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Development Of Environmentally Sustainable Warm Mix Asphalt Using Sasobit And Nanomaterials

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Abstract: Recent attention has been given to using alternative processes to reduce mixing and the compaction temperature without adversely affecting the final pavement product. Warm mix asphalt (WMA) is now an emerging solution to reduce production temperature, improve compaction as well as emission reduction. The aim of the research is to determine the impact of using Sasol wax additives " Sasobit®" on reducing mixing and compaction temperature by 20 -40 degrees lower than hot mix asphalt (HMA) of the surface course with both virgin aggregate and reclaimed asphalt pavement (RAP).
Within this study, Sasobit® is added with amounts ranging from 0.5% to 3% with an increment of 0.5% by binder asphalt weight; with virgin and reclaimed aggregate at three different temperatures(120 -130 -140 C). The results are compared to (HMA) of 150 ^{o}C. Also 0.50% of nano carbon and 9% of nano montmoronite and kilonit were tried. The results showed that adding Sasobit with 2% - for (RAP) mixture - the performance improves by20%. - for virgin mixture -stability increases by 45% more than control specimen at 130 ^{o}C. On the other hand; nanomaterials additives did not show any significance improvement.

Keywords: *Sasobit®, WMA, HMA, RAP, Sasobit®, nano silica, nano carbon.*

I. INTRODUCTION

Bitumen is a thermoplastic and viscoelastic material. Its deformation characteristics affected by load, with time rate of load application and temperature. It is neither elastic nor viscous in behavior. At low temperature it exhibits elastic behavior while at high temperature it exhibits viscous behavior (Gandhi et al.. 2008).

The neat binder lacks the proper viscous-elastic balance that usually occurs due to an effective elastic network created by molecular association. It is hypothesized that proper visco-elastic balance can be formed by creating molecular entanglement in a bitumen through the use of high molecular weight polymeric additive (Edwards et al., 2003).

Although the percentage of the binder is relatively small, the binder influences pavement performance more than the aggregate as environmental factors, such as high temperature due to solar radiation, and freeze at low temperature affects the binder more than the aggregate .(Gandhi et al. 2008).

The reclaimed asphalt pavement (RAP) is one of the most recycled materials in the world. But few societies understand that asphalt layers are completely recyclable and reusing of asphalt pavement, as well as other waste materials, which save great deal of money and valuable resources (SABA, 1992).

The first use of RAP for the road construction was date back to 1915 (Taylor. 1997). However, the development of reclaimed asphalt pavement usage occurred in the 1970's during the oil crisis, when the cost of the asphalt binder as well as the aggregate shortages where high near the construction sites (Sullivan, 1996). In 1997, with the Kyoto Protocol adaptation by parties and implementation in 2005, recycling received major attention and broader application in the road construction industry (Reyes et al., 2009).

The asphalt industry and its agency are constantly looking for methods to improve pavement performance, increase construction efficiency, conserve resources and advance environmental stewardship (Newcomb, 2007). To achieve these goals, warm mix asphalt (WMA) technologies, now under evaluation worldwide, tend to reduce the viscosity of asphalt and provide the mixing and compacting temperatures in the range of 20-55°C lower than typical hot mix asphalt (HMA) (D'Angelo et al., 2008).

Sasobit®is manufactured by Sasol Wax in South Africa the most common wax additive in WMA in the United States, Its molecular chain length ranges from 40 to more than 115 carbons atoms. (Sasol Wax, 2008). Sasobit® is a Fischer-Tropsch wax, which is a synthetic aliphatic hydrocarbon wax by heating coal or natural gas with water to 180 to 280 °C (356 to 536 °F) in the presence of a catalyst (D'Angelo et al. 2008)

II. OBJECTIVES

- Study the behavior of recycling materials in road construction.
- Study the effect of adding relatively high percentages of reclaimed aggregate pavement (RAP) to warm mix asphalt (WMA)
- Reduce mixing and compaction temperature using warm mix additives.

- Compare the performance of using additives with virgin and reclaimed aggregate.

III. BACK GROUND

Addressing using recycled asphalt pavement (RAP) incorporated with wax additives into HMA mixture to face the challenge of increasing the cost of raw materials and to gain environmental friendly mixture. The Federal Highway Administration (FHWA) and the Environmental Protection Agency (EPA) report 80 percent of the removed asphalt pavement is reused of new roads (FHWA, 1993).

Transportation agencies have developed construction specifications that allow asphalt producers to add RAP to HMA, but only up to 25 percent. However, increasing the RAP content in pavements may increase the inconsistency of the HMA end product (NCHRP 2001).

Penny (2006) evaluated the use of heated RAP materials with emulsion and the use of HMA with Sasobit as base course materials. The use of Sasobit helped to achieve almost similar work abilities and compatibilities at lower temperatures, as compared to those of HMA with neat asphalt binder. There was no substantial difference between the modulus of the Sasobit and hot mix asphalt samples. In another study of using 100% RAP HMA as a base course (Tao and Mallick, 2009), the workability of RAP was improved at temperatures as low as 110^{o}C with the addition of Sasobit®.

The main parameter to produce hot mix is to provide sufficient temperature which reduces the viscosity of the asphalt to effectively coat the aggregate and allow compaction of loose mix. WMA achieves adequate coating by reducing the asphalt viscosity in a number of ways. A 2002 examination tour of Europe by councils of FHWA, National Asphalt Pavement Association (NAPA), Asphalt Institute (AI), and contractors and consultants acknowledged four WMA technologies: Aspha-Min, Sasobit®, Asphaltan-B, and WAM-Foam. A follow up WMA scan tour of Europe in 2007 identified at least 12 technologies (Prowell 2007).

Kanitpong et al. (2007) studied the properties and performance of paraffin (Sasobit®) modified binders and mixes found: the mix workability was improved, particularly with polymer modified binders, enhanced the resistance to densification under traffic load, and a (however, at low temperatures certain damage was detected, may be due to the effects of confined moisture in the mix).

Austerman et al, (2009) showed that the addition of 1.5% Sasobit altered the Performance grade of the base binder from a Performance grad 64-28 to a PG 70-22 and addition of 3.0% Sasobit changed the PG to a PG 70-16. The addition of Sasobit reduced the viscosity of the binder, with the largest viscosity reduction occurring with the dosage of 3.0% Sasobit. The decreases of binder viscosity and improvement in binder grading without increasing the viscosity indicates a reductions in temperatures by Sasobit (Wasiuddin et al. 2007).

(Hakseo,K,2010) pointed in his research that the use of styrene butadiene styrene (SBS) modified asphalt mixtures and combine it with the relatively new warm mix asphalt (WMA) technology. Two WMA technologies, micro water (Aspha-min) and synthetic wax (Sasobit) based, were used to assess their efficiency in SBS modified asphalt mixtures. Consequently, the addition of Sasobit significantly decreased the viscosity of the binders at 135°C while the addition of Aspha-min increased the viscosity of the binders due.

A research by Ahmad, K, et al. (2013); was carried out to determine if the addition of warm mix asphalt additive (sasobit®) affects the stiffness of the virgin bitumen on increasing the amount of reclaimed asphalt pavement (RAP), used with sasobit-additive, which indicated that the addition of sasobit on virgin binder increases the stiffness at low and intermediate temperatures. The same trend was observed at high service temperature of 135°C.

The U.S. National Nanotechnology Initiative stipulates that Nanotechnology involves research and technology development at the atomic, molecular, or macromolecular levels, the length scale of approximately 1 to 100 nm (nanometer) range, to provide a fundamental understanding of phenomena and materials at the nano-scale and to create and use structures, devices, and systems that have novel properties and functions because of their small and/ or intermediate size (Mann, 2006).

Nanotechnology therefore allows the design of systems with high functional density, high sensitivity, special surface effects, large surface area, high strain resistance, and catalytic effects. All attributes are directly or indirectly the result of the small dimensions of nano-particles (Teizer, 2012).

Amorphous nanosilica is qualified as nanobiopesticides. Silica nanoparticles have been used in the industry to reinforce the elastomers as a rheological solute (Chrissafis et al. 2008) and cement concrete mixtures (Quercia&Brouwers, 2010). Silica nanocomposites have been attracting some scientific interest as well. The advantage of these nanomaterials resides in the low cost of production and in the high performance features (Lazzara et al. 2010).

The addition of nanosilica into the control asphalt improved the recovery ability of asphalt binders. The low-temperature grade of nanosilica modified asphalt binder was the same as the control asphalt binder, and the properties and stress relaxation capacity of nanosilica modified asphalt binder was the same as the control asphalt. The anti-aging performance and fatigue cracking performance of nanosilica modified asphalt binder and mixture were enhanced and the rutting resistance and anti-stripping property of nanosilica modified asphalt mixture were also enhanced significantly. Meanwhile, the addition of nanosilica into the control asphalt binder did not greatly affect the low-temperature properties of asphalt binders and mixtures (Yao et al. 2012b).

Nanostructured carbon materials, including carbon nanotubes (CNTs), carbon nanofibers (CNFs), graphene (GR), graphene oxide (GO), and fullerene, are promising elements that can be used in many practical areas (Hanus ,M. J., et al 2013), (Chen,S. J., 2011). many researches point that using nano silica and nano carbon with RAP cold in place mixture increase the mixture properties as percentage of 7%, nanosilica and 0.50% nanocarbon so the addition of optimum temperature with sasobit optimum percentage in virgin and RAP mixtures is prepared to investigate the effect of adding nano materials at lower temperature than conventional hot mixture. Among more recent additives used to reduce oxidative aging is nano-clay (montmorillonite, kilonite), nano-clay has been used commonly in the adhesive and polymer industry to enhance their mechanical and physical properties such as stiffness, toughness, strength and thermal stability.(Lee et al ,2005).

(Roy et al. 2007) enhanced the compressive and shear strength of thermoplastic polymers using only a small weight percent of nanoclay reinforcement. When the polymer penetrates between the adjacent layers of the nanoclay, the gallery spacing is increased and the resulting morphology is an intercalated structure.

Worker health benefits result from an improved worker environment with reduced worker exposure to fumes and aerosols, and temperature during placement and compaction, which may lead to greater productivity and worker retention (D'Angelo et al. 2008, Perkins 2009). Environmental and economic benefits were gained by using additives and reduce the temperature with reduce energy consumed and reduction in $_{CO2}$ emissions, and resulting reduction Burner fuel savings with WMA typically range from 20 to 35%, with 50% being possible for some technologies (D'Angelo et al. 2008, Mallick et al. 2009).Emissions such as $_{CO2}$ and dust are reduced when lower temperatures are used in the plant. Reductions of $_{CO2}$ can range from 15 ~ 40% and dust can be reduced by 25 ~ 50% (Perkins 2009).

IV. METHODOLOGY

The aim of this study is to evaluate the laboratory performance of using additives Sasobit® with different amounts/percentages to reduce HMA temperature for both virgin and reclaimed aggregate. To fulfill the aforementioned purpose, gradation of materials took place to use in marshal stability test and in turn to determine the volumetric properties of the mixture.

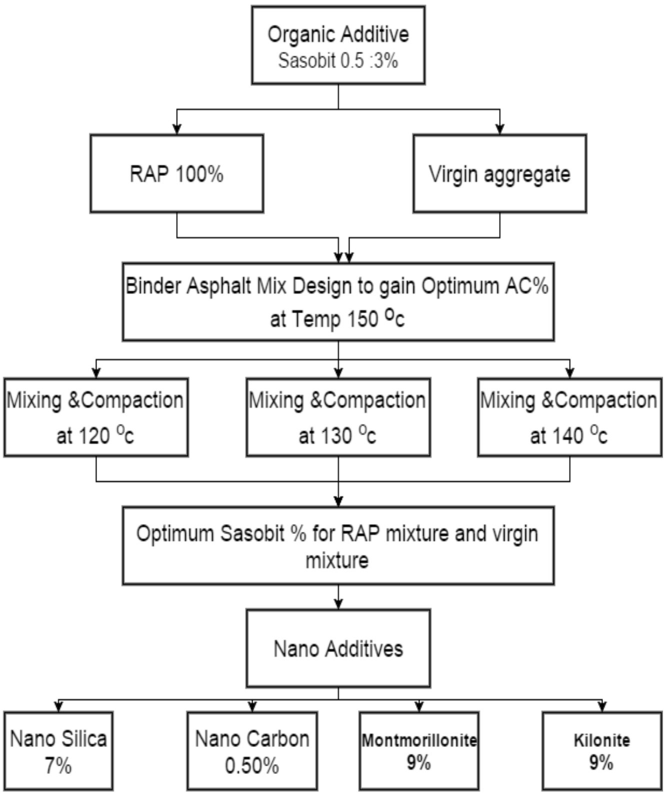

Figure 1: Experimental work plane

4.1 Material

Virgin aggregate selected for granular surface course in Cairo was used for this study. Gradation and engineering properties of the gravel aggregates are given in Table 1. to achieve the job mix formula of aggregate

The proportioning of course aggregate class1 of 37 and class2 of 18%,naturalsand of 25% with manufactured sand of 20%The virgin aggregate was subjected to sieve analysis using AASHTO T27 sieve analysis for fine and coarse aggregates.

Table 1: Gradation of virgin aggregate

Sieve size	Passing%	specification	
1"	100	100	100
3/4"	91	80	100
1/2"			
3/8"	71	60	80
No.4	61	48	65
No.8	40	35	50
No.30	28	19	30
No.50	22	13	23
No.100	8	7	15
No.200	6	3	8

Reclaimed aggregate selected for granular surface course in Cairo was used for this study. The proportioning of reclaimed aggregate pavement (RAP) was 83% and virgin aggregates with 12% manufactured sand and 5% powder to achieve the mix aimed job mix formula. The reclaimed aggregate was subjected to sieve analysis using AASHTO T 27 as shown in Table 2.

Table 2: Gradation of reclaimed aggregate

Sieve size	Passing%	Specification	
1"	100	100	100
3/4"	100	80	100
1/2"	100	100	100
3/8"	91	80	100
No.4	57	55	75
No.8	40	35	50
No.30	24	18	29
No.50	18	13	23
No.100	8	8	16
No.200	5	4	10

Asphalt binder using asphalt 60/70 as binder with both virgin and reclaimed aggregate with sasobit wax additives at different temperature ranges, to get the effect of sasobit percentages the following tests were submitted and give the results as in the following Table 3.

Table 3: Effect of incorporation of sasobit wax to bitumen 60/70

Sample	N1	1	2	3	4
Asphalt (60/70) ,%wt	100	99.0	98.5	98.0	97.5
Sasobit ,%wt	0.0	1.0	1.5	2.5	3.0
Penetration , dmm	64	50	46	42	40
Softening point , ^{o}C	47.8	52.6	66.9	75.9	84.6
Ductility cm	>100	>100	>100	100	96
Brookfield Viscosity@135 ^{o}C,cP	385	338	332	325	305

4.2 Experimental work

The mix design of virgin aggregate proportions with asphalt binder of 4 to 6% with an increment of 0.50 to determine the optimum asphalt binder content to meet the requirements for stability of 900 kg, maximum density, flow (0.01") range (8 - 16), Air voids range (3 - 5) and minimum void mineral aggregate of 15 % the properties of the designed mix is shown in Table 4 and the optimum values is presented in Figure2.

AC%	Unit weight	AV	VMA	Stability	Flow
4.0	2.313	5.95	14.67	338	13.5
4.5	2.315	5.26	15.03	670	12.3
5.0	2.317	4.54	15.36	1666	8.8
5.5	2.314	4.04	15.87	1325	5.6
6.0	2.312	3.50	16.33	1031	5.1

Table 4: Mix design of virgin aggregate

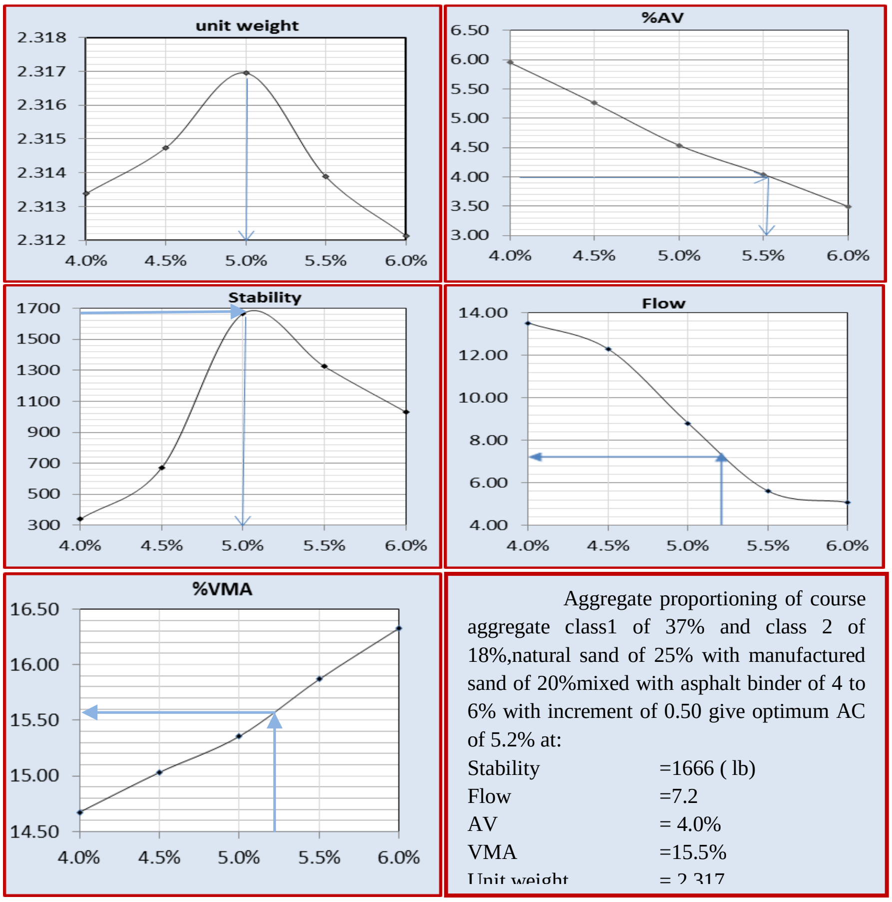

Figure 2: Virgin mix design charts

Table 5 presented the optimum mix results with percentages of Sasobit® of 0.5% to 3 % with an increment of 0.5% by binder asphalt weight at the different temperatures of 120 -130 -140 ^{o}C; compared to control at 150 ^{o}C.

Table 5: Stability (bi) of virgin mixture

Stability of virgin aggregate mix						
Temp ^{o}C	Sasobit %					
	0.5	1	1.5	2	2.5	3
120	884	1118	1318	1405	1622	1482
130	1232	1670	1792	1967	2276	2120
140	1195	1425	1687	1918	2551	2266
150	1574	1574	1574	1574	1574	1574

The results shows that at 2.5% sasobit a small improvement occurred at 120^{o}C; better results manifested at 130^{o}C at sasobit percentage ranging from 1 to 3% with 45% increase in stability value at 2.5%. At 140^{o}C, the same trend as 130^{o}C mixtures occurred with 62% increase in stability.

Table 6: Flow (0.01") of virgin mixture

Flow of virgin aggregate mix						
Temp °C	Sasobit %					
	0.5	1	1.5	2	2.5	3
120	16.5	13.7	11.6	8.1	7.6	7.3
130	11.6	10.2	9.5	9.0	8.5	8.4
140	12.5	10.6	8.9	7.1	6.3	5.8
150	6.8	6.8	6.8	6.8	6.8	6.8

Table 6 showed that at 120 and 130°Cthe the flow values decrease with the increase of Sasobit percentage within limits, while at 140 °C with increase in Sasobit from 2 to 3% the flow has lower values than the limits.

Table 7: AV% of virgin mixture

%AV of virgin aggregate mix						
Temp °C	sasobit %					
	0.5	1	1.5	2	2.5	3
120	6.2	5.3	4.5	3.8	3.4	3.0
130	6.7	5.4	4.5	3.7	3.2	3.0
140	6.9	5.1	4.2	4.0	3.8	3.6
control	5.8	5.8	5.8	5.8	5.8	5.8

Table 7 indicated that for all different temperatures of 120 -130 -140 °C air voids values are more than the upper limit values at 0.50% and 1% of Sasobit while other Sasobit percentages achieved the code limits.

Table 8: Unit weight of virgin mixture

unit weight						
Temp °C	sasobit %					
	0.5	1	1.5	2	2.5	3
120	2.372	2.380	2.388	2.391	2.386	2.383
130	2.358	2.378	2.386	2.394	2.392	2.384
140	2.354	2.386	2.394	2.384	2.377	2.367
150	2.397	2.397	2.397	2.397	2.397	2.397

As shown in Table 8 the maximum unit weight of the mixtures occurs at 2% sasobit for 120 °C, 130°C and at 1.5% for 140°C.

Table 9: VMA of virgin mixtures

%VMA of virgin aggregate mix						
Temp °C	sasobit %					
	0.5	1	1.5	2	2.5	3
120	15.9	15.7	15.9	16.3	16.9	17.5
130	16.1	15.8	15.9	16.2	16.7	17.4
140	16.2	15.6	15.7	16.5	17.2	18.0
control	14.3	14.3	14.3	14.3	14.3	14.3

The results presented in Table 9 showed that the void mineral aggregate increase with Sasobit percentage increase; except at 0.50% Sasobit has a little increase in void mineral aggregate than 1% Sasobit.
Mix design of Reclaimed aggregate proportions with asphalt binder of 4.75 to 6% with increment of 0.25 to determine the optimum asphalt binder content to meet the requirements for stability of 900 kg, maximum density, flow (0.01") range (8 - 16), Air voids range (3 - 5) and minimum void mineral aggregate of 15 % see Table 10 and Figure 3.

Table 10: Mix design of reclaimed aggregate

AC%	Unit weight	AV	VMA	Stability	Flow
4.75	2.349	5.84	14.58	1109	9.63
5.00	2.355	5.27	14.62	1266	9.45
5.25	2.367	4.41	14.40	1584	8.73
5.50	2.375	3.73	14.34	1816	8.63
5.75	2.392	2.68	13.96	1644	7.67
6.00	2.383	2.66	14.48	1620	7.29

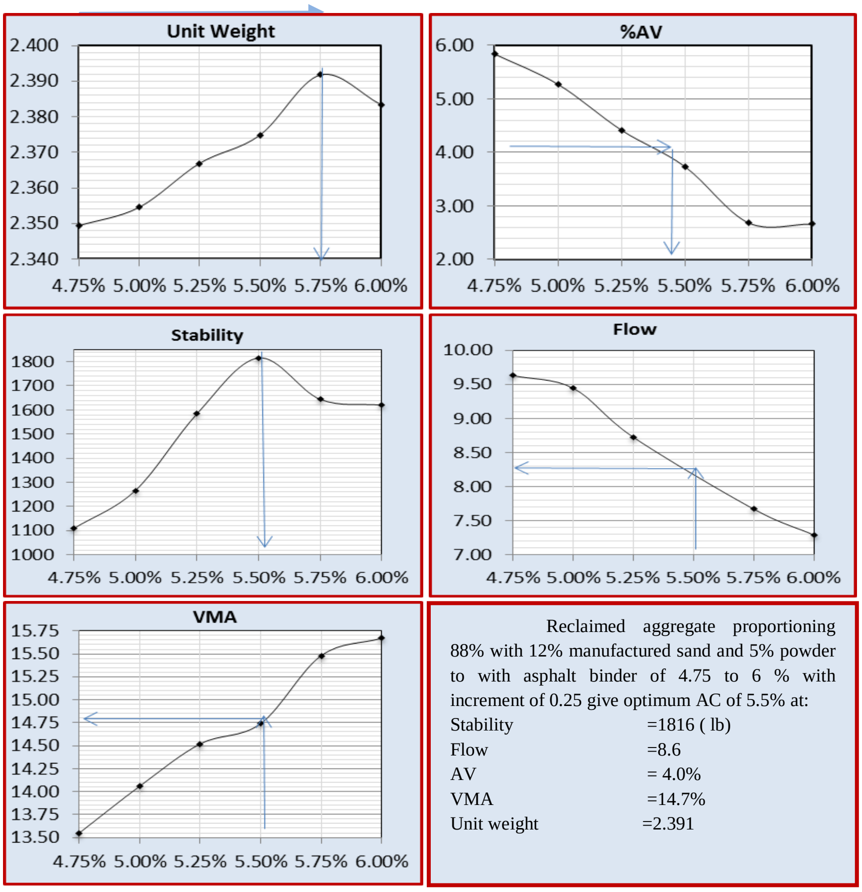

Figure 3: RAP mix design charts

Table 11 shows the mix design results with percentages of Sasobit of 0.5% to 3 % with an increment of 0.5% by binder asphalt weight at different temperature of 120 -130 -140 ^{o}C compared with control (HMA) of 150 ^{o}C.

Table 11: Stability (lb) of (RAP) mix

Stability of (RAP) mix						
Temp ^{o}C	Sasobit %					
	0.5	1	1.5	2	2.5	3
120	0	0	0	0	0	0
130	820	1182	1708	2164	2034	1693
140	1301	1548	1651	2044	2281	1944
150	1816	1816	1816	1816	1816	1816

For mixture at 120 ^{o}C the mixture failed to act as other mixtures at lower temperature due to the binder in reclaimed aggregate is not completely melted. Stability increase - in ascending order - at 130^{o}c with maximum increase of 20% at 2% Sasobit and at 140^{o}C increase of 26% at 2.5% sasobit (Table 11).

Table 12: Flow (0.01") of (RAP) mix

Flow of (RAP) mix						
temp	Sasobit %					
	0.5	1	1.5	2	2.5	3
120	0.0	0.0	0.0	0.0	0.0	0.0
130	15.9	15.0	13.3	11.6	10.6	8.8
140	14.0	13.5	12.8	12.1	10.7	9.8
150	8.6	8.6	8.6	8.6	8.6	8.6

Table 2 showed that the flow values decrease with the increase of sasobit percentages and within the code limits but more than control values.

Table 13: AV% of (RAP) mix

Percentage of air voids of (RAP) mix						
temp	sasobit %					
	0.5	1	1.5	2	2.5	3
120	0	0	0	0	0	0
130	6.8	5.9	5.3	4.7	4.6	4.5
140	6.1	5.0	4.3	3.2	3.0	2.8
150	5.7	5.7	5.7	5.7	5.7	5.7

Air voids at 130 ^{o}C and 140^{o}C performed as required by the code limits except at 0.50% and 1% of sasobit where results were marginally more than limits.

Table 14: Unit weight of (RAP) mix

Unit weight of (RAP) mix						
Temp ^{o}C	sasobit %					
	0.5	1	1.5	2	2.5	3
120	0	0	0	0	0	0
130	2.355	2.364	2.367	**2.368**	2.356	2.347
140	2.365	2.380	2.383	**2.398**	2.388	2.380
150	2.391	2.391	2.391	2.391	2.391	2.391

Table 14 presented that the maximum unit weight of the mixtures occurs at 2% sasobit for 130and 140^{o}C.

Table 15: VMA of (RAP) mix

%VMA						
Temp ^{o}C	sasobit %					
	0.5	1	1.5	2	2.5	3
120	0	0	0	0	0	0
130	16.2	16.3	16.7	17.1	17.9	18.7
140	16.1	16.0	16.4	16.3	17.1	17.8
control	14.7	14.7	14.7	14.7	14.7	14.7

The results showed that the VMA increase with Sasobit percentage increase except at 0.50% sasobit shows a marginal increase in the void mineral aggregate than 1% sasobit at 140^{o}C as presented in Table 15.

Table 16: Virgin mixtures of optimum Sasobit with nanomaterials

Fresh Mixture With Nanomaterials					
	Stability	Flow	AV%	Unit Weight	VMA
2.5% Sasobit at 130 ^{o}C	2276	8.5	3.2	2.392	16.7
Control at 150 ^{o}C	1574	6.8	5.8	2.397	14.3
Montorolnite	1358	10.1	4.2	2.367	17.5
Kolinit	1429	9.8	3.2	2.390	16.7
NanoSilica	1733	9.8	3.1	2.393	16.6
NanoCarbon	1534	10.3	4.2	2.367	17.6

Adding the nanomaterial presented in Tables 16 for virgin mix shows in the following table nanomaterials does not have a significant effect on the mixtures stability even there is a small improvement in stability versus control in case of using Nanosilica. In spite of this effect, an improvement takes place in flow, air voids, unit weight and void mineral aggregate more than control limitations.

Table 17: RAP mixtures of optimum sasobit with nanomaterials

RAP Mixture With Nano Materials					
	Stability	Flow	AV%	Unit Weight	VMA
Sasobit 2.0% at 130 °C	2164	15.9	4.7	2.368	17.1
Control at 150 °C	1816	8.6	5.7	2.391	14.7
Montorolnite	1575	14.2	3.9	2.379	17.0
Kolinit	1693	9.2	3.4	2.386	16.9
NanoSilica	1538	11.8	3.1	2.393	16.6
NanoCarbon	1871	12.1	3.9	2.374	17.3

In the same trend Table 17 for RAP mix, no effect of using nanomaterials in stability of mixtures with Sasobit additives, compared with control mix Nano carbon, has a little increase in stability than control. On the other hand, improvement of mixture performance as air voids improved which lead to better compaction performance and increase density of the mixture. Furthermore, voids mineral aggregate meet the minim requirement.

V. ANALYSIS OF RESULTS

Results of this research provide an improvement of mixing and compaction at low temperature for both virgin and reclaimed mixtures.

5.1 Analysis of stability results

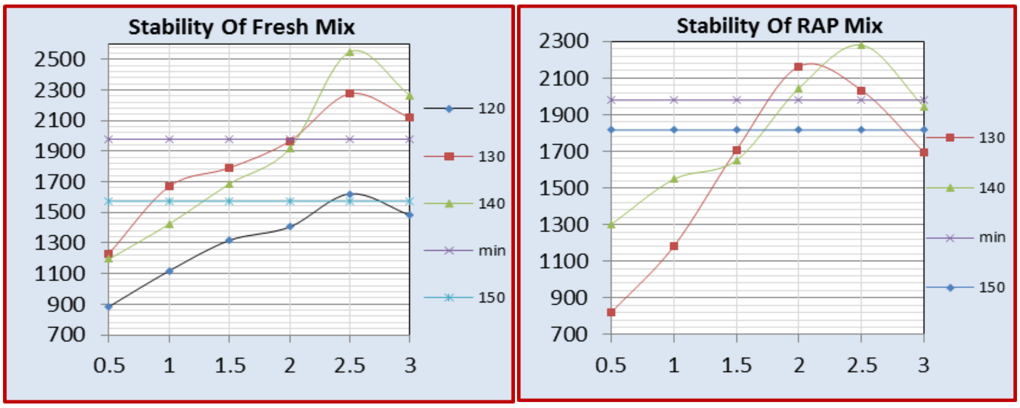

Figure 4: Stability of virgin and RAP mixtures

5.1.1 Virgin Mix

As shown in Figure 4 the gained stability of laboratorial data for virgin mixture sat different percentages of sasobit additives with mixing temperature of 120 -130 -140 °C. At 120°C, the mixture tends to fail to act as a control specimen for different Sasobit percentages. In addition, it does not meet the minimum requirements. At 130°C,the mixture gives the best stability values at Sasobit percentages of 0.50 to 2%, yet still less than the control and minimum requirements.At2.5% an increase in stability of 45% and at 3% meets the requirements yet starting to down wards to 35% increase in stability. At a temperature of 140°C,the mixture gives a stability increase of about 62%at 2.5%of Sasobit while decreases again to give 44% at 3% Sasobit.

5.1.2 RAP Mix

As shown in Figure 4, the gained stability of laboratorial data for RAP mixtures at different percentages of Sasobit additives with mixing temperature of 120 -130 -140 °C.

At a relatively low temperature of 120 °C, there claimed aggregate does not melt with the asphalt content causing non-binding. The mixture is thus incoherent and failed to be tested. At temp of 130 °C, stability had the same trend with a maximum increase of 20% at Sasobit 2% and 15% at 2.5%.At a temperature of 140 °C, the mix still has a stability better than at 130 °C yet less than the requirements; with a maximum increase of 15% at Sasobit 2% and 26% at 2.5%.

5.2 Analysis of Flow results

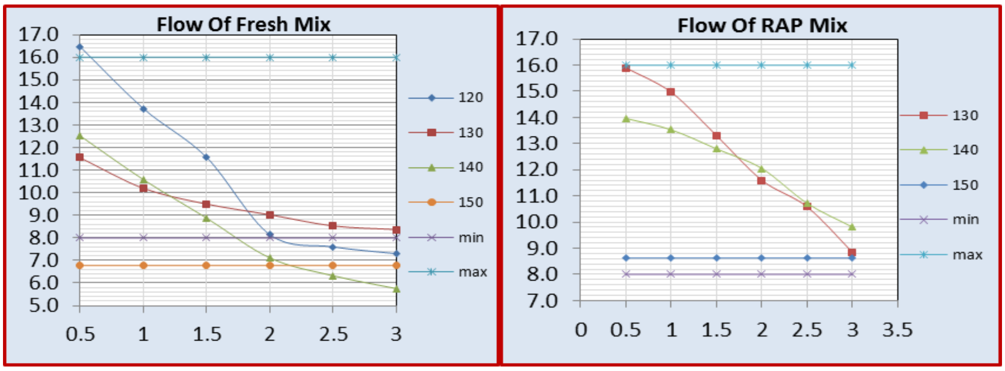

Figure 5: .Flow of virgin and RAP mixtures

5.2.1 Virgin Mix

As shown in the Figure 5 the flow improved for all tested temperatures till 2% Sasobit. Negative effects occur after that except at temp of 130^{o}C .Ata temperature of 120^{o}C, flow values fall between the requirement and control limits till 2% sasobit and failed to meet the requirements at 2.5;3% due to decrease in density than the control value. At temp of 130^{o}C all flow values meet the requirements with higher values than the control. At temp of140^{o}Cthe values decrease with the increase of sasobit percentages but failed to act within the limitation at 2,2.5 and 3% sasobit.

5.2.2 RAP Mix

As shown in Figure 5 the gained flow of laboratorial data for RAP mixtures at different percentages of Sasobit additives improved with mixing temperature of 120 -130 -140 ^{o}C. At a temperature of 120^{o}Cthe mixture failed. At a temperature of The 130^{o}C flow decreases with the increase of Sasobit percentages and has best value of about 25% decrease at sasobit 3%.At a temperature of 140^{o}C,the mixtures meet the requirement limits with increase than the control value .

5.3 Analysis of %AV results

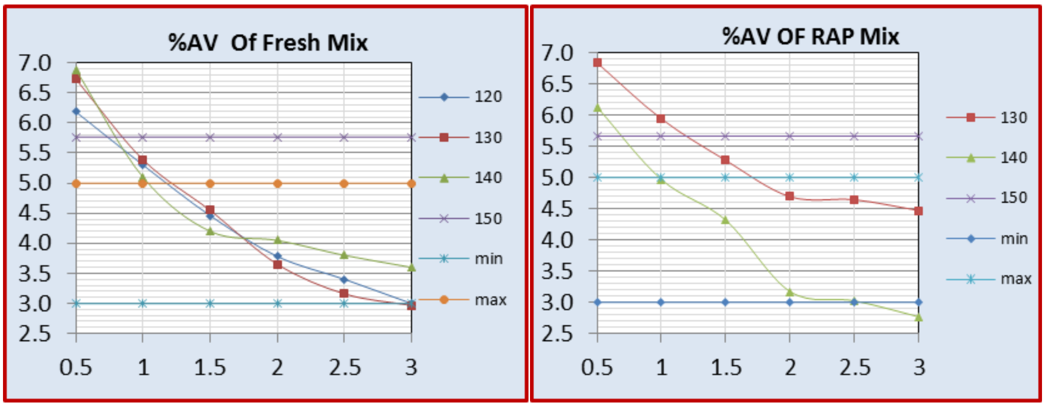

Figure 6: AV% of virgin and RAP mixtures

5.3.1 Virgin Mix

Adding sasobit improves air voids due to improving compaction the same trend for air void percent start at 0.50% Sasobit out the limitation and decrease air voids fall within range with increase in Sasobit percentage for the entire temperature range (see Figure 6).

5.3.2 RAP Mix

Air void improved with high percentage of sasobit from1.5% at temp 130^{o}Cand fall between the limitation ,at high temperature 140 observed that to improve air voids need close range of Sasobit from (1 to 2.5)% (see Figure 6).

5.4 Unit weight for virgin aggregate and RAP laboratory data.

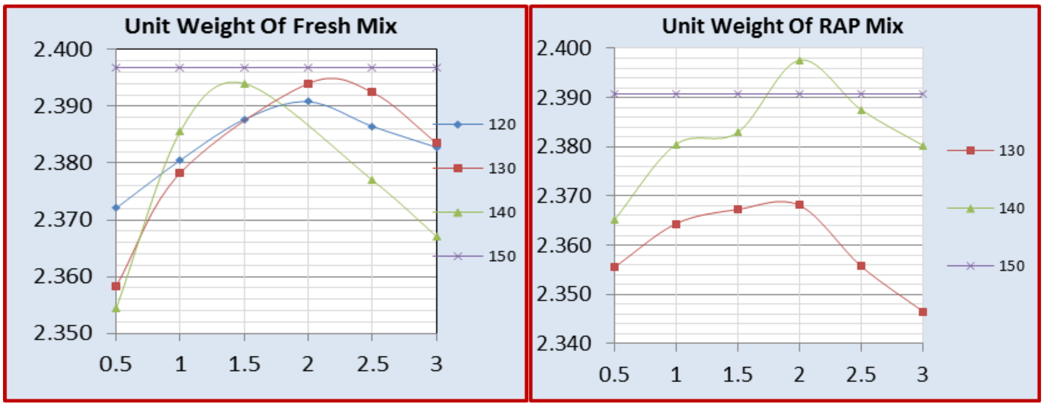

Figure 7: Unit weight of virgin and RAP mixtures

5.4.1 Virgin Mix

Figure 7 presented the different temperature and as it shows that density is less than the control mix.

5.4.2 RAP Mix

Figure 7 presented the different temperature and as it shows that density is less than the control mix. Lower density for both 130°C and 140°C than the control, small improvement occurs for temperature 140°C at 2% Sasobit.

5.5 VMA for virgin aggregate and RAP.

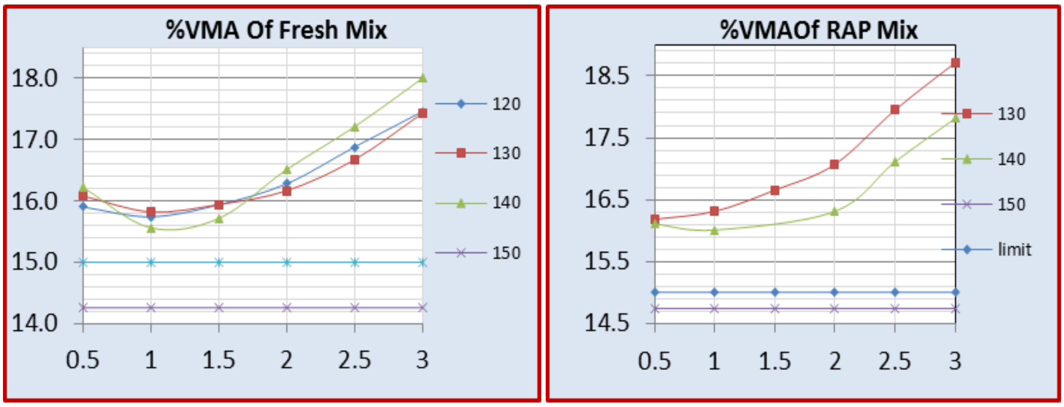

Figure 8 : VMA of virgin and RAP mixtures

5.5.1 Virgin Mix

Sasobit improves void mineral aggregate for all temperature range the total void mineral aggregate meet the control and requirements (see Figure 8).

5.5.2 RAP Mix

At 130°Cgives better void mineral aggregate than at 140°Cand both meet the standard requirements (see Figure 8).

5.6 Analysis the results of adding optimum WMA additive to nanomaterials

5.6.1 Stability of virgin and RAP mixtures with nanomaterials

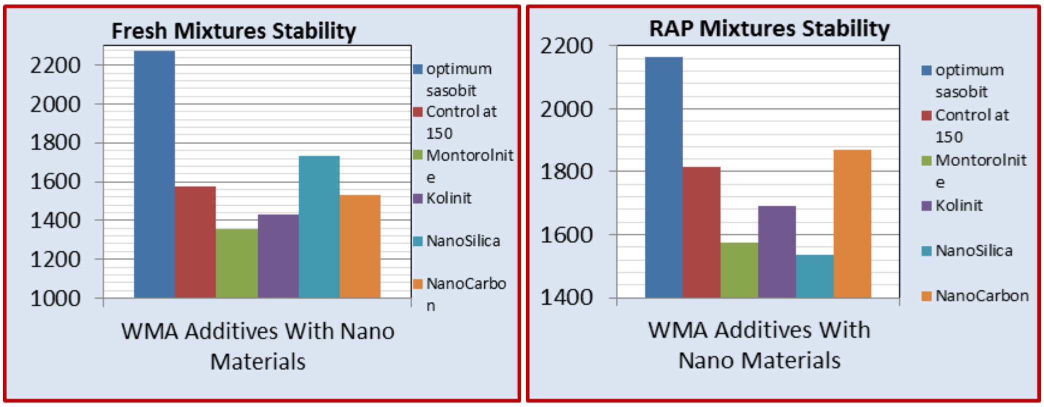

Figure 9: Stability of virgin and RAP mixtures with nanomaterials

As presented in Figure 9 for fresh and RAP mixtures nanomaterials don't reach the control value of stability with optimum sasobit. Only nanosilica has reached the control value for fresh mix and Nano carbon for RAP mix.

5.6.2 Flow of virgin and RAP mixtures with nano materials

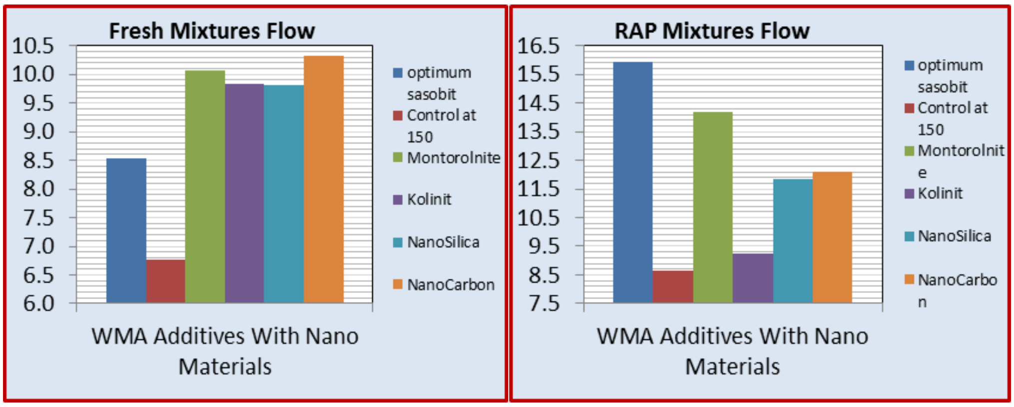

Figure 10: Flow of virgin and RAPmixtures with nanomaterials

In the fresh mixture, all nanomaterials gave improved flow values; better than the optimum and control value which increases rutting and crack resistance, in RAP mixture nanomaterials meet control requirement with better result for Montmoronite clay than other additives but still less than the mixture with optimum Sasobit only (see Figure 10)

5.6.3 AV of virgin and RAP mixtures with nanomaterials

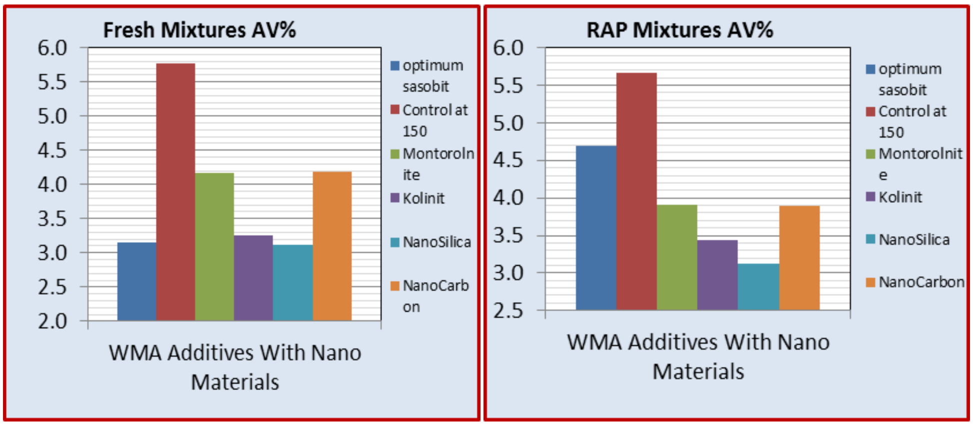

Figure11: AV% of virgin and RAPmixtures with nanomaterials

As shown in Figure 11; for fresh mixture all nanomaterials improve air voids in the mix than the optimum mixtures with Sasobit, for RAP mixture failed to tend as in fresh, less air voids than the optimum and control; however, it remain within the accepted code criteria.

5.6.4 Unit Weight of virgin and RAP mixtures with nanomaterials

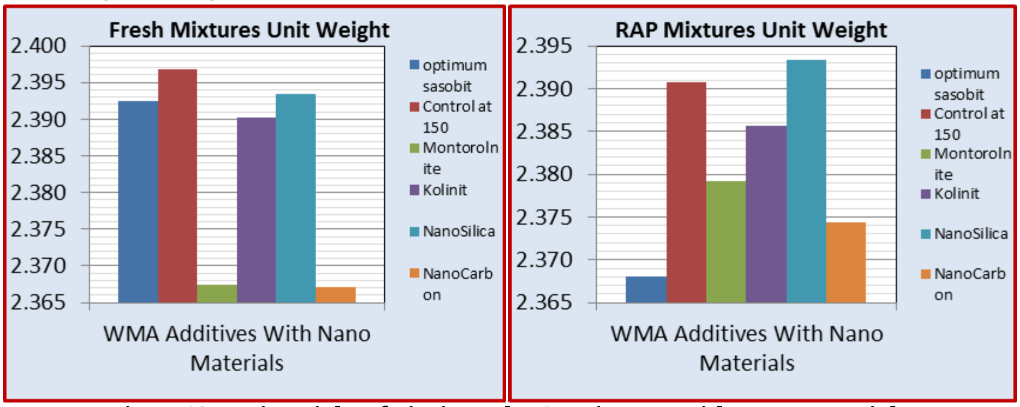

Figure12: Unit weight of virgin and RAPmixtures with nano materials

Figure 12 indicated that there was no any significant improvement of using nano material compared to the original mixes with and without sasobit.

5.6.5 VMA% of virgin and RAP mixtures with nanomaterials

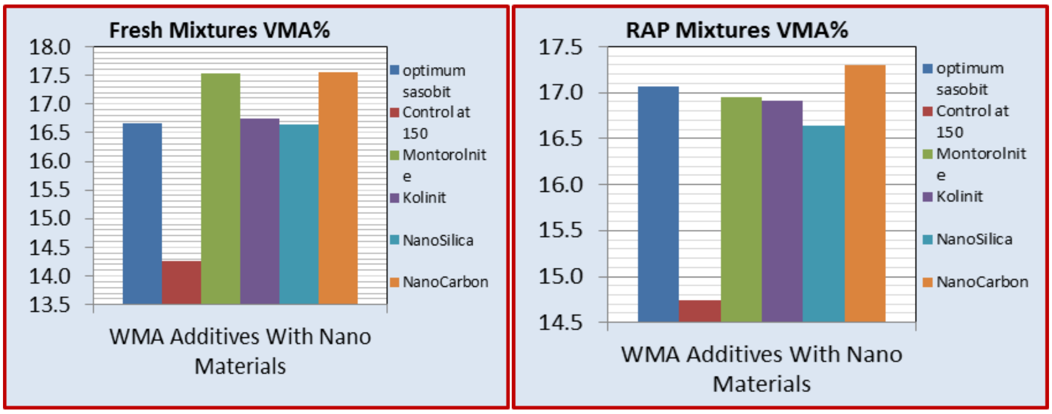

Figure 13: VMA of virgin and RAP mixtures with nanomaterials

Both fresh and RAP mixtures with nanomaterials sufficiently improve the void mineral aggregate, better results than the control and reach the requirements.

VI. CONCLUSION AND RECOMMENDATIONS

In this study the application of Sasobit content took place ranging from 0.50 to 3% by binder weight with an increment of 0.5as warm mix additives for virgin and reclaimed aggregate mixtures at different temperature range of 120, 130 and 140^{o}c. Research is on-going to investigate the incorporation of RAP with the sasobit additive and nanomaterials, as well as conducting performance all Marshall mix properties to compare and analysis the effect on each property. The drawn conclusions are list below:

1. Adding sasobit to **virgin aggregate** mixture have **optimum Sasobit content of 2.5% at 130 ^{o}C**, in spite of the optimum value being at 140^{o}C, the flow was out of limits and for cost issues. Adding sasobit to **reclaimed** aggregate mixture has **optimum Sasobit content of 2.0% at 130 ^{o}C**.
2. The **binder properties are significantly enhanced** and the grading of 60/70 changed without any negative affect on the mix performance.
3. Using nanomaterials **did not significantly enhance the performance** of the used mixtures. Therefore, in the future research using nanomaterials with polymerized asphalt binder.
4. It is necessary to evaluate the effect of **using other WMA additives** technologies in asphalt mixture performance.

5. To validate these research findings, further research **using other types and sources of virgin and reclaimed aggregate recovered bitumen is required**. In addition trying to use different percentages of RAP Materials is recommended.
6. **Future performance test such as compression, fatigue, indirect tensile, rutting and complex modulus is recommended.**
7. Using the RAP as warm mix is an environmentally sustainable and economic solution. Therefore, a strategic study is recommended to validation and document **using warm mix additives in road construction industry in Egypt**.

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