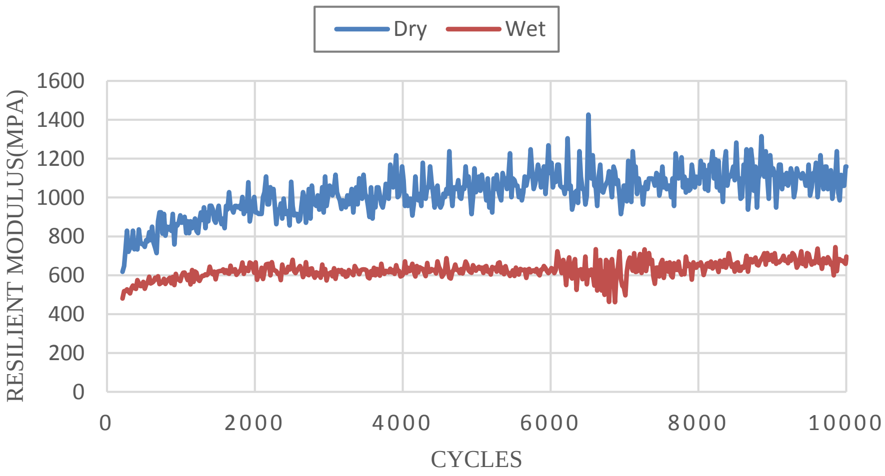

Figure 7. Variation of the resilient modulus with loading cycles for the dry and saturated specimens at 5˚C and loading frequency of 10Hz

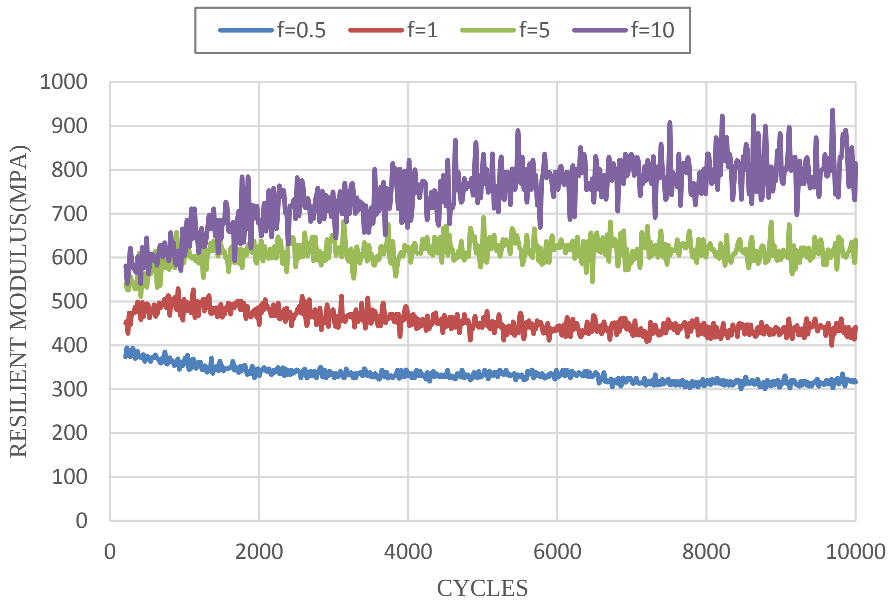

Figure 8. Variation of the resilient modulus with loading cycles for the dry specimens at 40˚C

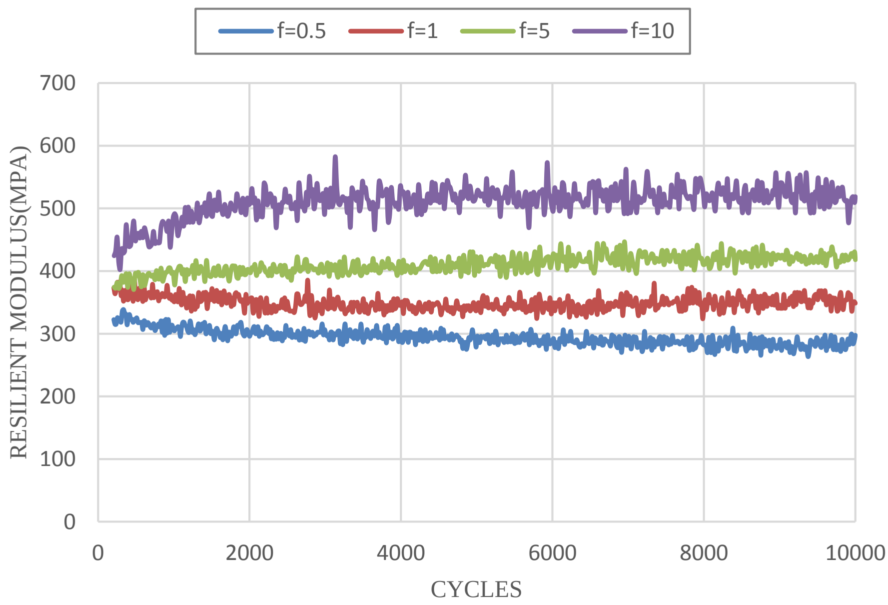

Figure 9. Variation of the resilient modulus with loading cycles for the saturated specimens at 40˚C

Therefore, it can be inferred that during the 100sec of loading time, densification of the specimens at 40˚C and stress level of 200kPa is completed. On the completion of densification at the loading cycles of 200 and 1000, corresponding to the loading frequencies of 0.5 and 1Hz, respectively, shear deformation commences. However, due to the lower loading time at the loading frequencies of 5 and 10Hz the shear deformation has not commenced at that loading cycles. Previous studies on the asphalt mixtures without SBS modifier, have shown that the densification has been completed at lower loading cycles [Dehnad et al. 2013], indicating that SBS postpone the occurrence of shear deformation and failure. Therefore, it can be stated that, for the loading frequency of 10Hz, the densification has not been completed during the 10000 loading cycles, resulting in the increase of resilient modulus during the 10000 loading cycles. However, it is expected that, after 10000 loading cycles, resilient modulus levels off to an approximately constant value, similar to that in loading frequency of 5Hz, after which the decreasing trend commences.

Figure 9 shows the variation of resilient modulus of saturated specimens versus loading cycles at temperature of 40˚C and loading frequencies of 0.5, 1, 5 and 10Hz. Comparison of the results in Figure 9 with those in Figure 8 corresponding to dry condition shows that, at all loading frequencies, the resilient modulus at dry condition is significantly higher than that in saturated condition. However, the trend in both conditions is the same, as described earlier in this section.

Another common behavior which can be seen in Figure 8 and 9 is the increase of resilient modulus with loading frequency. At higher frequencies, the loading time decreases, resulting in more resilient behavior for the mixture and higher resilient modulus.

The results in Figures 4, 5, 6 and 7 show that the difference between the dry and saturated resilient modulus increases with increasing loading frequency. While the difference of the dry and saturated resilient modulus at loading frequency of 0.5Hz is 50MPa, the difference at the loading frequency of 10Hz is 400MPa. By increasing the loading frequency and reduction of loading time, the pore water pressure is not completely dissipated and causes more damage to the cohesion of binder and the adhesion of aggregate particles and binder and higher reduction in resilient modulus of saturated specimens.

Figures 10 and 11 show, respectively, the variation of resilient modulus of the mixtures in dry and saturated condition at different frequencies and temperature of 5˚C. Comparing Figure 10 with 8, and Figure 11 with 9 reveals that, at both dry and saturated condition, the effect of frequency on resilient modulus decreases with decreasing temperature. As can be seen in Figure 11, the resilient modulus at all frequencies is almost the same. This is attributed to the existence of water with a temperature close to freezing temperature around and inside the specimen, which sustains a part of the applied load and reduces the effect of frequency.

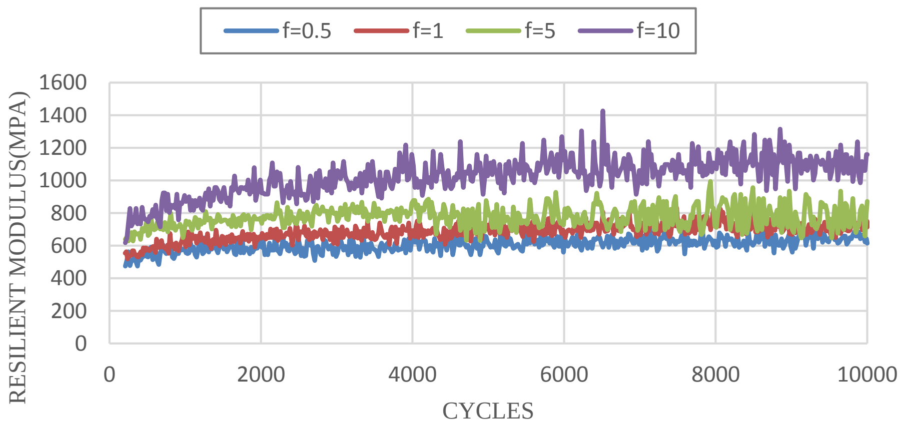

Figure 10. Variation of the resilient modulus with loading cycles for the dry specimens at 5˚C

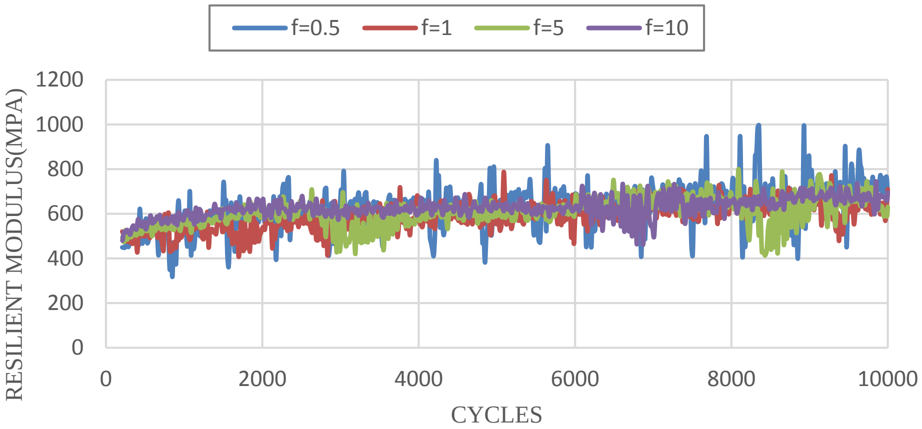

Figure 11. Variation of the resilient modulus with loading cycles for the saturated specimens at 5˚C

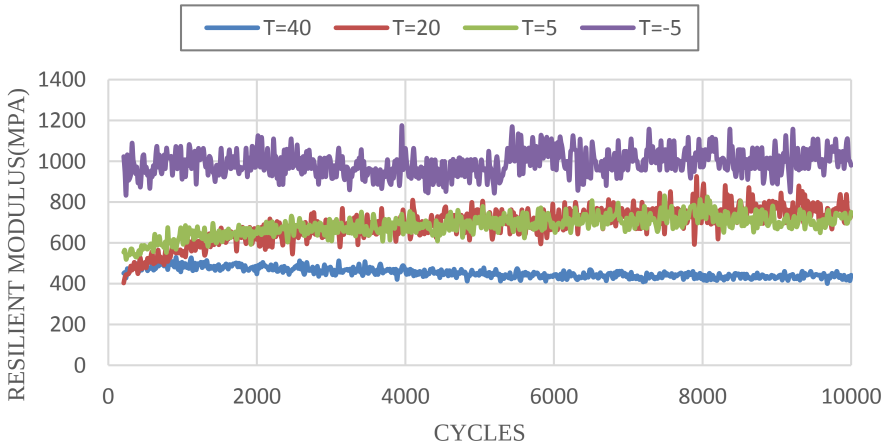

Figure 12. Variation of the resilient modulus with loading cycles for the dry specimens at loading frequency of 1Hz

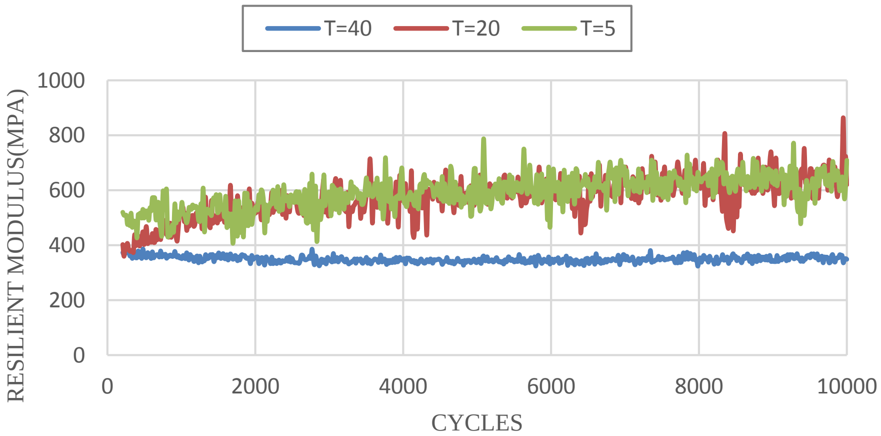

Figure 13. Variation of the resilient modulus with loading cycles for the saturated specimens at loading frequency of 1Hz

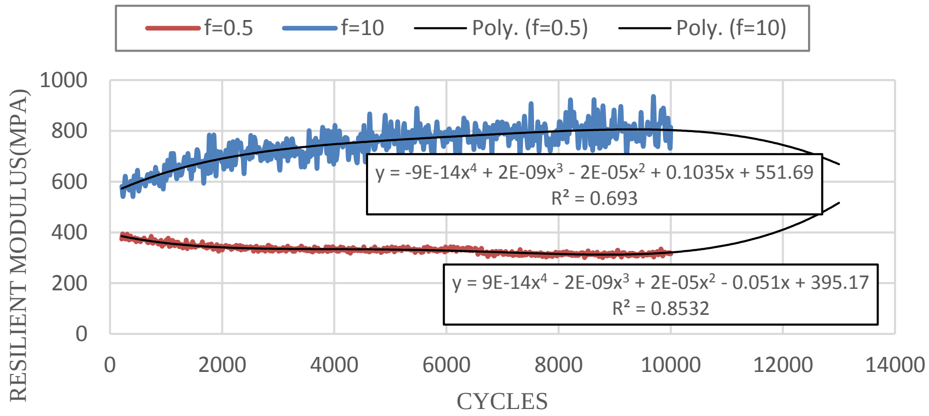

Figure 14. Equation of the fourth degree model for the resilient modulus of asphalt concrete in dry condition and at 40˚C

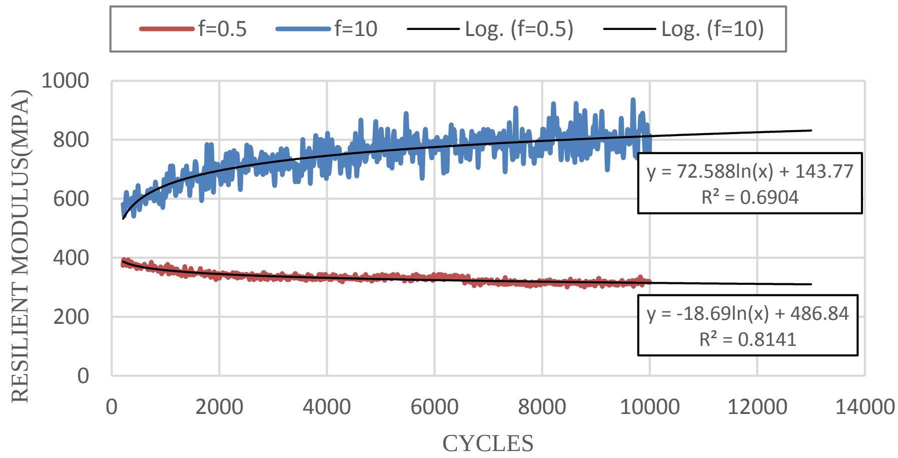

Figure 15. Logarithmic equation model for the resilient modulus of asphalt concrete in dry condition and at 40˚C

The variation of the dry and saturated resilient modulus of SBS modified mixture with number of cycles for the frequency of 1Hz and different temperatures of -5, 5, 20 and 40˚C are depicted in Figure 12 and 13, respectively.

As can be seen, the resilient modulus of the mixture increases with decreasing temperature, which is due to the increase of the viscosity of the binder with decreasing temperature leading to the increase of the resistance against deformation. Therefore, the resilient strain of the mixtures decreases with decreasing temperature resulting in the increase of resilient modulus. It is also worthy to note that, as can be seen in Figure 12 and 13, the behavior at 40˚C is different from that at the rest of temperatures. It can be stated that, at 40˚C, the shear deformation of the specimen has occurred and the mixture is close to the failure condition. In addition, it can be seen that the behavior and dry and saturated resilient modulus values at 5 and 20˚C are almost the same, which is attributed to the use of SBS modified binder. The SBS modified binder has a higher softening point, and at the range of temperatures between 5 and 20˚C, the difference between the temperature of the mixture and softening point is much higher than that at 40˚C and the effect of temperature is not significant.

5. Developing a Model for Resilient Modulus

At lower frequencies and high number of loading cycles the creep test may last long. For example, at the loading frequency of 0.5Hz with 10000 number of cycles, the test last more than 5 hours and 30min., and it last 2 hours and 45 min. at the loading frequency of 1Hz. Moreover, in some cases, where the mixtures have higher stiffness, more than 10000 loading cycles is required to capture the creep behavior of the mixture [Khodaii and Mehrara, 2009; Mehrara and Khodaii, 2011; Khodaii et al. 2014], for which the testing time and cost is higher and, due to the difficulty in controlling the temperature and testing conditions for long time, the accuracy of results is affected.

Developing a model to accurately simulate the behavior of the mixtures is useful to solve the problem. In this research, it has been tried to develop a model for prediction of the resilient modulus of the polymer modified mixture beyond the 10000 loading cycles at different loading frequencies and temperatures in dry and saturated conditions.

Figure 14 and 15, show, respectively, the model for resilient modulus in dry condition against the number of loading cycles at 40˚C and frequencies of 0.5 and 1Hz by 4^{th} degree polynomial and logarithmic functions. By evaluating different functions, these functions were selected as they were found to be more appropriate for prediction of the resilient modulus of the SBS modified mixture in dry and saturated conditions over the frequencies and temperatures used in this research. Comparing the predicted resilient modulus for the 3000 loading cycles beyond the 10000 by the quadratic and logarithmic functions in Figure 14 and 15, respectively, it can be seen that, the logarithmic function can more accurately predict the realistic resilient modulus of the mixture. it is also worthy to note that, similar to the creep behavior, the variation of the resilient modulus against loading cycles, is expected to have three distinguished initial, secondary and tertiary regions [Khodaii and Mehrara, 2009; Mehrara and Khodaii, 2011; Ahari et al., 2013; Zhou et al., 2004]. Therefore, similar to the creep, it is more appropriate to use a three stages model for the resilient modulus. The models were developed using the initial 8000 loading cycles, and verified using the remaining 2000 loading cycles, among which, the logarithmic functions were found to be more appropriate for describing the behavior of the mixtures.

The value of R^2 is an important factor for a regression model. The closer to 1 the less error in prediction of the realistic values is expected. The R^2 values of the regression models ranges from 0.6 to 0.8, with approaching to 0.6 at lower temperatures. It can be described by the highly scattered values of the resilient modulus, especially at low temperatures and high frequencies, as seen in Figures 4 to 13. However, the trend of variation of resilient is important, and as can be seen in Figure 14, the fitted function can fairly predict the average values of resilient modulus. Therefore, it can be stated that, as the resilient modulus values are inherently scattered, the R^2 values in a range of 0.6 to 0.8 are acceptable.

6. Conclusions

In this research, using dynamic creep test, the variation of the resilient modulus with loading cycles of a SBS modified asphalt concrete in dry and saturated conditions at different temperatures and loading frequencies has been investigated. In addition, a model has been developed for prediction of the resilient modulus over a wider range of loading cycles. The following are the brief results which can be drawn from this study.

- Over the range of temperatures and frequencies used in this study, the moisture damage potential of the mixtures can be predicted by comparison of the plots of resilient modulus in dry and saturated condition obtained from dynamic creep tests.
- In dry condition, the resilient modulus increases with increasing loading frequency, while, in saturated condition, only at 40˚C,

the resilient modulus increases slightly with increasing loading frequency and, at lower temperatures, the resilient modulus does not change significantly with the loading frequency.

- At both dry and saturated conditions, the resilient modulus of the mixture increases with decreasing temperature. In addition, at both dry and saturated conditions, the effect of the loading frequency on the resilient modulus decreases with decreasing temperature. Therefore, the test temperature of 40˚C is recommended for investigation of the effect of loading frequency on the resilient modulus.
- Similar to the creep behavior, three regions can be distinguished for the variation of resilient modulus with loading cycles. For the initial region, logarithmic function can be successfully used for prediction of the variation of resilient modulus with loading cycles.

7. References

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