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Modification of Hot Mix Asphalt Using Ethylene Vinyl Acetate (EVA) for Hot and Arid Regions

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Abstract Permanent deformation or rutting is a primary failure mode of hot mix asphalt (HMA) pavements especially in hot and arid region. The aim of this study was to achieve the viability of using Ethylene Vinyl Acetate (EVA) as a modifier of hot mix asphalt, for alternative industrial asphalt in flexible pavement preservation material at hot and arid region. The type of asphalt used was 60/70 pen. This research was conducted to get the difference about strength and durability aspect on asphalt modified with EVA with several percentages namely 2%, 4%, 6%, 8% and 10%. All of the hot mix asphalt (HMA) was prepared based on Marshall Mix design properties in terms of Marshall Stability Test (MS) to get Optimum Bitumen Content, strength and durability. The tests conducted were Marshall Stability Test, Indirect Tensile Strength Test (ITS) in different temperatures (20°C, 40°C and 60°C) an unconfined Compressive Strength Test (UCS) at temperature 45°C. The Marshal properties, unconfined compressive strength (UCS), Indirect Tensile Strength test (ITS) were conducted.The result showed that marshal stability, Marshal Quotient increase with increase in EVA modifier. However, Marshal Flow decreases when EVA modifier was increased. All the values of unconfined compressive strength (UCS) and Indirect Tensile Strength test (ITS) increased with an increase in EVA modifier. Therefore, EVA could be used as aggregate substitute for flexible hot mix asphalt at hot and arid region because it is temperature tolerant and can prevent asphalt cracking.
Keywords: EVA modifier, HMA, Thin surfacing, ITS, UCS.

تعديل خليط الأسفلت الساخن باستخدام خلات فينيل الإيثيلين (EVA) للمناطق الحارة والجافة

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الملخص التشوه الدائم أو التمزق هو طريقة فشل أولية لأرصفة الإسفلت المزيج الساخن (HMA) خاصة في المناطق الحارة والجافة. كان الهدف من هذه الدراسة هو تحقيق جدوى استخدام خلات فينيل الإيثيلين (EVA) كمعدل للخلط الساخن للإسفلت الصناعي البديل في مادة الحفظ المرنة للأرصفة في المناطق الحارة والجافة. نوع الأسفلت المستخدم كان 70/60. تم إجراء هذا البحث لمعرفة الفرق حول جانب القوة والمتانة على الأسفلت المعدل باستخدام EVA بنسب عدة وهي 2% ، 4% ، 6% ، 8% و 10%. تم تحضير كل خليط الإسفلت الساخن (HMA) بناءً على خصائص تصميم Marshall Mix من حيث اختبار Marshall Stability Test (MS) للحصول على أفضل محتوى من البيتومين وقوة ومتانة. كانت الاختبارات التي تم إجراؤها هي اختبار مارشال للثبات، واختبار مقاومة الشد غير المباشر (ITS) في درجات حرارة مختلفة (20° و 40° و 60°) واختبار قوة الانضغاط غير المحصورة (UCS) عند درجة حرارة 45°. تم إجراء اختبار مارشال ، قوة الانضغاط غير المحصورة (UCS) ، اختبار قوة الشد غير المباشر (ITS) ، وأظهرت النتائج أن ثبات الحركة ، حاصل المارشال يزداد مع زيادة معدل EVA. ومع ذلك ، يتناقص تدفق مارشال عندما تم زيادة معدل EVA. زادت جميع قيم قوة الضغط غير المقيدة (UCS) واختبار قوة الشد غير المباشر (ITS) مع زيادة معدل EVA. لذلك ، يمكن استخدام EVA كبديل مجمع للخلط الساخن المرن للإسفلت في المناطق الحارة والقاحلة لأنه يتحمل درجات الحرارة ويمكن أن يمنع تكسير الأسفلت.
الكلمات المفتاحية: معدل EVA، HMA، السطح الرقيق ، ITS، UCS.

1. Introduction

In the recent years, existing highway networks in Libya exhibit poor geometric characteristics and low levels of service which result to high accident rates on highways. This situation affects the country's growth. The Libyan government, in its aim to enhance economic growth, has firmly stressed the development of transport infrastructure on roads with the aim of implementing a national road network. Under the present plan, a number of major roads will be subjected to instant improvement to become dual carriageways. The highway in hot and arid region is one of the important roads in the country in which the Libyan government has started investing by renewing this highway. The need to enhance the infrastructure of road transport requires the Libyan government to embark numerous studies to cope with the problems associated with road accidents. Therefore, the time is right to demand a policy that will improve road infrastructure. The

Libyan government has conducted several studies to overcome these problems [1- 4]. One of these policies is improve asphalt road construction quality in hot and arid region in Libya.

The modern use of asphalt for road and street construction began in the late 1800s, and grew rapidly with the emerging automobile industry. Since that time, asphalt technology has made giant strides such that today the equipment and techniques used to build asphalt pavement structures are highly sophisticated. Road also can be differentiated to many type based on climate, construction and many things. Based on climate can be differentiated to cold, warm and hot region.

Recently, increased traffic levels, heavier loads, and extreme weather conditions have urged road authorities to develop new, or advance existing solutions, in order to improve the resistance of the road pavements to the adverse effects of mechanical and environmental loading. Many countries in Africa have hot and arid region. Hot and arid region is regions that have lack of available water and have a high temperature. Besides Libya, Senegal, Upper Volta, Chad in the south, Morocco, Algeria, and Egypt in the North Africa have same climates.

Asphalt binder modification by means of polymer addition, either virgin or recycled and used individually or in a blend mode, has proved to have the potential to enhance the bituminous properties, most typically those related to high temperature performance characteristics, thereby postponing the effects of permanent deformation and fatigue damage [5, 6]. However, depending on their nature, the manufacturing of these polymers can also increase the environmental impacts of the asphalt binder in the mixture [7].

Therefore, the scope of this study is to test the polymer modified Asphalt mixture on rut and fatigue resistance. This study also aims to analyze and compare the maximum amount of the ethylene-vinyl-acetate (EVA) in a mixture that can resist rut the most at hot and arid region of Libya. By conducting Marshall Test, optimum modified bitumen with different amounts of the EVA that will be mixed into the marshal samples in this study.

1.1 Ethylene Vinyl Acetate (EVA)

Distress in HMA pavements reduces the durability of HMA pavements and increases road maintenance costs [8]. Researchers have evaluated improving the asphalt mix using different additives, polymers, nonmaterial, fillers, fibers, recycled materials, to name a few important ones [5, 9 -16].

Some of these additives, in addition to their environmental benefits, improve the engineering properties and performance of the asphalt mixture [17, 18]. Also, researchers have used various materials such as Recycled asphalt materials (RAM) to improve the technical properties of the asphalt mix. The results improved the technical properties of the asphalt mix [19].

Polymers are among the useful additives for modifying the properties of bitumen and asphalt. In their research, Hafeez and Kamal [20] evaluate the effects of polymer on the asphalt and conclude that it improves the technical properties of the asphalt mix [20]. Khattak and Baladi [21] studied the effects of using polymers as modifiers and stated that polymers make the bitumen more resistant to loading and less sensitive to thermal changes. It should be noticed that while the additives may improve the technical properties of the asphalt mix, it would be impossible to use them in the asphalt if it is not economically justifiable.

Ethylene vinyl acetate (EVA) polymer is compatible with most types of bitumen and has good consistency at normal temperatures for transport and mixing [22]. The bitumen modified with EVA polymer has got a higher softening point and displays more stiffness and viscosity. It does not need a higher admixture and compaction temperature. When modified bitumen is used in the surface layer of the asphalt, it increases the resistance to permanent deformation [22].

EVA is a copolymer containing the amorphous vinyl acetate and semi crystalline polyethylene, which is used to improve the properties of asphalt mix [23, 24]. The polyethylene blocks are probably crystallized and form areas that act as knots for cross-linking. At ambient temperature, EVA polymer displays viscoelastic specifications due to the existence of crystallized areas. These areas are melted and form a liquid [22].

Pareek,et.al. [25], conclude that performance of Polymer Modified Bitumen is better than that of conventional bitumen (60/70). Polymer modified bitumen is found to have a high elastic recovery (79%). Modified bitumen has better age resistance properties. The loss in weight on heating in thin film oven is 6 times higher as compared to conventional bitumen of 60/70. Study conducted by Shafii [26], confirmed that asphalt mixture using EVA modified asphalt increased the value of Marshall Stability and air voids and at the same time decreased the flow and unit weight value. The characteristic of the ethylene-vinyl-acetate (EVA) copolymer used in this research are showed Table 1.

Table 1. Specification of the Ethylene-Vinyl-Acetate (EVA)

ITEM	METHOD	UNIT	H21B1
Vinyl Acetate Content	TPC Method	Wt. %	18
Melt Flow Rate	ASTM D1238	g/10 min	2
Density	ASTM D792	g/cm^3	0.94
Tensile Strength at Break	ASTM D638	Kg/cm^2	230
Elongation	ASTM D638	%	800
Surface Hardness	ASTM D2240	Shore D	32
Stiffness	ASTM D747	Kg/cm^2	500
Vicat Softening Point	ASTM D1525	^oC	63
Brittle Point	ASTM D746	^oC	<-75
ESCR	ASTM D1693	Hr	>300

Based on above background, this research was conducted to study the polymer modified bitumen for thin surfacing overlay of hot mix asphalt (HMA) for hot and arid region. Huang, et. al. [27], indicated that the conventional mixtures exhibited higher laboratory strength characteristics than the CRM mixtures. The pavement sections constructed with CRM asphalt mixtures showed overall better performance indices (rut depth, fatigue cracks, and IRI numbers) than the corresponding control sections after five to seven years of traffic. Kok. et. al [28], used natural asphalt modified hot mixture and showed that the stiffness modulus of mixtures decreased with increasing temperature. Walubita, et. al. [29], indicated that asphalt-binder aging has detrimental effect on the fracture response and cracking-resistance of HMA mixes, which can be captured based on the DT test. Therefore, the asphalt-binder aging needs to be considered and properly accounted for during the material design and analysis stages of HMA mixes. Yero, et. al [30], suggested the trend is with an increase in additive the binder viscosity decreases at high temperature as it stiffens and becomes hard at low temperature, thereby increasing the softening point and reducing the penetration of the binder. According to previous researches, this research was used Ethylene-Vinyl-Acetate (EVA) because it has outstanding compatibility in some cases and cheaper than SBS. In this study, the quantity of bitumen that will be used in hot mix asphalt (HMA) thin surfacing are 5.0%, 5.5%, 6.0%, 6.5% and 7.0% by the weight of the mix. The sample will be tested at 20^{o}, 40^{o} and 60^{o}Celcius for ITS and 45^{o}Celcius for UCS based on temperature at hot and arid region as summarize in Table 2.

Table 2. Comparison of this research with previous researches

No	**Previous Research**	**This Researches**
1	Huang, *et. al.* (2002) [27]: Louisiana Experience with Crumb-rubber Modified Hot-Mix Asphalt Pavement Result : -The CRM mixture had higher Marshall flow than the control -The CRM mixtures lower ITS and MR than the control mixtures. Lack of this research: -Use of Crumb-rubber Modified bitumen as a binder in Hot Mix asphalt - Tested by Marshall Stability and Flow test - The indirect tensile strength (ITS) and strain test is conducted at 25 °C -Applications of crumb-rubber modified (CRM) hot-mix asphalt in Louisiana.	- Use of EVA Modified bitumen as a binder in Hot Mix asphalt - Tested by Marshall Stability, Flow, Bulk and Marshall Quotient test - The EVA mixture higher ITS and UCS than unmodified mixture. - The indirect tensile strength (ITS) and test is conducted at 20 °C,40°C and 60 °C - applications of EVA modified hot mix asphalt for hot and arid region.
2	Kok B.V., *et. al.* (2012) [28]: evaluation of the mechanical properties of natural asphalt-hot mixture Result : - The strength value of natural asphalt modified mixture is greater than that of the control mixture Lack of this research : -Using Natural asphalt B 50/70 is hard to find - The indirect tensile strength (ITS) and test is conducted at 60 °C	- Using bitumen 60/70 penetration grade is easy to find - The indirect tensile strength (ITS) and test is conducted at 20 °C, 40°C and 60 °C
3	Walubita, *et. al.* (2012) [29]: Evaluation of HMA Cracking Resistance as a function of Laboratory Aging Based on The Direct-Tension Test Result : - Asphalt-binder aging has a detrimental effect on the fracture response and cracking-resistance of HMA mixes, which can be captured based on the DT test. Lack of this research : -Using SBS is high cost application. -5% SBS by weight of mix - Direct Tention (DT) test is conducted at 60 °C.	-Using EVA is a cost-effective application - EVA (0%, 2% and 4 %) by weight of total mix - The indirect tensile strength (ITS) and test is conducted at 20 °C,40°C and 60 °C
4	Yero, *et. al.* (2012) [30]: Evaluation of Bitumen properties modified with additive Result : - The trend is with an increase in additive the binder viscosity decreases at high temperature as it stiffens and becomes hard at low temperature, thereby increasing the softening point and reducing the penetration of the binder. Lack of this research : - use of sasobit wax-modified bitumen as a additive in hot mix asphalt - hardly mixing process	-use of Ethane-Vinyl-Acetate (EVA) as a additive in hot mix asphalt - tested by Marshall, Indirect Tensile Strength (ITS) and unconfined compressive strength (UCS). -easily mixing process

2. Research Methodology

This research was conducted to study the use of polymer modified bitumen for thin surfacing at hot and arid region. The bitumen content that will be used in hot mix asphalt (HMA) thin surfacing are 5.0%, 5.5%, 6.0%, 6.5% and 7.0%.Hot Mix Asphalt was modified with 0%, 2%, 4%, 6%, 8% and 10% EVA. Moreover, for the temperature test, it was tested at 20^{o}C until 60^{o}C. The specimen was tested by 3 tests of Marshall, Indirect Tensile Strength (ITS) and Unconfined Compressive Strength (UCS). In this research, survey the literature conducted is to find references that have relevance to the topic of research and then summarize the literature and compare some of journal to find the comparison of hot mix asphalt (HMA) thin surfacing overlays by polymer modified bitumen for hot and arid. The collecting technical data and specification of the bitumen and hot mix asphalt that was used for overlay design in hot and arid region. From the data that has collected was used to design the new overlay by polymer modified bitumen.

2.1 Research Variables and Parameters

2.1.1 Research Variables

i. Dependent Variable, Strength of bituminous material (Y): variable to be predicted magnitude
ii. Independent Variable, Variation range of polymer (X).The ethylene-vinyl-acetate (EVA) will be added into HMA thin surfacing in this research are 2%, 4%, 6%, 8% and 10%.

2.1.2 The Parameters

The Parameters that we use in the research are:

i. Stability (S)
ii. Flow (F)
iii. Bulk specific gravity of mix (Gm)
iv. Porosity
v. Marshall Quotient (MQ)

$$Y = ax^2 + bx + c \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The parameters that used are shown in the Table 3.

Table 3 Parameters for HMA thin surfacing test

			Analysis	**How to measure**
Parameters	Marshal properties		- Marshall stability - Flow - Marshall Quotient (MQ) - Bulk specific gravity of mix (Gm) - Porosity	Marshal tests
Variables	**EVA Modifier**	2% 4% 6% 8% 10 %	- Marshall properties - Unconfined compressive - Indirect tensile strength	- Marshall tests - Unconfined compressive test - Indirect tensile strength test
	Bitumen (5%-7%)		Bitumen content	Optimum Bitumen Content
Temperature		20 ^{0} 40 ^{0} 45 ^{0} 60 ^{0}	- Unconfined - compressive - - Indirect tensile strength	- Unconfined - compressive test - Indirect tensile - strength test

2.2 Primary Data and Secondary Data

Primary data of this research was from the result which produced in laboratory. The tests were conducted in laboratory: compressive strength and modulus of elasticity. This data such as stress, strain or elongation, maximum load etc was required to finish the analysis of this research. Secondary data that used in this research was characteristic of aggregate, characteristic of bitumen, characteristic of mineral filler, characteristic of the ethylene-vinyl-acetate (EVA) copolymer. Aggregate blending involved the process of proportioning the aggregates to obtain the desired gradation that were well within the gradation limits.

2.3. Validation Data

Validity of data is an important factor in a research, because before the data analyzed must first run into checking or testing. Proving the validity of the observed results are in accordance with reality and is consistent with the actual or occurrence. So in the end the resulting data is true data and without engineering. In this research, the researcher used validation data by compared the data from previous research with the data obtained of this research [31].

2.4 Marshall Test:

The Marshall Test method allows the researcher to choose optimum asphalt content to be added to specific aggregate blend to mix where desired properties of density, stability and flow were meet. The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method [32]. According to JKR/SPJ/rev 2005 the procedures of Marshall Test are:

i. Prepare the specimen for the standard stability and flow test using 75 blow/face compaction standards.

ii. Bulk specific gravity determination for the specimen test. Stability flow values determination.

iii. Specific gravity analysis and air void parameters for determining the percentages air voids in the compacted aggregate, the percentage air voids in the compacted aggregate filled with bitumen and the percentage air voids in the compacted mix. The Marshall Mix design in this research is shown in following Table 4.

Table 4. The Marshall Mix design

Type	**Asphalt Bitumen (%)**				
Variation of	5%	5.5%	6.0%	6.5%	7.0%
Ethylene	2%	2%	2%	2%	2%
vinyl	4%	4%	4%	4%	4%
acetate	6%	6%	6%	6%	6%
(EVA)	8%	8%	8%	8%	8%
Copolymer	10%	10%	10%	10%	10%

2.5 Indirect Tensile Strength Test:
For strength test the researcher use ITS (Indirect Tensile Strength) method, from this method it can be know the strength from the hot mix asphalt thin surfacing overlay by polymer modified bitumen for hot and arid region as shown in Figure 1. The value of ITS is used to evaluate the relative quality of bituminous mixtures in conjunction with laboratory mix design testing and for estimating the potential for rutting or cracking. The results can also be used to determine the potential for field pavement moisture damage when results are obtained on both unconditioned and conditioned samples [33]. In this research was used 3 variations temperature in this test. The temperatures are 20^o, 40o and 60ocelcius. So, we will know strength of EVA modified polymer of thin surfacing HMA for hot and arid region with the different time. The EVA mix design for ITS is shown in following Table 5.

Table 5. Optimum bitumen of variation EVA copolymer content for ITS Test

Type	Optimum EVA Content (%)		
	20C^0	40C^0	60C^0
Variation of Ethylene vinyl acetate (EVA) Copolymer	2%	2%	2%
	4%	4%	4%
	6%	6%	6%
	8%	8%	8%
	10%	10%	10%


Figure 1. Indirect Tensile Strength Test (ITS)

2.6 Unconfined Compressive Strength Test:
The unconfined compression test is used to measure the shearing resistance of cohesive soils which may be undisturbed or remolded specimens. An axial load is applied using either strain-control or stress-control condition as shown in Figure 2. The unconfined compressive strength is defined as the maximum unit stress obtained within the first 20% strain [33].In this research will use 1 temperature in this test. The temperature is 45^{o}celcius.This temperature according to temperature at hot and arid region. So, we will know the resistance of EVA modified polymer of thin surfacing HMA for hot and arid region. The UCS test procedure according to Department Of Transportation California is:

1. Place specimen on base of holder and set holder on compression device.
2. Lower loading piston until it contacts specimen push rod. Contact will be noted by slight reading on load readout gauge.
3. Zero out readout gauge, check strain rate setting, and begin test.
4. Continue test until load values decrease or until 20% strain is reached.
5. Make a moisture determination and also a sketch of specimen showing failure conditions such as slope angle, if measurable. Obtain classification tests as needed. The EVA mix design for UCS is shown in following Table 6.

Table 6. Optimum bitumen of variation EVA copolymer content for UCS Test

Type	Optimum EVA Content (%)
	45C^0
Variation of Ethylene vinyl acetate (EVA) Copolymer	2%
	4%
	6%
	8%
	10%


Figure 2. Unconfined Compressive Strength Test (UCS)

3. Result and Discussion
This research was conducted to study the polymer modified bitumen for thin surfacing overlay of hot mix asphalt (HMA) for hot and arid region. The use of polymer modified bitumen to improve the service life of the pavement especially for thin surfacing overlay. This research was used Ethylene -Vinyl-Acetate (EVA). In this study, the quantity of bitumen that was used in hot mix asphalt (HMA) thin surfacing are 5.0%, 5.5%, 6.0%, 6.5% and 7.0% by the weight of the mix. The sample was tested at 20^o, 40^{o}and 60^{o}Celcius for ITS and 45^{o}Celcius for UCS based on temperature at hot and arid region.

4.1 The Optimum Bitumen Content
A. Materials Preparation
The main materials used in this research were aggregate, asphalt and ethylene vinyl acetate (EVA). The asphalt test result as shown in Table 7.The results of the hot mix asphalt are conducted to prove that the asphalt used is qualified according to SNI standard. All properties of the materials used were measured for further analysis consideration. Several tests were conducted in order to measure their properties according to the specification referred were ASTM.

The penetration test is an empirical test that measures the consistency (hardness) of asphalt with EVA, softening point test measures the temperature in which the asphalt with EVA reaches certain softness at the softening point temperature of asphalt with EVA The ductility test measures the maximum distance for the bitumen with EVA ductility without breaking, The Specific Gravity Test was conducted to measure the mass and volume of the asphalt with EVA sample and to determine its maximum specific gravity.

Table.7. Data result of Asphalt

Test type	Unit	Specification	Result
Penetration	(0,1 mm)	60-70	65.27
softening point	°C	≥48	50
Asphalt density		≥1,0	1.06

Based on data result of asphalt in Table 4, the asphalt is used in this study meets the specifications of SNI standard that can used in this research. The penetration for bitumen was 65.27 PEN which was fall in 60 PEN – 70 PEN of the SNI Standard. The Softening point for bitumen was 500C more than 480C of the SNI Standard. The ductility has value 1060 mm more than 1000 mm of the SNI standard.

B. The Mixing asphalt with Eva

In order to make the asphalt samples, first, the bitumen was mixed with different percentages of EVA polymer, and then, the asphalt samples were made using the modified bitumen. The bitumen and EVA were mixed based on AASHTO-M320 and ASTM-D6373 standards. In this study, five different ratios of EVA mixing with asphalt 60 /70 with 100 grams which are 2%, 4%, 6%, 8% and 10% EVA of bitumen weight was used four tests: a penetration Softening point, ductility and Specific Gravity. The sample of bitumen modified EVA are shown in Figure 3.

Figure 3. Sample bitumen 60/70 with EVA

Procedure the mixing asphalt with EVA:

1. Weigh the appropriate levels of EVA predetermined levels.
2. Melt the EVA until completely liquid reaches a temperature of about 1000C.
3. After that, heat the asphalt pen 60/70 until the temperature reaches about 700C.
4. Once the liquid EVA input liquid asphalt, then stir until smooth using a wooden or a tool like that can be used for stirring.
5. Once completely blended and chill until ready to be tested specimen penetration, density, etc.

When we added 2 grams of EVA with 100 grams of bitumen we got good results in penetration, ductility, specific gravity and softening point test based on SNI Standard. From the Table 8, the penetration for bitumen with 2% EVA was 63.4 PEN which was fall in 60 PEN – 70 PEN of the SNI Standard. The Softening point for bitumen with 2% EVA was 54.50C more than 480C of the SNI Standard. The ductility has value 1020 mm more than 1000 mm of the SNI standard. The value of specific gravity was 1.030 gr/cc more than 1gr/cc based on SNI Standard as shown in Table 8.

When 4 grams of EVA with 100 grams of bitumen, the penetration for bitumen with 4% EVA was 63.80 PEN which was fall in 60 PEN – 70 PEN of the SNI Standard. The Softening point for bitumen with 4% EVA was 74.50C more than 480C of the SNI Standard. The ductility has value 1003 mm more than 1000 mm of the SNI standard. The value of specific gravity was 1.112gr/cc more than 1gr/cc based on SNI Standard as shown in Table 9.

Furthermore, when we add 6 grams of EVA with 100 grams of bitumen, specific gravity and softening point test and we got a failure in penetration, ductility based on SNI Standard. From the table, the penetration for bitumen with 6% EVA was 33.80 PEN which was fall out 60 PEN – 70 PEN of the SNI Standard. The Softening point for bitumen with 6% EVA was 62.50C more than 480C of the SNI Standard as shown in Table 10. The ductility has value 720 mm less than 1000 mm of the SNI standard. The value of specific gravity was 1.020 gr/cc more than 1gr/cc based on SNI Standard.

Moreover, at 8 grams of EVA with 100 grams of bitumen, specific gravity and softening point test we got a failure in penetration, ductility based on SNI Standard. From the table, the penetration for bitumen with 8% EVA was 11.40 PEN which was fall out 60 PEN – 70 PEN of the SNI Standard. The Softening point for bitumen with 8% EVA was 55.50C more than 480C of the SNI Standard. The ductility has value 435 mm less than 1000 mm of the SNI standard. The value of specific gravity was 1.063gr/cc more than 1gr/cc based on SNI Standard as shown in Table 11.

Finally, at 10 grams of EVA with 100 grams of bitumen we got a failure in penetration, ductility and specific gravity based on SNI Standard. From the table, the penetration for bitumen with 10% EVA was 4.80 PEN which was fall out 60 PEN – 70 PEN of the SNI Standard. The Softening point for bitumen with 10% EVA was 600C more than 480C of the SNI Standard. The ductility has value 270 mm less than 1000 mm of the SNI standard. The value of specific gravity was 0.944gr/cc less than 1gr/cc based on SNI Standard as shown in Table 12. From the result the research use Unmodified HMA and HMA modified EVA with 2% and 4%.

Table.8. Data result of HMA with 2% EVA

No	Test type	SNI Standard		Characteristic	Unit	Result
		Min.	Max.			
1	Penetration	60	70	63.4	10^{-1} mm	OK
2	Softening point	48	-	54.5	^{0}C	OK
3	Ductility	1000	-	1020	mm	OK
4	Specific Gravity	1	-	1.030	gr/cc	OK

Table.9. Data result of HMA with 4% EVA

No	Test type	SNI Standard Min.	SNI Standard Max.	Characteristic	Unit	Result
1	Penetration	60	70	63.80	10^{-1} mm	OK
2	Softening point	48	-	74.5	^{0}C	OK
3	Ductility	1000	-	1003	mm	OK
4	Specific Gravity	1	-	1.112	gr/cc	OK

Table.10. Data result of HMA with 6% EVA

No	Test type	SNI Standard Min.	SNI Standard Max.	Characteristic	Unit	Result
1	Penetration	60	70	33.80	10^{-1} mm	FALSE
2	Softening point	48	-	62.5	^{0}C	OK
3	Ductility	1000	-	720	mm	FALSE
4	Specific Gravity	1	-	1.020	gr/cc	OK

Table.11. Data result of HMA with 8% EVA

No	Test type	SNI Standard Min.	SNI Standard Max.	Characteristic	Unit	Result
1	Penetration	60	70	11.40	10^{-1} mm	FALSE
2	Softening point	48	-	55.5	^{0}C	OK
3	Ductility	1000	-	435	mm	FALSE
4	Specific Gravity	1	-	1.063	gr/cc	OK

Table.12. Data result of HMA with 10% EVA

No	Test type	SNI Standard Min.	SNI Standard Max.	Characteristic	Unit	Result
1	Penetration	60	70	4.80	10^{-1} mm	FALSE
2	Softening point	48	-	60	^{0}C	OK
3	Ductility	1000	-	270	mm	FALSE
4	Specific Gravity	1	-	0.944	Gr/cc	FALSE

C. Sieve Analysis and Aggregates Gradation

The aggregates were blended and sieved as shown in Table 13. The aggregate samples passing from each sieve size were collected based on the percentage of the weight.

Table 13. Aggregate gradation specification for Mix HMA

Gradation specifications					
Sieve	**% passing by weight**			**% retained**	**weight per sieve (gr)**
Size (mm)	Min	Max	Medium	0	0
25	100	100	100	0	0
19	85	95	90	10	0
12.5	65	75	70	20	120
9.5	20	28	24	46	168
4.75	16	24	20	4	312
2.36	12	21	16.5	3.5	120
Pan	0	0	0		480
Total Aggregate					1200

At the preliminary stage, aggregate were sieved according to AASHTO T 27-88 and separated according to the size of sieves on the selected aggregate gradation. The aggregate gradation specification and the selected gradation used in this study are shown in figure 4.

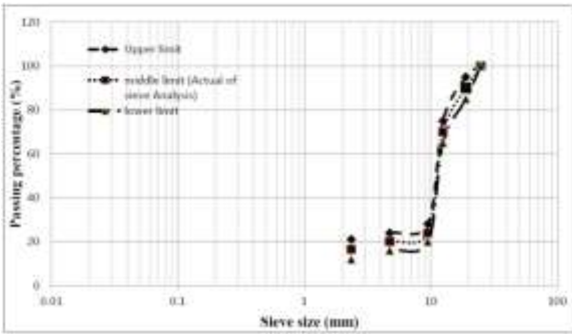

Figure 4. Aggregate gradation

In this study, sieve analysis was conducted to separate the aggregate according to the sieve size. Hot Mix Asphalt mixtures specifications require aggregate particles to be within a certain range of sizes and for each size of particle to be presented in a certain proportion.

D. Marshal Test

The results of Marshall Test i.e. stability, porosity, flow, bulk, Marshall Quotient (MQ) for HMA modified with 0 %, 2%, 4% EVA are summarized in Table 14.

Table 14.The optimum value of marshal tests for HMA modified with 0%, 2%, and4% EVA

Mixture properties	0% EVA	0% EVA	0% EVA
Marshall Stability (kg)	1450.02	1780.95	1857.77
Porosity	15.52	14.11	12.87
Flow (mm)	2.28	2.25	2.03
Bulk	2.08	2.118	2.15
Marshall Quotient	724.43	856.61	990.15

As shown in Table 14 the marshal stability, bulk and MQ values increase as the amount of EVA modifier of hot mix asphalt increases. Whereas porosity and flow decrease as the percent of EVA increases.

i. Optimum Bitumen Content

The optimum bitumen content by Marshall Experiment was performed on bitumen content of 5% to 7% with an interval of 0.5. Before the Marshall test done, volumetric test conducted that include thick measurement and weight object test that include weight in the air, and the weight of the SSD in the water, the measurement results obtained are used in the calculations to obtain the value of the density, SG_{mix} and porosity.

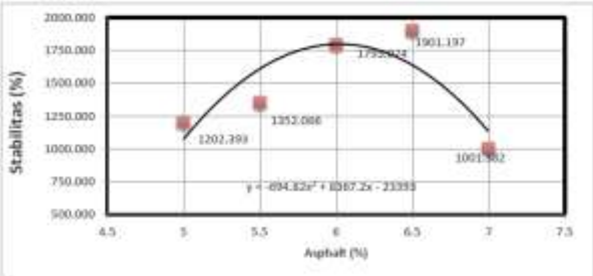

Figure 5.the stability of Thin Surfacing HMA with 0% EVA

While Marshall testing is performed to determine the value of stability, flow and Marshall Quotient of each test specimen. From these values can be determined with the best mix properties of optimum bitumen content. The optimum bitumen content (OBC) at HMA with 0% EVA is 6.02%, while, the OBC at EVA modified HMA are 5.98%, and 5.48 for 2%, and 4%, respectively. The differences in the optimum bitumen content between the three types are due to difference in EVA content for the production of mixtures. Optimum bitumen content for thin surfacing HMA with 0% EVA is determined by the graph presented in Figure 5.

The optimum bitumen content of the asphalt level will result the best characteristic properties in a mixture of asphalt. The optimum bitumen content is used as a basis for the calculation of the asphalt content for the manufacture of test specimens. To find the value of the optimum bitumen content in thin surfacing HMA with 0% EVA calculation of the regression equation relationship between the stability and bitumen content as follows:

$$y = -694.82x^2 + 8367.2x - 23393$$
$$2(-694.82x) + 8367.2 = 0$$
$$x = 6.02$$

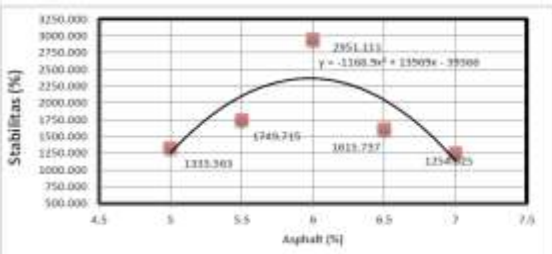

Figure 6. The stability of Thin Surfacing HMA with 2% EVA

The optimum bitumen content for thin surfacing HMA with 0% EVA is 6,02 % Optimum bitumen content for thin surfacing HMA with 2% EVA is determined by the graph presented in Figure 6.

While to determine the optimum bitumen content of thin surfacing HMA with 2% is used calculation of the regression equation relationship between the stability and bitumen content as follows:

$$y=-1168.9x^2 + 13969x - 39366$$
$$2(-1168.9x + 13969 = 0$$
$$x= 5.98$$

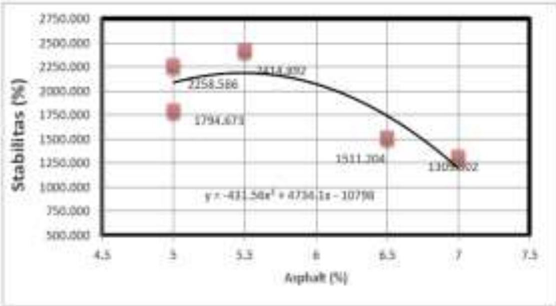

Figure 7.the stability of Thin Surfacing HMA with 4% EVA

The optimum bitumen content for thin surfacing HMA with 2% is 5.98 %. Optimum bitumen content for thin surfacing HMA with 4% EVA is determined by the graph presented in Figure 7. While to determine the optimum bitumen content of thin surfacing HMA with 4% is used calculation of the regression equation relationship between the stability and bitumen content as follows:

$$y= -431.56x^2 + 4734.1x - 10798$$
$$2(-431.56x) + 4734.1 = 0$$
$$x= 5.48$$

The optimum bitumen content for thin surfacing HMA with 4% EVA is 5.48 %.

ii. Stability Test

Stability is the ability of the mixture to withstand maximum load to avoid deformation resulted from traffic activities or in other words, it is the maximum capability of a mixture of a mix split mastic asphalt specimen in bearing the load that finally causes plastic flow, deformation, and permanent transformation such as corrugation, rutting, and bleeding. The stability number of the specimen was obtained by reading the Marshall Dial stability meter (measuring device) which is corrected based on the calibration instrument and specimen thickness. The results of Stability HMA modified with 0 %, 2%, and 4% EVA are summarized in Table 14 – 16. The value of Stability can be calculated using equation 2.

$$S = q \times k \times H \times 0.4536 \ \ldots\ldots. (2)$$

Where:

S: Stability (Kg)

q: Stability of the equipment readings (lb)

k: Calibration factor (30.272)

H: Correction thick specimen

0.4536: Unit conversion from lb to Kg

Table 14. Stability result of HMA with 0% EVA

Bitumen Content (%)	q (Lb)	q x k x 0,4536 (Kg)	H (mm)	S (Kg)
5	54	741.494	2.89	2141.529
5	23	315.882	2.78	878.182
5	15	205.971	2.85	587.467
Average				**1202.393**
5.5	29	398.210	3.21	1278.876
5.5	25	343.284	3.03	1040.796
5.5	45	617.912	2.81	1736.526
Average				**1352.066**
6	45	611.146	2.68	1639.234
6	51	700.300	2.76	1934.696
6	49.5	679.703	2.66	1805.292
Average				**1793.074**
6.5	59	810.151	2.79	2259.7.82
6.5	49	672.838	2.62	1764.727
6.5	48.5	665.972	2.52	1679.082
Average				**1901.197**
7	43	590.449	2.2	1296.774
7	27	370.747	2.44	904.623
7	25	343.284	2.34	802.749
Average				**1001.382**

Hot Mix Asphalt without EVA with asphalt content 6.5% has optimum stability value of 1901.197 Kg.

Table 15. Stability result of HMA with 2% EVA

Bitumen Content (%)	q (Lb)	q x k x 0,4536 (Kg)	H (mm)	S (Kg)
5	27	370.747	2.67	990.822
5	58	796.420	2.78	2214.545
5	32	439.404	1.81	795.321
Average				**1333.563**
5.5	27	370.747	2.89	1070.764
5.5	51	700.300	3.03	2123.223
5.5	55	755.226	2.72	2055.158
Average				**1749.715**
6	75	1029.853	2.63	2707.828
6	79	1084.779	2.76	2996.883
6	49.5	679.703	2.66	3148.624
Average				**2951.111**
6.5	30	411.941	2.87	1181.997
6.5	68	933.734	2.62	2449.009
6.5	36	494.330	2.46	1216.205
Average				**1615.737**
7	28	384.479	2.28	875.650
7	33	453.136	2.44	1105.651
7	57	782.689	2.28	1782.573
Average				**1254.625**

HMA modified with 2% EVA has optimum stability value of 2951.111 Kg at 6% asphalt content.

Table 16. Stability result of HMA with 4% EVA

Bitumen Content (%)	q (Lb)	q x k x 0,4536 (Kg)	H (mm)	S (Kg)
5	45	617.912	2.89	1784.607
5	76	1043.585	2.60	2715.929
5	62	851.346	2.67	2275.221
Average				**2258.586**
5.5	55	755.226	3.03	2289.750
5.5	60	823.883	3.25	2675.559
5.5	55	755.226	3.02	2279.366
Average				**2414.892**
6	43	590.449	2.71	1599.724
6	50	686.569	2.71	1860.144
6	58	796.420	2.42	1924.151
Average				**1794.673**
6.5	45	617.912	2.39	1476.398
6.5	44	604.181	2.44	1474.201
6.5	45	617.912	2.56	1583.013
Average				**1511.204**
7	40	549.255	2.38	1306.712
7	42	576.718	2.34	1348.619
7	38	521.792	2.44	1273.173
Average				**1309.502**

HMA modified with 4% EVA has optimum stability value of 2414.892 Kg at 5.5% asphalt content. The relationship between Stability test with EVA content for HMA is shown in Figure 8.

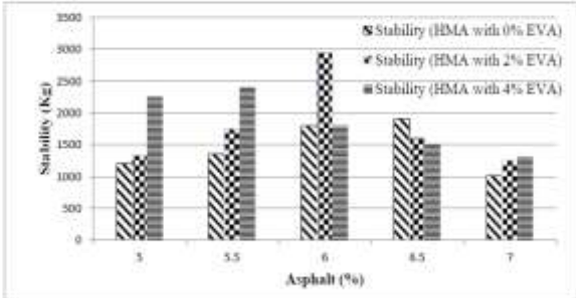

Figure 8.Comparison of Stability test for HMA with 0%, 2%, and 4% EVA

From the result it can be concluded that the higher EVA percent increase stability. This supported by [34-37], when increase EVA percent increase stability. The addition of EVA will give the lower penetration. As a result, the hardness and stiffness of bitumen have been increased when EVA were added.

iii. Flow Test

Flow is the amount of vertical deformation that occurred from the beginning of loading process until the decrease of stability condition. The value of flow can be read from the reading of the flow meter that shows the deformation of specimen in 0.01 mm along with the reading of stability value of the hot mix asphalt mixture.

Flow signifies that the magnitude of mix decline (deformation of specimen) with high fatigue score and low stability score above the maximum limit tends to be plastic. Conversely, the magnitude of the mix decline with low fatigue score and high stability score below the optimum limit tends to be ductile and easy to crack if exposed to loading. The relationship between flow tests with EVA modifier for HMA is shown in Figure 9.

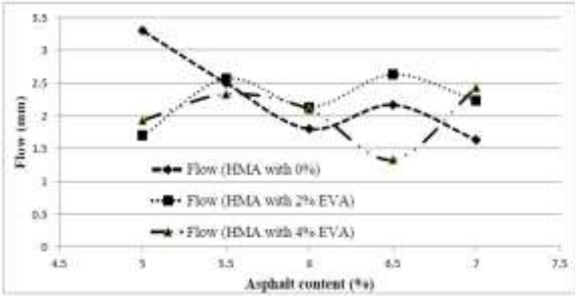

Figure 9. Comparison of Flow test for HMA modified with 0%, 2%, and 4% EVA

Through the comparison of the test results in Figure 4, it was found that flow test value of hot mix asphalt decrease as the EVA content increase from 0% to 2%. The flow test value increase as the EVA content increase from 2% to 4% with simultaneous increase in asphalt content from 5% to 5.5% for 0% EVA and eventually increases asphalt content further increase from 5% to 5.5% for 2% EVA. According to [34], Adding EVA to the asphalt mix up to 3% by weight of bitumen increases the flow. Thus it can be concluded that the higher the EVA content decrease flow but higher asphalt content increase flow. With the addition of the asphalt content the mixes become less flexible and the resistance to deformation increase resulting in a high flow value.

iv. Marshal Quotient (Mq)

Marshal Quotient is the ratio of stability and flow (fatigue) that is used as an approach to the degree of stiffness or flexibility of the mixture. The value of Marshall Quotient can be calculated using equation 3:

$$\mathrm{MQ} = \frac{S}{f} \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Where:
MQ = Marshall Quotient (kg/mm)
S = stability value (kg)
f = flow (mm)

The results of Marshall Quotient (MQ) HMA modified with 0 %, 2%, 4% EVA are summarized in Table 17 - 19.

Table 17.Marshall Quotient result of HMA with 0% EVA

Asphalt Content (%)	Stability (Kg)	Flow (mm)	MQ (Kg/mm)
5	1202.393	3.300	478.29
5.5	1352.066	2.500	620.22
6	1793.074	1.800	1007.41
6.5	1901.197	2.167	875.27
7	1001.382	1.633	640.94

Table 18.Marshall Quotient result of HMA with 2% EVA

Asphalt Content (%)	Stability (Kg)	Flow (mm)	MQ (Kg/mm)
5	1333.563	1.700	921.53
5.5	1749.715	2.567	754.82
6	2951.111	2.133	1409.85
6.5	1615.737	2.633	626.78
7	1254.625	2.233	570.09

Table 19.Marshall Quotient result of HMA with 4% EVA

Asphalt Content (%)	Stability (Kg)	Flow (mm)	MQ (Kg/mm)
5	2258.586	1.933	1179.59
5.5	2414.892	2.333	1209.66
6	1794.673	2.100	862.12
6.5	1511.204	1.333	1145.89
7	1309.502	2.433	553.52

The increase in the flow value will decrease the Marshall Quotient value. The value of MQ in the HMA plan is used as an approach to HMA flexibility value. This relationship between the Marshall Quotient and EVA modifier for HMA is shown in figure 10.

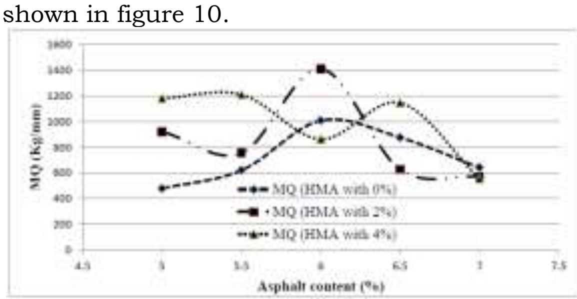

Figure 10. Comparison of Marshall Quotient (MQ) for HMA with 0%, 2%, and 4% EVA

Through the comparison of the Marshall Quotient test results in figure 4.8 it was found that the optimum marshal quotient value of hot mix asphalt without EVA is with asphalt content 6% by 1007.41 kg/mm, while HMA modified with 2% EVA has MQ value 1409.85 kg/mm at 6% asphalt content; HMA modified with 4% EVA has MQ value of 1209.66 kg/mm at 5.5% asphalt content. Thus it can be concluded that the higher EVA content increase marshal quotient.

5.2 Unconfined Compressive Strength (UCS)

Unconfined Compressive Strength Test (UCS) was conducted to determine the resistance to permanent deformation of normal and modified hot mix asphalt mixtures (at 45°C) and loads as shown in Figure 11. It was conducted by applying a static load to a specimen using OBC and then measuring the maximum load. It is noticed that the permanent deformation of the asphalt mixtures correlated with the rutting potential. Experimental objects testing is done using UTM (Universal Testing Machine) to obtained strong push by the unit KN, and then a strong press is made to the calculation unit KPa. The unconfined compression test is by far the most popular method of shear testing because it is one of the fastest and cheapest methods of measuring shear strength. The value of UCS can be calculated using equation 4.

$$F = \frac{P}{A} \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where:

F= compressive strength, lbs/in2 (kN/m2)
P = maximum load, lbf (kN)
A = cross sectional area, in2 (m2)

The unconfined compressive strength is affected by EVA composition. As shown in Figure 5. Hot mix asphalt with 0% EVA has the highest unconfined compressive strength followed by HMA modified with 0%, 2%, and 4%. Through the study of the relationship between the value of UCS and temperature change, it is found that Hot mix Asphalt modified EVA 4% is more sensitive to heat than unmodified HMA.

Table 20. Results of UCS for each EVA (0%, 2%, and 4%) at 45°C

Sample No.	EVA content	P (KN)	A(mm²)	UCS (KN/m²) Kpa	Average
1		73.62	7857.142	9369.818182	
2	0%	104.84	7857.142	13343.27273	**9940.42**
3		55.85	7857.142	7108.181818	
4		82.63	7857.142	10516.54545	
5	2%	65.27	7857.142	8307.090909	**8804.30**
6		59.63	7857.142	7589.272727	
7		92.29	7857.142	11746	
8	4%	72.21	7857.142	9190.363636	**10068.12**
9		72.82	7857.142	9268	

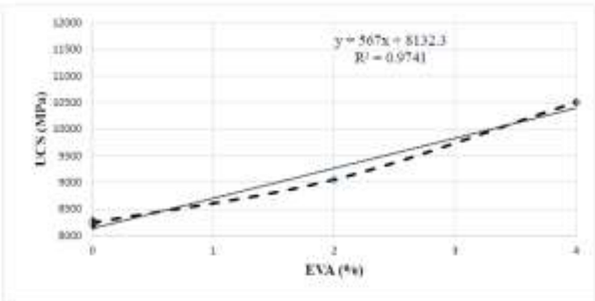

Figure 11. Results of UCS for each EVA (0%, 2%, and 4%) at 45°C

5.3 Indirect Tensile Strength Test (ITS)

This test was conducted under hot and dry conditions; it was determined by measuring the ultimate load to failure of a specimen. It is the measure of pavement response in terms of stresses. Three samples for each type of asphalt with EVA were tested at temperatures (20°C, 40°C, and 60°C). The results can be seen in Figure 6. The value of ITS was calculated using equation 6:

$$ITS = \frac{2F}{3.14(h.d)} \dots\dots\dots\dots\dots\dots \text{(5)}$$

Where:

ITS: Indirect tensile strength, psi
F: Total applied vertical load at failure, lb.
h: Height of specimen, in.
d: Diameter of specimen, in

$$ITS = \frac{2F}{3.14(h.d)} \dots\dots\dots\dots\dots\dots\dots\dots \text{(6)}$$

$$ITS = \frac{2 * 27541200}{3.14(101 * 39)}$$

$$= 4453.456615 \text{ KPa}$$

Table 21.Results of ITS for each EVA (0%, 2%, and 4%) at 20°C, 40°C and 60°C

EVA Content	ITS at 20°C	ITS at 40°C	ITS at 60°C
0%	8319.30 KPa	4239.12 KPa	2061.64 KPa
2%	9736.04 KPa	4031.868 KPa	981.2635 KPa
4%	12863.57 KPa	5321.307 KPa	1650.316 KPa

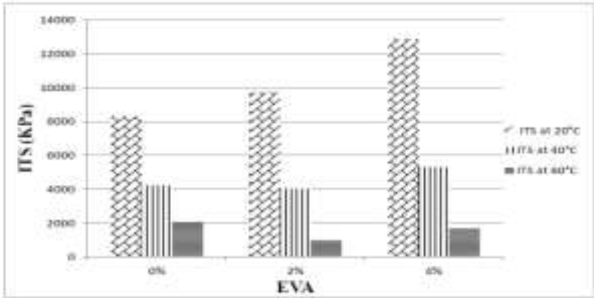

Figure 12. Results of ITS for each EVA (0%, 2%, and 4%) at 20°C, 40°C, and 60°C

From Figure 12, it is clear that ITS value increase following the increase the proportion of EVA for both for HMA modified with 0%, 2%, and 4%EVA. The different EVA compositions have exponential increase with the increase the degree of temperature. The maximum different was at lowest temperature of 20°C and minimum different was at highest temperature of 60°C. The reason of these phenomena is cohesion (bonding) between aggregate and asphalt bitumen decreases by increase of temperature.

i. At a Temperature 20°C
The ITS value of 0% EVA is lower than Hot Mix Asphalt modified with 2% (8318.304 MPa as compared with 9736.04 MPa), almost lower than HMA modified with 4% EVA mixtures. ITS value of HMA modified with 4% EVA is higher than HMA modified with both 0% and 2% EVA. The highest ITS value at a temperature 200C was obtained for HMA modified with 4% EVA.

ii. At a Temperature 40°C
The ITS value of 0% EVA is more than Hot Mix Asphalt modified with 2% (4239.121MPa as compared with 4031.868MPa), almost lower than HMA modified with 4% EVA mixtures. ITS value of HMA modified with 2% EVA is lower than HMA modified with both 0% and 4% EVA. The highest ITS value at a temperature 400C was obtained for HMA modified with 4% EVA.

iii. At a Temperature 60°C
The ITS value of 0% EVA twice higher than Hot Mix Asphalt modified with 2% (2601.642 MPa as compared with 981.263MPa), more than HMA modified with 4% EVA mixtures. ITS value of HMA modified with 2% HMA is lower than HMA modified with both 0% and 4% CR. The highest ITS value at a temperature 600C was obtained for HMA modified with 0% EVA.

Generally speaking, the ITS value across all temperatures for the HMA modified with 0% EVA was lower than HMA modified with both 2% and 4 % EVA. The highest ITS value was obtained. Therefore, ITS value of 0 % EVA<2% <4% for all tested temperatures as the temperature increases from 200C to 600C, the ITS value of unmodified HMA (0% EVA) sharply decreases. The ITS value of HMA modified with 4% EVA decreases by more twice time of its value0% EVA (8319.304 MPa to 4239.121MPa), 2%EVA (12863.57 MPa to 5321.307MPa)

Through the above observation, the hot mix asphalt modified with 4% EVA is more sensitive to temperature changes by using ITS test compared with EVA modified HMA mixtures.

4. Conclusions and Recommendations

Hot Mix Asphalt HMA was modified with 2%, and 4% Ethane-Vinyl-Acetate (EVA), which could be used as EVA for flexible hot mix asphalt at hot and arid region because it is temperature tolerant and can prevent asphalt cracking. Ethane-Vinyl-Acetate (EVA) provides the resistance to permanent deformation of bituminous mixtures. The comparison of the results of Marshall Test showed that Asphalt 60/70 pen was less stable than HMA modified with EVA mixtures. Marshal stability, Marshal Quotient increase with higher EVA modifier. However, Marshal Flow decreases when EVA modifier was increased. The result of ITS and UCS tests show that Hot Mix Asphalt modified with 4% EVA mixture was highest performance at all temperatures. HMA modified mixture was more sensitive to temperature changes compared HMA unmodified with Ethylene -Vinyl-Acetate (EVA) mixtures. The ITS is affected by temperature, they decrease as the temperature increases. The ITS and UCS are affected by EVA composition. The reasons why some differences in values of ITS and UCS tests as compared to other research results are due to the differences in: Aggregate gradation, OBC, Asphalt type, Mix conditions, machine type, and binder content. Therefore, the addition of Ethylene -Vinyl-Acetate (EVA) as modifier of Hot Mix Asphalt has effect on the properties of HMA. Based on this study, recommendations for further works are drawn as follows: This research was conducted to evaluate the applicability of Ethylene -Vinyl-Acetate (EVA) as hot mix asphalt modifier. IT was found that most of the test values increased as the percent of Ethylene -Vinyl-Acetate (EVA) increases, which can contribute to prevent asphalt permanent deformation. Therefore Ethylene -Vinyl-Acetate (EVA) can be used as HMA modifier in filed project works. However, to get a more general conclusion, the laboratory investigation should be extended to include other aggregate and asphalt types.

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