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EFFECT OF POLYMER MODIFICATION ON ASPHALT CEMENT PROPERTIES

Yassir Nashaat A. Kareem
Assistant Lecturer
Department of Civil Engineering, Diyala University, Iraq
E-mail: yasirna83@yahoo.com
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ABSTRACT: - As traffic volumes and axle loads have continued to increase over the years, it has been found that asphalt cement used in road construction has a less capable of rutting resistance, thermal cracking, fatigue damage, stripping, and temperature susceptibility. Hence the need to develop and improve the asphalt cement with a higher level of performance. In the present study, 60-70 asphalt cement from Daurah Refinery was used, and two types of polymer modifications as Ethyl Vinyl Acetate (EVA) and Styrene Butadiene Styrene (SBS) have been used to prepare of modified asphalt cement at different percentage by weight (2%, 4%, and 6%). The effect of polymer modifications on asphalt cement properties are evaluated by many conventional tests such as (penetration, softening point, viscosity, ductility, elastic recovery, and specific gravity) that have been made on the modified and natural asphalt cements. By comparing the physical and mechanical properties of the modified and natural binders, it is found that the properties of the modified asphalt cement are enhanced manifold. Modified asphalt cement with exhibits greater elastic recovery, higher softening point, greater viscosity, greater cohesive strength and greater ductility. The optimum content of the modifier is 4% for SBS modifier, and 6% for EVA modifier.
Keywords: Modified asphalt cement, Styrene butadiene styrene, Ethyl vinyl acetate**.**

1- INTRODUCTION

The modification of asphalt cement has been shown to improve the performance of the pavement. Pavements constructed with modified binders exhibits greater resistance to rutting and thermal cracking, and decreased fatigue damage, stripping and temperature susceptibility. Modified binders have been used with success at locations of high stress, such as intersections of busy streets, airports, vehicle weigh stations, and race tracks. This paper is the review of research that has been conducted on modified binders over the last three dacades. Modification of asphalt cementous binders has become the need of pavement mix design, particularly in the United States, Canada, Europe and Australia. Specific modifiers that are mostly used include polyethylene, rubber, Styrene Butadiene Styrene, Ethyl Vinyl Acetate, Sulphur etc. The commercial and rheological properties of the modified binders have been studied and found satisfactory as far as the performance of the pavement is considered. Asphalt cement used in an asphaltic surfacing should have such temperature viscosity characteristics that the surfacing can resist plastic deformation at high temperature and at the same time brittle cracking at low temperatures. For many locations in the country, the commercially available asphalt cements have temperature viscosity characteristics that are not able to satisfy both the requirements and this situation results in premature failure of asphaltic surfacing.

If an asphalt mix used in a surfacing is made somewhat stiffer, it can have longer fatigue life and can take traffic loads for a longer period of time. This extra stiffness to the asphalt cement can be provided by using different modifiers. The addition of polymers, rubbers etc. to asphalt cement have been shown to improve performance. Pavement with modified asphalt cement exhibits greater resistance to rutting, thermal cracking, fatigue damage, stripping and temperature susceptibility. Polymer modified binders can be used with success at locations of high stress, such as intersections of busy streets, airports, vehicle weigh stations, and race tracks.[12]

The modified asphalt cement used in the road construction has advantages such as lower susceptibility to daily and seasonal temperature variations, Higher resistance to deformation at elevated pavement temperature, Better adhesion between aggregate and binder, Higher fatigue life, Delay of cracking including reflective cracking, Overall improvement in performance under extreme climatic condition and heavy traffic condition.

2- BACKGROUND LITERATURES

Many researchers have shown their interest in studying the properties of the modified binders and evaluating their advantage over the conventional asphalt cement. The major studies carried out by different researchers using Styrene Butadiene Styrene (SBS) and Ethyl Vinyl Acetate (EVA) are discussed below.

Lu and Iscasson (1997) reported SBS polymer modification increases the binder elasticity at high temperatures and improves the flexibility at low temperatures. These improved properties should lead to an increased resistance to asphalt rutting and cracking at high and low temperatures, respectively. A significant improvement in the rheological characteristics is observed when the SBS content is increased from 3% to 6% by weight. The modified binders containing branched SBS exhibit a higher elasticity and less temperature susceptibility than the modified binders with linear SBS at high temperatures but these two polymer types do not differ in their effects at low temperatures. [10]

Airey (2002) reported that the rheological properties of asphalt cement are improved by means of EVA polymer modification. The semi crystalline EVA copolymer provides the modification of asphalt cement through the crystallisation of rigid three-dimensional networks within the asphalt cement. Conventional penetration, softening point, Fraass, ductility and high temperature viscosity tests have demonstrated the increased stiffness (hardness) and improved temperature susceptibility of the EVA PMBs. [2]

Airey (2003) studied the effect of SBS polymer modification on the conventional polymer content. Although the decrease in penetration is relatively uniform with increasing polymer content but there is significant larger increase in softening point at high polymer content of 5% and 7%. In addition to the increase in stiffness, the increased penetration indices of PMB indicate a significant reduction in temperature susceptibility with polymer modification particularly at higher polymer content. [3]

Gonzalez et al. (2004) revealed that the viscoelastic properties of a 60/70 penetration grade asphalt cement are improved when either a virgin EVA or a recycled EVA copolymer of similar vinyl acetate content are mixed with it. Risk of cracking at low temperatures and rutting at high temperatures, are both reduced. Better viscoelastic features are obtained with the Asphalt cement modified with recycled EVA, probably due to the presence of carbon black, which acts like a filler in this material. Stability tests performed combining oscillatory flow and microscopy results disclose that blends with the higher polymer proportion (3%) are susceptible of phase separation after 24 h of storage at 165˚C, but 1% blends are stable for at least 4 days. A general evaluation of the results indicates that the performance of this asphalt cement as a binder for road pavement is particularly improved when 1% of recycled EVA or virgin EVA is added. [9]

Romeo et al. (2010) conducted a laboratory investigation to evaluate the effect of SBS modifiers on HMA-cracking performance. Both cross-linked and linear SBS polymer-modified mixtures as well as the control unmodified mixture were tested using the SUPERPAVE IDT (Indirect Tensile) and the SCB (Semi Circular Bending) test. Polymer modification at intermediate temperatures does not have significant effect on the resilient modulus, but during tensile creep testing, the rate of creep was lower implying less microdamage accumulation. Polymer modification has also proven to improve tensile failure limits of mixtures and makes the stress states more homogeneous. [11]

3- EXPERIMENTAL PROGRAMME

3.1 Materials

The materials used in this study are:

1. Asphalt cement

One type of asphalt cement binder used in this study, it is (60-70) penetration grade from Daurah Refinery. The physical properties of natural asphalt cement that used are tabulated in Table 1.

2. Additives

Many different polymers are used to modify the asphalt binders and each has their own associated physical properties. In this study, two types of polymer modifications are used, one is thermoplastic polymer as Ethyl Vinyl Acetate (EVA), and other is elastomeric polymer as Styrene Butadiene Styrene (SBS). The additive was added to asphalt cement binder by weight at different percentage (2, 4, and 6) %.

3.2 Preparation of Blends

To prepare the blends of modified binders, about 1.5 kg of asphalt cement binder was taken in a 3 litre metal container and heated to fluid condition. The mixing of modifiers is carried out using a mechanical stirrer. Asphalt cement binder was heated to a temperature of 170ºC and the appropriate quantity of SBS copolymer and EVA was added separately for each container. For SBS modified binder, the temperature was maintained between 175ºC to 180ºC and contents were gradually stirred for about 2 hours [10]. For EVA modified binder, the temperature was maintained between 170ºC to 185ºC and contents were gradually stirred for about 80 minutes. [2]

3.3 Testing Methodology

To study the effect of polymer modification on asphalt cement properties, the following conventional tests were conducted on the prepared blends of modified and natural asphalt cement.

1. Penetration Test

The penetration test is one of the oldest and most commonly-used tests on asphalt cements. It is an empirical test which measures the consistency (hardness) of asphalt binder at a specified test condition. In the standard test condition, a standard needle of a total load of 100 g is applied to the surface of a sample at a temperature of 25 °C for 5 seconds. The amount of penetration of the needle at the end of 5 seconds is measured in units of 0.1 mm (or penetration unit). The test is conducted as per ASTM D5-2006. [7]

2. Softening point Test

The softening point is the temperature at which the substance attains a particular degree of softening under specified condition of test. The softening point of asphalt cement is determined as per ASTM D36-2009. [5]

3. Viscosity Test

The ratio between the applied shear stress and the rate of shear is called the coefficient of viscosity. This coefficient is a measure of the resistance to flow of the liquid. It is commonly called the viscosity. The viscosity of a fluid is highly dependent on the temperature. It gets reduced with the increase in temperature. To determine the influence of temperature on the viscosity of asphalt cement binders we have to determine the viscosity at different temperatures. Brookfield viscometer is used for the purpose and the test is conducted as per ASTM D4402- 2006. [6]

4. Ductility Test

The ductility test measures the distance a standard binder sample will stretch without breaking under a standard testing condition (5 cm/min at 25 °C). It is generally considered that asphalt cement with a very low ductility will have poor adhesive properties and thus poor performance in service. The test is conducted as per ASTM D113-2007. [4]

5. Elastic Recovery Test

The elastic recovery of the asphalt cement is evaluated by measuring the recovery of the binder thread formed by the elongation of binder specimen when it is cut down by a scissor at standard conditions. The elastic recovery test is carried out as per AASHTO T301-2013. [1]

6. Specific Gravity Test

The specific gravity of asphalt cement binder is defined as the ratio of mass of a given volume of the bituminous material to the mass of an equal volume of water, the temperature of both being specified as 27±0.1ºC. The specific gravity is influenced by the chemical composition of binder. Increased aromatic type compounds increases the specific gravity. The test is conducted as per ASTM D70-2009. [8]

4- TEST RESULTS AND DISCUSSION

The results of the tests conducted on modified and natural asphalt cement are analyzed and discussed below.

4.1 Analysis of Test Results

1. Penetration Value

The penetration values of the modified and natural asphalt cement are tabulated in the Table (2) and shown in Figure (1). It was found from the results that the values of penetration decreases as (8 to 18) mm by increasing of SBS modifier content (from 2% to 6%) into asphalt cement, and as (17 to 25) mm by increasing of EVA modifier content (from 2% to 6%) into asphalt cement, that indicate to improvement of asphalt cement grade from soft to hard property by increasing of modifier content. The penetration values of EVA modified binder were lower as (8 mm) than values of SBS modified binder at various contents. The EVA modified binder at 6% content is more hardness and lower penetration value by 39 percent and 15 percent as compared with natural asphalt cement and SBS modified binder respectively. Either, the SBS modified binder at same proportion is lower penetration value by 28 percent as compared with natural asphalt cement.

2. Softening Point

The softening point values of the modified and natural asphalt cement are tabulated in the Table (2) and shown in Figure (2). According to the test results, the softening point values tend to increases as (16 to 28) °C by increasing of SBS modifier content (from 2% to 6%) into asphalt cement, and as (13 to 224) °C by increasing of EVA modifier content (from 2% to 6%) into asphalt cement. Such incident makes asphalt cement better resist deformation at high temperature as well as protects the mixture from bleeding. At (6%) modifier content, the softening point for SBS modified binder was a maximum value that higher than natural asphalt cement by 70.8 percent, either for EVA modified binder was higher than natural asphalt cement by 50 percent.

3. Viscosity

The viscosity values of the modified and natural asphalt cement are tabulated in the Table (2) and shown in Figure (3). The results illustrated that the viscosity values increases as (609 to 2520) cSt by increasing of SBS modifier content (from 2% to 6%) into asphalt cement, and as (527 to 2230) cSt by increasing of EVA modifier content (from 2% to 6%) into asphalt cement. An increasing in viscosity helps reduce softening and bleeding problems for asphalt materials at high temperature. It also helps strengthen adhesion with aggregates, reduce rate of stripping, and increase stability for road surface. However, workability of mixes should be cared. The viscosity values at various contents of SBS modified binder were higher than values of EVA modified binder. The increasing rate has been very clear in the values of the viscosity for modified binders with SBS and EVA. At (6%) modifier content, the viscosity value for SBS modified binder was a maximum that higher than natural asphalt cement by 330 percent, either for EVA modified binder was higher than natural asphalt cement by 290 percent.

4. Ductility

The ductility values of the modified and natural asphalt cement are tabulated in the Table (2) and shown in Figure (4). Results of the test showed that the ductility values tend to decreases as (14 to 24) cm by increasing of SBS modifier content (from 2% to 6%) into asphalt cement, and as (38 to 71) cm by increasing of EVA modifier content (from 2% to 6%) into asphalt cement. Also seen at (6%) modifier content, the EVA modified binder has minimum value of ductility that lower than natural asphalt cement by up to 67.6 percent, while seen that the SBS modified binder has a value also lower by 22.8 percent at the same percentage content.

5. Elastic Recovery

The elastic recovery values of the modified and natural asphalt cement are tabulated in the Table (2) and shown in Figure (5). Test results indicated to increases in elastic recovery values as (10 to 19) % by increasing of SBS modifier content (from 2% to 6%) into asphalt cement, and as (3 to 11) % by increasing of EVA modifier content (from 2% to 6%) into asphalt cement. The values of SBS modified binder were higher than values of EVA modified binder at various contents. As noted at (6%) modifier content, the rate of increasing in the values of elastic recovery as compared with natural asphalt cement was 26.7 percent of SBS modified binder, and 15.5 percent of EVA modified binder.

6. Specific Gravity

The specific gravity values of the modified and natural asphalt cement are tabulated in the Table (2) and shown in Figure (6). Test results indicated to decreases in specific gravity values as (0.004 to 0.008) gm/ cm^3 by increasing of SBS modifier content (from 2% to 6%) into asphalt cement, and as (0.005 to 0.011) gm/ cm^3 by increasing of EVA modifier content (from 2% to 6%) into asphalt cement. The EVA modified binder obtained values of lower specific gravity as compared with SBS modified binder at various contents. At (6%) modifier content, the rate of decreasing in the values of specific gravity as compared with natural asphalt cement was 1.0 percent of EVA modified binder, and 0.78 percent of SBS modified binder.

7. Penetration Index

Penetration Index indicates temperature susceptibility. This is a relationship between penetration value and softening point of asphalt cement. The following equation illustrates the penetration index calculation:

$$\mathrm{PI} = \frac{20\,(1 - 25\mathrm{A})}{(1 + 50\,\mathrm{A})} \qquad (1)$$

$$\mathrm{A} = \frac{\log(\mathrm{Pen.\,at\,25°C}) - \log 800}{25 - \mathrm{softening\ point}} \qquad (2)$$

The penetration values and softening point values are used to calculate the penetration index of the modified and natural asphalt cement. Asphalt cements normally used for road construction purposes have a penetration index between +2 and -2. Asphalt cements with a penetration index below -2 are substantially Newtonian and usually characterized by brittleness at low temperatures. Coal tar pitches also fall within this group. Asphalt cements with a penetration index above +2 are usually less brittle. Blown asphalt cements usually fall within this group. The penetration index values of the modified and natural asphalt cement are tabulated in the Table (3).

4.2 Discussion on Results

The percentage of modifiers is optimized on the basis of empirical tests as per international standards (ASTM & AASHTO) followed in Iraq. In this study, add of Ethyl Vinyl Acetate (EVA) and Styrene Butadiene Styrene (SBS) as polymer modifications to the asphalt cement, which resulted in a significantly improvement and effective in the physical and mechanical properties of the natural asphalt cement. The results of the conducted tests indicated to that values of penetration, ductility and specific gravity have decreased with increasing of modifier content into asphalt cement while a values of softening point, viscosity and elastic recovery have increased with increasing of modifier content into asphalt cement. The choice of the optimum content of the modifier is based on the physical properties. The requirement of penetration, softening point and ductility is satisfied at 4% of EVA and 4% of SBS as per most of the specifications used worldwide. From penetration index point of view, 4% for SBS, 6% for EVA can be used in paving asphalt cement as the PI value lies somewhat between +2 to –2. From empirical properties, both EVA and SBS modified binders can be used in high temperature areas such as middle and southern Iraq. However, EVA modified binders will be more suitable at high temperature and heavy traffic areas such as Baghdad and Basra. The SBS modified binders can be used for cold and moderate climatic areas such as Tikrit and Kirkuk, and very cold and low temperature areas such as Mosul and Kurdistan region as it shows high ductility value.

5- CONCLUSIONS

Through this study, there are several conclusions have been reached as shown below:

1. Polymer modified asphalt cement tend to exhibit increased softening point values as (16 to 28) °C by increasing of SBS and as (13 to 224) °C by increasing of EVA, viscosity values as (609 to 2520) cSt by increasing of SBS and as (527 to 2230) cSt by increasing of EVA, and elastic recovery values as (10 to 19) % by increasing of SBS and as (3 to 11) % by increasing of EVA, that help in reduce deformation, bleeding, and increase road pavement stability at high temperature.
2. Improvement a gradation of asphalt cement from soft to hard property through the decreasing in penetration values as (8 to 18) mm by increasing of SBS and as (17 to 25) mm by increasing of EVA . That helps in increase elasticity and stiffness of asphalt cement at high temperature to prevent rutting and to prevent the pavement cracking from being stiff at low temperature.
3. The addition of Styrene Butadiene Styrene (SBS) to asphalt cement improves ductility, viscosity, elastic recovery and the adhesive properties of the binder. It also enhances the rheological properties of modified asphalt cement.
4. The penetration, ductility, and specific gravity of the Ethyl Vinyl Acetate (EVA) modified binders, decreases as compared with the natural asphalt cement while the softening point temperature and viscosity increases. It also improves the temperature susceptibility of the asphalt cement.
5. The optimum content of the modifier was 4% for Styrene Butadiene Styrene (SBS), and 6% for Ethyl Vinyl Acetate (EVA) according to penetration index IP value and physical properties of modified asphalt cement.

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Table 1: The Physical Properties of Used Asphalt Cement (60-70)

Property	Test Method	Test Result	Specifications as SORB/R9 (2003)
Penetration at 25 °C, 100 gm, 5 sec, (1/10mm).	ASTM D5	64	60 – 70
Softening Point, R&B, °C	ASTM D36	48	--
Ductility, at 25 °C, 5 cm/min, cm	ASTM D113	> 100	> 100
Flash Point, °C	ASTM D92	283	> 232
Specific Gravity, g/cm^3	ASTM D70	1.023	--
Elastic Recovery at 15 °C, %	AASHTO T301	71	--
Viscosity at 135 °C, cSt	ASTM D4402	760	--

Table 2: Conventional Properties of Modified and Natural Asphalt Cement

Property	(60-70) Binder	(60-70)Binder + SBS			(60-70)Binder + EVA		
		Modifier Content %			Modifier Content %		
		2	4	6	2	4	6
Penetration at 25 °C (mm)	64	56	49	46	47	42	39
Softening Point (°C)	48	64	72	76	61	68	72
Viscosity at 135 °C (cSt)	760	1369	2464	3280	1287	2050	2990
Ductility (cm)	105	91	87	81	67	43	34
Elastic Recovery (%)	71	81	87	90	74	79	82
Specific Gravity (g/cm^3)	1.023	1.019	1.016	1.015	1.018	1.014	1.012

Table 3: Penetration Index of Modified and Natural Asphalt Cement

Binder	Modifier Content (%)	PI
(60 -70) Binder	0	-0.4493
(60 -70) Binder + SBS	2	1.9460
	4	2.0018
	6	2.6378
(60 -70) Binder + EVA	2	1.4515
	4	1.8569
	6	2.0220

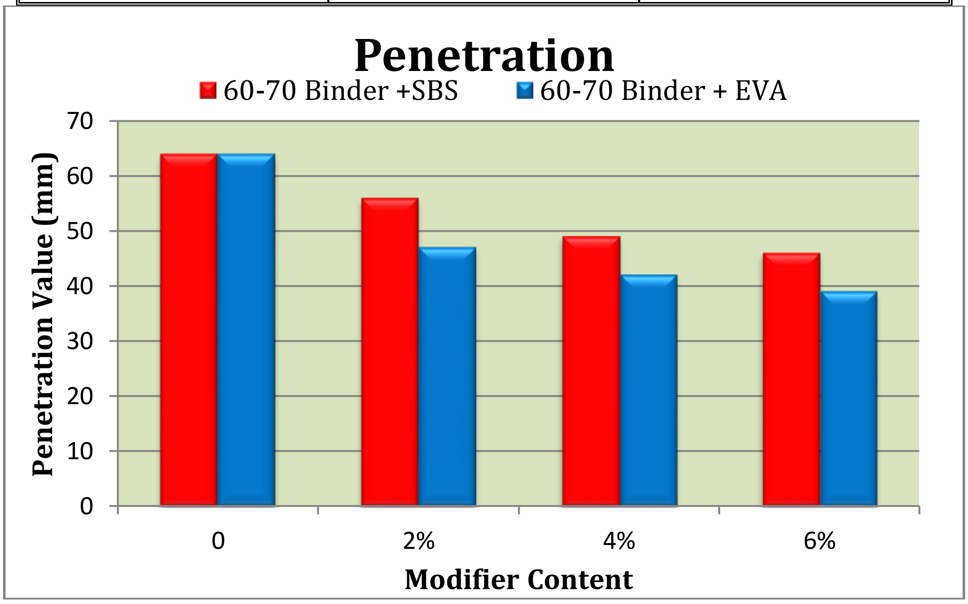

Figure 1: Penetration Values of Modified and Natural Asphalt Cement

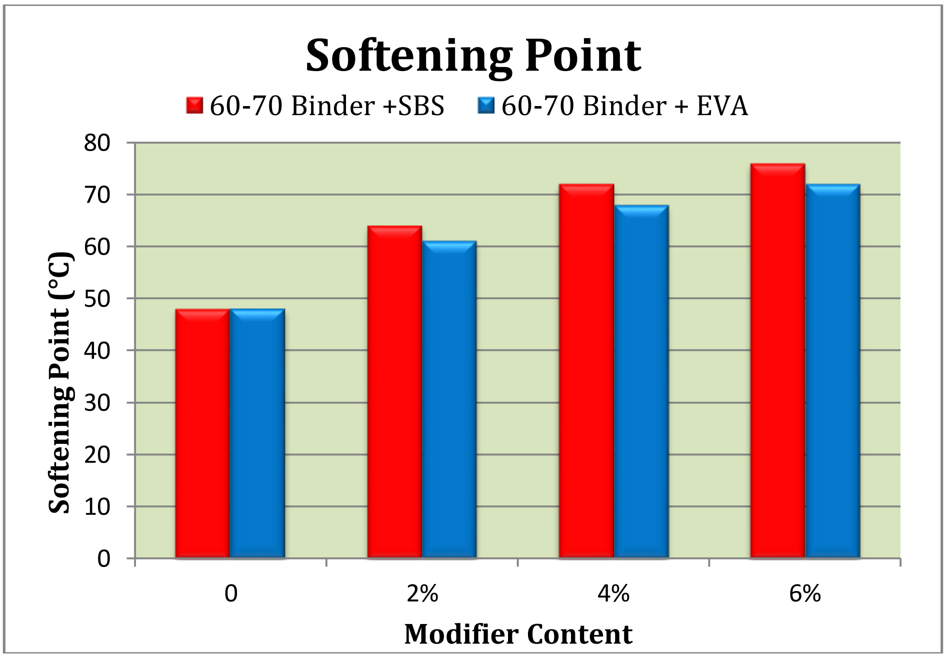

Figure 2: Softening Point Values of Modified and Natural Asphalt Cement

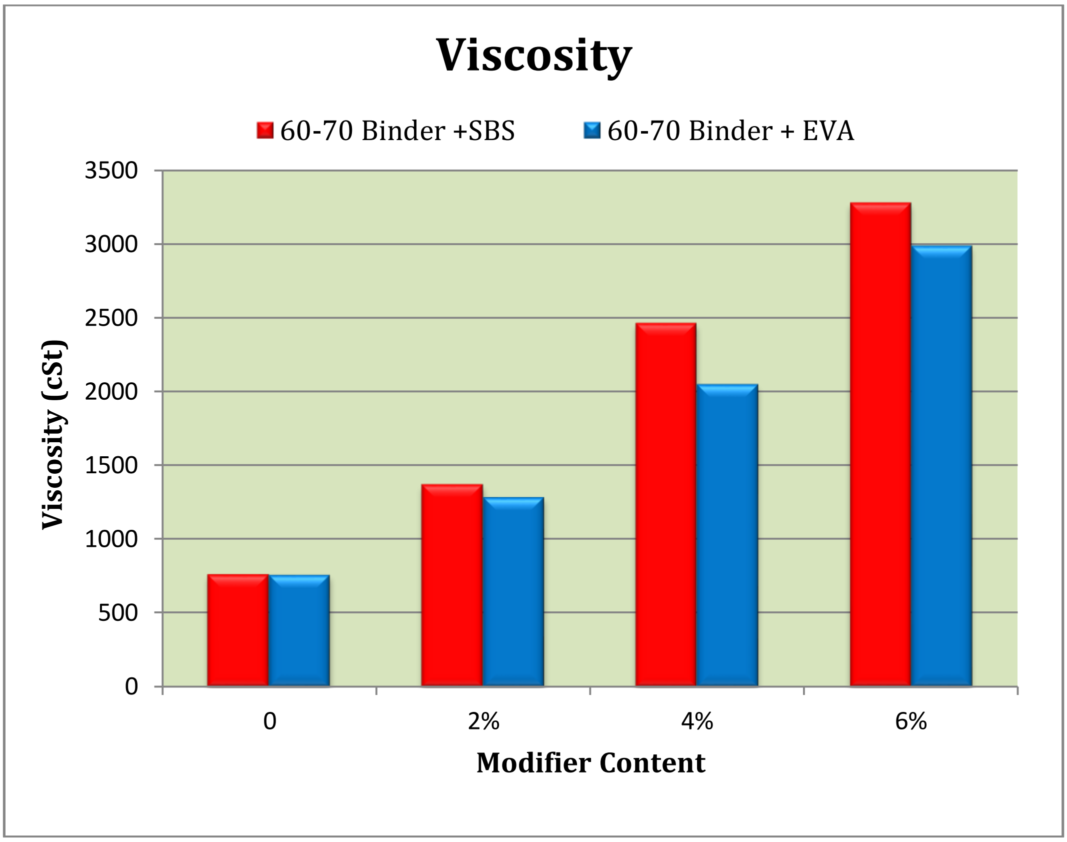

Figure 3: Viscosity Values of Modified and Natural Asphalt Cement

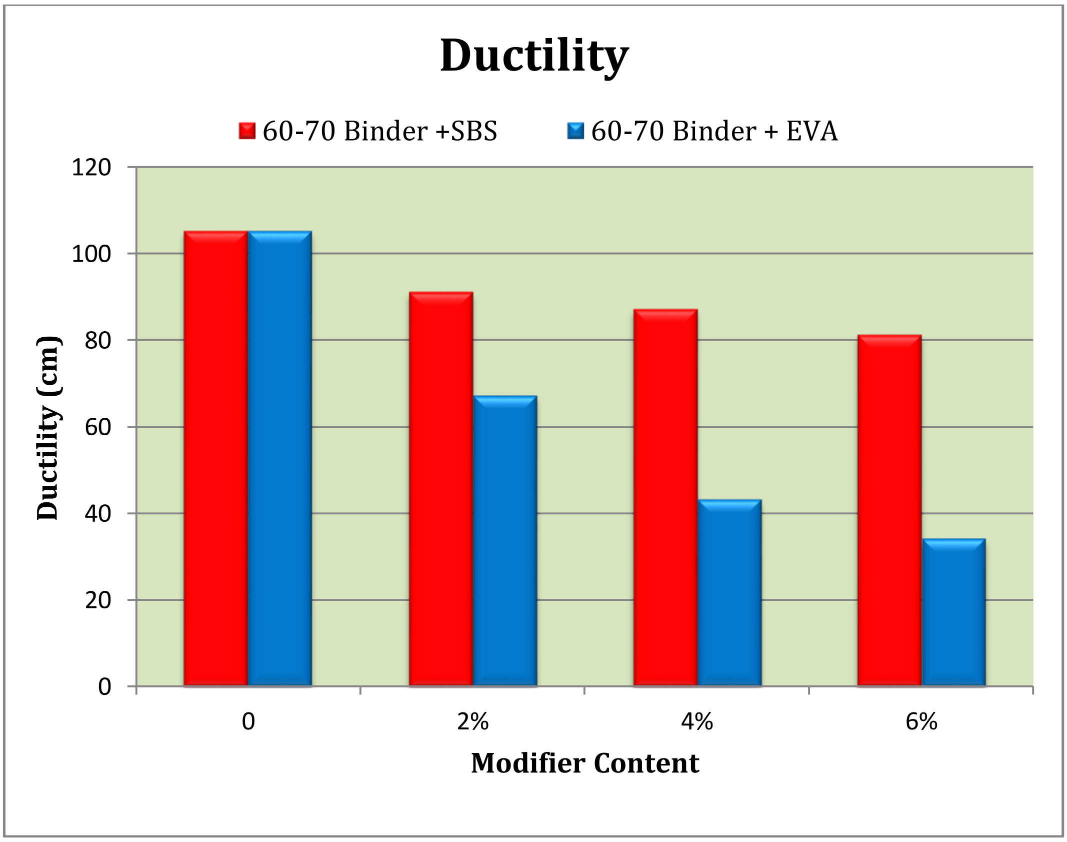

Figure 4: Ductility Values of Modified and Natural Asphalt Cement

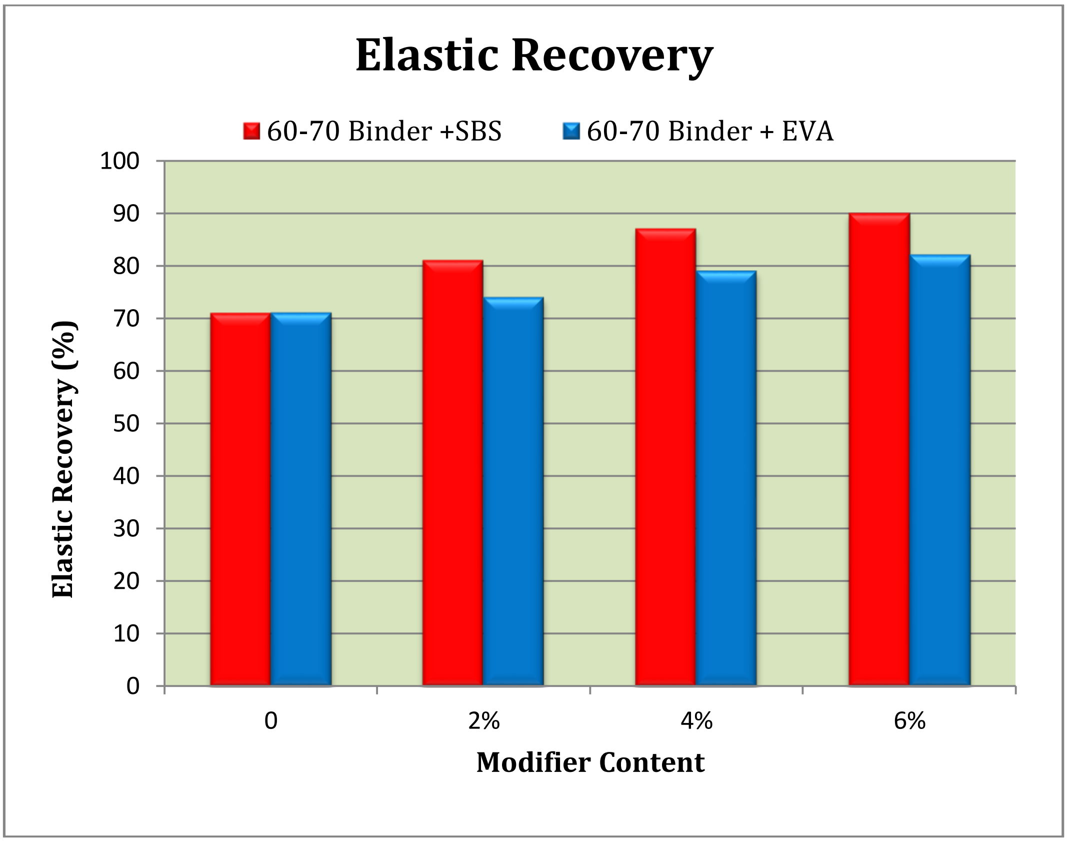

Figure 5: Elastic Recover Values of Modified and Natural Asphalt Cement

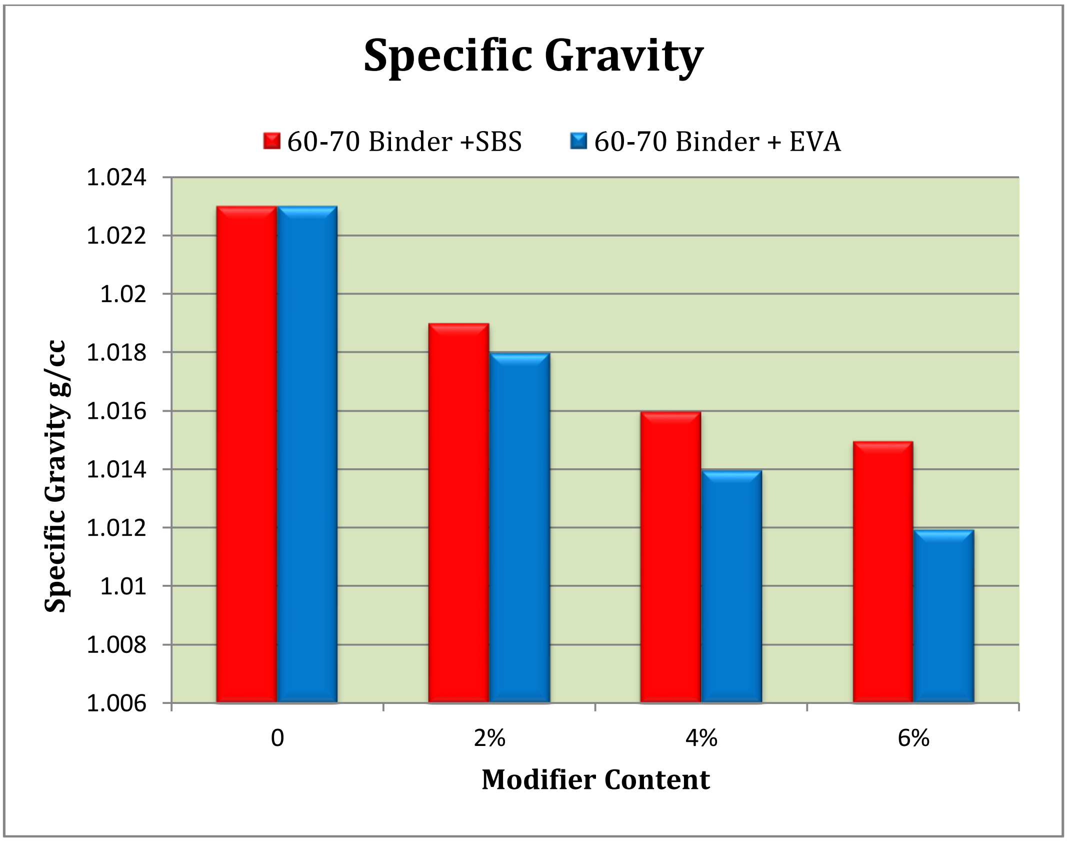

Figure 6: Specific Gravity Values of Modified and Natural Asphalt Cement

تأثير التعديل بالبوليمر على خواص الأسمنت الاسفلتي

ياسر نشأة عبد الكريم
مدرس مساعد
كلية الهندسة – جامعة ديالى

الخلاصة:

ان اعداد المركبات وحمولات نقل البضائع مستمرة في الزيادة مع الوقت, وبهذا وجد ان الأسمنت الاسفلتي المستخدم في انشاء الطرق وخصوصا الطبقات الاسفلتية للرصف له قابيلة قليلة على مقاومة التشوهات المستقبلية التي قد تحدث. في هذه الدراسة استخدم سمنت اسفلتي ذو قوام 60–70 من مصفى الدورة , ونوعين من البوليمرات (الإيثيل خلات الفينيل والستايرين البيوتاديين الستايرين) استخدمت لتحضير الأسمنت الاسفلتي المعدل بنسب مختلفة (2, 4, 6)% من الوزن. ان دراسة تاثير التعديل بالبوليمر على خواص الأسمنت الاسفلتي تمت وفقا لعدة فحوصات منها (الاختراق, نقطة الليونة, اللزوجة, ليونة الاستطالة, ليونة الاسترداد, والوزن النوعي) التي اجريت على الأسمنت المعدل والطبيعي. بمقارنة نتائج الخواص الفيزيائية والميكانيكية للأسمنت الاسفلتي الطبيعي والمعدل, وجد ان خواص الأسمنت الاسفلتي المعدل قد تحسنت وتعززت بشكل ملحوظ. وان الأسمنت الاسفلتي المعدل يمتلك اعلى قيمة في المرونة الاستردادية, نقطة اليونة, اللزوجة, مقاومة التماسك و ليونة الاستطالة. كما لوحظ ان المحتوى المثالي للبوليمر المعدل في الاسمنت الاسفلتي هو 4% للبوليمر المعدل نوع ستيرين بوتيدين ستيرين و 6% للبوليمر المعدل أثيل فينال أسيتيت.