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Improving the Performance of Asphalt Mixtures Using Nano Silica

[1]*Metwally G. Al-Taher,* [1]*Hassan D. Hassanin,* [2]*Mokhtar F. Elgendy and* [2]*Ahmed M. Sawan*

[1]Construction Engineering & Utilities Department, Zagazig University, Zagazig, Egypt
[2]The Higher Institute of Engineering, El-Shorouk City, Cairo, Egypt

Abstract: Asphalt pavements are exposed to distresses especially cracks and rutting. These defects are encountered within the pavements as a result of deficiencies in mixture characteristics and increasable traffic loads. They occurred due to deficiency in asphalt binder and/or the mixture. This paper studies how to improve the asphalt mixture characteristics using Nano Silica (NS). The research includes studying the characteristics of the modified mixtures using NS. The tried NS contents are 3, 5, 7, 9 and 11% by bitumen weight. Marshall, Wheel Tracking, Indirect Tensile Strength (ITS) and Direct Compression (DC) Tests are used to evaluate the obtained characteristics. Results indicate that the most suitable NS content is 7% by weight of asphalt. Modifying the asphalt mixture by 7% NS increases the Marshall stability by 25%, decreases the flow by 19%, obtaining approximately the same unit weight and keeping the air voids percentage and other mix properties within the accepted limits. It also increases the DC value by 7%, increasing the ITS value by 2.7% and decreases the rutting depth by 40%. Generally, adding NS success in improving the characteristics of asphalt mixtures.

Key words: Modification · Nano silica (NS) · Wheel Tracking · Asphalt Mixture · Characteristics · Fatigue · Cracks

INTRODUCTION

The asphalt concrete mixture consists of two major components; aggregates and binder. The aggregate represents the major amount in the mixture about 95% while the binder represents about 5% by total mixture weight. Although this amount of binder is small, it has a greater effect on the characteristics of the obtained mixture [1]. Many studies were conducted to improve the quality and characteristics of the asphalt concrete mixtures. They used different types of modifiers such as polymers, rubbers …. etc. to enhance the mixture characteristics [1- 3]. NS is one of the modifiers that researchers started to focus on using it for the modifications of different pavement layers such as subgrade, base and subbase [4, 5]. Nano-technology is the science of the phenomena peculiar to matter on the scale from 1 to several hundred nanometers (10^{-9}m). Some unique features of matter emerge when features are on the nano scale and the appreciation of these new properties opens new opportunities that had been ignored in the past decades due to the lack of technology. These new emerging opportunities offered by nano-science which is consider one of the most important areas of researching from the middle of the twentieth century to nowadays. Yazan Issa [4] investigated the change in mixture characteristics by adding about 10% by weight of rubber to the mixture. It was found that the resulted mixture achieves improvements in both of workability and compaction efficiency. Using silica fume has a major effect in enhancing engineering properties of the tested soil [6-8]. A new amorphous silica source recently introduced to the world of science is NS [9]. Among all the nano materials, NS is widely used material in the cement and concrete to improve their performance [10, 11]. NS behaves not only as filler to improve the microstructure, but also acts as an activator to promote the pozzolanic reaction, which enhances the formation of the hydrated products [12]. Al-Salami and Al-Gawati [13] investigated the pozzolanic reaction of NS prepared to study its effect in improving physical, mechanical and engineering properties of hardened blended cement. The NS was blended with calcium hydroxide (CH) with various percentages 10%, 20%, 30% and 50% using water to CH ratio of 0.35. The mixtures were kept at relative humidity of 100% for 7 days. Bahmani *et al* [14] studied the effect of

Corresponding Author: Ahmed M. Sawan, The Higher Institute of Engineering, El-Shorouk City, Cairo, Egypt.
Mob +2010670902337, E-mail: ahmedsawan1991@gmail.com.

Nano materials (NM) on consistency, compaction, hydraulic conductivity and compressive strength of the soil treated with cement.it was found a significant change after using NM with the treated soil. So, the main aim of this paper is to study the effect of using NS on the physical and mechanical properties of asphalt mixtures.

MATERIALS AND METHODS

Asphalt Binder: Suez asphalt 60-70 is used in the study. Its specific gravity is 1.021, while its physical properties including penetration and viscosity are presented in Table (1).

Aggregates: Crushed dolomitic aggregates (fine and course) are used to constitute the mixture in conjunction with the filler as well as the asphalt cement. The characteristics of the used aggregates are presented in Table (2).

Nano Silica Components: Table (3) shows the components of NS, while Figure (1) shows its shape.

X- Ray and Scanning Electron Microscopy Tests: X-ray and scanning electron microscopy (SEM) tests are used to show the component and particle of molecules of NS. Figures (2) and (3) show the results of these tests.

Modified Asphalt Cement: Asphalt cement is heated in an oven at a temperature of 150°C. Then the suitable quantity of heated asphalt is taken and placed in a steel beaker. The suitable quantity of NS is added into the beaker to be mixed with the asphalt. Mixing is continuing until the binder becomes homogeneous. NS is used by quantities range from 3 to 11% by weight of bitumen.

Characterization of the Modified Asphalt Cement: The physical characteristics of the modified asphalt are obtained through conducting the required consistency tests. Penetration and viscosity only are focused in the study.

Characterization of the Modified Asphalt Mixtures: To define the properties of both modified and control asphalt concrete mixtures. Marshall Test is used. The first set of

Table 1: Asphalt Cement Properties

Property	AASHTO Designation No.	Result	Specifications Limits
Penetration at 25°C,(0.1mm)	T- 49	66	60-70
Rotation Viscosity at 135°C,.(Cst)	T- 201	380	≥ 320
Flash point, (°C)	T-48	268	≥ 250
Softening point, (°C)	T-53	52	45-55

Table 2: Aggregate Properties

Property	AASHTO Designation No.	Coarse Aggregate Size (1)	Coarse Aggregate Size (2)	Fine Aggregate	AASHTO Limits
Los Angeles abrasion	AASHTO 96	35.22%	31.42%	---	40 Max
Bulk (S.G)	AASHTO (85-77)	2.5	2.51	2.65	---
Saturated and dry surface (S.G)	AASHTO (85-77)	2.56	2.6	---	---
Apparent (S.G)	AASHTO (85-77)	2.66	2.66	---	---
% Water absorption	AASHTO (85-77)	2.10%	2.26%	---	5 Max

Table 3: NS Components

Sample Name	SI
Date	16-09-2015
Time	23:28:32 PM
R_wp	6.64
Alite_Sum	0
Lime	0.06
Periclase	0.09
Quartz	0.19
Anhydrite	0.24
Calcite	0.28
Mulite	0
Magnetite	0
Hematite	0
Thenardite	0
Rutile	0
Si_amorph	99.15

Fig. 1: Shape of NS.

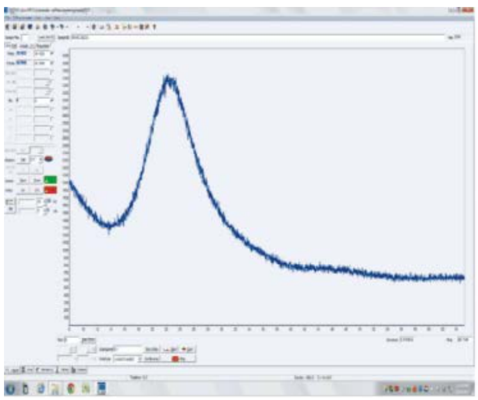

Fig 2: X-Rays test of NS

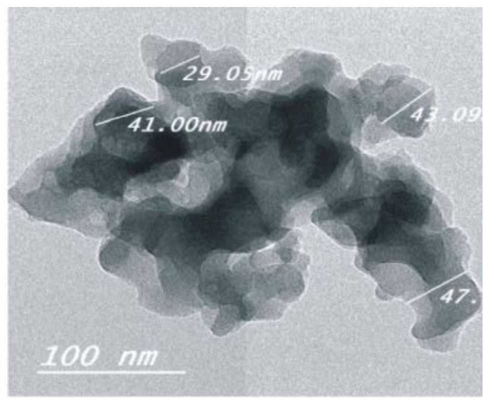

Fig. 3: SEM of NS

specimens is prepared to define the mix properties of the control mix through defining the optimum asphalt content (OAC) and the mix stability, flow, unit weight, air voids, voids in mineral aggregates (VMA) and voids filled with bitumen (VFB). Another four sets of specimens are prepared with modified asphalt cement with different NS contents to define the optimum NS content that achieves the desired mix properties.

Direct Compression (DC) Test: This test is used as per ASTM (D-1074) to define and investigate the engineering behavior of the modified mixtures using NS under the effect of crushing loads. The preparation of test specimens is the same as Marshall Specimens. Three specimens with OAC and other three specimens with optimum modified asphalt contents are prepared and tested in the DC test apparatus. The DC values (S_c) are calculated using the following equation: $S_c = P / \frac{\pi D^2}{4}$, [kg/cm^2] where; P is the load in kg and D is the specimen diameter in cm.

Indirect Tensile Strength (ITS) Test: The ITS test as per AASHTO (T322-03) involves loading a cylindrical specimen with compressive load which acts parallel to and along the vertical diametrical plane. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load. This tensile strength causes the specimen to fail by splitting or rupturing along the vertical diameter. ITS values (S_t) are determined by using the following equation: S_t = 2P/(ðHD), (kg/cm^2), where: P is the applied load in kg, H is the specimen height in cm and D is the specimen diameter in cm.

Wheel Tracking (WT) Test: This test is carried out according to AASHTO (T324-04). It describes a procedure for testing the rutting of hot mix asphalt (HMA) pavement compacted samples in the WT device. This test provides information about the rate of permanent deformation occurred under the effect of moving a concentrated traffic load. A laboratory compactor has been designed to prepare slab specimens. The test is used to determine the premature failure susceptibility of HMA due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage. This test measures the rutting depth and number of passes or time to the final rutting depth for both control and the modified HMA mixtures.

RESULTS

Effect of Adding NS on Asphalt Cement: Mixing NS with bitumen improves the penetration characteristics; the penetration decreases from 6.50mm to 5.40mm which represent about 16.92%, as shown in Figure (4). Also, modifying asphalt cement using NS resulted in changing the properties of asphalt. The viscosity increases from 378 to 415 centistokes after adding NS which represents about 9.79% as shown in Figure (5). These findings are in agreement with Mostafa (2016) [15].

Effect of Adding NS on Marshall Stability: Adding NS to the asphalt mixtures changes the characteristics of the mixtures. Figures (6) and (7) show that an increase in Marshall Stability is occurred with the increase in NS contents from 3% to 7% and then it decreases by an increase in NS contents up to 11%. The optimum NS content that achieves maximum stability is 7%. Adding 7% NS increases the stability by 25%, where the stability increases from 2880 to 3500 kg. Also, this finding is in agreement with Mostafa (2016) [15].

Effect of Adding NS on Marshall Flow: Figures (8) shows a significant decrease in Marshall Flow by using NS and this is in agreement with Mostafa (2016) [15]. While Figure (9) shows values of flow at OAC, it is found that the flow decrease as the NS content increases up to 4% by weight of asphalt content. Then it increases by an increase in NS content and all values of the modified mixes are lower than value of the control mix. The first decrease is due to the gaining densification that resulted in increasing stability and accordingly decreasing flow. After the mix reaches to the maximum densification and stability, any addition of NS resulted in making the mixture tends to be more flexible and increasing its tendency to be deformed. This leads to make the modified mixtures capable of resist the tendency to deformation under traffic loads.

Effect of Adding NS on Unit Weight (γ): Figures (10) and (11) show an increase in unit weight with the increase in NS content up to about 4%, then it deceases gradually until it reaches its minimum value at 11% NS. The maximum unit weight is 2.31g/cm^3 which

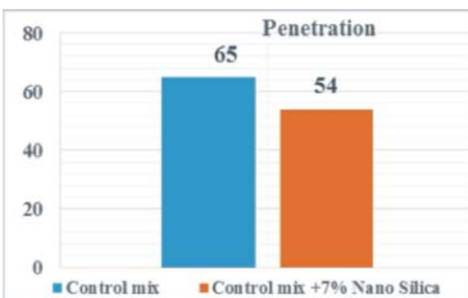

Fig. 4: Effect of Adding NS on Penetration

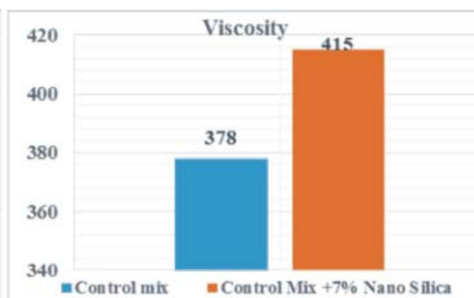

Fig. 5: Effect of Adding NS on Viscosity

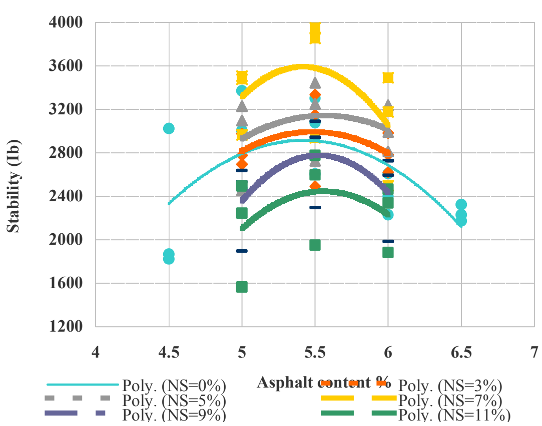

Fig. 6: Effect of Adding NS on Marshall Stability

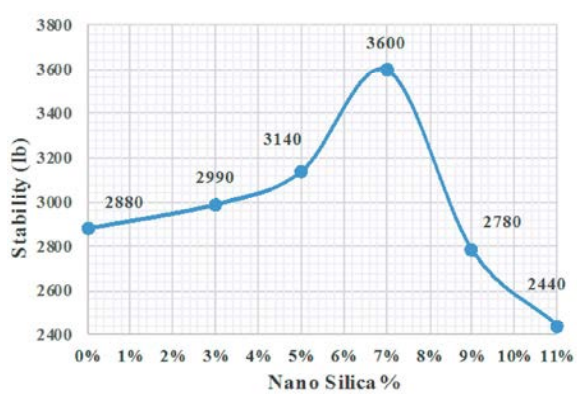

Fig. 7: Effect of adding NS on Marshall Stability at OAC

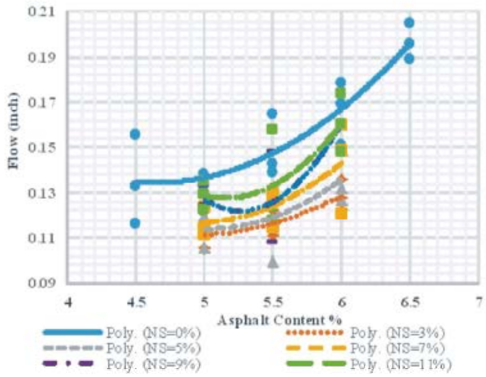

Fig. 8: Effect of adding NS on Marshall Flow

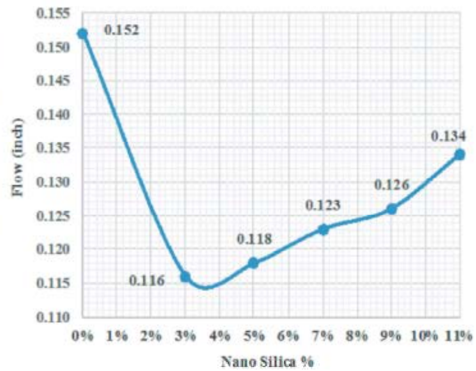

Fig. 9: Effect of adding NS on Marshall Flow at OAC

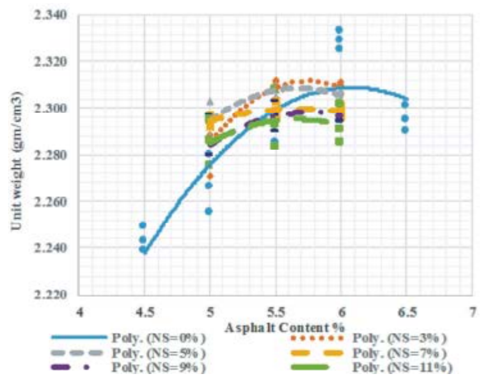

Fig. 10: Effect of adding NS on Unit Weight

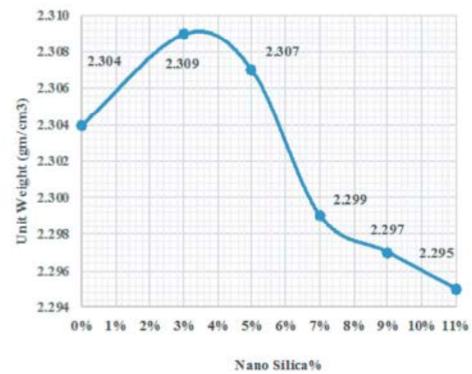

Fig. 11: Effect of adding NS on Unit Weight at OAC

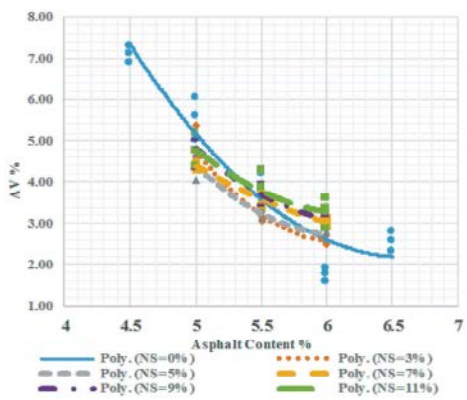

Fig. 12 Effect of adding NS on AV%

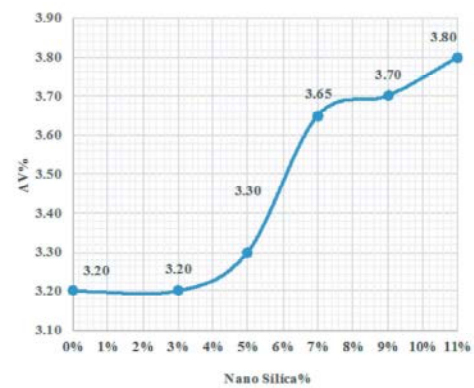

Fig. 13: Effect of adding NS on AV% at OAC

occurs at 3.5% NS. Figure (10) shows that the obtained unit weight from the modified mixture are greater than those of the control mixture for NS contents of 3 and 5%.

Effect of Adding NS on Air Voids Percentage (AV%): Figures (12) and (13) show a significant increase in AV% by an increase in NS contents. Figure (12) shows that all the obtained AV% for different NS contents are within the accepted range for asphalt mixtures. Also, Figure (13) shows the obtained values of AV% at OAC.

Effect of adding NS on Voids in Mineral Aggregate (VMA%): It is found that VMA% increases by an increase in NS contents as shown in Figures (14) and (15). The highest value of VMA% is obtained at 11% NS, while the lowest one is occurred at 3% NS. Also, it is seen that VMA% values at OAC of the tested specimens decrease up to 5% NS, then a significant increase is occurred as shown in Figure (15).

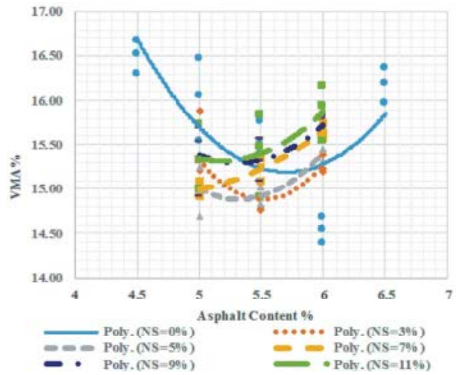

Fig. 14: Effect of adding NS on%VMA

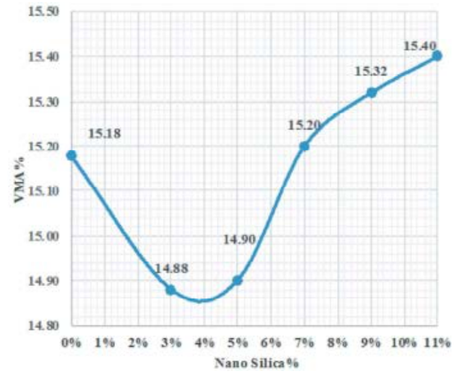

Fig. 15: Effect of adding NS on%VMA at OAC

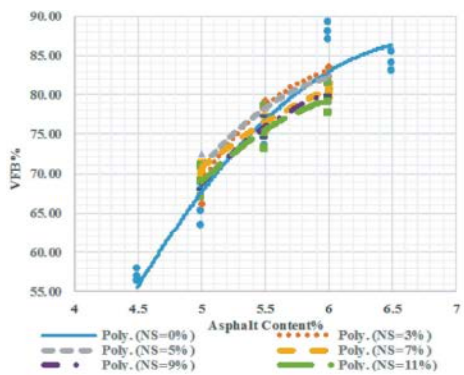

Fig. 16: Effect of adding NS on VFB%

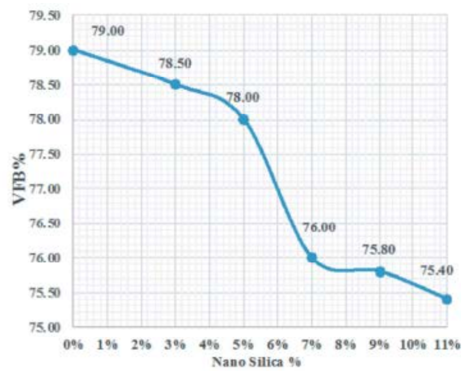

Fig. 17: Effect of adding NS on VFB% at OAC

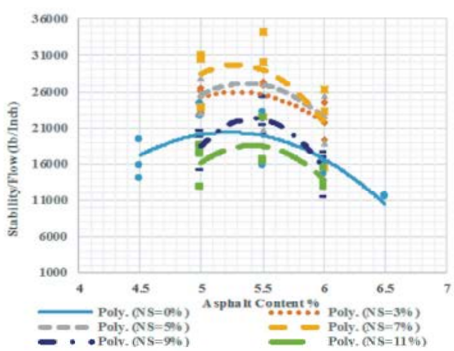

Fig. 18: Effect of Adding NS on Marshall Stiffness

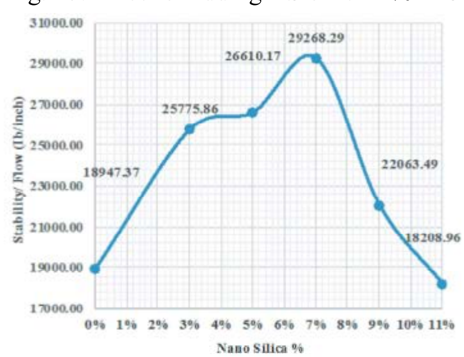

Fig. 19: Effect of Adding NS on Marshall Stiffness at OAC

Effect of adding NS on Voids Filled with Bitumen Percentage (VFB%): Figure (16) shows the increase in VFB% due to the increase of the asphalt content while, Figure (17) shows a decrease in VFB with an increase in NS content keeping the asphalt content at the OAC. The reduction in VFB occurs due to the presence of the fine NS particles those penetrate into the voids instead of asphalt.

Effect of adding NS on Marshall Stiffness (Stability/Flow) (lb/inch): The mixture stiffness is defined as the ratio of the stability to the flow which defines the ability of the asphalt mixture to resist deformation under the applied loads. Figures (18) and (19) show the relations between the stiffness and both of asphalt contents with different amounts of NS at constant OAC. Figure (19) shows that the stiffness increases by an increase in NS until it reaches its maximum value at 7% NS; then it deceases accordingly. The Figure also shows that the values of stiffness of the modified mixtures are greater than the value of the control mixture except the mixture with 11% NS. The stiffness values of both control and the modified mix with 7% NS are 1900 and 29268 Ib/ inch, respectively. Finally, NS improves the mixture stiffness by about 54%.

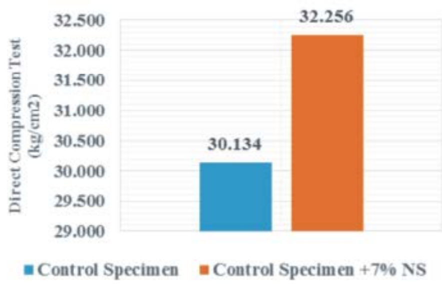

Fig. 20: Effect of Adding NS on DC

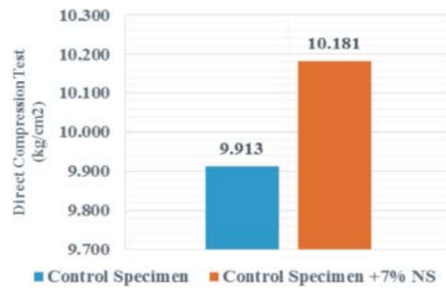

Fig. 21: Effect of Adding NS on ITS

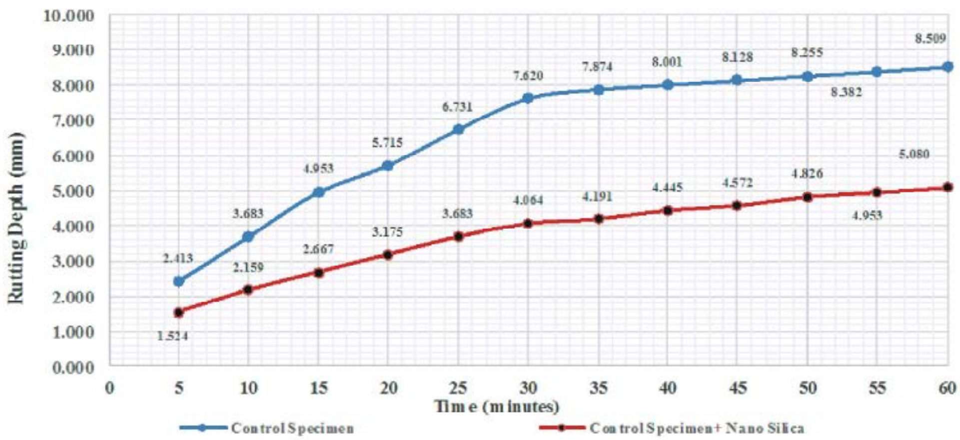

Fig. 22: Effect of adding NS on Rutting Depth

Effect of Adding NS on DC Test: Figure (20) shows the results of the (DC) test for both the modified and control mixture. The DC value increases from 30.14 to 32.26 kg/cm^2. It provides an improvement by about 7%.

Effect of Adding NS on ITS: The results of ITS test are shown in Figure (21). The results indicate that the ITS value increases from 9.913 to 10.181 kg/cm^2 which represents an improvement by about 2.70%. This means that adding 7% NS to the asphalt mixture will enable the mixture to resist the tensile stresses.

Effect of Adding NS on Rutting Depth: Figure (22) shows the results of WT test for both of control and modified mixtures (the modified mixture treated with 7%NS). Readings are recorded each five-minute increment up to 60 minutes as a test period. Results indicate that the rutting depths for the modified mixture are generally lower than those for the control mixture. Generally, the rutting depth increases with the increase in NS for both control and modified mixtures. The behavior of the two mixtures are similar but with low rutting depths for the modified mixture. The 60 minutes rutting depths for the treated mixture are lower than values of the control mixture by about 40%. This means that the modified mixture shall be capable of resisting rutting rather than the unmodified control mix. This finding is in agreement with Yusoff *et al.* [16].

CONCLUSION

It is concluded that adding NS to the asphalt binder improves the physical characteristics of the asphalt binder. It decreases the penetration and increases its viscosity. The optimum NS content is found to be 7%. Modifying the asphalt mixture by 7% NS increases Marshall Stability by 25% and decreases the flow by 19%. Also, it increases the mixture stiffness by 54%, maintaining the unit weight and AV% within the accepted limits. As well as it improves the DC test value by 32%, increases the ITS value by 2.7% and enhances the rutting resistance by 40%.

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