



Effect of Polymer Additive on Nano Materials Modified Asphalt Mixtures

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Authors' contributions

This work was carried out in collaboration among all authors. Author AEAEM designed the study, analyzed and revised the results and wrote the first draft of the manuscript. Author MEO managed and revised the analyses of the study. Author SS conducted the laboratory tests and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Recently, by the increase of traffic volumes and tonnages, modern axle arrangements and more wheel compressions, the needs to the highway asphaltic pavements have increased, requiring an improvement in the performance of asphaltic materials. With a view to enhance the performance of asphalt mixture, the pure asphalt binder requires to be modified with appropriate modifiers. In recent years, pavement technologies and investigators have put their attentions on nanotechnology. In this research, Nano Clay particles (NC) as well as Nano Silica particles (NS) and one polymer additive (Styrene- Butadiene-Styrene (SBS) were utilized with asphalt binder. The addition ratios of nano materials were (1%, 2% and 3%) mixed with 5% SBS by weight of the asphalt binder. Marshall test and wheel tracking test were used to estimate the influence of nano particles and SBS on hot mix asphalt (HMA) performance. The results illustrated that nano materials and SBS improved the stability, flow and Marshall quotient that indicated to the rutting or plastic deformation resistance of modified asphaltic mixtures.

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1. INTRODUCTION

Service period of flexible pavement is one of the most important matters in many countries due to its effect on economy. Flexible pavement deteriorations decrease the service period of the pavement. The majority of widespread pavement deteriorations is rutting damage which is often occurred in the shape of plastic deflection and fatigue cracking deterioration [1,2]. In recent years, nano technology has become a promising and creative technique in the material industry, and nano materials have been widely applied to various fields across the world. The scientific board on emerging and recently specified health dangers defines nano material as a material with one or extra outer dimensions, or an internal structure owning one or extra dimensions of 100 nm or less arrangement, and which can display new characteristics contrasted to the same material with no nano-scale features [3]. Many studies evaluated the effects of nano modifications in the asphalt mixture performance. Three types of nano particles were used silica, zero-valent iron and bentonite nano clay blended with 35/50 penetration grade. For all the modifications, the amount of nano particles was calculated to be 4% of the mass of the final modified binder. The results showed that nano modifications lead to improvements in the performance. Nano silica improved stiffness and permanent deformation [4,5].

Iskender [6] investigated the characteristics of hot asphalt mixes if modified with nano clay. It was founded that the using asphalt mixtures modified by nano clay provided more deformation, water damage and cracking resistance at adding content of 2.0%. Water damage resistance increased with increasing nano clay concentrations. Bayekolaei et al. [7] studied the influences of nano-modified asphalt binders and the addition of polymer additive (Styrene Butadiene Styrene (SBS)) on plastic deformation resistance. The results showed that the nano material addition improved the rutting properties of asphalt mixtures, rheological properties of modified binders, Marshall stability and resilient modulus. These results match with many studies as [8,9,10] studied the effect of using different modifiers on asphalt mixes such as rock asphalt, nano silica and polymer additive SBS. The results indicated that nano-silica and rock asphalt improved the performance of pavement. The mixtures that modified by rock asphalt, nano-silica and SBS provided increased

values for temperature persistence, cracking reluctance at low-temperature, stripping resistance and sturdiness more than mixtures modified by 5% SBS only.

2. EXPERIMENTAL WORK

2.1 Materials

Nano Clay (NC) that manufactured locally at Al-Azhar university- Egypt, was used in this study. Nano Silica (NS) that manufactured by Malven Ltd-Italy was utilized in this study. One additive was mixed to the bitumen content. The polymer additive named styrene butadiene styrene (SBS) that bought from Egyptian company "Chemicals for Modern Building (CMB)" was used for this research. Table 1 shows the characteristics of NC and NS. The properties of (SBS) are illustrated in Table 2. The main properties of asphalt binder are shown in Table 3.

Dolomite aggregate, crushed sand and powder were used in Hot Mix Asphalt (HMA) preparation. Aggregate sizes and gradation agree with the 4D wearing surface requirements for Egyptian Code [11] as shown in Table 4. The physical properties of the aggregate are presented in Table 5.

2.2 Nano Materials Characterization

The nano clay and nano silica were first characterized using the transmission electronic microscope TEM in the dry powder state to determine their particle size distribution as shown in Figs. 1 & 2. The TEM analysis was conducted in the laboratories of National Research Center (NRC). The TEM images show that most of NC and NS particles range size from 10 to 50 nm with some particles exceeded 100 nm. TEM was performed at Egyptian national research center. Nano materials were analyzed also using the x-Ray Diffraction (XRD) to investigate the material structural properties, such as single-and polycrystalline materials. When an incident x-ray beam reaches a sample, it is diffracted from the crystal planes by special angle θ . As shown in Figs. 3 and 4, nano clay peak was observed at $20\approx 27^\circ$ while nano silica peak obtained at $20\approx 22^\circ$. The highest intensity of the counts peak was 60 for NS, which indicates a good particle distribution, while the intensity was about 1250 for NC, which indicates a poor particle distribution. XRD was performed at Egyptian national research center.

Table 1. Nano materials characteristics

Nano Clay		Nano Silica	
Properties	Value	Property	Value
Organic alternate	2M2HT	Particle denomination	Silica. (RI 1.450, AI 0.010)
Particular superficies area	220.0–270.0(m ² /g)	Particle sucking indicator	0.010
Weight wastage on inflammation	43.0 (%)	Concentricity	0.20660 (%)
Density	0.5–0.7 (g/cm ³)	Pureness	+99 (%)
Moisture ratio	1.0 – 2.0 (%)	Particular surface area	140.30 (m ² /g)
X-ray outcome (d001)	31.50 A	Density	0.20 (g/cm ³)

Table 2. Properties of SBS

Property	Value	Test standard [14]
Protraction at fracture (%)	700.0	ASTM.-D 412
Dissolved flow indicator (g/10 min)	1 (190°C,5 kg)	ASTM.-D 1238
Specific gravity (g/cc)	0.940	ASTM.-D 792
Rigidity (Sh A)	82.0	ASTM.-D 2240
Tensile intensity (MPa)	18.0	ASTM.-D 412
Field stickiness (Pa.s)	20.0 (Toluene sol.25% wt.)	ASTM.-D1084
300% Modulus (MPa)	2.50	ASTM.-D 412

Table 3. Characteristics of bitumen

Property	Value	Criterion
Viscosity at 135 (°C)	449.0	AASHTO.-T201
Flash degree (°C)	250.0	AASHTO.-T48
Breakthrough (100 g, 5 s, 25°C), 0.10 mm	61.0	AASHTO.-T49
Mellowing degree (°C)	49.0	AASHTO.-T53

Table 4. Aggregate particle size distribution

Sieve #	Percentage (%)	EGP Limits (%) (4D)
1"	100.0	100
4/3"	100.0	80-100
8/3"	75.6	60-80
#4	54.9	48-65
#30	20	19-30
#50	13	13-23
#100	9	7-15
#200	7	3-8

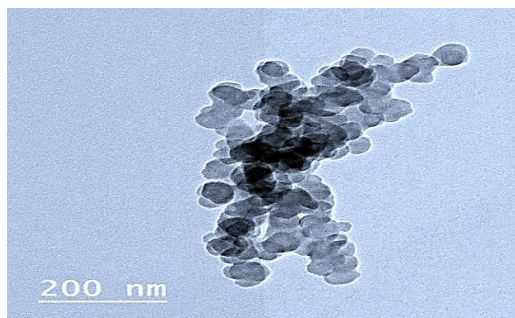


Fig. 1. TEM image for NC

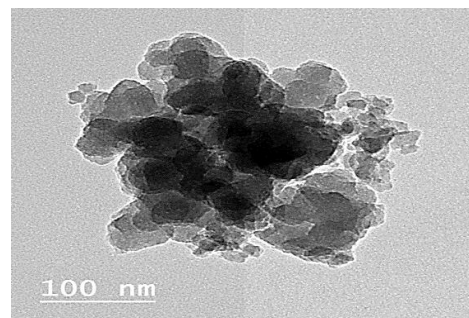


Fig. 2. TEM image for NS

Table 5. Physical properties of the aggregate

Properties	Standard	Value	Specification limit
Los Angeles abrasion loss (%)	AASHTO-T96	24.0	Max 40.0%
Absorption fine aggregate (%)	AASHTO-T85	2.70	Max 5.0%
Plasticity index, fine Aggregate	AASHTO-T90	Non	Non
Bulk specific gravity (g/cm ³)	AASHTO-T85	2.59	---
Absorption coarse aggregate (%)	AASHTO-T85	2.20	Max 5.0%

2.3 Preparation of HMA Mixtures and Tests

Due to the large specific surface area and the high surface energy, nano materials have a great inclination to agglomerate to form secondary particles. When nano materials are poorly dispersed in base asphalt binder, the modified effect of the nano composites will be similar to that of the micrometer sized composites. Hence, it is necessary to disperse nano materials uniformly to overcome the agglomeration problem. In order to achieve a homogenous mixture of asphalt and nano materials, a high shear mixer was adopted as shown in Fig. 5.

The description and sampling techniques have been stated in detail in self-previous research [12]. Nano materials were first dissolved on to 600g weight of binder followed by the addition of SBS polymer using a high shear mixer at a high shearing rate (Fig. 5). It is necessary to determine how the materials should be combined together, then the modified binder samples were tested using a scanning electronic microscope (SEM) to determine the combination conditions of asphalt and nano, and the quality of dispersion of nano materials in nano scale (Fig. 6). SEM

was performed at Egyptian national research center. Samples (5 mm diameter) as shown in Fig. 7 from the modified binder were taken and placed in a vacuum reservoir and then covered with a thin layer of gold as shown in Fig. 8 before placing under the scanning electronic microscope (SEM). SEM was performed at Egyptian national research center. The SEM image is shown in Figs. 9 and 10 for NC and NS in asphalt binder respectively. Both of NC and NS have homogeneously distributed without agglomeration. The modified asphalt binders as well as the control sample were prepared as illustrate in Table 6.

Marshall design method is the current mix design method used in Egypt. Thus, a mix design was prepared using the Marshall method according to AASHTO-T245 standard [13]. Dense graded asphalt mix "4D" was used according to the Egyptian code Standard. The optimum binder content (OBC) for this mix was found to be 5.65%. Marshall flow, stability and quotient (MQ) were calculated for different modified mixtures and compared with the control mix. A wheel tracking test was performed to evaluate the effect of adding nano materials and polymer additives in bituminous mixtures on their resistance to deformation or rutting.

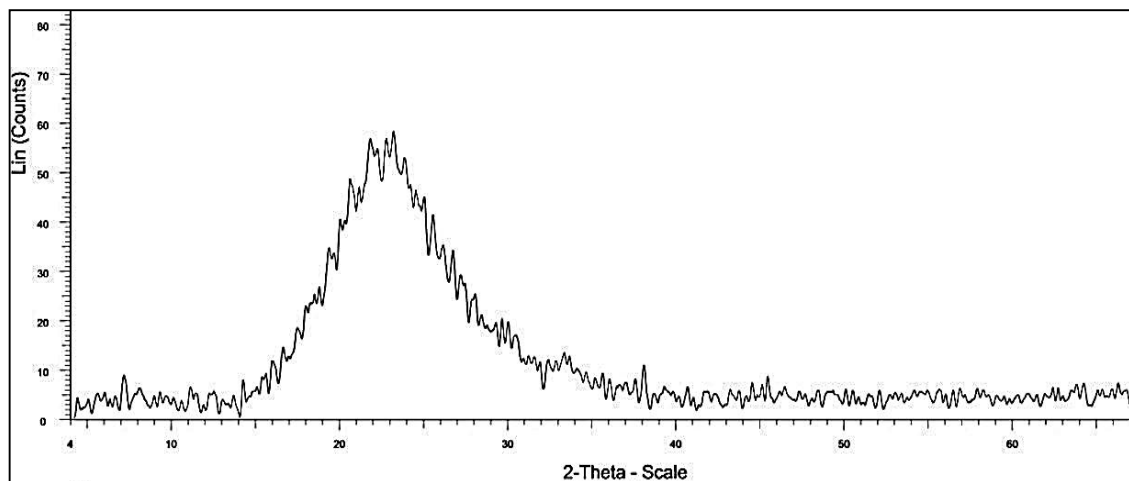


Fig. 3. X-ray diffraction (XRD) for NS

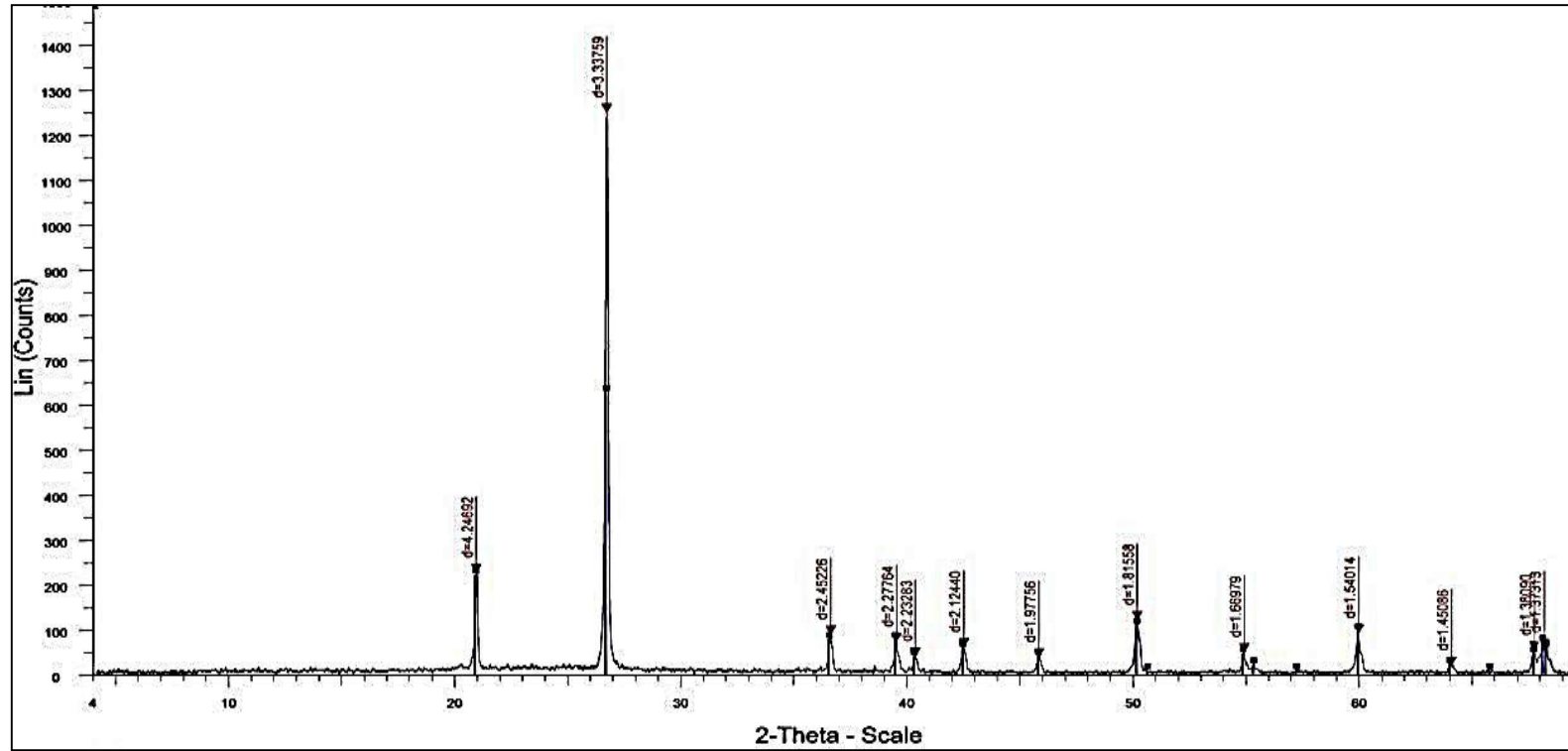


Fig. 4. X-ray diffraction (XRD) for NC



Fig. 5. High shear mixer



Fig. 6. Scanning Electronic Microscope (SEM)



Fig. 7. Binder sample before SEM



Fig. 8. Sample in vacuum reservoir

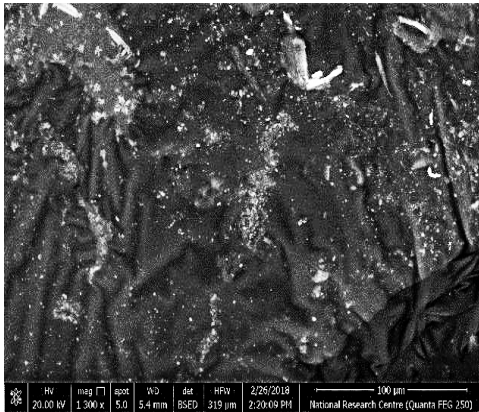


Fig. 9. SEM image for NC

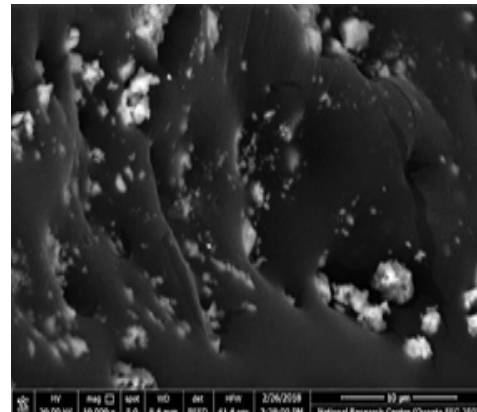


Fig. 10. SEM image for NS

Table 6. Asphalt binder samples

Binder type	Sample code	Description
Unmodified binder (Base asphalt)	Control	Asphalt binder penetration grade (Control binder).
(Modified binders) with nano clay.	NC3	Control asphalt +3%NC
(Modified binders) with nano silica.	NS3	Control asphalt +3%NS
(Modified binders) with nano clay and 5% of (SBS).	NC1SBS	Control asphalt +(1%NC+5%SBS)
	NC2SBS	Control asphalt +(2%NC+5%SBS)
	NC3SBS	Control asphalt +(3%NC+5%SBS)
(Modified binders) with nano silica and 5% of (SBS).	NS1SBS	Control asphalt +(1%NS+5%SBS)
	NS2SBS	Control asphalt +(2%NS+5%SBS)
	NS3SBS	Control asphalt +(3%NS+5%SBS)

3. RESULTS AND DISCUSSION

3.1 Marshall Test Results

The maximum load of failure in Newton and the elastic flow of the specimen in mm were recorded. The stability is the maximum load that

the specimen can carry. The flow is the compression that the sample undergoes between no load and maximum load. Fig. 11 illustrates the effect of nano materials and SBS composition as well as effect of nano materials only on the Marshall stability. It is illustrated that the addendum of nano clay and nano

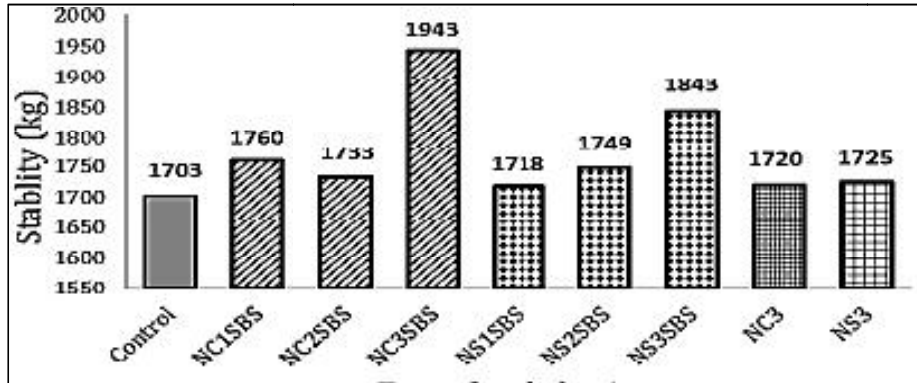


Fig. 11. Influence of Nano Clay, Nano Silica and SBS on the Marshall stability

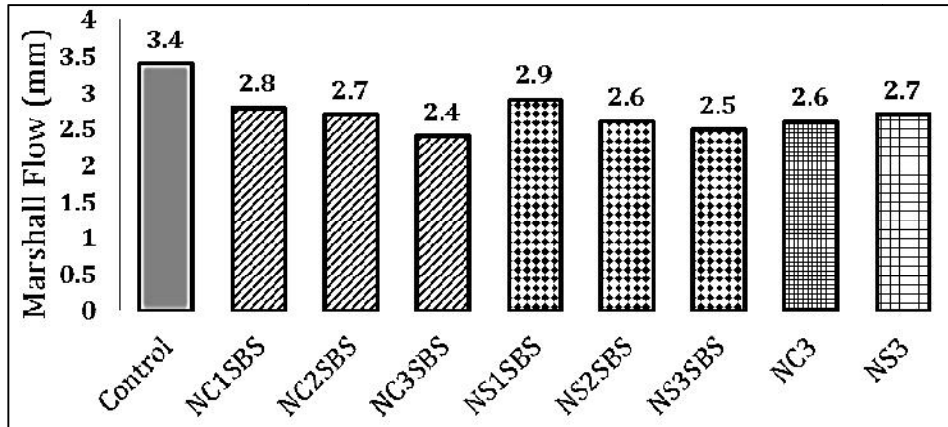


Fig. 12. Impact of Nano Clay, Nano Silica and SBS on the Marshall flow

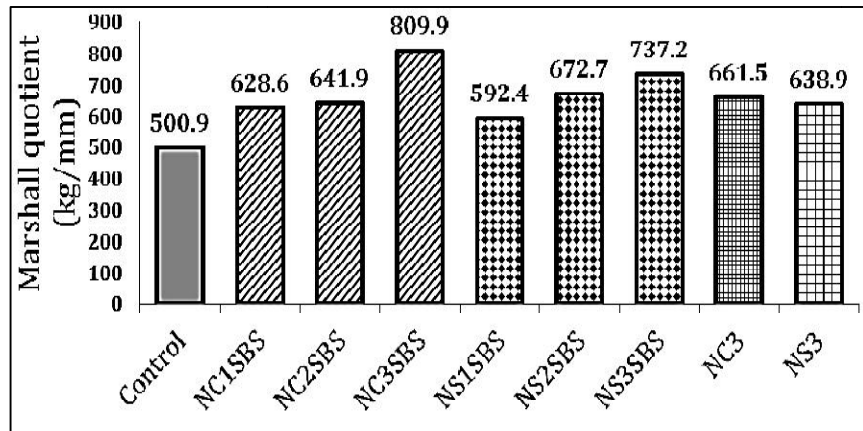


Fig. 13. Influence of Nano Clay, Nano Silica and SBS on the Marshall quotient

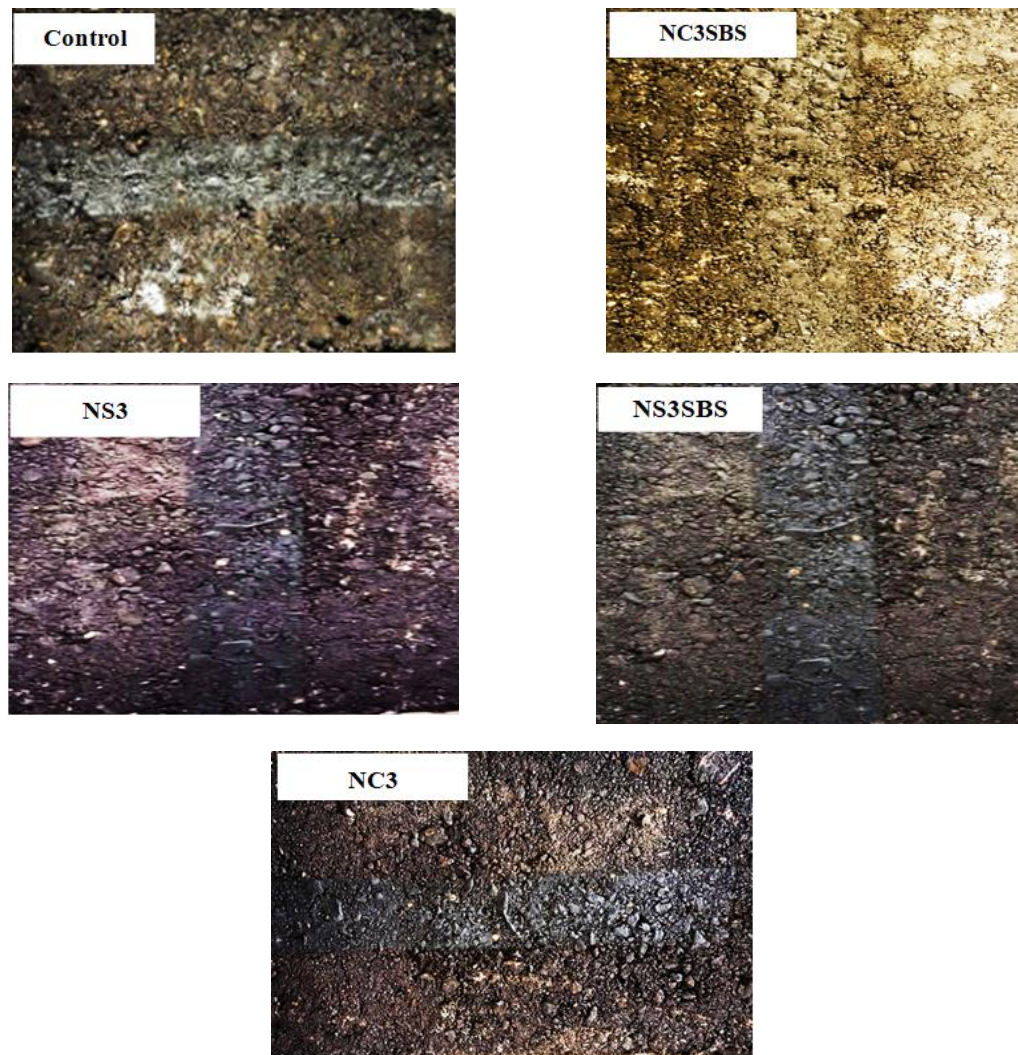


Fig. 14. Rutting depth for asphalt mixtures modified by nano materials and SBS

silica increase the Marshall stability value compared to unmodified asphalt mixtures. The using of polymer additive SBS with (3% NC or 3% NS) improves the Marshall stability compared with addition of nano materials only up to about 12.9% and 6.8% respectively. Using of SBS on nano clay or nano silica improves the Marshall stability compared with control sample by variation ratios shown in Table 8. When using (3% NC+5% SBS), the maximum stability is achieved.

The Marshall flow is the compression distance that the Marshall sample undergoes between no load and maximum load during the test. Fig. 12 shows the effects of NC, NS and SBS on the Marshall flow. It can be illustrated that the Marshall flow values get better at using nano clay

and nano silica than them for unmodified mixtures. The variation ratios in flow values between modified and unmodified mixtures are shown in Table 7. The addition of SBS on (3% NC or 3% NS) improves the Marshall flow compared with nano materials only up to about 7.7% and 7.4% respectively. When using (3% NC+5% SBS) the best Marshall flow is obtained.

Marshall Quotient (MQ) known as the rigidity ratio; the ratio of stability to flow value of the asphalt mixture. Fig. 13 illustrates the effect of using nano materials and SBS on Marshall quotient. The Marshall quotient values for all modified mixtures increase compared with the control sample by variation ratios shown in Table 8. Addition of SBS on (3% NC or 3% NS)

Table 7. Variation ratios of stability, flow and Marshall quotient comparing with control mixtures

Asphalt mixes types	Variation ratio of stability (%)	Variation ratio of flow (%)	Variation ratio of Marshall quotient (%)
NC1SBS	3.3	-17.6	25.5
NC2SBS	1.8	-20.6	28.1
NC3SBS	14.1	-29.4	61.7
NS1SBS	0.9	-14.7	18.3
NS2SBS	2.7	-23.5	34.3
NS3SBS	8.2	-26.5	47.2
NC3	1	-23.6	32.1
NS3	1.3	-20.6	27.6

Table 8. Variation ratio of rutting depth

Asphalt mixes types	NC3SBS	NS3SBS	NC3	NS3
The variation ratio of rutting depth (%)	-71.4	-64.3	-50	-42.9

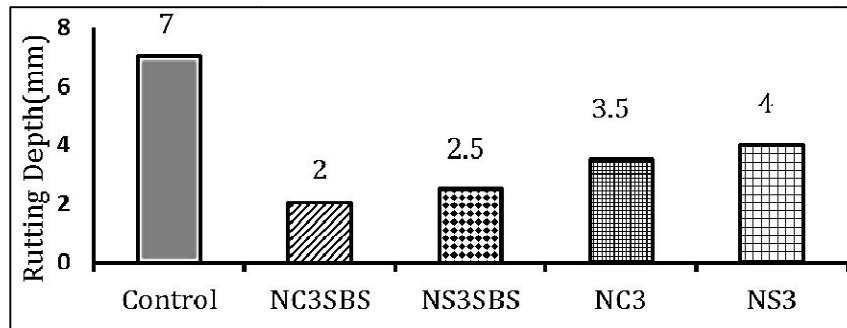


Fig. 15. Impact of nano clay, nano silica and SBS on the rutting depth

improves the Marshall quotient compared with addition of nano materials only by about 22.4% and 15.4% respectively. The higher Marshall quotient value was obtained when using a mix of (3% NC+5% SBS) in HAM. The increase in the stiffness of asphalt concrete nano modification can be related to the high surface area of nano clay and nano silica particles and their interaction with the binder by increasing asphalt absorption and making it stiffer.

3.2 Wheel Tracking Test Results

The objective of wheel tracking test was to determine the resistance of asphalt mix to plastic deformation (rutting). Fig. 14 illustrates the rutting depth after 10,000 wheels passes on slaps of control and modified asphalt mixtures. It can be observed from Fig. 14 that the wheel track for unmodified (control) sample is clearer and deeper than modified samples. Fig. 15 provides that the using of nano materials decreases the rutting depth values compared with control

asphalt mixtures by variations ratios shown in Table 8. It can be showed that all modified mixes provide lower rutting depth compared with the control mix where the addition of SBS on (3% NC or 3% NS) improves the rutting depth compared with addition nano materials only by about 42.9% and 37.5% respectively. The lowest rutting depth achieved when using (3% NC+5% SBS).

4. CONCLUSIONS

1. The use of nano clay and nano silica improved the results of Marshall test and wheel tracking test compared with control mixture.
2. The addition of SBS on (3%NC or 3%NS) had a significant impact on improving the Marshall stability compared with addition of nano materials only up to about 12.9% and 6.8% for 3%NC and 3%NS respectively.
3. The addition of SBS on (3%NC or 3%NS) decreased the Marshall flow by about 7.6% and 7.4% for 3%NC and 3%NS respectively

compared with addition of nano materials only.

4. The addition of SBS on (3%NC or 3%NS) had an obvious impact on decreasing the rutting depth by about 42.9% and 37.5% respectively compared with addition of nano materials only.
5. Using nano clay in HAM provided better performance than addition of nano silica especially at content 3%.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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