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The Use of Polymer Modification of Bitumen for Durant Hot Asphalt Mixtures

[1]Behbahani Hamid, [2]Ziari Hassan, [3]Noubakhat Shams

[1]Full Professor, Department of Civil Engineering, Iran Science and Technology, Tehran, Iran.
[2]Assistant Professor, Department of Civil Engineering, Iran Science and Technology, Tehran, Iran.
[3]Ph.D. Student, Department of Civil Engineering, Iran Science and Technology, Tehran, Iran.

Abstract: The add to in road traffic during the last two decades in mixture with an inadequate degree of protection due to shortage in funds has caused an accelerated and continuous deterioration of the road network in Iran. To alleviate this process, several types of procedures may be efficient, e.g., securing funds for preservation, improved roadway design, use of better quality of materials and the use of more effective construction methods. The use of polymer in asphalt combination as a modifier started in the 80s of the last century and has been tested in a number of countries around the World. In this research, SBS as one sort of polymers is used to investigate the impending prospects to enhance asphalt mixture properties. Two types of polyethylene were extra to coat the aggregate SBS and EVA. The polymers were introduced to the mixture in two states (Grinded and not Grinded). Marshall Mix design was used, first to verify the best bitumen binder content and then further to test the modified mixture properties. The optimum asphalt substance was 5.4%. Marshall Mix design requires the purpose of the percentages of air voids and air voids of mineral aggregate. The research involves selected laboratory performance tests, which were conducted on modified asphalt mixtures. The results indicated that grinded SBS polymer modifier provides better production properties. The recommended proportion of the modifier is 3% by the mass of bitumen content. It is found to raise the strength, reduce the density and slightly increase the air voids and the voids of stone aggregate.

Key words: Hot asphalt mixtures, SBS, EVA, Best binder content, Fatigue achieve, Marshal Test, Durant

INTRODUCTION

The increase in road traffic during the last two decades in combination with an insufficient degree of maintenance due to shortage in funds has caused an accelerated and continuous decline of the road network in Iran. To alleviate this process, several types of measures may be effective, e.g., securing funds for maintenance, improved roadway design, use of better quality of materials and the use of more effective construction methods. The road network in Iran has a primarily flexible pavement design[2]. Several factors influence the performance of flexible courses, e.g., the properties of the components (binder, aggregate and additive) and the proportion of these components in the mix. Bitumen can also be modified by adding different Petroleum asphalted cement (AC) composed of aromatic hydrocarbons, paraffin and resins has been used for a variety of purposes, but most importantly for road surfacing.

Certain AC binder properties are required in this application to prevent the occurrence of three major pavement stresses, i.e., rutting, fatigue and thermal cracking. Pavement asphalt mixtures are sensitive to degradation agents such as heat, oxygen, ozone, chemicals, etc. to which they are exposed during their preparation, storage and service.

Considerable research in recent years has focused on improving the functional properties of the AC. The use of synthetic polymers as additives, via chemical or physical blending, has been shown to greatly improve the performance of conventional asphalts. The thermoplastic nature of these binders has displayed the ability to combine properties of elasticity, strength and adhesion to increase road life[10].

Improved properties also include greater resistance to aging and stability at high temperatures. Thermoplastic copolymers such as styrene-butadiene-styrene (SBS) have exhibited the greatest potential for bitumen modification. The SBS structure consists of a triblock chain having twophase morphology of styrenic block domains within a matrix of polybutadiene. The polystyrene end-blocks confer strength on the polymer, while the rubbery polybutadiene gives elasticity. When SBS is blended with AC, it is believed the electrometric phase of SBS

Corresponding Author: Behbahani Hamid, Full Professor, Department of Civil Engineering, Iran Science and Technology, Tehran, Iran.

absorbs the maleness from the oil fractions, forming a continuous network. The large-scale use of these polymers may be attributed to their networks, which are due to the theological properties of the modified binder and the interactions of bitumen constituents that increase the complex modulus and the elastic response[9].

The use of SBS as an asphalt modifier was first developed by SHELL Chemical Company. Considerable research has been done under different conditions to identify the various parameters that affect the properties of SBS modified asphalts. Much effort has also been dedicated to establishing the parameters that determine optimum mixing conditions (bitumen source, polymer content, bitumen polymer compatibility and aging), as well as the properties necessary to stabilize modified asphalt[12].

The addition of a SBS copolymer containing soft and glassy segments such as styrene-butadiene-styrene block is expected to affect the molecular microstructure of asphalted material. In theory, the soft segments provide greater toughness and low temperature cracking, while the hard segments improve the material's strength. The degree of modification depends on the nature of the base bitumen and on the AC-polymer compatibility. Thermal cracking, in particular, can be associated with phase separation, suggesting the immiscibility of the base bitumen and the polymer.

Literature Review: A wealth of information exists with regards to properties of SBS modified binders as well as their use in hot mix asphalt.Typical results are: lower ductility values occur at higher testing temperatures (10-25°C), but higher ductility values arise at lower temperatures (4°C) elastic recoveries are substantially increased generally small decreases occur in penetration values, though increases have been reported which were assumed to be as a result of the addition of aromatic oils (often called extender oils or diluents) softening points (R&B) can increase drastically with growing SBS content.

A graph displaying softening points vs. SBS content shows a typically S-shaped curve with a drastic increase in softening point around the 2.5 to 4.0% levels. This corresponds to the setting up of the network as mentioned earlier. A branched SBS polymer also indicates a larger increase in softening point than a linear one. Viscosities show large increases in the region of 40-70°C (improved rut resistance at service temperatures), relatively small increases at the handling temperatures at around 140°C and a decrease in viscosity below 0 °C (improved Fraas brittle point). Penetration Index (PI) values indicate a significant decrease in temperature susceptibility of the modified binder at SBS concentrations from as low as 3%. The influence of SBS on the properties of SBS modified binders is dependent on many things: nature and concentration of SBS polymer, nature of the bitumen, aging, thermal and mechanical history of the blend, and temperature at which the properties are tested.

Typical results are shown in Table 1 and Table 2. However despite the ready availability of typical results, it was found that publications often omit crucial information, so that results cannot easily be compared.

The addition of polymers typically increases the stiffness of the bitumen and improves its temperature susceptibility. Increased stiffness improves the rutting resistance of the mixture in hot climates and allows the use of relatively softer base bitumen, which in turn, provides better low temperature performance. Polymer modified binders also show improved adhesion and cohesion properties. Polymers can be also added to the asphalt concrete mixtures to form an aggregate coating material. The coatings would enhance surface roughness of the aggregates and thus, produce asphalt mixtures with superior engineering properties.

The polymers used in modifying bitumen are classified as plastomers, or elastomers. Plastomers include ethylene vinyl acetate, polyethylene (unstabilized and stabilized) and various compounds based on polypropylene. These products are normally milled into the asphalt binder at temperatures above 160°C by a high shear mixer[4,7]. These types of polymers are elastomeric, which describes the ability of a material to return to its original shape when a load is removed. These polymers increase the bitumen viscosity rather than elastomeric strengthening. In this research the use of SBS and Ethylene Vinyl Acetate (EVA)polymer, which is one type of plastomers, to modify asphalt mix properties was investigated. It is used as aggregate coating rather than modifying bituminous properties. The principle objectives of this research were to:

- Study the effect of adding SBS and EVA polymer on the hot mix asphalt.
- Determine the optimum percent of asphalt and SBS and EVA polymer in the hot mix asphalt.

ASTM code specifies that from a sample of coarse aggregate not less than 98% of the particles shall have one broken face and 60% shall have two or more broken faces; for the aggregate tested, 98% of the particles had two or more broken faces. Sieve analyses of the aggregate were done according to ASTM4402-1986, to determine the particle size distribution .The particle size distributions are presented in Table 3 and Figure1.

Table 1: SBS concentration levels found in implement (Coplantz, J.S. *et al.,* 1993)

SBS	Use
Below 3%	Bitumen dominates properties, limited modification benefit (benefits similar to SBR).
3-8%	Distinct network formation. Both bitumen and SBS influence properties. (Usual range for modification of seal and asphalt bitumen)
Above 8%	SBS dominates properties. (Typical levels for crack sealant)

Table 2: Classic properties of SBS modified bitumen (Coplantz, J.S. *et al.,* 1993)

Test	Max. Asphaltin phase	Max. Polymer phase
Penetration (0.1mm) 100g,5Sec,25°C	103	95
Ring and Ball (°C)	41	63
Ductility (cm) @ 4°C	23	74
Elastic Recovery 1 hr, 4 °C (%)	8	66
Absolute Viscosity (Ps) @ 60 °C	745	23000
Cinematic Viscosity (cSt) @ 135 °C	154	385

Table 3: Aggregate Gradations for all Test Series

Sieve Size (mm)	Percentage of Passing
37.5	100
19	84
6.7	53
2.36	34
1.18	26
0.600	20
0.300	17
0.150	12
0.075	6

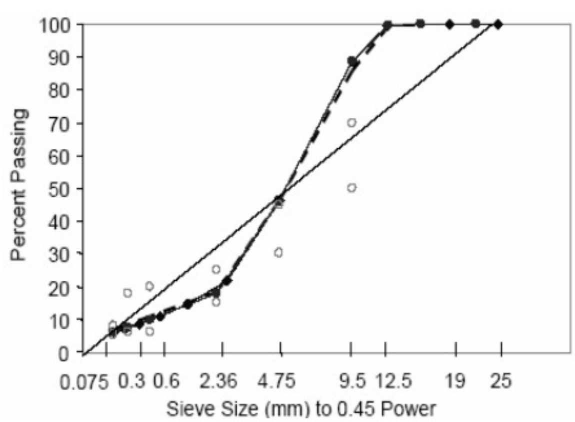

Fig. 1: Aggregate Gradations for all Test Series (up-Limit and Down-Limit)

MATERIALS AND METHODS

Bituminous Material: Asphalt binder 60/70 and 85/100 were used in this research. The laboratory tests performed to evaluate the bitumen properties were Specific Gravity, Ductility, Flash Point and Penetration, Softening point[1]

Aggregate Properties: The coarse and fine aggregates used were crushed limestone imported from Damavand district of Iran. The filler used was silica obtained to supplement the fine materials size in hot mix asphalt (HMA) mixture design. The laboratory tests performed on coarse aggregates were: Los Angeles Abrasion (ASTM C131–81), Aggregate Impact Value, Sieve Analyses (ASTM C136-84) Water Absorption, Specific Gravity (ASTM C127–88), Fractured Faces of Aggregate and Angularity (BS 812). The tests for fine aggregates were: sieve Analyses (ASTM C117–87) Friable Particles in Aggregate (ASTM C142–78), Specific Gravity (ASTM C128–88) and Water Absorption, while for filler the test was Specific Gravity only.

Polymer Modification Properties: SBS and EVA polymer are the most popular plastic in the world. SBS and EVA polymer is semi-crystalline materials with excellent chemical resistance, good fatigue and wear resistance and a wide range of properties. It has a very simple structure. A molecule of SBS and EVA polymer is a long chain of carbon atoms, with two hydrogen atoms attached to each carbon atom They are light in weight; provide good resistance to organic solvents with low moisture absorption rates[6].

SBS offers good corrosion resistance and low moisture permeability. It can be used in applications where corrosion resistance is important, but stiffness, high temperatures and structural strength. EVA offers excellent impact resistance, light weight, low moisture absorption and high tensile strength. The percentages of SBS and EVA polymer, that were added to the asphalt mixture that has been designed after determining the optimum bituminous material content (5.4% of mixture weight), were 3,4,5 and 6% by weight of bitumen content. Three samples for each percent SBS and EVA polymer were prepared and tested. Adding the SBS and EVA polymer aimed at providing aggregate coating and not enhancing the bituminous material properties[11].

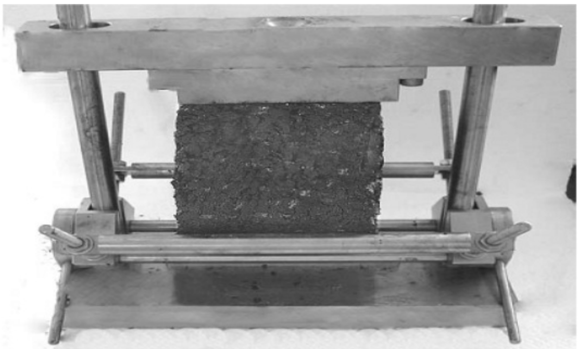

Fig. 2: photograph of indirect tensile test (IDT) equipment (UTM)

Sample Preparation: The performance of an asphalt mixture is based on the determination of the correct proportion of aggregate and asphalt and air, which are measured by volume. Three samples were used to prepare asphalt mixtures with one-bitumen content. The average values of three samples for the unit weight, Marshall Stability and flow properties for each binder content were determined. Seven binder contents were considered (4.5, 5, 5.5, 6, 6.5, 7 and 7.5%). All examined asphalt concrete mixtures were prepared in accordance with the standard 75-blowMarshall design method for designing hot asphalt concrete mixtures, designated as (ASTM Designation: D 1559-89) using automatic compaction.

The optimum bituminous content was 5.4%. Eighty-four samples of asphalt concrete mixtures were prepared at this binder content to test the effect of adding the SBS and EVA polymer to the mixture. The procedure of adding the SBS and EVA polymer is completed by heating the coarse aggregate of each specimen until it reached a (180-190ºC).

The heating temperature and duration was chosen based on material characteristics and results of many experimental trials. Two series of tests were done. The variable in the first series of tests of laboratory compacted specimens was bitumen content, to determine the effect of variations in bitumen content within the allowed envelope of the Iran mix specification. The second series of tests involved Indirect Dynamic Testing (IDT) at different temperatures on a bituminous mix used tested.

The Indirect Tensile Fatigue Test is used to measure the loading required to create failure in a specimen due to the onset of cracking. Test specimens of bituminous mixtures, of 100 mm diameter, and 80 mm thick, prepared in the laboratory are placed in the Indirect Tensile Fatigue Loading frame. The sample is then subjected to a repeated diametric loading force, the resulting horizontal diametric deformation is then measured using two LVDT's (Linear Variable Differential Transformer's) each at an axes 90 degrees from the applied force. Figure2 and 3 show UTM (Universal Testing Machine) and it's Soft ware.In addition, two vertically mounted LVDT's are used to monitor vertical deformation of up to 10mm.

$$S_t = \frac{2000.P}{\pi.t.d} \qquad (1)$$

Where :

S_t = tensile strength (kPa);
P = maximum load carried by the sample
T = specimen thickness (mm); and
D = specimen diameter (mm).

Conlusions: A comparison between asphalt mixture performance due to type and state of the added SBS and EVA polymer is presented below. The comparison also includes the conventional asphalt mixture (No SBS and EVA polymer), which acts as the control group.

- The bulk density of the modified asphalt concrete mixtures and regardless of the modified type or state is lower than the conventional asphalt concrete mixture 3 (2.293 *gr/cm*^{3}). For both types of modifier and at both states of treatment, the maximum bulk density is found when the SBS and EVA polymer content is around 3%. Although the difference in bulk density due to type and state of the modifier is marginal, asphalt concrete mixture modified with SBS has highest bulk density3 (2.28 *gr/cm*^{3}). The general trend shows that the bulk density increases as the modifier content increases until it reaches the peak that is associated with the highest bulk density.
- The stability of the modified asphalt concrete mixtures and regardless of the modified type or state is higher than the conventional asphalt concrete mixture - no modifier (1450 kg). The stability modifier content relationship varies according to the type of modifier. The highest stability was reported for asphalt mixture that is treated with SBS modifier (2347 kg), which is higher than mixture treated with the same type of modifier but in not grinded state. Figures 3 and 4 show that the IDT stability asphalt concrete mixture modified by using SBS and EVA is steadily increased by the increase of the modifier content[8].
- The flow of the modified asphalt concrete mixtures and regardless of the modified type or state is higher than he conventional asphalt concrete mixture no modifier (2.55 mm).

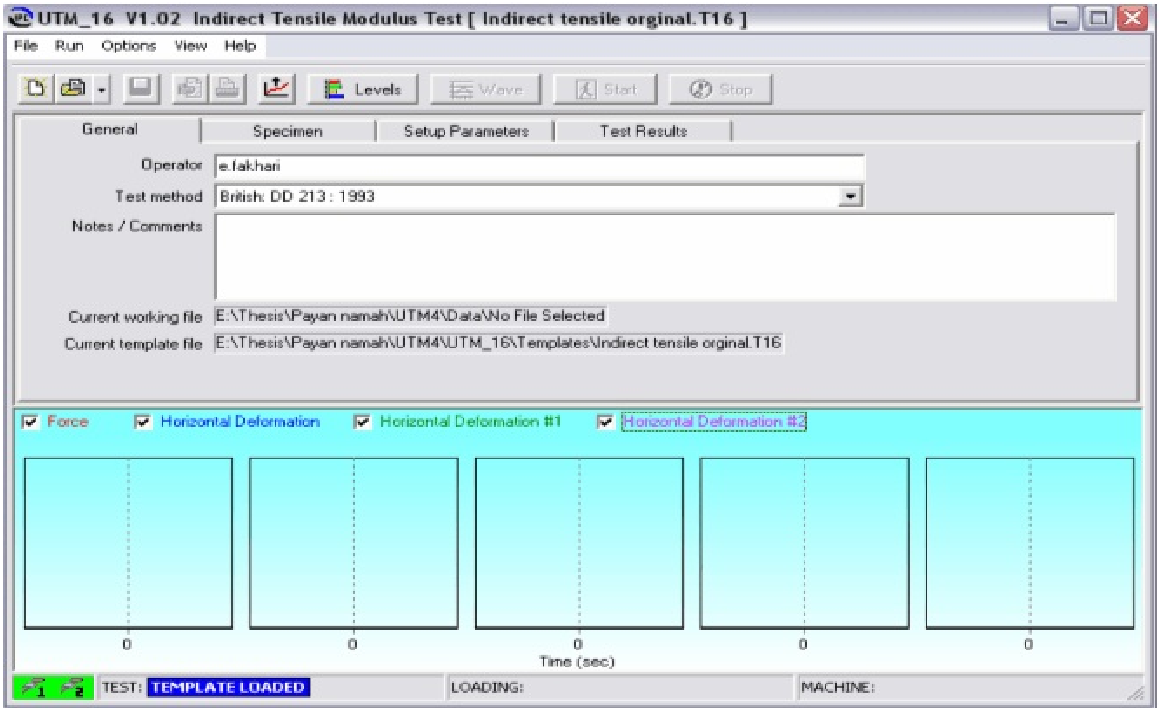

Fig. 3: pictures of indirect tensile test (IDT)Soft ware interface

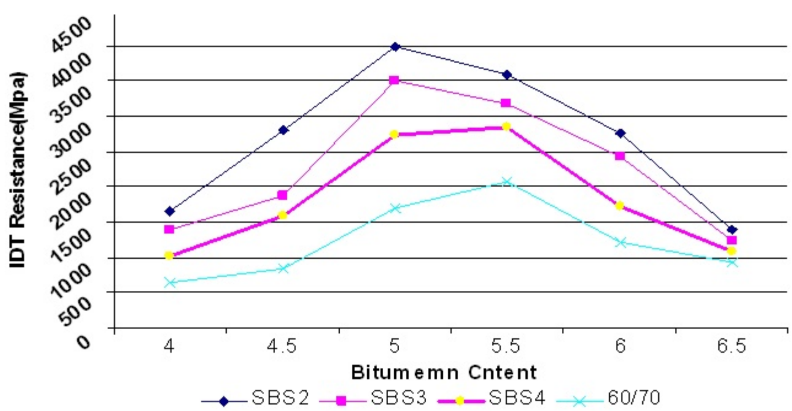

Fig. 4: Variation of indirect tensile test result (for Various SBS Content)

- Void of mineral aggregate (VMA) percentage-SBS and EVA polymer content relationships: In general, the VMA percentage of the modified asphalt concrete mixtures and regardless of the modified type or state is higher than the conventional asphalt concrete mixture- no modifier (14.1%). Only mixtures modified with modifier content of 3% by weight of bitumen, regardless of it type, have a minimum VMA contents that approximate the no-additive mixture case. The VMA content of asphalt mixtures modified with SBS and EVA are the lowest among other modified asphalt concrete mixtures. On the other hand, the VMA content of asphalt mixtures modified with not SBS and EVA are the highest among other modified asphalt concrete mixtures.
- The optimum modifier content is selected as the content that satisfies the following:

- Maximum Bulk Density
- Maximum Marshall Stability
- Minimum Flow
- The minimum AV or the closet percentage to AV content of 4%
- Maximum VMA content

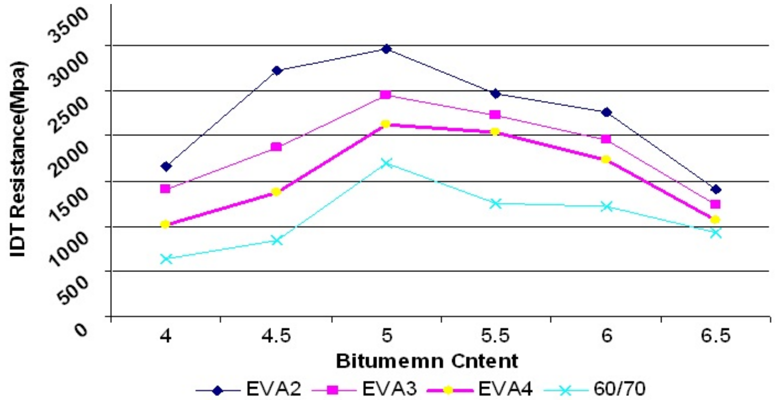

Fig. 5: Variation of indirect tensile test result (for Various EVA Content)

The maximum bulk density was reported for asphalt mixture modified with grinded HDPE at a by experimentation, the appropriate amount of SBS and EVA polymer was determined to be (6-18%) by weight of the optimum asphalt percent (5.4%), which equates to (0.34-1.03%) by weight of total aggregate. However, the optimum modifier content was found to be 12%, which equals only 0.68% of the total aggregate weight. This amount did not coat all individual aggregate particles, particularly if it is not grinded. However, it did provide a rougher surface texture that would enhance the asphalt mixtures engineering properties. The grinded SBS and EVA polymer, providing better coating for the aggregate as the surface area of the polymer increases that would be attached easily to the aggregate.

The results of the study indicated that the modified mixture have a higher stability and VMA percentage compared to the non-modified mixtures. This would positively influence the rutting resistance of these mixtures. The air void contents of the modified mixture are not far from that of the non-modified mixture. Air void proportion around 4% is enough to provide room for the expansion of asphalt binder to prevent bleeding or flushing that would reduce the skid resistance of the pavement and increase Fatigue resistance susceptibility.

Overall, using the SBS and EVA polymer in asphalt mixture reduces pavement deformation; increase fatigue resistance and provide better adhesion between the asphalt and the aggregate.

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