Developing New Design Criteria of Asphalt Pavement Mix Using Nano-Materials and Polymer-Materials

Abdelzaher E. A. Mostafa, Waleed M.F. Tawhed, Mohamed R. Elshahat

Abstract*— In the context of the wide demand of high quality of bitumen, this research was initiated with the objective of enhancing the asphalt mix properties. Variable additives percentages of nanomaterial and polymer material were investigated, experimentally, in order to determine their effect on asphalt properties. Three nano materials (i.e. nano-silica, nano0kaolinite and nano-montmorlinit) and three polymer materials were considered (i.e. SBS, polypropylene, and polyethylene). Modified specimens (with 1, 3, 5, 7, and 9% of nano and polymer material) were prepared. Rheological properties tests were conducted (i.e. penetration, softening, flash point and viscosity). In addition, mechanical properties tests were carried out (i.e. Marshall, compression, and indirect tensile tests). Results were obtained and analyzed. They indicted that additives enhanced rheological and mechanical properties of asphalt mix.

***Index Terms*— Hot Asphalt Mix; Polymerized-Materials**

I. INTRODUCTION

Asphalt is a binder material that should resist environmental conditions, rutting, heavy stresses and low temperatures. Accordingly, it should be enhanced [Asphalt Institute; Eurobitume, (2011)] [2].

Road development, new cities construction, increasing road network led to a rapid increase in bitumen consumption. [Becker, Y., et. al., (2001)] [3] reported that bitumen consumption is 102 million tons per year, 85% of which is implemented in pavements.

Bitumen production is a complex process that depends on the raw material quality (crude oil) and refinery process. Accordingly, more attention is directed towards enhancing the bitumen in order to improve its performance (i.e. adhesion, sensitivity to temperature, oxidation resistance, friction properties, durability and aging resistance) [Shen, J.A. et. al., (2011)] [4].

There are many asphalt modifiers (i.e. resins, sulfer, metal complexes, rubbers, polymers, fibers and chemical agents) [Abdel-Lateef, T.H., (2009)] [5].

In the context of the wide demand of high quality of bitumen, this research was initiated with the objective of enhancing the asphalt mix properties. Accordingly, a methodology was designed to encompass a literature review, experimental work and analyzing so as discussing the results to select the proper percentages of material and polymer additives percentages.

II. LITERATURE REVIEW

Many researchers are involved in investigating the enhancement of bitumen. Among them, for example, are:

Abdel-Lateef, T.H., (2009) et al. investigated the effect of different percentages of PET to HMA on the mix properties. Marshall, indirect tensile strength, rutting test and bending tests were carried out to assess the properties enhancement, where the results indicated that using PET enhanced the stability, indirect tensile strength, stiffness, and rutting. They documented that there was a decrease in flow, failure strain, and rutting depth. In addition, the results indicated that 13% PET provided an optimum ratio [5].

Qing, X., et. al., (2009) reportted that softening and ductility enhanced the bitumen by adding 10 wt. % of mechano-chemically devulcanized tire rubber (m-GTR) and SBS. This resulted in a decrease in road deformation and an increase in the viscous modulus (G’’) and elastic modulus (G’) [6].

Romeo, E., et. al., (2010) examined the impact of SBS modifiers on the hot asphalt mix properties. SUPERPAVE IDT (Indirect Tensile) and the SCB (Semi Circular Bending) tests were carried out in order to evaluate the change in the product characteristics. The results indicated that polymer modifications do not induce significant effects on the resilient modulus, at intermediate temperatures. On the other hand, the tensile creep test provided a decrease in the rate of creep, which implies the occurrence of reduced accumulations of micro-damage [7].

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Ghasemi, M., et. al., (2012) investigated the ipact of nano-SiO2 and SBS on asphalt mixtures. Five asphalt binders, with polymer modified bitumen by 5% SBS, were investigated using different nano-SiO2 percents (i.e. 0, 0.5, 1, 1.5, and 2%). The mixtures (i.e. bitumen with SBS and SiO2) were prepared in a high shear mixer. They investigated the rheological properties (i.e. modified bitumen [softening point, penetration and ductility]). In addition, Marshall test was applied to all specimens. The results indicated that the asphalt

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mixture with 5% SBS and 2% nano-SiO2 powder provided the best results among all the tested specimens. Accordingly, this modification was perceived to enhance the physical and mechanical properties of asphalt binder so as mixtures [8].

Yazdani, A., et. al., (2012) implemented L16 orthogonal array of the Taguchi method in order to find out the optimum polymeric Nanocomposite bitumen mixture. They defined three main factors:

Factor (A) Polypropylene (PP) with percents: 2,4,5,7 %wt.
Factor (B) Styrene-butadiene-Styrene (SBS) : 1,3,4,5 %wt
Factor (C) Nanoclay with percents: 1,1.5,2,3 %wt

All samples encompasssed 4.5% bitumen 60/70. Softening tests were carried out in order to determine the best modifier compression. 3% SBS, 5 % PP, and 1.5% Nanoclay were detected to be the ideal Nanocomposite asphalt binders. The results indicated that the compressive strength and softening point were enhanced by 55% [9].

Walters, R.C., (2014) investigted the bio-char and nano-clay effect on asphalt rheological properties, where two nano materials (nano-clay ‘Cloisite 30B’ a naturally inorganic mineral, and bio-char) were examined. Rotational Viscometer (RV) tests were carried out, at 120, 135 and 150°C, to evaluate the enhancement in their properties. The results indicated that using nano-particles and bio-modified enhanced the high temperature performance and aging resistance. XRD ascertained that the reason was the alteration of the layer spacing in nano-clay [10].

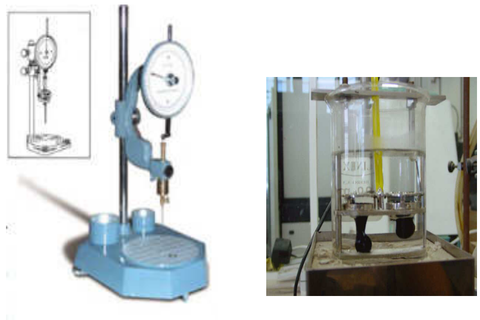
III. EXPERIMENTAL WORK

An experimental work was achieved in order to compare the attained enhancement in the rheological so as mechanical properties of bitumen and asphalt mixtures due to the nano or polymer material addition. The polymerized materials percentages were varied (i.e. 1, 3, 5, 7, and 9% by bitumen weight). Implmented polymer materials were styrene butadiene styrene (SBS), polyethylene, and polypropylene; figure (1). Nano and polymerized materials were mixed with pure bitumen by a mechanical mixer; figure (2). Penetration (i.e. ASTM-D5 standard), softening point (i.e. ASTM-D36 standard), flash point (i.e. ASTM-D3143-13 standard) and viscosity (i.e. ASTM-D4402 standard) tests were carried out to evaluate the rheological properties enhancement of modified bitumen; figure (3). In addition, Marshall (i.e. ASTM D5581 - 07a 2013), unconfined compression test and Indirect tensile tests; figure (4) were carried out to investigate the mechanical properties (i.e. stability, flow, indirect tensile stress, compression stress, and modulus of elasticity) in the modified polymer and nano-polymer asphalt (with nano kaolinite). Moreover, the performance of the modified asphalt mix, in rutting wheel track test was carried out; figure (5). Figure (6) indicates the preparation steps of the specimen. Marshall mix design was achieved in order to determine the optimum bitumen percent in the mix. Finally, the effect of polymer materials properties were compared to the results of nano material of Abdelzaher et al [1].

SBS Polyethylene Polypropylene

Figure (1): Nano-Materials

Figure (2): Mechanical Mixer



Penetrati Softening

Viscosity Test Flash

Figure (3): Rheological Properties of Bitumen

Marshall Test Unconfined Compression Test

Figure (4): Tests of Asphalt Specimens

Figure (5): Wheel Track Test

a) Mechanical Mixer

b) Casting Moulds

c) Marshall Compactor

d) Cooling Specimen

e) Getting Out Specimen

f) Specimen in Water Bath

Figure (6): Casting and specimens preparation

IV. RESULTS

Results were obtained fom the experimental work. They were plotted; presented on graphs and discussed here, as follows:

- Figures (7) to (10) indicate that (7%) and (9%) are the optimum percentages of nano-silica and nano-kaolinite so as nano-montmorlinite , respectively. It is obvious that the optimum percent of polymer-materials is (9%). Apparent is also that the optimum percentages provide a penetration rduction by 35.38%, 21.5%, 24.62%, 23.08%, 18.46%, and 13.85% for SBS, nano-silica, polyethylene, nano-kaolinite, polypropylene and nano-montmorlinite, respectively, while softening increased by 54.17%, 29.17%, 27.5%, 27.08%, 25%, and 16.67% for SBS, nano kaolinite, polypropylene, nano silica, polyethylene and nano montmorlinite, respectively.
- Figure (7) indcates that the increase in nano-materials or polymer-materials change the grade of bitumen. The optimum percent of polymer changed the grade to 40-50 while optimum percent of nano-materials changed the grade to 50-60. In addition, the flash point increased by 8.33%, 7.5%, 6.25%, 5.83%, 5.42%, and 5% for nano-kaolinite, polypropylene, nano-montmorlinite, polyethylene, SBS and nano-silica, respectively. Also, the viscosity increased by 6.44%, 5.32%, 4.76%, 3.92%, 3.92%, and 3.36% for nano-silica, polyethylene, polypropylene, SBS, nano-kaolinite and nano-montmorlinite, respectively.
- Figure (10) indicated that the behavior of nano-kaolinite is similar to SBS and polyethylene is similar to polypropylene.
- Figure (11) indicated that the optimum percent of bitumen is 5.5%, obtained from Marshall mix design.
- Figures (12) to (17) provide a comparison between the mechanical properties of polymer modified asphalt mix and nano-materials modified asphalt mix. The following was noticed:
    - At optimum percentages, the stability increased by 60.78%, 50.5%, 37.5%, 31.75%, 17.6%, and 17% for polypropylene, polyethylene, nano-kaolinite, nano-silica, nano-montmorlinite and SBS, respectively.
    - On the other hand, the flow decreased by 21.75%, 21%, 19.22%, 13.65%, 13%, and 13.4% for polypropylene, nano-kaolinite, polyethylene, nano-montmorlinite, nano-silica and SBS, respectively.
    - Air voids decreased by 17.13%, 16.85%, 15.5%, 13%, 6.5%, and 3.65% for nano-kaolinite, SBS, nano-montmorlinite, nano silica, polyethylene and polypropylene, respectively.
    - VMA decreased by 3.7%, 3.66%, 3.4%, 3.3%, 1.38%, and 0.76% for nano-kaolinite, SBS, nano-silica, nano-montmorlinite, polyethylene and polypropylene, respectively.
    - Unit weight increased by 0.61%, 0.61%, 0.57%, 0.53%, 0.2%, and 0.12% for SBS, nano-kaolinite, nano-silica, nano-montmorlinite, polyethylene and polypropylene, respectively.
    - Rigidity increased by 105%, 86%, 73.8%, 51.6%, 36.2%, and 35% for polypropylene, polyethylene, nano-kaolinite, nano-silica, nano-montmorlinite and SBS, respectively.
- Figures (18) to (22) indicated that nano-kaolinite and polypropylene are better than other implemented materials with respect to the mechanical properties of asphalt mix. Obvious was that increasing the percent of nano-kaolinite more than 5% decreased the air voids and flow than the specification limits. Accordingly, it was decided to considered in the design. This percentage decreased the air void, flow, and VMA by 13%, 37.3% and 7%, respectively, while it is increased both stability so as unit weight by 26.8% and 0.5%, respectively.

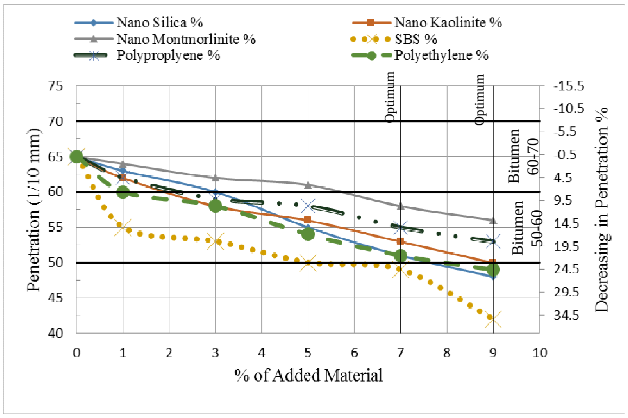


Figure (7): Effect of Nano-Materials and Polymer-Materials on Penetration

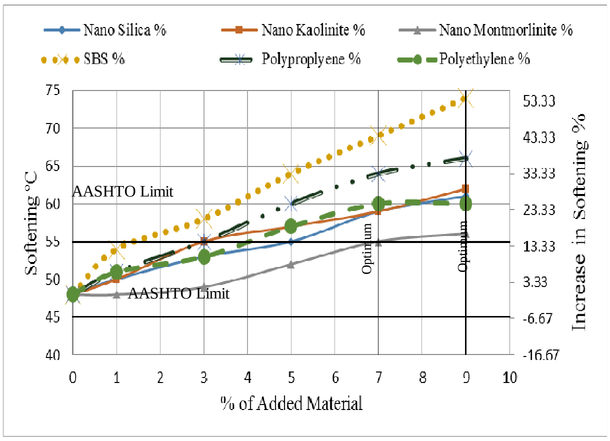


Figure (8): Effect of Nano and Polymer Materials on Softening

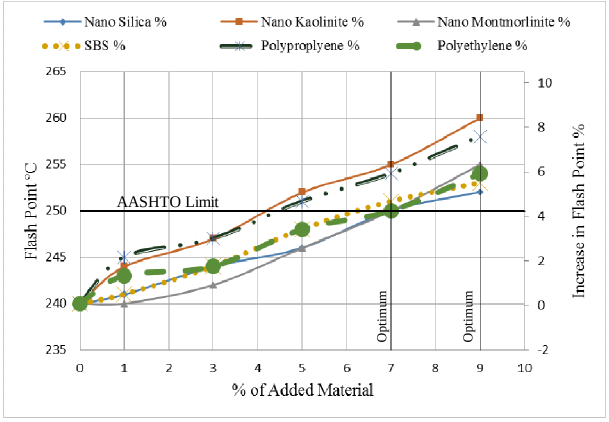


Figure (9): Effect of Nano-Materials and Polymer Materials on Flash Point

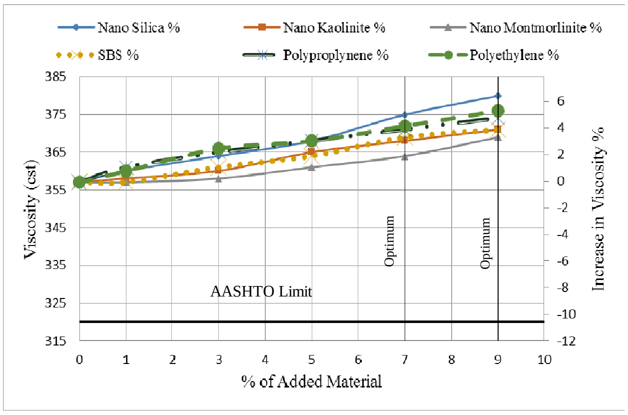
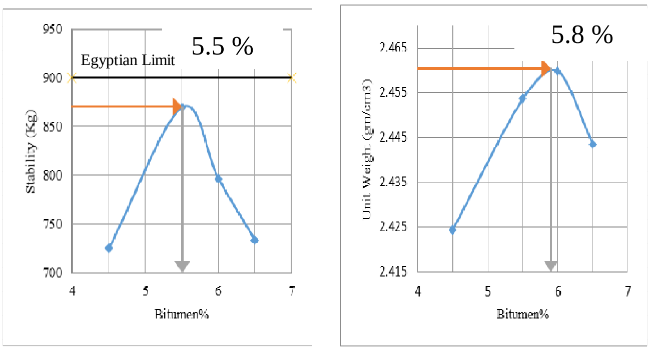
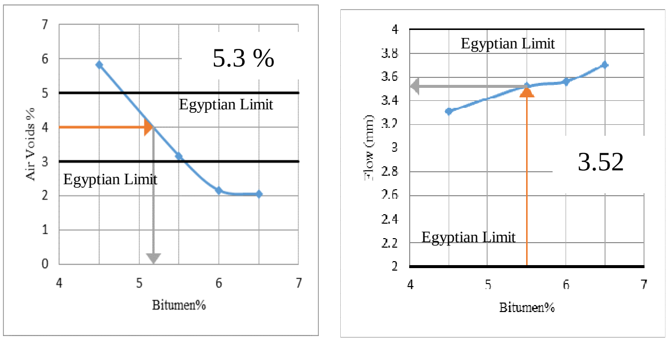


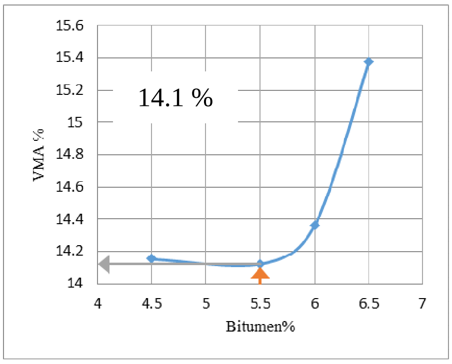
Figure (10): Effect of Nano-Materials and Polymer Materials on Viscosity



Stability Unit Weight



Air Voids Flow



VMA

Figure (11): Marshall Mix Design

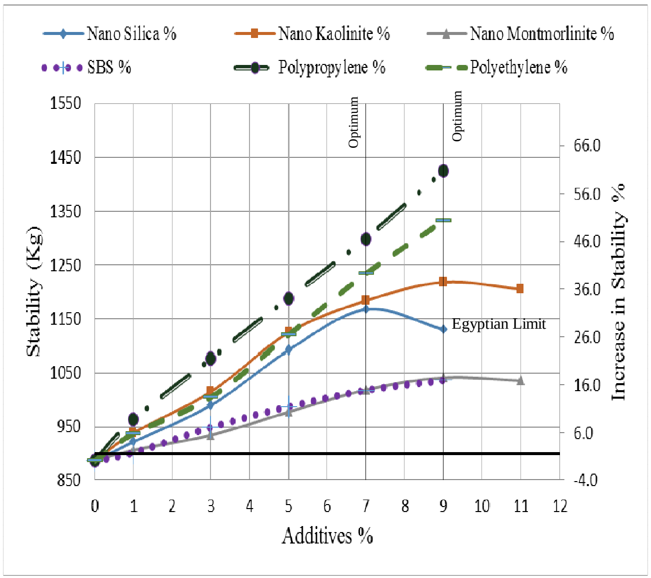


Figure (12): Behavior of Modified Bitumen in Stability

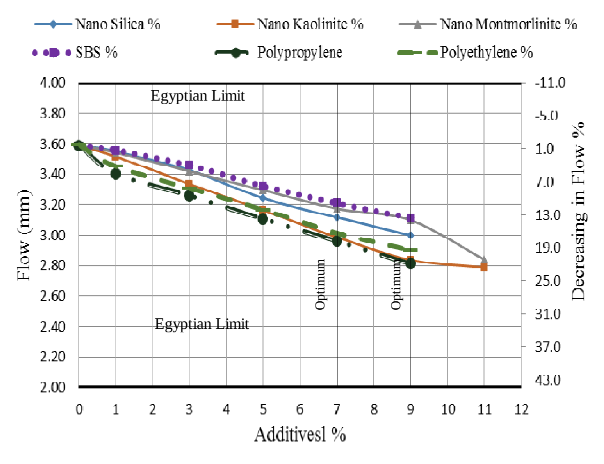


Figure (13): Behavior of Modified Bitumen in Flow

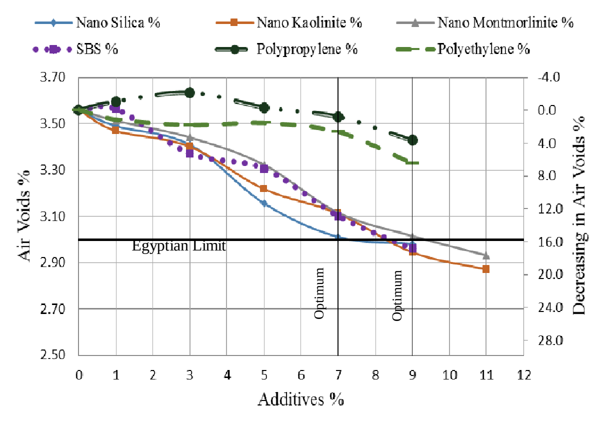


Figure (14): Behavior of Modified Bitumen in Air Voids

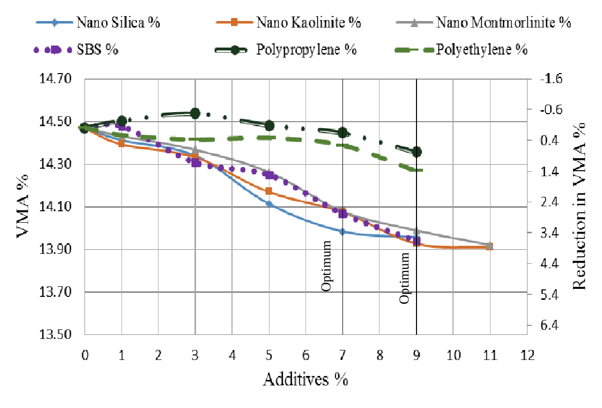


Figure (15): Behavior of Modified Bitumen in VMA

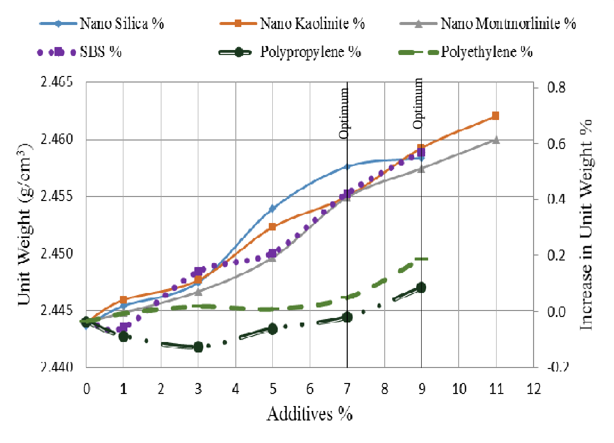


Figure (16): Behavior of Modified Bitumen in Unit Weight

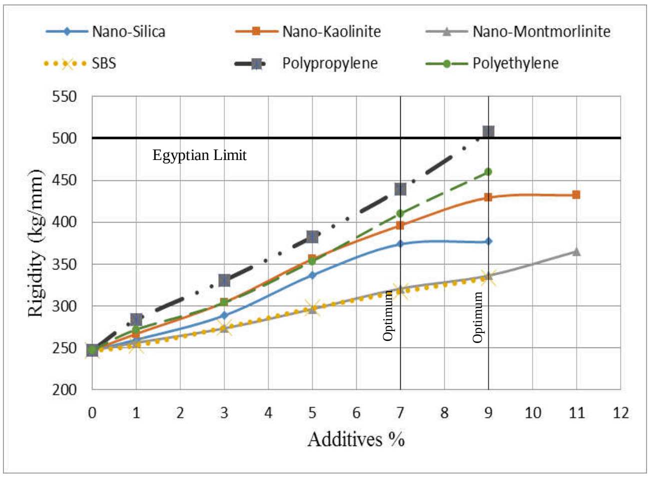


Figure (17): Behavior of Modified Bitumen in Rigidity

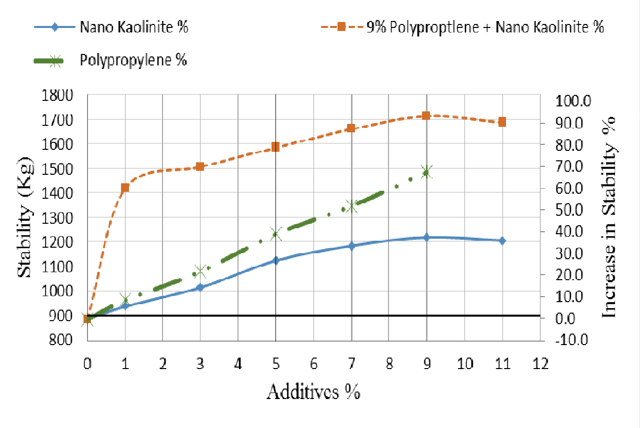


Figure (18): Effect of Nano-materials on Stability of Polymer Modified Asphalt Mix

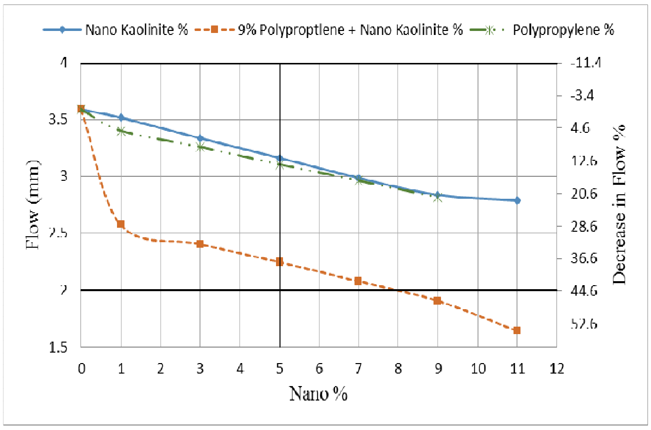


Figure (19): Effect of Nano-materials on Flow of Polymer Modified Asphalt Mix

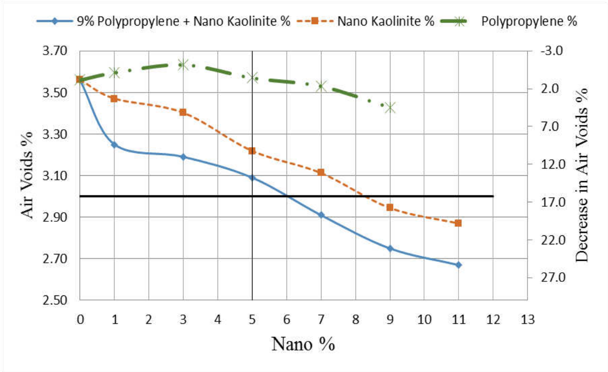


Figure (20): Effect of Nano-materials on Air Voids of Polymer Modified Asphalt Mix

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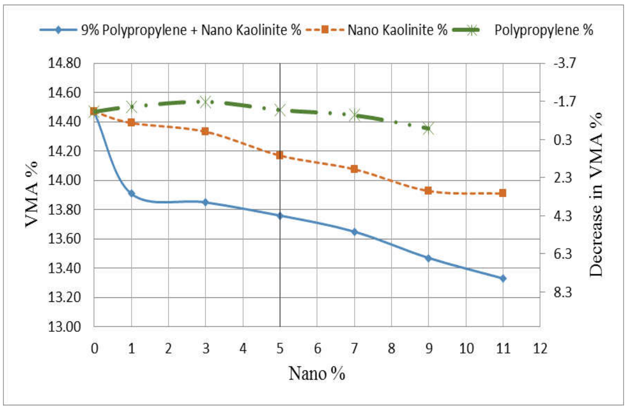

Figure (21): Effect of Nano-Materials with Polymer-Materials on VMA

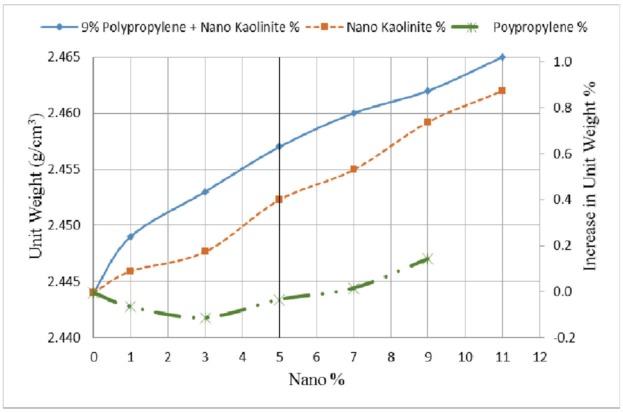

Figure (22): Effect of Nano-materials on Unit Weight of Polymer Modified Asphalt Mix

- Figures (23) to (27) present the performance of the modified asphalt mix. The following was noticed:
    - The optimum percentages of additives increase the compressive strength by 41.14%, 36%, 29.4% and 17.6% for nano-kaolinite, polypropylene, nano silica and polyethylene, respectively but it decreased by 5.9% in case of SBS, and is not significant for nano-montmorlinite.
    - Indirect tensile strength increased by 200.8%, 174%, 93.5%, 60.16%, 50%, and 40.65% for polypropylene, polyethylene, nano-kaolinite, SBS, nano-silica and nano-montmorlinite, respectively.
    - Modulus of resilience increased by 93%, 32.5%, 32.5% for nano-silica, nano-kaolinite and nano-montmorlinite, respectively, while it decreased by 23%, 32.5%, and 32.5% for SBS, Polypropylene and polyethylene, respectively. Modulus of toughness increased by 0%, 47.6%, and 19% for nano-silica, nano-kaoliniteand nano-montmorlinite. SBS, respectively. Polyethylene decreased modulus of toughness by 19% while polypropylene increased it by the same percent.
- Figure (28) to Figure (32) present the performance of modified asphalt mix using both polypropylene and nano-kaolinite. The following was noticed:
    - At the optimum percent, the compressive strength was increased by 47% compared to the conventional mix, 8.7% compared to implementing polypropylene only and 4.2% than using nano-kaolinite only.
    - Indirect tensile strength increased by 273.3% compared to the conventional mix, by 24.4% compared to using polypropylene only and by 93.16% compared to using nano-kaolinite only.
    - Modulus of elasticity increased by 34.2% compared to the conventional asphalt mix, by 10.7% relative to polypropylene only and by 2% relative to nano-kaolinite only.
    - Modulus of resilience increased by 93% compared to the conventional asphalt mix, by 185% compared to polypropylene only and by 45.5% compared to nano-kaolinite only.
    - Modulus of toughness increased by 28.5% relative to the conventional asphalt mix, by 8% relative to polypropylene only and it decreased by 13% compared to nano-kaolinite only. This indicated its non-effectiveness.
- Figure (33) present the wheel track test for nano-materials modifying asphalt mix under wheel weighting 70kg in temperature 60̊ c , while figures (34) and (35) present the rutting test results. They indicated the behavior of modified asphalt mix compared to the conventional asphalt mix, as follows:
    - For conventional asphalt mix, the maximum rutting was 15.589 mm, which occurred mostly in the first 4000 cycle.
    - For the first 4000 cycle, rutting is 12mm, which mean that about 75% of rutting happened in the first 4000 cycle and 25% of rutting happened in subsequent cycles.
    - For all types of nano-materials, the rate of rutting increased during all cycles. Maximum rutting was 4.228mm, 5.247mm, and 5.808mm for nano-kaolinite, nano-montmorlinite and nano-silica, respectively.
    - Nano-materials decreased the rutting depth by 72.9%, 66.34%, and 62.75% for nano-kaolinite, nano-montmorlinite and nano-silica,respectively. According to BS 598-110[11] the maximum allowable rutting is 7mm.
    - Conventional asphalt mix reached this limit at 1500 cycle while nano-materials reached it at 1500 cycle.
    - Polypropylene and polyethylene nearly have the same behavior of conventional asphalt mix.
    - Maximum rutting are 12.092mm and 13.4mm for polypropylene and polyethylene, respectively.
    - For the first 4000 cycle rutting was 10.945mm and 11.769mm for polypropylene and polyethylene, respectively, which means that about 90% of rutting occurred within the first 4000 cycle after that they become stable, compared to the conventional asphalt mix.
    - For SBS, the maximum rutting depth is 4.416mm and the rate of increase in rutting for polypropylene and polyethylene occurred after 5000 cycles.
    - Polymer-materials decreased the rutting depth by 71.7%, 22.4%, and 14% for SBS, polypropylene and polyethylene, respectively.
    - Polyethylene and polypropylene reached to the maximum rutting depth after 2000 cycles. They increased the rutting life with 33%.

- The rutting of nano-kaolinite with polypropylene modified asphalt mix. This indicated that nano-kaolinite with polymer enhanced the asphalt mix in the same manner as nano-kaolinite only.
- The maximum rutting depth is 4.116mm. It decreased the rutting by 73.6% compared to the conventional asphalt mix by 66% compared to polypropylene only while it decreased the rutting by 2.65% compared to the nano-kaolinite only.

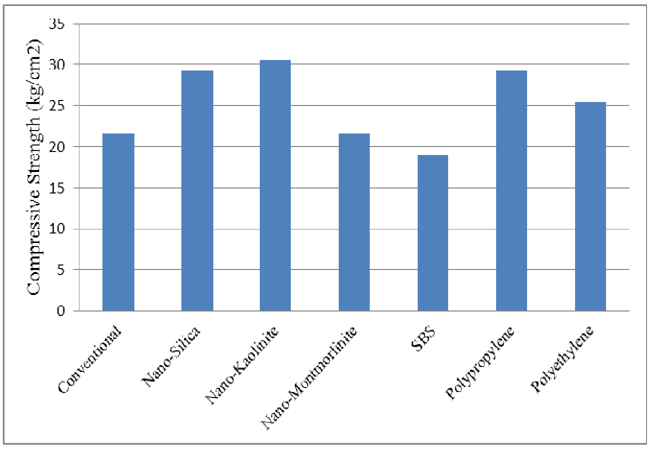

Figure (23): Behavior of Modified Asphalt Mix in Compressive Strength

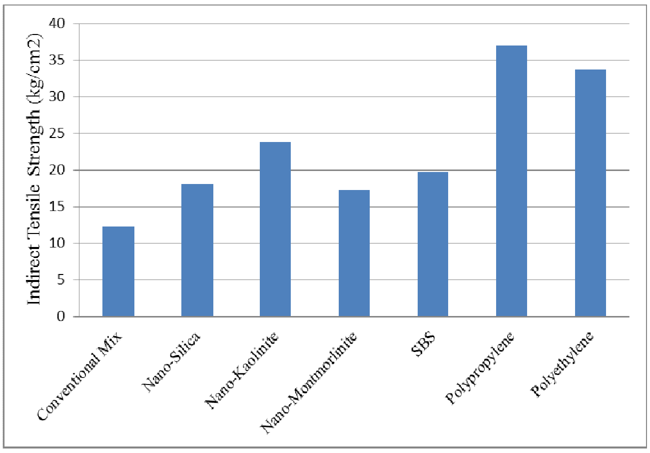

Figure (24): Behavior of Modified Asphalt Mix in Indirect Tensile Strength of Elasticity

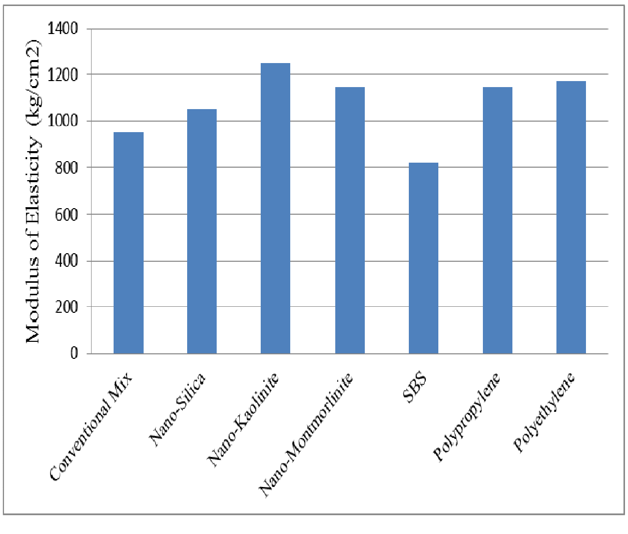

Figure (25): Behavior of Modified Asphalt Mix in Modulus of Elasticity

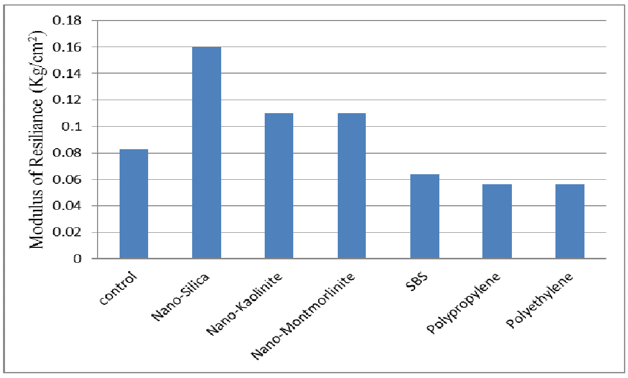

Figure (26): Behavior of Modified Asphalt Mix in Modulus of Resilience

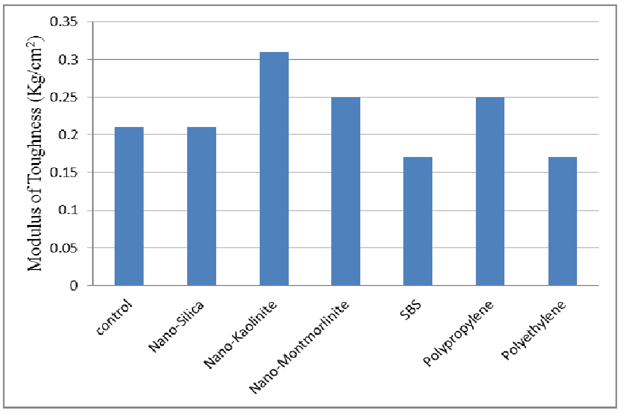

Figure (27): Behavior of Modified Asphalt Mix in Modulus of Toughness

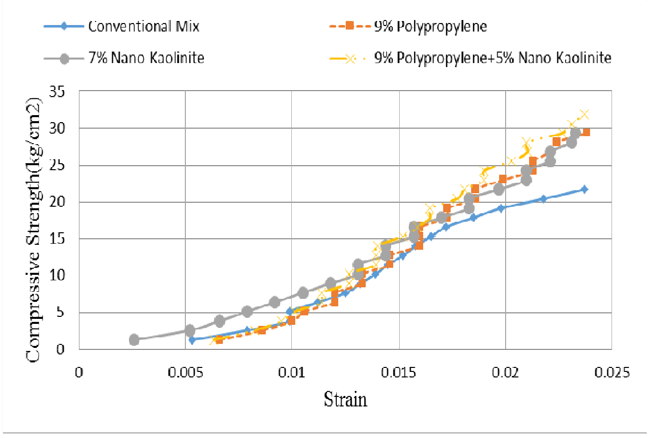

Figure (28): Effect of Nano-Kaolinite with Polypropylene on Stress-Strain

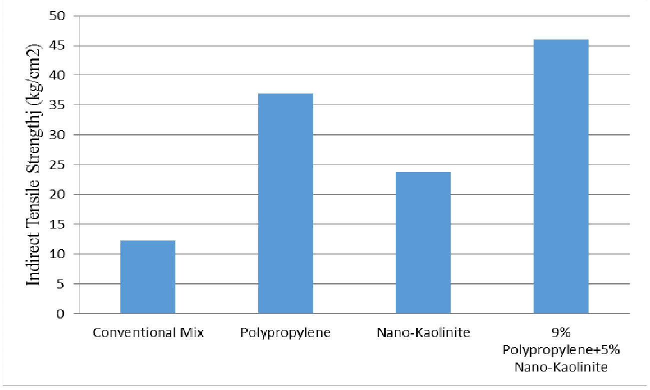

Figure (28): Effect of Nano-Kaolinite with Polypropylene on Indirect Tensile Strength

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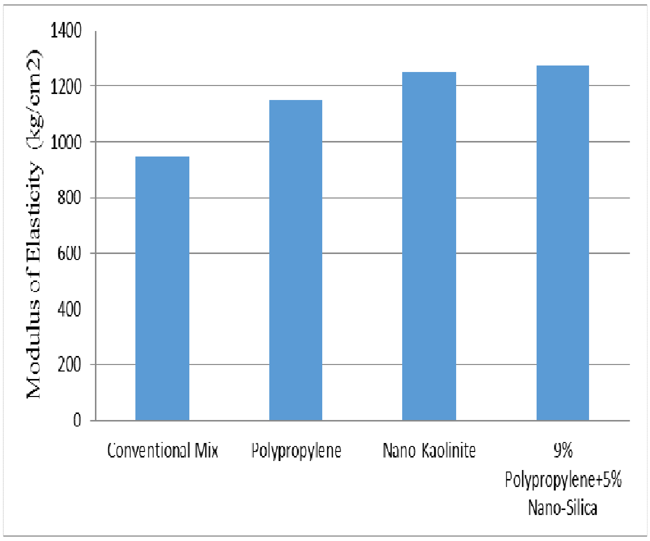

Figure (29): Effect of Nano-Kaolinite with Polypropylene on Modulus of Elasticity

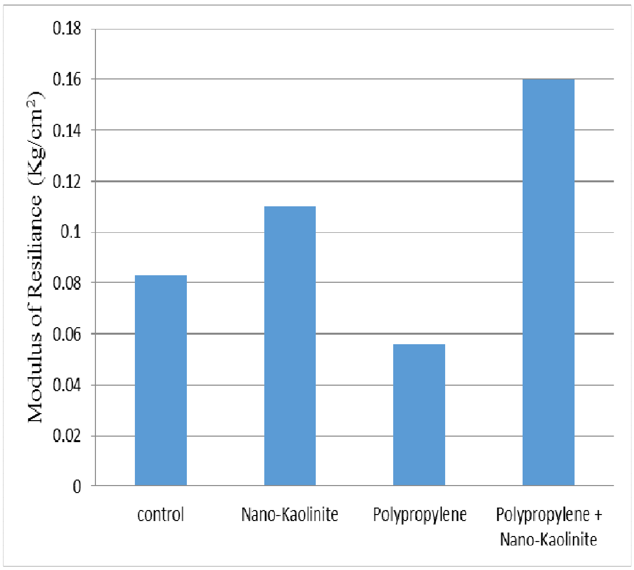

Figure (30): Effect of Nano-Kaolinite with Polypropylene on Modulus of Resilience

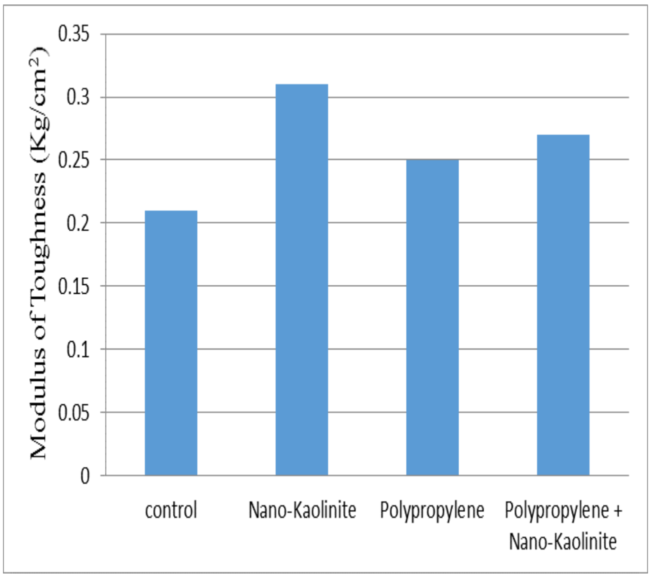

Figure (32): Effect of Nano-Kaolinite with Polypropylene on Modulus of Toughness

Figure (33): Wheel Track Test

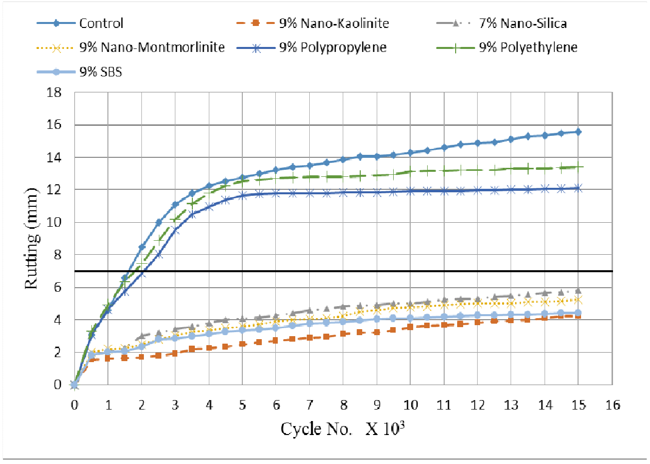

Figure (34): Rutting Behavior of Nano-Materials and Polymer in Modifying Asphalt Mix

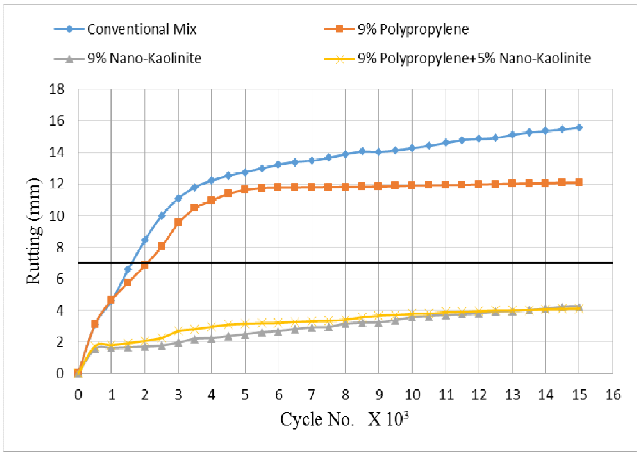

Figure (35): Rutting Behavior of Nano-Materials with Polymer Modifying Asphalt Mix

- Table (1) is presented to encompass the number of cycle that provided the maximum rutting depth for nano-materials and the equations of the trend lines, for all types.
- According to equation (1) the number of load repetition is calculated and tabulated in Table (2). From the results, the maximum increase of load repetition is attained for

nano-kaolinite with 6.24%.

$N_f = f_1\ \varepsilon_t\text{-}f_2\ EI\text{-}f_3$ ……………… (1)

Where; $f_1 = 0.0795$; $f_2 = 3.291$; $f_3 = 0.854$,

Table (1): Equations of Trend Lines for Nano-Materials Rutting

Nano Type	Equation	R	Cycle No.
Silica	$y = -2E\text{-}23x^6 + 8E\text{-}19x^5 - 2E\text{-}14x^4 + 2E\text{-}10x^3 - 8E\text{-}07x^2 + 0.0025x + 0.2511$	0.9904	21000
Kaolinite	$y = -2E\text{-}23x^6 + 9E\text{-}19x^5 - 2E\text{-}14x^4 + 2E\text{-}10x^3 - 7E\text{-}07x^2 + 0.0017x + 0.3319$	0.9804	33000
Montm.	$-2E\text{-}23x^6 + 8E\text{-}19x^5 - 2E\text{-}14x^4 + 2E\text{-}10x^3 - 9E\text{-}07x^2 + 0.0023x + 0.3947$	0.9806	28000

According to equation (1) the number of load repetition is calculated and tabulated in Table (2). From results the maximum increase in no. of load repetition is for nano-kaolinite with 6.24%.

$N_f = f_1\ \varepsilon_t^{-f3}\ EI^{-f3}$ ……………… (1)

Where; $f_1 = 0.0795$; $f_2 = 3.291$; $f_3 = 0.854$,

Table (2): Number of Load Repetition for Modified Asphalt Mix

Material	E (kg/cm^2)	Strain ε_t	NLR	NLR Increase %
Conventional	950	$7x10^{-4}$	5497605	---
7% Nano-Silica	1050	$6.8x10^{-4}$	5552450	1
9% Nano-Kaolinite	1250	$6.4x10^{-4}$	5840737	6.24
9% Nano-Montmorlinite	1150	$6.6x10^{-4}$	5667768	3.1
9% SBS	820	$7.2x10^{-4}$	5681838	3.35
9% Polypropylene	1150	$6.6x10^{-4}$	5667768	3.1
9% Polyethylene	1175	$6.6x10^{-4}$	5564622	1.22
9% Polypropylene + 7% Nano-Kaolinite	1275	$6.4x10^{-4}$	5742793	4.46

- Figure (36) presents the assumed cost of each implemented material. There is an increase in initial cost for nano-modified and polymer-modified asphalt mix . For example:
    - Bitumen cost = 3 LE/kg
    - Aggregate cost = 90 LE/km
    - Nano-Material cost = 250 LE/kg
    - Polypropylene cost = 25 LE/kg
    - Polyethylene cost = 20 LE/kg
    - SBS cost = 80 LE/kg

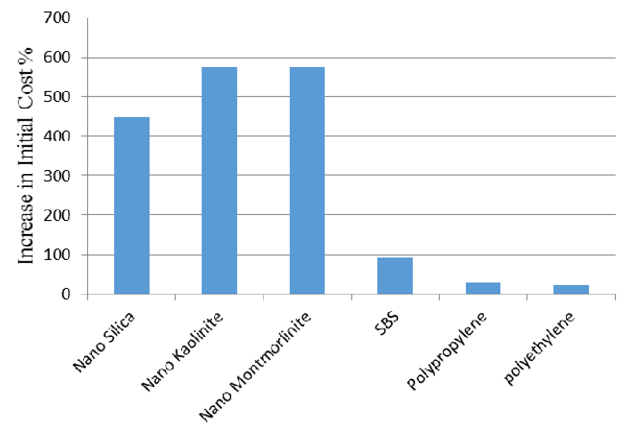

Figure (36): Increase in Modified Asphalt Mix Cost

- For comparison purposes, the cost optimum percentages are taken as datum and the following is provided:
    - For nano-modified asphalt mix, nano-silica, kaolinite nano-clay and montmorlinite nano-clay the increase in the cost was 447%, 575%, and 575%, for polymer modified asphalt mix, SBS, polypropylene, and polyethylene increase the cost by 93, 29, and 23%, respectively.
    - It is expected in the future that the price of nano-materials to be similar to cement or slightly higher than it. The raw materials of manufacturing nano-materials are not expensive. After constructing many factories for producing nano-materials, the traditionally price will be normal price.
- Figure (37) presents the increase in cost for asphalt pavement if the cost of nano-materials is more than 10 times of cement cost. If Cement cost = 0.6 LE/kg; Assume Nano-Materials cost = 10 LE/kg. The following was perceived:
    - The increase in cost for nano-materials does not exceed 28%.
    - It gives increase in fatigue life about 6% and in addition the very high resistance for rutting which decrease the final cost of nano-materials modified asphalt mix.
    - For roads that acequire high resistance to rutting with 30% increase in stability, nano-kaolinite and nano-silica are suitable.
    - Nano-kaolinite will increase the fatigue lifetime by 6% while nano-silica does not increase the fatigue life.
    - Nano-montmorlinite and SBS are suitable for roads as they have a high resistance to rutting with an increase in stability by 15% and an increase in fatigue lifetime

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by 3%.

- For roads that acquire high stability and high strength regardless to rutting, polypropylene and polyethylene are suitable. They increase the stability and compressive strength by 55% and 30% in addition slightly improvement in rutting. Furthermore, polypropylene increases the fatigue life than polyethylene.

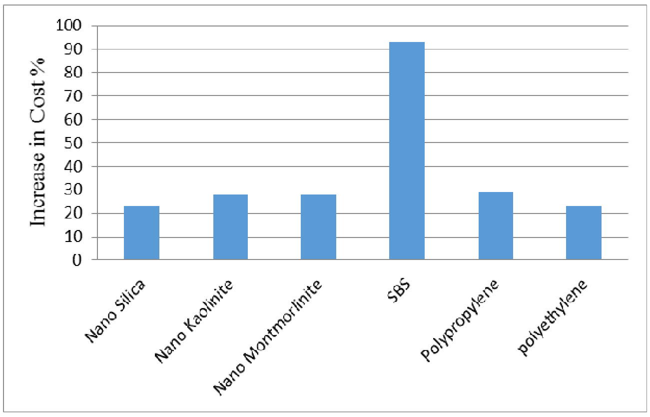

Figure (37): Expected Increase in Modified Asphalt Mix Cost in Future

- **New Design Criteria Based on The Outcomes of The Results**
  - For roads that acquire high resistance to rutting with 30% increasing in stability, nano-kaolinite and nano-silica are suitable in addition. Nano-kaolinite will extend the fatigue life time by 6% while nano-silica will not.
  - Nano-montmorlinite and SBS are suitable for roads that acquire high resistance to rutting with increasing in stability by 15% and an extend in fatigue life time by 3%.
  - For roads that acquire high stability and high strength, regardless rutting, polypropylene and polyethylene are suitable. They increased the stability and compressive strength by 55% and 30%. In addition, slight improvement in rutting occurred. Furthermore, polypropylene extended the fatigue life more than polyethylene.
  - New design criteria are presented in Table 4-14, where the best material in enhancing the performance of asphalt mix is nano-kaolinite with optimum percentage 9%. Although, it is not economic, it is expected to be within the norm in the future.
  - Accordingly, this research suggested that asphalt pavement design should include rutting depth and use SBS so as nano-materials, as additives. This would extend its life time by 5% and its cost would be reduced by 25% in the future.

Table 4-14: New Design Criteria

	Optimum Percent %	Fatigue and Compression		Crack	Best Material
		NLR %	Rutting Life Time%	ITS (kg/cm^2)	
P.P	9	3.1	6	200	Nano-Kaolinite
SBS	9	3.35	1900	60	
N-K	9	6.24	1841	93	
Mix	9% P.P + 5% N-K	4.46	1847	273	

V. CONCLUSION AND RECOMMENDATIONS

Based on the results obtained from this research, the following conclusions are provided:

1) Nano-materials and polymer-materials improve the mechanical properties of the asphalt mix (i.e. increase each of stability, unit weight, modulus of elasticity, compression stress, and indirect tensile strength) while it is decreases flow, air voids, voids in mineral aggregate.
2) There is interfere between lines represent nano-materials and lines represent polymer-materials, which mean that polymer does not perform better than nano-materials or vice-verse.
3) SBS has the highest effect on each of penetration, and softening by 54.17%, and 35.38%, respectively while nano kaolinite has the highest effect on flash point by 8.33% and viscosity by 6.44%.
4) Polypropylene has the highest effect on stability and flow by 60.78% and 21.75%, respectively, while nano silica has the highest effect on air voids, VMA and unit weight by 13%, 3.4%, and 0.61%, respectively.
5) Nano-kaolinite has the highest effect on compressive strength and modulus of elasticity by 41.14%, and 41.8%, respectively, while polypropylene has the highest effect on indirect tensile strength by 200.8%
6) Using nano-kaolinite, as an additive for polymer modified asphalt, improves all properties but it should not exceed 5%, which causes a decrease in the air voids and flow than the code specifications.
7) Using nano-materials increase modulus of resilience and toughness while, polymers decrease them.
8) Nano-materials in addition to SBS decrease rutting depth more than 60% while, polymers decrease it up to 20%.
9) Service life is extended by 6.24%, 3.1%, 3.35%, 3.1%, 1.22%, and 4.46% for nano-kaolinite, nano-montmorlinite, SBS, polypropylene, polyethylene and mixture of polypropylene with nano-kaolinite, respectively.
10) Initial cost increased by 447% for nano-silica and 575%

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for nano-kaolinite and nano-montmorlinite, while SBS, polypropylene, and polyethylene increased the initial cost by 93%, 29%, and 23%, respectively.

11) For roads that acquire high resistance to rutting with 30% increasing in stability, nano-kaolinite and nano-silica is suitable in addition nano-kaolinite will extended the service life by 6% while nano-silica would not.
12) Nano-montmorlinite and SBS are suitable for roads that acquire high resistance to rutting with increasing in stability by 15% and increased the service life by 3%.
13) For roads that acquire high stability and high strength regardless rutting, polypropylene and polyethylene are suitable. They increase the stability and compressive strength by 55% and 30% with a slightly improvement in rutting. Furthermore, polypropylene extended the service life more than polyethylene.

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