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INVESTIGATING THE EFFECT OF NANO-SILICA ON THE SPECIFICATION OF THE SASOBIT WARM MIX ASPHALT

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Abstract

In this investigation, Nano-silica has been added in three percentages of 2%, 4% and 6% to improve the physical, rheological and mechanical properties of warm mix asphalt (WMA) containing 2% Sasobit. Several experiments have been conducted to evaluate and characterize the prepared samples. The results of investigations indicated that by increasing the percentage of Nano-silica, the qualification and functionality of the warm mix asphalt has been improved. Resilient modulus of WMA was slightly increased by increasing the Nano-silica content. So, the response of pavement to traffic loading at 25°C has been improved. Depth of cracking at a specified load cycles was decreased dramatically by adding the Nano-silica to the Sasobit WMA. At the same time, the stiffness of modified samples was much lower than control WMA. As a result, the Nano-silica extends the fatigue life of asphalt concrete. In addition, the wheel tracking test results depicted that the rutting depth have been reduced by increasing the Nano-silica content. Regarding the results of qualification tests, 4 wt% of Nano-silica was selected as the optimum content.

Keywords: Warm Mix Asphalt, Sasobit, Nano-silica, Resilient Modulus, Fatigue, Rut Depth.

1. Introduction

As we know, the technology of the warm mix asphalt has attracted the serious attention of researchers during the recent decades. The researchers have been constantly trying to improve the technical qualification of this type of asphalt. So that, regarding the augment of its environmental benefits and decline of fuel consumption, this sort of asphalt can be presented as a suitable alternate for the hot asphalt [1]. Reduction of required energy to heat the materials in mixing period is the most important advantage of WAMA, and this reduction terminates to lower project cost. Another benefits compared to the normal hot mix asphalt (HMA) such as less asphalt fumes during production and lay-down, and reduction of toxic gas emissions from asphalt plants are available [2].

Usage of warm mix asphalt (WMA) has been increased in recent years, rapidly. For example, the superstructure projects using the warm mix asphalt have been carried out in the American states of Alabama, Florida, Indiana, Kansas, Maryland, Missouri, Ohio, Vermont, North Carolina, Tennessee, Texas (San Antonio), Wisconsin, Ontario, Alberta and Washington. Warm mixes have received some attention in Europe and Australia since around 2000 [1, 3].

The pavement industry in North America started to give warm mixes some interest a few years later and in June 2005 the National Center for Asphalt Technology (NCAT) published two reports about the use of Sasobit, a synthetic wax, and Aspha-min, a synthetic zeolite, in warm mix asphalt. In Germany, Sasobit is used as much as 2.5% of the whole weight of bitumen that this proportion, regarding the stiffing effect, must not exceed 3%. Also in U.S.A., proportions of 1% to 1.5% are usually utilized. Sasobit decreases the mix and compaction temperatures, and reduces the heat energy required. It also significantly decreases the CO_2 emission when combined with the recovered bitumen from RAP [2, 4].

Nanotechnology is the creation of new materials, devices, and systems at the molecular level as phenomena associated with atomic and molecular interactions strongly influence macroscopic material properties [5-6]. A nano particle has at least one dimension measuring less than 100 nanometer (nm) [7-8]. Due to their small size, usually nanomaterials have the higher reactivity and special surface properties, which can be used for industrial products [9]. Due to the special properties of the above-mentioned nanomaterials, they are appropriate to be implemented in asphalt pavements [10-14]. In recent studies, Nanoclay material was added to modify the basic asphalt binder, and it was found that it could increase the shear complex modulus and reduce the strain failure rate of basic asphalt [15]. Furthermore, the addition of nanoclay in the basic asphalt binder could weaken the moisture susceptibility of asphalt mixture [5, 7, 16]. Also, the carbon nano-fiber was used for the asphalt binder modification [17-18]. From the viscosity and dynamic shear rheometer (DSR) test results, it was concluded that the viscoelastic response and rutting resistance of carbon nono-fibers, as well as the fatigue life of modified asphalt binder have been improved [17, 19, 20].

Nano-silica has been used in medicine, drug delivery, and engineering. The merits of Nano-silica are the low cost of production and high performance features. Nano-silica is a relatively new inorganic material that is used due to its potentially beneficial properties (e. g., huge surface area, strong adsorption, good dispersal ability, high chemical purity, and excellent stability). Nano-silica has been used as an additive, catalyst carrier, rubber strength agent, plastic filler, and as a graphite viscosity agent among other uses in various industries. Due to these potentially beneficial properties, Nano-silica has the potential to be used as an asphalt modifier for improving asphalt performance [17, 21]. In addition, the combination of Nano-SiO2 and SBS was mixed with stone matrix asphalt, and the physical and mechanical properties of asphalt binders and mixtures were improved [22-23].

Regarding the widespread use of the Sasobit in warm mix asphalt, the Sasobit modified WMA has been used in this study. The effect of different contents of Nano-silica (including 2, 4 and 6 wt% of Nano-silica) on the Sasobit WMA have been investigated. Various qualification test methods were conducted on the prepared samples to determine the influence of Nano-silica on the fatigue life, rutting and cracking of asphalt concretes.

2. Materials

2.1 Nano-silica

The Nano-silica in white color (Sigma-Aldrich, USA) has been used in accordance with the properties and characteristics mentioned in the Tables 1 and 2.

Table 1 Analysis of Nano-silica

SiO2	Ti	Ca	Na	Fe
>99%	<120 ppm	<70 ppm	<50 ppm	<20 ppm

Table 2 Properties of Silicon Oxide Nanoparticle

Particle Size	Purity	Bulk Density	Surface Area	True Density
20-30 nm	+99%	<0.10 g/cm^3	180-600 m^2/g	2.4 g/cm^3

2.2 Bitumen and Sasobit

The most common bitumen grade (60/70 penetration grade) from Isfahan refinery (Iran) was used as a base binder in this research. The properties of the utilized bitumen have been shown in Table 3.

Flak Sasobit, a mixture of hydrocarbons with long-chain produced by a Fischer-Tropsch synthesis, was prepared from SasolWax (SasolWax Co., South Africa). The Sasobit wax possesses a melting point of 98°C and its penetration degree in 25°C is less than one tenth millimeter.

Table 3 Characteristics of utilized bitumen.

Ductility at 25 °C, cm	Softening point, °C	Penetration at 25°C, 0.1mm	Penetration Index (PI)
+ 100	51	68	-0.20

3. Experimental method

The hot melting method was used for mixing of neat bitumen with Sasobit and Nano-silica. In this method, the bitumen modifiers were gradually added to the base binder at the elevated temperature (about 160°C for Sasobit and 180°C for the Nano-silica). The constant amount of Sasobit, 2 wt%, was selected for all of the samples, while the amount of Nano-silica was varied between 2-6 wt% based on the original binder. It is assumed that the viscosity of binder is too low to diffuse the baffle spacing of Nano-silica and prevent the agglomeration of it at such a high temperature.

According to the National Center for Asphalt Technology (NCAT), the standard mixing model of ordinary warm asphalt according to figure 1 have been used to prepare the asphalt mixtures.

In order to produce the asphalt mixtures containing the bitumen modified with Sasobit and Nano-silica additives, the aggregate temperature of 130°C was selected.

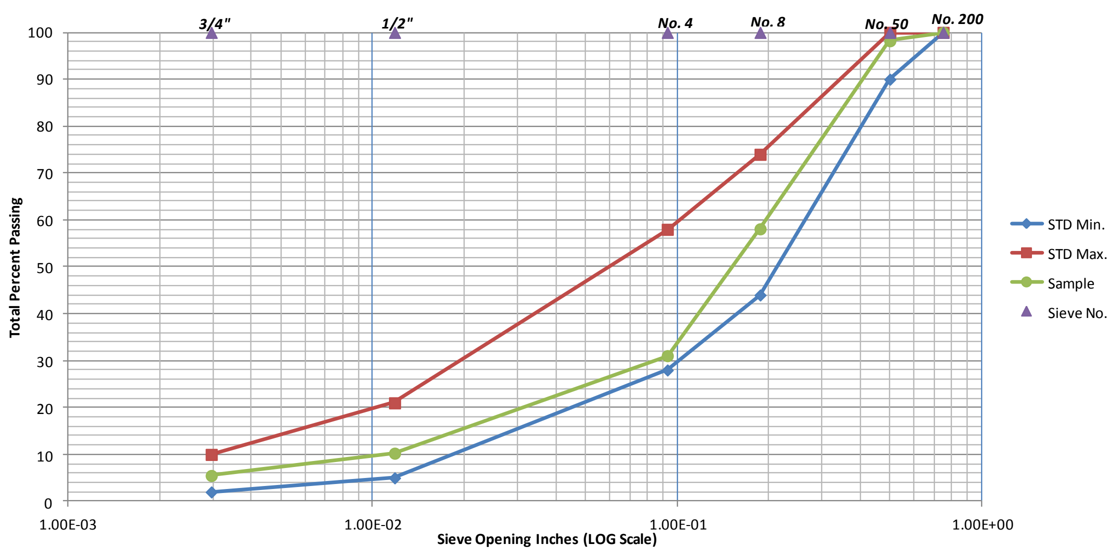

Figure 1 The specifications of the asphalt grading (passing from sieve, %)

4. Result and discussion

4.1 Resilient modulus test

In order to investigate the efficiency of resilience, firstly, the samples were stored at the temperature of 25°C for 24 hours. The load of 1000 N was applied at 25°C on the samples in a repeatable loading period with the frequency of 1 Hz. The loading and resting period of 0.1

and 0.9 s were selected, respectively. The test was done by measuring the ITS (indirect tensile strength) of samples following ASTM D4123 standard test method.

Resilient modulus is the ratio of applied stress to the recoverable part of strain, after a certain number of load cycles. Increase the resilient modulus results in the better performance of the mixture at the specific temperature. This modulus is an estimation of elastic modulus to analyze the response of pavement to traffic loading.

The effect of Nano-silica on the resilient modulus of warm mix asphalts have been shown in figure 2. As it has been shown in this figure, Nano-silica has positive effect on the resilient modulus of warm mix asphalt. It can be seen that the value of resilient modulus has slightly increased by increasing the Nano-silica from 0 to 6%.

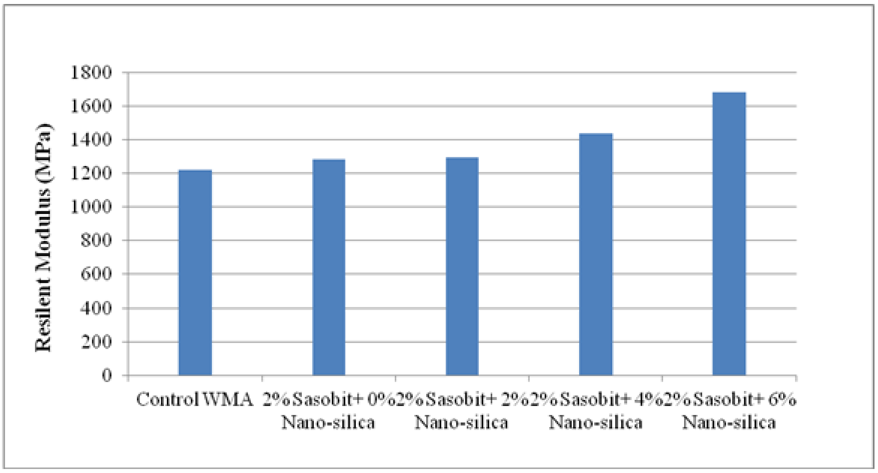

Figure 2 The effect of Nano-silica on the resilient modulus of the warm mix asphalt

4.2 Repeated load permanent deformation test

The figure 3 illustrates the various stages of the fatigue mechanisms of the warm asphalt prepared with modified bitumen. At the first stage, some tiny cracks appeared on the thin cover of bitumen among the sands which has been shown in the initial part of the graphs. These rapid changes happened in the transition stage of the thermo mechanical phenomenon, which is due to the viscoelastic subsidence in the asphalt mixes.

At the second stage, these thermal changes was ended and the initial cracks was appeared which resulted to the larger crack pattern. Finally, at the third stage, a big crack was rapidly developed and the breaking of the asphalt sample was occurred.

The purpose of this test is the measurement of fatigue response of cylinder samples of asphalt mixes (100 mm diameter and 150 mm height) to the repeated loading cycles, prepared by gyratory compactor at 88 gyrations. In indirect tension apparatus, the asphalt sample subjected to loading and relaxation for the large number of cycles. In each cycle, the samples were exposed to 25-millisecond loading and then rested for 125-millisecond. Whole of the operation was done with the frequency of 0.66 Hz. The temperature of the test chamber was 25°C and the test performed for up to 10000 cycles or until reaching 10-millimeter permanent deformation.

Figure 3 offers a more exact evaluation of the effect of Nano-silica additive on the fatigue resistance of the warm asphalt produced by Sasobit. As shown in this figure, there is a positive correlation between the percentage of Nano-silica and fatigue properties of samples (the number of the loaded cycles to cracking). It clearly has been shown that the control sample has maximum depth of cracking, while sample with 6% Nano-silica has the lowest cracking. Nano-silica could shift the fatigue deformation of asphalt samples to the higher cycles and increase the resistance of samples against cracking at a specified loading period. 6% Nano-silica showed a much higher resistance at 25°C. This phenomena is probably due to sever decrease in air voids of WMA [3].

As a result, the 4 wt% is the optimum content for Nano-silica and further increase could influence other critical properties of WMA.

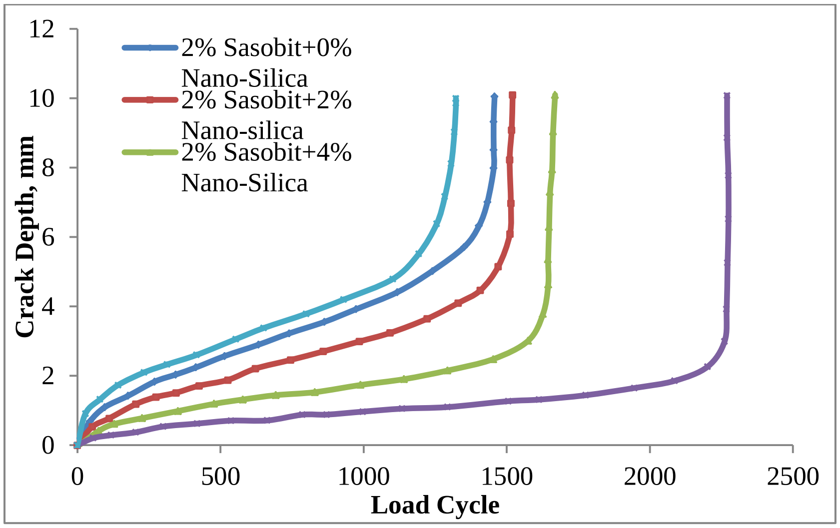

Figure 3 Plot of depth of cracking against the number of load cycles.

4.3 Four point bending beam test

During the fatigue lifetime of pavements, an asphalt concrete would be subjected to a high number of load cycles, which could lead to fatigue failure. The four-point bending beam test is used to determine the effect of bending forces on the fatigue life and stiffness of asphalt mixtures. The test was carried out under a half –sine uploading cycle with the frequency of 10 Hz, at the state of controlled prostration (the fixed prostration level of 400Kpa) and at the temperature of 20°C.

The tests were kept on until achieving 75% of the initial stiffness. The evolutions of stiffness for different samples versus number of cycle are shown in figure 4.

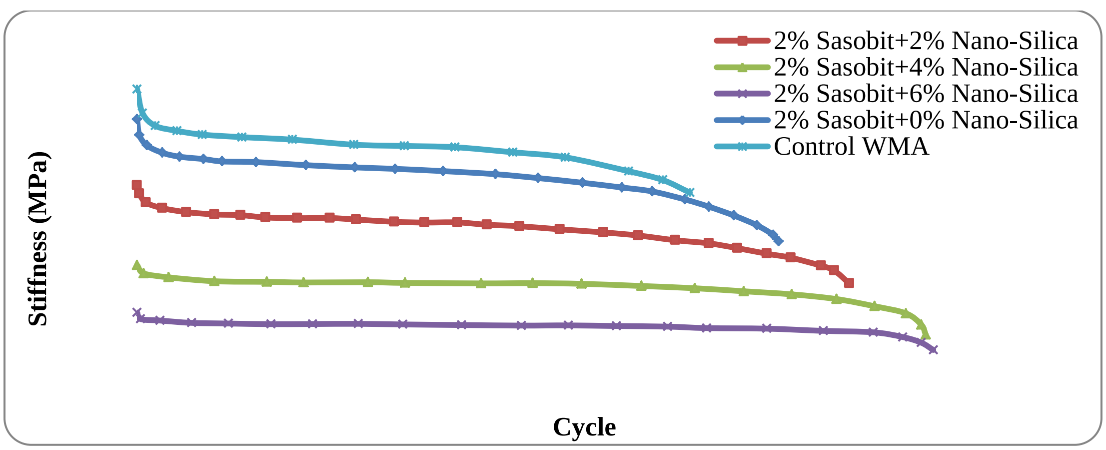

Figure 4 Plot of cumulative stiffness against the number of load cycles

As shown in figure 4, by increasing the Nano-silica contents, the number of load cycles at a specific stiffness was increased. It is clearly obvious that the sample with 6% Nano-silica has the minimum stiffness and tolerates higher number of load repetitions. So the Nano-silica increases the fatigue life (when the stiffness reduced up to 59% of its initial value) of asphalt concrete.

The slope of flexural curve for control WMA was higher than modifies samples, which deduces the lower fatigue life and faster fatigue cracks grow in it.

4.4 Rutting in Hamburg Wheel Tracking Test

The rutting and permanent deformation of asphalt samples were illustrated using wheel tracking device. The depth of track was measured during the test in millimeter and the results have been shown in figure 5.

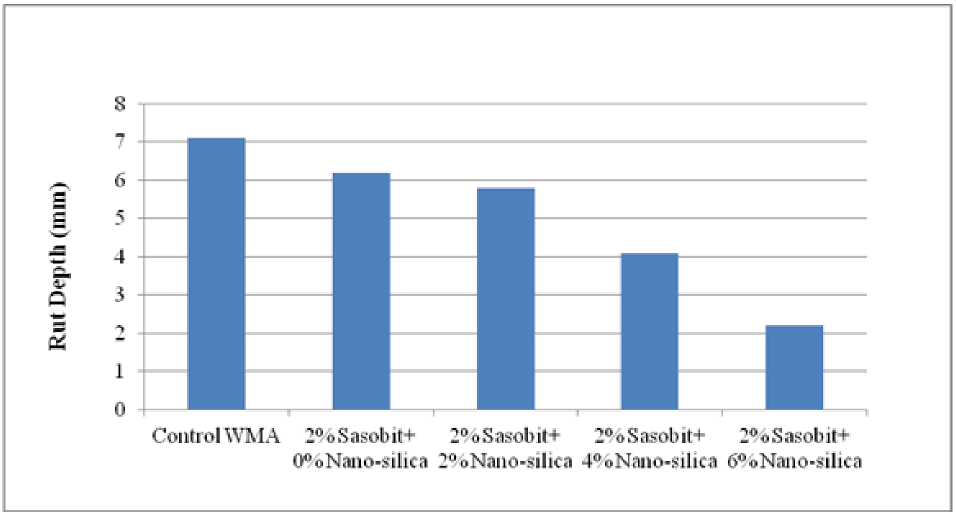

Figure 5 Rut depth after a certain wheel passes from the Hamburg.

The results depicted that the depth of rutting in asphalt mixtures have been reduced by increasing the amount of Nano-silica in them. The samples containing 4% and 6% Nano-silica showed 38 and 48% reduction in rutting depth, respectively. As a result, the asphalt concretes containing Nano-silica were more resistance against rutting and permanent deformation. This phenomenon is due to significant temperature susceptibility decrease in modified binders with Nano-silica.

5. Conclusion

The effects of Sasobit and Nano-silica addition to the asphalt mixture have been investigated in this study. The results of control WMA, and samples modified with Sasobit and different contents of Nano-silica were compared. The results implied that the combination of Sasobit and Nano-silica improves the rutting resistance as well as tensile strength of asphalt mixture. Wheel track test showed that asphalt concrete with modified binders are less temperature susceptible and have less rut depth and permanent deformation. The samples prepared with Nano-silica modified binder showed less fatigue cracks at a certain loading cycles. 4 wt% is selected as the optimum Nano-silica content for the bitumen modification because it has shown the best performance at road service life.

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