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Determination of water sensitivity of nanosilica added hot mix asphalt

Nanosilika katkılı sıcak karışım asfaltın suya karşı hassasiyetinin belirlenmesi

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Abstract

In this study, the effects of nanosilica (NS) additive on the water sensitivity of hot mix asphalt (HMA) pavements were investigated. For this, NS-modified asphalts were prepared by adding NS at rates of 1%, 3%, 5% and 7% by weight to the pure B 160/220 asphalt. In the study, first of all, the physical properties of pure and modified asphalts were determined by penetration, ductility and softening point experiments, and their viscosities were determined by rotational viscometer (RV) experiment. Then, the optimum asphalt content of the mix was determined according to the Marshall design method. Hot mix asphalt specimens were prepared by keeping this determined ratio constant for pure and modified asphalts. Prepared pure and NS added modified mixture specimens were subjected to Marshall stability, retained Marshall stability (RMS) and indirect tensile strength (ITS) tests. The physical test results showed that the hardness and machinability temperatures of the modified binders increased up to 5% NS. According to the mixture test results, it was determined that NS additive had a positive effect on the sensitivity of road pavements to water, since Marshall stability, RMS and indirect tensile strength ratio (ITSR) values showed significant increases at 5% NS.

Keywords: Asphalt, Nanosilica, Hot mix asphalt, Retained marshall stability, ITS.

Özet

Bu çalışmada, nanosilika (NS) katkısının sıcak karışım asfalt (HMA) kaplamaların suya karşı hassasiyeti üzerindeki etkileri araştırılmıştır. Bu amaçla, saf B 160/220 asfalta ağırlıkça %1, %3, %5 ve %7 oranlarında NS eklenerek NS modifiyeli asfaltlar hazırlanmıştır. Çalışmada öncelikle saf ve modifiye asfaltların fiziksel özellikleri penetrasyon, düktilite ve yumuşama noktası deneyleri ile viskoziteleri ise dönel viskozimetre (RV) deneyi ile belirlenmiştir. Daha sonra Marshall tasarım yöntemine göre karışımın optimum asfalt içeriği belirlenmiştir. Belirlenen bu oran saf ve modifiye asfaltlar için sabit tutularak sıcak karışım asfalt numuneleri hazırlanmıştır. Hazırlanmış olan saf ve NS katkılı modifiye karışım numuneleri Marshall stabilitesi, kalıcı Marshall stabilitesi (RMS) ve dolaylı çekme mukavemeti (ITS) deneylerine tabi tutulmuştur. Fiziksel test sonuçları, modifiye bağlayıcıların sertlik ve işlenebilirlik sıcaklıklarının %5 NS'ye kadar arttığını göstermiştir. Karışım test sonuçlarına göre, Marshall stabilitesi, RMS ve dolaylı çekme mukavemeti oranı (ITSR) değerlerinin yine %5 NS miktarında önemli artışlar göstermesi sebebiyle, yol kaplamalarının suya karşı hassasiyeti üzerinde NS katkısının olumlu bir etkisi olduğu tespit edilmiştir.

Anahtar kelimeler: Asfalt, Nanosilika, Sıcak karışım asfalt, Kalıcı marshall stabilitesi, ITS.

1. Introduction

Various environmental factors (temperature, water, etc.) and traffic loads are the two main causes of deteriorations in hot mix asphalt (HMA) pavements. Deteriorations in the pavements (rutting, cracks, water-induced deteriorations, etc.) decrease the pavement performance, reduce the service life of the pavement and minimize driving comfort [1,2].

The service life, durability and performance of the pavement mainly depend on how well the asphalt can bond and adhere to the aggregate surface under different conditions [3]. The water on the pavement leaks into the mixture, causing the bond between asphalt and aggregate to weaken, and this is called "loss of adhesion". The loss of adhesion causes the HMA

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pavement to loosen and soften, which is expressed as "segregation" or "loss of cohesion" of the materials in the mixture. When the pavement is exposed to water, important problems occur in the chemical structure of both the asphalt and the aggregate, and as a result, the asphalt begins to decompose from the aggregate. In short, it is possible to state that the deformation caused by water in the HMA pavement is directly related to the loss of adhesion and cohesion [3-5]. In other words, the water in the pavement weakens the adhesion by entering between the asphalt and the aggregate and adversely affects the cohesion by causing decomposition in the structure of the mixture. This causes the pavement to deteriorate. On the other hand, other environmental factors such as the construction of the pavement and the design of the hot mix (air gap percentage, asphalt film thickness, etc.), high temperature, age of the pavement, freeze-thaw cycles, and the properties of the additives in the mixture are also important factors affecting water damage [1, 2, 6].

In order to reduce the deformations caused by water in pavements, silane additives, especially hydrated lime, portland cement, surface agent additives and various traditional liquid additives are used [2,6]. It has been seen in many studies that lime reacts with the structure and strengthens the bond between asphalt and aggregate, especially as a result of adding lime to HMA [2,5,7,8]. However, in recent years, various polymers have also been used in hot mixes to reduce water-induced deteriorations. In many studies, it has been stated that the use of some polymers in asphalt modification, albeit limited, functions as anti-stripping additives [2,9,10]. In addition, the use of various nano-sized materials such as nanosilica in asphalt modification has also been started recently.

Nanosilica is a white crystalline material that is abundant on Earth, in nanometer size and has the chemical formula SiO_2. Compared to other nanomaterials, nanosilica is among the most advantageous nanomaterials due to its lower production cost and higher performance properties [3,11]. This material, which has a large surface area, good dispersion ability and adsorption, has superior properties such as good strength and thermal stability at high temperatures. In addition, nanosilica is a frequently used material to produce silica gel, silica gas and similar materials [3,12].

When the studies using nanosilica additive in asphalt modification were examined, it was stated that nanosilica increased the viscosity, softening point and elasticity modulus of asphalt, while decreasing its consistency and ductility [12-14]. In other studies, it was stated that the rheological properties of nanosilica-modified binders improved and their temperature sensitivity decreased [13, 15]. In another study, it was stated that the fatigue life of nanosilica-modified asphalts increased more than nanocalcium carbonate and nanotitanium, and adding 4% nanosilica to asphalt increased the fatigue life of asphalt [16]. It has been observed that the thermal properties of hot mix asphalts are significantly improved with the use of nanosilica additive in HMA mixtures, thus the stiffness modulus of the mixtures increases and the nanosilica increases its resistance to the loads on the HMA pavement [14]. In some studies, it has been observed that the additive of nanosilica retards the oxidation of the asphalt mixture, increasing its stability against moisture damage, and increasing the anti-peeling properties of the mixture, resulting in longer fatigue life and high permanent deformation resistance of the pavement [17-20].

In the current studies carried out so far, it is seen that the nanosilica additive is mostly used in asphalt modification and the physical and rheological properties of asphalt are investigated. In other studies, the properties of nanosilica added mixtures such as fatigue, permanent deformation and fracture resistance were investigated.

In this study, unlike previous studies, the effect of nanosilica additive on the water sensitivity of HMA pavements was investigated. In the study, the effects of nanosilica additive on the resistance of HMA pavements to the harmful effects of water were tried to be determined by Marshall stability, RMS and ITS experiments.

2. Materials and Method

2.1. Materials

In the study, three kinds of materials were used, which are pure asphalt with penetration class B 160/220, nanosilica (NS) additive and crushed limestone aggregate.

The physical properties of asphalt supplied from Turkish Petroleum Refineries Inc. (TUPRAŞ) are given in Table 1. Nanosilica additive (Figure 1) was obtained from Elkem Silicone Material factory and its properties are given in Table 2. The physical properties of the crushed limestone aggregate used for the HMA pavement design are given in Table 3 and its gradation is given in Table 4.

Table 1. Properties of asphalt

Properties	Standard	Limit	Result
Penetration (0.1mm)	ASTM D5	160-220	163
Softening point (°C)	ASTM D36	35-43	41.6
Ductility (cm)	ASTM D113	min. 100	125
Flash point (°C)	ASTM D92	min. 220	244
Specific weight (g/cm^3)	ASTM D70	1.0-1.1	1.038
Penetration index (PI)	-	-	-0.27
Mass loss (%)	ASTM D2872	max. 1.0	0.47

Figure 1. Nanosilica additive

Table 2. Properties of nanosilica

Properties	NS
Form	Ultrafine amorphous powder
Odor	Odorless
Melting point (°C)	1550-1570
Solubility (Water)	Insoluble/Slightly soluble
Solubility (Organic Solvents)	Insoluble/Slightly Soluble
Density (g/cm^3)	2.2-2.3
Particle size (nm)	11-13
Surface area (m^2/g)	200

Table 3. Physical properties of aggregate

Properties	Standard	Limit	Result
Coarse aggregate apparent specific gravity (g/cm^3)	ASTM C127	-	2.711
Coarse aggregate volume specific gravity (g/cm^3)		-	2.648
Coarse aggregate water absorption (%)		max.2	0.88
Fine aggregate apparent specific gravity (g/cm^3)	ASTM C128	-	2.750
Fine aggregate volume specific gravity (g/cm^3)		-	2.664
Fine aggregate water absorption (%)		max.2	1.17
Filler apparent specific gravity (g/cm^3)	ASTM D 854	-	2.751
Abrasion loss, Los Angeles (%)	ASTM C131	max.30	28
Frost loss (%)	ASTM C88	max.10	4.5
Flat and long grains (%)	ASTM D4791	max.10	4

Table 4. Aggregate gradation

Sieve (mm)	**19**	**12.5**	**9.5**	**4.75**	**2.36**	**1.18**	**0.6**	**0.3**	**0.15**	**0.075**
Passing (%)	100	94	84	58	35	22	16	12	8	5

2.2. Method

2.2.1. Preparation of NS added asphalt binders

In the study, pure asphalt was first heated up to 150°C. Then, by adding 1, 3, 5 and 7 wt% nanosilica to the asphalt, the resulting blends were mixed with a mixer at 1200 rpm for 60 minutes at the same temperature, and modified asphalts were prepared.

In the study, pure and nanosilica-modified asphalts were coded as P, P+1NS, P+3NS, P+5NS and P+7NS, respectively.

The physical properties of the pure and modified asphalts obtained were determined by conventional tests, and the workability properties were determined by the RV test. All the results obtained are given in Table 5.

Table 5. Test results

Properties	**Binder types**				
	P	**P+1NS**	**P+3NS**	**P+5NS**	**P+7NS**
Penetration (0.1mm)	163	134	129	124	146
Softening point (°C)	41.6	42.8	44.8	45.1	42.6
Ductility (cm)	125	117	113	109	115
PI	-0.27	-0.57	-0.05	-0.004	-0.32
Mass loss (%)	0.47	0.08	0.10	0.15	0.06
Viscosity (135°C)	287.5	320.0	330.0	350.0	320.0
Viscosity (165°C)	100.0	115.0	135.0	150.0	125.0
Mixing temperature	153	156.1	157.6	159.2	156.1
Compaction temperature	136.4	140.5	141.2	142.7	139.8

When Table 5 is examined, it is seen that the penetration and ductility values of the modified asphalts decreased up to 5%NS and then increased with the addition of NS. On the other hand, with the increase in the additive ratio, it is observed that the softening point values of the binders increase regularly up to this ratio and then decrease. In this case, it is possible to state that with the addition of NS, the hardening tendency of the binder increases up to 5%NS and the temperature sensitivity decreases. When the viscosity values of the binders are examined in the same table, it is seen that the viscosity values of the modified binders with the addition of NS also increased (especially at the rate of 5%NS) compared to the pure binder. The mixing temperatures in the plant and the compaction temperatures on the road, determined by using these obtained viscosity values, also increased with the increase in the NS additive ratio. All these results show that NS additive hardens the consistency of asphalt binders and therefore more energy can be spent during mixing in the plant and paving-compaction on the road.

2.2.2. Preparation of NS added hot mix asphalts

In order to determine the sensitivity of HMAs to water, mixture specimens were prepared by Marshall design method according to ASTM D1559 standard, using pure and NS added asphalts (Figure 2). For this, firstly, optimum asphalt content (OAC) for hot mixes was determined by using aggregate and pure asphalt. Then, based on this content, hot mix specimens were prepared using pure and modified asphalts. For each mixture specimen, 1100 g aggregate was weighed and asphalts were processed at their mixing and compaction temperatures to obtain HMA specimens. The specimens were prepared by making 75 blows on each surface of the specimen, a total of 150 blows, with the free-dropping hammer from a height of 457 mm.

In the study, pure and NS added mixture specimens were coded as P, P+1NS, P+3NS, P+5NS and P+7NS, respectively.

Figure 2. Prepared marshall briquettes

3. Experimental design

3.1. Marshall stability test

The resistance of hot mixtures to plastic flow is determined by Marshall stability and flow test (ASTM D1559). In the experiment, after the heights and weights (in air, water and saturated) of the hot mix specimens are determined, the specimens are kept in a water bath with a temperature of 60±1 °C for approximately 40 minutes. At the end of the time, the specimens are removed from the water bath and placed in the Marshall stability device, and the stability and flow values of the specimens at the time they break at a loading speed of 50±2 mm/min are determined. The stability value indicates the highest load that HMA pavements can resist against deformations, and the flow value indicates the deformation that occurs when this load value is reached. In the experiment, if the heights (h) of the specimens are different from 63.5 mm, the correction coefficients (c) are determined by using the equation (1) [2].

$$c = 5.24e^{(-0.0258h)} \tag{1}$$

Marshall ratio (MQ) values, which are known as a measure of the hardness of hot mixtures and their resistance to deformations, can also be calculated with the help of the stability and flow values obtained as a result of the experiment. The MQ value is obtained by dividing the stability value of the mixture with the flow value, and a high MQ value indicates that the pavement is resistant to deformations [2].

3.2. Retained marshall stability (RMS) test

The resistance of asphalt pavements to water-induced deterioration can be determined by the RMS test. For this purpose, the mixture specimens are kept in a water bath at 60±1°C for 24 hours and subjected to loading with Marshall stability device. RMS value is determined by proportioning the obtained stability value to the normal stability value of the specimen. The high RMS value of the mixture specimen indicates that the HMA pavement has higher resistance to water [4].

3.3. Indirect tensile strenght (ITS) test

The ITS test is performed to characterize the tensile stresses that occur in the structure of HMA pavements exposed to heat and loads. The test is carried out according to the AASHTO T245 standard and using the Marshall stability tester. In the test, the mixture specimens are subjected to vertical loading in the direction of the diameter plane at a loading speed of 50 mm per minute, and fracture is ensured. As a result of the experiment, a relationship can be established between these fractures in HMA pavements and the structure of the pavement. With the experiment, information can be obtained about the hardness and durability of the pavement, which are the main parameters of permanent deformation resistance at medium temperatures, and also about the cohesion strength of the HMA pavement. The ITS values of the mixture specimens may vary depending on the cohesion ability of the hot mixture, and this change is largely due to the properties of the asphalt. The ITS value of the mixture specimens can be determined with the help of equation (2). The Pmax value in the equation represents the maximum load applied to the specimen, t the specimen thickness, and d the specimen diameter [2,4].

$$ITS = \frac{2\text{Pmax}}{\pi t d} \quad (2)$$

3.4. Water damage resistance test

The sensitivity of HMA pavements to water is commonly determined according to the AASHTO T283 standard. According to the standard, HMA specimens are divided into two groups as "un-conditioned" and "conditioned". Un-conditioned specimens (ITSdry) are kept in a water bath at 25°C for 2 hours. Conditioned specimens (ITSwet) are first subjected to vacuum treatment so that the air spaces are filled with an average of 70% water. Then, the specimens are wrapped with cling film and frozen in the freezer at -18°C for 16 hours, and at the end of the time, the specimens are kept in a water bath at 60°C for 24 hours. At the end of 24 hours, the specimens taken from the water bath are subjected to the ITS test using the Marshall device after they are kept in the water bath at 25°C for 2 hours. At the end of the experiment, the indirect tensile strength ratio (ITSR) values of the specimens are calculated with the help of equation (3). ITSR values of HMA pavements are expected to be more than 80% in terms of their resistance to water-induced deterioration [2,4].

$$\text{ITSR}=(\text{ITS}_{\text{wet}}/\text{ITS}_{\text{dry}})\times 100 \quad (3)$$

4. Experimental Results

4.1. Marshall stability test results

Hot mix specimens were prepared by using pure B160/220 binder and 1100 g aggregate for the mix design. For this purpose, by keeping the aggregate amount constant, asphalt was added at the rates of 3.5% - 4% - 4.5% - 5% - 5.5% - 6% and 6.5% by weight of the aggregate, and three mixture specimens were prepared for each percentage. After determining the height and various weights (air, water, saturated) of each specimen, the volume specific gravity (Dp), void ratios (Vh), void ratios between aggregates (VMA), and asphalt-filled void ratios (Vf) of all specimens were determined. Then, Marshall stability and flow values of all specimens were determined by Marshall stability device.

The determined volumetric and mechanical properties of the mixture specimens prepared with pure binder are given in Table 6, and the graphs of the change of these properties with asphalt are given in Figure 3.

Table 6. Volumetric and mechanical properties of mixture specimens

Asphalt (%)	Dp (g/cm^3)	Vh (%)	VMA (%)	Vf (%)	Stability (kg)	Flow (mm)
3.5	2.331	8.8	15.03	40.92	1006	2.33
4	2.350	7.4	14.75	49.26	1076	2.58
4.5	2.375	5.8	14.28	58.91	1201	3.07
5	2.399	4.2	13.80	69.30	1236	3.37
5.5	2.411	3.1	13.81	77.28	1199	3.73
6	2.414	2.3	14.08	83.39	1151	3.97
6.5	2.408	1.9	14.70	86.74	1235	3.32

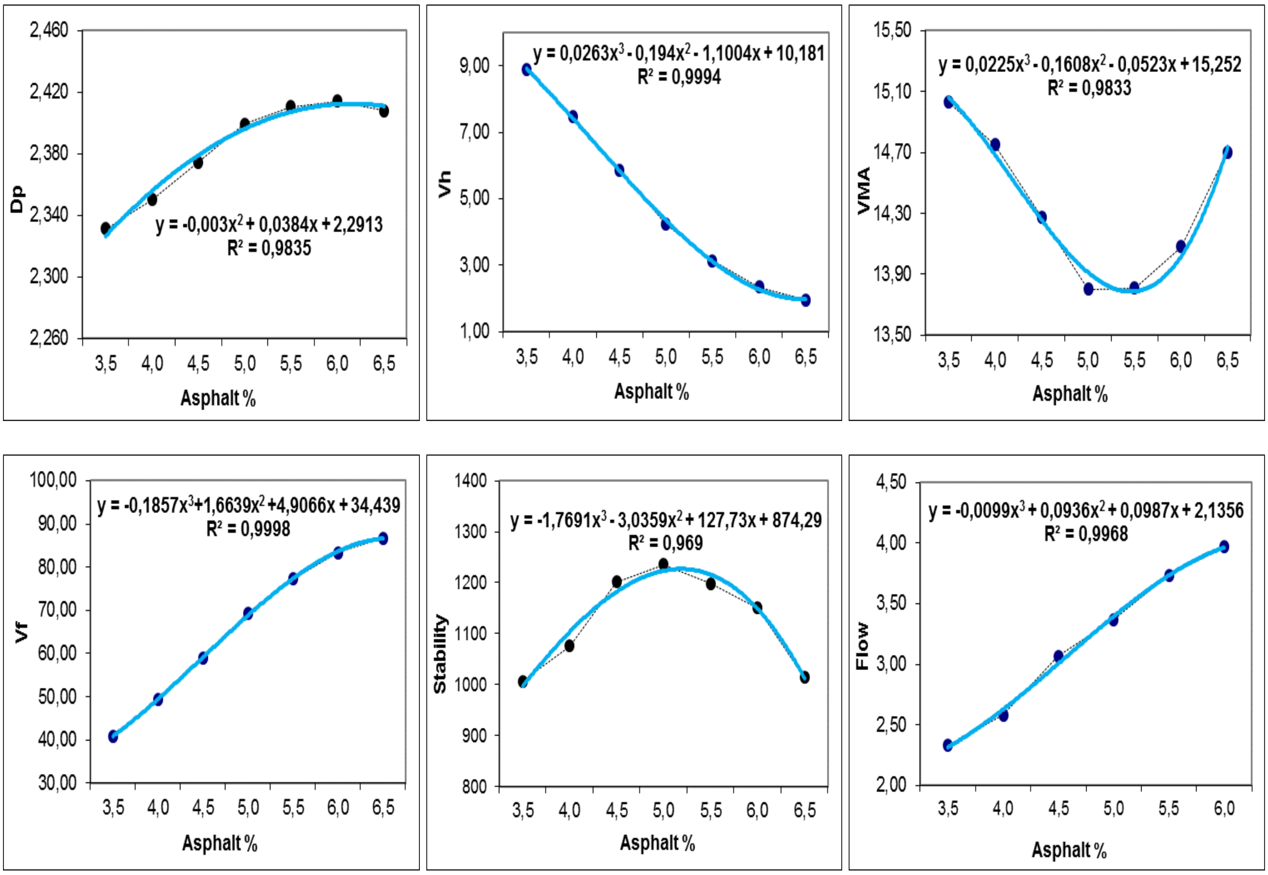


Figure 3. Variation graphs of specimen properties depending on asphalt amount

With the help of the graphics in Figure 3, the optimum asphalt ratio was determined as 5.2% by taking the arithmetic average of four different asphalt percentages, where Dp and stability were maximum, Vh was 4% and Vf was 70%. At this determined ratio, three control specimens were prepared and the compatibility of the results obtained from them was compared with the Highways Technical Specification (HTS) values (Table 7). In the study, it was seen that the results of the control specimens provided the limit values for the surface course of the asphalt concrete in HTS.

Table 7. Results of control specimens

Mixed types	Dp, (g/cm^3)	Vh, (%)	VMA, (%)	Vf, (%)	Stability, (kg)	Flow, (mm)
P	2.408	4.06	14.71	72.37	1180	2.48
P+1NS	2.410	4.14	14.76	72.32	1226	2.35
P+3NS	2.414	4.17	14.82	73.00	1269	2.24
P+5NS	2.420	4.29	14.96	72.56	1284	2.16
P+7NS	2.421	4.42	14.74	72.48	1204	2.42
HTS	**-**	**3-5**	**14-16**	**65-75**	**>900**	**2-4**

In the study, hot mix specimens were prepared with pure (P) and NS modified binders based on the determined optimum ratio (5.2%). This optimum ratio was kept constant in order to compare the NS added modified mixture specimens with the pure mixture (P) specimens. Marshall stability and flow values obtained from pure and NS added hot mix specimens are shown in Figure 4.

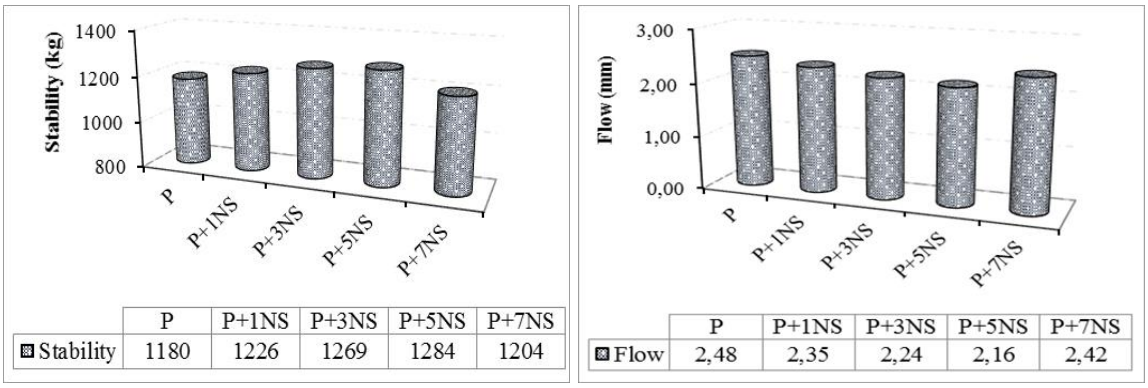


Figure 4. Marshall stability and flow values of the mixture specimens

Considering Figure 4, it is seen that the stability values of the mixtures with NS additive increased by 3.9%, 7.5%, 8.8% and 2.0%, respectively, compared to the pure specimen. This increase in the stability values of the mixtures with NS additive shows that NS increases the resistance of asphalt pavements against permanent deformations. When the results are examined, it is seen that the highest stability value is reached in the mixture with 5% NS. In this case, it is possible to state that the mixture with the highest resistance to permanent deformations is the mixture with 5% NS additive. Again, when Figure 4 is examined, the flow values of the mixture specimens with NS additives showed little change compared to the pure (P) mixture specimen. The flow value simulates the plastic or flexible behavior of the pavement under traffic loads. The fact that the flow changes of the specimens remained almost at the same level indicates that there will be no major change in the behavior of the HMA pavement during fracture with the addition of NS.

In the study, MQ values of the specimens were also calculated to determine the hardness and resistance to deformations of all the mixture specimens, and the results are shown in Figure 5.

When Figure 5 is examined, the MQ values of the modified mixtures changed with the increase in the NS ratio. These changes are 9.7%, 19.1%, 24.8% and 4.6% increase compared to the pure (P) mixture. According to these results, it can be stated that the highest increase is seen in the mixture specimens with 5% NS additive, and therefore, the specimens with 5% NS additive are the most resistant to shear stresses.

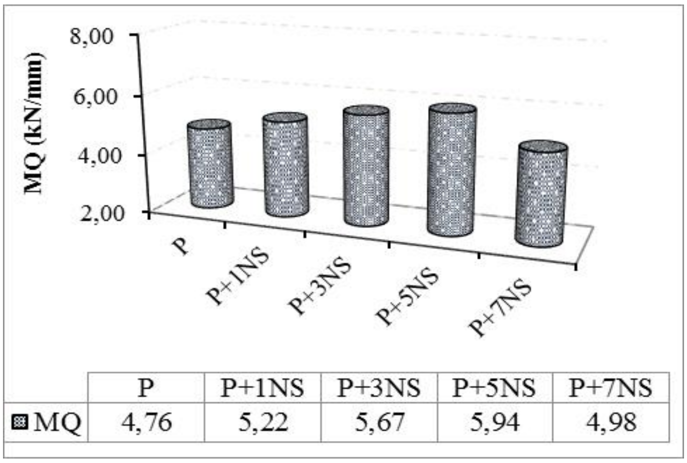
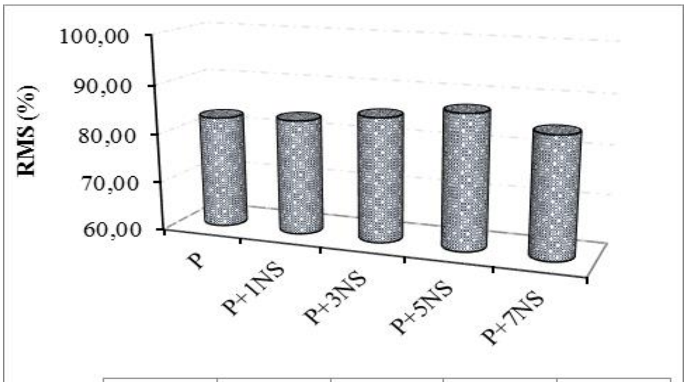


Figure 5. MQ values of the mixture specimens

4.2. RMS test results

In order to determine the effects of NS additive on moisture damage resistance of HMA pavements, RMS values of pure and NS added mixture specimens were determined and the results are shown in Figure 6.



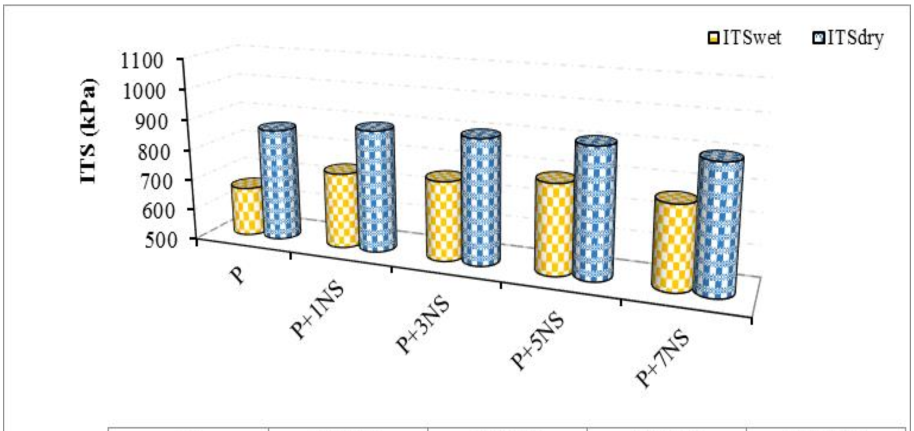
	P	P+1NS	P+3NS	P+5NS	P+7NS
RMS	82,79	83,4	85,25	87,3	84,48

Figure 6. RMS values of mixture specimens

When Figure 6 is examined, it is seen that the RMS values of the modified mixtures change with the increase in NS compared to the pure mixture. These changes occurred as 1.0%, 3.0%, 5.4% and 2.0% increases, respectively, compared to the pure mixture. According to these results, it can be said that the highest RMS value is obtained in mixtures with 5% NS additive, and therefore the highest moisture damage resistance occurs in mixtures with 5% NS additives. As a result, it can be stated that the increase in RMS values with the addition of NS increases the adhesion ability of the NS additive between aggregate and asphalt and has an improving effect on the cohesion ability of the mixture, and therefore NS causes an increase in the moisture resistance of the pavement.

4.3. ITS and moisture resistance test results

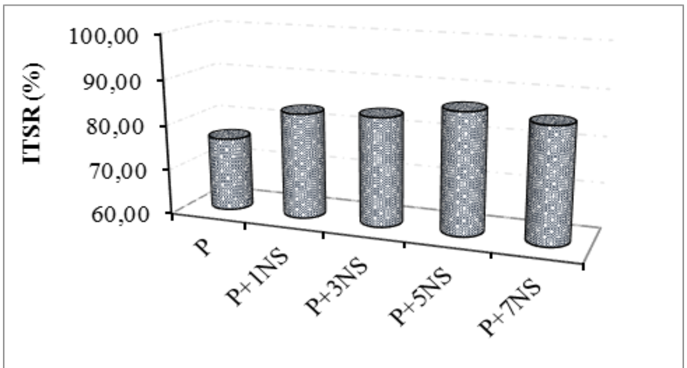
In order to determine the effects of NS on the moisture resistance of HMA, the prepared conditioned and unconditioned pure (P) and NS added mixture specimens were subjected to the ITS test. The determined ITS and ITSR values of the specimens are given in Figure 7 and Figure 8, respectively.



	P	P+1NS	P+3NS	P+5NS	P+7NS
ITSwet	659,66	744,46	756,23	788,44	765,25
ITSdry	865,12	894,05	901,26	910,86	898,55

Figure 7. ITS values of mixture specimens

When Figure 7 is examined, the tensile strength values of the conditioned mixture specimens (ITSwet) with the increase of NS increased by 12.9%, 14.6%, 19.5% and 16.0%, respectively, compared to the pure mixture (P). On the other hand, ITS values of unconditioned mixture specimens (ITSdry) increased by 3.3%, 4.2%, 5.3% and 3.9%, respectively. The increase in the ITSwet and ITSdry values of the specimens with the increase in the NS additive ratio in the mixture shows that the resistance of the HMA pavement, which is exposed to traffic loads, against the tensile stresses that can occur under these loads increases.



	P	P+1NS	P+3NS	P+5NS	P+7NS
ITSR	76,25	83,27	83,91	86,56	85,16

Figure 8. ITSR values of mixture specimens

When Figure 8 is examined, with the increase of the NS additive ratio, the ITSR values of the mixture specimens increased by 9.2%, 10.0%, 13.5% and 11.7%, respectively, compared to the pure mixture. According to these results, the highest ITSR value was observed in the mixture with 5% NS. The fact that the ITSR values of the NS added specimens were higher than 80% indicates that the NS additive improves the cohesion ability of the mixtures and makes the pavements more durable in terms of moisture resistance. For this reason, it is possible to state that modified hot mixtures prepared by adding NS will have high resistance to deterioration caused by water effects.

When the RMS and ITSR results are evaluated together, it has been determined that the NS additive has a positive effect on the moisture resistance of the road pavements by increasing the adhesion and cohesion ability of the mixtures, especially by 5% NS.

5. Conclusions

In the study, the effects of nanosilica (NS) additive on the resistance of road pavements to the harmful effects of water were investigated and the following results were obtained.

- ✓ When the physical results of the pure and NS added binders were evaluated, it was observed that the consistency of the asphalts with NS additive was hardened and the binder class changed to B 100/150.
- ✓ According to Marshall stability results, it was observed that the stability of the mixtures increased by 8.8% with NS additive and the highest stability value was obtained from the mixtures with 5% NS additive.
- ✓ According to the MQ results, the highest MQ value was obtained from the mixtures with 5% NS additive and it was observed that the NS additive provided an improvement in the resistance of HMA pavements to shear stresses.
- ✓ According to the RMS results, it was observed that there was an increase of 5.4% in the resistance of the hot mixtures against the effects of moisture with the addition of NS, and this increase was obtained from the mixtures with 5% NS.

- ✓ According to the ITSR results, it was observed that the highest value was obtained from the mixtures with 5% NS addition and the addition of NS improved the moisture resistance of the road pavements by 13.5% by increasing the adhesion and cohesion ability of the hot mixtures.

- ✓ It is considered that it may be useful to investigate the effect of nanosilica additive on the moisture resistance of the mixture by adding it directly to the hot mixture in future studies.

As a result, it is possible to state that the use of nanosilica (NS) additive in modification has an improving effect on the sensitivity of road pavements to water by increasing the stability, shear and moisture resistance of hot mixes.

6. Author Contribution Statement

In the study, Author 1 and Author 3 contributed to forming the idea, the analysis of the results, provision of the materials and examination of the results; Author 2 contributed making the design, the analysis of the results, checking the article in terms of content and literature review.

7. Ethics Committee Approval and Statement of Conflict of Interest

There is no need for an ethics committee approval in the prepared article. There is no conflict of interest with any person/institution in the prepared article.

8. References

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