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IMPROVING OF RECLAIMED ASPHALT PAVEMENTS USING STYRENE-BUTYL ACRYLATE POLYMER

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ABSTRACT
According to the most recent surveys, the European area produced 265 mil tons of asphalt for road applications in 2014, while the amount of available Reclaimed Asphalt Pavement (RAP) was more than 50 mil tons. The use of RAP in new blended mixes reduces the need of neat bitumen, making RAP recycling economically attractive. This study investigates the potential use of styrene-bacrylate polymer and extracted Reclaimed Asphalt Pavement (RAP) in Hot Mix Asphalt (HMA) with different percentages by the weight. In fact, the twofold purpose of this research is to improve the performance of asphalt pavement and mitigate the environmental impacts caused by waste tires and aged asphalt pavement. To achieve this aim, styrene-bacrylate polymer was used in different percentages by weight of extracting asphalt. In the present research, four different asphalt mixtures including modified of the extracted bitumen with 2, 4 and 6% of the polymer and control mix was modified by virgin bitumen. The modified binder was tested for physical characteristics, while the mix prepared were tested and evaluated using Marshall test methods. The research revealed that using 4% of styrene-bacrylate polymer producing hot mix asphalt (HMA) with higher stability compared to the control mix.

***Keywords**: Asphalt; Polymer; Stability; Reclaimed Asphalt Pavements*

I. INTRODUCTION

Recycling hot mix asphalt (HMA) results in a reusable mixture of aggregates and aged asphalt binder known as Reclaimed Asphalt Pavement (RAP) [1, 2]. RAP is the residue which is created when milling damaged pavements for maintenance and rehabilitation purposes. The use of reclaimed asphalt pavements (RAP) as a component of new hot asphalt mixes passes sustainable development polices and is environmentally friendly and compatible technology. Using the old asphalt bitumen in the newly blended mixtures and, therefore, reducing the required new bitumen content, makes the use of RAP in HMA mixtures economically attractive [3, 4]. It is considered that the most economical use of RAP is in the intermediate and surface layers of flexible pavements because the less expensive RAP binder can replace a portion of the more expensive virgin binder [5, 6]. A hundred percent of the reclaimed asphalt can be recycled [7] with different methods: hot recycling in asphalt plant, hot in-place recycling, cold in-place recycling and full depth reclamation are the most commonly applied techniques [8]. The performance of road surfaces can be improved by modifying bitumen [9]. One of the ways of maintaining the performance of asphalt pavements is by the use of polymers can significantly increase the resistance of asphalt mixture to permanent deformation, thermal fracture, fatigue cracking at low temperatures and they are also decease plastic flow and increase shear modulus at high temperatures [10]. Compatibility between polymer and bitumen should be high enough to avoid phase separation. Styrene Butyl Acrylate (Styrene Bacrylate) is one of polymers which is used to improve the properties of asphalt pavements. The present study is a part of a wider research on performances and durability of asphalt mixtures made with RAP [11]. The research is divided into three stages: in the first stage, the bitumen extracted from RAP and the solid materials evaluated. The second stage, styrene-bacrylate polymer added to the extracted bitumen for improving the bitumen characteristics [12]. Application of Marshall Stability forms the last stage of the experiment. Asphalt applied as Hot Mix Asphalt (HMA). Asphalt which conforms to Marshall properties are showing high resistance to stresses caused by high loads, high working temperatures and low temperatures due to weather conditions. HMA design using virgin asphalt as a control mix and hot mixes using the modified asphalt by polymer to investigate Marshall characteristics [13]. The effects of modifying extracted asphalt of RAP with styrene-bacrylate polymer physical properties have been widely investigated. The objective of the research is to comprehensively characterize RAP mixtures in terms of performances of asphalt mixtures and bitumens by observing Marshall characteristics out of mix designs [14]. In this study Marshall stability and flow obtained and air voids, voids in mineral aggregate, unit weight and voids filled with bitumen calculated and shown in the curves to define the optimum asphalt content and the best percentage added of polymer to the extracted bitumen [15]. HMA provides the best Marshall stability due to better to proper mixing of asphalt binders and aggregates. This paper investigates how different ratios of styrene bacrylate polymer enhance the properties of RAP.

1.1 Problem statement

Despite recent advancements in the design of asphalt mixtures containing Reclaimed Asphalt Pavement (RAP), it still in Egypt cautious in their regulations to avoid durability problems related to the recycling process. Modifications to the current specifications are needed to assure that satisfactory performance will result from the reuse of RAP mixes.

1.2 The objectives of the work

The main objective of this study is to investigate the best practice of reclaimed asphalt pavements (RAP) in Egypt. Also, improve the mechanical and physical characteristics and hence improving the quality asphalt paving, increase asphalt-paving age and reduce the cos. The objectives of this research are set as follows:

1. Determined the effect of using 100% RAP instead of using virgin aggregates and asphalt.
2. Investigate the effect of thermoplastic elastomers polymer as asphalt modified.
3. Investigate the optimum modified asphalt content to improve the asphalt mix properties

II. EXPERIMENTAL

Materials

Reclaimed Asphalt

The reclaimed asphalt pavement RAP used in this study was obtained from a highway pavement in Cairo – Alexandria road, by milling the thickness of the pavement corresponding to a single layer (surface course) in order to obtain a homogeneous material. After twenty years in service, the pavement presented fatigue cracking, and thus the RAP binder would be expected to be very hard after being exposed to such long term aging.

The coarse and fine aggregates from RAP were dolomite type. The gradation of Asphalt Concrete (AC) mixture complying with Dense – Graded 4D, a typical gradation used for binder asphalt course pavement in Egypt, gradation results and asphalt content are presented in Table 2. The nominal maximum size of aggregates is 19 mm.

Extracted Asphalt

The paving mixture is extracted with trichloroethylene, using the extraction equipment applicable to the particular method. The bitumen content is calculated by difference from the mass of the extracted aggregates, according to specification ASTM D 2172 – 11. The bitumen content calculated after evaporation of the solvent.

Styrene – Bacrylate Polymer

Aqueous polymer (or hybrid) latexes are attracting increasing research interest because they are environmentally friendly and have good mechanical strength and weather resistance and they have promising applications in high-performance coatings, adhesives, etc.

In the past few decades, Styrene–butyl acrylate have been studied extensively for a wide variety of applications, including improved mechanical properties, gas barrier performance, improved thermal properties, and flame

retardancy. Styrene–butyl acrylate have many specific properties such as good film-forming, gloss, transparency, and mechanical properties, and they have been widely used as coatings, paints, and adhesives. However, in some circumstance, poor water resistance and thermal resistance, and low pencil hardness greatly limit their application.
Thermoplastic elastomers are usually more effective than plastomers for bitumen modification. One of the most popular thermoplastic elastomers as bitumen modifiers is styrene – bacrylate polymer. Styrene-Bacrylate Polymer provided by Sigma-Aldrich Co. was used as an extracted asphalt modifier. The polymer is soluble in CHCl3, THF and toluene and has many specific features such as good film-forming, gloss, transparency, mechanical properties, and their corresponding products have been widely used as coatings, paints, and adhesives. The needle penetration, ductility and softening point were carried out to detect the properties of this modified asphalt binder according to the Egyptian Standard Specification. The test results are presented in Table 1.

The results from the modified extracted asphalt tests clearly indicate that the asphalt binder used in this study is acceptable when compared with the specification.

Surfactant
Surfactant (also called invertor or breaker) Surfactants are shorthand for the term "surface active agents" and can be added in small quantities to overcome the imbalance in surface energy of the substrate and the surface tension of the fluid. Surfactants provide an alternative solution. In addition to surfactants modifying the surface tension of the fluid, they also can control the hydrophilic or hydrophobic nature of the fluid to develop the balance required for adsorptive equilibrium. Nonylphenol Ethoxylate used as surfactant nonionic type and it is known as NP-9 Surfactant, chemically stable in the presence of dilute acids, bases and salts, produced by Sigma-Aldrich Co. was used as a surfactant with extracted asphalt before mixing with polymer.

Testing Program

Preparation of modified asphalt
The calculated amount of extracted asphalt was heated to a temperature not more than 90ºC above its soft ening point. Surfactant NP_9 was added in percentage of 10% by weight of the extracted asphalt to improve the durability of the extracted bitumen. The polymer amount was added slowly at temperatures ranging between 160ºC – 180ºC in percentages of 2, 4 & 6 % by weight of extracted asphalt. Styrene-Bacrylate Polymer was mixed under high-speed mixer of500 rpm and stirring for 2 hours. The end point was determined visually. The virgin and polymer modified asphalt samples(PMAs) were characterized by conventional asphalt test saspenetration test (ASTMD5 – 06), softening point test (ASTMD36 – 06),specific gravity (ASTMD70 – 09), kinematic viscosity test (ASTMD2170 – 10).

Characteristics of solid materials
The solid materials were obtained after extraction of bitumen from RAP and tested for sieve analysis of fine and coarse aggregate (ASTMC136 – 14), resistance to abrasion using Los Angeles machine (ASTMC131 – 14) and bulk specific gravity of fine and coarse aggregates (ASTMC128 – 15 &127 – 15 respectively).

Preparation of HMA samples
In this step; the asphalt paving mixes were prepared using Marshall test method (ASTM D 6927 – 15 & AASHTO T245 – 97 (2008)) [16-17]. In this test, for each compacted sample of the asphalt paving mix, the stability and flow are measured while the unit weight and air voids are calculated to define the optimum asphalt content. In this step; hot mixes asphalt using of virgin and modified asphalt samples were prepared using the Marshall test procedure.

All the mixes were designed according to the Egyptian Specification limits for dense graded hot mix asphalt (Dense –Graded 4D) for binder course knowing that;

Mix (1): "control mix" it consisted of virgin asphalt sample AC added to RAP
Mix (2): it consisted of polymer modified extracted asphalt PMA using a content of 2% of Styrene-Bacrylate polymer added to RAP.

Mix (3): it consisted of polymer modified extracted asphalt PMA using a content of 4% of Styrene-Bacrylate polymer added to RAP.

Mix (4): it consisted of polymer modified extracted asphalt PMA using a content of 6% of Styrene-Bacrylate polymer added to RAP.

III. RESULT & DISCUSSION

Modification of asphalt

Table (1) illustrates that, modification of asphalt with styrene-bacrylate polymer produces a binder more hardener than the virgin sample as it has lower penetration and higher kinematic viscosity and softening point. This attributed to that this type of polymer produces a fine dispersion of the polymer in molten (solvating) phase with no disturbance of the bitumen structure as it is a thermoplastic and flexible polyolefin which does not contain any double bonds. Generally, the polymer creates a network to the asphalt molecule.

Evaluation of characteristics of HMAs prepared

In accordance with the Egyptian standard, the optimum asphalt content of the AC mixture was determined using the Marshall mix design methodology. Traditional Marshall compaction tests of HMA were carried out in the laboratory at 150 ^{0}C with 75 blows on each side of cylindrical samples.

The results show that the stability increases with the increasing asphalt content up to the optimum asphalt content and thereafter decreases. The increase in stability can be attributed to improved adhesion between the aggregate and bitumen. It can be seen from the results that the flow decreases with increasing polymer content. The slight decrease in flow value shows may be due to the quantity of the polymer used in the mixture. However, all mixtures met the Egyptian Specification for Road. Air void content, stability and other characteristics are illustrated in Table 4.

From Tables 2 – 4 and Figures 1 – 8 and comparing to control mix (1) the following results are detected;

- Optimum asphalt content decreased compared to control mix (0.03 % for 2% modified polymer, 0.053 for 4% modified polymer and 0.063 for 6% modified polymer)
- Stability increased by polymer modification from 1250 Kg to control mix to 1360 Kg for 4% polymer.
- Marshall Stiffness increased by using 4% polymer to achieve 116.24 Kg in comparing to102.46 Kg for control mix.
- Air voids slightly decreased from 4.8 % to 4.4 %

Indirect Tensile Strength increased from 9.2 Kg/cm^2 to control mix to 9.6 Kg/cm^2 for 4% polymer

Table 1. Characteristics ofAsphalt Used

Characteristics	Mix Number				Egyptian Standard Specification Limits for Binder Course
	Virgin AC	AC (2% S-BuA)	AC (4% S-BuA)	AC (6% S-BuA)	
Physical Properties:					
Penetration (@25 ^{0}C, 100g, 5s)0.1 mm	64	55	51	46	60/70
Kinematic Viscosity (@ 135 ^{0}C) cSt	347	350	520	810	>320
Softening Point (ring & ball) ^{0}C	46.5	48	51	55	45/55
Specific Gravity (@ 25/25) ^{0}C	1.02	1.061	1.094	1.12	NS(*)

NS (*): not specified

The table describe the physical properties for virgin asphalt and for modified extracted asphalt with different percentages of styrene – butyl acrylate polymer

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Table 2: The Average Gradation for (RAP) five Samples Lies within the Limits of the Egyptian Standard Specification (Dense –Graded -D)

Sieve Size	Gradation before extraction % Passing	Gradation after extraction % Passing	Limits of the binder mix Egyptian Standard Specification (Dense –Graded 4D),2008
37.5 mm (1½")	100	100	-------
25.0 mm (1")	100	100	80 – 100
19.1 mm (¾")	84.1	88.5	70 – 90
12.5mm (½")	76.4	80.3	-------
9.5mm (⅜")	68.4	72.1	55 – 75
4.75mm #4	54.3	59.7	45 – 62
2.36mm #8	39.2	43.8	35 – 50
0.6mm #30	19.5	24.6	19 – 30
0.3 mm #50	11.4	14.5	13 – 23
0.15mm #100	2.4	8.2	7 – 15
0.075mm #200	0.45	3.3	0 – 8
Bitumen content %	3.88%		3.5 – 7.0

The table above illustrating the limits of the binder mix Egyptian Standard Specification (Dense –Graded 4D) and the test results of extraction and gradation of coarse and fine materials before and after asphalt extraction

Table 3: Aggregate Physical Properties

Property	AASHTO Test Method	Coarse Aggregate		Fine Aggregate	Mineral Filler	AASHTO Specification
		Agg. (1)	Agg. (2)			
Los Angeles Abrasion Test (Loss wt. %)	T 96 – 83	19.2	18.4	-----	------	Max. 40 %
Bulk specific gravity G_{sb}	T 85 – 85	2.50	2.478	2.65	2.701	------
Apparent specific gravity	T 85 – 85	2.62	2.615	------	------	------
Specific gravitySSD	T 85 – 85	2.684	2.679	------	------	------
Water absorption (Wt. %)	T 85 – 85	1.16	1.17	------	------	Max. 5 %
Stripping Test	T 85 – 85	>95 %	>95 %	------	------	>95 %

Table 3 clearing the physical properties of coarse and fine aggregates after extraction process according to American Association of State Highway and Transportation Officials (AASHTO)

Table 4: Marshall Characteristics of the Asphalt Mixes Prepared

Characteristics	Mix Number				Egyptian Standard Specification Limits for Binder Course
	Control Mix (1)	(2% S-BuA) (2)	(4% S-BuA) (3)	(6% S-BuA) (4)	
Optimum Asphalt Content Before Extraction (%)		3.88			
Optimum Asphalt Content (%)	5.503	5.473	5.45	5.44	NS(*)
Stability of the mix (kg)	1250	1320	1360	1300	Min 700 Kg

Unit weight of the mix (gm/cm3)	2.308	2.310	2.312	2.309	NS(*)
Flow of the mix (0.01 inch)	12.2	12.4	11.7	11.5	8 – 16
Air voids of the mix (%) Va	4.8	4.55	4.5	4.4	3 – 8
Voids in Mineral Agg (%) VMA	15.25	15.2	15	15.03	Min 15 %
Voids Filled with Bitumen (%) VFB	68.52	69.74	69.0	68.86	60 – 70
Marshall stiffness Kg/in	102.46	106.45	116.24	113.04	NS(*)
Indirect Tensile Strength (kg/cm2)	9.2	9.4	9.6	9.5	Min 9.0 %
Modified Asphalt add to RAP (%)	1.62	1.59	1.57	1.56	NS(*)
Polymer Modified Asphalt %	0.0	0.032	0.063	0.094	NS(*)

NS (*): not specified

The table above shown the compression between control mix using virgin asphalt and three other modified extracted asphalt by styrene – butyl acrylate polymer for Marshall characteristics

II. COST INVESTIGATION

Cost is an important factor in terms of recyclability and reuse of material and can be an incentive to use such material. Overall, there is a critical need to understand the use of recycling of existing damaged asphalt pavement materials to produce new pavements with considerable savings in materials, energy and cost. In addition, aggregates and binders from old asphalt pavements are still valuable even though the damaged pavements have reached the end of their service lives. The construction industry will certainly recognize the economic benefits of using recycled materials, such as crushed RAP aggregates for base courses of the pavements.

As shown in the Table 5, to calculate reuse of 1 cubic meter of RAP it needs 37.5 kg of virgin asphalt and 230 ml of surfactant where using 4% modified asphalt you it needs 36.3 kg of virgin asphalt 1.45 Kg of styrene – butyl acrylate and 230 ml of surfactant

- The following table also shown the total cost for using 1 m^3 which is enough for paving a section with length 15.4 m, width 3m and thickness of 0.05 m.
- It was observed that, the cost when using 4% modified polymer is 29.31 of the total cost when using virgin HMA which saving 70.69% of the total cost
- The cost for producing 1 m3 virgin HMA is 1000 Egy pound, where the cost for reuse RAP modified with 4% polymer is 293.1 Egy pound.

Table 5: Required amounts of polymer and surfactant to reuse RAP

Characteristics	Mix Number			
	Control Mix (1)	(2% S-BuA) (2)	(4% S-BuA) (3)	(6% S-BuA) (4)
Optimum Asphalt Content (%)	5.503	5.473	5.45	5.44
Optimum Asphalt Content Before Extraction (%)	3.88			
Modified Asphalt add to RAP (%)	1.62	1.59	1.57	1.56
Polymer Modified Asphalt (%)	0.00	0.032	0.063	0.094
Surfactant (%)	10.0			
Required polymer, surfactant and asphalt calculation for reusing RAP				
	Control Mix	(2% S-BuA)	(4% S-BuA)	(6% S-BuA)

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	(1)	(2)	(3)	(4)
Volume m^3 ……………………….(1)	1	1	1	1
Unit weight of the mix (gm/cm^3)...(2)	2.308	2.31	2.312	2.309
Ton …….………………..(1)/(2)= (3)	2.308	2.310	2.312	2.309
Modified Asphalt add to RAP (Kg)	37.5	36.8	36.3	36.02
Styrene – butyl acrylate (kg)	0.0	0.74	1.45	2.16
Surfactant NP_9 (L)	0.23	0.23	0.23	0.23
Price of Styrene – butyl acrylate (Kg) /Egy. Pound	24			
Price of Surfactant (L) /Egy. Pound	18			
Price of Virgin Asphalt (Kg) /Egy. Pound	7			
Cost of Styrene – butyl acrylate for the mixture	0.0	17.66	34.85	51.87
Cost of Surfactant for the mixture	4.16	4.16	4.16	4.16
Cost of Virgin Asphalt for the mixture	262.21	257.59	254.09	252.14
Total Cost for using RAP for 1 m^3per Egy Pound	266.37	279.41	293.1	308.17
The Cost for using HMA for 1 m^3per Egy Pound	1000			
Total percentage cost of RAP	26.64 %	27.94 %	29.31 %	30.82 %
The saving percentage of using RAP	73.36 %	72.06 %	70.69 %	69.18 %

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Figure 1 Optimum Asphalt Content graph for all mixes

The stability increased for mixes (2%S-BuA) and (4%S-BuA) and then decreased for mix (6%S-BuA). The value increased from 1250 Kg to 1320 and 1360 Kg. and decreased to 1300 Kg. In percentages of 5.6%, 8.8% and 4% respectively

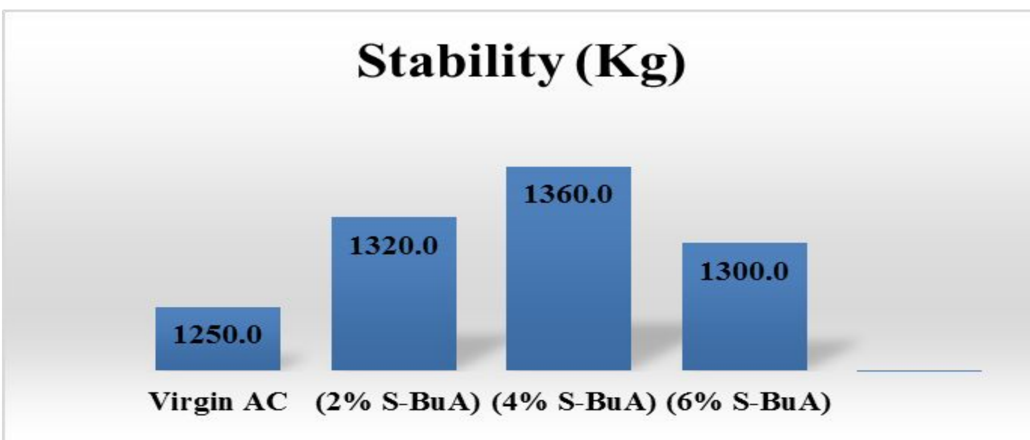

Figure 2 Stability graph for all mixes

The stability increased for mixes (2%S-BuA) and (4%S-BuA) and then decreased for mix (6%S-BuA). The value increased from 1250 Kg to 1320 and 1360 Kg. and decreased to 1300 Kg. In percentages of 5.6%, 8.8% and 4% respectively.

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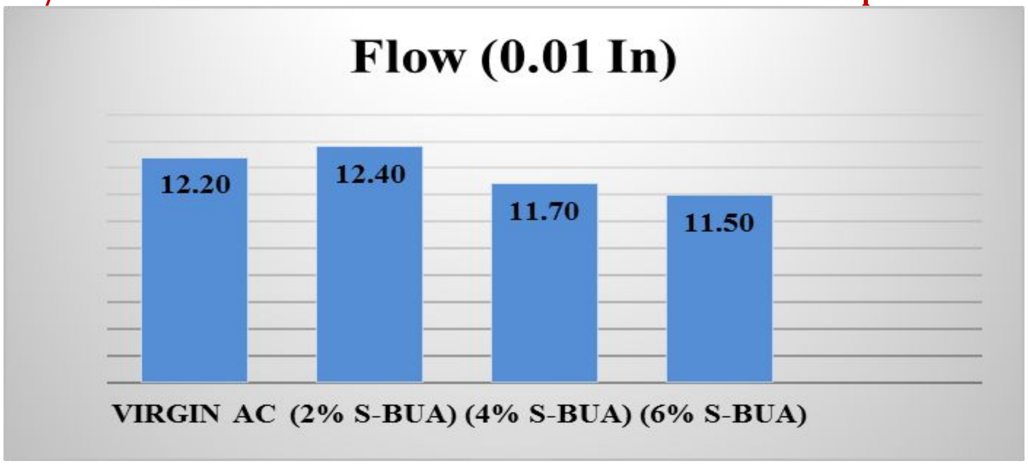

Figure 3 Flow graph for all mixes

The slight decrease in the flow value for mixes (2%S-BuA) and (4%S-BuA) in percentages of 4.09% and 5.73% respectively is due to the increase in stability values.

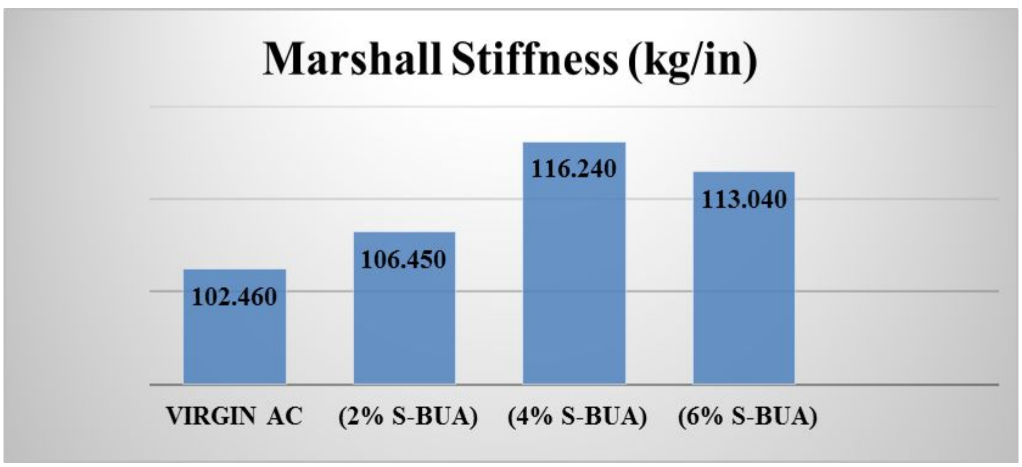

Figure 4 Marshall Stiffness graph for all mixes

Marshall Stiffness of the prepared mixes increased from 102.4 for control mix to 106.4, 116.2 and 113.04 for mixes no. 2, 3 and 4 in percentages of 3.9, 13.44 and 10.32 respectively. This is due to the increase of stability and decrease in flow values of asphalt mix using different percentages of polymer.

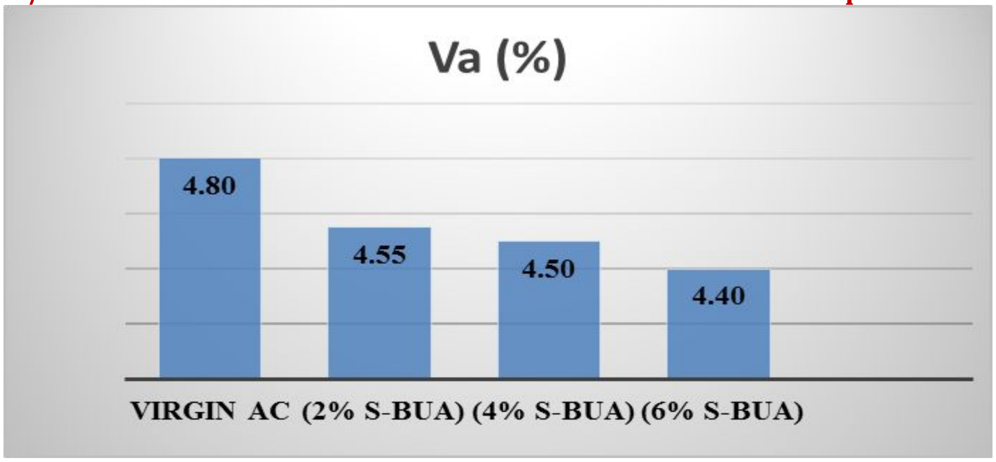

Figure 5 Air Voids graph for all mixes

The percent of air voids in mix for modified mixes have slight decreasing from 4.55 to 4.5 and 4.4 respectively.

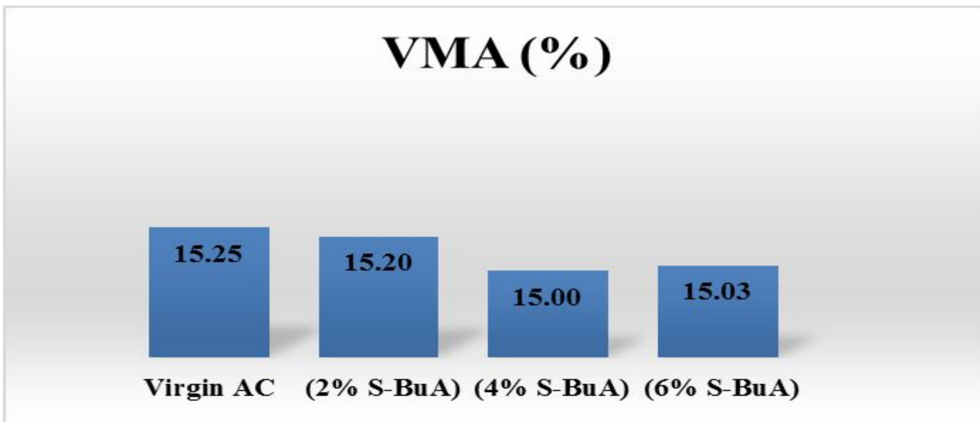

Figure 6 Voids in Mineral Aggregates graph for all mixes

The percent air voids in solid materials decreased for mix (2%S-BuA) and (4%S-BuA) from 15.2 to 15.0 and then increased for mix (6%S-BuA) to 15.03.

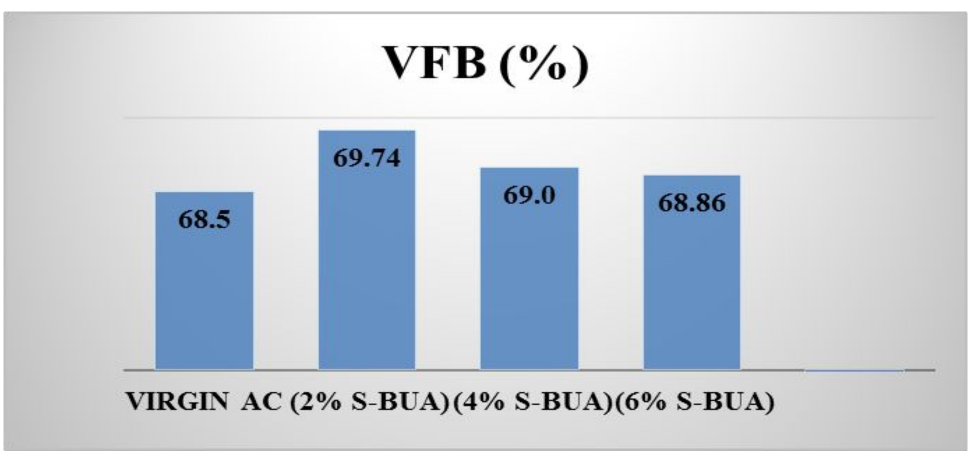

Figure 7 Voids Filled with Bitumen graph for all mixes

The percent voids filled with bitumen increased for all modified mixes comparing to control mix. It increased for mix (2%S-BuA) to 69.74 then decreased to 69.0 for mix (4%S-BuA) and 68.86 for mix (6%S-BuA)

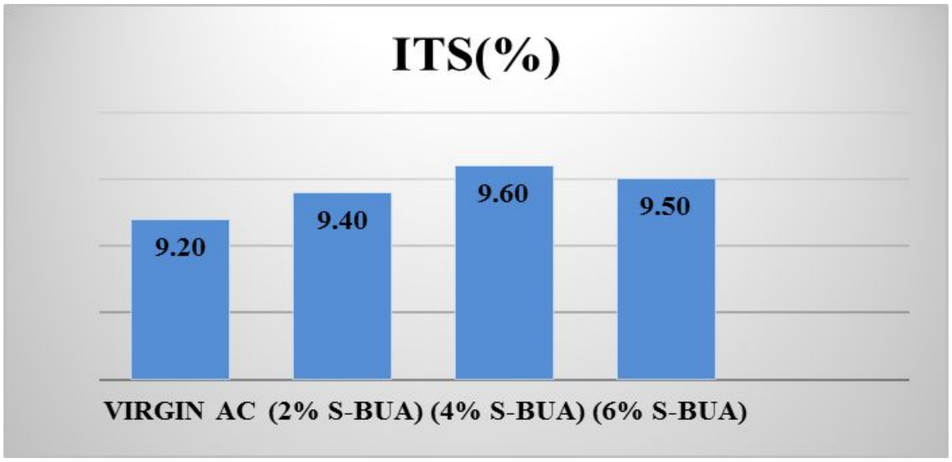

Figure 8 Indirect tensile strength graph for all mixes

Indirect tensile strength increased for (2%S-BuA) to be 9.4% and for (4%S-BuA) gives 9.6% then decreased for (6%S-BuA) to 9.5%

IV. CONCLUSION

The possibility of reducing the cost of asphalt modified by polymer without impairing quality of binder is proved. Asphalt modified by polymer composition complies with the requirements of Egyptian Standard Specification and has characteristics that are typical for using special polymer modifier: Styrene Bacrylate. This study focuses one valuating the effects of polymer to modifying reclaimed asphalt pavement in order to improve the quality of paving and reduce the cost of asphalt. In this research, a content of4%of styrene-Bacrylate was used as an extracted asphalt modifier. The research results shown a slightly change in stability this due to the milled asphalt mixture included 3.88% asphalt, the optimum asphalt content was ranging between (1.56 – 1.62 %) which designate the polymer modified by (0.032 – 0.094%).

All mixes types of HMA having high stability and this will lead to produce an asphalt mix in a higher performance and accordingly long service life.

- The research achieved to use RAP with required quality according to required specification with low cost and saving up to 70% of total cost

V. RECOMMENDATION

According to test results and investigation study of using RAP with different percentages of modified polymer, it is recommended to reuse RAP with 4% modified polymer in order to save not less than 70% of the total cost.

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