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Technical and economic feasibility of asphalt performance using modified bitumen with SBS polymer from construction management approach in Khozestan province

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ABSTRACT

One of the ways of making pavements with high quality is making some amendments in consumption bitumen so that the final asphalt mixture would have a higher quality in order to use in the tropics. The aim of this study is study on SBS polymer in order to modify of the properties of polymer modified bitumen has been to SBS bitumen characteristics. The lack of bitumen qualifications modification led to procedural failures caused by the heat of the tropics regions. Obviously, bitumen characteristics modification cause to produce higher quality asphalts in order to use of pavement in tropical regions. With producing this kind of asphalts, maintenance costs of highways will be reduced. In this research, was attempted various methods to remove these drawbacks. Technical assessment to evaluate the effect of SBS polymer on bitumen properties include two types of tests Bitumen tests and asphalt tests. In this research Comparison the effects of the polymer amount on penetration, softness and density degree of bitumen and also asphalt was examined. Since it is currently challenging to perfectly achieve all expected polymer modified bitumen properties at the same time, some compromised recommendations are given in this paper, among which greatly enhancing the properties with an acceptably high cost, significantly reducing the cost with relatively poor properties and their combinations.

1. Introduction

Bitumen is a petroleum product, which are widely used. Iran is one of the world's oil-rich countries that exports millions of barrels of oil around the world. Because of the abundance of oil products, bitumen be used for road construction and using asphalt pavements is the most economical option. Bitumen due to special properties such as flexibility, hydrophobicity, and low cost is as one of the main materials used in the production of asphalt used for road pavement. Overall, in Iran and the world, nearly 70 percent of the bitumen production is used in road construction (Yousefi, 2000).

Due to the importance of road building and produced bitumen properties, it has considered for use in hot and cold asphalt mixes (Sadraldini, 2002). Despite its very high usage, there are various restrictions for use it. Among these restrictions, the issues rutting at high temperatures and thermal cracking at low temperatures, which restrict the use of bitumen in different temperature conditions can be mentioned.

Also, the bitumen used in asphalt production despite low weight percent (4 to 6 percent) has a very large impact on the strength and stability of the road in front of erosion factors and thus any improvement in bitumen properties ultimately will improve performance of the road cover (Sadraldini, 2002).

2. Material and method

To consider all the different conditions and traffic need for computational software that take calculations and draws graphs of the data output compares. To do this, MATLAB software environment was use (with coding).

Enter required input data in the form of Excel files, and then do the calculations required and desired outputs in the graphic form was displayed.

3. Results

3.1. The SBS polymer properties and their impact on the graves

Copolymer of styrene - butadiene - styrene is a three-block copolymer which two block styrene separated from each other by one butadiene block.

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These copolymers can be linear or radial and comprise a three-dimensional elastic network of polystyrene phase at pitch and are connected to each other by phase poly butadiene. In the polymers of styrene - butadiene - styrene, which is used in the road building bitumen, usually styrene form between 20 and 30 percent of the total weight of the polymer. High percent of styrene can cause incompatibility problems with pitch and create problems in distribution and instability of storage at high temperatures (khorasgani, 2008).

3.2. Effect of SBS polymer on bitumen properties

Among all modifiers bitumen, SBS polymer is most used, because this polymer causes:

- mechanical properties of bitumen are increased
- elasticity properties of bitumen are increased
- Prevent premature aging at bitumen.

Despite all the advantages that can be seen in the bitumen modification by SBS polymer, its compatibility with bitumen is low and this is a major obstacle in producing of bitumen with improved properties. This incompatibility is caused at the high temperature and can be solved this problem in two ways:

1. Macroscopic method: by adding a type of filler called KC, bitumen and SBS polymer compatibility will be improved by reducing their density difference.
2. Microscopic method: in this method using polymeric particles shrink at the nano metric dimensions, the problem of incompatibility of bitumen and polymer and instability of storage at high temperature will be prevented.

3.3. Technical Evaluation

Technical assessment to evaluate the effect of SBS polymer on bitumen properties includes two types of tests:
1. Bitumen tests
2. Asphalt tests

3.3.1. Bitumen tests

In this section we review the results of the various tests of bitumen and compared them. Performed Tests are including items such as: penetration degree, softness degree and bitumen density.

In order to better assess of changes in the characteristics of bitumen, quantities amounts are presented as linear graphs (Figs. 1, 2 and 3).

In order to determine the status of changes to the base asphalt, base bitumen graph has been shown red horizontal line in the diagram. This diagram displays the basic amount of each indicator in control pure bitumen.

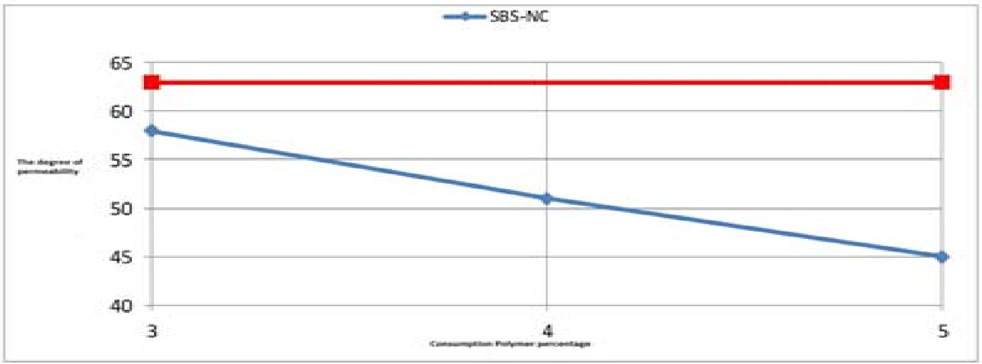

Fig. 1: Comparison of the effects of the polymer amount on penetration degree of bitumen

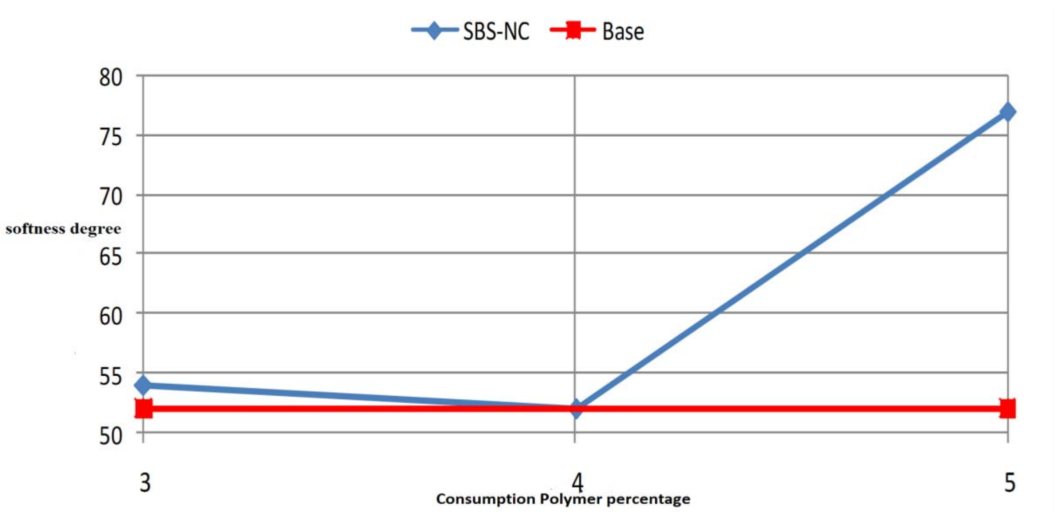

Fig. 2: Comparison of the effects of the polymer amount on softness degree

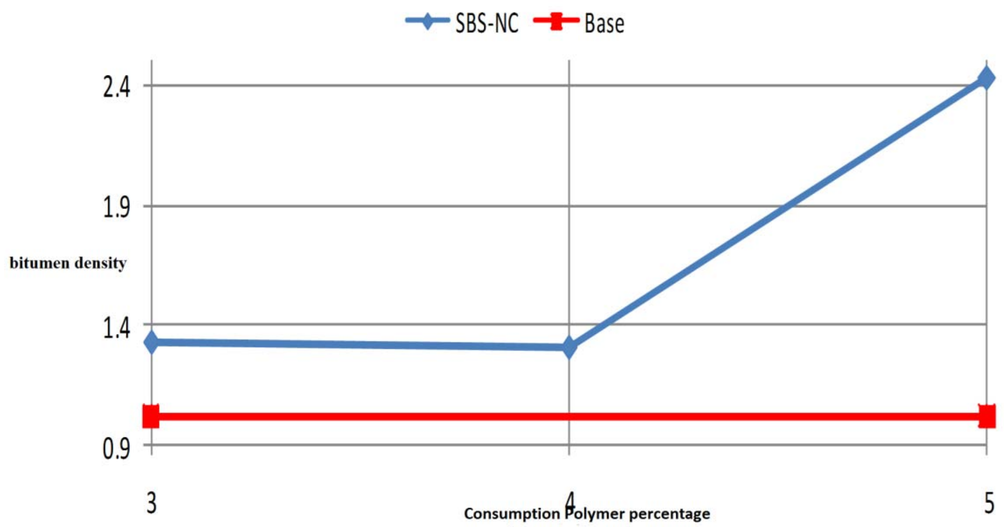

Fig. 3: Comparison of the effects of the polymer amount on bitumen density

Results of bitumen tests were summarized in Table 1. As you can see, by increasing the amount of consumption polymers on base bitumen, the degree of permeability has been reduced but density and bitumen softness degree has been increased.

Table 1: The tests results of pure bitumen and modified bitumen with SBS polymer

SBS			base bitumen without polymer	Polymer Consumption
5	4	3	0	Percent of polymer
SBS-NC-5	SBS-NC-4	SBS-NC-3	Base	Code of View
Nano clay			-	Additive material
SBS-NC			Base	Code of View
1	1	1	*0*	Percent of Additive
2.43	1.31	1.33	1.015	Density
45	51	58	63	The degree of permeability
77	52	54	52	softness degree

3.3.2. Asphalt tests

Another test was conducted for the production of asphalt mix using pure bitumen and aggregate sampling in the Khozestan province (lime type) compared with production of asphalt mixtures using modified bitumen and aggregate sampling in the Khozestan province (of lime).

These tests include the following: The specific gravity of asphalt, Marshall Strength and softness

As Figs. 4, 5 and 6 show, with increasing the amount of polymer to a central point, the amount of weight will be increased and then will be decreased. Also, this procedure is the same for endurance of samples Marshall. The reverse of these changes are also visible for the percent of empty space of sample asphalt and aggregates.

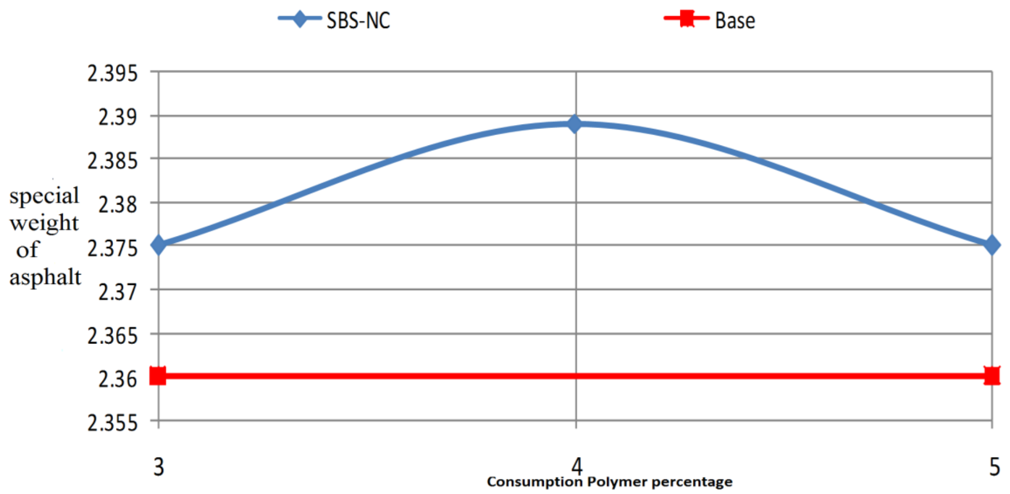

Fig. 4: Comparison of the effects of consumption polymer measure on the special weight of asphalt for Binder asphalt with calcareous materials

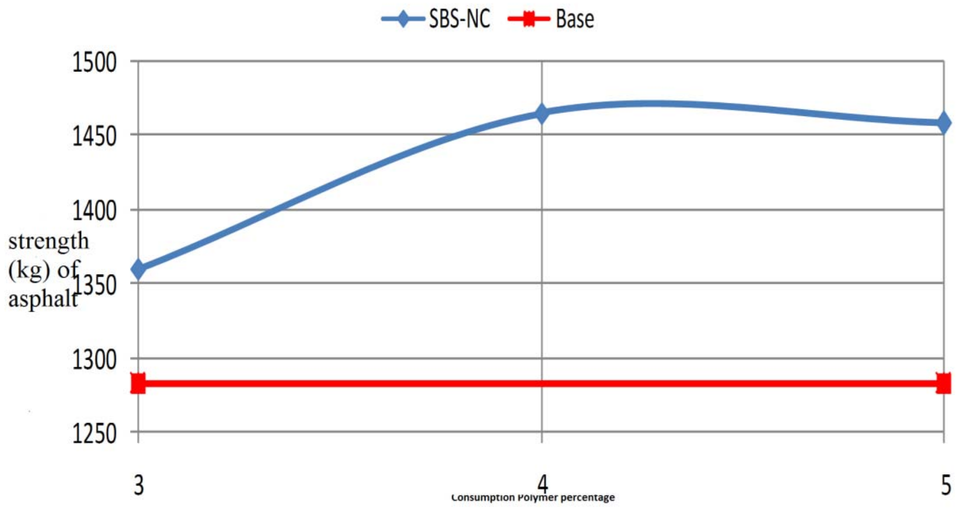

Fig. 5: Comparison of the effects of consumption polymer measure on the strength (kg) of asphalt for Binder asphalt with calcareous materials

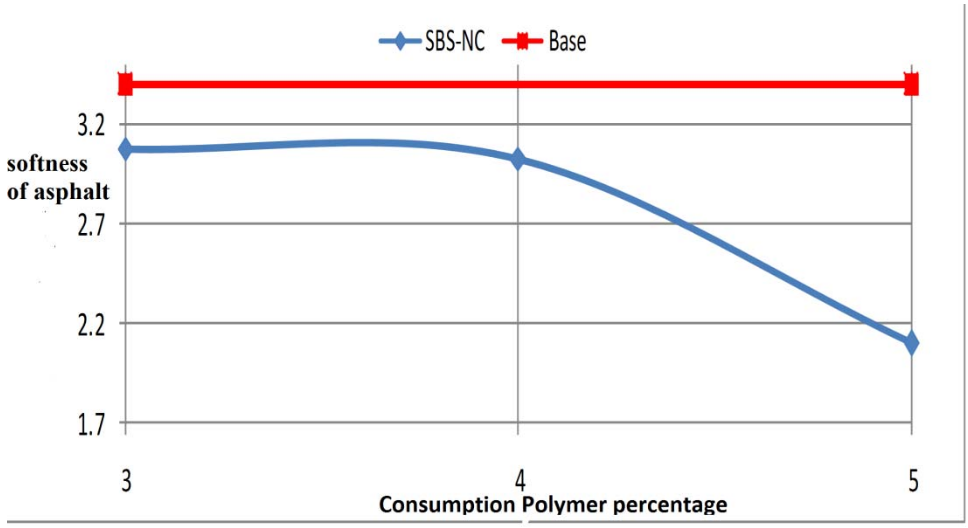

Fig. 6: Comparison of the effects of consumption polymer measure on the softness of asphalt for Binder asphalt with calcareous materials

3.4. Survey results of bitumen and asphalt testing

As you can see in Tables 2, using the SBS polymer has improved bitumen and asphalt properties.

Table 2: Summarized Marshall results of modified bitumen by SBS polymer for Binder asphalt with calcareous materials

SBS			base bitumen without polymer	Consumption Polymer
5	*4*	*3*	*0*	Percent of polymer
SBS-NC-5	SBS-NC-4	SBS-NC-3	Base	Code of View
Nano clay			-	Additive material
SBS-NC			Base	Code of View
1	1	1	0	Percent of Additive
2.375	2.389	2.375	2.36	special weight of asphalt
1458	*1465*	1360	1283	strength (kg)
2.10	3.03	3.08	3.4	softness of asphalt (mm)

3.5. The economic assessment

3.5.1. Determining the estimate thickness for different traffic

In order to economic evaluations must be addressed thickness of the pavement in the first step. Pavement thickness has been determined based on the Ashto calculation method and building materials. Of course, in Ashto method, the weather conditions also determine the quality of pavement that due to the freezing conditions in the Khuzestan province is not certain, it is not considered and only the properties of the materials has been used.

The point in this design is desired to obtain the optimal thickness based on minimizing the cost. For this purpose, the GRG nonlinear optimization method has been used. In order to determine the optimal thickness, minimize the total thickness of the pavement with regard to the measure of rupture at each layer has been used.

In this study, the thickness of the asphalt layers, for eight traffic types (150.000, 300.000, 600.000, 1.200.000, 2.400.000, 4.000.000, 700.000 and 9.000.000) and based on eight various resilient modulus was obtained. Table 3, 4, 5 and 6 were presented necessary thicknesses for the least traffic and the heaviest traffic for better comparison.

Table 3: Pavement thickness with ordinary bitumen

Base Soil resilient modulus								layer	Number of standards axis (8.2 ton)
1960	1400	1120	700	630	490	280	147		
11	11	11	11	11	11	11	11	asphalt	150.000
10	10	10	14	16	10	10	10	base	
0	0	0	0	0	14	30	53	sub-base	
24	24	24	24	24	24	24	24	asphalt	9.000.000
15	15	16	18	18	18	18	18	base	
0	0	0	18	24	35	63	99	sub-base	

Table 4: The thickness of the asphalt modified with SBS polymers 2%

Base Soil resilient modulus								layer	Number of standards axis (8.2 ton)
1960	1400	1120	700	630	490	280	147		
11	11	11	11	11	11	11	11	asphalt	150.000
10	10	10	14	16	10	10	10	base	
0	0	0	0	0	14	30	53	sub-base	
24	24	24	24	24	24	24	24	asphalt	9.000.000
15	15	16	18	18	18	18	18	base	
0	0	0	18	24	35	63	99	sub-base	

Table 5: The thickness of the asphalt modified with SBS polymers 4%

Base Soil resilient modulus								layer	Number of standards axis (8.2 ton)
1960	1400	1120	700	630	490	280	147		
10	10	10	10	10	10	10	10	asphalt	150.000
10	10	10	14	10	10	10	10	base	
0	0	0	0	10	14	30	53	sub-base	
22	22	22	22	22	22	22	22	asphalt	9.000.000
15	*15*	*15*	18	18	18	18	18	base	
0	0	0	18	23	35	63	98	sub-base	

Table 6: The necessity thickness for the modified asphalt with SBS polymers 5%

Base Soil resilient modulus								layer	Number of standards axis (8.2 ton)
1960	1400	1120	700	630	490	280	147		
10	10	10	10	10	10	10	10	asphalt	150.000
10	10	10	14	10	10	10	10	base	
0	0	0	0	10	14	30	53	sub-base	
22	22	22	22	22	22	22	22	asphalt	9.000.000
15	*15*	*15*	18	18	18	18	18	base	
0	0	0	18	23	35	63	98	sub-base	

As you can see in the above tables, thickness for the modified asphalt with SBS polymers has been decreased compared to conventional asphalt for different traffics and resilient different coefficients.

3.5.2. The economic calculations

Economic calculations for all types of available bitumen and for different thicknesses of pavement which have been calculated based on different traffic have been carried. Economic calculations on the basis of operational indicators and costs of life cycle index were done.

3.5.3. Index of construction costs

To determine operating costs indexes of polymer asphalt based on thickness specified in the tables for various traffic and resilient modules, based on the costs associated with the procurement, transportation and distribution of materials and costs related to machinery used, operating cost index for each category of asphalt materials was studied. Assumptions considered in this study are as follows (Figs. 7, 8, 9 and 10):

A- Cost calculation based on annual run assumption has been 250 km asphalt pavement or asphalt pavement. In the end costs for each kilometer asphalt pavement with 11 m^2 width were determined.

B- Studies were investigated based on the overall approach and the coefficients have not determined based on superior contractors. The reason for this is due to approximate authorities to determine coefficients by contractors on tenders. So, the base cost is considered in this analysis.

C- For each category of pavement, used machinery costs has been considered. Due to this fact that the costs have been calculated assuming an annual pavement assumption and machinery life 5 years is considered, so all the costs of machines to multiply in 0.2 in order to take annual fee into accounts. Also 30% of the machines annual cost has been included for estimate of machinery fuel costs and repairs.

D- For each of the used asphalts, in addition to the tabular output of costs in order to better assess of the situation, three-dimensional diagrams of the cost are prepared and presented based on region soil resilient modulus and the amount of 8.2 ton passing traffic.

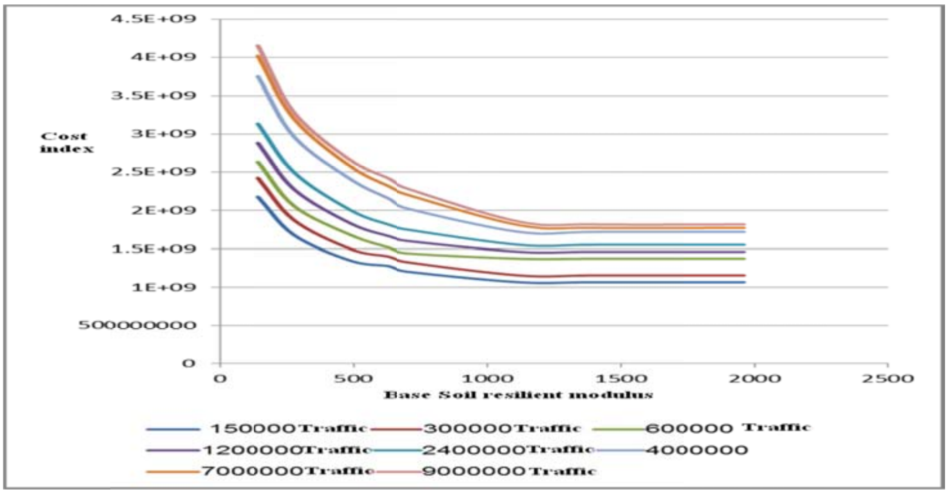

Fig. 7: Index of construction costs with typical asphalt

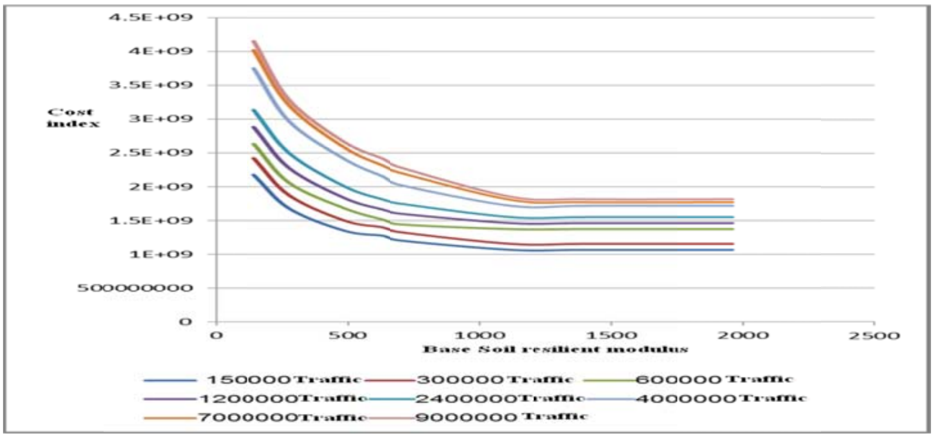

Fig. 8: The operating costs of modified asphalt with 3% SBS

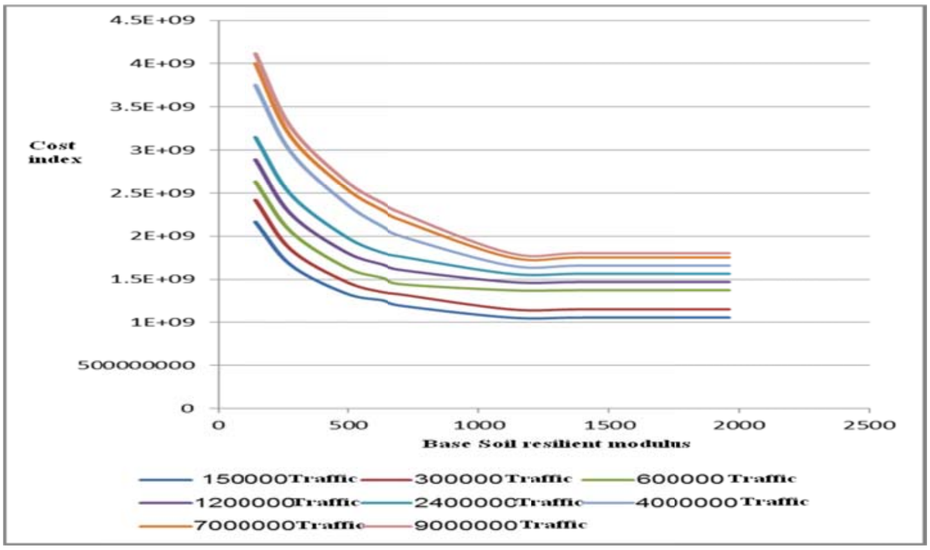

Fig. 9: The operating costs of modified asphalt with 4% SBS

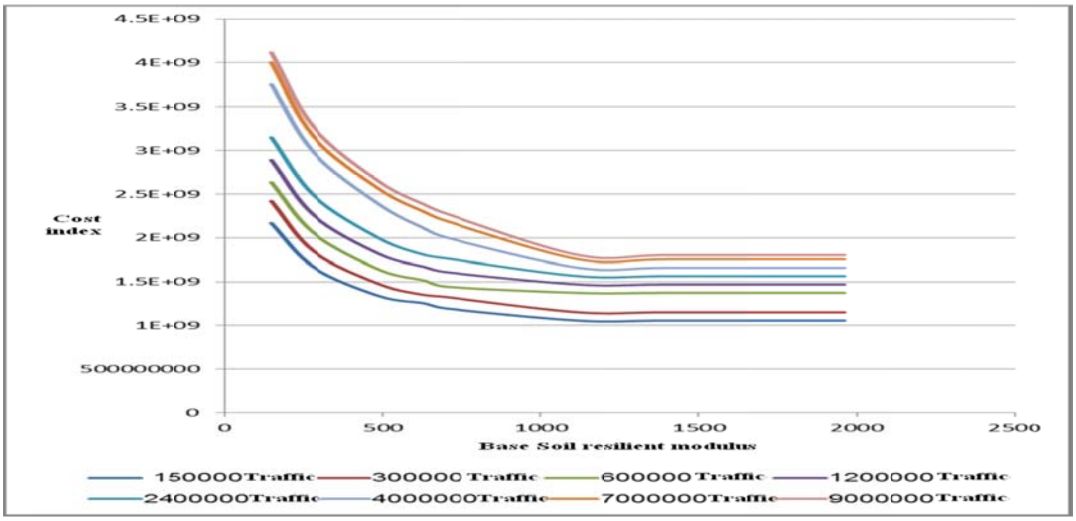

Fig. 10: The operating costs of modified asphalt with 5% SBS

According the calculated costs at time of the project execution would be spent more cost to implement of polymer asphalt pavements than typical asphalt. Of course, the following should be noted in this regard:

However, typical asphalt has lower running costs than polymer asphalt which has been modified with bitumen, but the quality and life-cycle of them are lower which this effect on life-cycle cost analysis.

3.5.4. Determine the pavement life cycle costs indexes

Considering that in addition to the bitumen properties, other parameters are effective in the life of the pavement and life cycle costs, if we use SBS polymer bitumen, the life-cycle cost index of pavement will increase as much as 1, 2, 3, 4 and 5 years.

In fact, the addition measure in the life-cycle due to modified bitumen properties, assuming a 5-year useful life of existing asphalt pavement are considered to extend the life-cycle of 1/2, 1/4, 1/6, 1/8 and 2 equal.

The following figures (Fig. 11, 12, 13 and 14) show the pavement life cycle costs indexes with increasing three-year of life cycle.

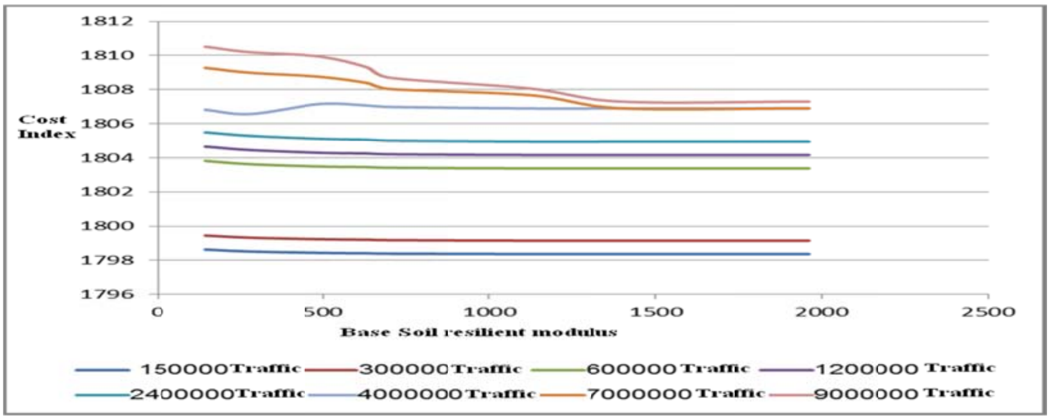

Fig. 11: Typical asphalt

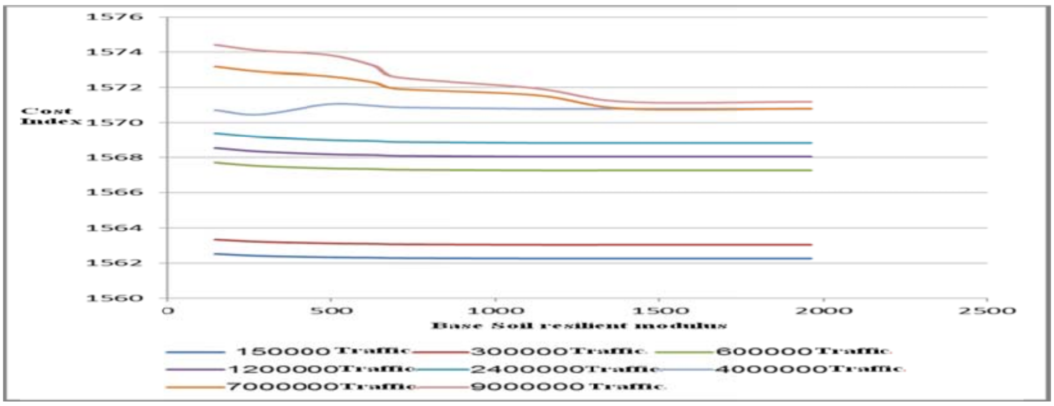

Fig. 12: Asphalt modified with SBS 3 percent

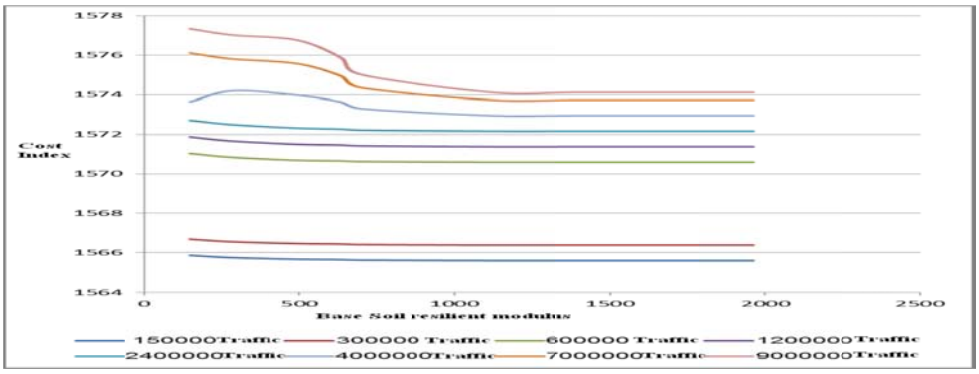

Fig. 13: Asphalt modified with SBS 4 percent

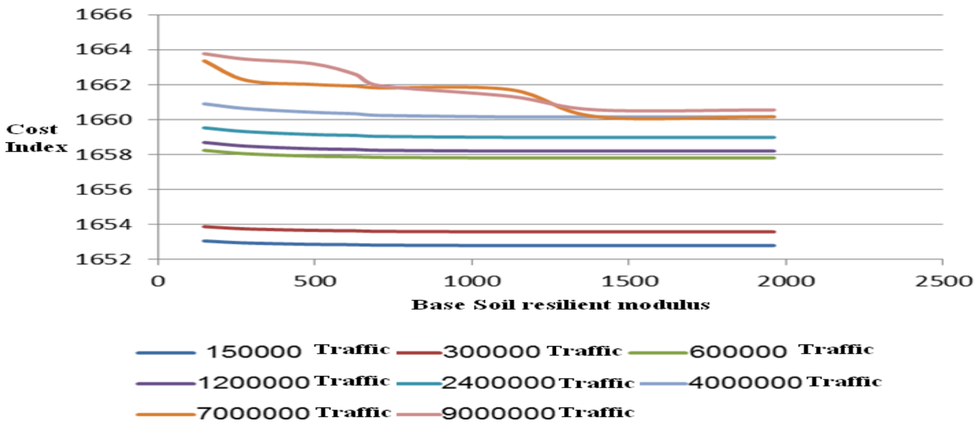

Fig. 14: Asphalt modified with SBS 5 percent

4. Results and discussion

Figs. 11, 12, 13 and 14 show pavement life cycle cost index with increasing a three-year life. These graphs are analyzed with the MATLAB software which investigated for eight different thicknesses of pavement based on; eight resilient modulus and eight different traffic more broadly.

as you see, although operating costs has been increased due to the life cycle costs for each of the polymers has been fallen sharply as a result, the use of polymers for the producing asphalt seems to be effective.

5. Conclusion

According to the results of bitumen tests, with an increase in consumption polymers on base bitumen, the degree of permeability of bitumen has been reduced and density and degree of softness has been increased.

According to the results of asphalt tests, with an increase in the amount of polymer to an average point, amount of special weight is increased and then is decreased. Also, this procedure is the same for strength of Marshall Samples.

The costs run of using typical asphalt is lower than polymer asphalt, but the quality and life-cycle of them are lower which this effect on life-cycle cost analysis.

Based on the results the following conclusions and recommendations are stated:

1- Polymer modification has been proven to be an effective way to improve bitumen properties to some extent by many researchers and has been used widely in practice. However, the currently popular polymer modifiers have various disadvantages limiting their application. Some important problems with bitumen polymer modification are still not well understood. More efforts are supposed to be made to promote a further development.

2- Researchers tried various solutions to remove drawbacks of currently used polymer modifiers, among which saturation, functionalizing (including application of reactive polymers) and using extra additives (sulfur, antioxidants and hydrophobic clay minerals). These solutions do overcome some disadvantages of polymer modified bitumen, but most cause some new problems. So more research needs to be carried out in the future to solve these problems and find new ways to modify bitumen effectively and cheaply.

3- Since it is currently challenging to perfectly achieve all expected polymer modified bitumen properties at the same time, some compromised ways might be optional for the future development of bitumen polymer modification: greatly enhancing the properties with an acceptably high cost, significantly reducing the cost with relatively poor properties or their combinations. Functionalizing is considered as a promising way to enhance the properties of currently used polymers and develop new-type polymer modifiers with much greater success in the future.

4- It is recommended that future research on bitumen polymer modification pay more attention to the following points:

• Function development of enhancing adhesion with aggregates for polymer modifiers;
• Long-term performance of polymer modified bitumen; and
• Recyclability of polymer modified bitumen.

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