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Improving The Properties of Hot Asphalt Mixture By Using Nano Silica

A Project Submitted to the Civil Dep. College of Engineering, University of kufa in Partial Fulfillment of the Requirement for the Degree of B.Sc. in Civil Engineering

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DEDICATION

To my parents and to my family who made this accomplishment possible.

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Also We Thank OUR families, for their encouragement, patience.

To all of them all love and respect …

Abstract

Pavement material is characterized by number of failures modes at low and high temperature such as cracking, fatigue cracking, or permanent deformation which causes a reduction of quality and performance, Any improvement in service life of road pavements will be off course of a great economical advantage and any modifications of asphalt are attempts to extend the service life and improve the performance of asphalt pavements, In this study a forward investigation of Nano silica

Several physical properties of asphalt with and without Nano silica have been conducted which were penetration, softening, Ductility ; then studying its effect on the mechanical properties of Marshall Stability and Indirect tensile strength test ; by adding different contents of Nanosiica ,1 wt.%,2 wt.% and 4 wt.%. Results showed that the optimum Nanosilica is 2%. On the other hand, there is a significant increase in the mechanical properties and the durability of the modified mixtures i.e. with 2% Nano silica in comparison with the control mixtures.

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CHAPTER 1

Introduction

Introduction

Asphalt has complicated chemical composition with exhibits both viscous and elastic properties that heavily depend on both time and temperature [yildirim 2007;peters et al.2010]. However the chemical composition of asphalt is quite complex ,therefore ,researchers mainly use percentage of Saturates, Asphaltene ,Resin and Aromatic to compere various asphalt binder produced from different origins. composition of each asphalt binder is typically grouped into two categories: asphaltenes and maltenes .the latter can be further subdivided into saturates, aromatics and resins [Petersen ,1984].

The main role and function of asphalt when using it in road paving asphalt mixtures is to bind aggregate particles in order to compose pavement that is as strong as possible to sustain external stresses , Such stresses could be due to the loads of passing traffic (vehicles) or due to severe environmental boundary conditions (moisture and temperature) for long time.

The most common distresses that could face unmodified paving asphalt is the rutting deformation (due to high temperature) and cracking (due to low temperature).

Many studies have recently dealt with these problems in asphalt roads and several solutions were proposed. using nano-materials to modify asphalt and/or asphalt mixtures characteristics is one of these state-of-the-art solutions.

The use of nano –materials has seen a tremendous development in recent years mainly due to their surface properties and their effectiveness in altering hierarchical structure of composite materials [you et al.,2011;Yao et al.,2012 b;Onechie et al.,2013;Fine,2013] .

A nano particle has at least one dimension lower than 100 nanometer (nm) [Golestani el al.2012, Yang and Tighe 2013,You et al .2011,yu et al. 2019] .Regarding to their small size , nano-materials have usually higher reactivity and higher specific area(Yu et al. 2015) .Due to the above –mentioned benefits for utilization in paving technology [Arabani and Faramarzi 2015; Galooyak et al. 2010; Golestani et al 2015; Jamal Khattak et al.2013; Karahancer et al.2014].

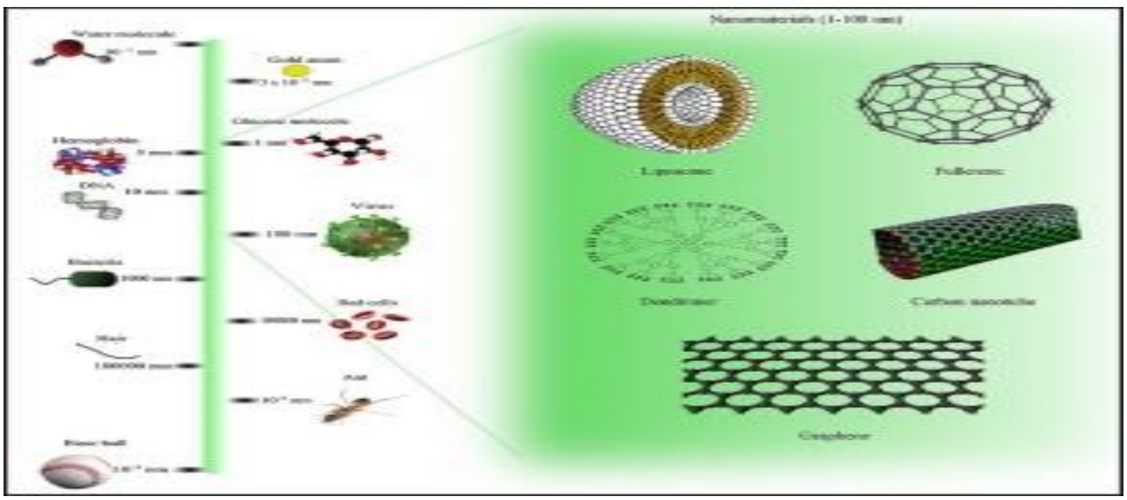


Figure (1-1)- examples of Nano- materials

In recent years , Nano clay material has been used to improve the various properties of base binder[Jahromi and Khodaii 2009; Ziari et al .2014] .It was found that Nano clay could enhance the complex modulus and decrease the failure strain of base binder . furthermore ,it could reduce the moisture susceptibility of final asphalt concrete. The carbon nano –fiber has also been utilized modification of the asphalt binder .

Nano –silica is used in several industries including medicine and engineering .The benefits of Nano-silica are the low production costand high performance feature .Nano-silica has large surface area ,strong adsorption ,good dispersal ability ,high chemical purity, and excellent stability .therefore ,in this study ,the nano-silica was used to modify the asphalt binder at concentrations of 1%, 2% and 4% by weight of the base asphalt binder. Rheological ,chemical and morphological characterization of neat and modified asphalt binder was conducted to evaluate the performance of nano – silica modified asphalt binder.

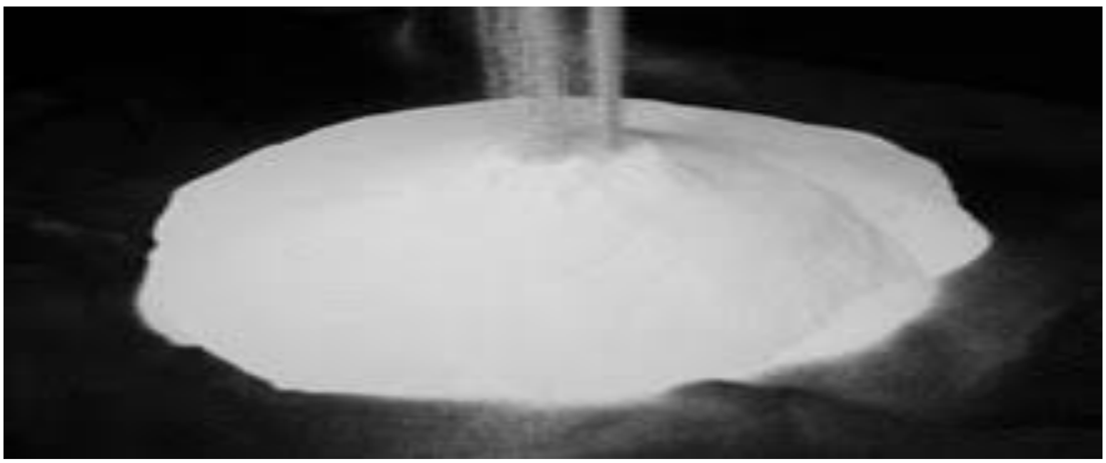


Figure 2 –show the shape of Nano -silica

The aim of this study

This research studies the potential effects of nanomaterial which is Nano silica on the physical properties of bitumen such as penetration, softening, and ductility used in hot-mix asphalt.

CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

Hot Mix Asphalt Pavement

Asphalt pavement refers to any paved road surfaced with asphalt. Hot Mix Asphalt (HMA) is a combination of approximately 95% stone, sand, or gravel bound together by asphalt cement, a product of crude oil. Asphalt cement is heated aggregate, combined, and mixed with the aggregate at an HMA facility. The resulting Hot Mix Asphalt is loaded into trucks for transport to the paving site. The trucks dump the Hot Mix Asphalt into hoppers located at the front of paving machines. The asphalt is placed , and then compacted using a heavy roller, which is driven over the asphalt. Traffic is generally permitted on the pavement as soon as the pavement has cooled.

Hot Mix Asphalt Types

There are three main types of HMA; well-graded, open graded, and stone matrix mixes. For maintenance works, other types of mixes can be utilized .

Dense-Graded Mixes

This hot asphalt mix is the most common mix used because it can provide great impermeable characteristics allowing water to run away from the surface area.

The name comes from the aggregate size used while mixing the raw materials to produce the asphaltic composition. It can also be subdivided as fine-graded or coarse-graded, depending on the majority of the aggregates in the final product.

This type of asphalt is ideal for all traffic conditions and has great performance under structural conditions, friction, and for surfacing and repairing needs.

Stone Matrix Asphalt

This mix was developed to maximize rutting resistance and to have great durability. Due to the process of production, this asphalt mix is more expensive than regular dense-graded mixes. Its design is based on higher asphalt content, modified asphalt binder, and fibers. This asphalt type has been used since 1980's and can be used in numerous road and driveway applications.

Due to its high costs, it is recommended to be used on high volume interstate highways to get benefits from its durability and endurance.

It will also increase driver’s safety due to the impressive friction capabilities with tires; it will also minimize tire noise and will reduce reflective cracking.

Mineral fillers and additives are used to minimize asphalt binder drain-down during construction while increasing the amount of asphalt binder used in the mix and to improve mix durability.

Open-Graded Mixes

The difference from the first two with the open-graded mixes is the permeability characteristic. This hot mix asphalt is designed only with crushed stone and a few grains of sand in the mix. There are two major classifications of this type of mix:

- Open-graded friction course- Air voids minimum requirement are 15%, and no maximum air void percentage is specified. This mix is only used for surface courses. It has a smoother surface finish than the dense-graded. Its low cost of placement counteracts the high cost of producing it. However, make sure that you are not clogging or sealing the pores as this action will dramatically reduce and degrade asphalt performance and stability.
- Asphalt treated permeable bases - It is used only under dense-graded, stone mix or portland cement concrete for drainage. It is used for drainage purposes below dense-graded, stone mix, or Portland cement concrete. [JUAN RODRIGUEZ , (2017)] .

Advances of Nanotechnology in asphalt mixtures

the advances in using nano-materials in hot mix asphalt. The clay nano-particles are the primary materials applying in asphalt construction. Adding nano-particles like nanoclay, nanosilica, and nanotubes in asphalts normally increase the viscosity of asphalt binders and improves the rutting and fatigue resistance of asphalt mixtures. Using nanoclay as the second modifier in polymer modified asphalts can improve the storage stability and the aging resistance of polymer modified asphalts. Various Atomic Force

Microscopy (AFM) techniques (e.g. tapping mode imaging, force spectroscopy, and nano-indentation) as well as X-ray diffraction (XRD) experiments can be conducted on modified asphalt binders to characterize the micro or nano-scale structures of nano-asphalts. Through the reasonable selection of nano-materials used in asphalt, nano-modified asphalt can offer many benefits in hot and cold regions.[Jun Yang , et al, (2013)] .

Benefits of Nanotechnology in Asphalt Mixtures

In general, Nanotechnology will produce benefits in two ways – by making existing products and processes more cost effective, durable and efficient and by creating entirely new products.

In particular to asphalt and asphalt mixture properties, Nanotechnology has the following known benefits.

- Improve the storage stability in polymer modified asphalt.
- Increase the resistance to UV aging.
- Reduce the moisture susceptibility under water, snow and deicers.
- Improve the properties of asphalt mixtures at low temperature.
- Improve the durability of asphalt pavements.
- Save energy and cost.
- Decrease maintenance requirements.

In 2012, Mojtaba Ghasemi et al. [12] reported the potential benefits of nano-SiO2 powder and SBS for the asphalt mixtures used on pavements. Five asphalt binder formulations were prepared using various percentages of SBS and nano-SiO2 powder. Then, Marshall samples were prepared by the modified and unmodified asphalt binders. The results of this investigation indicated that the asphalt mixture modified by 5% SBS plus 2% nano-SiO2 powder could give the best results in the tests carried out in the current study so that this modification can increases physical and mechanical properties of asphalt binder and mixtures. The modified bitumens were prepared by a high shear mixer. The physical properties of the modified bitumens (such as softening point, penetration and ductility) were measured. The obtained optimum bitumen content for the control mixtures was 6.3% which was used for preparing all other modified mixes in order to maintain consistency throughout the study.

In 2013, M. Faramarzi et al. attempted to promote technical characteristics of asphalt mixture using carbon nanotubes as an additive material for bitumen. In this study, marshal test parameters of hot mix asphalt, modified with 0.1, 0.5, and 1% carbon nanotubes, are investigated and compared to conventional asphalt mix. Wet and dry process methods are most practical ways of mixing CNF in AC. It was decided that the best method to adopt for this investigation was dry process. According to the results, the more carbon nanotubes increase, the better asphalt concrete specifications will be. Thus sample containing 0.01 carbon nanotubes by weight of bitumen, has the best results. This sample regarding Marshal Stability 32.53 percent and Marshal Ratio 44.71 percent is higher than the control sample. Also Marshal flow 8.4 percent and specific gravity 0.68 percent is lower than control sample. It should be noted that despite the decrease in flow, it is still within the permitted regulation. The initial cost of both samples 0.005 and 0.01 is higher than the control sample but for total cost, the amount and type of work should be investigated. When using modified mix, due to its high stability, the lower layer thickness will be less than the control mix and then the amount of total costs will decrease.

During , 2016 , Mahmoud Enieb et al. Characteristics of asphalt binder and mixture containing nanosilica the characteristics of asphalt binder containing 0%, 2%, 4% and 6% of NS have been investigated in terms of the penetration, softening point, viscosity, and changes in chemical bonds using the Fourier Transform Infrared (FTIR) Spectroscopy. An additional laboratory study was conducted to characterize the performance properties of the corresponding asphalt mixtures based on the resilient modulus, indirect tensile strength, fracture energy, moisture susceptibility, and fatigue life. Overall, the addition of NS material has a positive influence on different properties of the asphalt binder and mixture and can be used to construct durable pavements, thereby reduce the life-cycle costs of the pavement used to construct durable pavements, there by reduce the life-cycle costs of the pavement.

In 2016, Mostafa Alizadeha et al, They studied the effect of nano-particles of calcium montmorillonite and slag of electric arc furnace on the modified bitumen has been investigated, modified with 3, 5, 7 and 9 percent weighting. These particles were mixed with bitumen through powder and with different percentages in the high shear mixer. Then, three common tests i.e. softening point, penetration, and ductility were done on the samples. Results have showed that addition of slag could more affect the mixture against calcium montmorillonite. With addition of slag to the bitumen, all three properties were improved but calcium montmorillonite caused reduction of penetration index of the bitumen. For investigating surface morphology of the sample, the Scanning Electronic Microscope (SEM) was used. SEM results show that both materials are distributed in the bitumen successfully but in some parts there is no cohesion between bitumen and calcium montmorillonite.

CHAPTER 3

MATERIALS PROPERTIES AND TYPE OF TESTING

Chapter Three

MATERIALS PROPERTIES AND TYPE OF TESTING

3.1 MATERIALS PROPERTIES

Hot mix asphalt (HMA) contains two essential components, asphalt and aggregate materials. The asphalt works as a binder to hold together the aggregate particles, which forms the aggregate structure in the mixture. Having the largest particle size, coarse aggregate particles often form the skeleton of the aggregate structure and control transfer of the traffic and environmental loads to the underlying base, sub base and subgrade layers . In this study we sets tow type of asphalt mixture , first unmodified mixture and second modified mixture (with nanosilica) .

3.1.1 Asphalt

the aggregate in hot mix bound together by Asphalt binder , the asphalt binder in hot mix equal to 5% from mix weight. In this study we used 40-50 grade, Then Nanosilica was added to this type of bitumen with different percentages by weight of asphalt.

Figure (3-1) Asphalt

3.1.2 Aggregates

The significant role played by aggregate materials in the volumetric design of hot mix asphalt inherently links aggregate properties to the strength, stability, and performance of pavement. Mechanical responses of HMA under traffic and environmental loads have been attributed to the properties of aggregate structure, asphalt content and stiffness, and their interactions (Anderson et al., 2002;Ahlrich, 1996).the Aggregates used in hot mix according Iraqi standard shall be of uniform quality, crushed to size as necessary and shall be composed of sound, tough, durable particles, with or without natural or mineral fillers, as required .the aggregates we used is type AIII , it properties shown in table (3-2) and figure (3-2) shows aggregate size according to particle size using sieve analysis.

Figure (3.2): aggregate size separation by using sieve analysis.

Table (3.2): Physical properties of aggregates.

Property	ASTM designation	Test results	SCRB specifications
Coarse aggregate			
Bulk specific gravity	C 127	2.64	….
Apparent specific gravity	C 127	2.695	…
Percent wear by Los Angeles abrasion, %	C131	22.7	30 Max.
Soundness loss by sodium sulphate Solution, %	C88	3.4	12 Max
Flat and elongated particles, %	C 4791	5	10 Max.
Degree of crushing, %	D5821	96.	90 Min
Fine aggregate			
Bulk specific gravity	C127	2.67	…
Apparent specific gravity	C127	2.701	…
Sand equivalent, %	D2419	57	45 Min.
Angularity, %	C1252	54	…
Clay lumps and friable particles, %	C142	1.85	3 Max

3.1.3 Mineral filler

Mineral filler shall consist of limestone or other stone dust. Portland cement, hydrated lime or other inert non-plastic mineral matter from approved sources according to Iraq standard .In this study Ordinary Portland cement was used as the mineral filler in HMA sample. Table (3-3) shows the properties of this cement.

Table (3.4) Physical properties of fillers.

Property	Portland cement
Passing sieve No. 200, (%)	94.76
Specific gravity (ASTMC188-95)	3.1

3-2 TESTING:

3-2-1 Testing on asphalt binder

The testing were conducted on both unmodified asphalt cement and modified samples have been prepared. The modified samples are prepared by adding different ratios of Nano silica (1% ,2% 3%) , and its effect was evaluated by the aid of penetration and softening point and ductility tests results, figure (3-3)shows sample prepared.

Figure (3-3) sample prepared

3-2-1-1 Penetration test

Penetration test is an empirical test used to measure the consistency of asphalt cement . Generally the penetration of a bituminous substance may be defined as The distance of the needle penetration the material vertically under a given weight(100g), at a certain time and a certain temperature (the test has been done in different temperature 15c, 25c ,35c).figure (3-4) shows penetration test .

Figure (3-4) penetration test.

3-2-1-2 Softening point test

the purpose of this test is to set the soften point of the bitumen using a ring and A ball in hot bath .As the temperature increases the Asphalt moves from hardness to The Softness . Therefor this test can be used to compare between types of asphalt. Figure (3-5) shows softening point test .

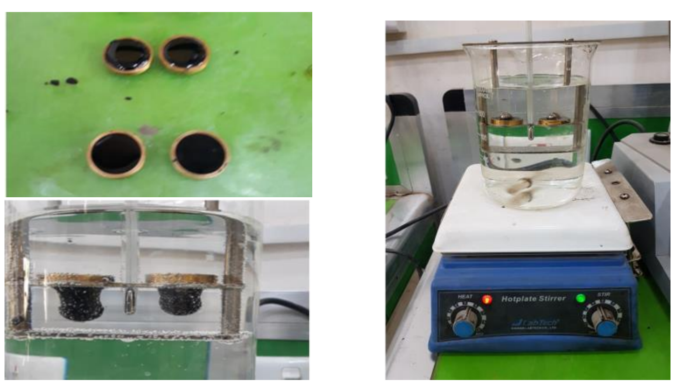


Figure (3-5) shows softening point test

3-2-1-3 Ductility test

Ductility is the asphalt characteristic for ability to the elongation when it was pulling in both ends by specific force, speed and Temperature (25c). This will provide un idea about the asphalt stability and capability to resist the external efforts .figure (3-6) shows ductility test.

figure (3-6) ductility test

3-2-2 Testing on hot mix

Hot mix asphalt may be referred to by several names. In different sections of the state it may also be referred to as bituminous concrete, hot plant mix, asphalt concrete, blacktop or Superpave. Hot mix asphalt is composed of aggregate bound together into a solid mass by asphalt cement. In this study ASTM specification D1559-89 was used as a guide to prepare the HMA mixture.

At the beginning of the preparation of the asphalt mixture, the gravel was prepared with a weight of (1140) and heated by the heat, and add the asphalt 40 -50 is also heated up to 150^{o}C to assure the adequate mixing temperature with the aggregate.

After mixing with temperature (150-160 c) and molding it, the mixture is compacted according to the Marshall mix design method standards which states that Marshall compactor should be used to apply 75 blows per each sample side. Automatic compactor was used .figure (3-7) shows samples preparation and testing.

This part of the project involves conducting a number of laboratory experiments on modified and standard asphalt mixtures , These tests are Index of Retained Strength (IRS) test is used to evaluate AC mix durability , Marshall test results (stability and flow) and Indirect Tensile Strength test which its used to determine the tensile properties of the bituminous mixture.

Figure (3-7) samples preparation and testing.

3-2-2-1 Marshall Stability and flow test

The Marshall stability and flow test provides the performance prediction measure for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the test specimen at a loading rate of 50.8mm/minute. The ASTM D6927 specification is used to prepare, compact and test the samples for computing Marshall, The asphalt mix sample is a 2.5in. height by 4.0in diameter cylinder . Before the test, the sample was prepared are by placing them in the water for a period of (40 min) at 60C. Figure (3-8) Marshall Stability and flow.

Figure (3-8) Marshall Stability and flow

3-2-2-2 Indirect tensile strength test

The indirect tensile strength test (IDT) is used to determine the tensile properties of the bituminous mixture which can further be related to the cracking properties of the pavement. Low temperature cracking, fatigue and rutting are the three major distress mechanisms. A higher tensile strength corresponds to a stronger cracking resistance. At the same time, mixtures that are able to tolerate higher strain prior to failure are more likely to resist cracking than those unable to tolerate high strains. A lot of research work has been reported on the performance of bituminous pavements relating the tensile strength of bituminous mixtures. According to ASTM D4123 specification standard the samples was prepared and testing. The test includes applying compressive load on the AC cylindrical specimen along its diameter and with 50.8 mm/min rate figure (3-9) indirect tensile strength, and an indirect tensile stress along the specimen diameter can be computed as follows:

$$\sigma t = \frac{2 \times Pmax}{\pi HD} \qquad (1)$$

where σt is the indirect tensile strength in KPa, $Pmax$ is the maximum applied load, KN, D is the specimen diameter(m) and H is the specimen height(m).

Figure (3-9) indirect tensile strength

3.2.2.3 Moisture damage - Index of Retained Strength (IRS)

In order to investigate the effect of water on the compressive strength of hot mixtures, the index of retained strength is determined. This valueis an indicator of their resistance to moisture susceptibility. The test was conducted at a temperature of 25˚C and the load at which the specimen fails is taken .According to ASTM D6927 specification standard The sample was prepared by placing the samples in a water bath maintained at 60˚C for 24 hour, figure (3-10) shows water bath. The test includes applying compressive load on the AC cylindrical specimen with 50.8 mm/min rate. Accordingly, the Index of retained strength is computed mathematically using Eq. (6) below.

IRS=$\frac{S2}{S1} \times 100\%$ (2)

Where IRS is the percentage of Index of Retained Strength,, S1 is the Marshall stability of the dry condition specimens, KN, and S2 is the Marshall stability of the wet condition specimens, KN .

Figure (3-10) water bath.

3.2.2.4 Volumetric properties

Air voids are small airspaces or pockets of air that occur between the coated aggregate particles in the final compacted mix. A certain percentage of air voids is necessary in all dense-graded highway mixes to allow for some additional pavement compaction under traffic and to provide spaces into which small amounts of asphalt can flow during this subsequent compaction. ASTM D2726 and ASTM D3203 specification is utilized to compute dry bulk density. Following are the corresponding mathematical models:

Dry density=$\frac{\text{weight in air}}{\text{SSDweight} - \text{weight inwater}}$ (3)

where SSD is the weight of the saturated-surface dry samples, gm.

Air voids %= $\left(1-\frac{\text{dry density}}{\text{SGmax}}\right)\times 100\%$ (4)

where SG_{max} is the maximum specific gravity for the mixture computed in comply with the ASTM D2041 specification. Noting that the percentages of coarse aggregate (CA), fine aggregate (FA), filler (F) and asphalt (A) are by weight of total mix respectively.

VMA= $100\%-\frac{\text{Gmb}\times\text{Ps}}{\text{Gsb}}$ (5)

Where Ps is percentage of aggregate in the total mix and Gsb is the aggregate bulk specific gravity.

VFA= $\frac{(VMA-AV)}{VMA}\times 100\%$ (6)

CHAPTER 4
Results and Discussion

Chapter Four

Results and Discussion

Several types of testing were conducted to indicate the effect of adding Nano silica material to the pure (unmodified) bitumen (40 -50 penetration grade). The tests include penetration, softening point and ductility, From the results of this testing on binder, the optimum Nano silica percentage was indicated .And Marshall Stability and flow, Indirect Tensile Strength, Index of Retained Strength (IRS), Volumetric Properties ,to indicate the effect of adding Nano silica material to hot mix asphalt .

4.1. Effect of Nanocarbon on Penetration Test Results

Penetration test was carried out for the unmodified bitumen and modified bitumen with different percentages of Nano silica i.e. 1%, 2% and 4% by weight of asphalt. The test was performed at different temperatures (15,25,35 c) , . Figure 4-1 shows the penetration results at these temperatures The results of the test show that, the value of the penetration increases when the temperature increases and decreases when temperature decreases for both for the unmodified bitumen and modified bitumen with different percentages of Nano silica , However the penetration decreases for modified bitumen with Nano silica added at all percentages. The most interesting point is that the slope of the binder with 2% Nano silica is the lowest one and the penetration at high temperature decreased highly in comparison with the unmodified bitumen while there was no very little increases at low temperature.

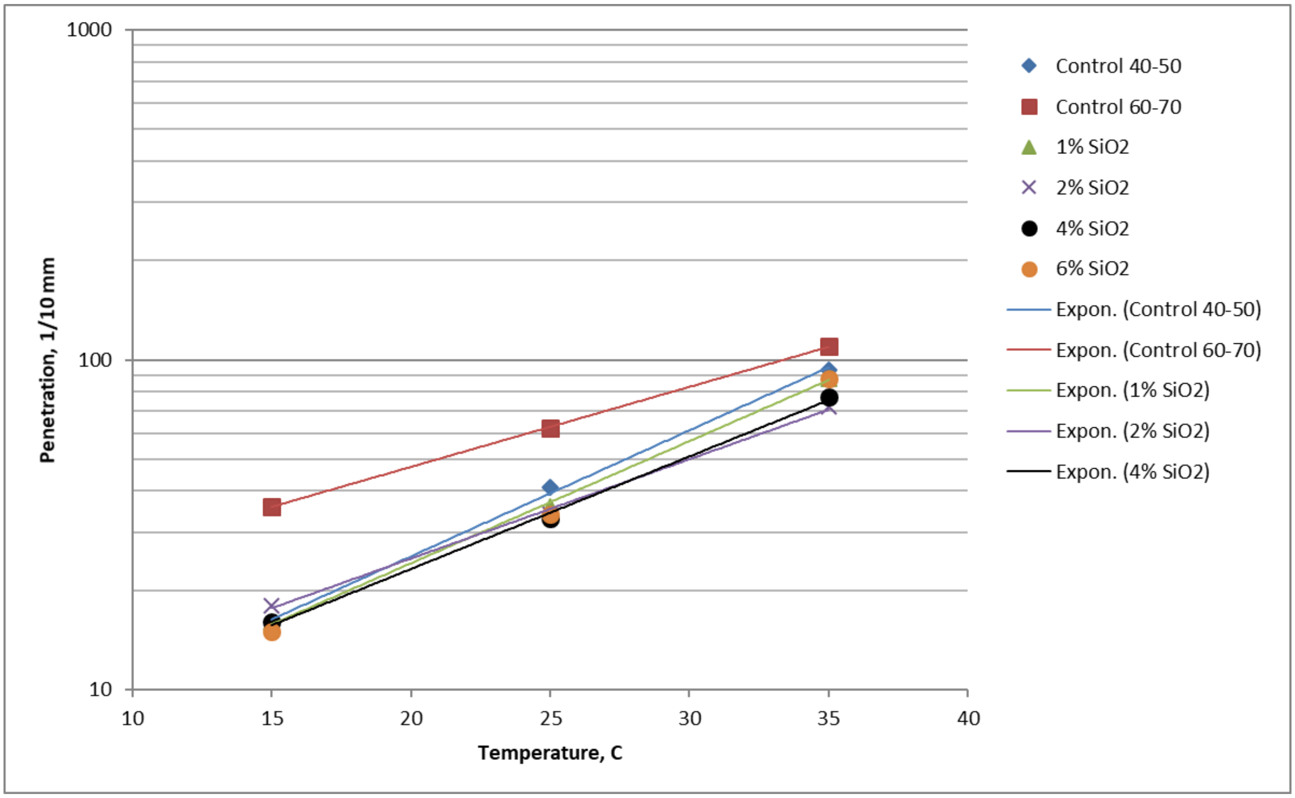


Figure (4.1): Effect of Nano-silica on Penetration

4.2. .Effect of Nano silica on Softening Point Test Results

Table 4-2 shows the results of the softening point for all types of binder unmodified and modified binders with different percentages of Nano silica.

Table (4.2) the results of softening point

Sample	Softening point (c)
NEAT	42.5
NSMA -1%	42.5
NSMA -2%	42.25
NSMA -4%	42.25

4-3. Effect of Nano silica on Ductility:

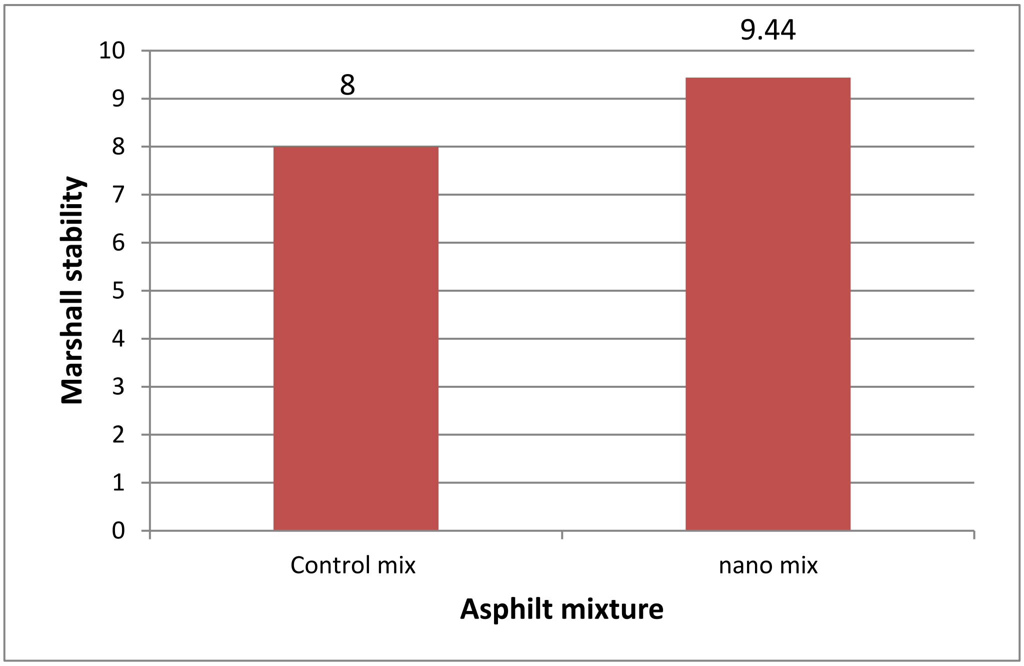
Table (4.3) show the results of ductility test for both unmodified bitumen and modified bitumen with different percentages of Nano silica. According to the Iraqi highways standard, the value of ductility should be higher than 100 cm, the results have achieved from the test is less than (100) for (2%, 4%). It can be stated that adding Nano silica to binder make it more stiff.

Table (4.3) the results of ductility test

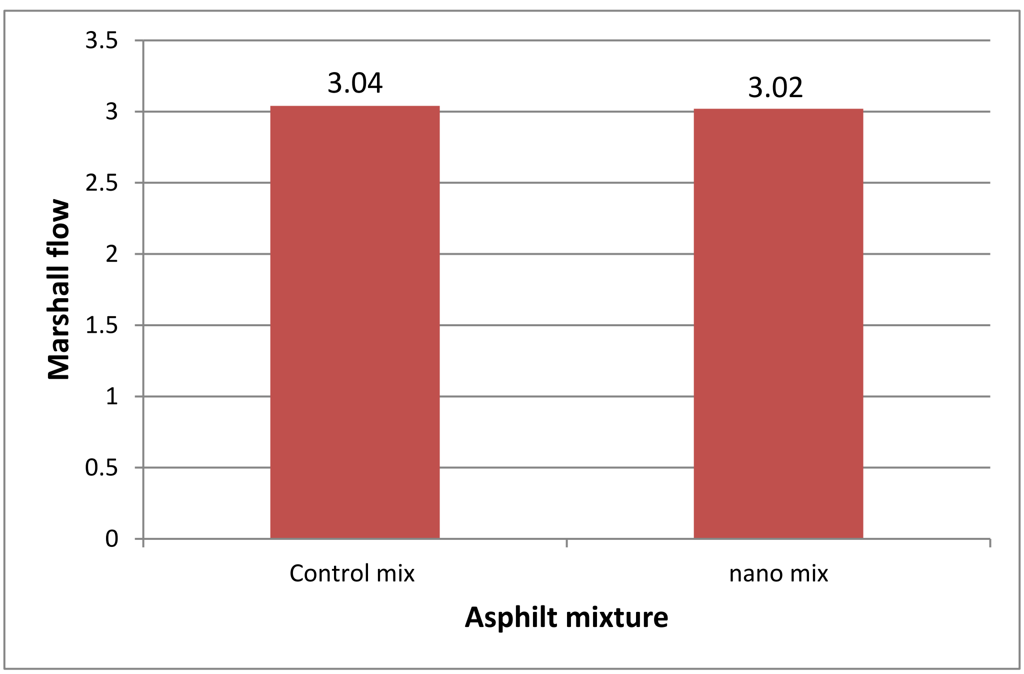
TEMPRETURE	25 C
NEAT	>100
NSMA -1%	>100
NSMA -2%	81.25
NSMA -4%	70

4.4. Effect of Nano silica on Marshall Stability and flow

According to the Iraqi standard specifications, Marshall stability should be larger or equal to 8 KN for surface courses and flow (3-4). Figures 4-4 and 4-5 present Marshall Stability and Marshall flow, respectively. The figure Marshall stability increased significantly when 2% of Nano Silica has been added to the base bitumen. Also, Marshall stability increased by more than 17% for the modified mixtures in comparison with the control mixtures.



Figures (4-2) Effect of Nano silica on Marshall Stability.



Figures (4-3) Effect of Nano silica on Marshall flow.

4.5 Effect of Nano silica on Indirect Tensile Strength:

The results of indirect tensile strength are shown in Figure 4-6. From the result of testing, ITS increased by almost 7% for modified mixtures in comparison with the control mixtures.

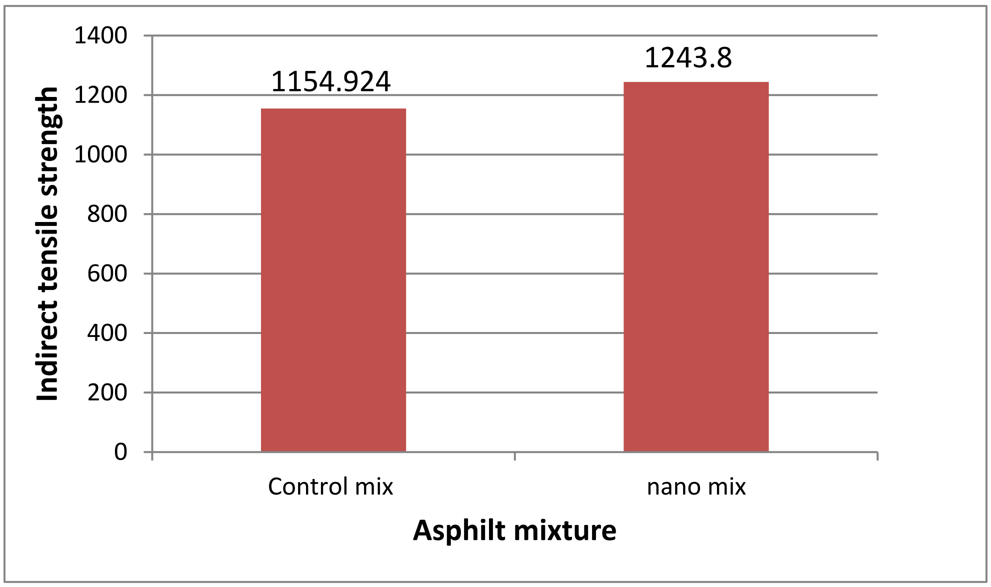


Figure (4-4) Effect of Nano silica on Indirect Tensile Strength

4.6 Effect of Nano Carbon on Index of Retained Strength (IRS)

The results of index of retained tensile strength are shown in Figure 4-7. From the results IRS increased from 75 to 92%. According to the Iraqi standard specifications, IRS must exceed 70%, therefore the modified mixtures comply with this specification.

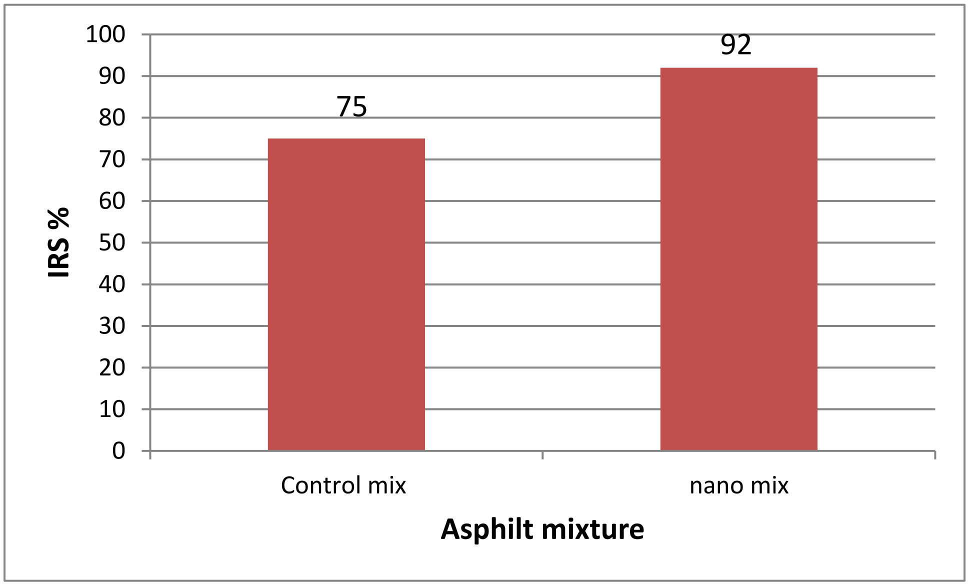


Figure (4-5) Effect of Nano silica Index of Retained Strength (IRS)

CHAPTER ٥
Conclusions

Chapter Five

Conclusions

Several key conclusions can be reached based on the experimental results

1. After the penetration test we found the penetration distance less than the base binder so that mean the stiffness is getting higher
2. The results of Ductility test show that the modified binder is getting more stiff by adding Nano silica
3. It has been observed that the addition of Nano silica (2%) increased the Marshall Stability by more than 18%, and the flow is with the acceptable range of the Iraqi specification (3-4).
4. The addition of Nano silica increased the retained stability (IRS) from (75-92)%, According to the Iraqi standard specifications, IRS must exceed 70%, therefore the modified mixtures satisfy this specification.
5. Indirect tensile strength (ITS) increase by almost 7% for modified mixtures in comparison with the unmodified asphalt concrete mixtures.

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