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Enhancing the performance of asphalt mixtures by adding EVA wastes

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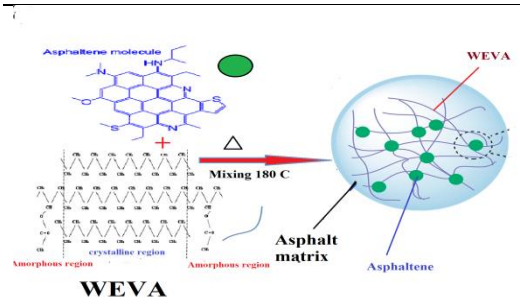
Abstract

Herein the current study, the suitability of improvement of both the workability of the asphalt during construction and its deformation resistance in service using EVA (ethylene-vinyl acetate copolymer) waste were evaluated at 2%, 4%, and 6% of waste (by weight) from binder with the addition of 2% waste cement powder to HMA (high modified asphalt) was verified via the estimation of physical properties implying (penetration test, softening point, flash point and viscosity test). Additionally, SEM, TGA and rheological analyses were utilized for modified asphalt binder whereas Marshall Test was done for HMA using waste cement powder as filler instead of limestone one. The results revealed that the physical properties of polymer modified asphalt (PMAs) such as softening point, penetration grade, penetration index, viscosity, and flash point were improved by adding waste EVA. Consequently, Marshall Stability for the results of HMA appeared highly improvement in stability, flow, unit weight and air voids.

Fortunately, these results cleared that the addition of 4% waste EVA and 2% of the cement filler produced better properties and fatigue resistance to the mix. Lastly, the testing should be framed in the context of protecting the environment and sustainable development as a result of being suggest a functional use for wastes otherwise sent to landfill, while the use of natural raw materials at the same time is limiting.

Key words: Enhancing, asphalt mixtures , EVA waste



Graphical abstract

1. Introduction

Since more than twenty years, a number of new experimental techniques was done to investigate the possibility to shift some of the natural components in the materials used in road construction using industrial by-products and waste materials from recycling processes. The preliminary use of bitumen in asphalt is to serve as the glue or binder which can be mixed with mineral aggregate (stone or sand) particles [1].

In addition, recent advances for bitumen used for pavement applications involve various polymeric additives in order to template performance and reduce rutting, cracking and water susceptibility [2]. Undoubtedly, the features of polymer modified bitumen, named "PMB", depend strongly on both the type of the added polymer and its percentage from which two classes i.e. plastomers and elastomers are used at the virgin or at the recycled state [3]. Besides, the chemical compatibility of a great range of polymers is added to bituminous materials. Hence, the optimization of the mixing process conditions and the effect of particle sizes of the added polymers are widely studied throughout the viscous flow measurements [3-7].

Ethylene vinyl acetate copolymer (EVA) is the most common elastomer used for bitumen modification while EVA is a thermoplastic copolymer

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obtained by copolymerization of ethylene and vinyl acetate. The compatibility of PMB is a complicated phenomenon due to the complex nature of both the physical and chemical properties of bitumen and the polymer [8-10]. Some researchers reported the use of different methods of modifying bitumen using EVA copolymer [11–16]. No doubt that filler is categorized as a fine material which can be used to modify the properties of asphalt binder and asphalt concrete mixture where Portland cement, hydrated lime, fly ash, limestone dust, and clay particles are considered as fillers regardless they are not as a part of the aggregates [17] . They are modifiers to improve the temperature susceptibility and durability of the asphalt binder as well as the asphalt concrete mixture [18]. The moisture susceptibility can be reduced using the mineral fillers, for instance, hydrated lime [19,20]. In addition to utilization of mineral fillers, the strength and stiffness of asphalt concrete can be increased [21]. It is essentially to study the mineral filler characteristics as a result of its enhancing the performance of asphalt concrete in particular to raise the stability and durability against rutting and shoving.

Lesueur et al. proved that the durability of asphalt concrete mixtures can be increased by 2–10 years on using about 1–1.5% of hydrated lime in the mixture [20] . Portland cement utilized as the filler was found to improve the anti-stripping properties of asphaltic concrete [22,23]. Sequentially, the significant improvement on the moisture resistance characteristics can be depicted when fly ash is employed to replace the cement and hydrated lime in producing asphalt concrete mixtures [24,25]. Based on various studies, hot-mix asphalt may be designed and produced from many different aggregate types, a wide range of aggregate size combinations and various binder types. Each mix possesses particular properties which make it suitable for specific conditions of use. The used modified binders include bitumen rubber, polymer-modified binders and other modifiers. The modification of asphalt cement may be accomplished by adding the components that raise the strength of the material or otherwise alter its properties. However, the asphalt mix is normally modified to improve one or more of the engineering properties such as durability, fatigue resistance and resistance to plastic deformation.

On the other hand, the use of a modified binder is sometimes accompanied by a modification to the aggregate grading which would permit these mixes to accommodate more binder, thereby improving their flexibility and crack resistance. Marshall Test is carried out to measure the resistance to plastic flow of cylindrical specimens of asphalt mixtures or asphalt core samples loaded on the lateral surface. Moreover the environmental factors such as air and water have a pronounced effect on the durability of asphalt concrete mixtures [26]. As a consequence, this current investigation aims at the use of the waste PEVA which is one of the principal plastomers used in road construction in order to improve both the workability of the asphalt during construction and its deformation resistance in service at 2%, 4%, and 6% (by weight) from binder with the addition of 2% waste cement powder in HMA. Lastly, the testing should be framed in the context to protect the environment and sustainable development.

2. Experimental

2.1. Materials

Petroleum Company in Suez City, Egypt.

Waste EVA (Ethylene vinyl Acetate) which produced from Waste of Plastic.

Solid Materials: -Dolomite aggregate is of size 2 and size 1 obtained from attaka query (Suez governorate). The coarse aggregate consists of crushed rock retained on 2.36-mm sieve.

-Crushed Sand was obtained from attaka query. Fine aggregate consists of natural rock passing through 2.36-mm sieve and retained on 75-micron sieve. Clean, hard, durable and dry aggregates which are free of dust or any other deleterious matters, were used. Filler material consisting of finely divided mineral matter is free of organic matter as well as it is the fine of crushed sand. Dust Cement filler passes from sieve 200.

-Produced from Suez Cement Company.

2.2. Experimental procedure

The testing program included the following steps.

2.2.1. Characterization of virgin asphalt 60/70

The virgin asphalt sample was tested as listed in Table (1). For penetration (ASTM D5), softening point (ASTM D36), specific gravity (ASTM D70) and kinematic viscosity (ASTM D4402), the results are cited in Table (1). Pen 25: penetration value at 25 ^{0}C, 0.1 mm & SP softening Point, ^{0}C. Also, asphalt sample was tested for TGA, SEM, rheology test and FTIR analyses.

2.2.2. Characterization of solid aggregate.

2.2.2.1 Physical analysis of solid materials.

2.2.2.1.1. Sieve analysis of solid materials

As mentioned in Tables (2&3) the Characteristics of solid materials are as follows:

A. Sieve analysis of fine and coarse aggregate

This method is used initially to estimate the grading of materials proposed for their use as aggregates. The results are utilized to determine compliance of the particles size distribution with

applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. In this test, a sample of dry aggregate of a known weight is separated through a series of sieves of progressively smaller openings numbers 1"(25mm), 3/4"(19mm), 1/2"(12.5mm), 3/8"(9.5mm), NO. 4 (4.75mm) for determining the particle size distribution. The pass percent for the material can be calculated.

Table (1): Physical characteristics of virgin asphalt sample.

Test	AC	SP*
• **Penetration (@ 25ºC , 100 g, 5 s), 0.1mm**	**64**	**60/70**
• **Softening point (ring and ball), ºC**		
• **Penetration index**	**50**	**45/55**
• **Specific gravity (@ 25ºC) using a pycnometer,**	**-0.40**	**-2: +2**
• **Flash point (Cleveland Open Cup), ºC.**		**NS****
• **Kinematic viscosity (@ 135ºC), cSt.**	**1.02**	**+250**
• **<u>Thermal Gravimetric Analysis (TGA)</u>**	**300**	**>320**
***** Initial degradation temperature, ºC.**	**335**	
***** Final degradation temperature, ºC.**	**246.0**	
***** Total weight loss (wt. %).**	**520.0**	
Chemical Composition	**85.14**	**NS****
Maltene (wt %)	**73.8**	**NS****
Asphaltene (wt %)	**23.6**	**NS****

N.B.* Standard specification for ‘‘General Authority for Roads, Bridges and Land Transportation in Egypt”. Item No. 102.1. ** Not specified. *** According to literature, max. Difference is 2.

The temperature susceptibility of virgin and modified asphalt sample was expressed in terms of penetration index (P.I) using the penetration (at 25 ºC) and softening point values.

P.I can be evaluated from the following equation:

$$(P.I) = \frac{\{1952 - (500)\log pen - 20\ softening\ point\}}{(50 \log pen - softening\ point - 120)} \quad \text{…….(1)}$$

Table (2): Characteristics of solid materials

Item		Size 2	Size 1	Crushed sand	Filler
Loss Angles abrasion Test	**ASTM C131**				
- after 100 revolutions, %wt (*)		**4.5**	**5.8**	**-**	
- after 500 revolutions, %wt (**)		**26.6**	**24**	**-**	
Specific gravity	**ASTM C127**				
- Bulk Specific gravity		**2.511**	**2.521**	**2.573**	
Bulk Specific gravity(SSD) (***)		**2.562**	**2.567**	**2.595**	
- Apparent Specific gravity		**2.645**	**2.644**	**2.632**	**2.725**
Absorption (%wt) (****)		**2.0**	**2.8**		
Sodium sulfate soundness (%)	**ASTM C88**	**1.30**	**2.330**	**1.5**	
Per crushed	**ASTM D4791**	**96.5**	**97.5**	**-**	**-**

B. Sieve Analysis of mineral filler

In this test, a weight of 500 gm of filler is washed on sieve No. 200 then dried. The sample is running through smaller sieves numbers 8(2.36mm), 16(1.64mm), 30(0.6mm), 50(0.3mm), 100(0.15mm), and 200(0.075mm), respectively. Gradation is similarly estimated as percentages of the material passing each sieve on the basis of total sample weight.

2.2.2.1.2. Resistance to abrasion by use of Los Angeles machine

This test is a measure of degradation of mineral aggregates of standard grindings resulting from a combination of actions implying abrasion, impact, and grinding in a rotating steel drum which contain a specified number of steel spheres, and the number which depends upon the grading of the test sample.

Then the contents roll within the drum with an abrading and grinding action until the shelf plate picks up the sample and the steel spheres, and consequently cycle is repeated.

After the prescribed number of revolutions (100 and 500), the contents are removed from the drum and the aggregate portion is sieved to measure the degradation as percent loss. The abrasion resistance is expressed as the loss (difference between the original mass and the final mass of the test sample) as a percentage of the original mass of the test sample. The loss percentage can be given by:

$$A = (B - C) / B \quad (2)$$

Where

A: The loss percentage

B: total weight (g) of sample

C: Weight of the pass(g) from No. 170 mm sieve

Table (3): Gradation of solid material used

TYPE / Sieve size inches (mm)	Coarse aggregate Size (2)	Coarse Aggregate Size 1	Crushed sand	Filler	Cement Filler
	Silicious lime stone	Silicious lime stone	Fine Silicious lime stone	Limestone	
1" (25.4)	100	100	100	100	100
3/4" (19)	85.5	100	100	100	100
1/2" (12.7)	21.9	100	100	100	100
3/8" (9.5)	4.8	81.9	100	100	100
No.4 (4.76)	1.3	11.1	100	100	100
No.8 (2.38)		0.6	86.2	100	100
No.30 (0.59)		0.3	48.3	100	100
No.50 (0.297)		0.2	33.3	100	100
No.100 (0.149)		0.2	31	99.7	99.9
No.200(0.075)		0.2	7.7	94.9	96.7

2.2.2.1.3. Bulk specific gravity and absorption of solid aggregate

A. Bulk specific gravity and absorption of coarse aggregate

In this test, a sample of aggregate is immersed in water for approximately 24h to essentially fill the pores. Then, it is removed from the water, dried and weighed. Subsequently, the sample is weighed while submerged in water. Finally the sample is oven dried and weighed. Using the mass and weight measurements, it is possible to calculate three types of specific gravity and absorption. Bulk specific gravity is the characteristic generally used for evaluating the volume occupied by the aggregate in various mixtures containing aggregate. Bulk specific gravity (Saturated Surface Dry) (SSD) is used if the aggregate is wet, that is, if its absorption has been satisfied. Conversely, the bulk specific gravity (oven –dry) is used for computations on drying the aggregate or assumed to be dry. Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles not including the pore space within the particles which is accessible to water. Absorption values are used to calculate the change in the mass of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition, when it is deemed that the aggregate was in contact with water long enough to satisfy most of the absorption potential .

- Bulk specific gravity = $A / (B - C)$ (3)
- Bulk specific gravity (SSD) = $B / (B - C)$ (4)
- Apparent specific gravity = $A / (A - C)$ (5)
- Absorption percent = $\{(B - A) / A\} \times 100$ **(6)**

Where

A: Weight (g) of oven dry specimen in air

B: Weight (g) of saturated- surface dry specimen in air

C: Weight (g) of saturated specimen in water

B. Bulk specific gravity and absorption of fine aggregate

This test is used for the same purpose as that used for coarse aggregate except that using a pycnometer and the corresponding terms are calculated as follows:

- Bulk specific gravity = $A / (B + S - C)$.(7)
- Bulk specific gravity (saturated surface dry basis) = $S/(B+S-C)$ (8)
- Apparent specific gravity = $A / (B + A - C)$.(9)
- Absorption, percent = $\{(S - A) / A\} \times 100$ **(10)**

Where

A : Weight (g) of oven dry specimen in air.

B : Weight (g) of a pycnometer filled with water.

C : Weight (g) of a pycnometr with sample and filled up to the calibration.

S: Weight (g) of saturated surface-dry specimen.

2.2.2.1.4. Liquid limit of soils

The liquid limit of a soil is the water content at which the soil passes from a plastic to liquid state. Here, the sample weighing about 100 g taken from the thoroughly mixed portion of the material passing the sieve No. 40 (0.425mm) is placed in the mixing dish and thoroughly mixed with 15 to 20 ml of distilled or demineralized water by alternately or repeatedly stirring, kneading and chopping with a spatula. Further water additions should be done in increments of 1 to 3 ml.

Each increment of water is thoroughly mixed with soil. Just testing is commenced in the test device, no additional dry soil should be added to the moistened soil.

The sample is squeezed and spread with spatula to level and at the same time trimmed to a depth of 10 mm at the point of maximum thickness. After testing in the device, the sample is oven dried to a constant weight at 110± 5 ºC and weighed.

The water content of the soil is expressed as the moisture content in percentage of the weight of the oven dried soil and can be obtained by:

%moisture = (mass of water / mass of oven dried soil) x100 ……..(11)

2.2.2.1.5. Plastic limit and plasticity index of soil

The plastic limit of the soil is the lowest water content determined at which the soil remains plastic .The plasticity index of the soil is the water content range expressed as a percentage of the mass of the oven – dried soil within the sample in a plastic state . In this test, a sample weighing about 20 g from the thoroughly wet and mixed portion of sample passing the No. 4 sieve (0.425mm). The air dried soil is placed in a mixing dish and thoroughly mixed with distilled or demineralized water until the mass becomes plastic to be easily shaped into a ball. A mass weighing about 8 g is taken from the sample. A thread of the sample is formed, rolled to about 3.2 mm diameter and break into six or eight pieces. The sample is reformed and rerolled many times until the thread crumbles no longer be rolled into thread. The sample is oven dried at 110 ± 5 ºC until constant weight and weighed. The plastic limit is calculated as follows

Plastic limit = (mass of water /mass of oven dry soil) x100 ……(12)

2.2.4. Preparation of PMAs using WEVA [27]

In-situ polymerization of virgin asphalt and three levels of WEVA (2, 4 and 6 % by weight of asphalt) were prepared in suitable cans. Then a high shear mixer was dipped into the can and set to 3000 rpm. The polymer was added gradually (5 g/min). Temperature was kept within 180 ºC during the polymer addition and subsequent mixing. Then, stirring was performed for 2 h after complete addition of polymer, initiator and cross-linking agent with fixed amount 2 ml into asphalt [28]. Below high temperature, partial carbon–carbon double bonds of WEVA molecules were opened to form free radicals. Moreover, asphaltene molecule, or micelle contains more than one carboxylic group. So; a chemical network theoretically will form. Unfortunately, it is difficult to detect the real nature of chemical bonds formed during cross-linking due to the extremely complex chemical nature and composition of asphalt. Fig. (1) illustrates a schematic reaction of in-situ polymerization of WEVA and asphalt.

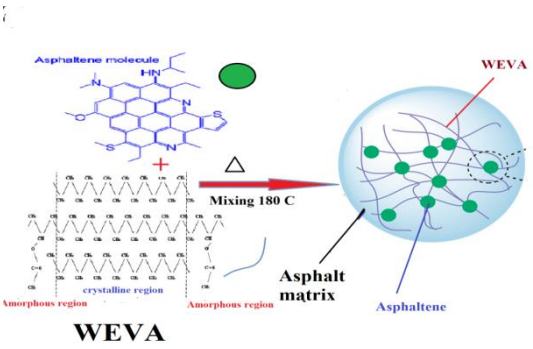


Fig. (1): Sschematic reaction of WEVA and asphaltene into asphalt matrix.

2.2.4. Preparation of hot mix asphalt and properties

Hot mix asphalt samples were prepared using virgin asphalt and modified binders and were evaluated using the Marshall test method (ASTM D-6927).

The mixes were designed according to the standard limits of surface (wearing) course 4C. The job mix was formulated (%wt.) as cited in (Table 4) using coarse and fine aggregates, sand and filler as 33, 30, 32 and 5 wt.%, respectively. The mixes were tested for maximum load and flow. Density and air voids in mixes and solid materials were evaluated.

In this test, the necessary steps implemented for the design of hot mix asphalt concrete may be outlined as follows:

a- Number of specimens prepared. The used percents of asphalt by weight of aggregate are 4, 5, 6, and 7. Three samples of each percent were prepared to take the mean value of the test.

b- Preparation of aggregates; aggregates are dried to constant weight at (110 ±5) ºC and are separated by dry sieving into the desired mesh size. The temperature of mixing aggregate and asphalt are in the range of 155 ºC to 175 ºC.

c- Preparation of mold for compaction hammer test (for each test specimen), the amount of each size fraction required to produce a batch which will result in a compacted specimen (2.5±0.05 inches in highest) is weighed. This will normally be about

1100gm. The pan is placed in the oven and heated to a temperature more than the mixing temperature by nearly 10ºC . The required amount of asphalt cement (previously heated to the mixing temperature) is weighed. The aggregate and asphalt cement is then mixed.

d- The specimens are compacted in the mold and 75 blows are applied to each side with special compaction hammer weighing 4.5 Kg (10 Ibs), which are filled from distance 18" (inch), then they are removed and allowed to cool over night.

e- The Marshall stability testing head was used to test the specimens, and a Marshall flow meter was used for determining the amount of strain at the maximum load for the test. The stability, flow, specific gravity and void analysis were carried out for each series of test specimens.

f- Asphalt content can be determined which is the average content of asphalt at the maximum of both stability; unit weight and the mean of limits is from 3 to 5 % of air voids in mix.

Table (4): Job mix formula of the hot asphalt mix.

Sieve Size, inch (mm)	Size (2)		Size (1)		(Crushed sand)		Waste Cement powder		JMF(*)	Standard gradation (4C)	
	Passing(%wt)		Passing(%wt)		Passing (%wt)		Passing(%wt)			Min	Max
1" (25.4)	100	24	100	26	100	45	100	5	100	100	100
3/4"(19)	92.9	22.3	100	26	100	45	100	5	98.3	80	100
3/8"(9.5)	8.1	1.9	68.9	17.9	100	45	100	5	69.8	60	80
NO.4(4.75)	2.0	0.6	11.0	2.9	100	45	100	5	53.5	48	65
NO.8(2.36)			2.1	0.5	70.1	31.5	100	5	37.0	35	50
NO. 30(0.6)					51.7	23.3	100	5	28.3	19	30
NO. 50(0.3)					30.9	13.9	100	5	18.9	13	23
NO. 100(0.15)					8.7	3.9	95	4.8	8.7	7	15
NO. 200(0.075)					5.9	2.7	80	4.0	6.7	2	8

N.B: (*) Job Mix Formula

2.2.5. Characterization and evaluation of PMAs samples prepared.

2.2.5.1. Physical characteristics.

Physical characteristics for PMAs are listed in Table (5).

2.2.5.2. TGA analyses.

Thermal gravimetric analysis (TGA) can be illustrated in Fig. (2) and which was carried out using SDTQ 600 thermo gravimetric analyzer (TA-USA) to test the thermal stability of the virgin asphalt sample at 25–800 ºC with a heating rate of 10 ºC/min under dynamic nitrogen gas.

2.2.5.3. SEM photographs.

The SEM photographs of asphalt virgin and its modified blends were determined using scanning electron microscopy (SEM; Philips) as shown in Fig. (3).

2.2.5.4. FTIR

Infrared spectra of the investigated virgin asphalt and its modified blends (containing 5 wt % waste polymers) were recorded via FTIR spectrophotometer (Model 960 Mooog, ATI Mattson Infinity Series, USA). The spectra of all the studied samples were measured in the range of 4000 – 400 cm^{-1} by summing 32 scans at 4 cm^{-1} resolution and 32 background scans.

2.2.5.5. Rheology test.

The Brookfield DV-III Ultra Programmable Rheometer was used to measure fluid parameters as shear stress and viscosity at given shear rates and temperature.

The operation principle of the DV-III Ultra is to drive a spindle (which is immersed in the test fluid) through a calibrated spring. The viscous drag of the fluid against the spindle is measured by the spring deflection which is measured by means of a rotary transducer. The rheology test was run at 60 ºC and 130 ºC.

3. Results and Discussion

3.1. Physical properties of Virgin and modified asphalt samples.

Table (5) shows the physical characteristics of virgin and polymer modified asphalt samples. Comparing to the virgin asphalt sample, the characteristics of PMA are seem to be completely different as illustrated in the following.

- The penetration values decreased from 64 to 57, 53 & 44 in case of using WEVA in content of 2%, 4% and 6%. The percent decrease is 10.9, 17.2 and 31.2 respectively.

-Softening point values increased from 50 for virgin asphalt to 59 ,64&67 at different contents of 2% ,4% ,6% of WEVA in percentages of 18 , 28 and 34 respectively.
-Specific gravity value of virgin asphalt increased from 1.02 to 1.06 ,1.13 and 1.17 for PMA samples in case of using WEVA in percentages of 3.9 , 10.7 and 14.7 respectively.
- The kinematics viscosity value is obviously increased from 335 c St for virgin asphalt to 1800 ,2100 ,2150 c St at contents of 2,4&6% of WEVA in percentages of 437.3 , 528.7and 543.7respectively.
- The P.I value increased from - 0.40 for virgin asphalt sample to 0.999, 1.695and 1.856 for PMA samples using contents of 2, 4 and 6% of WEVA. The percentages of increase are 349.75, 523.7 and 564 respectively.
- From all the previous results it is obvious that, polymer modified asphalt samples using WEVA are more hardening and has less temperature susceptibility than that using SBR. This due to the chemical constituents and WEVA polymer composed of aliphatic chains which are easily embedded into oil phase so, the cross liking contents increased and a network is formed.
It is obvious that the modified samples are harder than the virgin one as seen in Table (5). An increase was depicted in softening point, specific gravity and kinematic viscosities whereas a decrease in penetration value was observed. Moreover, a penetration index increased with the addition revealing an increase in the waste EVA from 2 wt. % to 6 wt. %. As a result of asphalt modification, both of its cohesion and elasticity are enhanced. At higher service temperatures, the stiffness modulus of the polymer phase was found to be higher than that of matrix [28].

These reinforcing properties of the polymer phase contribute to the viscosity increase. On the other side, the stiffness modulus of the dispersed phase was observed to be lowered than that of the matrix at lower temperatures and which minimized its brittleness. Consequently, the dispersed polymer phase enhanced the engineering properties of asphalt in terms of viscosity, softening point and toughness.

Generally, the modified samples are more harder than the virgin one as cited in Tables(1 & 2). There was an increase in softening point, specific gravity and dynamic viscosities and a decrease in penetration value with an additive increase in the waste polymer content 2 wt.%, 4 wt.% and 6 wt.%. This is related to the increase of asphaltenes content and the decrease of aromatic and resin contents with the addition of waste polymers to the virgin asphalt sample and with raising the polymer content. Also, data reveal that the saturate and consequently n-paraffin contents are slightly increased with the addition of waste EVA modifier to the virgin asphalt sample, while, they clearly decrease with the addition of waste EVA modifier. This is attributed to the nature and accordingly the chemical molecular composition of the waste polymer used. As a result of asphalt modification, its cohesion and elasticity are both enhanced. At higher service temperatures, the stiffness modulus of the polymer phase is higher than that of matrix. These reinforcing properties of the polymer phase contribute to the increase in viscosity. At low temperatures, the stiffness modulus of the dispersed phase is lowered than that of the matrix, which reduces its brittleness. Consequently, the dispersed polymer phase enhances the engineering properties of asphalt in terms of viscosity, softening point and toughness [29].

Table (5): Physical properties of Virgin and 2%, 4% and 6% EVA modified asphalt.

Characteristics	Virgin asphalt (AC)	Modified asphalt binder using Asphalt+ EVA		
		2%+ EVA	4%+ EVA	6%+ EVA
- Penetration (at 25 ºC, 100 g, 5s) 0.1mm	64	57	53	44
- Softening point (ring and ball) ºC	50	59	64	67
- Specific gravity (at 25 ºC)	1.02	1.06	1.13	1.17
- kinematic viscosity (at 135 ºC) c St	335	1800	2100	2150
- penetration index (P.I)	-.40	0.999	1.695	1.856
-Flash point	300	380	500	576
-Heating point	445	536	600	690

Table (6): Molecular type composition of modified asphalt 60/70 (AC).

Molecular type composition	**Virgin asphalt AC_1**	**Modified asphalt AC_1 with**
Saturate content, wt.%	**10.59**	**10.61**
∗*n*-Paraffin content, wt.%	**1.63**	**2.55**
∗Iso- & cyclo-paraffin content, wt.%	**9.3**	**7.5**
Aromatic content, wt.%	**35.1**	**38**
Resin content, wt.%	**33**	**24.6**
Aromatics & resin content, wt.%	**65.5**	**61.3**

3.2. TGA analyses

Undoubtedly, the addition of waste EVA to asphalt produced PMA samples that have lower decomposition percentages comparing with waste polymers themselves as illustrated in Fig.(2). For example, the use of WEVA led to a decrease in the decomposition percentages from 100% to 85% due to an increase in asphaltene content for PMA as compared with virgin one [29]. The virgin and PMA samples have nearly the same thermal stability.

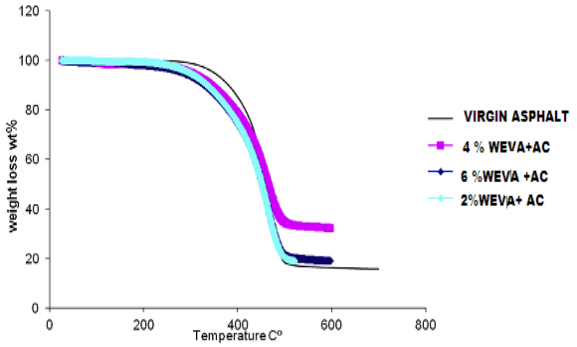


Fig. (2): TGA curves of AC virgin and 2%, 4% and 6%Waste EVA modified asphalt.

3.3. SEM photographs.

In SEM photos of the virgin and polymer modified blends, the light phase in the picture represented polymer spheres swollen by asphalt compatible fractions
(e.g., aromatic oils) are spread (dispersed phase) homogeneously in a continuous asphalt phase. Polymer particles extensively spreading on PMA's surface led to a decrease in engineering features such as toughness and tenacity. This may be attributed to differences in molecular weight, polarity and structure of the used polymers. A chemical dissimilarity exists between asphalt and polymer and as a consequence the swollen polymer and the dark phase is the asphalt. The morphology of PMA samples is the result of the mutual interaction of polymer and asphalt, and, consequently, is influenced by asphalt composition and polymer nature and content. There is a good compatibility between asphalt and waste polymers. As shown in Fig.(3),SEM analysis revealed that addition of 4% content of both WEVA copolymers produced the most compatible mix of asphalt and each polymer separately [30].

3.4. FTIR analysis

An FTIR spectrum of AC sample is represented in Fig. (4) On the wave number scale (4000-400 cm^{-1}) and the major bands were derived as follows:
- The vibration of carbon dioxide, O=C=O, band appears at about 2316 cm^{-1}.

C-H aliphatic single bonds appear at around 2800 - 3000 cm^{-1}.
- The non-aromatic C=C double bonds appear in the 900-1000 cm^{-1} region.
- The carbonyl group C=O double bonds appear in the region of 1650-1800 cm^{-1} with specific bands for acids (1650 - 1700 cm^{-1}), esters (1740-1750 cm^{-1}), aldehyde and ketones (1720- 1750) cm^{-1}. Also, aromatic rings show breathing vibrations centered at around 1600 cm^{-1}. The major bands in the parent AC asphalt sample were identified as typical hydrocarbon absorbencies at 2951 and 2889 cm^{-1}.

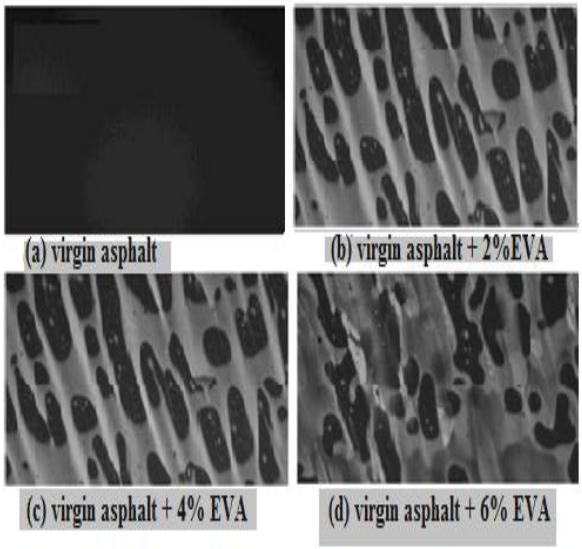


Fig. (3): SEM photo of AC virgin and 2%, 4% and 6%Waste EVA modified asphalt

Additionally, weaker bands were noticed at 1456 and 1300 cm^{-1} for CH_2 and CH_3 while a peak band at 3400 to 3700 cm^{-1} is assigned for the presence of alcohols. Acid halide appeared in the region of 500 to 760 cm^{-1}. Besides, a sharp absorption peak at 720 cm^{-1} confirms the presence of chloroalkane. The appearance of band at 3170 cm^{-1} confirms the presence of CH aromatic group causing the hardness of asphalt sample. Lastly, AC has absorption band at 1621 cm^{-1} for C=C-C assigned for stretching in aromatic olefins.

As illustrated in Fig. (4), FTIR spectra of (a) WEVA (b) Virgin asphalt (c) WEVA modifier asphalt (at content 4% WEVA) where new groups are detected as follows :

- Band at 1021.13 cm^{-1} for C-O-C
- Band at 720 cm^{-1} shows (-CH2-) is attributed to ethylene group which found in WEVA.
- Band at 1738.22 cm^{-1} for C-O of ester.

- These groups may appear due to the chemical interaction of asphalt and C=O group at WEVA structure.

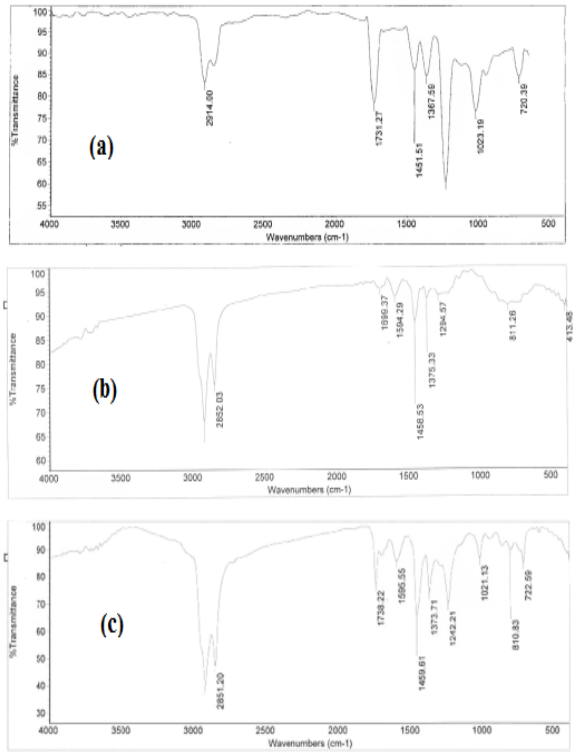


Fig. (4): FTIR spectra of (a) WEVA (b) Virgin asphalt (c) WEVA modified asphalt

3.5. Rheology test.

A. Viscosity and Temperature

Herein, the effect of temperature variation for which the coating is detected may be exposed to the viscosity for all samples. This test at developing the temperature–viscosity charts. As indicated in Fig.(5), the viscosity values were observed to decrease as the test temperature increased regardless of the polymer·s type and content. The blend viscosity raised as the polymer content increased at the desired temperatures from 60 to 150°C, and this increase was depicted in both viscous and elastic moduli. Comparably to virgin sample, the percent increase in viscosity at 60°C was 213, 360 and 371% on using the waste EVA at content levels 2, 4& 6% , respectively . At higher temperatures, the viscosity also increased in less percentage than that reported at lower temperatures. At 130°C, the viscosity value increased in percentages of 4.7, 105 and 158.5% & 4, 33.7, 97.6% , respectively for the same addition level on using EVA. This reveald that the added polymer reacted with virgin asphalt and formed cross-linkage between asphalt and it is polymer forming a chemical network causing the formed PMAs to be more rigid and difficult to flow**.** However, the percent increase in viscosity value on the use of EVA as an asphalt modifier which may arise from the presence of the cross-linkage with waste PEVA monomer. Hence, the formed network is much tougher and harder and therefore the viscosity slightly increased in percent. In fact the flow behavior (rheological properties) is achieved by the change in physical properties of the prepared samples.

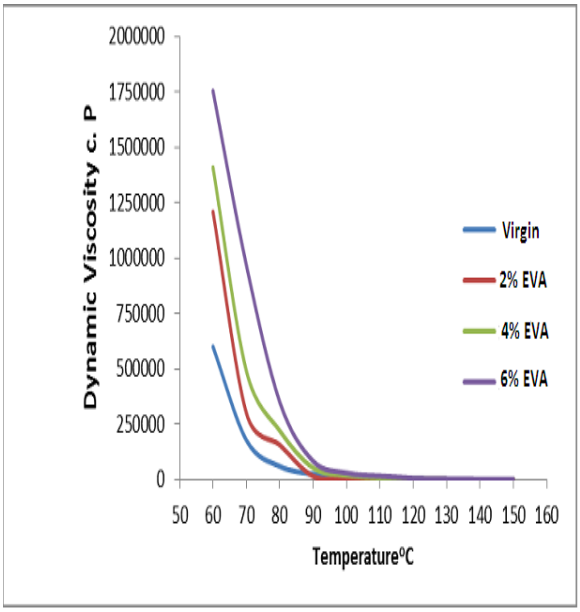


Figure (5): Dynamic viscosity with temperature of PMA using EVA Waste.

B. Shear Rate and shear stress

The shear rate- shear stress of asphalt and its modified samples is detected at
60 **º**C and 130 ºC as follows:

As seen in Fig.(6), the virgin asphalt and PMAs samples do not undergo strain rates proportional to the applied shear stress reveal that all the samples undergo non- Newtonian matters. Besides, the viscosity of such fluids will therefore alter as the shear rate is varied. Thus, the experimental parameters of viscometer model, spindle and speed affect the measured viscosity of the non-Newtonian fluid.

Non-Newtonian flow can be envisioned as a mixture of molecules with different shapes and sizes. As they pass during the flow, their size, shape, and cohesiveness will estimate how much force is required to move them. At each specific rate of shear, the alignment may be different as well as more or less force may be necessary to maintain motion. On the other hand, there are several types of non-Newtonian flow behavior, characterized by the way of fluid's viscosity changes in response to variations in shear rate.

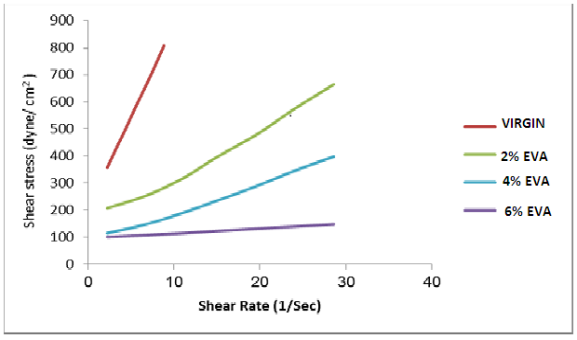


Figure (6): Shear stress- shear rate curves of PMA using EVA at 60°C.

3.6. Job Mix Formula of solid materials.

Based on the standard gradation of the selected surface course (4C) and on the gradation of the solid materials, the design gradation of the paving mix is depicted in Table (5) while the gradation curves can be illustrated in Fig. (7).

The percentages of solid materials in the mix are; aggregates of size (2) as 24% (by wt), aggregates of size (1) as 26% (by wt), and crushed sand as 45% (by weight), and waste cement powder as 5% (by wt).

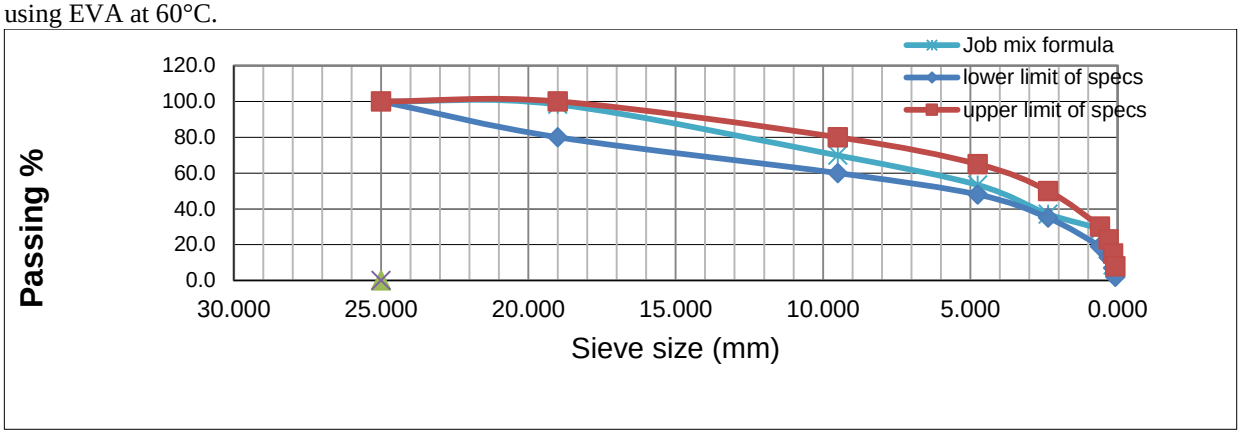


Fig. (7): Job Mix Formula of solid materials

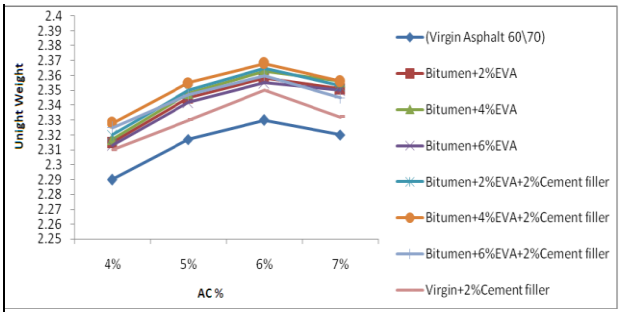
3.7. Characteristics of prepared asphalt paving mixes

All the prepared mixes were found to comply with the standard specification of HMA for surface course in roads having high traffic volume as reported in Table (7) and indicated in Figs. (8(A- E) & 9). For optimum asphalt content on using the waste cement powder with virgin asphalt (optimum asphalt content decreased from 5.7 to 5.5 in percentages 3.5 %.) whereas on the use of waste EVA in percentages 2, 4,6% decrease from 5.7 to 5.4,5.5, 5.6 in percentage s 5.3 %, 3.5%, 1.7 %.

Lastly, in case of using 2, 4, 6% waste EVA +2% waste cement powder decrease from 5.7 to 5.3, 5.5, and 5.6% in percentages 7, 3.5, 1.7 %.

Table (7): characteristics of prepared HMA

Characteristics	Virgin asphalt Mix(1)	Virgin asphalt +2%Cement filler Mix(2)	Using modified asphalt with					
			Bitumen +EVA			Bitumen +%EVA+2%cement Dust		
			2%	4%	6%	2%	4%	6%
-Optimum asphalt content%	5.7	5.5	5.4	5.5	5.6	5.3	5.5	5.6
Stability of the mix -asphalt(N)	1190	1450	1700	2500	2450	1860	2600	2400
-Unit weight of the mix(g/cm3)	2.336	2.343	2.355	2.362	2.355	2.355	2.358	2.359
-Flow of the mix (mm)	3.2	3.4	3.6	4.0	4.4	3.8	4.2	4.6
-Air voids in the mix (%)	3.2	2.5	3.0	3.1	3.1	3.0	2.8	3.1
-Air voids in solid materials,%	15.3	14.7	14.0	13.8	14.1	14.2	13.9	14.1
Voids in mineral aggregate (VMA)	79	83	78.6	77.5	78	78.9	79.8	78
-Marshall stiffness, (N/mm)	425	467	524	568	560	538	550	536



(A): Marshall Curves of Unit Weigh

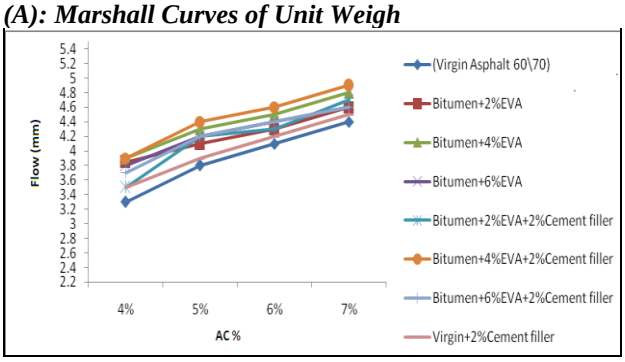
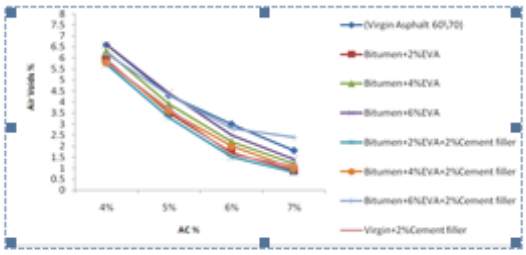


Fig (B): Marshall curves of Flow t



Fig(C): Marshall Curves of Air Voids

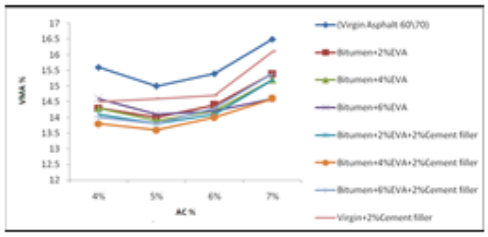


Fig (D): Marshall curves of VMA

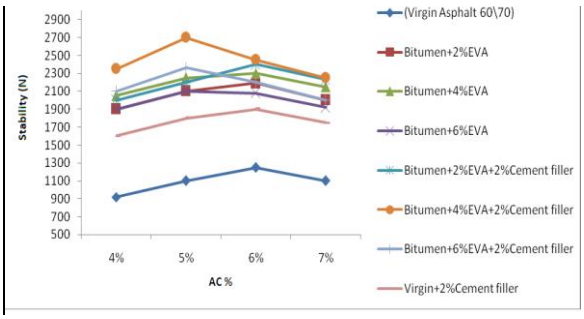


Fig (E): Marshall curves of Stability (N)

Fig (8): Marshall curves of HMAs

Stability and Marshall Stiffness on using waste cement powder with virgin asphalt stability and Marshall Stiffness increase from 1190 to 1450 N in percentages 22 %.

In case of using waste EVA in percentages 2, 4, 6%, stability increased from 1190 to 1700, 2500 and 2450 N at 40 %, 101% and 105 % and also stiffness increased. In case of using 2, 4, 6% waste EVA +2% waste cement powder, stability increased from 1190 to 1860, 2600 and 2400N at 55, 102, 100 %.

An increase in stability can be characterized as an improvement in the adhesion among aggregate and bitumen. Stability of conventional bituminous mix increases by increasing the percent of EVA up to 4%. After this, stability decreases on further addition of EVA whereas the increase in Marshall Stability enhances the rutting resistance [31-34].

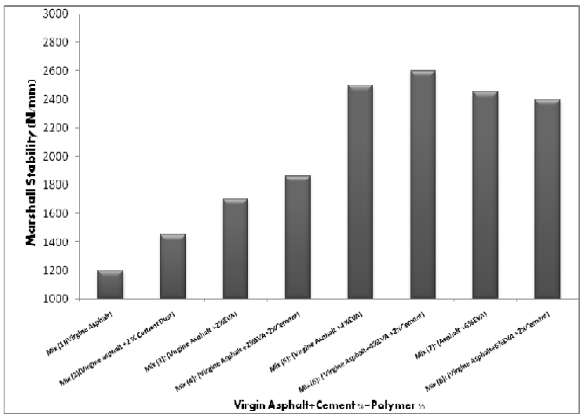


Fig (9) : Effect of polymer type and content on the stability of the prepared mixes.

For unit weight of the mix (g/cm^3) on using waste cement powder with virgin, unit weight of
The mix increased from 2.336 to 2.343 (g/cm^3) in percentage of 0.30%. On the other side, when the waste EVA was used in percentages 2, 4,6%, the unit weight exceeded 2.336 to 2.355,2.362 and 2.355 g/cm^3 at 0.8 %, 1.1%, 0.8 %, respectively. Besides, on using 2, 4, 6% waste EVA +2% waste cement powder, the stability raised from 2.336 to 2.355, 2.358 and 2.359 g/cm^3 in percentage of 0.815%, 0.94% and 9.8 %, respectively. The density increase reveals more compact packing and reduction in voids between the aggregates.

With respect to flow of the mix (mm), at the use of waste cement powder with virgin, flow increased from 3.2 to 3.4 (g/cm^3) in percentage of 6.2% whereas on utilizing waste EVA in percentages of 2, 4and 6%, the unit weight exceeded 3.2 to 3.6,4.0 and 4.4 g/cm^3 in percentages of 12.5 %, 25% and 37.5

% respectively. In spite of using 2, 4 and 6% waste EVA +2% waste, cement powder Flow raised also from 3.2 to 3.8, 4.2 and 4.6 g/cm^3 at 18.7%, 31.2% and 44 %, respectively.

On contrast, for air voids (AV) in the mix (%), the waste cement powder on utilizing with virgin, the flow decreased from 3.2 to 2.5 % at 22%. Also, on using the waste EVA in percentages of 2, 4 and 6%, AV % diminished from 3.2 to 3, 3.3 and 3.2 g/cm^3 at 6.2 %, 12.5% and 6.2 %, respectively.

Additionally, at the use of 2, 4 and 6% waste EVA + 2% waste, cement powder AV % reduced from 3.2 to 3, 2.8 and 3.1 g/cm^3 at 6.5%, 12.5% and 3.1 %, respectively. As indicated in Table (7), the addition of waste EVA led to increasing the stability, unit weight, flow and Marshall Stiffness while air voids decreased. In addition, the mineral constituents of cement powder strengthened the filler and accordingly HMA whereas limestone filler included weak constituents like gypsum.

Voids in mineral aggregate (VMA) represent the volume of intergranular void space between the aggregate particles of a compacted mixture, including the air voids and the volume of bitumen not absorbed into the aggregate as shown in Fig.8 (**D**). . 4% EVA shows lowest VMA at optimum binder content [35].

Voids filled with bitumen (VFA) graphs are shown in Table (8). From the graphs, it is obvious that the values of VFB for all mixes containing EVA are lower than those of the control mix (0% EVA), implying that the addition of EVA reduces VFB values.

As a consequence, the increased air voids in the mix which is caused by the viscosity increase of PMA samples as well as the solid aggregates led to decreasing the unit weight [36].

As a result of using the modified asphalt in mixes, preparation, the asphalt content decreased as compared with HMA on utilizing the modified asphalt and waste cement powder which may be attributed to the increase of asphalt viscosity reducing the quantity absorbed by the aggregate.

Lastly, on utilizing HMA with modified asphalt and waste cement powder, it was found to possess the hardest of modified mixes, as it has the highest stability and air voids in mix and solid aggregate as well as the lowest flow value which may arise from the toughness of waste EVA itself.

So, less than 4% of EVA+ waste cement powder may be recommended for the use in surface course. In addition, the use of HMA with modified asphalt and waste cement powder had the highest flow value in comparison with the unmodified mixes. This gave flexibility to the mix as reported in Table (7) which is considered one of the most important factors playing an important role in road paving due to the chemical nature of modifier. It is well known that by increasing the hot mix performance, it will cause an increase in the mix service life time and accordingly the maintenance cost will decrease**.**

5. Conclusion

The objective of our study is to use the waste EVA as one of the principal plastomers used in road construction to improve both the workability of the asphalt during construction and its deformation resistance in service at 2%, 4% and 6% (by weight) from binder with adding 2% waste cement powder in HMA. The suitability of improvement was verified via the estimation of physical properties implying (penetration test, softening point, flash point and viscosity test), SEM, TGA and rheological test for modified asphalt binder and for HMA using waste cement powder as filler instead of limestone filler.
Marshall Test was carried out and the experimental data revealed that:

- -Polymer modified asphalt which obtained by blending at 2%, 4% and 6% of waste EVA with virgin asphalt 60/70 to improve the physical properties which increased the softening point, viscosity and flash point while the penetration grade and penetration index decreased.
- EVA improved Marshall Characteristics increasing the stability and flow.
- 2% cement filler was added to EVA modified asphalt to improve Marshall Characteristics, increasing the stability and flow whereas the air voids diminished.
- Increasing the softening point and viscosity of waste EVA modified asphalt + 2% cement filler led to increase the temperature susceptibility while rutting, fatigue and oxidation reaction decreased.
- Using the waste EVA + 2% cement filler modified asphalt in Pavement Roads caused an increase service life time of asphalt Pavement Roads and consequently decreased the economy of Roads insurance.
- The optimum percent of polymer addition was selected to be 4% EVA + 2% cement filler.

6. Conflicts of interest

"There are no conflicts to declare".

7. Acknowledgments

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