Laboratory Performance of Stone Matrix Asphalt Mixtures Containing Recycled Asphalt Pavements

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Abstract: Stone matrix asphalt (SMA) is a gap-graded mix developed in Germany in the 1960's, to resist the wear and tear on pavements caused by studded tires. Later the mix was found to be more rut resistant and durable than conventional dense-graded mixtures and this encouraged other European countries also utilize this mixture. Reclaimed Asphalt Pavement (RAP) material is generated when the damaged pavement is milled, crushed, sometimes fractioned, and stockpiled for use as an additional component in the asphalt mixture. The main objective of this research was to predict pavement behavior in Egypt by investigating the mechanical and volumetric properties of the stone matrix asphalt mixtures after adding RAP. From the result of the volumetric and the mechanical properties of the mixtures and tensile strength ratio, The SMA mixtures containing manufacture fiber (S_1 and S_2) performed better than other mixtures and resistance moisture damage.

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1. Introduction

SMA is hot mixture asphalt that was developed in Germany in the late sixties. SMA has been utilized in other European countries for more than two decades to provide higher rutting resistance as well as studded tyre wear [1]. Because of its success in Europe, the United States of America (USA) also launched the construction of SMA pavements in some states, in collaboration with the Federal Highway Administration [2, 3]. Recent studies have shown that more than 28 states in the USA utilize SMA because of its increased durability, up to 20%–30%, compared to conventional mixtures [4].

Utilizing the SMA mixture provides us with a stable stone-on-stone skeleton that is caught with each other by a rich mixture of asphalt cement, filler, and additive [5].

The advantages associated with the use of SMA include high resistance to inverter cracking, improvement against aging and reduced traffic noise [6]. Adding of a small quantity of fibers or polymer modifiers is recommended to prevent the drainage of binder during transport and placement [7]. A standard SMA mixture composition contains 70%–80% coarse aggregate, 8%–12% filler, 6.0%–7.0% binder, and 0.3% fibre [8].

RAP, is the code given to removing and/or reprocessed pavement materials contains asphalt and aggregates [9].

Asphalt recycling is not a new idea, cold recycling dates which it is back to the early 1900's. [10]. Many official agencies have reported important savings while RAP is applied (Page and Murphy 1987) [11].

Considering material and structure cost, it was evaluated that using reclaimed HMA pavement supply a saving ranging from 14 to 34% for a RAP content varying among 20 to 50% (Kandhal and Mallick 1997) [12].

In 1996, it was estimated that about 33% of all asphalt pavement in the United States was recycled into the HMA (Sullivan 1996) [13].

Adriana Vargas (2007) [14] estimated the effect of RAP on combined aggregate feature, asphalt binder properties, and overall performance of SMA mixtures. Results showed that, tests of the aggregate properties of the combined blends indicated that addition of RAP changes the LA abrasion and F/E particle content depending on the properties of the RAP aggregates in relation to the use of RAP changed the engineering properties of the resulting binder blends due to the increased old to new binder ratio. The stiffness of the binder blend (G*/sin , G*sin and creep stiffness) increase with RAP content, particularly increasing the fatigue cracking potential.

2. Experimental program

Coarse aggregate is comprised of aggregate composition retained on a 4.75mm test sieve. Coarse aggregate was obtained from Arab Contractor's company breaker in Ataqa and were resulted from dolomite aggregates. The coarse aggregate was received as two sizes (Grade$_1$ and Grade $_2$). The basic physical properties of the coarse aggregate are presented in Table (1).

Table (1) Physical Properties of Coarse Aggregate

Test Name	Designation Code	Egyptian Spec. [15]	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

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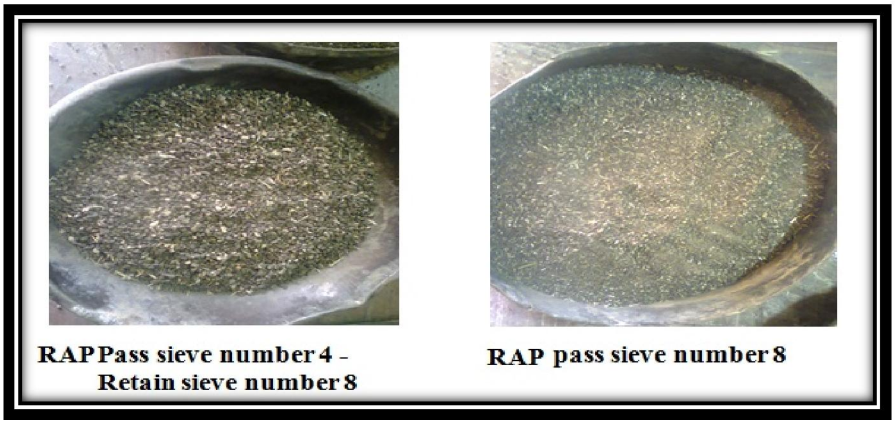


Figure (2) The Specimen of Fine RAP

3. Mix Design

Three gradations were selected (AASHTOO gradation (S$_1$) and two gradations chosen by the researcher (S$_2$ and S$_3$)). The six mixes contain 80% fresh aggregate, 20% RAP and 0.3% manufacture fiber (by weight of total mix). The selected mix aggregate gradation confirms to the midpoint of the specification. Their gradations are shown in Table (2). S$_1$ and S$_2$contain Nominal Maximum Aggregate Size (NMAS) of 12.5 mm, whereas S$_3$ have NMAS of 19 mm.S$_1$ was selected to represent the gradation according to AASHTOO specifications. Table (3) shows a summary of the specification for designing

SMA (AASHTO MP8-01) [16]. S_1 was considered as a control mix.

Table (2) Gradations of Investigated SMA

Sieve Size	% passing					
	S_1		S_2		S_3	
	Limitations[16]	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

Table (3) Specification for Designing SMA (AASHTO MP8-01) [16]

Property	Requirements
Asphalt content, %	6 minimum
Air voids, %	4
VMA, %	17 minimum
VCA, %	$< VCA_{DRC}$
TSR, %	70 minimum
Drain down, %	0.3 max

4. Testing and Measurements

4.1 Asphalt Cement Test

Table (4) shows the qualification tests applied to the asphalt cement as well as test conditions and accepted Egyptian specifications.

Table (4) Tests of Asphalt Cement

Test Name	AASHTO Designation	Result of Asphalt		Egyptian Specification [140]
		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.**

4.2 Marshall Test

In this study, three specimens are prepared for each bitumen content in accordance with ASTM D 1559 using 50 blows/face compaction standards. The domains of bitumen content for SMA mixtures are 5.5 – 7.5%. All bitumen content shall be in percentage by weight of the total mix. Immediately the freshly a mount specimens have cooled to place 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 soft curve drawn through the plotted values. The average of the binder content symmetric to VMA of 17 % and an air void of 4% is look as the optimum binder content (Brown, 1992) [17].

The Marshall quotient (MQ), which is an indicator of opposition of the bituminous mixture versus deformation, is also calculated. MQ values can be applied as a measure of the material's resistance to shear stress, perpetual deformation and rutting in service. Higher MQ values indicate rigid and more resistant mixtures [18]. MQ is as illustrated in the following equation:

$$\mathbf{MQ} = \frac{\text{Stability}}{\text{Flow}}\ \mathbf{lb/in} \qquad \textbf{Equation (2)}$$

4.2.1 Retained Marshall Stability (RMS)

This method was used to determine the retained Marshall stability by using Marshall Compaction specimens after curing periods of one day in a water bath at 60° C. Determine the retained Marshall stability is as illustrated in the following equation:

$$\textbf{Retained Marshall Stability} = \frac{\text{SoakedStabilityx100}}{\text{StandardStability}} \qquad \textbf{Equation (3)}$$

4.3 Indirect Tensile Strength Test [ASTM D 4123]

The indirect tensile test was developed independently by Carneiro and Barcells[19] in Barazileand Akazawa [20] in Japan. Indirect tensile test set-up is presented in Figure (3). The equations for tensile stress at failure have been developed and simplified. These equations assume the HMA is homogeneous, isotropic, and elastic [21]. The test was conducted at 25 ^{o}C. The indirect tensile strength (ITS) is calculated as follows:

$$ITS = 2P/(\pi.t.d)\text{.............. ... } \textbf{Equation (4)}$$

Where:

ITS = Indirect tensile strength, psi,

P = Ultimate applied load at failure, ib,

t = Thickness of specimen, inch; and

d = Diameter of specimen, inch.

4.4Tensile Strength ratio (TSR)

The TSR test is oftentimes used to guess the moisture susceptibility of an asphalt mixture. The results applied to predict long-term stripping sensitivity of bituminous mixtures. A higher TSR value typically specified that the mixture performed well with a good opposition to moisture damage. This test is behaved as per ASTM D 4867 specifications. The TSR is as explained in the following equation:

$$TSR = \frac{ITS_{Wet}}{ITS_{dry}} \qquad \textbf{Equation (5)}$$

Where

ITS wet = ITS of wet specimen in the set

ITS dry = ITS of dry specimen in the set

4.5 Wheel Track Test

Wheel tracker typically measures the rutting produced by the repeated passage of a wheel over glossy asphalt concrete samples. It was used to estimate the resistance of rutting of the asphaltic material, under standard defined status of load and temperatures, i.e. 25, 45 and 60^{0}C. In this research we will test the sample at 60^{0}C. Specimen dimension was 30*25 cm, 5 cm thickness.

Figure (3) Indirect Tensile Strength Test Set-Up

5. Marshall Test Results

Figure (4) shows that, Maximum stability is 890.17, 810.87, 773.87, 772.43, 748.64 and 732.87 for S_3, S_2, S_1, S_{3a}, S_{2a} and S_{1a}, respectively. It is noted that the mixtures of S_1, S_2, and S_3 give the maximum stability at 7% bitumen content, whereas the mixture of S_{1a}, S_{2a}, and S_{3a} give the maximum stability at 7.5% bitumen content.

Figure (5) shows that, by increasing bitumen content, the flow is increasing for all mix. Maximum flow is achieved at 7.5 % bitumen content. The maximum flow is 4, 4, 3.90, 3.77, 3.70 and 3.60 for S_{1a}, S_{3a}, S_{2a}, S_1, S_2 and S_3, respectively.

Figure (6) shows that, maximum MQ is 307.63, 264.69, 238.52, 202.83, 198.81 and 183.22 for S_3, S_2, S_1, S_{3a}, S_{2a} and S_{1a} mixes respectively.

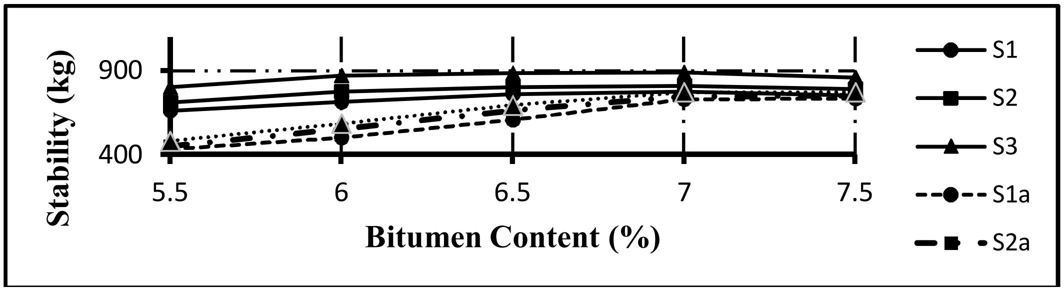


Figure (4) Variation of Stability with Different Bitumen Contents

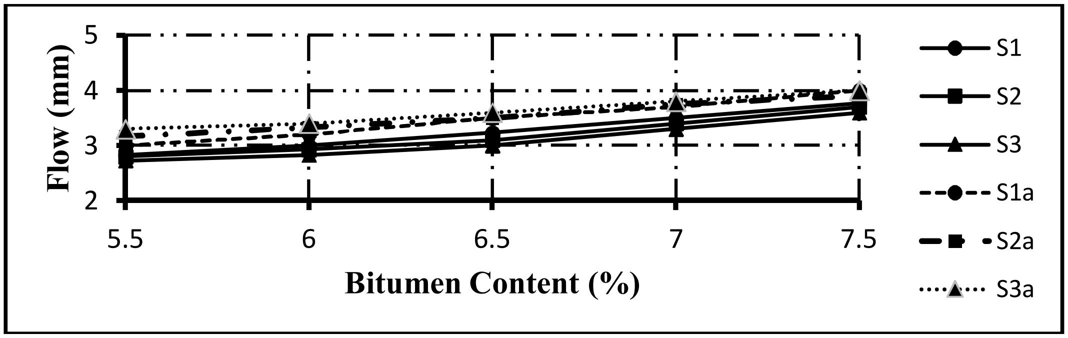


Figure (5) Variation of Flow with Different Bitumen Contents

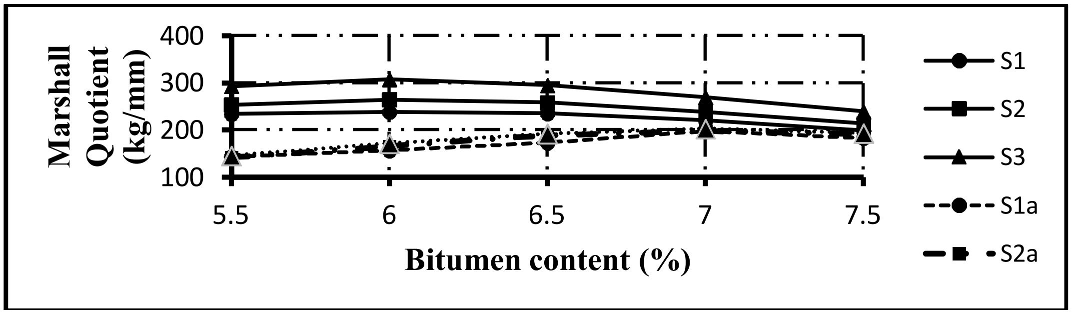


Figure (6) Variation of MQ with Different Bitumen Contents

5.1 Comparison between Mixtures at Optimum Bitumen Contents

Test results have explained that the gradation of aggregate plays an expressive role on mechanical properties of SMA mixtures. Based on Marshall Test results, S_3 mix is recommended as optimum mixture, where S_3 mix exhibits the highest stability and Marshall Quotient. The variations of mechanical properties of manufacture fiber mixture at the optimum bitumen contents (O.B.C) are shown in Figures (7 to 9).

Flow values for all manufacture fiber mixtures are located within the Egyptian specification surface layer. It is observed that the gradation of aggregate and adding bitumen before filler have a great effect on the stiffness of the mixture.

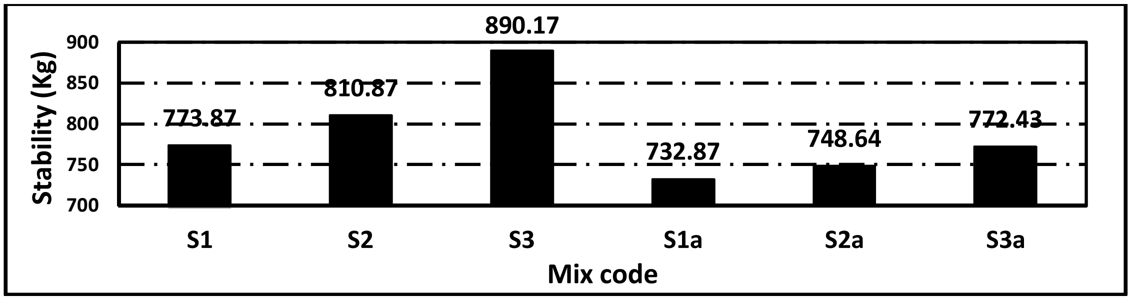


Figure (7) The Variations of Stability at O.B.C

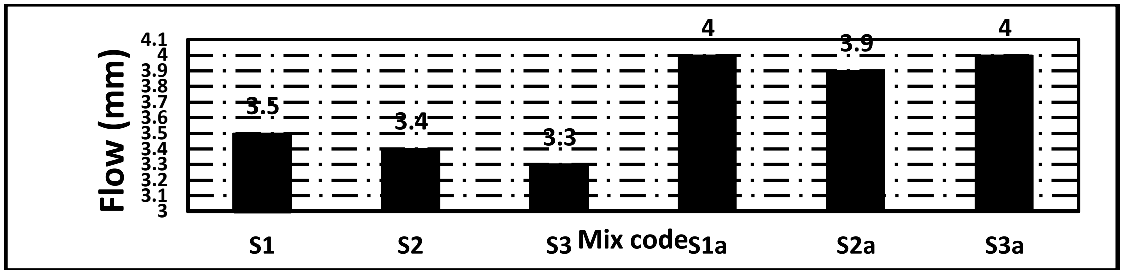


Figure (8) The variations of Flow at O.B.C

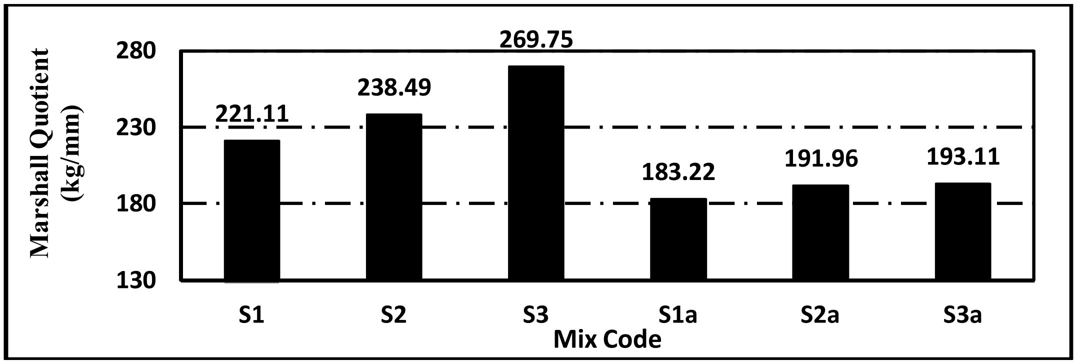


Figure (9) The Variations of Marshall Quotient

5.2 Effect of stripping on Retained Marshall Stability (RMS)

This test is conducted as per ASTM D 1075 specifications. Figure (10) shows that by increasing the immersion period the durability potential reduces. The highest RMS is obtained at S_1 and S_{1a} mixes while S_{2a}mixture obtains the lowest RMS. This result means that S_1 and S_{1a} mixes supply better durability and longer service life for the pavement.

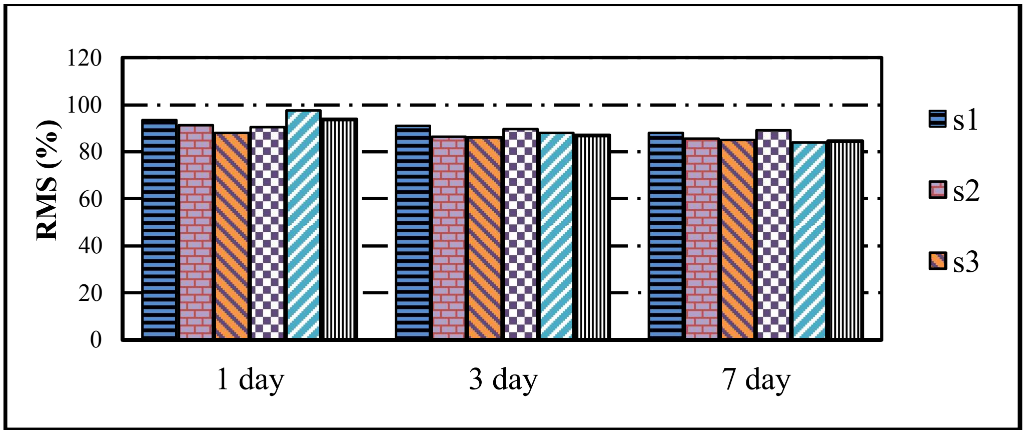


Figure (10) Effect of Stripping on RMS

5.3 Indirect Tensile Test Results (ITS)

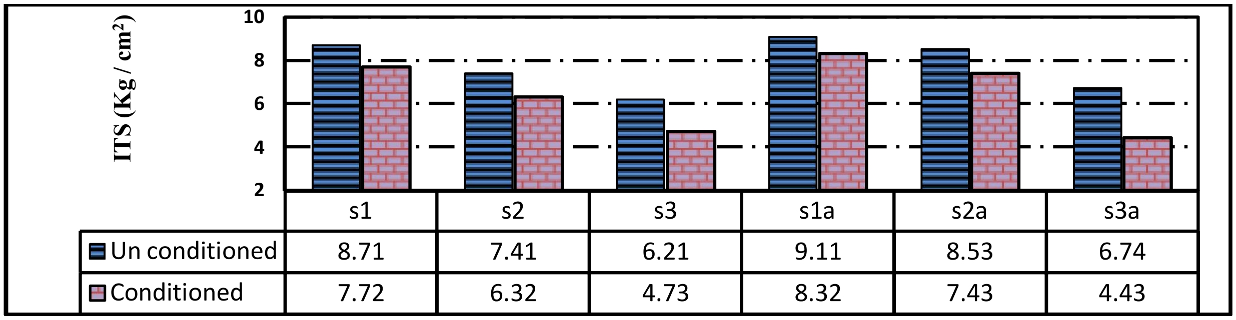
It is noticed from Figure (11) that, in unconditioned matter, the value of ITS of S_1 mix is better than the value of ITS of S_2 mix. Whereas in conditioned matter, the value of ITS of S_2 mix is better than the value of ITS of S_1. The higher ITS values are desirable as they correspond to a strong and durable mixture.

Also, it is noticed that, S_{1a} mixture shows a percentage increase (maximum) of 7.77% and 4.59% with respect to the control mixture (S_1) for unconditioned and conditioned samples respectively. Whereas S_{3a} shows a percentage decrease (minimum) of 42.61% and 22.62% with respect to the control mixture (S_1) for unconditioned and conditioned samples respectively. This indicates that the stone skeleton, with its high internal friction has a great impact on improving the tensile strength of the SMA mixtures. This indicates that the stone skeleton, with its high internal friction, will give excellent shear resistance, thus the gravel skeleton of S_1mix has high internal friction than S_2 and S_3 mix.

5.4 Effect of Moisture Damage on TSR Results

Figure (18) shows that, the tensile strength ratio (TSR) values of the control mixture are nearly 82%, which is more than 70%, a minimum TSR value set forth by AASHTO T283. This illustrates that the control mixture has less significant moisture susceptibility. All manufacture fiber mixtures satisfy the minimum required tensile strength ratios of 70%, except the mix $S_{3a,}$ indicating their better moisture resistance than the mix S_{3a}.

Figure (12) indicates that S_{1a} mixture has higher TSR than S_1 mix by about 3.03%, respectively, whereas S_{2a}, S_2, S_3 and S_{3a} mix have a lower TSR than S_1 mix by about 1.76, 3.83, 16.37and 25.84% respectively. S_1, S_2, S_{1a} and S_{2a} mixture, indicating its lesser water induced damage when compared to S_{3a} and S_3 mix.



	s1	s2	s3	s1a	s2a	s3a
▤ Un conditioned	8.71	7.41	6.21	9.11	8.53	6.74
▦ Conditioned	7.72	6.32	4.73	8.32	7.43	4.43

Figure (11) Variation of ITS for Manufacture Fiber Mixes

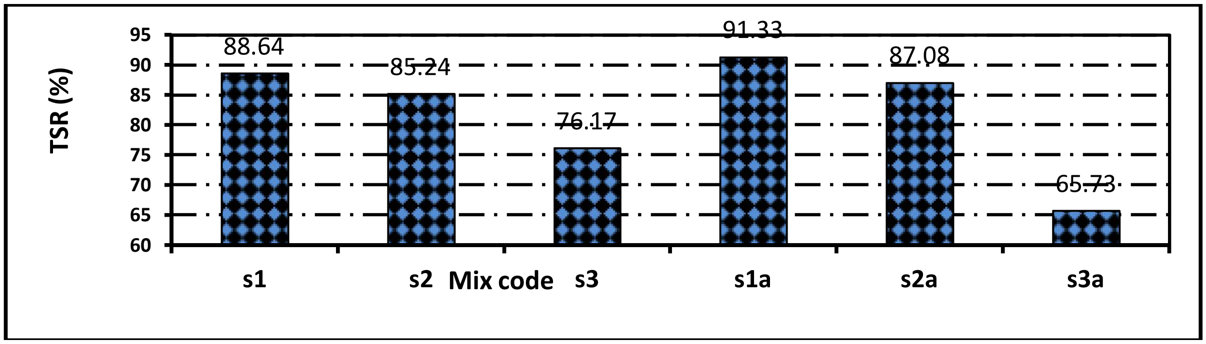


Figure (12) Variation of TSR for Manufacture Fiber Mixes

5.5 Track Wheel Test Results

Wheel tracker typically measures the rutting formed by the repeated passage of a wheel over prismatic asphalt concrete samples. The differences between spacemen of manufacture fiber mixture before and after the track wheel test are shown in Figure (13) and Figure (14). Figure (15) illustrates the relationship of rutting depth with time for manufacture fiber mixture. It can be seen from the Figure (15) that the rooting depth of control mixture (S_1) is obtained at 2.54 mm, whereas for S_{1a} mixture, it is 7.18 mm only after 60 minutes. A failure in rutting resistance is observed as bitumen are added after filler during mixing the material in the plate. The lowest rutting depth value is achieved at S_1 mix. Where it is higher than the rutting depth of S_{1a} by about 182.67%. This substantiates that stone skeleton of S_1 mix has better resistance to permanent deformation than a stone skeleton of S_3 mix, and the stone skeleton of S_3 mix have better resistance to permanent deformation than a stone skeleton of s_2 mix. In the wheel tracking test, none of the mixtures reached the 0.5 in (12.5mm) criterion of failure [22].

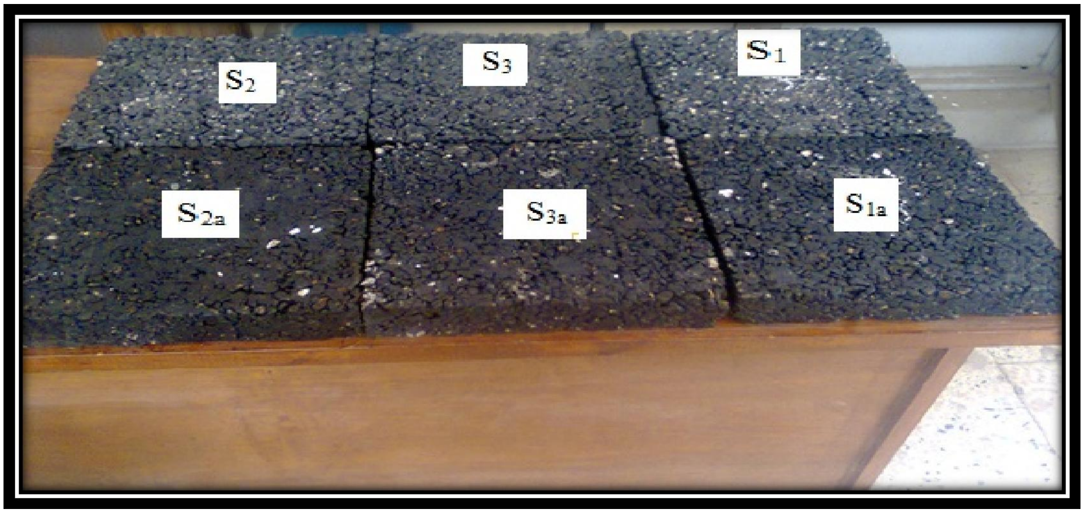


Figure (13) Spacemen of Mixtures before Track Wheel Test

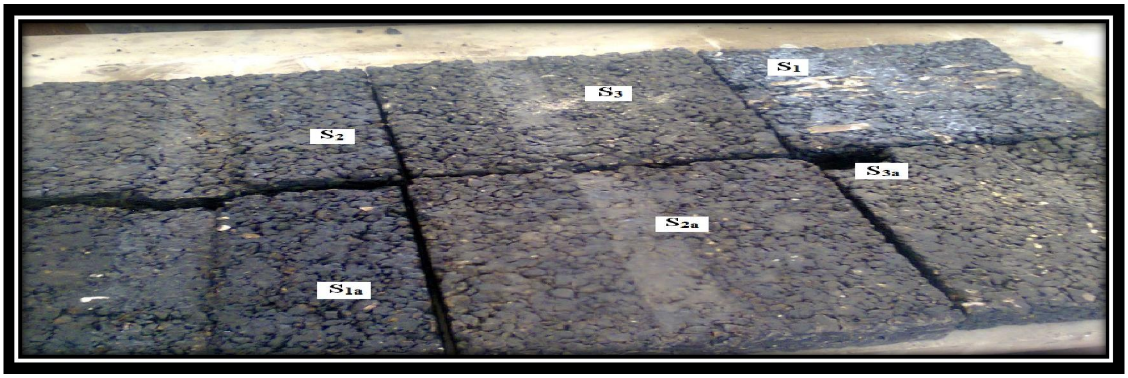


Figure (14) Spacemen of Mixtures after Track Wheel Test

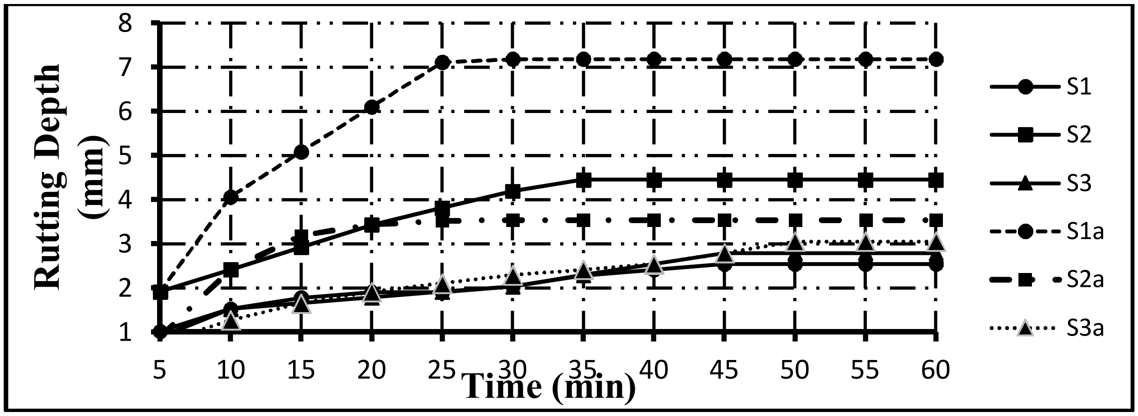


Figure (15) The Relationship of Rutting Depth with Time

6. 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}) were (7.0, 7.0, 7.0, 7.5, 7.5, 7.5 %) respectively.

2. The method of mixing "adding bitumen before mineral filler" is better than the method of mixing "adding bitumen after mineral filler".

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. 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. For all SMA mixtures, 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 and tensile strength ratio, The SMA mixtures (S_1 and S_2) performed better than other mixtures to resist moisture damage.

6. The rutting depth is increased by about 75.19, 9.84, 182.67, 39.37 and 20.07% of the rutting depth of control mixture when S_2, S_3, S_{1a}, S_{2a} and S_{3a} mix are used.

7. According to all test results, 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.

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