Enhancement of Physical Properties of Asphalt Binder by Using Silica Powder

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Abstract. One of the primary requirements for a successful pavement system can be regarded as the caliber of the road pavement. Therefore, various measures have been taken, such as improving pavement quality and structure design methods, to reduce the issues of fatigue cracks and rutting of roads. Since a few years ago, engineers have paid more attention to modifying and improving the performance of asphalt by adding various additives to improve the environment and lower the price of modified pavement mixture. Evaluation of employing modified asphalt cement at various percentages of particle size of silica powder is the main goal of this study. Three percentages of Particle Size of Silica Powder Nano silica and micro silica with 2, 4, and 6% of the weight of asphalt as a modifier for asphalt and their effect on the performance of asphalt mixtures at high temperatures. It was discovered that adding silica powder to asphalt cement would increase the softening point and viscosity and decrease ductility and penetration. Experimental results indicated that the Silica Powder positively contributed to the performance properties of asphalt.

Keywords: Silica Powder; penetration; asphalt cement; ductility.

1. INTRODUCTION

Highways are critical to a country's economic development, yet they are expensive to build and maintain. The highway system is designed to offer a suitable degree of serviceability and structural support for any traffic demand while maintaining appropriate safety criteria. Although traffic-related distresses have increased over the past several years, the serviceability of pavement materials has decreased, resulting in the common deformation of pavement. Furthermore, the rheological qualities of local asphalt binder may not have met performance grade criteria, particularly in terms of climate and traffic loads for pavements in Iraq, as evidenced by reference [1]. As a result, the demand for pavement materials layers has risen, as they want to improve the performance of current pavement materials. Furthermore, It has become simpler to research additional modifiers in improving asphalt binder materials and mixes attributed to a better understanding of asphalt binder properties and behavior due to better technology and the development of new materials. Natural materials, industrial by-products, waste materials, and meticulously engineered engineering goods are all examples of modifiers [2]. Fillers, recovered rubber products, fibers, and polymer types are all common modifiers [3].

Wide varieties of thermoplastic and thermosetting polymers may be utilized to alter [4,5]. Many researchers have looked at nanomaterials for altering cement, although compared to changed concrete, Nanomaterials for changing asphalt cement binder are relatively recent. Nanomaterials such as "Nano-silica, Nano-clay, Nano titanium, Nano hydrated lime, Nano-sized plastic powders, Nano-fibers, and Nanotubes" may all be utilized to modify asphalt [6-9]. Nano-silica represents one of the Nanomaterials that can improve asphalt binder mechanical characteristics. All across the world, colloidal silica, silica fume, and silica gels are made with silica as a key component [10]. These Nano-silica particles have been employed to make polymers stronger [11], and to improve the Portland cement concrete mixtures [12]. Because Nano-silica is cheap and good at what it does, it is a good thing [13-16]. Half have displayed an asphalt binder containing only 2-4% Nano-silica powder to decrease rut depth [17]. Several laboratory tests were employed to investigate the physical characteristics of the original, modified, and rejuvenated binders.

The distresses of road pavements are the main problem in sustaining the life cycle of flexible pavements. Improvement in the performance of flexible pavements is necessary to decrease these distresses. To improve, Iraq's highway pavements are exposed to several distresses due to adverse environmental conditions and heavy traffic. This problem has prompted researchers to enhance asphalt binders by investigating some alternative modifiers to be used. Nanomaterial is usually used in manufacturing and research as they get innovations. The physical dispersions or chemical reactions between asphalt binders and nanomaterials can alter the microstructures of asphalt binders and enhance the elastic performance of asphalt at high temperatures and the vicious performance at low temperatures. t. Such properties could justify the extra production cost of adding Nano-silica powders to the asphalts.

A control and modified asphalt binder containing varying quantities of silica powder were used to investigate the influence of particle size on asphalt binder physical attributes (penetration grade, Softening Point temperature, penetration index, flash point, and ductility).

2. MATERIALS AND METHODS

2.1 Asphalt Binder

The 60/70 penetration asphalt binder utilized in the current investigation was supplied from the Dora Refinery in Iraq's middle zone. The parameters of this asphalt binder are shown in Table 1.

Table 1: Properties of asphalt binder.

Test	Test Conditions	Standard	Results	Iraqi Specification's Standard Limits (SCRB/R9,2003) [24]
Penetration	25°C , 0.1mm	**ASTM D5 [18]**	68	**60-70**
Ductility	5 cm/min	**ASTM D113 [19]**	135	**>100**
Flash and Fire point	---	**ASTM D92 [20]**	Flash 300°C Fire 310°C	**> 232 °C** **---**
Rotational viscosity*	@135℃ @165℃	**ASTM D4402 [21]**	430 Pa. sec 128 Pa. sec	**---** **---**
Thin film oven test	163 ℃, 50 gm, 5 hr	**Mass loss ASTM D1754**	Penetration 79 Ductility 135	**>52** **>50**
Softening point	…..	**ASTM- D36 [22]**	49	**---**
Specific Gravity	25 ℃	**ASTM D70 [23]**	1.031	
Penetration index	**…..**	**ASTM D36 [22]**	-0.7	**---**

2.2 Micro Silica Powder (MS)

Micro silica, a synthetic non-crystalline silicon oxide of grey color particles. It was purchased from a local market (production originated in China). The physical and chemical properties of micro silica are shown in Tables 2 and 3, respectively.

Table 2: Chemical composition of micro silica.

Oxide composition	Oxide content, %	ASTM -C1240 2018
SiO_2	91.51	Min. 85%
Fe_2O_3	0.44	<2.5%
Al_2O_3	0.71	<1%
SO_3	0.95	<1%
$K_2O + Na_2O$	1.38	<3%
CaO	0.90	<1%
L.O.I	4.39	Max. 6%

*Chemical compositions and physical properties according to the manufacturer's specifications

Table 3: Physical properties of micro silica.

Property	Value	(ASTM-C1240 2018)
Size	0.15	≈0.15μm
Color	Grey	-
Specific surface area	17000	≥ 15000 cm/g
Specific gravity, kg/m$_3$	2.2	-
Physical form	Powder	-
Bulk density	0.6	0.5 ± 0.1 kg/liter
Moisture	0%	< 2%

2.3 Nano Silica (NS)

White, hydrophobic powdered synthetic amorphous silica sourced from the Aerosol Company in North America is used as a binder modifier. According to the manufacturer's papers, the major features of Nano-silica are mentioned in Tables 4 and 5.

Table 4: Nano Silica Particles Physical Properties According to the Technical Sheet*.

Property	Result value
Physical form	Powder
Color	White
Size	15nm
Bulk density g/cm^3	0.1<
True density g/m^3	24
Specific surface area cm^2/g	100 ± 25

*Chemical compositions and physical properties according to the manufacturer's specifications.

Table 5: Chemical analysis of nano-silica powder*.

Property	Result value
SiO_2 content based on ignited material, wt. %	99.9
Ph	6.5 – 7.5

*Chemical compositions and physical properties according to the manufacturer's specifications

3. PREPARATION OF SPECIMENS

In two mixers, Nano and micro sizes powder were combined with asphalt. A mechanical mixer may be set to mix (micro-silica) at a constant rotational speed of (2000) rpm, while the high shear can be set to mix (Nano silica) at the same speed. The mixing time duration is regarded as a variable for mixers (60) minutes to make a homogeneous composite material. Based on the Recommendation of most researchers, the asphalt binder was warmed to 160°C. Then, gradually add weighted 2%, 4%, and 6% (low, medium, and high content) silica particles to the heated asphalt binder in a sealed steel container heated in an electronic oven for a period of time (60) minutes. Finally, the modified asphalt binder's physical and rheological characteristics were assessed.

4. RESULT AND DISCUSSION

4.1 Effect of Silica on Penetration and Softening Point of Asphalt Cement

The consistency of the asphalt and the temperature at which it flows are determined by the penetration grade and softening point temperature. The penetration values and softening point temperatures vary when the original and modified asphalt binder are combined, as shown in Figures 1 to 4. No matter how the powder was mixed in, it was clear that the penetration values went down and the softening point went up when silica powder was added. Silica particle diffusion and adsorption into the asphalt binder may stiffen the stiffened asphalt binder. Consequently, oily materials in the molten phase are decreased by silica powder absorption and resin conversion in a phase of asphalting of modified asphalt. Also, silica particle hardness is larger than asphalt binder hardness, and it meets the criteria [25]. In addition, the large surface area of asphalt modified by Nano-silica makes asphalt more consistent and harder than micro-silica-modified asphalt, leading to a significant reduction in penetration value and a rise in softening point temperature. Penetration values gradually decreased with an increasing percentage of Micro silica in the blending process, reaching a percentage decrease of 14.7% from 68 to 58 with 6% due to the addition of Micro silica, as depicted in Figure 1. The results of adding Nano silica to the asphalt penetration values are shown in Figure 2, in which a gradual decrease in the penetration values can be noticed until reaching a degree of 17.6% from 68 to 56 due to adding Nano silica up to 6%.

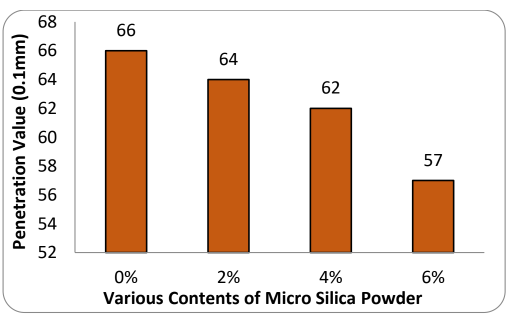

Figure 1: Penetration value with various contents of micro silica.

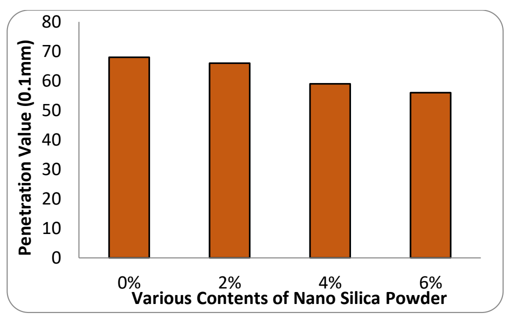

Figure 2: Penetration value with various contents of nano silica.

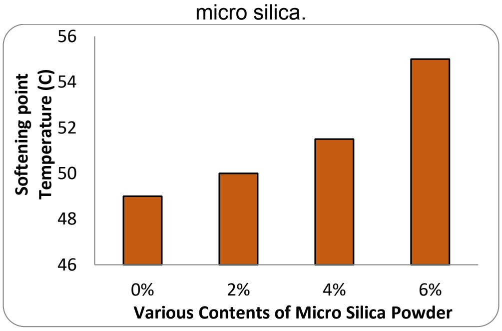

Figure 3: Softening point temperature and % micro silica.

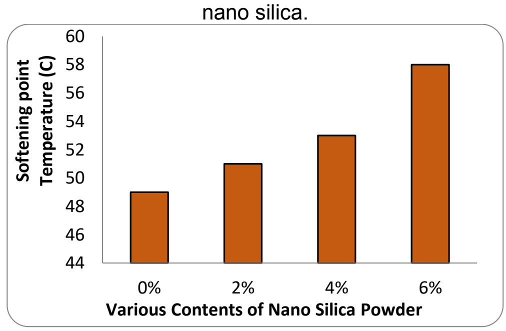

Figure 4: Softening point temperature % nano silica.

4.2 Effect of Silica Powder on Penetration Index (PI)

The temperature susceptibility of asphalt is measured using the penetration index (PI). The temperature susceptibility decreases with increasing penetration index number. Lower temperature susceptibility during the summer suggests greater resistance to low-temperature cracking and rutting deformation [26]. Figures 5 and 6 show the relationship between PI values and silica powder content. The addition of micro-silica enhanced the PI values, and a scan was shown. Furthermore, Nano-silica treated asphalt showed a significant reduction in temperature susceptibility. Because Nano-silica powder has a large surface area, the binder is more consistent and stronger than micro-silica-modified asphalt. The temperature resistance of the modified asphalt is improved when silica powder is added. The PI stays within the standard range of (+2.0 to -2.0), which is suitable for building highway pavements [27].

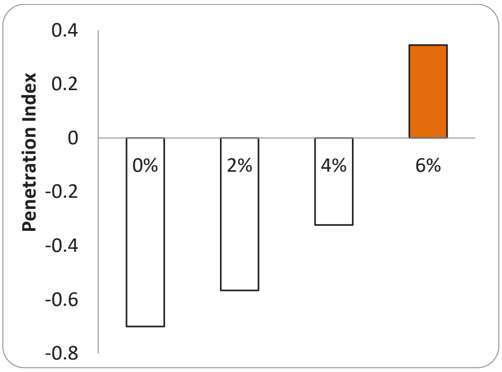

Figure 5: Penetration index and % micro silica.

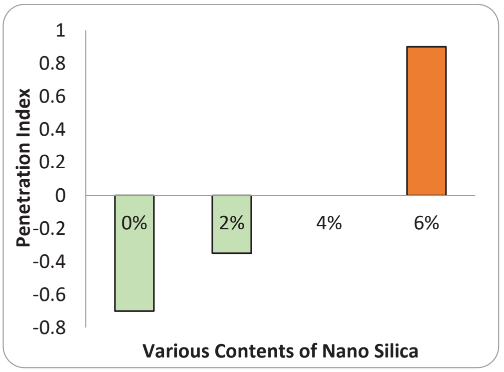

Figure 6: Penetration index and % nano silica.

4.3 Effect of Silica Powder on Ductility

The ductility characteristic shows cohesiveness of asphalt. Furthermore, the test is thought to disclose the modified asphalt binder's homogeneity and flexibility and its resistance to low-temperature fractures. The ductility values versus silica powder content are shown in Figures 7 and 8. By increasing the percentage of silica powder, the ductility value fell. This might be due to reduced light volatiles in the molten state.

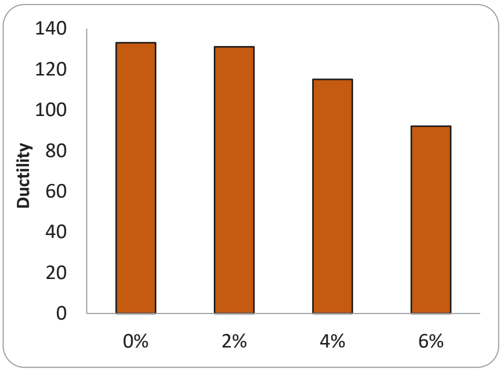

Figure 7: Ductility and % micro silica.

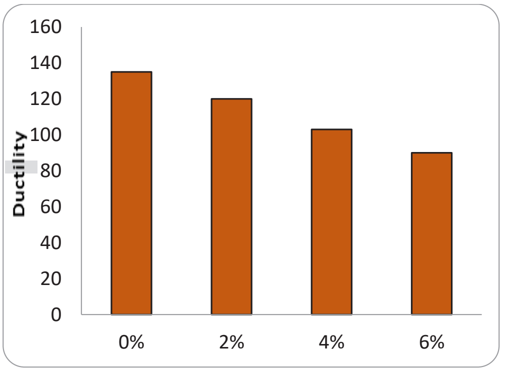

Figure 8: Ductility and % nano silica.

4.4 Effect of Silica Powder on Flash Point

The Flashpoint of the asphalt determines its safety requirements. Figures 9 and 10 demonstrate the relationship between flash point values and silica powder addition percentages. The flashpoint value rose as the silica powder concentration increased. This might be due to the molten phase containing fewer light volatiles, which are combustible compounds. Silica particles also have a high melting point and are non-flammable. Furthermore, because of the enormous surface area of Nano-silica particles, a significant rise in flashpoint temperature is seen within Nano silica modified asphalt.

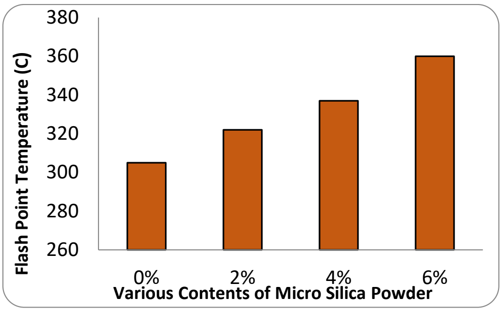

Figure 9: Flashpoint and %micro silica.

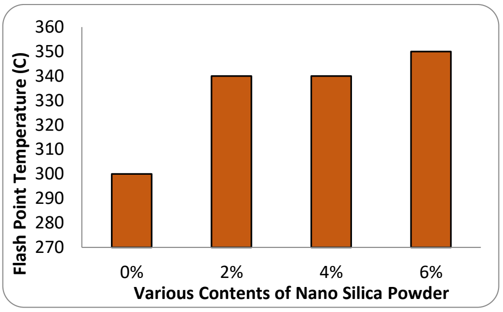

Figure 10: Flashpoint and %nano silica.

4.5 Effect of Silica Powder on Rheological Properties: Rotational Viscosity of Asphalt Binder

Analysis and comparison of the rheological properties of the control and modified asphalt binder with standard requirements, such as viscosity, were conducted. The rotational viscosity test determines the desired workability of asphalt at high temperatures (during mixing and compaction). Original and modified asphalt binders' temperature-dependent viscosities with changing silica powder concentrations. Figures 11 to 14 show the connection between rotational viscosity and silica powder content in the original and modified asphalt binder. With the addition of silica powder, the viscosity increases. The enhanced stiffness of the modified asphalt may have been due to the silica particles' absorption and diffusion into the asphalt binder. Because oily materials may be reduced molten phase by absorbent silica powder and turning it into resin materials during asphalting, and because the hardness of silica particles exceeds asphalt binder [25,28]. It is reasonable to assume that the thicker binder film made from Nano-silica modified asphalt is more durable than the thinner binder film made from micro-silica-modified asphalt since Nano-silica modified asphalt has a substantially higher viscosity [25]. In addition, the viscosity values of modified asphalt decrease with an increase in test temperature, regardless of the mixing technique. Furthermore, it is essential to note that the Iraqi standard [25] specifies the lowest viscosity value for asphalt binders, which is 400 (c.p) at 135 ℃, and that all viscosity results obtained for asphalt binders modified with (silica) are more significant than the value specified by the Iraqi standard.

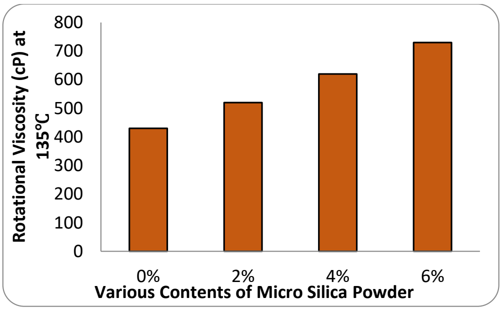

Figure 11: Viscosity value and % micro silica.

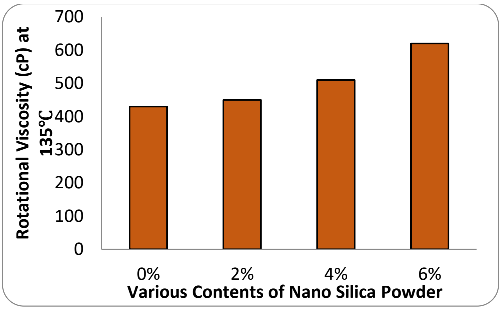

Figure 12: Viscosity value and %nano silica.

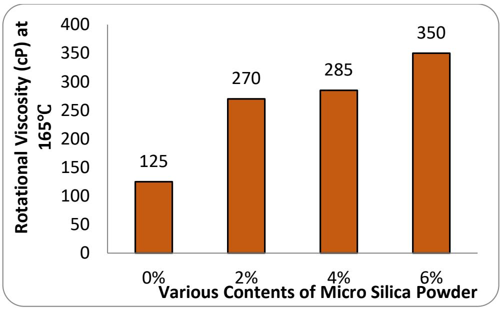

Figure 13: Viscosity value and % micro silica.

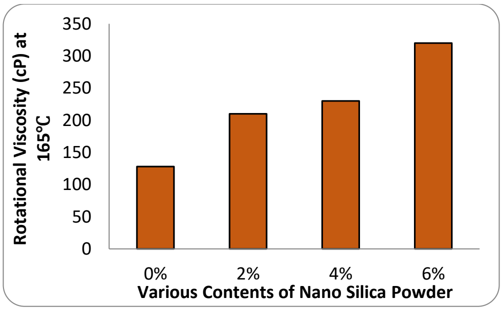

Figure 14: Viscosity value and % nano silica.

4.6 Effect of Silica Powder on Retained Penetration after TFOT

Following a thin film oven test, maintaining the penetration of the asphalt binder is used to determine the short-term aging of the asphalt binder (TFOT). Figures 15 and 16 show the relationship between the maintained penetration percent and the silica powder concentrations. By increasing the amount of micro-silica powder used at a revolution rate of 2000 rpm, the retained penetration percent was lowered. This could be attributed to reducing the light volatile components in the molten phase. The addition of Nano-silica powder, on the other hand, increases the sustained penetration percentage because of its large surface area. Furthermore, the elevation in maintained penetration percent was detected within high shear mixing, which defines homogenous dispersion of Nano silica particles, increasing the aging resistance. The SCRB requirements prohibited the maintained penetration by more than (50%).

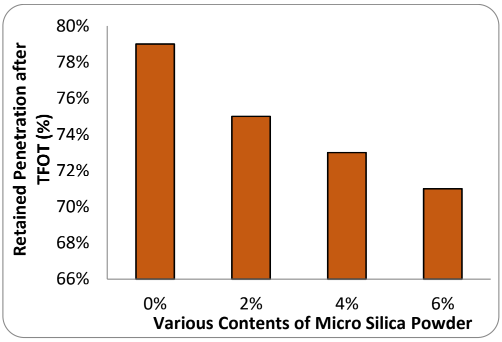

Figure 15: Retained penetration and % micro silica.

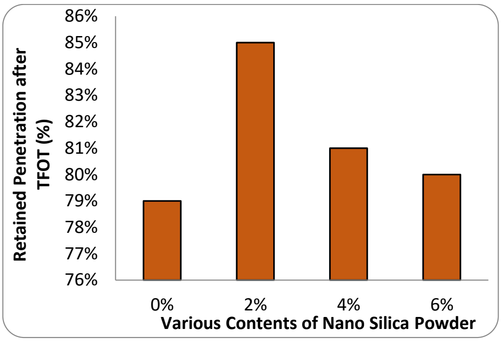

Figure 16: Retained penetration and %nano silica.

4.7 Effect of Silica Powder on Retained Ductility after TFOT

After the thin film oven test, the retained ductility is utilized to evaluate the short-term aging of the asphalt (TFOT). As shown in Figures 17 and 18, silica powder concentration directly affects the maintained ductility percentage. At a revolution rate of 2000 rpm, it is clear that the silica powder addition lowered the retained ductility percent. This might be due to the reduction of oily material in the molten phase. For high shear mixing, however, NS-modified asphalt contains a higher percentage of retained ductility than micro silica, resulting in improved aging resistance. As a result of the SCRB's restrictions, the remaining ductility was reduced by (25 cm) [26].

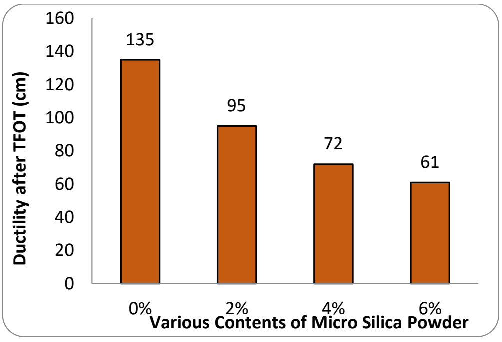

Figure 17: Retained ductility and % micro silica.

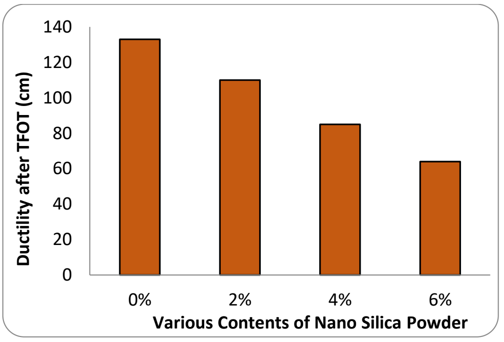

Figure 18: Retained ductility and % nano silica.

5. CONCLUSIONS

The following conclusions can be derived and stated below based on the data gained in this investigation with material limitations:

- Employing micro and Nano-silica powder reduced penetration while raising the softening point temperature. When compared to the control asphalt binder, all types of modified asphalt binder improved penetration and softening point temperature of 6% silica powder concentration.
- Adding silica to modified asphalt improves temperature susceptibility (P.I.) values. However, compared to the other types of asphalt binder, the modified asphalt binder with a 6% NS powder concentration had a greater penetration index (PI). Adding silica reduces ductility of modified asphalt. The mechanical mixing of asphalt treated with 6% MS powder results in a significant loss in ductility.

- It was found that the addition of 4 % of Nano and micro silica by weight of asphalt was adequate to improve the physical features of the modified asphalt binder when compared to the standard asphalt with greater PI value, a lower penetration value, a higher softening point temperature, and a ductility value within the permitted range.
- Adding silica to the modified asphalt increases its rotational viscosity regardless of the mixing procedure. The viscosity value of NS-modified asphalt increased significantly.
- According to the results of the modified asphalt binder's rheological properties, 4% micro and Nano-silica concentration were suitable for developing rheological features and rutting performance.

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