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Comparing the Effect of Nanomaterial and Traditional Fillers on the Asphalt Mixture Properties

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Abstract

Several parameters affect asphalt mix performance against loading and environmental conditions. Minor changes in the filler amount or type can cause obvious changes in the asphalt mixture properties. Accordingly, in this research attempts have been made to optimally make asphalt mixture strong against loading and environmental conditions by changing the type, size and percentage of filler used in asphalt mixture. In this line, the effect of two types of cement and nano-silica fillers in two different percentages was investigated and compared as an alternative for part of the main filler in asphalt mixture samples made by two types of limestone and granite aggregate. Cement filler by 2% and 4% of the aggregate mass as the alternative for part of the main filler is added to stone materials before mixing with binder, but nano-silica filler by 2% and4 % of weight of the binder as the alternative for part of the main filler is added to binder and a modified and homogeneous binder is produced using a high speed mixer. In the following, considering the optimum binder content for each mixture, resilient modulus tests were conducted to determine the strength performance against loading and indirect tensile strength ratio was used to determine moisture sensitivity of asphalt mixtures. Results obtained from resilient modulus tests show that the use of nano-silica and cement has been capable of favourably improving the resilient modulus of samples containing these two types of fillers. The improvement of the resilient modulus of samples containing nano-silica is very significant. Additionally, the studies conducted based on the indirect tensile strength ratio show that both types of alternative fillers, especially cement has been capable of desirably improve the strength of asphalt mixtures against moisture damage.

Keywords: Hot Mix Asphalt; Filler; Nanomaterials; Moisture Damage; Resilient Modulus.

1. Introduction

Asphalt mixtures are widely used materials that produced for paving of road surfaces. For many years, moisture has been recognized as a major factor in the premature damage of asphalt mixtures [1], because the entrance of moisture into the asphalt mixture composition is the main reason of aggregate-binder adhesive failure and/or cohesive failure in binder or mastic [2-4]. Figure 1 shows schematic of these 2 mechanisms.

Several factors affect damages intensity, including the aggregate and binder properties, asphalt mixture properties, construction and implementation methods, dynamic effects due to moving vehicles, anti-stripping additives type and properties and Etc. [5, 6]. However, so far, the mechanism of these effects has not been correctly determined, and this causes a variety of methods to be presented in order to increase asphalt mixtures strength to moisture [6]. Accordingly, one of the proposed methods is using appropriate fillers, because the existence of filler play an important role in modifying asphalt mixture properties based on its characteristics [7, 8]. Additionally, filler as one of the components of

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asphalt mixes can affect the two mentioned mechanisms, including adhesive failure and cohesive failure [9-11]. It is worth mentioning that over recent years and in line with the advent of nanotechnology, the importance of this issue has caused nanomaterials to be used to modify binder and asphalt mixtures properties by researchers [12-14]. Therefore, in this research unlike other researches that only mineral fillers are used to making asphalt mixtures, attempts have been made to investigate and comparing the effect of traditional mineral fillers and nanomaterials on the mechanical properties and durability of hot mix asphalts against moisture damage**.**

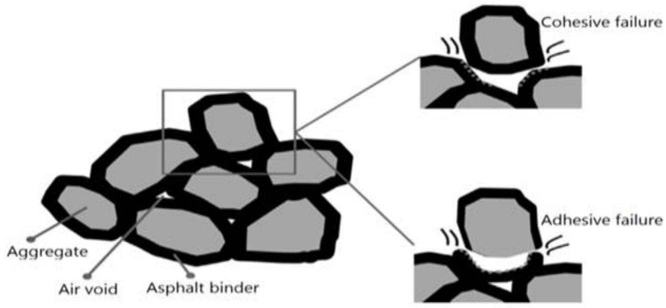

Figure 1. Adhesive and cohesive failures due to water damage [4]

1.1. Literature Review

As aforementioned, the effect of materials type on the strength to moisture damage is undeniable. In this line, research studies have shown that the role of filler in increasing asphalt mixes strength to moisture induced damage (adhesive failure and cohesive failure) is very significant such that some of fillers (e.g., cement fillers, amorphous carbon powder, etc) causes a reduction in moisture sensitivity as well as an increase in water desorption of asphalt mixtures, and finally they change moisture sensitivity of mixtures. Even, the change in fillers' size also affects the moisture sensitivity [15, 16]. In addition, fillers concentration and their minerals type can affect mastic stiffness [17]. Moreover, in a research study, Xie, et al. [18] shows that treated fly ash with coupling agent (CFAM) filler leads to increased fatigue life, positive effect on creep, increased load bearing capacity and increased indirect tensile strength in asphalt mixtures. From the thermodynamic point of view, Sakanlou, Shirimohamdi and Hamedi [19] in their research, at first, investigated the role of various fillers on moisture sensitivity of asphalt mixes, and then thermodynamic parameters were calculated with and without considering filler in dry and wet states. Finally, using statistical analyses, the relationship between important thermodynamic parameters was calculated with and without considering the effect of filler to determine whether the method used in the lack of the effect of filler in surface free energy method requires to be modified or not. The result showed it is necessity to use the effect of filler on calculating thermodynamic parameters in investigating moisture sensitivity of various asphalt mixes.

On the other hand, this issue importance has caused nanotechnology to be entered into this area of science. In this line, in their research, Partl, et al. [20] predicted the high potential of nanotechnology in technological advancement of asphalt pavement in the areas of material design, construction, properties, tests, monitoring and modeling. Furthermore, Liao, et al. [21] investigated the modification of mixture by titanium oxide as an effective factor against destruction of ultraviolet radiation and burnout. The results of their analysis showed that titanium oxide in nano dimensions can positively affect binder aging process. Titanium oxide leads to low rates of aging if it is used in low rate. In another study conducted by Ghaffarpour Jahromi and Khodaii [22], the asphalt pavement modification was investigated using 2 types of common and well known nanoclay, including Nanofill and Cloiste. Results from strength to binder fatigue show obviously that the modification of binder by nanoclay leads to increased adhesion and shear strength of binder such that the strength to permanent deformation which is a kind of shear deformation has increased using nanoclay, but due to reducing the binder flexibility, adding nanoclay has decreased binder performance against fatigue, especially at low temperatures. Van De Ven and Molenaar [23] found that when a specific binder stiffness and viscosity are not affected by adding a kind of montmorillonite nanoclay, another kind of montmorillonite nanoclay will affect the stiffness and viscosity. In addition, the binder strength to aging will improve. In another study, the effects of adding Airosil200 nanoparticles to stone materials on Marshall characteristics of asphalt samples in Topeka layer were investigated. The strength of samples containing 0.157 % of nanoparticles was greater by 14.4 % than the strength of samples without nanoparticles. This research shows that the greatest effect of adding Airosil200 nanoparticles has been on the samples' strength, and it has no significant effect on other parameters [24]. In another study on the effect of nanomaterials on moisture damage of asphalt mixtures it was found that using these materials leads to the strength to moisture improvement and increased fatigue life [1]. Mahmoud Enieb and Aboelkasim [25] investigated the feasibility of using nanosilica in bituminous pavements from the perspective of asphalt binder and corresponding mixture characteristics. The result of their research showed the addition of nanosilica 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.

In the light of the above, in the previous research it is observed that the role of filler on the main mechanisms of moisture damage, including cohesive failure and adhesive failure is of paramount importance. Therefore, in the current research attempts have been made to optimally make asphalt mixture strong against loading and environmental conditions by changing the type, size and percentage of filler used in asphalt mixture.

The most important objectives of the current research include:

1. Investigating the effect of filler type on resilient modulus characteristics;
2. Investigating the effect of filler type on moisture sensitivity of asphalt mixtures.

2. Research Methodology

2.1. Laboratory Program

In the current research 2 types of base aggregate (lime stone and granite aggregate), stone powder filler, binder of 60-70 PEN , and 2 types of additives (Portland cement and nano-silica) were used. The combination of the base and modified binders and aggregates together with filler causes 10 different combinations of aggregate-binder to be created. It is worth mentioning that nano-silica is added to binder as an additive, while the cement is added to stone materials before mixing. The common point of the two additives is that both of them are considered as the alternative to filler weight. It means that their weight is subtracted from main fillers. In the following figure, the method used in this research can be observed. In order to conduct indirect tensile strength ratio tests and resilient modulus, at first, a series of tests should be conducted to determine the optimum binder content. After the optimum binder content was determined for each compound, the indirect tensile strength ratio and resilient modulus tests were done.

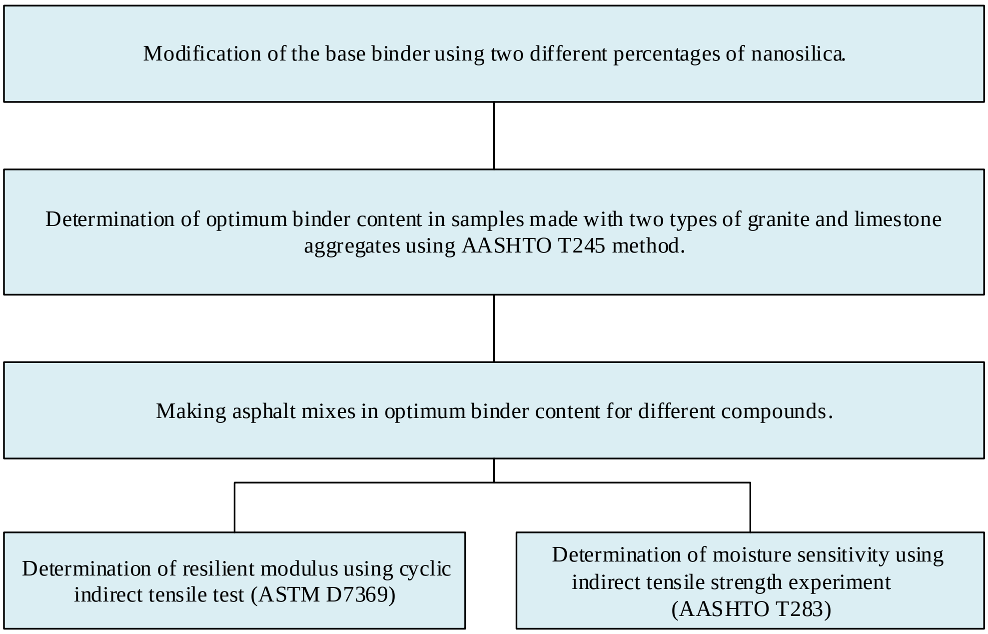

Figure 2. Laboratory program flowchart

2.2. Materials

As mentioned, 2 types of the base aggregates used in this research are the lime stone and granite aggregates. These aggregates constituting minerals are presented in the following table.

Table 1. Mineral characteristics of aggregates used in this research (%)

Aggregate	Silicon dioxide, SiO_2	Aluminium oxide, Al_2O_3	Ferric oxide, Fe_2O_3	Magnesium oxide, MgO	Calcium oxide, CaO
Limestone	16.58	4.84	3.87	2.24	72.47
Granite	52.19	6.05	7.08	2.92	31.75

In the current research, cement was used as an alternative to filler by 2% and 4% of the aggregate mass. The second material used in this research was nano-silica which was added to the binder by 2% and 4% of the binder mass. In the following figure, images captured by electron microscopy are shown.

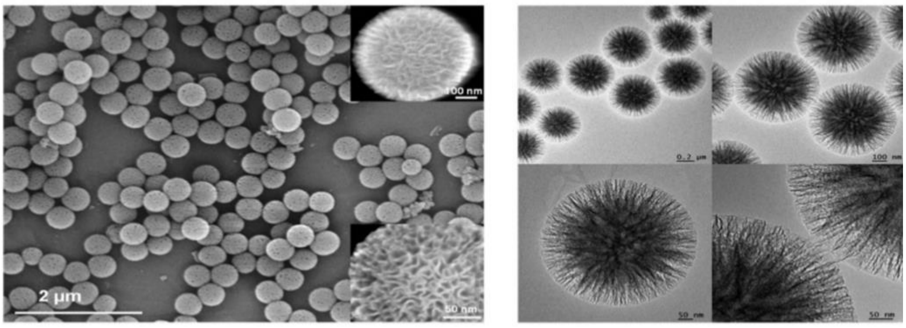

Figure 3. SEM image of nanomaterials used in this research

2.2.1. Binder Modification

According to the previous research, it was observed that the percentage of nano additives to improve the asphalt mixture performance is about 0.5%-8%. That is why 2% and 4 % of nano-silica was used in order to modify binder in this research. Moreover, in order to properly mix the additive to binder, a high speed mixer device available in the laboratory of Biocompatible Polymers of Iran Polymer and Petrochemical Research Centre was used. This mixer has the ability to rotate up to 12000 rpm. In the current research the maximum rotation capacity of this mixer was used. To this purpose, the binder was heated up to 140-150 Cº and nanomaterials were gradually added to it. The mixing process continues for 25 minutes so that nanomaterial particles can be homogenously distributed in the binder space. In order to prevent the reduction of binder temperature, the heater surrounding the binder container was used. A schematic of this mixer is shown in the following figure.

Figure 4. Modification of the binder with nano additives

3. Tests

3.1. Test of Moisture Damage Sensitivity Based on AASHTO T283 Standard

In order to do moisture sensitivity test through the modified Lottman method, 3 samples in wet conditions and 3 samples in dry conditions should be made for each mixture. Based on this standard, samples with a diameter of 100 mm and a height of 63.5±2.5 mm or samples with a diameter of 150 mm and a height of 95±5 mm are tested. The samples should be compacted in a way that the percentage of the air void between them is 7±0.5%. In order to achieve the intended air percentage, at first the number of the required hits to reach this percentage of compaction should be determined. To this purpose, at first 2 samples should be made, one compacted by 40 hits and the other with 55 hits, and then, the air void percentage of each one is obtained. If the air percentage between these 2 numbers of hits is 7%, the number of the required hits for 7% of the air voids is determined using interpolation search. If the air percentage is still greater than 7% in 55 hits, the samples are compacted by 75 hits such that the air void percentage corresponding to 75 hits is obtained. Then using interpolation between the air void percentage corresponding to 55 and 75 hits, the number of the required hits to reach at 7% of the air voids is determined [26].

After compacting, the samples' diameter, height and weight are measured. Then the bulk specific gravity and the maximum specific gravity are measured, and the samples' volume and the amount of the air voids volume will be calculated. Finally, half of the samples in each group (3 samples) remain in dry conditions (dry samples) and half of them (3 samples) are put in wet conditions (wet samples).

In order to place the second group samples under wet conditions, at first samples are saturated for 5 minutes using partial vacuum conditions (the absolute pressure of 13-67 Kpa). Then the samples are kept for 5-10 minutes in saturation state without partial vacuum conditions. In the following, the samples are withdrawn and their mass is measured. Using the mass of the absorbed water and the amount of the air volume, the samples' saturation percentage is obtained. If the saturation percentage is less than 70%, the samples should be placed again in vacuum conditions. If the saturation percentage of the samples is more than 80%, the sample is considered to be damaged and a new sample should be made instead of it. For the new sample, less vacuum condition time is considered for the saturation percentage to become 70%-80%. The samples saturation method is shown in Figure 5.

Figure 5. Saturation of the compacted asphalt samples

The saturated samples are put in plastic bags and 10 ml water is added to them. They are kept in freezer at -18Cº for 16 hours. Then the samples are put into hot water bath at a temperature of 60 Cº, plastics are removed and the samples would be allowed to remain at this temperature for 24 hours. In the following, the samples are brought to the room temperature (25 Cº) and remain in this temperature for 24 hours; these samples are called wet or conditioned samples. The indirect tensile strength and resilient modulus tests are performed on the wet and dry samples. As shown in the following figure, in the indirect tensile strength test, loading is done with 5.08 cm (2 in)/ min until failure is occurred in the sample. The amount of load at failure moment is recorded.

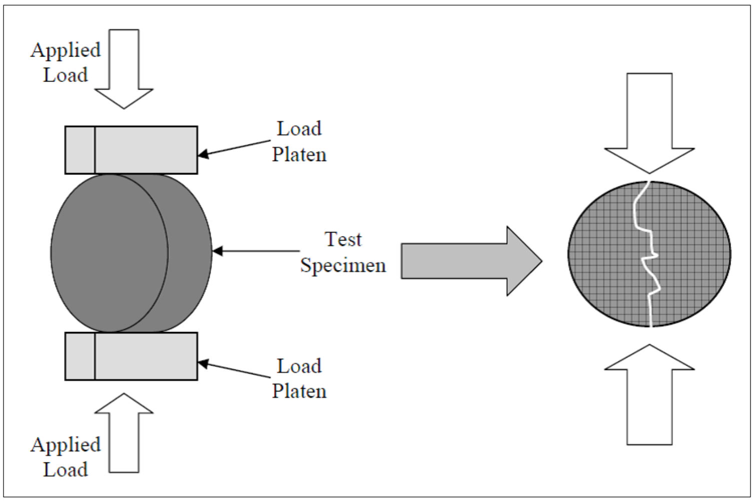

Figure 6. Schematic of indirect tensile test illustrating experiment set-up (left) and location of failure (right) [27]

The indirect tensile strength is obtained for the samples using the following equation:

$$ITS = 2000F/t\pi d \tag{1}$$

Where:

ITS= Indirect tensile strength value (KPa);

F= Force value at failure moment (N);

t= Thickness of asphalt sample (mm);

d= Diameter of asphalt sample (mm).

The mean of the indirect tensile strength of dry samples (3 samples) and wet (3 samples) are calculated separately. The moisture sensitivity or stripping potential of asphalt mixtures with the indirect tensile strength mean of wet to dry samples ratio (%) is calculated based on the following equation:

$$\text{TSR} = \left(\frac{\text{ITS}_{\text{wet}}}{\text{ITS}_{\text{dry}}}\right) \times 100 \quad (2)$$

Where:

TSR= Indirect tensile strength ratio (%);

ITS_{wet}= The mean of the indirect tensile strength in wet samples (KPa);

ITS_{dry} = The mean of the indirect tensile strength in dry samples (KPa).

3.2. Resilient Modulus Test

Resilient modulus is an important parameter used in mechanistic pavement design. This parameter is an important input in multilayer elastic theories or finite elements models to calculate the response of the pavement under traffic loading. Resilient is a property of a material showing the amount of the absorbed energy when it is deformed elastically. Due to simplicity and the ease of the usage of the field and laboratory asphalt mixture samples, the indirect tensile test under repeated loading is the most common method to calculate resilient modulus. Similar to indirect tensile strength, this test includes loading along the sample diameter. In the current research, this test was done based on ASTM D7369-11 [28]. In the resilient modulus test, sinusoidal loading was done with loading period of 0.1s and resting period of 0.9 s for samples at a temperature of 25 Cº in 50 pre-loading cycles and 5 main loading cycles. The samples' placement in the universal testing machine (UTM) method is shown in Figure 7.

Figure 7. Samples placement in the resilient modulus test

The loading and deformation in the resilient modulus test through indirect tensile method are shown in Figure 8.

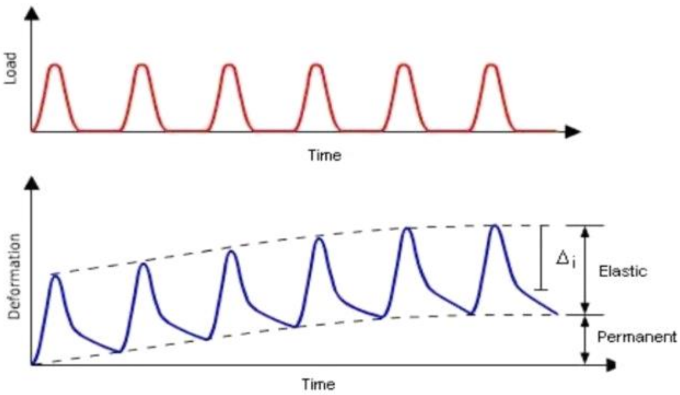

Figure 8. Schematic of loading in the resilient modulus test [29]

In order to obtain the resilient modulus, Equation 3 is used.

$$Mr = \frac{p(v + 0.27)}{H \times L} \quad (3)$$

Where,

M_r= Resilient modulus (MPa);

P= The maximum amount of repeated vertical force (N);

V= Poisson ratio of asphalt mixture which is equal to 0.35;

H= Horizontal reversible deformation (mm);

L= The samples' height (mm).

4. Results and Discussion

4.1. Indirect Tensile Strength Ratio

The indirect tensile strength of the same asphalt mixtures in wet to dry conditions ratio is the most common indicator to determine the moisture sensitivity of an asphalt mixture before its implementation, which can help with prediction of asphalt mixture performance in design stage. Results obtained from this indicator in the asphalt mixture samples made in this research are presented to investigate changes in moisture sensitivity of samples made by aggregates, binders, and additives.

Figures 9 and 10 show the results of moisture sensitivity indicator used in this research. As it is observed, the indirect tensile strength indicator of wet to dry samples ratio (%) is always less than 100, because it is expected that the asphalt mixture strength will be reduced due to saturation process and placing in the freeze-thaw cycle. The reduction in the indirect tensile strength of samples in wet conditions can be attributed to the loss of the aggregate-binder adhesion and/or the binder cohesion caused by the presence of samples in the moisture exposure. In addition, it is observed that the samples made by the limestone aggregate have the highest strength against moisture damage, which is in agreement with the results of previous research [29-31]. In the following, the role of the aggregate type and 2 anti-stripping additives used in this research in moisture sensitivity of asphalt mixtures is discussed.

The results of Figure 9 show that the use of 2% and 4% of cement has caused the indirect tensile strength ratio in the samples made by limestone aggregates to be increased from 79% to 87% and 90%, respectively. Additionally, the use of nano-silica has caused the indirect tensile strength ratio parameter in the samples containing 2% and 4 % of this material to be increased by 81 % and 82%, respectively. As it is obvious, the cement had significantly outperformed nano-silica. In fact, it seems that the use of nano-silica had no significant effect on moisture sensitivity of asphalt mixtures of this group. Of course, this does not mean that this material is ineffective. In fact, the increase ratio of indirect tensile strength in the samples modified by nanocilica in the wet and dry conditions has been close to each other, which has caused the indirect tensile strength in the base and modified samples to be slightly different. The next point which holds true for all the samples of this research is that, in general, it is difficult to increase the strength of asphalt mixtures made by limestone aggregates, because these samples (in the state without additives) have a very high strength to moisture.

The results of Figure 10 show that the moisture sensitivity indicator or the indirect tensile strength ratio in the samples made by granite aggregate is very lower than limestone aggregates. The use of cement and nano-silica to improve the strength of the samples made by granite aggregates has been more useful in comparison to limestone aggregates. The use of 2% and 4 % of cement has caused the indirect tensile strength ratio to reach from 63% to 78% and 82%, respectively in the samples made by granite aggregate. The use of 2% and 4 % of nano-silica has also caused this indicator to reach to 68% and 71%, respectively, which is not still considered to be an acceptable value despite the improvement compared to the base state. Similar to the samples made by limestone aggregates, it is observed that the Portland cement has outperformed nano-silica in the samples of this group.

A variety of factors affects the occurrence of moisture damage and asphalt mixture strength to it. One of the most important of them is the composition of the aggregates constituting minerals used in asphalt mixture. Two minerals SiO_2 and CaO (or $CaCO_3$) lead to a fundamental change in the hydrophobicity or hydrophilicity of asphalt mixture. The more the content of SiO_2 mineral, the higher the hydrophilicity of the aggregate is, and vice versa. Conversely, when the content of CaO mineral is more, indicates the higher hydrophobicity of the aggregates and vice versa [32].

In order to determine the composition of the aggregates constituting minerals, XRF test was performed in this research. Accordingly, Table 1 shows the compounds of the minerals constituting 2 types of aggregates used in this research. As it is obvious from data presented in this table, a major part of granite aggregate is formed by silicon dioxide (SiO_2) which causes strong acidic properties in the granite aggregates. In this type of aggregate, the percentage of the strong basic parts such as calcium oxide (CaO) is very lower than the acidic part. On the contrary, in the limestone aggregate it can be observed that the percentage of SiO_2 mineral is very low compared to CaO mineral. In fact, the main reason of the high strength of limestone aggregate and binder is due to the formation of non-solvable bonds (covalent) in the water, which are formed owing to the physical reaction between calcium on the aggregates surface and some of the binder performance groups. In the opposite point, it can be refer to granite aggregates in which the amount of SiO_2 mineral is high leading to a high water absorption in them [33]. In fact, hydroxyl groups (OH) are found on the acidic aggregate surface (e.g., granite). These groups (SiOH) form a hydrogen bond with carboxylic acid groups which is very effective in the binder-acidic aggregate adhesion [34], but this hydrogen bound is easily broken in the presence of water and these 2 groups are separated from each other and each of which makes hydrogen bound with water molecules. This means that the hydrogen bound formed between water molecules and the aggregate SiOH, as well as between water molecules and binder COOH are preferred to the hydrogen bound between the aggregate SiOH and binder COOH, and this bond is broken.

In addition to the aggregates constituting minerals, the failure percentage is an issue whose role in the moisture damage occurrence has been investigated in the previous research. The better the aggregate has a broken composition, the better the aggregate lock and bind force is provided. But, on the other hand, it causes the wettability and binder residual to be hardly provided in the sharp points; and the binder debonding from sharp edges occurs more easily. Considering the opposite role mentioned for failure parameter, it can be said that this parameter had no clear effect on reducing or increasing the moisture sensitivity of different asphalt mixtures. Moreover, considering the regulation requirements with regard to the high percentage of failure in the aggregates used in the asphalt mixture layers, the failure percentage of the aggregates used in this research was close to each other making it impossible to compare samples with different percentages of failure. The percentage of the additive used in this research was determined based on the previous research and the initial tests so that a percentage could be selected that have the best performance. Of course, the selected percentage in different aggregates and binders should be different. As the aim in the current research was not to make the most robust asphalt mixture against moisture, it was decided to use limited percentages in all samples so that the effect of additive percentage causes no confusion in the analysis of the results.

The use of additives in the samples made by 2 types of aggregates causes an increase in the asphalt mixture strength to moisture and improves the indirect tensile strength ratio indicator. As it is obvious from data presented in Figures 9 and 10, the use of additives had the least effect on the strength of asphalt mixtures made by limestone. The reason can be attributed to the proper aggregate-binder adhesion in the base state. In the unmodified state, a proper adhesion is also created with binder which is an acidic material. Utilizing fillers used as anti-stripping materials similarly increases the strength of the samples containing this aggregate both in dry and wet conditions. This leads to the slight improvement of indirect tensile ratio indicator against moisture in the samples made by this type of aggregate. Considering the samples made by acidic granite aggregate, using these fillers leads to the proper improvement of asphalt mixture performance against moisture.

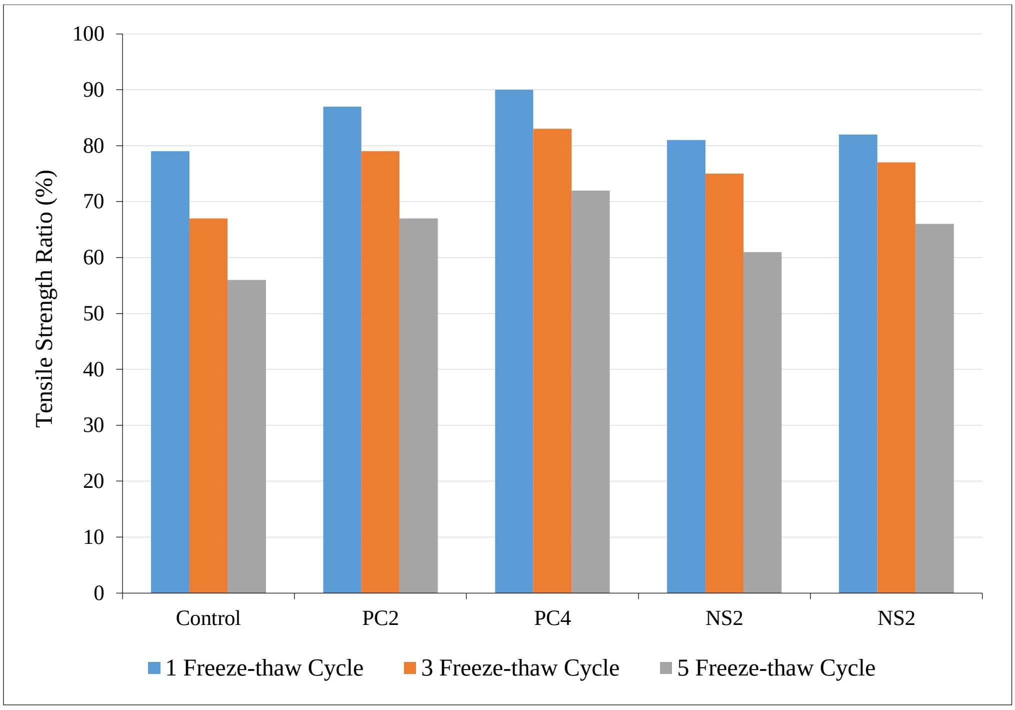

Figure 9. Indirect tensile strength ratio in samples made with limestone aggregates

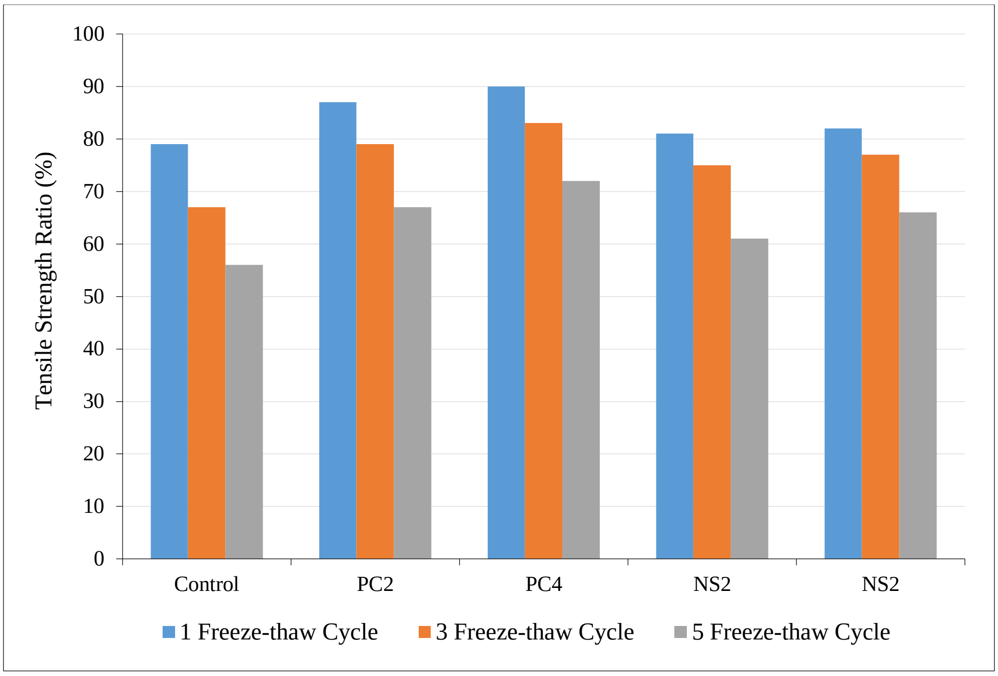

Figure 10. Indirect tensile strength ratio in samples made with granite aggregates

4.2. Resilient Modulus Test Results

Results of resilient modulus test for samples made by limestone and granite aggregates are presented in the following figures. In order to better express the results of resilient modulus, the following tables were used in which a comparison has been made between resilient modulus in the samples made by limestone and granite aggregates. In the table related to resilient modulus results of the samples made by limestone aggregates, it is obvious that using any type of additive used in this research has caused a significant increase in the resilient modulus amount. The resilient modulus amount in the samples made by base binder was 1296 Mpa, this parameter increased to 1426 and 1456, respectively as a result of using 2% and 4% of Portland cement as filler. In addition, it is observed that the incremental effect of resilient modulus in the samples made by binder modified by nano-silica is more evident compared to Portland cement. The use of 2% and 4% of nano-silica has increased resilient modulus amount up to 1489 and 1552 MPa, respectively.

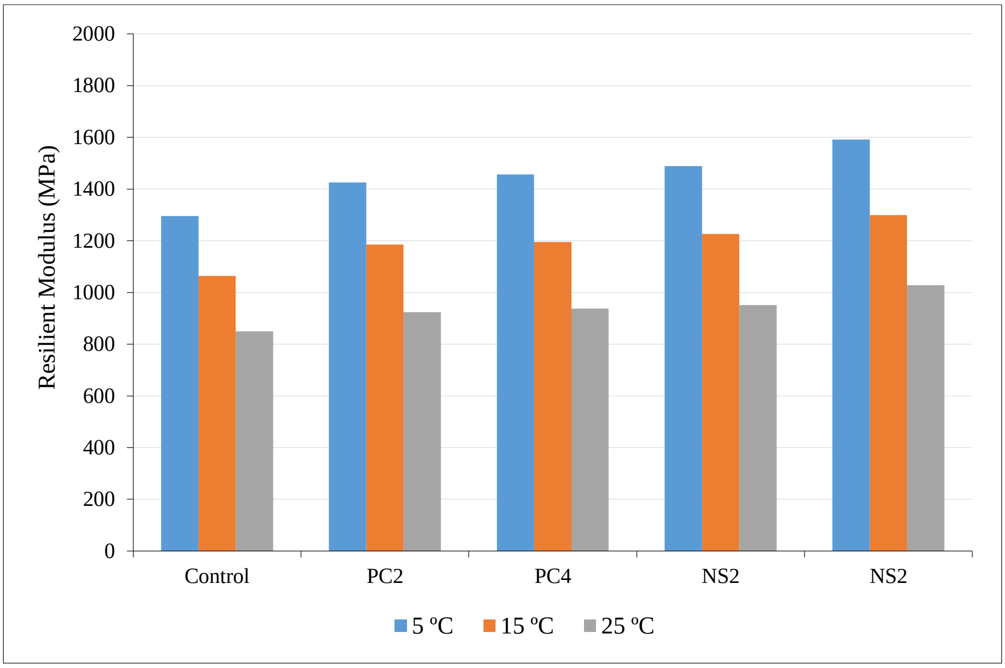

Figure 11. Resilience modulus in samples made with granite aggregates

A similar trend can be observed in the resilient modulus increase in samples made by granite aggregate in comparison to the samples made by limestone aggregate. In the following table, it is obvious that adding nano-silica additive to binder and Portland cement which is added to the stone materials has been capable of significantly improving resilient modulus amount. Similar to the samples made by limestone aggregates, in the samples made by granite aggregate it is observed that the use of nano-silica showed a better performance in increasing resilient modulus of asphalt mixtures. Using 2% and 4% of nano-silica has caused resilient modulus amount to be increased from 1435 MPa in the base samples to 1765 and 1945 MPa, respectively. It should be noted that the use of 4% of stone materials weight with cement filler, shows a better performance in comparison to using 2% of nano-silica filler weight.

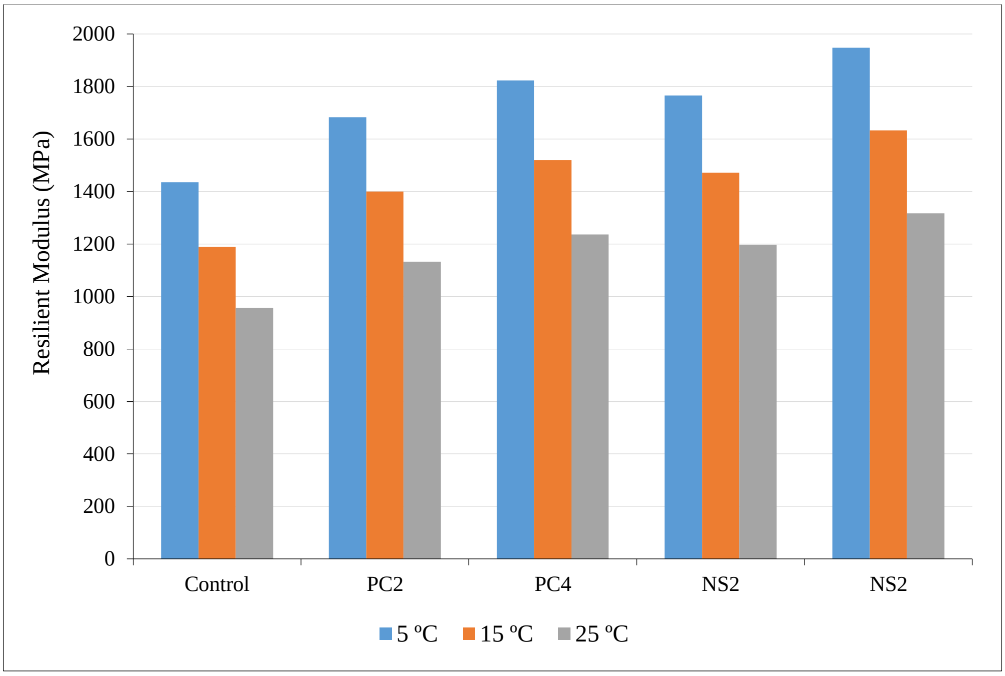

Figure 12. Resilience modulus in samples made with limestone aggregates

4.3. Statistical Analysis

In order to accurately assess the effects of anti-stripping agents on the moisture susceptibility of the mixtures, a t-test was conducted at different mixtures, the results of which are presented in Table 2. In this analysis, the TSR was selected as an indication of the moisture resistance of mixes.

Table 2. Statistical analysis of the effects of PC and NS on the moisture damage of asphalt mixes

Independent Samples Test		Levene's Test for Equality of Variances		t-test for Equality of Means		
		F	p-value	t	df	p-value
Limestone with PC	Equal variances assumed	3.61	0.065	-2.131	38	0.04
	Equal variances not assumed				33.893	0.04
Limestone with NS	Equal variances assumed	3.71	0.058	-2.016	9	0.03
	Equal variances not assumed				8.76	0.03
Granite with PC	Equal variances assumed	3.16	0.073	-2.254	9	0.00
	Equal variances not assumed				8.64	0.00
Granite with NS	Equal variances assumed	3.02	0.078	-2.258	9	0.02
	Equal variances not assumed				8.61	0.02

Based on Levene's test, it is obvious that the samples have equal variances and the data related to the equality of variances should be used. It can also be observed from t-test results that the usage of PC and NS had a considerable effect on the wet-to-dry ITS of the mixtures, improving the resistance of asphalt mixtures against moisture induced damage.

5. Conclusions

In order to improve resilient modulus and the hot mix asphalt strength to moisture, certain percentages of nano-silica and Portland cement were used as an alternative to the part of the filler (2% and 4%). In the following, in order to determine the optimum binder content for each compound, the resilient modulus tests were performed using indirect tensile method. And the indirect tensile strength ratio was used to determine the sensitivity of different samples against moisture. The most important results obtained from this research include:

- The use of cement led to the better performance in improving the asphalt mixture strength to moisture. The ratio of increase in the indirect tensile strength in the samples modified by nano-silica in the wet and dry conditions was close to each other leading to the slight difference of moisture sensitivity indicator or the TSR in the base and modified samples.
- TSR value in the samples made by granite aggregate was very lower than limestone aggregates. The use of cement and nano-silica to improve the strength of the samples made by granite aggregates had been more useful in comparison to limestone aggregates.
- The use of additives had lest effect on the strength of asphalt mixtures made by limestone. The reason can be attributed to the proper aggregate-binder adhesion in the base state. In the unmodified state, a proper adhesion is also created with binder which is an acidic material. Considering the samples made by acidic granite aggregate, using these fillers leads to the proper improvement of asphalt mixture performance against moisture.
- The composition of the aggregates constituting minerals used in asphalt mixture are affect the moisture resistance of them.
- None of the samples containing binder modified by nano-silica in the samples made by granite aggregate could bring the TSR of the samples made by granite aggregate to 75%.
- The use of cement and nano-silica could significantly increase the resilient modulus. This improvement in the samples made by nano-silica additive was more evident. Additionally, the samples made by granite aggregate showed a better performance in the resilient modulus test.

6. Conflict of Interest

The authors declare no conflict of interest.

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