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Evaluating the Performance of Half Warm Asphalt Mixtures Using Reclaimed Asphalt Pavement (RAP)

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ABSTRACT

This paper introduces a study of producing Half –Warm Mix Asphalt (HWMA) using Reclaimed Asphalt Pavement (RAP) and make a comparison of the performance of HWMA and hot mix asphalt (HMA) with and without RAP .The study aims to reduce the consumption of natural aggregate resources using the materials from the damaged pavement. In addition, it discusses the environmental/economic impact by minimizing the gas emissions and fuel consumption, as HWMA can be produced at low temperatures. Three types of mixes were prepared for this purpose. The first was the conventional Hot Mix Asphalt (HMA), named control mix which was prepared at 155^{o}C and the second was the mix containing 70% RAP: 30% virgin aggregate and prepared at 155^{o}C, named HMA-RAP. The third mix was HWMA which contained 70% RAP: 30% virgin aggregate and prepared at 90^{o}C, named HWMA-RAP. HWMA was prepared using a binder modified with Ethoxylated NonylPhenol (NP9). The tried percentages of NP9 were 10, 15, 20, and 25% by weight of bitumen. Experimental tests were carried out to evaluate the engineering properties of mixes. All mixes were designed using the Marshall mix design method. Marshall stability and flow test, Indirect Tensile Strength (ITS) test, and Wheel Tracking test were conducted. The results showed that all mixtures achieved Marshall mix design limits. Producing HWMA-RAP increased Marshall stability, enhanced Marshall Quotient (MQ), and slightly changed the optimum asphalt content (OAC). A significant improvement was observed in ITS values for HMA-RAP and HWMA-RAP. The final rut depth of HWMA-RAP mixtures was almost as same as these values of the traditional mixtures. Finally , it can be concluded that HWMA-RAP performed as same as /better than the conventional mix.

Keywords: Half–Warm Mix Asphalt (HWMA); Reclaimed Asphalt Pavement (RAP); Hot Mix Asphalt (HMA); Marshall Test; Wheel Tracking Test.

1. INTRODUCTION

Most of the road network over the world are constructed using asphalt pavement. Thus, saving and reducing the cost of asphalt pavement manufacturing becomes essential with keeping its quality. The reclaimed asphalt pavement (RAP) plays a major role in saving costs by the reduction in natural resources consumption. Also, the use of RAP in pavement reduces the waste materials generated from the damaged pavement and leads to a reduction of its impact on the environment [1,2]. Due to the huge cost of virgin materials and asphalt binder, the modern techniques aim to provide new materials with high durability and performance at a low cost [3]. Use of RAP in both cold and hot asphalt mixes is considered a good alternative for cost reduction [4]. Recycling pavements had become one of the attractive pavement restoration alternatives in the world [5]. The percentage of RAP in hot mix asphalt (recycled mixtures) depends on various factors and it varied from 0 to about 100%. The previous studies noted that the desired percentage of RAP used in asphalt mixtures varied from 60:70% [6].

Producing HMA has a negative effect on the environment. Thus, various studies investigate another technique called warm mix asphalt (WMA) and half warm mix asphalt (HWMA). The concept of this technique is manufacturing asphalt mixes at low mixing and compaction temperatures [7]. WMA is produced and mixed at temperature range of 100 and 140°C, while HWMA ranges from 66-100°C [6]. Mixes produced using the WMA method are almost as same as or better than HMA in durability and performance [8]. Mallick et al. (2007) noted that WMA mixes prepared with RAP had similar properties compared to the conventional HMA mixtures [9]. It should be mentioned that the procedure of WMA and HWMA production is using additives such as organic and chemical additives. Chemical additives as polymers and emulsifying agents, improve the workability and compaction of bituminous mixes. Chemical additives reduce both of mixing and compaction temperatures of a mix. The WMA technology helps in reducing mixing temperatures by 20 to 30 ^{o}C compared to HMA due to chemical composition changes during the mixing process [10,11]. Therefore, in this study the chemical additive used in preparing HWMA is called Ethoxylated NonylPhenol (NP9).

Various studies investigated and analyzed the engineering properties of asphalt mixes prepared by a combination of RAP and modern techniques (WMA and HWMA). Some of these studies noted that the mixtures produced using RAP had higher modulus [12–20]. In Europe, studies evaluated the use of up to 60% RAP material in asphalt mixes [21–23]. Brock and Richmond (2007) classified the usage of RAP in asphalt mixes into five stages ranging from 0-50% RAP with intervals of 10% [24]. The Use of foamed bitumen to produce RAP–WMA mixes helps in increasing RAP content compared to other WMA investigations [25,26].The Maryland State Highway Administration (MSHA) constructed an asphalt pavement section of the road using 45% RAP in the base course and 35% in the surface wearing course using Sasobit as an additive. The study investigated that the stiffness of both WMA and HMA met the design specification limits [27]. The previous studies noted that the performance of WMA-RAP enhanced / as same as compared to conventional HMA mixes. The rutting performance of WMA-RAP was similar to that of HMA [28]. The use of surfactant additive resulted in improved rut resistance of WMA mixes[29]. Botella R.et al. (2016) conducted a study to produce HWMA at low temperatures with high percentages of RAP (50:100%).

The mixtures were manufactured at 100^{o}C and compacted at 80^{o}C with different percentages of RAP. The findings showed that the engineering properties, cracking resistance, and fatigue resistance was close to those expected from the conventional HMA mixtures [30]. Lizarraga et al. (2017) studied the mechanical performance of HWMA- RAP mixes [31].The results from the laboratory specimens and the site cores indicated that the performance of HWMA- RAP (70% and 100% RAP) is comparable to that of HMA. It encouraged greater confidence in promoting the use of these types of sustainable asphalt mixes. Also, Din and Mir (2020) studied the use of Copper Slag (CS) using RAP materials to produce WMA asphalt mixes and the results indicated that the engineering properties were enhanced compared to the control mixes [32].

Eloufy et al.(2022) [33] evaluated the use of NP9 on traditional HMA. This paper involves an extension of Eloufy et al.(2022) study and evaluates HWMA-RAP for wearing surface layer using a chemical additive (NP9).

2. OBJECTIVES OF THE STUDY

It is proved that the use of HWMA-RAP would be a sustainable solution, as it would result in lowering harmful gas emissions. This study aims to evaluate the performance of HWMA-RAP mixture compared to traditional HMA (with and without RAP).

3. MATERIALS

Pavement materials consist of asphalt binder and aggregates (Virgin and RAP).

3.1 Asphalt Binder

The used asphalt cement has a grade of 60/70 which was produced by El-Nasr Company –Suez City. The physical properties of the used bitumen are presented in Table 1.

Table 1: Physical Characteristics of Asphalt Binder

Property	AASHTO Designation No.	Result	Specification Limits
Penetration at 25 °C, (0.1mm)	T 49	66	60-70
Softening Point, °C	T 53	48	45-55
Flash Point, °C	T 48	270	≥ 250
Kinematic Viscosity at 135 °C, mm^2/s	T 201	426	≥ 320

3.2 Aggregate

The virgin dolomite aggregates used in this study were obtained from Attaka – Suez City. The aggregate gradation is presented in Figure 1,while Table 2 represents the physical properties.

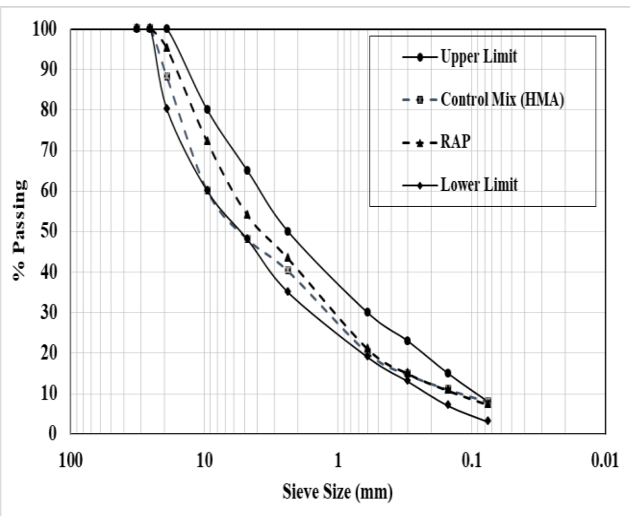

Figure 1: Aggregate Gradation for Control and Rap Mixtures

3.3 Reclaimed Asphalt Pavement (RAP)

The RAP used in this study was obtained from Arab-Contractor Company from the damaged pavement. Asphalt cement (AC) content was determined by the extraction test in accordance with ASTM D2172 [35]. The AC was 5.2%. The aggregates extracted from RAP were graded and then blended with virgin aggregates to fulfill the required gradation. The physical properties of RAP aggregate are shown in Table 2.

3.4 HWMA Additive

The selected HWMA additive was Ethoxylated NonylPhenol (NP9). The properties of NP9 are presented in Table 3.The tried percentages of NP9 were 10, 15, 20, and 25% by weight of bitumen.

Table 3: Properties of NP9, [33]

Chemical Formula	C15H24O
Molar Mass	220.35 g/mol
Appearance	Light yellow viscous liquid with phenolic smell
Density	0.953 g/cm3
Melting Point	-8 to 2°C
Boiling Point	293 to 297°C
Solubility in Water	6 mg/L (pH 7)

4. TESTING PROGRAM

Several tests were carried out to evaluate the performance of HWMA-RAP used in wearing coarse layer. These tests include the preparation of modified bitumen by NP9, Marshall test, Indirect Tensile Strength test and Wheel Tracking test.

Table 2: Aggregate Physical Properties (RAP and Virgin Aggregates)

Property	AASHTO Designation No.	Agg. (1)	Agg. (2)	RAP	Fine Aggregate (Sand)	Mineral Filler	Specification Limits (4C Mix) [34]
Los Angeles abrasion, %	AASHTO 96-(2006)	26.00	26.00	36.00	----	----	40 Max.
Bulk (S.G)	AASHTO (85-77)	2.551	2.572	2.394	2.490	2.75	----
Saturated and Dry Surface (S.G)	ASHTO (85-77)	2.631	2.619	2.428	2.532	----	----
Apparent (S.G)	AASHTO (85-77)	2.719	2.698	2.478	2.574	----	---
% Water Absorption	AASHTO (85-77)	2.40	1.80	1.40	1.30	----	5Max.

4.1 Preparation of Modified Bitumen Using NP9

This study is the continuation of the findings and the outcomes of Eloufy et al. (2022). In the study, the bitumen was prepared using NP9 with percentages of 10, 15, 20, and 25% by weight of bitumen. It was found that adding NP9 enhanced the workability by reducing viscosity at lower temperature (90°C) as presented in Table 4. The kinematic viscosity at 90°C and 135°C decreased with the increase in NP9 percentages. Viscosity at 10% NP9 decreased to 536 centistokes at 90°C which is almost near the value of virgin bitumen at 135°C.Therefore, all percentages of NP9 will be tried at a mixing temperature of 90°C.

Table 4: Properties of Binder Modified by NP9, [33]

NP9 %	Penetration at 25°C, (0.1mm)	Kinematic Viscosity, Centistoke	
		135°C	90°C
0.0%	66	426	--
0.5 %	62	317	1479
0.75 %	70	313	1472
1.0 %	79	309	1463
1.5 %	95	302	1455
1.75 %	103	296	1447
2.0 %	110	288	1442
3.0 %	137	285	1428
5.0 %	196	270	1341
10.0 %	222	105	536

4.2 Marshall Test

Marshall test was performed in accordance with ASTM D6927–15 [36]. Three different mixes were prepared and tested in the Marshall test. The first was a control mix mixed at 155°C with virgin aggregate (Control) and the second mix was HMA-RAP prepared at 155°C, while the third was mixed at 90°C (HWMA-RAP).The experiment was conducted on mixes that have been kept in a water bath maintained at 60°C for about 30-45 minutes. Finally, Marshall parameters ,stability, flow, air voids (AV%), voids in mineral aggregate (VMA %), mixture unit weight, and Marshall Quotient (MQ) were determined.

4.3 Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR) Tests

ITS test was carried out for all mixes, control, HMA-RAP, and HWMA-RAP in accordance with AASHTO T 283 [37] to determine ITS values. Half of the prepared specimens were immerged in water for 24 hours at 60°C (conditioned specimens). The rest half of the specimens were kept un-conditioned . All specimens (conditioned and un-conditioned) immerged in a water bath maintained at 25°C before testing. The loading is applied to the specimens at a constant rate of 50 mm/min. The TSR is determined using Equation (1) [38].

TSR% = (Conditioned Specimens ITS / Un-Conditioned Specimens ITS)*100 (1)

4.4 Wheel Tracking Test

This test provides information about the rate of permanent deformation from a moving concentrated load in accordance with AASHTO T324 [39]. This test measures the rut depth values and number of passes or times to the final rut depth.

5. RESULTS AND DISCUSSIONS

5.1 Marshall Test Results

The results of the Marshall test conducted on HWMA-RAP with different percentages of NP9 at optimum asphalt content (OAC), HMA and HMA-RAP are presented in Table 5. The maximum stability was obtained for the asphalt mix containing 10%NP9. Marshall Quotient (MQ) and flow for mixes with 10% NP9 were 359 kg/mm and 3.90 mm respectively. These values indicated that these mixes are flexible rather than those prepared without NP9. Although, all mixes were met the target limits for wearing surface at heavy traffic conditions [34]. The optimum value of NP9 can be selected as 10%. Thus, a comparative study for all three mixes was conducted. These mixes were HWMA-RAP which were prepared with 10% NP9 , the second was the control mix (HMA), and the third was HMA-RAP as shown in Figures 2 to 5. Figure 2 shows the values of Marshall stability for the three mixes. These values indicated that the highest value of Marshall stability was observed at HWMA-RAP mix with 1400 kg compared to 1215 kg and 1345 kg for the control and HMA-RAP mixes respectively. The increase in stability was 15.22% and 4.08%. Figure 3 shows Marshall flow values for the control, HMA-RAP, and HWMA-RAP mixes. The results showed that a significant change occurred using RAP in HMA and HWMA. Producing HMA containing

RAP aggregate changed the flow value from 3.20 mm to 2.90 mm with a reduction of 9.40%.While manufacturing HWMA -RAP at 90°C reduces this value to 3.90 mm with an increase of 21.88 %. MQ is an indication of mixture stiffness as it is the ratio of Marshall stability and Marshall flow. Figure 4 shows the results of MQ for all mixes, MQ value of the control mix (prepared with virgin aggregate at 155°C) was 380 kg/mm as a reference value. It was changed to 464 kg/mm and 359 kg/mm for HMA-RAP and HWMA -RAP respectively. Also, OAC slightly changed by the change of mix type, this value decreased by producing HWMA -RAP compared to the control mix as shown in Figure 5. From these findings, it can be noted that the production of HWMA using RAP aggregate made the mixture more flexible compared to the control and HMA-RAP mixtures.The results investigated that HWMA-RAP can resist cracks more than other mixtures.

Table 5: Marshall Test Results for HWMA-RAP, Control (HMA) and HMA-RAP at OAC

Marshall Properties	HWMA-RAP				Control , (HMA)	HMA-RAP	Specification Limit (Heavy Traffic)
	10% NP9	15% NP9	20% NP9	25% NP9			
OAC, %	5.80	5.90	6.10	5.50	5.90	5.5	4-7.50
Stability , Kg.	1400	1220	1190	1315	1215	1345	Min. 900
Unit Weight, gm/cm^3	2.35	2.36	2.36	2.35	2.35	2.34	---
Flow, mm	3.90	3.00	2.90	3.35	3.20	2.90	2-4
AV, %	3.00	3.50	3.70	2.80	3.60	3.30	3-5
VMA, %	16.9	16.6	15.8	18.0	16.3	16.8	Min. 15
MQ, kg/mm	359	407	410	393	380	464	200-500 [40]

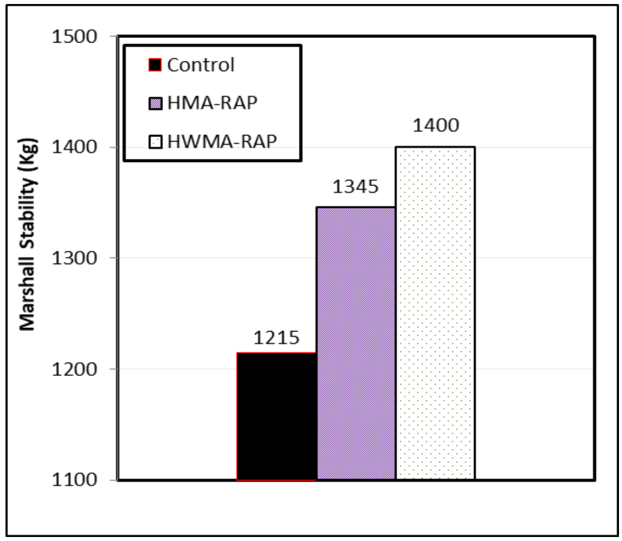

Figure 2: Marshall Stability for All Mixes at OAC.

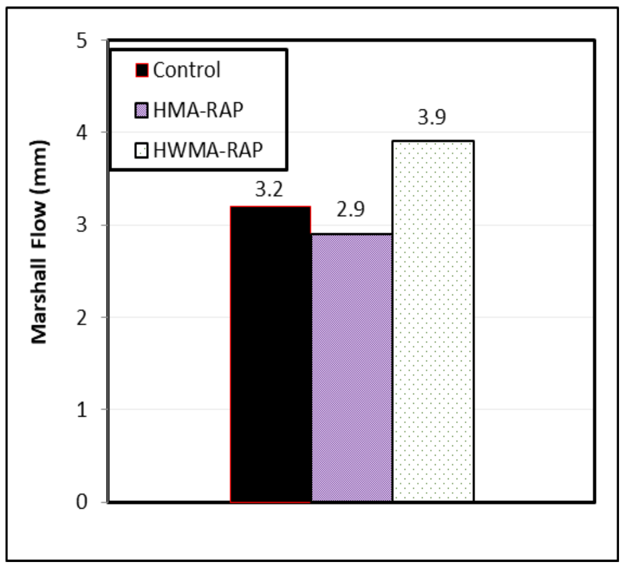

Figure. 3: Marshall Flow for All Mixes at OAC

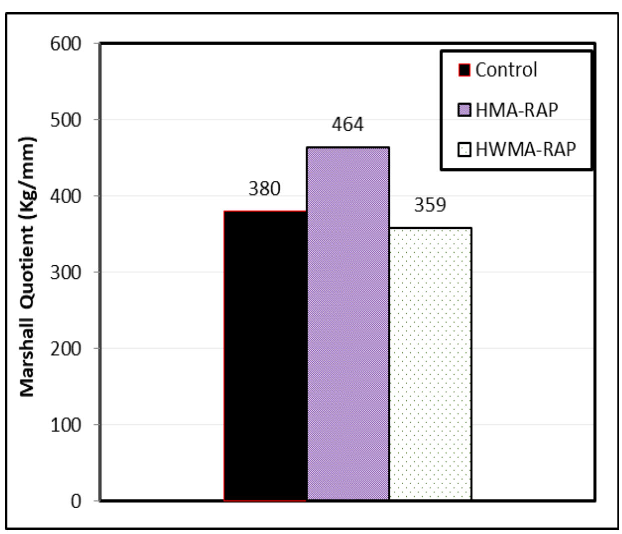

Figure 4: Marshall Quotient (MQ) for All Mixes at OAC

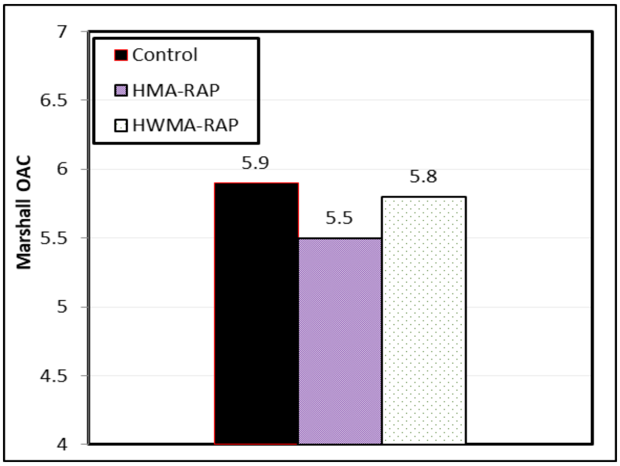

Figure 5: Optimum Asphalt Content (OAC) Values for All Mixes

5.2 ITS and TSR Tests Results

ITS test considers an indicator of the mixture performance and durability, as the reason for specimen failure is the weakness of adhesion between aggregate and bitumen. Thus, this study represents the behavior of mixtures prepared using RAP aggregate in both HMA and HWMA mixes. The results of the ITS test are shown in Figure 6, while Figure 7 shows the results of TSR %. The ITS value at HWMA-RAP slightly increased compared to the control and HMA-RAP mixes. Also, the conditioned specimens of HWMA-RAP recorded a TSR% value of 94% which was almost as same as both of control and HMA-RAP specimens. Also, it should be noted that, the tensile strength ratio values were found greater than 80% for all mixes indicating a cceptable resistance to moisture damage. However, the results noted that the production of HWMA using Rap aggregate introduced a good resistance against tensile splitting in both conditioned and un-conditioned mixes. TSR% values were almost as same as or better than the values of HMA and HMA-RAP mixes mixed at 150^{o}C.

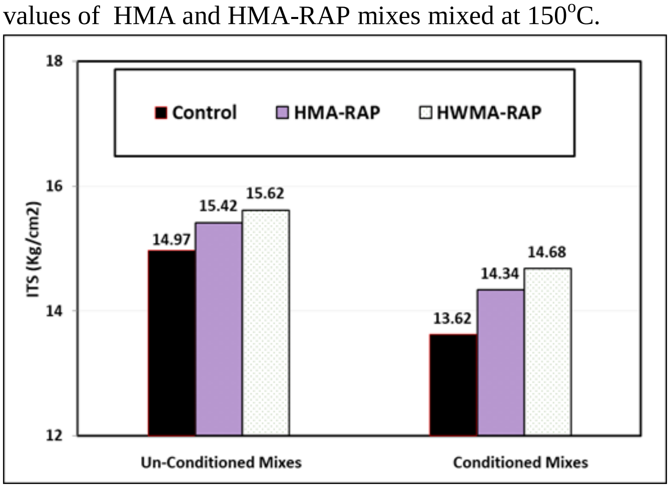

Figure 6: ITS Values for Conditioned and Un-Conditioned Mixes

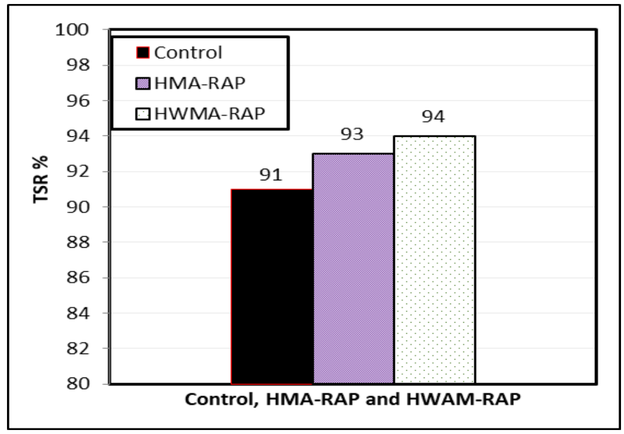

Figure 7: TSR % Values for All Mixes

5.3 Wheel Tracking Test Results

The wheel tracking test measures the susceptibility of mixtures to permanent deformation and it considers a destructive test. Figure 8 shows the relation between rut depth in mm and loading time in minutes for all mixes. While,the maximum rut depth values are shown in Figure 9. The results of the wheel tracking test showed that the values of final rut depth for control mixture as same as HMA-RAP mixture. In contrast, this value for HWMA-RAP was lesser than the value for control mixture by 2%. Therefore, it is inferred that HWMA containing RAP materials resists rutting as same as both control and HMA-RAP mixtures.

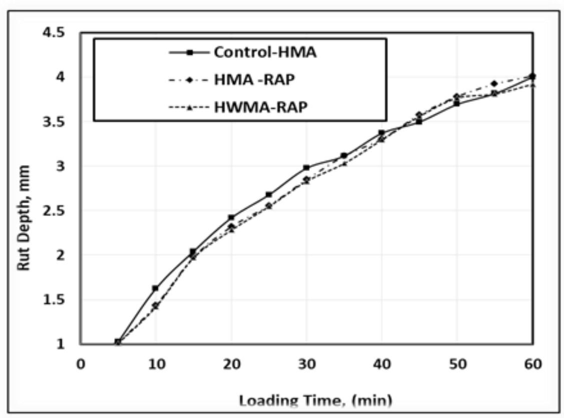

Figure 8: Rut Depth (mm) vs. Loading Time (min.)

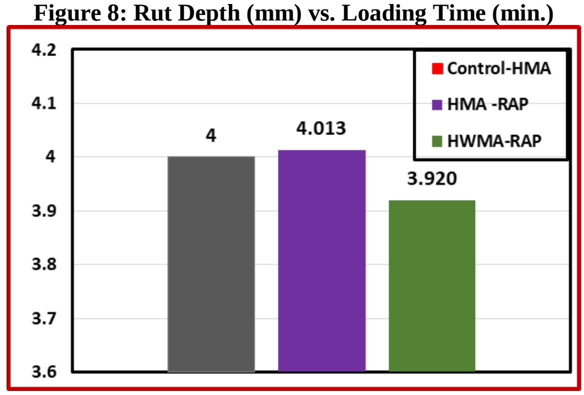

Figure 9: Final Rut Depth for All Mixes

5.4 Cost and Environmental Analysis

Eloufy et al.(2022) [33] found that producing HWMA without RAP costs 13% more than a conventional mix. Using RAP in producing asphalt mixes makes savings in both aggregate and added bitumen. The existing bitumen in recycled asphalt (5.2%) can save approximately about 60% of bitumen content. At current prices, aggregate and bitumen cost is about 10% and 70% respectively of the total cost of manufacturing asphalt mixes. Using 70% of RAP as a replacement of aggregate can save about 7% of the total cost. Bitumen existing in RAP can save about 42% of the total cost.Using RAP in producing HWMA saved about 49% of the total cost. From these results, HWMA-RAP saves about 36% of the total cost.In contrast, HWMA introduces an environmental benefit by reducing gas emissions. HWMA mixtures using NP9 at 90^{o}C reduced gas emissions for CO_2, NOx and VOCs by 28.66, 62.65 and 21.33% respectively, Eloufy et al.(2022) [33].

6. CONCLUSIONS

Based on the laboratory tests conducted on three different asphalt mixes, the following conclusions can be summarized:

1- Producing HMA-RAP and HWMA-RAP improved Marshall stability.

2- Marshall Quotient (MQ) decreased, due to the increase in both stability and flow.This reduction makes the mixture better against cracks.

3- OAC slightly changed for both HMA-RAP and HWMA-RAP.

4- The behavior of HWMA –RAP mixes in the ITS test was as same as the behavior of control and HMA-RAP mixes.

5- HWMA-RAP mixes resist rutting as same as the conventional mix.

6- Generally, HWMA-RAP performed as same as or better than conventional mixes.

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