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Evaluation of moisture sensitivity of Stone Matrix Asphalt Mixtures with Recycled Asphalt Pavements

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الملخص العربى

يناقش هذا البحث تقييم تأثير الرطوبة على حصائرخلطات الأسفلت الساخن المحتوية على أسفلت معاد استخدامه , وذلك نظرا لأن خلطات حصائر الأسفلت خلطات قوية وتعالج التخددات المنتشرة بصورة كبيرة فى مصر , وقد أثبتت هذه الخلطات كفائتها فى جميع دول العالم وبالتالى من الممكن استخدام هذه الخلطات لفاعليتها وكفائتها ومن الممكن اضافة الأسفلت المعاد استخدامه لهذه الخلطات لتقليل التكلفة, وقد أوضحت النتائج امكانية استخدام حصائرخلطات الأسفلت الساخن المحتوية على أسفلت معاد استخدامه

ABSTRACT

Economic and environmental considerations have prompted the use of reclaimed asphalt pavement (RAP) in new asphalt mixes[1]. When SMA technology was first implemented in the United States in 1991; there was no try with the use of RAP in this specialty mixture. Based on the success gained with the integration of RAP in conventional mixtures, the use of RAP in SMA mixtures necessary to be estimated.

This research evaluated the effect of moisture damage in SMA mixtures with RAP. Test results showed that, the mix S_3 achieving lower cost by about 2.46, compared to the TDAM, whereas mixes S_{2a} and S_{3a} achieving higher cost by about 11.23 and 10.63% respectively. Finally, the using of SMA mixture containing 20% RAP and 0.3% manufacture fiber (S_1) is the best mixture. It improves the volumetric, the mechanical properties of the mixture and resistance moisture damage. Moreover, it has approximately the same level of cost compared to the TDAM.

Keywords: Stone matrix asphalt, Reclaimed Asphalt Pavement, Moisture Susceptibility**,** Durability, Tensile strength ratio, Stripping

1 Introduction

Moisture susceptibility is mostly the cause of bad mixture durability, whereas moisture damage is the loss of strength and hardness of asphalt mixtures caused by the presence of moisture (Huang et al. 2009; Bhasin et al. 2007) [2 and 3]. The propagation of moisture damage generally occurs through two main mechanisms: the loss of adhesion (stripping) and loss of cohesion (softening) (Wasiuddin et al.2007 a; Cheng et al.2003a; Sebaaly et al. 2007; Hao and Liu2006) [4, 5, 6 and 7], or it may be caused by the absence of cohesive bond between binder and aggregate, generally due to moisture intrusion. This is called stripping, and it oftentimes starts at the top of the pavement and forward downward, resulting in raveling. It is mostly a function of aggregate type, although it can be caused by other agent such as poor drying or inadequate compaction [8]. Moisture susceptibility can be estimated in the laboratory by implementing stability, resilient modulus, or tensile strength testing for unconditioned and moisture conditioned specimen.

Callas, et al. [9] calculated the moisture damage and stripping behavior of 5 recycled mixtures, one of which applied an aggregate known to have stripping problems when it was primarily in place. The four different mixtures displayed no moisture damage would take place after short-term moisture conditioning (Lottman method), and two of the mixtures would strip after long-term conditioning. The moisture susceptible aggregate was examined with and without antistripping factor. The mixture with the factor did not strip after long term testing, but the one without the factor did. These outcomes proposed that RAP mixtures should be examineded for moisture susceptibility, and an anti-stripping factor should be used where it is needed.

2 Experimental program

Coarse aggregates (Grade $_1$) and (Grade $_2$) as well as breaking sand (pass 4.75 mm) from Arab Contractor's company breaker in Ataqa were used and resulted from dolomite aggregates, whereas manufacture fiber (MF) from Malaysia was used as shown in Figure (1). Dust cement from Helwan cement factories was used. The grading curve for used material is shown in Figure (2). The physical mechanical properties of natural aggregates are given in Table (1).

Figure (1) Manufacture Fiber

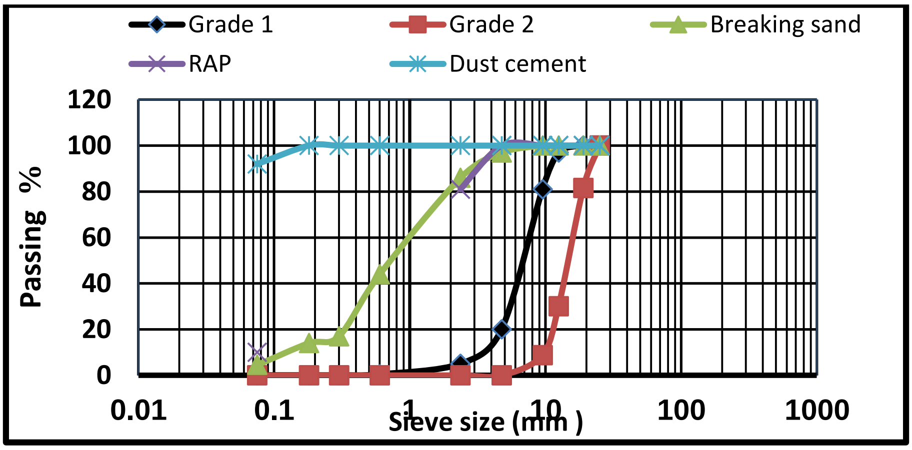

Figure (2) Grading for used material

Table (1) Physical and Mechanical Properties of Used Material

Test Name	Designation Code	Egyptian Spec. [10]	Test Result	
			Grade 2	Grade 1
Los Angeles Abrasion	AASHTO (T96)	≤ 40%	20	19
Water Absorption	AASHTO (T85)	≤ 5%	1.88	1.94
Apparent Specific Gravity	AASHTO (T85)	-	2.70	2.67
Elongated Particles	ASTM (D4791)	≤ 10%	3.5	6.6

RAP for this study was obtained by processing millings carried out by Arab Contractor's company on the Cairo to Alexandria agricultural road at station [170 + 600], right direction and these maintenance operations performed on the wear layer. The specimen of fine RAP is shown in Figure (3). Asphalt content It is found 6.76%.

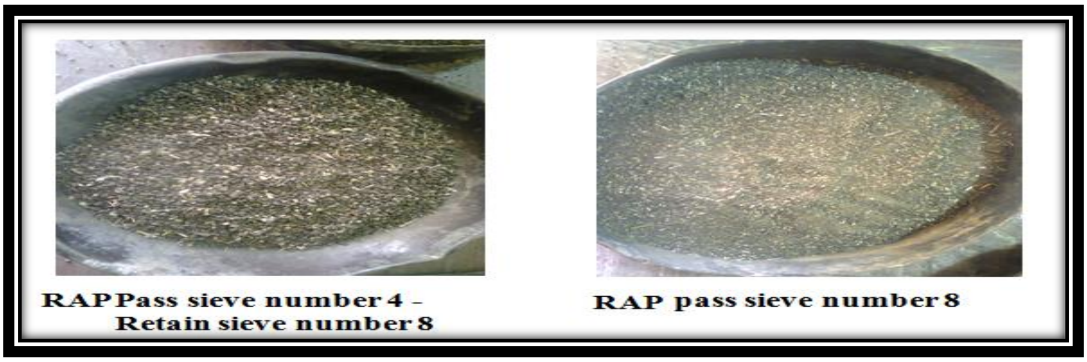

Figure (3) The Specimen of Fine RAP

Table (2) shows the qualification tests applied to the asphalt cement as well as test conditions and accepted Egyptian specifications.

Table (2) Tests of Asphalt Cement

Test Name	AASHTO Designation	Result of Asphalt		Egyptian Specification [10]
		Unmodified	Modified*	
Penetration, 0.1 mm	T 49	65	42	60 - 70
Kinematics Viscosity, Centistoke	T 201	334	337	≥ 320
Flash point, °C	T 48	273	280	≥ 250
Softening point, °C	T 53	49	55	45 - 55
specific gravity		1.02	1.04	

- **Modified asphalt = asphalt containing 0.3% manufacture fiber by total weight of the mix.**

2.1 Mix Design

Three gradations were selected (AASHTOO gradation (S_1) and two gradations chosen by the researcher (S_2 and S_3)). The details of the six mixes proportions are presented in Table (3). The selected mix aggregate gradation confirms to the midpoint of the specification. Their gradations are shown in Table (4).

Table (3) Mixture Gradation Proportions (Dry Material)

Fiber Type	Mixing Type	Mix Code	Composition, % (by weight)		
			Fresh Aggregate	RAP	Fiber (by Weight of Total Mix)
MF	Bitumen Before Mineral Filler	S_1	80	20	0.3
		S_2	80	20	0.3
		S_3	80	20	0.3
MF	Bitumen After Mineral Filler	S_{1a}	80	20	0.3
		S_{2a}	80	20	0.3
		S_{3a}	80	20	0.3

Table (4) Gradations of Investigated SMA

Sieve Size	% passing					
	S_1		S_2		S_3	
	Limitations[11]	Design	Limitations	Design	Limitations	Design
3/4"(19 mm)	100	100	100	100	92 - 100	96
1/2"(12.5 mm)	90 - 100	95	80 - 100	90	79 - 89	84
3/8"(9.5 mm)	50 - 80	65	40 - 70	55	55 - 85	70
No.4(4.75 mm)	20 - 35	27.5	22 - 37	30	22 - 37	30
No.8(2.36 mm)	16 - 24	20	16 - 24	20	16 - 24	20
No.200 (0.075 mm)	8 - 11	9.5	6.5 - 9.5	8	6.5 - 9	8

2.2 Laboratory Tests

2.2.1 Marshall Test

In this study, three samples are prepared for each bitumen content in identity with ASTM D 1559 using 50 blows/face compaction standards. The ranges of bitumen content for SMA mixtures are 5.5 – 7.5%. whole bitumen content shall be in portion by weight of the total mix. Immediately the freshly compacted samples have cooled to room temperature.

The average values of bulk specific gravity, stability, flow, VA, VMA and VFB gained above are plotted separately versus the bitumen content and a smooth curve drawn during the plotted values. The average of the binder content corresponding to VMA of 17 % and an air void of 4% is estimate as the optimum binder content (Brown, 1992) [12].

The Marshall quotient, MQ can be applied as a measure of the material's opposition to shear stress, perpetual deformation and rutting in service. Higher MQ values signal stiffer and more rigid mixtures [13]. MQ is as explained in the following equation:

$$\mathbf{MQ} = \frac{\text{Stability}}{\text{Flow}} \ \mathbf{Ib/in} \qquad \textbf{Equation (1)}$$

Moisture Conditioning

The presence of water in an asphalt pavement is unavoidable. Several sources can lead to the presence of water in the pavement. Yet almost all of studies aimed at a comparative measure of moisture damage, either via visual observations from field data or laboratory tests or via wet-versus-dry mechanical tests to give a so called moisture damage index parameter [14, 15 and 16]. In this research, the moisture conditioning was applied to evaluate the effects of water harm on the durability scope of compacted bituminous mixtures containing RAP in the laboratory. The hot-mix asphalt samples conditioning was perfect according to AASHTO T283 by submerging the samples in water at 60˚C ± 1˚C for various treatment interval (1, 3 and 7 days) and then placing in water bath room at 25˚C for 2 hour.

2.2.2 Indirect Tensile Strength Test [ASTM D 4123]

The indirect tensile test was advanced independently by Carneiro and Barcells [17] in Barazile and Akazawa [18] in Japan. The indirect tensile test is perfect by loading a cylindrical specimen (4 in diameter and 3±0.2 in thickness) with a single compressive load, which doing parallel to and along the vertical diametric plane. The equations for tensile stress at failure have been developed and simplified. These equations suppose the HMA is similar, isotropic, and elastic [19]. The test was carred at 25 ^{o}C. The indirect tensile strength (ITS) is calculated as follows:

$$\boldsymbol{ITS = 2P/(\pi.t.d)} \quad \text{……………………..………… Equation (2)}$$

Where:

ITS = Indirect tensile strength, psi,
P = Ultimate applied load at failure, ib,
t = Thickness of specimen, inch; and
d = Diameter of specimen, inch.

Tensile Strength ratio (TSR)

The TSR test is often times applied to estimate the moisture susceptibility of an asphalt mixture. The results applied to predict long-term stripping capability of bituminous mixtures. A higher TSR value typically specified that the mixture performed well with a good resistance to moisture damage. This exam is conducted as per ASTM D 4867 specifications. The TSR is as explained in the following equation:

$$\boldsymbol{TSR = \frac{ITS_{Wet}}{ITS_{dry}}} \qquad \textbf{Equation (3)}$$

Where
ITS wet = ITS of wet sample in the set
ITS dry = ITS of dry sample in the set

Durability Index (DI)

Durability Index was reali\ed as the average strength absence area enclosed between the durability curves.In this study, the formula in applied to calculate durability index is adopted from durability index formula when Marshall test. Durability index as studied from the following equation:

$$\mathrm{DI} = \left(\frac{1}{2\,tn}\right) \sum_{t=0}^{n-1} (s_i - s_{i+1}) * [2tn - (t_{i+1} - t)] \quad \textbf{Equation (4)}$$

Where:
Si+1 = percent retained strength at time ti+1
Si = percent retained strength at time ti
ti, ti+1 = immersion time (calculate from beginning of test)

3 Results and Discussion

3.1 Marshall Test Results

Table (5) shows results using Marshall Methods after being soaked in hot water for (0, 1, 3and 7) days at 60^{o} C**.** It is noticed that the Marshall stability for all mixes decreases by the increase of the immersion period, This result may be due to the water that can harm the structural safty of the aggregate interface and the less adhesive force caused by the raised in the viscosity of the asphalt concrete to reach the poor workable

and compaction status. Whereas, the Marshall flow increase by the increase of immersion time. However the stiffness decreases by the increase of immersion time.
Also, it can be noticed that, after immersing period of one day; the S_{2a} mixture achieves a minimum loss of stability (2.54%). Where this stability detrition is less than the stability detrition of the control mix by 3.88%. After immersing period of 3 and 7 days, the S_1 and S_{1a} mixes achieves a minimum loss of stability. Thus, it can be concluded that, the S_1 and S_{1a} mixes gain desired results of stripping after 7 days than other mixtures. All mixtures are located within the Egyptian specification limits (loss of stability, less than 25% except S_3 mix).

Table (5) Stripping Results Using Marshall Methods

Mix Code	Saturation Time (Days)	Stability (Kg)	Flow (Mm)	Marshall Quotient (Kg/mm)	Percent Marshall Stability (%)
S_1	0	773.87	3.50	221.11	100
	1	724.20	3.93	184.28	93.58
	3	703.87	4.37	161.07	90.95
	7	681.20	4.83	141.04	88.03
S_2	0	810.87	3.40	238.49	100
	1	740.87	4.08	181.59	91.37
	3	700.15	4.38	159.85	86.35
	7	693.29	4.80	144.44	85.50
S_3	0	890.17	3.30	269.75	100
	1	782.64	3.56	219.84	87.92
	3	765.46	4.23	180.96	85.99
	7	756.02	5.04	150.00	84.93
S_{1a}	0	732.87	4	183.22	100
	1	662.54	5.2	127.41	90.4
	3	657.87	5.44	120.93	89.77
	7	652.87	5.6	116.58	89.08
S_{2a}	0	748.64	3.90	191.96	100
	1	729.64	4.20	173.72	97.46
	3	658.64	5.00	131.73	87.98
	7	628.64	5.15	122.07	83.97
S_{3a}	0	772.43	4.00	193.11	100
	1	725.10	4.7	154.28	93.87
	3	672.43	5.4	124.52	87.05
	7	652.43	5.7	114.46	84.46

Figure (4) shows the effect of stripping on the loss of stiffness for manufacture fiber mixtures. It can be noticed that, after immersing period of one day; the S_{2a} mix achieves a minimum loss of stiffness than other mixtures. Whereas this stiffness detrition is less than the stiffness detrition of the control mixes by 7.16%. After immersing period for 7 days, the S_1, S_{1a} and S_{2a} mix achieves a minimum loss of stiffness. Thus, it can be concluded that, the best mixture of resistance stripping are S_1, S_{1a} and S_{2a} respectively.

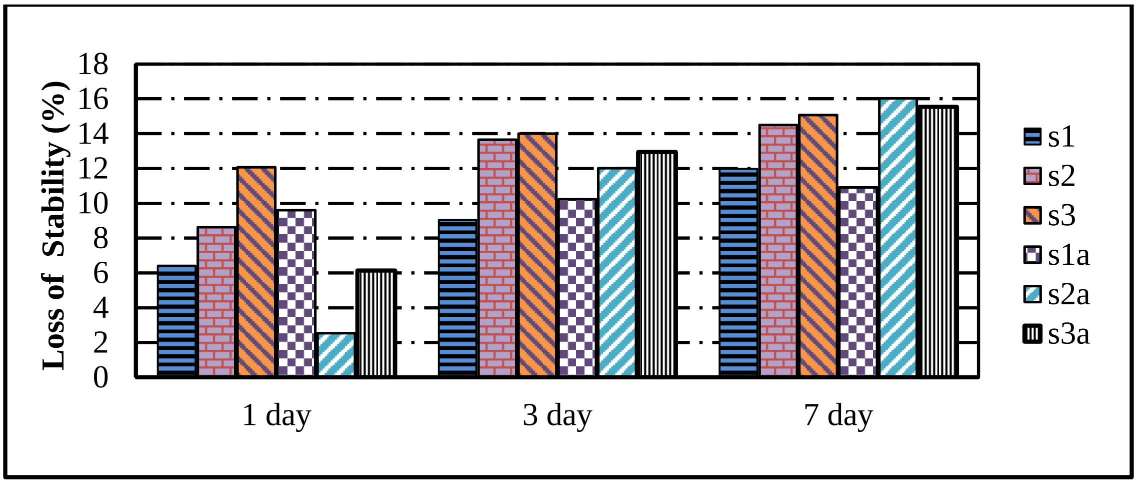

Figure (4) Effect of Stripping on Loss of Stability

3.2 Durability Index (DI)

Durability index is realized as the average strength loss area enclosed among the durability curves. Figure (5) show that the mixtures S_{1a}, S_{2a} and S_{3a} achieve total durability index (around 9.56,10.28 and 11.30%), therefor they are lower than the durability index for S_2 and S_3 mixtures, and they are increase than the control mixture by about 10.26,18.56 and 30.33% respectively. That means the S_1, S_{1a}, S_{2a} and S_{3a} mixture are the best mixture respectively to endure for a long service life. Whereas S_2 and S_3 mixtures have total durability index (around 11.84 and 12.90%), therefor they are higher than durability index for other mixtures, and they are more than the control mixture by 36.56 and 48.78% that means the S_3 mixture is the worst mixture to resistance moisture damage. This result agrees with the result of loss of stability and loss of MQ.

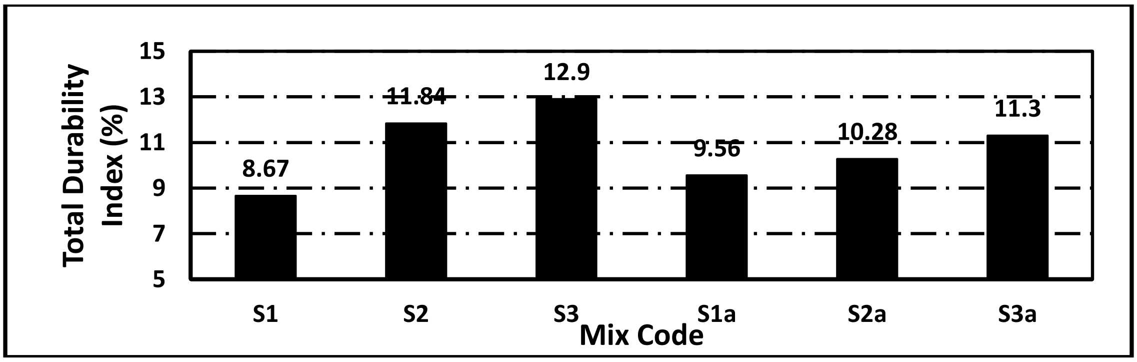

Figure (5) Durability Index for Manufacture Fiber Mixtures

3.3 Effect of Moisture Damage on TSR Results

The tensile strength ratio (TSR) is an reference of the amount of strength loss, due to the influence of water. Table (6) shows the results of TSR.

Table (6) Tensile Strength Ratio Results

Mix Type	Mix Code	Fiber %	ITS, Unconditioned Kg/ cm^2	ITS, Conditioned Kg/ cm^2	Tensile Strength Ratio (%)
Manufacture Fiber Mixture	S_1	0.3	8.71	7.72	88.64
	S_2	0.3	7.41	6.32	85.24
	S_3	0.3	6.21	4.73	76.17
	S_{1a}	0.3	9.11	8.32	91.33
	S_{2a}	0.3	8.53	7.43	87.08
	S_{3a}	0.3	6.74	4.43	65.73

Figure (6) shows the result of TSR for manufacture fiber mixes. It can be looked out that, the TSR values of the control mixture are about 82%, which is more than 70%, a minimum TSR value set forth by AASHTO T283. This explains that the control mixture has less important moisture susceptibility. All manufacture fiber mixtures accept the minimum required tensile strength ratios of 70%, except the mix S_{3a}, indicating their better moisture resistance than the mix S_{3a}.

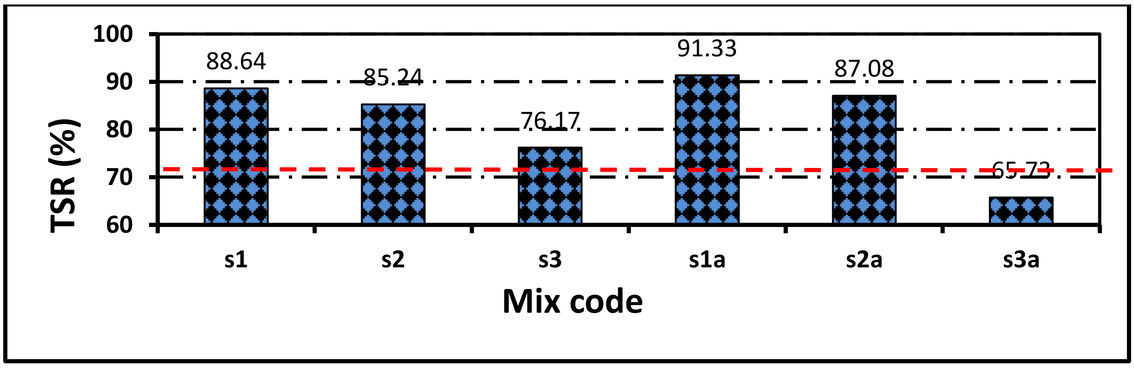

Figure (6) Variation of TSR for Manufacture Fiber Mixes

3 Cost Analysis of SMA

Table (7) shows the cost of one square meter of 5 cm thickness surface layer.

Table (7) Cost of 5 cm Surface Layer for SMA and Dense Asphalt Mixtures

Mix Code	RAP (%)	Material Cost LE/Ton	Operation Cost	Total Cost, LE/Ton	Bulk SG.	*Total Cost, LE/M^2	**Variation in Total Cost, (%)
S_1	20	415.32	45.5	460.82	2.33	53.69	4.85
S_2	20	413.952	45.5	459.452	2.35	53.99	5.44
S_3	20	400.776	45.5	446.276	2.238	49.94	-2.46
S_{1a}	20	399.416	45.5	444.916	2.366	52.63	2.79
S_{2a}	20	435.12	45.5	480.62	2.37	56.95	11.23
S_{3a}	20	435.12	45.5	480.62	2.357	56.64	10.63
4C	0	395.88	45.5	441.38	2.32	51.20	0.00

*** (Operation cost, LE/Ton) × Bulk SG × 0.05**
**** (Variation in Total Cost), based in TDAM (4C)**

Figure (7) shows that the mix S_3 achieving lower cost by about 2.46, compared to the TDAM, whereas mixes S_{2a} and S_{3a} achieving higher cost by about 11.23 and 10.63% respectively. Thus, it can be concluded that a substantial savings are accomplished by using S_3 mixture, Whereas the increasing in money is achieved at the mixture (S_{2a} and S_{3a}), and the increasing in the mixture (S_1 and S_2) is nearer to the saving of TDAM.

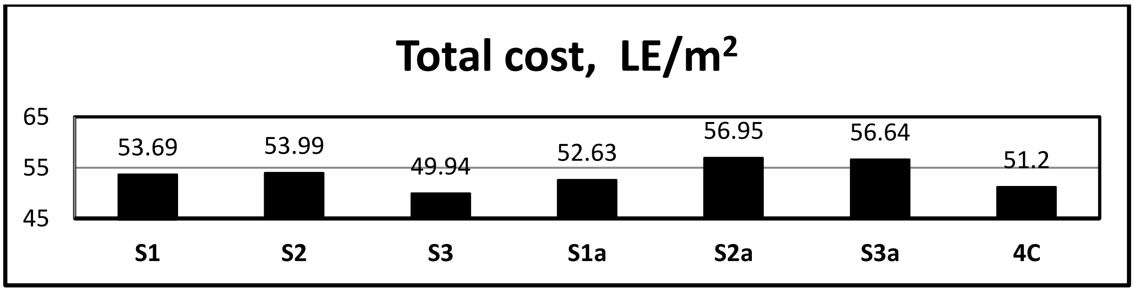

Figure (7) Costs of using Different Mixtures

5 Conclusions

Based on extensive laboratory evaluation of different SMA mixtures containing RAP, the main conclusions of this research can be concluded;

1. The optimum bitumen contents for the mixtures (S_1, S_2, S_3, S_{1a}, S_{2a}, S_{3a} and 4C) were (7.0, 7.0, 7.0, 7.5, 7.5, 7.5and 5.5%) respectively. With respect to the TDAM, optimum fresh bitumen content was increased by about 2.9% when SMA mixtures (S_1, S_2, and S_3) were used. Whereas it was increased by about 12% when SMA mixtures (S_{1a}, S_{2a}, and S_{3a}) were used.

2. Adding manufactures fiber to SMA mixture has shown elaboration in the volumetric, mechanical properties and elaboration in the stripping properties of the mixture. It can be understand that these steady in SMA provide better resistance against permanent deformations.

3. The gradation of aggregate Play a significant effect on the mechanical properties of SMA mixtures. The mixtures containing more coarse aggregate, achieve high stability.

4. For manufactures fiber steady SMA mixtures, with respect to the control mixture, the stability increases by about 4.78 and 15.03 % for S_2 and S_3 mix respectively. Whereas for S_{1a}, S_{2a} and S_{3a} mix the stability decreases by about 5.30, 3.26 and 0.19 % respectively. For Marshall Quotient value, it increases by about 7.86 and 22 % for S_2 and S_3 mix respectively. Whereas for S_{1a}, S_{2a} and S_{3a} mix the Marshall Quotient decreases by about 17.13, 13.18 and 12.66 % respectively.

5. ITS for S_1 mixture is the best, it is higher than TDAM by about 13.20, respectively.

6. For all SMA mixtures, Marshall Stability and Marshall Quotient decreased by increasing the immersion period, whereas the Marshall flow increased by increasing the immersion period. From the result of retained Marshall Stability, durability index and tensile strength ratio, The SMA mixtures containing manufacture fiber (S_1 and S_2) performed better than other mixtures to resist moisture damage.

7. The mix S_3 achieving lower cost by about 2.46, compared to the TDAM, whereas mixes S_{2a} and S_{3a} achieving higher cost by about 11.23 and 10.63% respectively

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