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EFFECT OF SBS MODIFIER AND RECYCLED ASPHALT MATERIALS ON RESPONSE OF FLEXIBLE PAVEMENT LAYERS

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Abstract

Knowing the developed stresses within flexible pavement layers that are mostly the combined effects of loading, environment influence, the material characteristics of pavement and subgrade is a prime criterion of pavement design and evaluation. The aim of this study is to explore the influence of using asphalt modifier on the tensile and compressive strain of pavement layers. The characteristics of four asphalt mix types, containing 4% Styrene Butadiene Styrene (SBS) by weight of asphalt, recycled mixes with 20% of Reclaimed Asphalt Pavement (RAP) and mix with 20% of RAP and 4% of SBS, are investigated for both surface and base layers. Those mixes are mainly categorized into reference mixes which are produced from virgin materials, contained modified mixes. This study indicates the typical strain characteristics encountered in a flexible pavement structure composed of two asphalt concrete, sub-base resting on subgrade subjected to static dual wheel load. Kenlayer, well-known software, is used analyse the flexible pavement. This software was used to examine the influence of addition the SBS and RAP materials to the asphalt concrete surface and base layers on tensile strain at the bottom of asphalt layers and vertical compressive strain at the top of subgrade soil. Using 4% of SBS modified asphalt in construction of surface layer could only decrease the tensile strain at the bottom of surface layer and could reduce the compressive strain at top of subgrade. Finally, it has been found that using SBS is better than RAP in improving asphalt binder characteristics.

Keywords: Flexible pavement, Kenlayer, Reclaimed Asphalt Pavement (RAP), Styrene Butadiene Styrene (SBS)

1. Introduction

Particularly, the flexible pavement consists of various layers, the top layers which are the highest resistant for compressive stress whereas the lower layers are with the lowest resistant for compressive loads [1-3]. Flexible pavements suffer generally from rutting which results from heavy traffic and severe environmental condition [4]. As a matter of fact, the well-known pavement engineering program is Kenlayer, which is utilized to analyse flexible pavement. In reality, it was developed by Huang [1] to deal with an elastic multilayer system under a circular loaded area. This program could be also dealt with multilayer systems under single or dual wheel while each layer has a various response like linear elastic, nonlinear elastic or viscoelastic. The Kenlayer, in particular, was developed to achieve the damage analysis, too [1].

To determine the stresses, deflections and strains for any pavement layer, Peattie, Jones and Fox [5-7] have developed various charts and tables. These solutions have been mainly derived on a Poisson’s ratio of 0.5 for all layers. These solutions have been developed using computer programs to gain flexibility in accommodating material properties and several loads. Poisson's ratios for materials have been used other than 0.5, in addition to the capability of ascertaining the influences of multiple wheel configurations and/or nonlinear material behaviour. Recently, elastic analysis tools were developed for pavement design and rehabilitation decision making [8].

The reclaimed asphalt pavement (RAP) is widely used because it reduces the need for virgin aggregate and asphalt, decreases the fuel consumption, and minimizes CO2 production. Notably, the RAP can reduce the fresh aggregate for road pavement construction up to 40%-60% with satisfied performance [9, 10].

Recent works have used mixes with the same characteristics as conventional mixes were implemented with RAP ratios between 10% and 30%. Mixtures using RAP ratios as high as 60% were also prepared; their performances mostly depending on the previous RAP homogenization and characterization treatments [11].

Higher RAP ratio leads to a higher susceptibility at low-temperature cracking of its recycled mixes [12]. As the RAP ratios increase, the fatigue performance of a fine aggregate matrix decreases. Furthermore, rejuvenator helps in enhancing the fatigue performance of a fine aggregate matrix [13]. The variance of the complex modulus between Hot Mix Asphalt (HMA) having 20% of RAP and HMA without RAP was insignificant. As HMA included 40% of RAP, the modulus of its recycled mix was 49% greater than that of the fresh mix [14]. The results from laboratory performances have showed that with higher RAP ratios, both fatigue and low-temperature performances are converted negatively.

There is a growing need to improve the performance properties of asphalt binders in order to minimize the occurrence of failure mechanisms [15]. The Styrene-butadiene styrene (SBS) polymer is well-known by increasing the stiffness of modified asphalt and consequently the asphalt performance will be better [16]. The SBS is a widespread modifier with high molecular polymer, which would improve the asphalt cement by miscible with asphalt cement [17]. The SBS-modified asphalt could enhance the high temperature rutting resistance, low-temperature crack resistance and anti-fatigue behaviour of flexible pavement [18]. Moreover, it improves Marshall properties such as flow, stability and air voids [19].

The SBS-modified asphalt is used vastly in several high-grade pavement in Chinaat presents to meet the requirements of traffic increment. SBS modified asphalt has a wide range of applications [20]. Obaid [21] evaluated the effect of SBS on the moisture sensitivity using different ratios (0.5,1.0,1.5, 2.0, 2.5, 3.0, 3.5, 4.0) by the weight of asphalt (40-50) from Al-Dura refinery in Iraq. The results indicated that 4% of SBS has the maximum rate of tensile strength ratio, indirect tensile strength and the moisture damage resistance.

Albayati and Mohammed [22] investigated the effect of asphalt cement modifier on the mechanical characteristics (resilient modulus, permanent deformation and fatigue properties along with Marshall characteristics). The (40-50) asphalt from Al-Dura refinery in Iraq was used with SBR at five various modification levels namely 0%, 1%, 3%, 5% and 7% by weight of asphalt binder. According to the experimental results, one could find out that the mixtures modified with SBR polymer have demonstrated an enhanced fatigue and permanent deformation characteristics in addition to superior elastic properties as a characterized via resilient modulus at 3 percent of SBR. After adding 3% of SBR as a polymer modifier, the asphalt concrete mix revealed lower possibility for permanent deformation in comparison with conventional mixtures. The use of SBR produced more durable asphalt concrete mixes with better serviceability.

This study presents a novel idea by enhancing the response of flexible pavement to change in properties of the asphalt concrete layers contain polymer and/or recycled materials.

2. Methodology

The methodology of this study could be summarized by using four asphalt mix types, which are prepared for both surface and base layers. Those mixes are categorized into control mixes prepared with virgin materials, modified mixes contained 4%SBS by weight of asphalt according to the results of previous studies for the same type of asphalt [21, 22], recycled mixtures with 20% RAP [9-14] and mixture with 20% RAP+4%SBS. Then, the optimum mixture is figured out to give the lowest strain using Kenlayer software.

3. Materials and Testing Program

3.1. Aggregate

Aggregate used is crushed a quartz aggregate that has been gotten from Al-Nibaie quarry. The used aggregates satisfy the specifications of fine and coarse to meet Type IIIA of wearing course gradation as required by State Corporation of Roads and Bridges (SCRB) specifications [23]. The standard tests have been done on the aggregate to assess its characteristics. Tables 1 and 2 demonstrates the results and the specification limits as determined by the SCRB [23]. The results indicate that the selected aggregate fulfilled the SCRB specifications [23].

Figures 1 and 2 show the gradation curves of aggregate being used in construction of wearing and base courses. Accordingly, the results are within the acceptable limits.

The asphalt cement with penetration grade (40-50) has been utilized in this work as virgin asphalt binder, provided from Al-Dura refinery south of Baghdad. The implemented tests on asphalt cement prove that its properties complied with the specification of SCRB [23]. Table 3 illustrates the physical properties of asphalt cement.

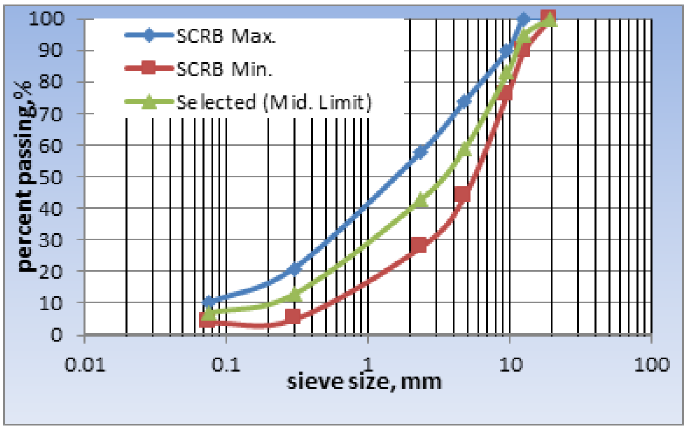

Fig. 1. Gradation of an aggregate for wearing coarse.

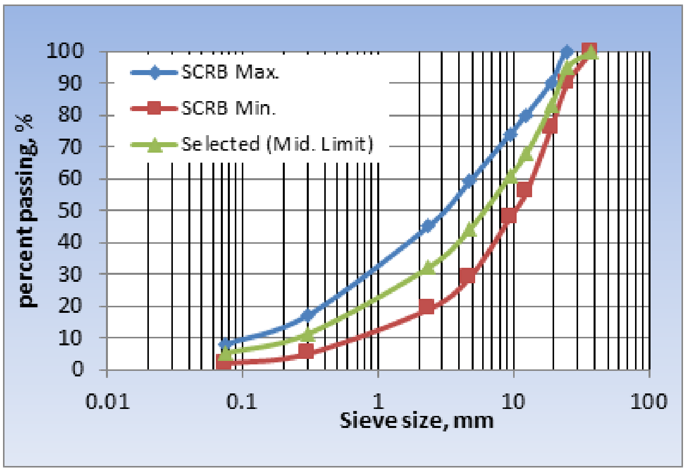

Fig. 2. Gradation of an aggregate for base course.

Table 1. Fine aggregate characteristics.

Property	ASTM Designation	Test Results	SCRB Specification
Bulk Specific Gravity	ASTM-C128-2001	2.631	--
Apparent Specific Gravity	ASTM-C128-2001	2.672	--
Percent Water Absorption	ASTM-C128-2001	1.5%	--
Percent Sand equivalent	ASTM-D2419-2002	52%	45% (Min.)

Table 2. Coarse Aggregate Characteristics.

Property	**ASTM Designation**	**Test Results**	**SCRB Specification**
Bulk Specific Gravity	ASTM-C-127	2.622	--
Percent Water Absorption	ASTM-C-127	0.5%	--
Loss Angeles Abrasion	ASTM-C131-2003	19.3	30-35 (Max.)
Soundness of Aggregates using Sodium Sulfate	ASTM-C88- 1999	4.30	12% Sodium Sulfate-Max.
Clay Lumps and Friable Particles in Aggregates	ASTM-C142- 1997	1.1	3.0 Max.
Percent flat and elongated particles	ASTM-D4791-2006	1.6	10% Max.
Percent Fractured pieces		97%	95% Min.

Table 3. Asphalt cement characteristics.

Property	Test condition	Units	ASTM Designation	Test Results	SCRB specification
Penetration	25C°, 100 gm,5 sec.	0.1 mm	ASTM-D5-2006	43.6	40-50
Flash point	--	°C	ASTM-D92-2005	335	Min.232
Softening Point	--	°C	ASTM-D36-1995	53.5	--
Ductility	25C°, 5 cm/min	cm	ASTM-D113-1999	113	>100
Specific Gravity	25C°	--	ASTM-D70-1997	1.032	--
Residue from thin film oven test			ASTM-D1754-1997		
-Retained penetration, of original	25C°, 100 gm, 5 sec.	%	ASTM-D5-2006	82	>55
-Retained Ductility	25C°, 5 cm/min		ASTM-D113-1999	58	25+

3.2. SBS Polymer modifier

The additive used in this study is SBS polymer which is a thermoplastic polymer that increases the general performance of flexible pavement by improving the stability, elasticity, and stiffness of asphalt binders. The SBS is softened at high temperature; therefore, it can be simply added and mixed with asphalt cement. The utilized SBS polymer has been brought from the Kraton Company in France. This percent is the best because the previous studies have selected 3, 4 and 5 percent and the choosing this percentage is good after several trials. The SBS was added to asphalt binder with a percentage 4% by the weight of asphalt. Figure 3 illustrates the viscosity-temperature chart for asphalt AC (40-50) used in determining the mixing and compaction temperatures. Table 4 indicates the SBS properties. Figure 4 illustrates the photo of SBS used in preparing modified asphalt mixes.

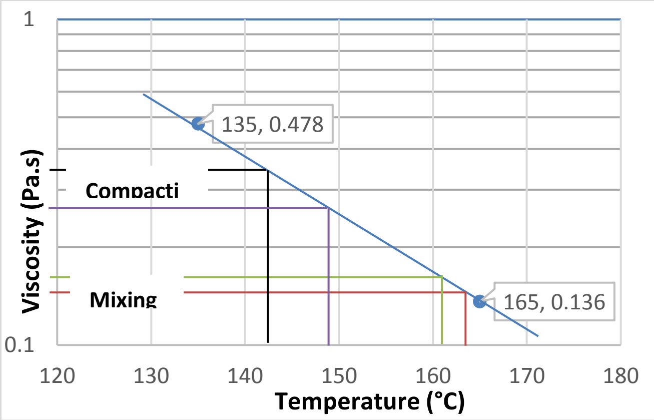

Fig. 3. Viscosity-temperature chart for asphalt AC (40-50).

Table 4. The main properties of SBS.

Properties	Result
Density(kg/m^3)	1247
Melting point	197
Apparent	White

Fig. 4. The photo of SBS used in preparing modified asphalt mixes.

3.3. HMA design procedure

The experimental works of this study have been done in the laboratories of Faculty of Engineering/Al-Mustansyriah University. The design asphalt binder content for control, modified, recycled, and recycled-modified mixtures for wearing course and base course layers was specified using Marshall mix design method.

The optimum asphalt binder content for all types of the mixtures was determined by using five percentages of asphalt contents (4.0, 4.5, 5.0, 5.5, and 6.0%) by weight of total mix for wearing course layer and (3.5, 4, 4.5, 5, 5.5%) by weight of total mix for base layer. After the aggregate gradation was chosen, the next step was to select the optimum asphalt content. In this study, Marshall Design procedure ASTM D 6927 [24] was used. The optimum asphalt content was selected according to the best stability, density and 4% air voids content. Four types of mixtures were prepared as below:

A. Control mixtures

Mixtures without adding additives were for both wearing course and base course.

B. Modified asphalt mixtures

Modified asphalt by 4% SBS polymer by weight of asphalt binder was used. This percent is the optimum one because the previous studies selected 3 , 4 and 5 percent by weight of asphalt and choosing this percentage is good after several trials.

C. Recycled mixture

Mixture with 20% RAP was prepared to indicate the influence of variation in aggregate gradation by adding RAP in the Mix for both surface and base layers. The percent of asphalt binder in reclaimed asphalt pavement was 3.91% from extraction test.

Tables 5 and 6 show mixtures properties at optimum asphalt contents for all types of mixtures and for both wearing course and base course respectively.

The indirect tensile test has been conducted on a Marshall specimen as indicated in Fig. 5 by diametric loading the specimens at a constant rate of 2 inch/min (50.8mm/min) and measuring the force required to break the specimen.

Table 5. Mixtures properties for wearing course at optimum asphalt content.

Marshal Property	Control Mix	3% SBS	4% SBS	20% RAP	20%RAP+4% SBS	S.C.R.B Specification Limit
Stability, KN	9.05	12.4	13.7	11.6	14.2	8 min.
Flow, mm	3.1	3	4.65	3.3	4.4	2-4
Va, %	4.7	4.4	4.1	4	4.45	3-5
VMA, %	15.5	16.15	15.7	18.3	18.35	14 min.
O.A.C, %	4.8	5.1	5.4	5	5.2	4-6

The indirect tensile strength (I.T.S) was determined using the following equation:

$$\text{I.T.S} = \frac{2Pult}{\pi t D} \quad \ldots(1)$$

where, I.T.S = Indirect tensile strength (MPa), *Pult* =Ultimate applied load at failure (N), *t* = Specimen thickness (mm), *D* = Specimen diameter (mm).

Table 6. Mixtures properties for base course at optimum asphalt content.

Marshal Property	Control Mix	3% SBS	4% SBS	20% RAP	20%RAP+4 % SBS	S.C.R.B Specification Limit
Stability, KN	7.4	8.5	11.9	7.9	13.8	5 min.
Flow, mm	3.9	3.35	4.3	2.9	4.03	2-4
Va, %	4	3.9	4.9	4.1	4.5	3-6
VMA %	14	15.59	15.9	13.3	14.1	12 min.
O.A.C, %	4.2	4.5	4.7	4.3	5	3.5-5.5

Fig. 5. Specimen tested in ITS device.

3.4. Indirect tensile resilient modulus test

The indirect tensile resilient modulus test has been performed at temperatures of using a Universal Test Machine UTM-25 apparatus at different temperature of 5, 25 and 40°C as stated by the modified ASTM *D4123* [24]. It is a repeated load indirect tension test for knowing the resilient modulus of the asphalt mixes. The recoverable horizontal deformation, ΔH was used to calculate the indirect tensile resilient modulus, MR in Eq. (2):

$$M_R = \frac{P.(0.27+\mu)}{t.\Delta H} \quad \ldots (2)$$

where, M_R = Resilient Modulus (MPa), P = Applied vertical load (N), t = Thickness of sample (mm), μ =Poisson's ratio, and ΔH = Horizontal deformation (mm).

A wave-sine load pulse was implemented at a frequency of 1 Hz, including 0.1s loading and 0.9s rest period [1]. The Poisson's ratio was assumed as 0.35. 100 load repetitions were selected to testing condition and finally five load repetitions were conducted to obtain the average of MR. Figure 6 illustrates the UTM-25 apparatus was utilized to find the Resilient Modulus. The results of resilient modulus test are shown in Fig.7.

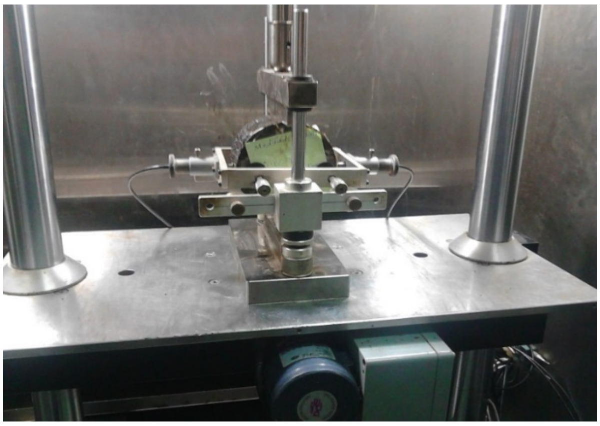

Fig. 6. UTM-25 apparatus.

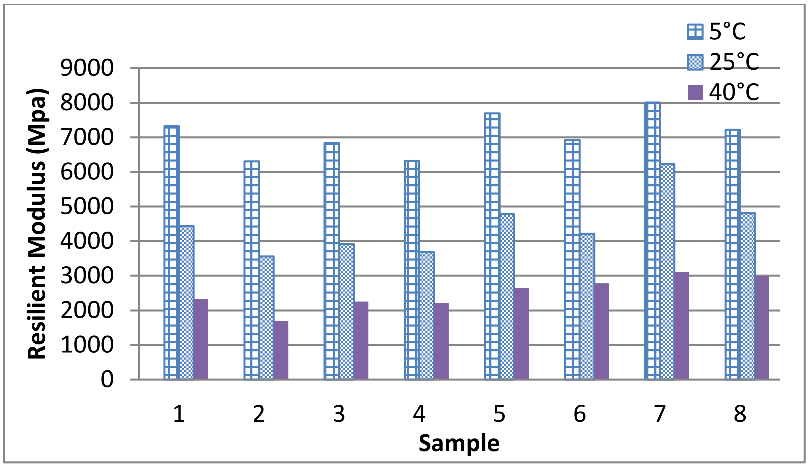

Fig. 7. Results of resilient modulus.

In this figure,

sample 1 = Modified asphalt mixture (4% SBS)- surface layer with 5% bitumen

sample 2 = Modified asphalt mixture (4% SBS)- base layer with 4% bitumen

sample 3 = Control asphalt mixture - base layer with 4% bitumen and

sample 4 = Control asphalt mixture - surface layer with 5.1% bitumen.

Sample 5 = Recycled surface RAP of 20%

Sample 6 =Recycled base RAP

Sample 7= recycled surface RAP +4% SBS

Sample 8 =recycled base RAP +4% SBS

Having indicated the values of MR at different temperatures (5 ºC, 25 ºC and 40ºC), sample No. 7 demonstrates the highest value of MR than other samples under all three temperatures as indicated in Fig. 7. Whereas, sample no.2 has the lowest values among the others; this means the combination of RAP and SBS giving better results.

4. Proposed Flexible Pavement Structure

A flexible pavement is consisted of several layers, known as subgrade, sub-base, stabilizer, binder and surface course. Whereas, several design considerations are included in a pavement from the geometric, functional and drainage characteristics, the structural design shows estimation of suitable thicknesses of each pavement layer. Various types of materials have been utilized to form a specific layer of a pavement structure. These materials indicate complicated response as exposed to load, temperature and moisture variations. The engineering properties of a pavement material bases on the relative composition of its components. The form of a pavement material is finalized through suitable mix design; hence, the desired levels of different engineering properties of the material are attained [25].

Primarily, an equivalent 80 KN (18 Kip) single axle load (ESAL) with dual tires was utilized. Fifteen million ESALs are assumed as a traffic loading during fifteen years of pavement service life. The use of ESAL depends on the results of experiments indicating that the influence of any load on the pavement performance can be characterized in terms of (ESAL) repetitions. SN value is a structural number that will be used in determining the thickness of each layer and according to the AASHTO equation (Eq. (3)) [26]:

$$SN=a_1D_1+a_2D_2m_2+a_3D_3m_3 \qquad \dots (3)$$

where; a_1, a2 and a3 are the layers coefficients for surfacing (asphalt concrete surface course =0.44 and asphalt concrete binder course =0.38), base (asphalt concrete base course =0.34) and sub-base (gravel sand soil subbase course =0.14) respectively. The values of D_1, D_2 and D_3, which represent the thickness for the same layers, are in inches. The drainage factor values of base and subbase (m_2 and m_3) are 1.0 and 0.8. The value of m3 is assumed for pavement saturation of 5 % and the drainage system is good. The roadbed resilient modulus for fine grained soil with soaked CBR of 10% or less, is computed by Eq.(4):

$$MR= 1500\ \text{CBR} \qquad \dots(4)$$

The CBR percent of subgrade is assumed to be 4% as minimum CBR required by SCRB specifications. Therefore, the resilient modulus of subgrade becomes 6 ksi (40 MPa). Claessen et al. [27] suggested relevant formula to estimate resilient modulus of subbase course depended on subgrade resilient modulus as indicated by Eq. (5):

$$MR= 0.2h0.45\times MR\ (soil) \qquad \dots (5)$$

Where, h= The thickness of sub-base layer in mm.

The various used parameters are shown in Table 7. Proposed thickness of flexible pavement structures have been obtained from AASHTO pavement design as indicated in Table 8.

Table 7. Pavement materials properties.

Variable	Value
Initial Serviceability, *Po*	4.2
Terminal Serviceability, *Pt*	2.5
Reliability Level, *R*	95%
Overall Standard Deviation, S_o	0.45
Performance Period (years)	15
Subgrade CBR value = 4 %, *MR*= 1500 * 4=	6000
SN required	5.62
ESALs over fifteen years	15,000,000

Table 8. Proposed thickness of flexible pavement structures.

Layer	Material	Layer coefficient	Drainage coefficient	Thickness, cm
1	HMA Type III, Wearing Course	0.44	1	5
2	HMA Type I, Base Course	0.34	1	20
3	Granular Material, Subbase	0.11	0.80	60

In proposal pavement modeling, the width and the length of the model were set at 5m, and the thickness of anisotropic subgrade is 5.40m in accordance with Alex [28] stated that the nodal radial strains were supposed to be negligible at approximately10 times a (radius of loaded area) from the center of wheel load. Furthermore, the nodal stresses and displacements were assumed to be trivial at 20 times below the pavement surface.

5. Determination of Critical Strains

To determine the critical strains, a set of dual tires with a dual spacing of 343 mm (13.5 in.), with a contact radius a of 136 mm (5.35 in.) are assumed for a single tire, 96 mm (3.78 in.) for dual tires. These radii are for an 18-kip (80-kN) single-axle load exerting a contact pressure of 100 psi (690 KPa). Figure 8 indicates the response point and pavement structure.

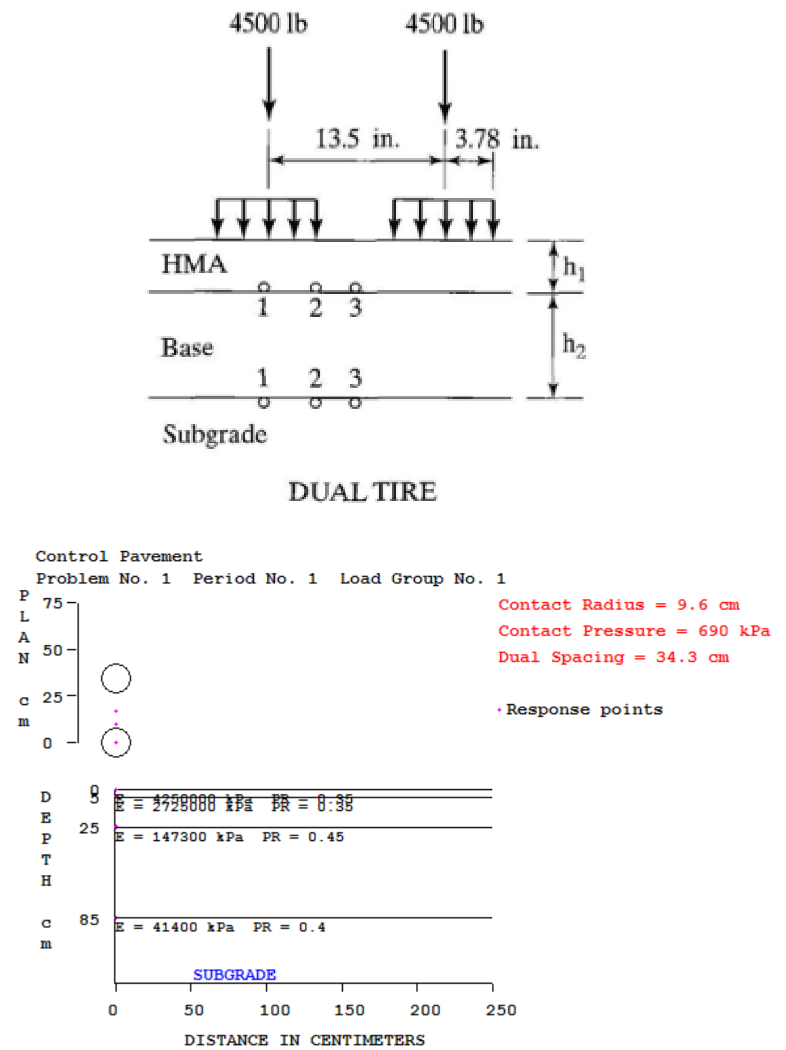

Fig. 8. Response point and pavement structure.

The tensile strain at the bottom of asphalt concrete layer(s) and the vertical compressive strain at top of subgrade were selected among the Kenlayer software output values, Figs. 9 and 10 present the effect of variations in asphalt paving types on the tensile and the vertical compressive strains.

As shown in Figs. 9 and 10, the use of 4% SBS modified asphalt in construction of surface layer only will decrease the tensile strain at bottom of surface layer and will reduce the compressive strain at top of subgrade.

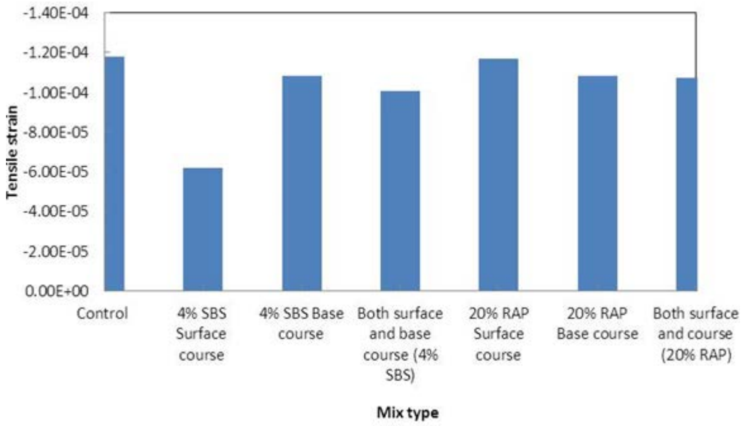

Fig. 9. Effect of variations in asphalt paving types on tensile strain.

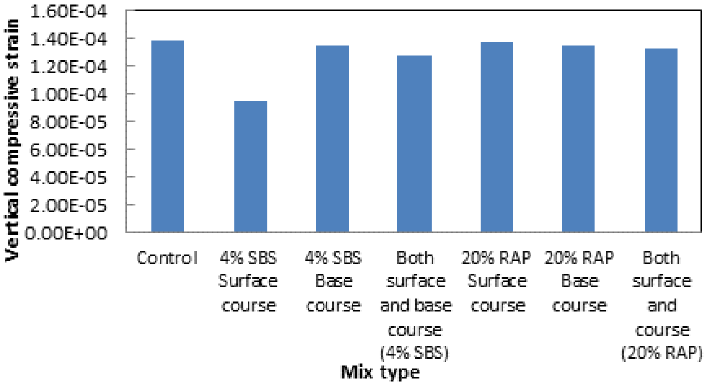

Fig. 10. Effect of variations in asphalt paving types on vertical compressive strain.

6. Conclusions

The main conclusions drawn from the current study are listed below:

- The SBS modifier is better than using RAP in construction of pavement structure.
- The tensile strain at bottom of surface course is lowest between other cases when this course contains 4% SBS by weight of asphalt used in preparing asphalt mixtures.

- It is concluded that surface course constructed from asphalt mixes with 4%SBS by weight of asphalt will withdraw the traffic loading and reduce the compressive strain at top of subgrade layer.
- Using the recycled asphalt mixtures containing RAP materials enhances the sustainability concept in construction of both surface and base courses to resist traffic loading.

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