Chapter 2

Aging Effects on Mechanical Characteristics of Multi-Layer Asphalt Structure

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Additional information is available at the end of the chapter

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Abstract

This chapter focuses on Asphalt ages during construction, transportation, application phases and service life, as well. Exposure of environmental conditions such as traffic and climate is one of the prominent reasons aging in asphalt. The most common mechanism of aging is the degradation in the chemical structure of the binder by oxidation. Asphalt aging could cause several serious issues on the pavement such as stiffening, stripping that accelerates fatigue cracking and different moisture-induced problems such as raveling and potholes. Therefore, various additives are used as modifiers to improve the mechanical properties of asphalt. The most commonly used modifiers are polymers. Styrene butadiene styrene (SBS) polymers are utilized to prevent from deteriorating against external factors during its service life and to delay its aging in asphalt pavement. In the scope of this study, it was aimed to provide the general perspectives on mechanical characteristics of multi-layer asphalt structure under the aging effects besides traffic conditions.

Keywords: asphalt, SBS, aging, polymer additive, numerical approach

1. Introduction

Asphalt ages during construction, transportation, application phases and during service life. One of the biggest causes of aging in asphalt is caused by exposure to environmental conditions such as traffic and climate. The most common type of degradation is the degradation of the chemical structure of the binder by oxidation. Some serious problems can be seen in the asphalt coating as a result of the aging of the asphalt. Oxygen, moisture, ultraviolet irradiation, heat radiation and traffic action ultimately lead to the changes in the molecular structures and chemical functional groups of asphalt. The consequence of asphalt aging can be several serious issues in the pavement, such as stiffening, stripping; that accelerates fatigue cracking, and different moisture induced distresses such as raveling, potholes, respectively. Therefore, various additives are used as modifiers to improve the engineering properties of the bitumen material. The most commonly used modifiers are polymers.

The investigations in asphalt pavement technology and its application fields have enabled the development and practical use of polymer modifiers. A number of researches have been carried out to investigate in asphalt pavement [1–15].

Various additives which are called modifiers have been contributed binder to increase the performance of asphalt. Modifiers are provided long term service life of asphalt and prevented them long term aging [17–20].

Polymer has been used commonly with asphalt for nearly 50 years as of additives. Many tests are being applied for increasing the properties of asphalt combination. [3].

The traffic load and temperature cause the asphalt coating to lose strength over time. SBS Block Copolymer is used commonly with binders in order to ensure the high quality of materials, increase the endurance of binder and hot mix asphalt pavement. Many studies have been found that Modified asphalt with SBS provided to endurance rutting in high temperature, fatigue behavior and low temperature cracking [17–20].

Hamid et al. determined different types of HMAs which are prepared with grinded and non-grinded SBS polymers. It was seen better result with grinded SBS polymer modifier. According to the test result, it was determined that there was slight increase in the air gap and aggregate volume, and endurance to stresses increased and the density decreased.

Qadi et al. probed the effect of multiple additives and modifiers on asphalt pavement. Polyphosphoric acid (PPA), liquid anti strip (LAS), and hydrated lime were selected for using of laboratory study. It was seen that the moisture sensitivity in asphalt mixtures decreased when used of Liquid Anti Stripe and hydrated lime [21].

Styrene butadiene styrene copolymers (SBSC) are classified as thermoplastic elastomers because of their elastic and thermoplastic characteristics, and are used as modifiers for the bitumen because of their important features contributing to the mechanical properties of the asphalt [22–24].

In numerical studies, it is performed Abaqus and Ansys program are widely used with non-linear viscoplastic finite element model (FEM) analysis. Furthermore; Due to the longitudinal dimension, 2- and 3-dimensional models are generally approved for the design of modeling [25, 26].

2. Aging behavior of asphalt

Most of the coating systems are located at moderate temperatures. The asphalt cement has both a fluid and an elastic solid character. Since the asphalt is an organic material, it reacts with the surrounding oxygen. Oxidation changes the structure and complexity of asphalt molecules. Oxidation causes to oxidation on the asphalt, aging or hardening, leading to further fractures.

Oxidation occurs more rapidly at higher temperatures. When the asphalt cement is heated, mixed more easily and compressed, the amount of breakage is considerable. The characteristics of asphalt cement under temperature changes and loading rates and aging stages are determined by their ability to perform as a binder in coating systems.

Asphalt cement within the coating; it is hardened under the influence of air, environmental condition and heat during the service life. It is occurred aging hardening and viscosity increase in the bitumen over the time. In the bitumen subjected to aging hardening, lower penetration and higher viscosity are seen, and it is stated that aging hardening results in lower adhesion and brittle fracture.

The aging index of asphalt is shown the following **Figure 1** in term of years.

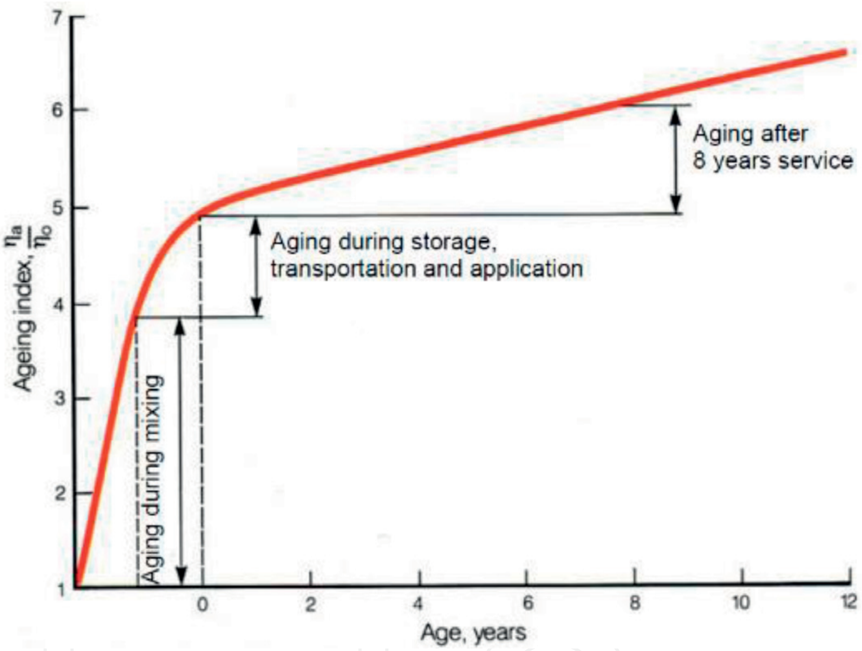

Figure 1. Asphalt aging index by years [27].

3. Factors effect on asphalt aging

As indicated before, asphalt in service condition interacts with many environmental and mechanical factors such as, atmospheric oxygen, dissolved oxygen, moisture, ambient and pavement layer temperatures, UV irradiation, traffic. Therefore, all these factors have minor to very severe effects in physical & chemical characteristics of asphalt, and subsequently these effects are reflected in either increase in viscosity, loosening adhesibility, or changes in moduli.

Stimulate asphalt aging has been shown in **Table 1** and the Petersen's findings have been presented in **Figure 2** respectively.

Factors	Influenced by					Occurring	
	Time	Heat	Oxygen	Sun-light	Beta & gamma rays	At the surface	In mass
Oxidation (in dark)	√	√	√			√	
Photo-oxidation (direct light)	√	√	√	√		√	
Volatilisation	√	√				√	
Photo-oxidation (reflect light)	√	√	√	√		√	
Photo-chemical (direct light)	√	√		√		√	
Photo-chemical (reflected light)	√	√		√		√	√
Polymerization	√	√				√	√
Steric or physical	√					√	√
Exudation of oils	√	√				√	
Changes by nuclear energy	√	√			√	√	√
Action by water	√	√	√	√		√	
Absorption by solid	√	√				√	√
Absorption of components at a solid surface	√	√				√	
Chemical reactions	√	√				√	√
Microbiological deterioration	√	√	√			√	√

Table 1. List of individual factors and conjoint factors that affect asphalt aging [28].

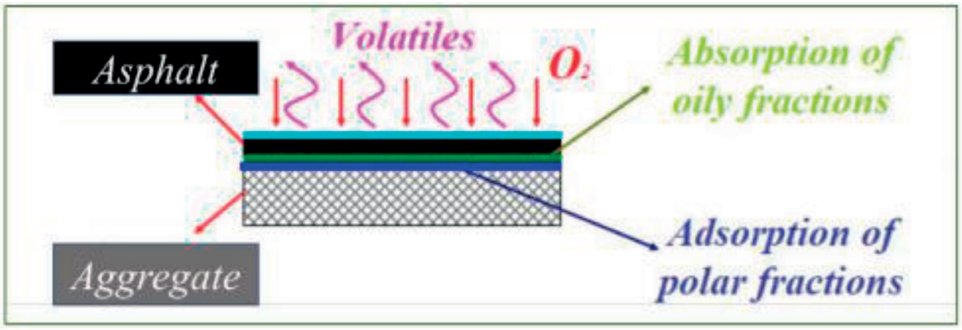

Figure 2. Illustration of asphalt aging process due to volatilization, oxidation, absorption and adsorption [28].

4. Bitumen modification

Bitumen exhibits viscoelastic properties as rheological structure. Bitumen, which plays a major role in many parameters of road performance, mainly cracking and permanent deformation resistance, also causes viscoelastic properties of asphalt mixtures. Generally, the amount of deformation in asphalt coating varies depending on the loading time and the temperature value.

The behavior of bitumen affected by static and dynamic loads is shown in **Figure 3**.

Permanent deformation (creeping), cracking (thermal or fatigue), moisture damage are the most common types of degradation in flexible coatings. Shortening the service life of road coverings under increasing traffic load has necessitated modification of bitumen. In recent years, based on polymers, the use of highly modified bituminous blends and mixtures has been increasing. As polymer additives and non-polymer additives as shown in **Table 2**.

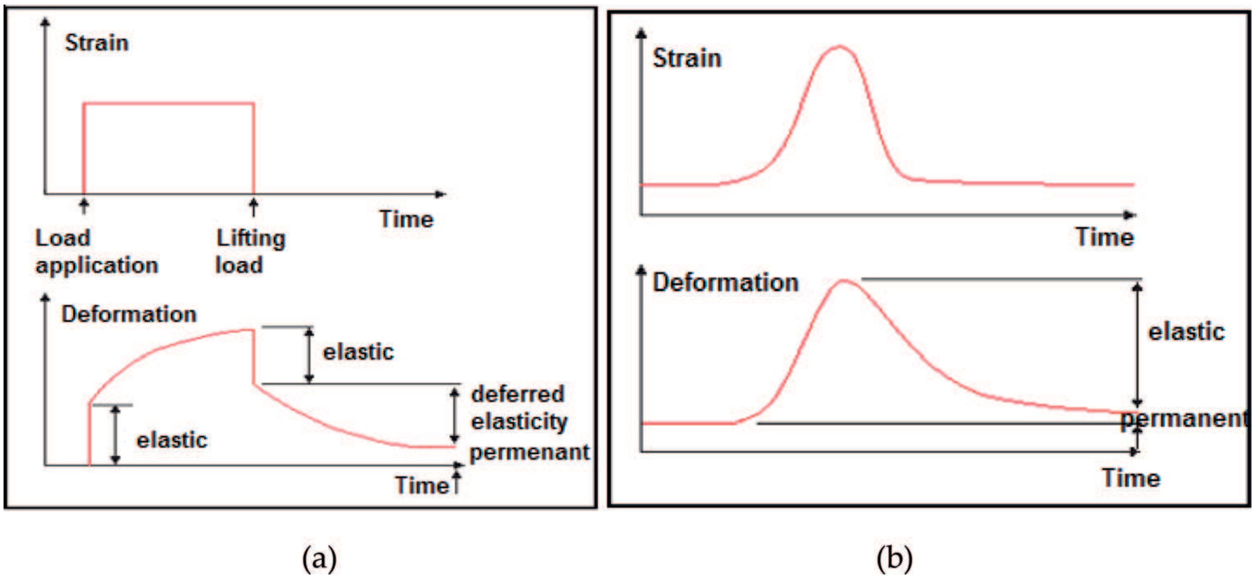

Figure 3. The behavior of bitumen affected by static load (a) and dynamic load (b) [27].

Modification types	**Specimens**
I. Modification with non-polymer additive	
a. Filler	Clay, black carbon, fly ash
b. Anti-peel additives	Organic Amines and Amids
c. Expander (Extendents)	Lignin and sulfur
d. Antioxidants	Zinc and lead antioxidants, phenolics
e. Organo-metal compounds	Amines
f. Others	Organo manganese compositions
	Organo carbon compositions
II. Modification with polymer additives	
a. Plastics	Polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC),
1. Thermoplastics	Polystyrene (PS), ethylene vinyl acetate (EVA)
2. Thermosets	Epoxy resins
b. Elastomers	Synthetic butadiene copolymer (SBR), Styrene-butadiene styrene copolymer (SBS),
1. Natural Rubbers	
2. Artificial Elastomers	Ethylene prokplendien harmoliper (EPDM), Isobutene isoprene copolymer (IIR)
3. Processed Rubbers	
4. Fibers	Polyester, fibers, polypropylene fibers
III. Chemical reaction modification	Additive reaction (bitumen + monomer) Vulcanization (bitumen + sulfur) Nitrogen reaction (bitumen + nitric acid)

Table 2. Bitumen modification types [29].

Usage purposes of modified bitumen applications:

- Control of fatigue cracks,
- Water impermeability,

- Increase of adhesion,
- Reduction of noise,
- Reduction of groove marks on wheel load can be summarized [37, 38].

Additives used in the modification of bituminous and bituminous mixtures and the benefits provided according to their shape of deterioration are shown in **Table 3**.

Modifier	Permanent deformation	Thermal cracking	Fatigue crack	Moisture damage	Aging
Elastomers	+	+	+		+
Plastomers	+				
Processed rubber		+	+		
Black carbon	+				+
Lime					+
Sulfur	+				
Chemical modifier	+				
Antioxidants					+
Hydrated lime				+	+

Table 3. Benefits of different types of modifications [27].

5. SBS polymer modified bitumen and properties

Styrene-butadiene styrene (SBS) polymer additives used as additives in bitumen are one of the most preferred additive materials since they give positive results in physical and mechanical properties of HMA blends.

SBS additive and its three-dimensional structure is indicated in **Figure 4**.

SBS polymers are randomly formed as bond shapes in different forms such as block, styrene, butadiene, and linear.

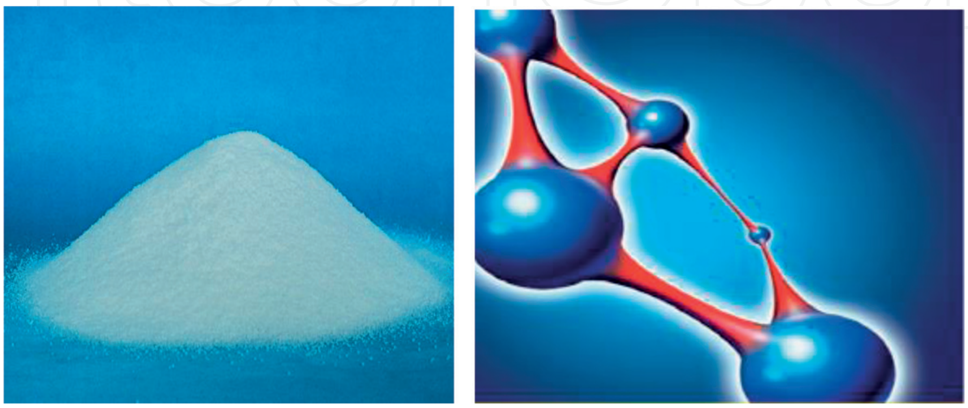

Figure 4. General view of SBS-additive and three-dimensional SBS structure [30].

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Molecular structure of SBS additives is illustrated in **Figure 5**.

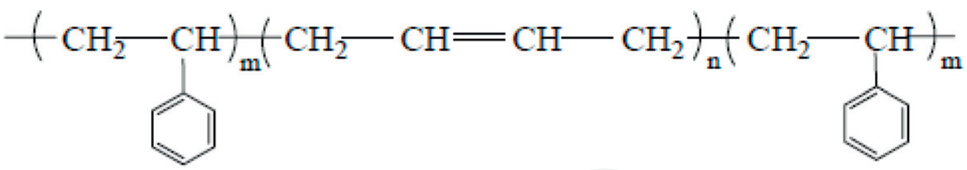

Figure 5. SBS molecular structure [31].

Figure 6 is indicated a three-dimensional view of asphalt-coated SBS molecules and the SBS modified bitumen structure consisting of asphaltic cell form and styrene butadiene bonds.

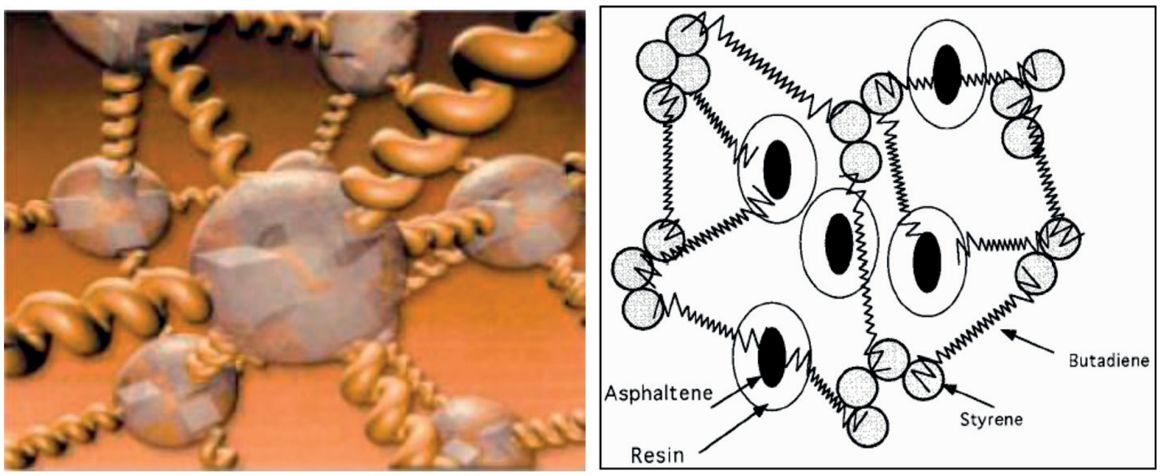

Figure 6. Three-dimensional appearance of asphalt-coated SBS molecules bond structure of SBS coated asphalt film [30, 32].

When the structure of SBS is examined, the following conclusions can be drawn:

- The polystyrene crowlings gives strength by forming physical cross-links.
- The polybutadiene bridges provide elasticity and flexibility.
- At 100°C, the polymer becomes fluid and the three-dimensional network structure recurs. Since the material is a thermoplastic elastomer, it does not lose anything in its heating and cooling properties.
- It maintains its characteristic between −40°C and + 80°C.

6. Materials and methodology

In this study, initially, some conventional tests were applied. The properties of bitumen and aggregates to be used in bituminous hot blends have been examined. In the performance tests; core samples were taken different time in 1 year period (1st, 4th, 8th and 12th months) and tested in **Figure 7**. Core samples achieved from the implementation of asphalt pavement which are prepared with SBS modified and neat bitumen of the asphalt pavement. When taking the

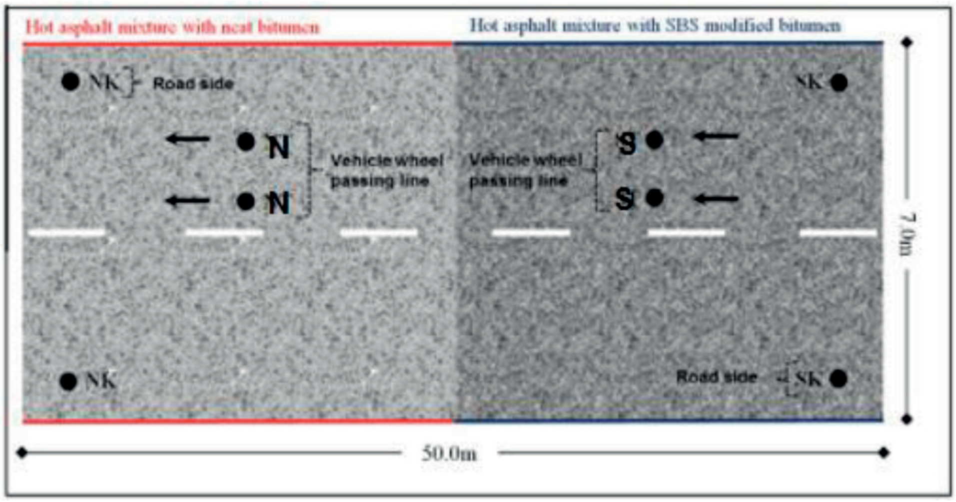

Figure 7. Core samples of hot mix asphalt (HMA) [33].

core samples, the edge of the road and the wheel passage areas are taken into consideration in **Figure 8**. In a one-year time period, 7432 equivalent axle loads were evaluated on trial path. Small axle tracks are not considered and are not taken into consideration because of using a secondary road. The effects of temperature on stability, stiffness, indirect tensile strength and fatigue resistance were investigated. Furthermore, it was examined Von Mises stress and vertical deformation of asphalt pavement on different time period with numerical analysis.

The location of the samples in asphalt and identification of the sample types are given in **Table 4**.

As a neat binder, asphalt binder of B 50/70 type taken from TUPRAS refinery was used. In modification, KRATON D 1101 contains styrene-butadiene styrene (SBS) block copolymer produced by Shell Bitumen was used.

The materials used in the layers that constituted the super structure of the road are; crushed aggregate chosen in the lower base layer, granular crushed aggregate chosen in the base layer, and crushed limestone aggregate chosen in road coating layer.

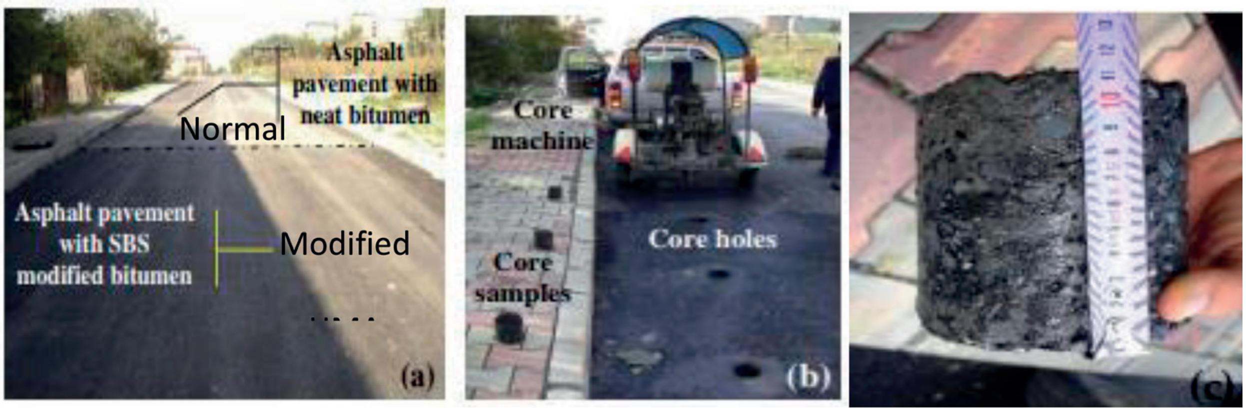

Figure 8. Asphalt pavement type (a), the core holes (b) and core sample (c) [33, 34].

Identification of the samples	State and location of samples
SK	SBS modified samples on road side
S	SBS modified samples on vehicle wheel passing line
NK	Neat samples on road side
N	Neat samples on vehicle wheel passing line

Table 4. Classification of drilling core samples of the HMA mixtures [33–35].

A solid model consisting of superstructure layers was created with namely Ansys using the finite element program. The solid model is designed by using the field parameters obtained by considering the environmental conditions such as traffic and climate. HMA design has been applied in the solid model, and only by doing so could real conditions were simulated with the analyses.

6.1. Numeric analyses

Numerical analyses assure significant advantages in using parameters derived from empirical studies to determine the stress and deformation characteristics of the superstructure of roads, corrosion, binder, base and sublayers, and to make future estimates. The Finite Element Method is often favored among other numerical approaches since it allows to make various changes and provides precise measurements in creating numerical models of physical problems. The Finite Elements Program used in numerical analysis is a numerical solution method developed for the analysis of problems expressed by differential equations. In the program, a continuous medium is branched by finite elements, and the equations are enrolled for one element, and integrated to derived system equations. As a result, complex differential equations considered for continuous media transformed into matrix format and it is reduced to a set of linear equations [36].

6.2. The finite elements method

The Finite Elements Method is a numerical solution method used frequently in engineering practices for the purpose of examining the continuous medium problems by examining them after dividing into a certain number of elements. In the scope of this method, the solution is obtained by dividing a medium or an object by finite elements and writing the rigidity matrix for each element, and then integrating the solutions for all elements. The numerical solutions of the differential equations that express the mechanical behavior of the system in question are written in matrix format. Generally, bigger matrices appear for the geometrical applications that require multiple elements. In solving such problems, the necessary linear algebraic operations are performed via computers.

6.2.1. The advantages of the finite elements programs

- The Finite Elements Formulation may be applied to many problems.

- It ensures the opportunity of speed and optimization that can be analyzed via computer.
- Any types of complex geometrical, material status and loading limit conditions may be defined.
- It facilitates the solution of integrated problems in ways such as tension, shape-shifting (statics) and consolidation (dynamics).
- The primary independent variables like place-shift, flow potential, which are selected, and the secondary unknown factors depending on these such as tension, shape-shifting, speed, and the amount of flow, etc., which are depending on these, are assessed together.
- Results that are close to reality are obtained with adequate element definitions [36].

In this chapter, a finite elements model was developed by using the ANSYS Finite Elements Program for the super-structure of the road. The models, which consist of asphalt coating, the base and sub-base include 79,045 elements and 558,224 nodal point in average.

Different models were prepared for various time periods, which were 1st, 4th, 8th and 12th Months, by considering the multi-layer structure of asphalt, the traffic and the environmental conditions [35].

The Finite element model (FEM) of road is given in **Figure 9**.

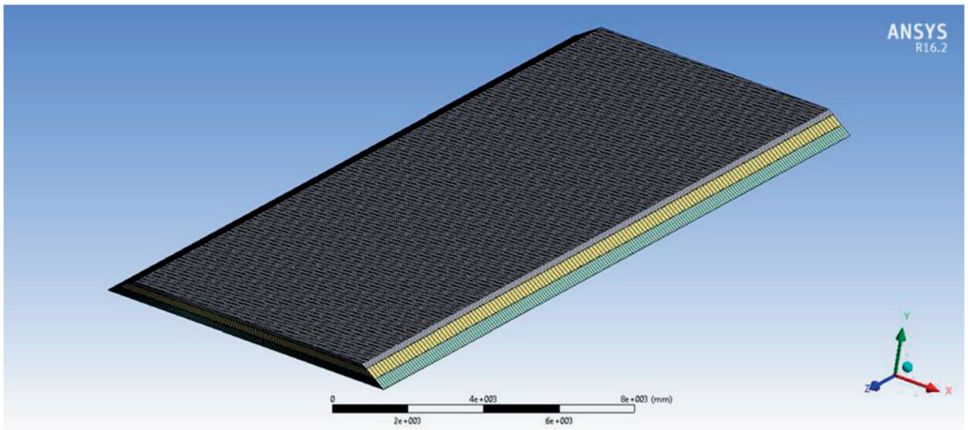

Figure 9. Finite element model (FEM) of road [34].

7. Results and discussion

7.1. Experimental results

Field and laboratory test works were conducted on the super-structure of the road for a time period of 1 year under traffic and environmental conditions. Drilling core samples were taken from the super-structure of the road in certain periods. The experimental part of the study was carried out in two stages. In the first stage, the physical properties of the aggregates and the neat and SBS modified bitumen which are using the asphalt mixture were determined. In the

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second stage, various tests performed HMA samples. The mechanical properties of the samples collected from the different asphalt pavement were examined in the 1st, 4th, 8th and 12th months for a one-year period.

7.1.1. Properties of bituminous binders and aggregates

The binder was used in B50/70 class and constituted the building block of the HMA, which was used in the road platform. The characteristics of the pure (neat) and HMA-modified bitumen are given in **Table 5** that the neat and SBS modified bitumen are a little susceptible to temperature in relation to the penetration index and they have a value above the limits of the specification as softening.

The gradation characteristics of the mixture are given in **Table 6**. The physical properties of the aggregate are shown in **Table 7**. It is understood that the aggregates used in the coating layer of HMA are within the limits of the related specifications in terms of their physical properties.

Property	Test method	Neat bitumen	SBS modified bitumen
Specific gravity (gr/cm^3)	EN 15326	1.022	1.017
Penetration (25°C, 0.1 mm)	EN 1426	B-61	B-68
Softening point (°C)	EN 1427	51.7	54.0
Ductility (25°C, cm)	EN 13589	>100	>100
Fraas breaking point (°C)	EN 12593	−17	−17.5

Table 5. The properties of the neat bitumen [34].

Sieve Size (mm)	12.5	9.5	4.75	2.00	0.425	0.18	0.075
Passed (%)	100	90.4	56.6	36.6	18.2	13.0	10.3

Table 6. Aggregate gradation.

Tested property	Standard	Coarse	Fine	Filler	Specification limit
Abrasion Loss % (Los Angeles)	ASTM C 131	20.5	—	—	Max 35
Frost action % (with Na_2So_4)	ASTM C 88	1.20	—	—	Max 10
Peel strength (%)	ASTM D903	60–70			Min 50
Flatness index (%)	BS 812	16.1			Max 30
Water absorption (%)	ASTM C127	0.38	0.88	—	
Specific bulk density (gr/cm^3)	ASTM C127	2.733	—	—	
Specific bulk density (gr/cm^3)	ASTM C128	—	2.678	—	
Specific bulk density (gr/cm^3)	ASTM D854	—	—	2.764	

Table 7. Aggregate characteristics [35].

7.1.2. HMA design properties

In order to determine the HMA design properties, the pure and SBS-modified asphalt concrete coating sample road platform was prepared by taking the aggregate gradation as the basis. The pure HMA optimum bitumen rate was determined as 4.95%, and the SBS-added HMA optimum bitumen rate was determined as 5.24%. The properties of the design criteria are given in **Table 8**, and it is observed that they meet the Conditions List criteria.

From the pavement spread and compacted according to the predetermined design the core samples were taken at three different time periods on the vehicle wheel passing line and banquette of the road. The core samples were sized to those of Marshall samples and they were tested by Stiffness Modulus, Indirect Tensile, Fatigue and Marshall tests.

The average volumetric characteristics of the core samples are given in **Table 9**.

In **Figure 10**, It is indicated that the alteration in the stability of the samples over time. According to the result of the experiment, there have been remarkable increases in the stability with the hardening in the asphalt coating over time. SBS modified specimens were found to have 24% greater stability at 1st month and 72% greater at 12th months, respectively, when compared to neat specimens. The Stability increased 34% in neat mixtures and 76% more in SBS modified mixtures, respectively for 12th month compared to 1st month.

Property	Pure HMA value	SBS modified HMA value
Optimum bitumen rate (%)	4.95	5.24
Practical specific gravity (Gmb, gr/cm^3)	2.415	2.411
Marshall stability (kgf)	1222	1170
Flow (mm)	3.03	3.58
Aggregate void ratio (Vma, %)	15.10	13.9
Asphalt void ratio (Vf, %)	73.93	75.4
Air void ratio (Vh, %)	3.94	3.10

Gmb, bulk specific gravity; Vh, air voids; Vf, voids filled with asphalt; Vma, the void volume between the aggregates.

Table 8. Design properties of pure and SBS-modified HMA [34, 35].

Specimen	Gmb	Vh (%)	Vma (%)	Vf (%)
N	2.267	8.929	19.362	53.899
NK	2.280	8.43	18.92	55.480
S	2.271	8.369	19.457	57.032
SK	2.280	8.004	19.136	58.188

Gmb, bulk specific gravity; Vh, air voids; Vf, voids filled with asphalt; Vma, the void volume between the aggregates.

Table 9. The volumetric characteristics of the core samples in the 1st month [35].

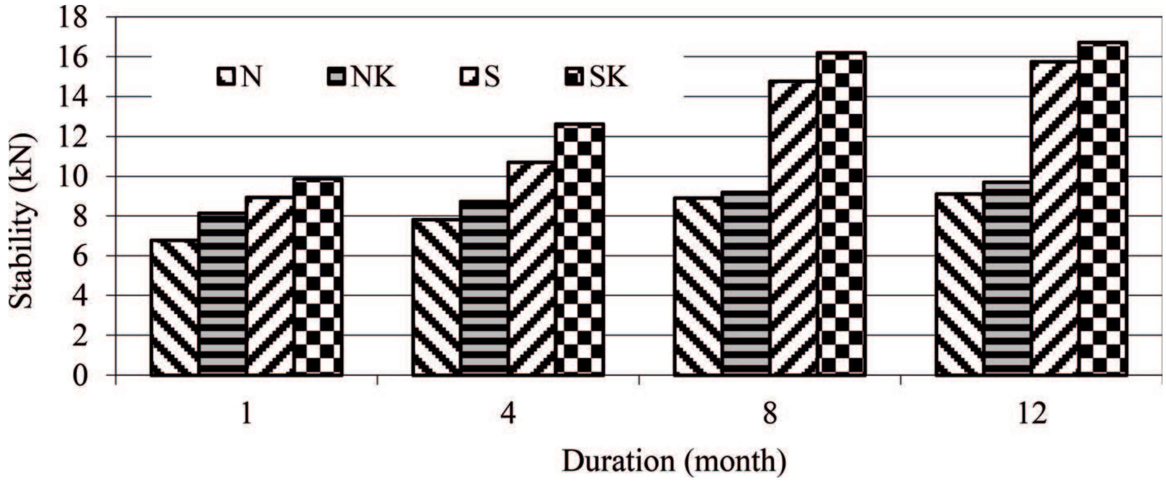

Figure 10. The change of stability in different period [35].

The change of the stiffness modules is illustrated in **Figure 11**.

In **Figure 11**, the stiffness modulus values show significant increase over time. In addition, the stiffness module of the samples taken from the edges and the vehicle wheel pass line of neat and SBS modified asphalt pavement were similarly affected by the time factor. SBS modified sample values increased by 8–27% more than neat sample values. The edge asphalt samples which are taken from banquette value were higher than the vehicle wheel passing. This difference is seen 2.3% to 11.8% in neat specimens and 1.8–10% in modified specimens. The reason for this increase is due to the fact that the samples from the edge are exposed to more water due to the transverse slope of the road [35].

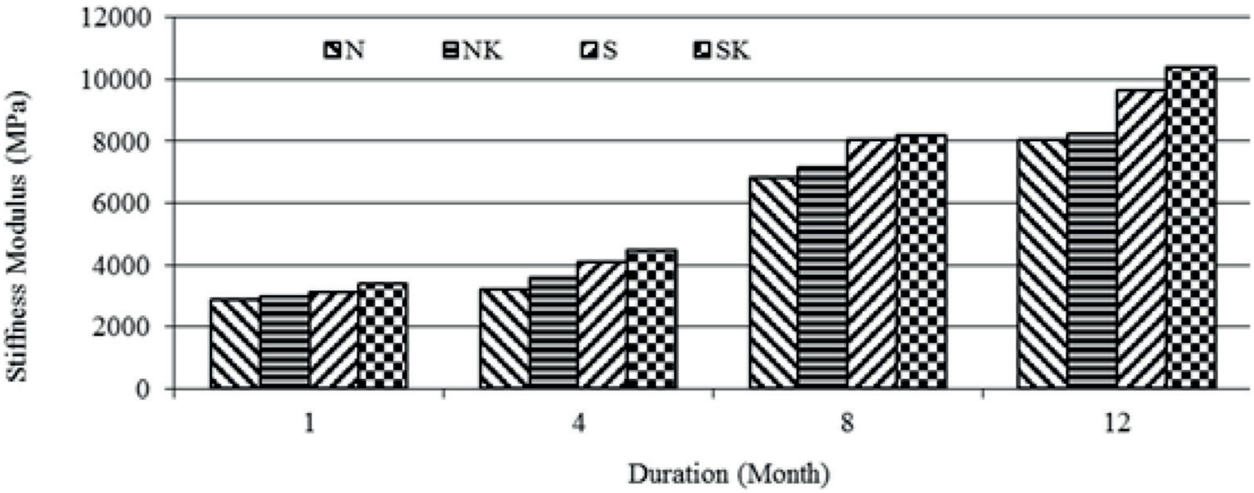

Figure 11. The change of the stiffness modules in different period [35].

The graph in **Figure 12** shows the average test results of the Indirect Tensile Strength Test.

In **Figure 12**, ITS values were found to be lowest at 1st month and highest at 12st months. In terms of monthly periods, ITS values of S and SK type core samples were more than N and NK type of core samples. It was realized the lowest values in the N type and the highest values in the SK type. The increase of samples from 1st to the 12th month were seen 42.68% NK, 49.89% N, 20.4% SK and 26.93% S type of samples, respectively.

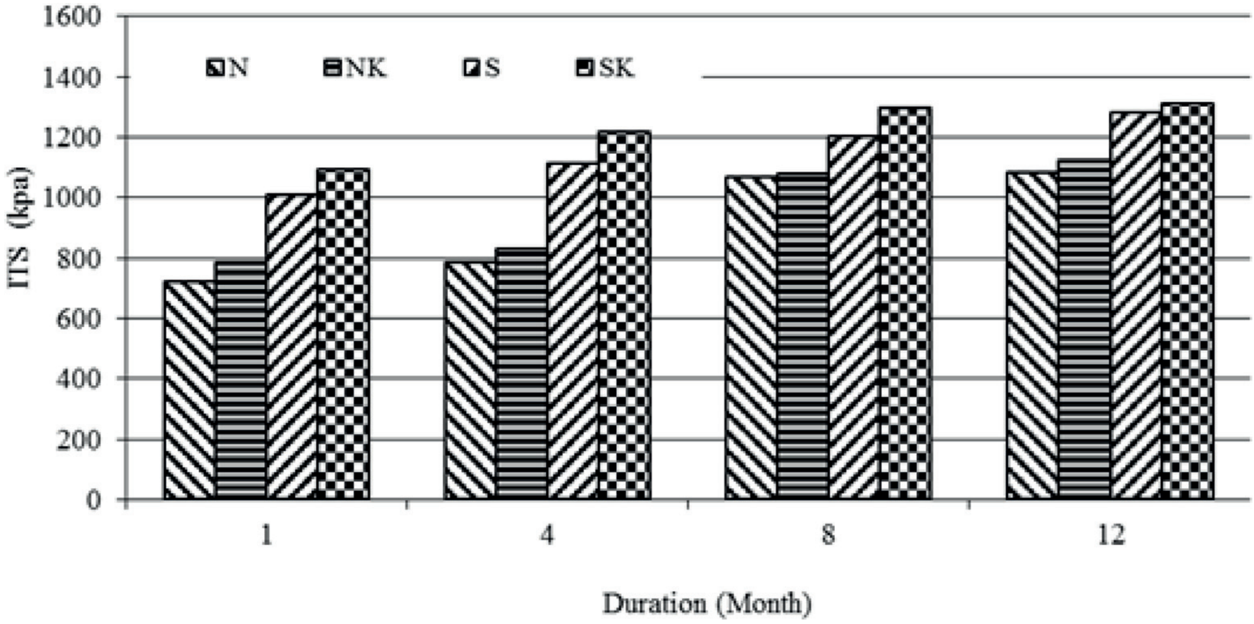

Figure 12. The change of the indirect tensile strengths in different period [35].

The change of fatigue strength in different period is given in **Figure 13**.

In **Figure 13**, it was observed that the loading repetition required for the samples to reach a level of deformation of about 2 mm was significantly increased using the SBS additive material. It was seen that the maximum loading repetition number (Nmax) values were increased after time period. The fatigue resistance of the samples with neat was lower than the SBS ones. The lowest deformation was gained from SK type samples. In the same manner, the highest Nmax values were achieved from SK type samples. It was clearly understood that

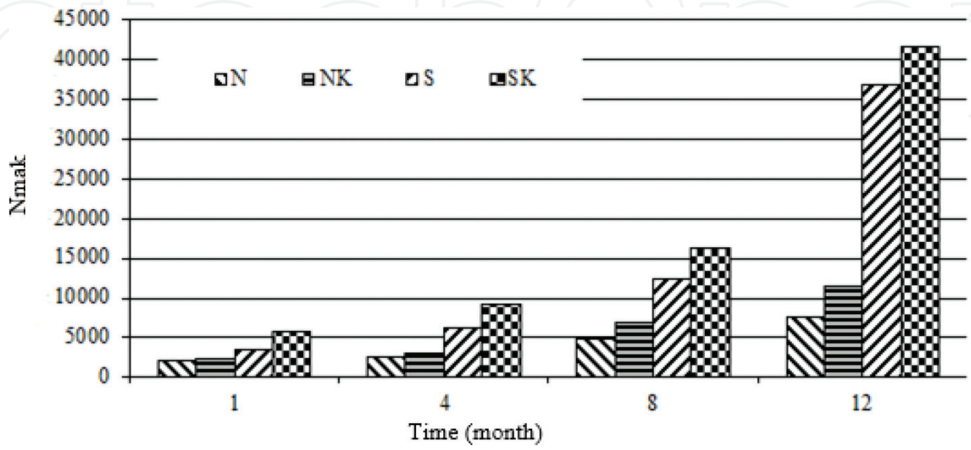

Figure 13. The change of fatigue strength in different period [35].

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the flexibility of bituminous hot mixtures decreased after aging and for this reason a more brittle fracture may occupy [35].

7.2. Numeric analyses result

FEM models have been solved to determine the Von Mises stresses besides vertical deformations in super structures of the road, as well.

The FEM models of the Von Mises stresses for one of sample material is given in **Figure 14**.

Numerical analysis was done by applying the finite element method on the super-structure of the road. Von Mises Stress properties of the road super-structure are evaluated in **Figure 15**.

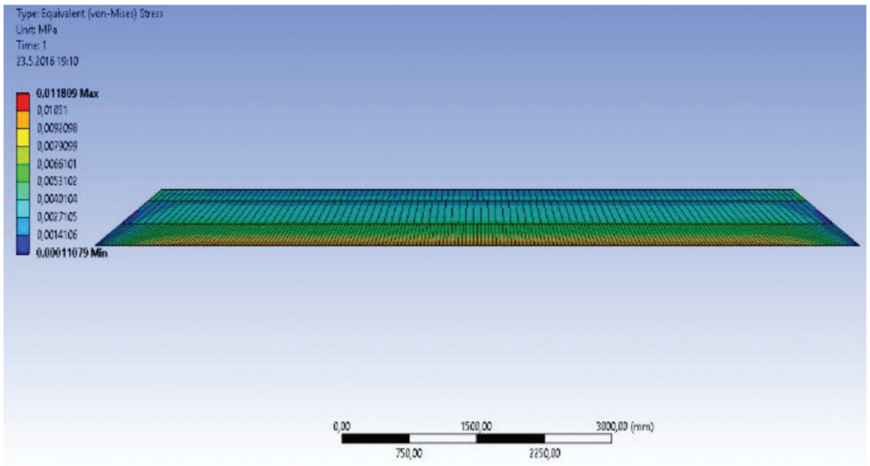

Figure 14. Von Mises FEM model [34].

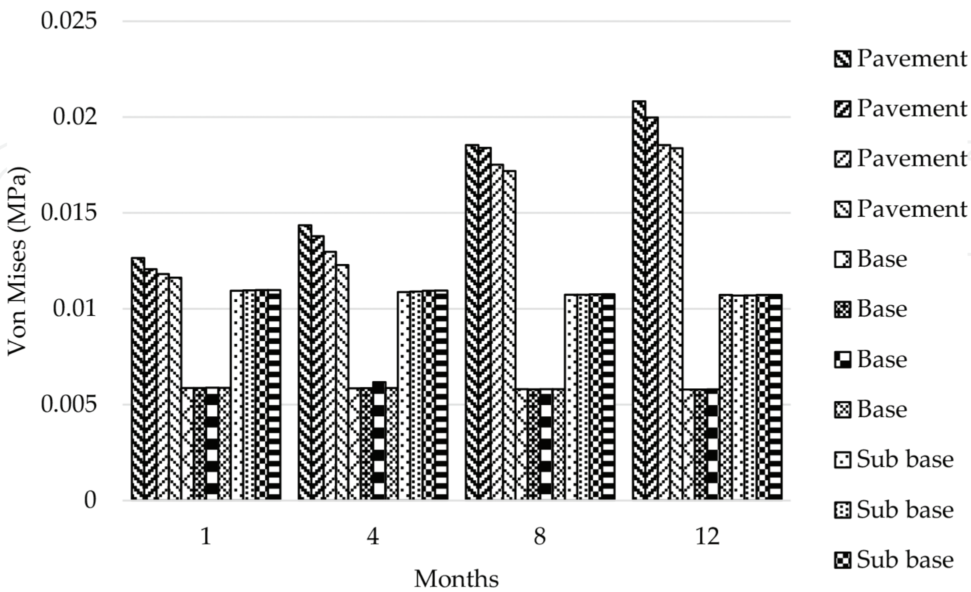

Figure 15. Von Mises tension-time changes of the super-structure of the road [34].

According to **Figure 15**; the highest Von Mises tensions were occurred the coating layer and the lowest values were observed in the base layer. It is fixed that The Von Mises tensions increased in the coating layer within 1 year period. It has been determined that the highest Von Mises tension were in SK type road coating whereas, the lowest Von Mises tensions were in N type coating. The Von Mises tensions of base layer indicated similarity properties and no significant changes were observed [34].

Vertical deformation (y)-time changes of the super-structure of the road is given in **Figure 16**.

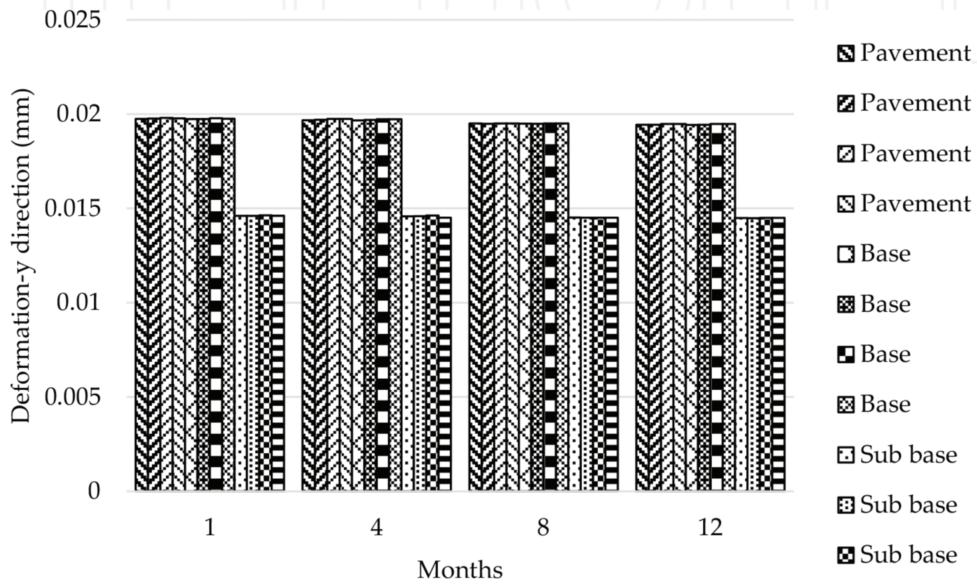

Figure 16. Vertical deformation (y)-time changes of the super-structure of the road [34].

When **Figure 16** is evaluated, it is seen that the highest vertical deformations are found at the base and lower base layers and the lowest deformations are found at the coating layer. Within a year, there have been small deviations in the amount of deformation. The amounts of deformation were confirmed as 0.014492 mm in SK-type, and 0.0145 mm in NK-type in the 12th month [34].

Von Misses stress and vertical deformation function and R^2 values are submitted in **Table 10**.

Layer types	Regression models	Function type			
		Von Mises stress function	R2	Vertical deformation function	R2
Coating	SK	$y = 0,0001x^2 + 0,0021x + 0,0101$	0,977	$y = 1E\text{-}06x^2–0,0001x + 0,0199$	0,9678
	S	$y = -3E\text{-}05x^2 + 0,003x + 0,0088$	0,9583	$y = -0,0001x + 0,0199$	0,9329
	NK	$y = 0,0099e^{0,1654x}$	0,9291	$y = 8E\text{-}06x^2–0,0002x + 0,02$	0,8994
	N	$y = 0,0001x^2 + 0,0019x + 0,0092$	0,9095	$y = -0,0001x + 0,0199$	0,8744
Base	SK	$y = 6E\text{-}07x^2-3E\text{-}05x + 0,0059$	0,9683	$y = -0,0001x + 0,0199$	0,9686
	S	$y = -4E\text{-}07x^2-3E\text{-}05x + 0,0059$	0,929	$y = -3E\text{-}06x^2-1E\text{-}04x + 0,0199$	0,9301
	NK	$y = -7E\text{-}05x^2 + 0,0003x + 0,0057$	0,4428	$y = 6E\text{-}06x^2–0,0001x + 0,0199$	0,9059
	N	$y = 0,0012x^2–0,0047x + 0,0096$	0,9282	$y = -3E\text{-}06x^2-9E\text{-}05x + 0,0199$	0,8785

Layer types	Regression models	Function type			
		Von Mises stress function	R2	Vertical deformation function	R2
sub base	SK	$y = 5E\text{-}06x^2–0,0001x + 0,0111$	0,9683	$y = 2E\text{-}06x^2-5E\text{-}05x + 0,0147$	0,9645
	S	$y = 5E\text{-}06x^2–0,0001x + 0,0111$	0,946	$y = -1E\text{-}06x^2-4E\text{-}05x + 0,0147$	0,923
	NK	$y = 3E\text{-}06x^2–0,0001x + 0,0111$	0,8963	$y = 7E\text{-}07x^2-5E\text{-}05x + 0,0147$	0,8528
	N	$y = -2E\text{-}07x^2-9E\text{-}05x + 0,0111$	0,8926	$y = 2E\text{-}05x^2–0,0002x + 0,0147$	0,9271

Table 10. Function and regression analyses of the relation between the super-structures of the road vertical deformation time [34].

When **Table 10** is examined, It is understood that R^2 values are close to 1 for all road layers. It has been inferred that numerical analyzes have supported empirical studies because of the strong relationship [34].

8. Conclusion

It came out that the performance characteristics of the SBS-added the HMA are improved due to the use of the SBS polymer material as compared to the unmodified ones. This is because when the SBS polymer is used, the adhesion between the aggregates increases. It has been seen that the flexible structure of asphalt is stiffened due to environmental conditions due to oxidation, which is caused by temperature changes and precipitation during transportation, storage, mixing and production processes. In addition to, as the air void ratio increases, the hardening time decreases due to air contact. The hardening of the asphalt road coating was found to be higher in the coating without additive material and it was appeared that the polymer increased the deformation resistance at high temperatures and increased the tendency to fracture at low temperatures.

Analytical calculations from different material types and different strata in the flexible road coating are complex. The traffic loads and the distribution of pressure on the superstructures of the roads are varied, and different materials are used on each layer, and therefore the mechanical properties and the load distribution ability vary. Climate and various environmental conditions affect the road. Because of these reasons, empirical studies must be promoted with numerical analyzes to establish performance characteristics of the road.

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