EFFECT OF HOT MIXTURE MODIFICATION ON OVERALL COST OF THE PAVEMENT

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Abstract

In pavement design method, since the surface number determined in accordance with subgrade bearing capacity, total equivalent single axle load, and serviceability index must be greater than or equal to the sum of the products of surface thickness and layer coefficients, many combinations exist. The parameters limiting these options are construction criteria and economy. Layer coefficients taken into consideration in pavement design are determined based on material properties. Lately, additives improving the mechanic properties of the material are being used, thus the conventional layer coefficients accepted by many agencies varies. In this study, the layer coefficients are determined by measuring the elastic modulus of bituminous hot mixtures modified by styrene-butadiene-styrene (SBS) and crumb used tires (CR).

Experimental results show that the elastic modulus of the modified mixtures increase with the additive content and this increase is more pronounced in SBS modification. It is determined that the additive modification has increased the layer coefficient by 18%. In order to find out how this improvement has affected the layer coefficients, analysis is performed within thousands of combinations and optimum solutions are found through Matlab software. While the required layer thicknesses decrease by using additives, hence the cost of pavement, the cost of additives increases. As a result, total costs and optimum additive rates are determined. It is concluded that the total costs do not increase significantly by using additives due to the contribution to the mechanical performance of it. These results are more pronounced for low subgrade bearing capacity and not affected by the change of traffic volume significantly. Moreover, while use of waste vehicle tires in hot mixtures does not increase the total cost of pavement it will also generate an economic value through the contribution to the prevention of the environmental pollution.

Keywords: Styrene-butadiene-styrene, crumb rubber, structural design, cost analysis.

1. Introduction

Highways produced with base asphalt cannot sustain to low speeds and heavy loads due to its drawbacks such as low elastic modulus, poor rutting and low fatigue resistance. Previous studies show the achievement of polymer additives on improving the mechanical properties of asphalt layers. [1-3].The another additive used for performance improvement of hot bituminous mixtures is crumb rubber obtained by used waste vehicle tires.The number of waste tires increased day-by-day causing a number of problems such as limited stockpiles, fire hazards and environmental concerns. Including high percentage of rubber, waste tires has been using for bitumen modification providing an economic sustainability and environmental protection. In the studies that were conducted on CR modified bituminous mixtures, it was stated that CR modification increased fatigue life of asphalt mixtures and its resistant against permanent deformations at high temperatures and it can be economically used instead of polymer [4-7]. It was indicated that this improvement effect of CR modification was resulted from the increase on viscosity and elastic component and formation of a thicker asphalt film thickness around the aggregate [8].

The flexible pavements including the bituminous and granular layers are designed by emprical methods.The commanly used AASHTO (American Association of State Highway and Transportation Officials) design method is based on using an abstract number that solved design equations called structural numbers (SNs). A SN expresses the structural capacity of the pavement structure required for given combinations of a total equivalent to 18-kip single axle loads (EASLs), soil support values, terminal serviceability indexes, and regional factors. This method is based on the pavement performance-serviceability concept developed during the AASHO Road Test. The method, utilizes layer coefficients to integrate a pavement structure using materials of varied supporting capacities. The principle variables on determining the layer coefficient are material types and material properties. The AASHTO Design Guide recommends using the elastic modulus as the standard material quality measure to account for material types and material properties [9].

In this study elastic modulus of the SBS and CR modified mixtures are determined experimentally and Pavement design including the modified bituminous layers are analysed according to AASHTOmethot by using Matlab program.

2.Pavement Design

Flexible pavements are constructed as layered. Traffic loads affect a wider area by descending towards lower layers from upper layers (Figure 1). Therefore, the stresses decrease towards the lower parts from the coating surface. Each layer receives the forces that affect it without being deformed and transfers it by spreading to the other layer below in a wider area. Since the stress decreases downward the layers at the bottom levels which have less bearing capacity and so can be constructed more economical ensures an optimum pavement design. [10].

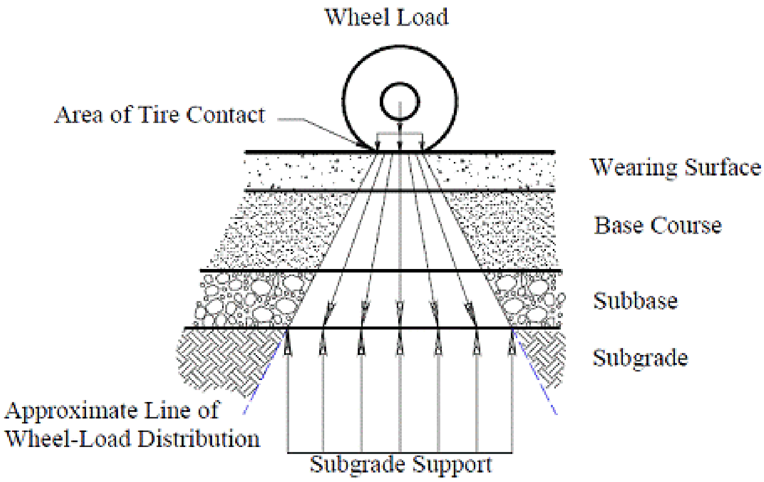

Fig.1 Load distribution in flexible pavement

The top layer of the pavement that receives the traffic loads is the coating. Since the pressure and the tensile strength that occur due to the traffic loads are at the highest levels, the coating layer must have a higher elasticity module when compared with the other layers of the pavement. This layer consists of two parts, surface (wearing) and binder courses, when necessary. The surface layer is also responsible for ensuring the sealing, i.e. being water-proof, and forming friction. Dense and gap graded bituminous mixtures, stone-mastic asphalt are used as surface layer extensively.

The main duty of the base layer is ensuring the basis for the coating layer and increasing the load-bearing ability of the pavement It must be able to resist the high shear stress stemming from the traffic loads and must stay in balance in high moisture rates. In addition, the base layer can help the drainage and also can ensure an additional protection against the frost effect. The base must be permeable enough to prevent water entrapment and provide uniform support across the pavement. Crushed rock or plant-mix base layers are used extensively.

The subbase layer is the lowest layer of the flexible pavement and is produced from the granular materials that have lower CBR values with a good drainage capacity that can resist frost blister, swelling and shrinking and similar volume changes, and increase the load carrying capacity. Sandy-gravel layer are used extensively.

3.AASHTO Design Method

The AASHTO approach to flexible pavement performance quantifies the pavement structure as a structural number (SN) and further divides the pavement structure into three constituent parts: surface, base, and subbase.

The basic design equation, obtained by the observation and measurements on test road, for determining the design structural number for flexible pavements is as follows.

$$Log_{W18} = Z_R S_0 + 9.36\log(SN+1) - 0.2 + \frac{\log\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4+\left[\frac{1094}{(SN+1)^{5.19}}\right]} + 2.32 log M_R - 8.07 \quad (1)$$

W18 = Predicted number of 18-kip equivalent single axle load applications
Z_R = Standard normal deviate
S_0 = Combined standard error of the traffic prediction and performance prediction
SN = Structural number indicative of the total pavement section required
ΔPSI = Loss in serviceability (po - pt)
po = Initial design serviceability index
pt = Design terminal serviceability index
M_R = Effective roadbed soil resilient modulus (psi)

The design structural number represents the overall structural capacity needed in the base and surfacing to accommodate the expected traffic loading [11]. Once the design structural number is determined, the design layer thicknesses can be computed by considering the relationship between the thickness and the layer type using the following equation:

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 \tag{2}$$

ai = ith layer coefficient
Di = ith layer thickness (inches)
mi = ith layer drainage coefficient

Accordingly, layer coefficients for a particular material can be thought to represent the SN contribution per unit thickness of that material to the total SN of the pavement structure.

The original layer coefficients were regression coefficients developed by relating layer thickness to a road performance determined on basis of the parameters of the AASHO Road Test. The layer coefficients can vary depending on a number of factors such as material type, material properties, type of layer, traffic level, and failure criterion. The principle variables are material types and material properties. The AASHTO Design Guide recommends using the elastic modulus as the standard material quality measure to account for material types and material properties. Layer coefficient values for different layers made of different materials are determined using empirical equations derived from field experiments. The determination of layer coefficient of asphalt concrete is given following equation [12].

$$a = 0.4 \log\left(\frac{E}{3000}\right) + 0.44 \tag{3}$$

Lately, additives improving the mechanic properties of the material are being used, thus the conventional layer coefficients accepted by many agencies varies. Although many agencies accept the asphalt concrete layer coefficient as 0.40-0.44; today, mixtures that are modified with various additives show higher resistance, and depending on this, have higher layer coefficient.

4.Experimental study

In experimental study the effects of additives on layer coefficients are determined by measuring the elastic modulus of SBS and CR modified hot bituminous mixtures. An asphalt cement, B 160–220, obtained from Turkish Petroleum Refineries was used as bitumen for mixture preparation. The SBS polymer used was KratonD-1101, supplied by the Shell Chemicals Company. Six SBS polymer modified bitumen (PMBs) were produced. The polymer contents ranged from a low polymer modification of 2% to higher degrees of modification, up to 6%, with a 1% increment. The crumb rubber (CR) used in this study was obtained by an ambient process. Six crumb rubber modified bitumens were produced. The crumb rubber contents ranged from 4% to 12%, with a 2% increment. The modified bitumens were produced with a laboratory-scale mixing device with a four-blade impeller (IKA) at a temperature of 180 °C for one hour at a rotation speed of 1000 rpm. A crushed coarse and fine limestone aggregate, with a maximum size of 19 mm, was selected as the dense-graded asphalt mixture. The asphalt mixture was designed in accordance with the standard Marshall mix design procedure. The specimens were compacted by using 75 blows on each side of cylindrical samples in 101.6 mm diameter and 63.5 cm thickness. The optimum bitumen content was found to be 5.0% by weight of aggregate for the unmodified asphalt mixes. This ratio was chosen for all mixtures so that the amount of bitumen would not confound the analysis of the test data. Elastic modulus test is done for determining the layer coefficient. Elastic modulus is the most popular form of stress–strain measurement used to evaluate their elastic properties and is considered a very important performance characteristic of a pavement formulation. The indirect tensile elastic modulus (E) test defined by BS DD 213 is a nondestructive test. The elastic modulus in MPa is defined as:

$$E = \frac{F(R+0.27)}{L.H} \quad (4)$$

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 five applications of the load pulse (mm), L is the mean thickness of the test specimen (mm), and R is the Poisson ratio (here assumed to be 0.35). The test was performed with controlled deformation, again using the universal testing machine (UTM). The magnitude of the applied force was adjusted by the system during the first five conditioning pulses such that the specified target-peak transient diametral deformation was achieved. A value of 6 lm was chosen so as to ensure that the signal amplitudes obtained from the transducers were sufficient to yield consistent and accurate results. During testing, the rise time, which 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 was set to 3.0 s. The test was performed at 25 °C. The variation on elastic modulus of mixtures by using additive are given in Fig.2.

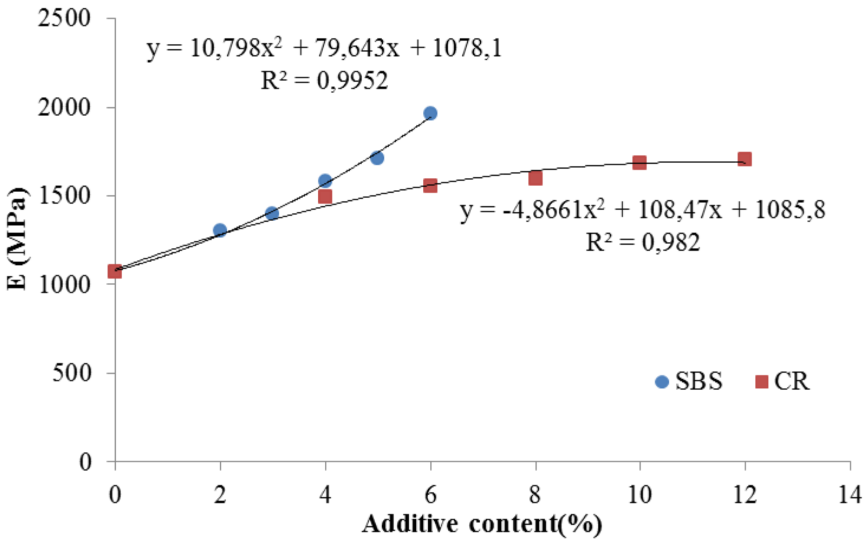

Fig.2 Variation on elastic modulus of modified mixtures

6-As seen in Fig.2 elastic modulus of modified mixtures increase with the increase of additive content. This increments is more pronounced for SBS modification. In CR-modified mixtures, the elasticity module increases at a high speed at first, and then the speed of the increase decreases. In SBS modification, on the other hand, there is a constant increase. The addition of 6% SBS increases the E value of the mixture in 83% when compared with the Control Mixture. Adding 12% CR increases this value up to 59%. The E value that is obtained with 5% SBS modification can be obtained with 12% rate in CR modification. The layer coefficients calculated via Formula 3 with respect to elastic modulus are given in Table 1.Here the values are multiplied by 2.8 in order to obtain the standart value of 0.44 for control mixture. The layer coefficients of binder layers are determined to satisfy 0.42 for control mixture.

Table 1 Layer coefficient of the materials

	a1,a2			a1,a2	
SBS (%)	Surface cource	Binder cource	CR (%)	Surface cource	Binder cource
0	0.440	0.420	0	0.440	0.420
2	0.474	0.454	4	0.497	0.477
3	0.486	0.466	6	0.505	0.485
4	0.507	0.486	8	0.509	0.489
5	0.521	0.501	10	0.518	0498
6	0.545	0.523	12	0.520	0.500
a3:0.13 (Crushed rock, CBR=100)					
a4:2.10 (Sandy-gravel, CBR=30)					

5- Results

In pavement design method, since the surface number determined in accordance with subgrade bearing capacity, total equivalent single axle load, and serviceability index must be greater than or equal to the sum of the products of surface thickness and layer coefficients, many combinations exist. The parameters limiting these options are construction criteria and economy. In this study thousands of combination occurred by the different values of the parameters in design criteria are analyzed according to AASHTO method through Matlab software and optimum solutions are found. Drainage factors and total loss in serviceability in all combinations are assumed as 1 and 1.7 respectively.

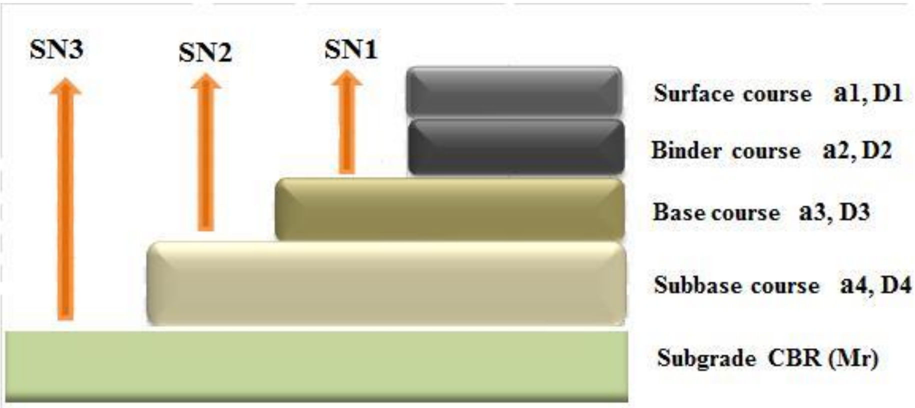

Fig.3 Structure of the flexible pavement

The variation on SN according to subgrade bearing capacity and ESAL are given in Fig.4. As seen in figure that the required SN values increase exponantially at low CBR values of subgrade. SN values are approch to a constant value with the increase of CBR value. This also indicates that the pavement can be designed with a large number of combinations at low CBR value. In Table 2 the SN values are given according to layer type and ESALs.

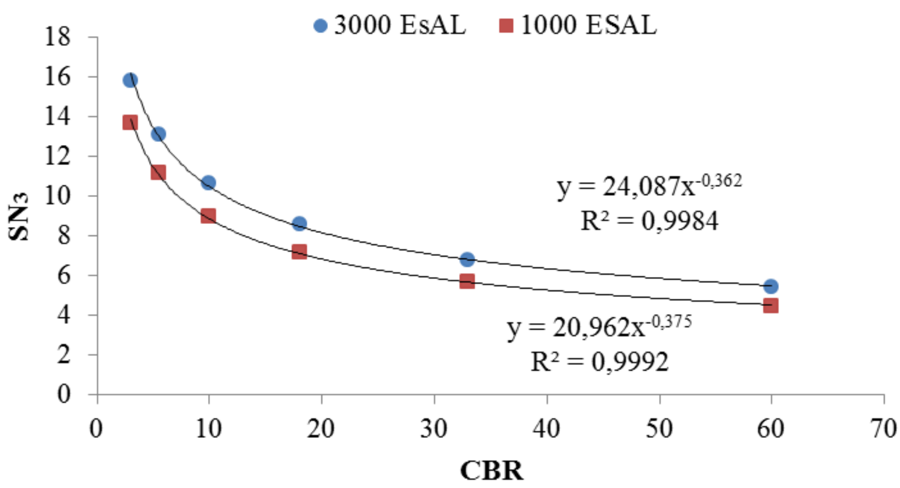

Fig.4 Variation of Structıral Number versus subgrade CBR

Table 2 Required SN values of the layers according to ESAL

SN	ESAL	Subgrade CBR=8	Subbase CBR=30	Base CBR=100
SN3	1000	9.91		
	3000	11.34		
SN2	1000		5.87	
	3000		7.04	
SN1	1000			3.60
	3000			4.39

As previously mentioned, the parameters that will limit the combinations to be formed are the production criteria and the economy. There are lower and upper limits for the thickness of each layer. Generally, the thickness of the layer of the bitumen mixtures that are compacted at once is between 1.5 or 3-fold of the biggest aggregate size in the mixture. For the base and subbase layers, this value must be 10 cm and 15 cm, respectively [13].

In the study the thickness of surface course, binder course, base course and subbase course are selected between 3-6 cm; 5-9 cm; 10-30 cm and 15-30 cm respectively By so-doing, 8820 combinations have been formed with the 4 different thickness values for the surface layer, 5 for the binder layer, 21 for the base layer, and 21 for the subbase layer. In the solutions, the optimum bitumen ratio for the surface layer was taken as 5%, the density of the mixture was taken as 2.3 gr/cm^3; the optimum bitumen for the binder layer was taken as 4.7%; and the density was taken as 2.2 gr/cm^3. According to the 2014 General Directorate for Highways unit prices, the costs of 1 ton coating, and the costs of additives according to the market condition are given in Table 3.

Table 3 Cost of the layers

Description	Unit	Cost (TL)
Surface layer	ton	52.65
Binder layer	ton	50.64
Crushed rock base layer	m^2/cm	0.2602
Sandy-gravel subbase layer	m^2/cm	0.1368
Styrene-butadiene-styrene SBS	ton	6000
Crumb rubber (CR)	ton	1000

The programe analysis all the combinations according to AASHTO method. The optimum layer thicknesses obtained for different ESAL and additive contents are given in Table 4 and 5.

Table 4 Layer thickness and costs according do SBS content

ESAL	Additive content (%)	D1 (cm)	D2 (cm)	D3 (cm)	D4 (cm)	Cost of avement (TL/m^2)	Cost of additive (TL/m^2)
1000	0	3	8	15	30	20.55	0
	2	3	8	12	30	19.77	1.406
	3	3	7	15	30	19.44	1.925
	4	3	7	13	30	18.91	2.565
	5	3	7	12	30	18.65	3.206
	6	4	5	14	30	18.16	3.517
3000	0	6	9	15	30	25.30	0
	2	5	9	15	30	24.09	1.806
	3	5	9	14	29	23.69	2.710
	4	4	9	15	30	22.96	3.337
	5	4	9	14	30	22.41	4.171
	6	6	6	15	30	21.95	4.717

Table 5 Layer thickness and costs according do CR content

ESAL	Additive content (%)	D1 (cm)	D2 (cm)	D3 (cm)	D4 (cm)	Cost of pavement TL/m^2	Cost of additive TL/m^2
1000	0	3	8	15	30	20.55	0
	4	3	7	14	30	19.18	0.427
	6	4	6	13	30	19.00	0.648
	8	3	7	13	30	18.90	0.855
	10	4	6	12	30	18.75	1.080
	12	3	7	12	30	18.65	1.282
3000	0	6	9	15	30	25.30	0
	4	6	8	12	30	23.04	0.606
	6	5	8	15	30	22.97	0.841
	8	4	9	15	30	22.87	1.112
	10	4	9	14	30	22.61	1.287
	12	4	9	14	30	22.61	1.668

As it is clear in the tables, in determining the most economical cost, the subbase layer, with its lowest price, has had the maximum thickness in all combinations. The thickness of the base course changes between 12 and 15 cm. The thicknesses of the bitumen layers have shown big differences when compared with the additive ratios

As it is clear in the tables, in determining the most economical cost, the subbase layer, with its lowest price, has had the maximum thickness in all combinations. The thickness of the base course changes between 12 and 15 cm. The thicknesses of the bitumen layers have shown big differences when compared with the additive ratios. The changes in costs in comparison with the additive ratios for the 3000 ESAL value of the SBS and CR modification are given in Figure 5 and 6, respectively. In the graphics, the pavement cost changing with the additive ratio is given in the primary axis, and the additional cost caused by the use of additives is given in the secondary vertical axis.

In both additive modifications, the pavement cost decreases because of the increase in the elastic modulus with the increase in the additive ratio. On the other hand, the use of additives causes an extra cost, and this cost increases with the increase in the additive amount. In the SBS modification, the pavement cost decreases in a fast and continuous pace with the increase in the additive ratio, the effect of the high additive ratios (in the CR modification) on the decrease of the cost of the pavement decreases.

However, the additional cost values that stem from the use of additives are at a much higher level in the SBS modification when compared with the CR modification. While the 6% SBS modification decreases the pavement costs in a rate of 3.35 TL/m^2, the use of additional additives cause an increase of 4.71 TL/m^2. While the 12% CR modification decreases the pavement cost in 2.69 TL/m^2, the use of additional additives cause an increase at only 1.65 TL/m^2.

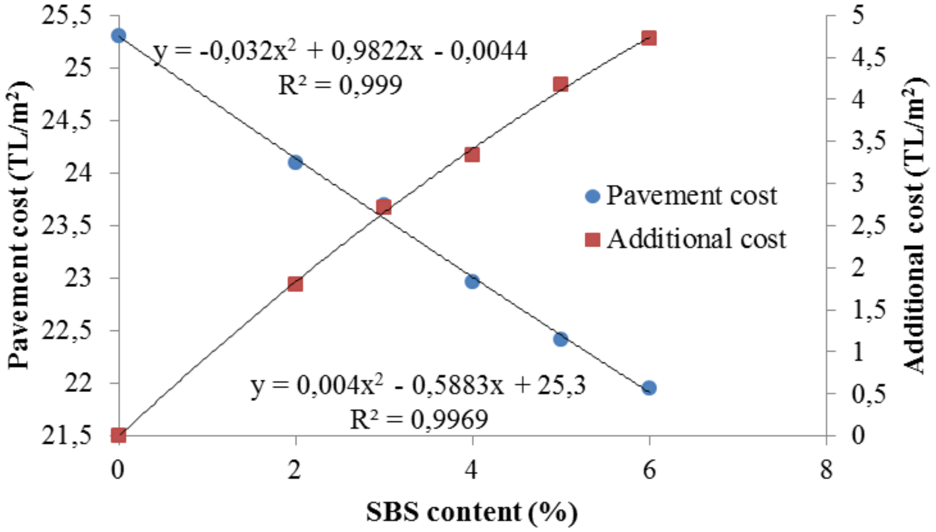

Fig.5 The variation on costs versus SBS content

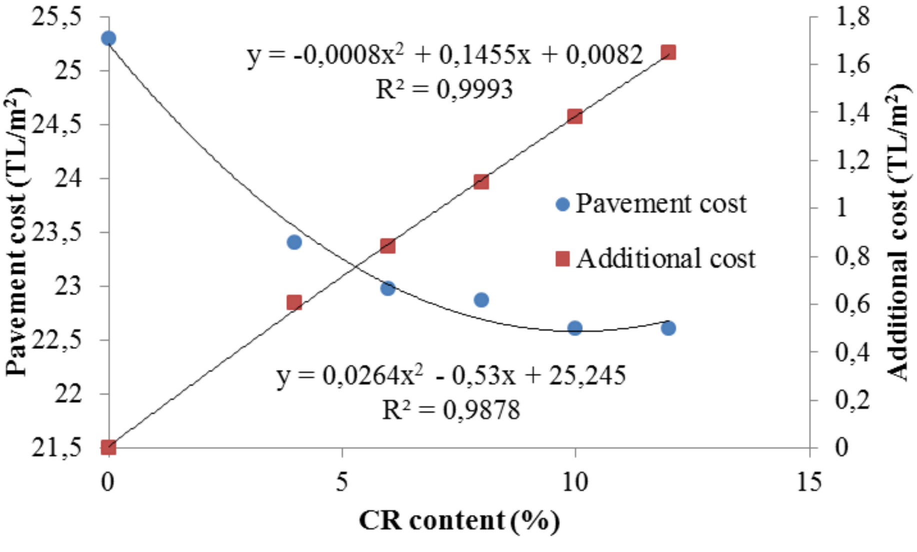

Fig.6 The variation on costs versus CR content

The change of the total costs with the additive ratio for SBS and CR are given in Figure 7 and 8, respectively. The total costs in SBS modification increase constantly with the additive ratio. However, since the high additive ratio is more effective on the elastic modulus, the effect of the increase of the SBS on the total cost start to decrease at the high additive ratio. The 5% and 6% SBS modification causes an increase of 5.01% and 5.35%, respectively in the total cost of the pavement. With the increase of the additive rate in CR modification, the total costs firstly decrease, and then start to increase. The lowest cost has been obtained in 8% CR rate. Although the CR modification is not as effective as the SBS on the elastic modulus, the additive cost being very low has caused the total cost to be low as well. The 8% CR modification decreases the total pavement cost at a rate of 5.21%. Even when the CR rate is used at 12%, the total pavement cost does not exceed the pavement cost without modification.

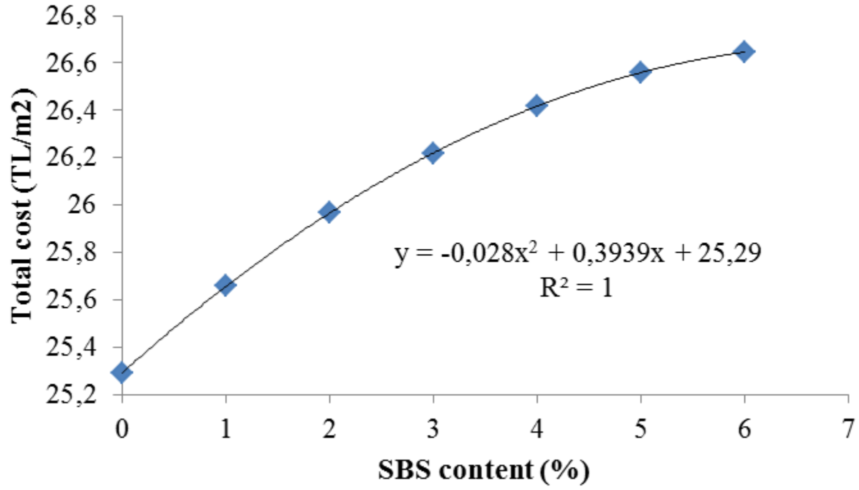

Fig.7 Effect of SBS content on total cost of pavement

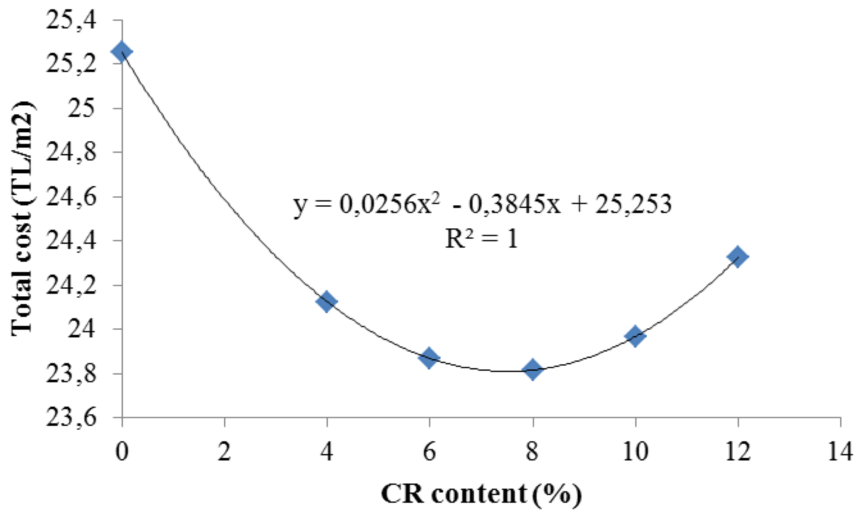

Fig.8 Effect of CR content on total cost of pavement

6.Conclusion

In this study, the cost analyses of the flexible pavement formed with bitumen hot mixtures modified at different rates with SBS and CR have been performed. For this purpose, firstly the effect of the additive rate on the elastic modulus of the hot mixtures has been determined in an experimental method. By using the Matlab Program, an optimum pavement design has been performed from among 8820 alternatives and the total costs of these alternatives have been determined.

The modification of the bitumen coatings with SBS additive, contrary to the expected excessive increase in the cost due to the extremely high additive cost, causes an increase at 5% in maximum use. This method decreases the thickness of the bitumen coated layers at a significant level because the SBS modified mixtures are very effective on the elastic module; and therefore, prevent the excessive increase in the cost that will occur due to the additives. Although the CR modification is not so effective on the elastic module as the SBS modification, the additive costs are extremely lower. Therefore, total pavement costs decrease with the use of CR. The optimum CR rate has been determined as 8%. In case the CR rate is 15%, the total pavement cost is equal to the unmodified pavement cost. Although the modified thinner pavements instead of unmodified thicker pavements will give the same performance in terms of the layer coefficients determined according to the elastic modulus, the additives used in thinner pavements become preferable in terms fatigue life, resistance to permanent deformations, and moisture damage. On the other hand, thinner CR-modified pavements that will give the same, even better performances in unmodified pavements will be a solution to the environmental pollution caused by the storage problems of the used vehicle tires which are waste materials.

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