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Laboratory evaluation of moisture susceptibility of organic warm mixes containing recycled asphalt

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Abstract

A huge economic saving can be realized when contributing reclaimed asphalt pavement (RAP) in the production of warm mix asphalt (WMA). Besides, it is an environmentally friendly alternative as it reduces gas emissions when using WMA and a reduction in the need for virgin materials when using RAP. Sixteen different mixtures were designed as a combination between WMA and RAP. RAP was added at rates 20%, 40%, and 65%. The same for WMA additive (Sasobit), it was added at rates 1.5%, 2.5%, and 3.5%. Retained Marshall Stability (RMS) were conducted to assess moisture susceptibility performance of mixtures with different RAP and Sasobit contents. From results, it was observed that the integration of RAP and WMA improves the stability performance by 194% for the conditioned mixes and 122% for the unconditioned mixes. Also, stability improves while increasing Sasobit content till the 2.5% Sasobit and then the stability declines. The higher the RAP content the better improvement in stability for both the conditioned and unconditioned samples. Although the high results of stability this indicate more brittleness of the mix, this observation should be more investigated.

Keywords: *HMA; WMA; Sasobit; Moisture susceptibility; RMS; Marshall Stability*

1. Introduction

Asphalt pavements are considered the most common type in Egypt and around the world. Nowadays, Egypt is passing a critical economic situation but the awareness that roads are the development locomotive for the national economy directed to a huge investment in the road network. In year 2015/2016, the expenditures for roads sector exceeded one billion dollars although the economic situation[8]. Consequently, for these expenditures, a huge amount of Recycled Asphalt Pavement (RAP) are generated from the milling process. Unfortunately, In Egypt, RAP is not used effectively in asphalt mixes but used mainly for landfilling.

Nowadays, RAP is widely used all over the world. Asphalt mixes containing RAP could perform as well as the conventional hot mixes with an improvement in performance for rutting and a good resistance to moisture damage[9]. In Japan, Rap represents an average of 47% in the asphalt mix. United States uses an average of 20% of RAP in asphalt mix[19]. Recently, European countries and the United States are expanding in the usage of RAP-WMA mixtures in both sides, the research, and the real use. RAP percentage could be increased when used in a WMA compared to HMA because of reduced mixing, laying, and compaction temperatures[14].

WMA is an asphalt mix produced at a lower temperature than the HMA. It was first introduced in Europe by the year 1997, it can be produced according to different techniques like organic, chemical additives, and foaming technologies. WMA have a lot of advantages like lower gas emissions, reduced oxidation of bitumen, paving season extension, and ability to haul for longer distances [6]. In 2014, the production of WMA in the USA reached 113 million ton which represents nearly one-third of asphalt production in the USA [10]. Studies and researches show that the percentage of RAP can be increased in WMA compared to HMA [14].

Recently, research about combining WMA and RAP in asphalt mixtures are gaining popularity. WMA additive was employed to obtain a WMA binder resulting from mixing virgin aggregates and RAP. Marshall mix design technique was employed to design all mixes in this research. WMA–RAP mixtures were produced using organic additive Sasobit with content of 0%, 1.5%, 2.5%, and 3.5% and at RAP content of 0%, 20%, 40%, and 65%. Marshall Immersion test was conducted to assess the moisture susceptibility of WMA–RAP mixtures for 16 different mixtures.

The following research aims to evaluate the different mix types of WMA and HMA while containing different percentages of RAP and WMA additives. Specimens were produced in the laboratory using materials found in Egypt and from a local contractor to validate with a large scale in plant production the effectiveness of the mix design.

The detailed objectives of this research were to:

- Evaluate WMA performance compared to conventional HMA for the Egyptian asphalt industry.
- Ensure performance of RAP materials compared to virgin aggregate for the Egyptian asphalt industry.
- Evaluate the effect of Sasobit and RAP on the moisture-induced damage according to materials found in Egypt.

2. Materials and Mix design

2.1 Aggregate

Aggregates used in this research included course aggregate (size 1&2), fine aggregate (natural and manufactured sand). Aggregates were collected from a local contractor among the common aggregates used in Egypt to produce asphalt mixes. The course aggregates were crushed stone. Fine aggregates comprise two types, the first one was a natural sand and the other one was manufactured sand. The average gradation for all aggregates is shown in table 1. Table 2 shows aggregate content in each mixture.

Table 1. Gradation of different aggregate sizes

Sieve Size (mm)	% Passing			
	Agg. 2	Agg. 1	Crushed sand	Natural sand
25	100	100	100	100
19	93.1	100	100	100
12.5	20.2	97.3	100	100
9.5	8.6	75.1	100	100
4.75	1.1	7.0	100	100
2.36	0	2.3	75.1	98.4
0.6	0	2.1	33.1	81.4
0.3	0	2.1	26.9	53.6
0.18	0	2.1	24.0	16.2
0.15	0	2.0	23.1	8.4
0.075	0	1.9	19.7	3.9

Table 2. Aggregate percentage in the mix

Mix	Agg. 2	Agg. 1	Crushed Sand	Natural Sand	RAP	Total
HMA	31	19	30	20	0	100
20% RAP	25	15	24	16	20	100
40% RAP	20	14	15	11	40	100
65% RAP	7	4	17	7	65	100

2.2 Virgin bitumen

The grade of bitumen used in this research was Bitumen 60/70, it was obtained from Suez refinery located in Suez governorate. This bitumen was used to produce all mixtures. Values of these virgin binder properties and requirements are shown in Table 3.

Table 3. Properties of bitumen

Property	Sample	Egyptian Code Limits	
		L.L	U.L
Penetration at 25^{o} C (ASTM D5) [2]	70	60	70
Softening Point (ASTM D36)[3]	45	45	55

2.3 RAP

In this research, a cold milling machine milled pavement. Samples were collected from a hauling truck at a collector road in Cairo, Egypt. RAP was processed in the laboratory to get its gradation and the RAP binder content. First, a solvent extraction method using centrifuge extractor process to remove the asphalt binder from the aggregate. Bitumen content in the sample was observed to be 6.47%. Second, RAP aggregate properties were measured from the extracted aggregate sample. Rap aggregate properties were gradation and the specific gravity was calculated and found to be 2.61according to ASTM standards [4,5]. Rap aggregate gradation is shown in Table 4.

Table 4. Sieve analysis results for extracted aggregates

Sieve Size (mm)	19.5	12.5	9.5	4.75	2.36
% Passing	100.0	96.8	94.1	80.3	61.5
Sieve Size (mm)	0.6	0.3	0.18	0.15	0.075
% Passing	35.3	18.7	10.5	8.8	5.0

2.4 WMA Additive (Sasobit)

Sasobit is a Fischer-Tropsch or synthetic wax that is formed during the coal gasification process and that has been used as a compaction aid and a temperature reducer[14]. This process integrates a low melting point additive that chemically changes the temperature-viscosity curve of the binder. Sasobit liquefies at about 100°C which leads to a reduction in bitumen viscosity. It is fully soluble at a temperature of 115°C.

On the other hand, Sasobit improves asphalt mixture resistance to deformation during the operating temperature range without affecting mixture low-temperature properties when compared to a conventional HMA [13]. Also, it improved the compactibility of the mixtures in both the shear gyratory compactor and vibratory compactor. Statistics indicated that an average reduction in air voids up to 0.9 percent was obtained. At the year 2010, more than 10 million tons of asphalt mixture has been produced around the world with Sasobit, most of it was used to produce WMA [14].

2.5 Mix Design

Mix design for this research was carried out to fulfil marshal mix design specification. Aggregate gradation followed the Egyptian code specification Egyptian code for constructing roads (part 9) 7]. Marshall mix design was carried out for four mixes which are the control mix (HMA) and three mixes with different percentages of RAP (20%, 40%, and 65%). The combined gradation of new aggregates and different percentage of RAP (20%, 40%, and 65%) are calculated to meet the desired specification requirements fulfilling the requirements of a surface layer 4C gradation as per the Egyptian code excluding the 65% RAP mix. It is calculated also as a surface layer but for category 6A as per the Egyptian code.

Gradation for mixes is shown in table 5. The Optimum Bitumen Content (OBC) is calculated for the four mixes as per marshal mix design. Table 6 shows the OBC for mixes and the values of flow, stability, bulk density, VMA, Air voids and VFA that relate to this Bitumen content. New asphalt content to be added to the recycled mix were presented in Table 6. OBC will be applied for WMA and three different percentages of sasobit will be added (1.5%, 2.5%, and 3.5%) to the mix. From Table 6, The ratio of stability to flow is known as the Marshall quotient [11,20].

Table 5. Mixtures composition and grading envelope

Sieve Size (mm)	HMA	20% RAP	40% RAP	Egyptian Code Limits (Mix – 4C)	
				L.L	U. L
25	100	100	100	100	100
19	97.9	98.3	98.6	80	100
9.5	66.9	72.2	75.9	60	80
4.75	51.7	57.4	59.3	48	65
2.36	42.7	46.4	47.0	35	50
0.6	26.6	28.3	28.3	19	36
0.3	19.2	19.1	17.7	13	23
0.15	9.0	9.0	8.2	7	15
0.075	7.1	6.6	5.6	3	8

Table 5 Continued. Mixtures composition and grading envelope

Sieve Size (mm)	65% RAP	Egyptian Code Limits (Mix - 6A)	
		L.L	U. L
19	100	100	100
12.5	92.4	100	100
9.5	88.8	85	100
4.75	76.6	65	80
2.36	59.7	50	65
0.6	34.4	25	40
0.3	20.6	18	30
0.15	10.3	10	20
0.075	6.9	3	10

Table 6. Comparison of Marshall Properties

Asphalt Mix Characteristics	Control	20 % RAP	40 % RAP	65 % RAP	Egyptian Code Limits For Wearing layers	
					Min	Max
Optimum AC%	5.37%	5.77%	5.23%	6.18%	-	-
New AC%	5.37%	4.39%	2.46%	1.68%	-	-
Bulk Density (ton/m3)	2.40	2.40	2.40	2.36	-	-
Stability	112	127	185	205	900	-

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(Kg)	0	0	0	0		
Flow (mm)	2.5	2.7	2.6	3.1	2	4
Marshall Quotient (kg/mm)	448	474	718	656	2001	-
Air voids %	3.60%	2.80%	2.80%	2.60%	3	5
VMA %	14.40%	14.40%	13.40%	15.50%	15	-
VFA%	73%	80%	80%	85%	-	-

3. Methodology

16-different asphalt mixes were studied and analyzed in this research. Mixes were studied to evaluate the performance of HMA against WMA and virgin aggregate against the recycled one. Four sets of mixes are going to be carried out, the first set will involve virgin aggregates and the second through the fourth set will involve different percentages of RAP inside the mix as 20, 40, and 65%. Each set will comprise four mixes, the first mix will have no WMA additive (Sasobit) added to the mix. The second mix through the fourth will contain a WMA additive (Sasobit) added as a percentage of 1.5, 2.5, and 3.5% from bitumen weight.

A prime performance characteristic linked to moisture damage is known as loss of adhesion in the asphalt mix. This action happens when water or water vapor gets in between the bitumen and aggregates thus breaking the adhesion between the bitumen and aggregates [13,16]. To evaluate that issue, an experiment is done in the lab to determine strength ratio between the conditioned specimen and unconditioned specimen. Specimens are prepared as per marshal mix design and compared to the minimum acceptable limits as per specifications.

Retained Marshall Stability (RMS) is the followed procedure for evaluating asphalt mix moisture susceptibility. The test follows the procedure of ASTM D1075 specification [1], a standard Marshall specimens (100 mm diameter and 63.5 mm height) were prepared. Two groups of specimens were prepared, the first group is the conditioned specimens which were kept in a 60^{o}C water bath for 24 hours, and afterward, specimens were tested for stability. The second group was tested for stability as per normal procedure then the results were reported as a ratio between conditioned and unconditioned [17].

4. Results and discussion

Fig. 1 shows the effect of different RAP percentages on the stability of asphalt mix. It is very clear that RAP included mixes have better stability than the conventional HMA[12]. All mixes passed the minimum requirement of the Egyptian code for highways (2008 Edition) which is 900 kg for heavy traffic highways. The control mix achieves 1120 kg while the 65% RAP mix records an improvement in stability by 85% over the control mix.

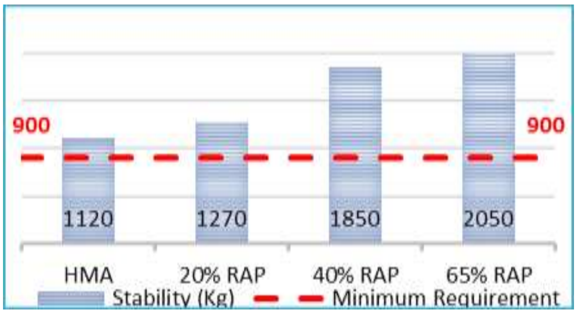
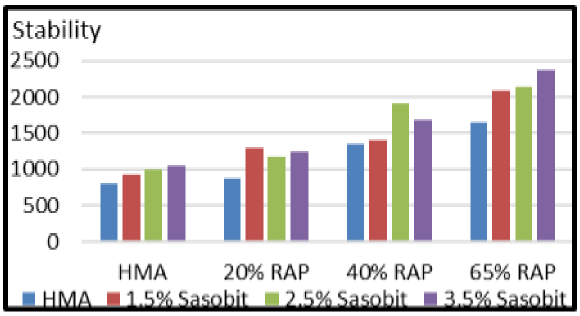


Fig. 1. Stability for different RAP content in mixture

Fig. 2 and 3 present a summary of Marshall Stability values for conditioned and unconditioned mixes prepared in this research. Fig. 2a and b show the stability for the conditioned mixes while Figs 3a and b show the stability of the unconditioned mixes. Each graph shows the whole results for the 16 mixes but in a different view. Fig. 2a and 3a show the results grouped by the RAP content used in the asphalt mix while Fig. 3b and 4b show them grouped by the Sasobit content. From Fig. 2 and 3, it was observed that the integration of RAP and WMA improves the stability performance by 94% for the conditioned mixes and 122% for the unconditioned mixes.



[1] Western Australia Specification

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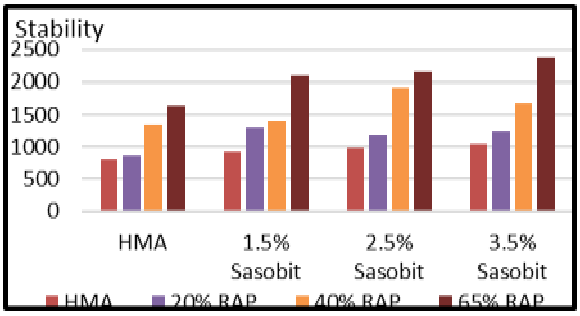
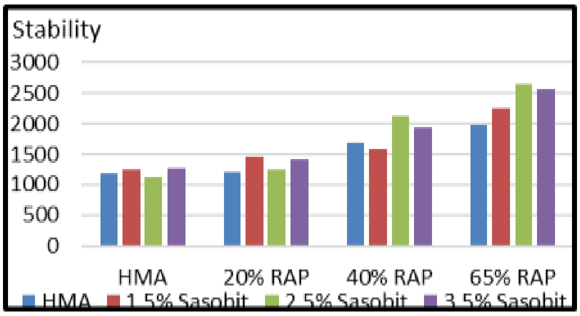


Fig. 2. Stability for conditioned mixes: a) Grouped by RAP %; b) Grouped by Sasobit %.



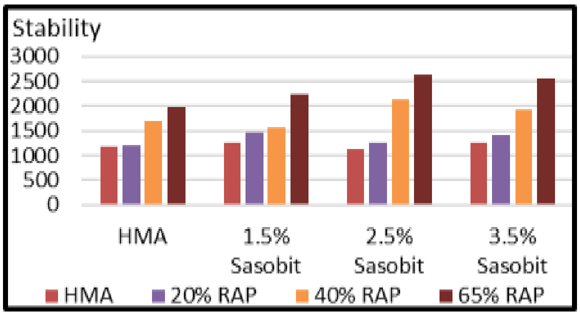
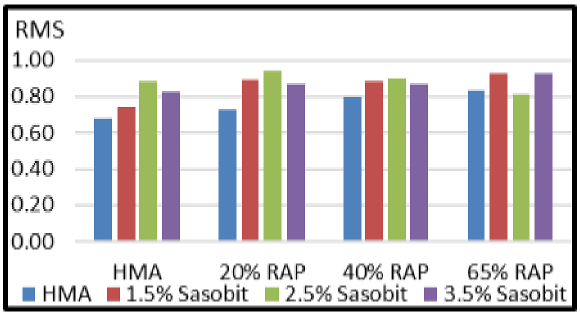


Fig. 3. Stability for unconditioned mixes: a) Grouped by RAP %; b) Grouped by Sasobit %.

From Fig. 2b and 3b, there is always noticeable increase in performance for the 40% and 65% RAP mixes for the different Sasobit % whether it is conditioned or unconditioned mixes. This trend could be obviously seen for the HMA, 2.5%, and 3.5% Sasobit. For the conditioned mixes, stability increased for the 40% RAP over the 20% RAP by 73% while the whole increase for the 2.5% Sasobit group is 117%. From Fig. 2a and 3a, another trend is observed, stability improves while increasing Sasobit content till the 2.5% Sasobit and then the stability decreases for the 3.5% Sasobit.

Fig. 4 present a summary of Retained Marshall Stability (RMS) values for mixes prepared in this research, the requirement of RMS for asphalt mixes should be greater than 80% [15] or 70 according to Nevada department of transportation [18]. Fig. 4a show the results grouped by the RAP % used in the asphalt mix while Fig. 4b show them grouped by the Sasobit content. Most of the mixes achieve the minimum requirement.

Fig. 4a shows a similar behavior to the previous Fig. 2a and 3a which that the RMS improves while increasing Sasobit % until the 2.5% Sasobit and then the stability decreases for the 3.5% Sasobit. Also, Fig. 4b shows the same behavior as per Fig. 2b and 3b which is the higher RAP content the better performance in stability and RMS. For Fig. 4b, A strange behavior for the 2.5% Sasobit seen and excluded from the analysis because it is opposite to the main trend of results, it could be an error in samples or in testing.



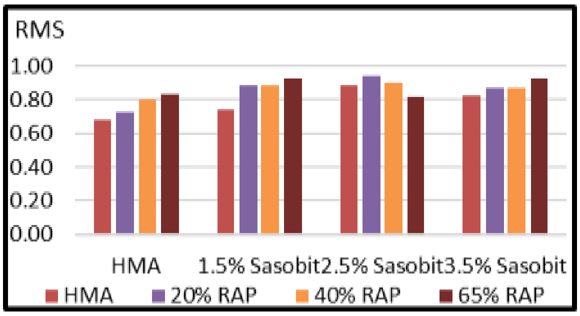


Fig. 4. RMS for mixes: a) grouped by RAP %; b) grouped by Sasobit %.

5. Conclusion

An integration of WMA and RAP were carried out at different combinations for a surface layer in this research, these combinations were evaluated by RMS procedure for evaluating the moisture susceptibility of different mixes. The following were concluded from the testing results:

- Integration of both WMA and RAP alone or together in the asphalt mix was very successful compared to the conventional HMA.
- The higher the RAP content in the mix the better improvement in stability for both the conditioned and unconditioned samples which leads also to an improvement in the RMS performance.
- WMA shows a similar trend to the RAP whereas increasing Sasobit content improves the mix performance but to a certain limit because the higher content of Sasobit stiffens the asphalt mixture.
- RAP has a better improvement to the mix than WMA and proved the possibility to construct a high-quality pavement with a similar performance to the conventional pavements even better.
- Based on the findings of this research it can be concluded that it is possible to design high-quality HMA with up to 65% RAP that meets the desired volumetric and performance requirements.
- Although the high results of stability this indicate more brittleness of the mix, this observation should be more investigated.
- Results shown here are a part of a large comprehensive study to encourage Egyptian highway agencies and contractors to integrate both WMA and RAP in the asphalt mix.

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