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Evaluating The Effects of Micro and Nano Size of Silica Filler on Asphalt Cement Properties

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K E Y W O R D S

Micro Silica, Nano Silica, Asphalt Binder, Modification Method.

A B S T R A C T

This research study examines the practicability of using micro and nano size silica to improve the asphalt characteristics. Asphalt cement penetration grade of (60 /70) was prepared using (0%, 2%, 4% and 6%) of silica filler by weight of asphalt and investigated in terms of the softening point, penetration, and penetration index, viscosity, and ductility values. To modify the asphalt binder, the silica powder was mixed by a mechanical blender set at (2000) rpm at a mixing temperature of 140°C. However, the main challenge is an agglomeration of nano-silica powder which can reduce the ductility of nano silica modified binder. Therefore, this paper studies the efficiency of mixing period to obtain a homogeneous composite binder while alleviating the agglomeration issue. To do so, the effect of periods of mixing ranged between (30 to 60) minutes were examined on characteristics of modified asphalt binders. Overall, the addition of silica filler has an encouraging impact on the asphalt binder rheological properties. Also, the ductility value decreases with the addition of nano-silica content, attributed to the huge surface area and degree of agglomeration. Furthermore, results exhibited that 6% of micro silica powder and 4 % of nano silica powder were reasonable to develop the rheological properties.

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1. INTRODUCTION

Asphalt cement is usually recognized as a common binding material used for constructing the road pavements material due to its exclusive viscos-elastic properties [1, 2]. However, in the past few years, higher traffic load universally together with the difference of climate circumstances led to the rapid failure of pavement materials. To control these impacts, the materials of highway pavements demand binder materials with greater performance than control asphalt binder currently used. Subsequently, now the flexible pavement construction requirement for modified asphalt [3].

In the modification technique of binder, numerous materials have been used for modifying the control asphalt and to enhance asphalt binder performance such as the styrene-butadiene-styrene [4–6], lime [7, 8], rubber [9], and waste powders [10].

Micro Silica is a fine amorphous silica powder which is produced by electrical arc ovens such as by products from the fabrication of silicon element. Micro silica has a large content of amorphous silicon oxide and the silica is spherical particles, the diameter usually is close to 0.2 µm [11].

The nano-silica is one of the nano-materials, with an inner structure having one lengths of the order of (100) nm. or less, and can display innovative characteristics compared with similar material with micro size features [12]. Moreover, it has been presented to be effective in improving the asphalt performance. Silica powder is a chief universal compound used in manufacturing fumed silica, silica gels and colloidal silica [13]. Silica powder has been used to strengthen polymer in the manufacturing [14] of Portland cement concrete [15]. The benefits of nano silica are its low manufacturing cost and its great properties performance [16]. Nano-silica has numerous features such a good stability, good dispersal ability, huge specific surface area, high chemical purity, and strong adsorption [17]. Using nano silica powder at (2-4) % of asphalt cement weight has been obtainable to reduce the depth of rut by approximately half [17 &18].

This research study aims to evaluate the impact of micro and nano of silica filler on the asphalt characteristics such as; softening point, penetration, penetration index, viscosity, and ductility by using three percentages range of (2 %, 4%, and 6%) of silica. Also, to assess the efficiency of the mixing period on the diffusion of micro and nano silica filler in asphalt.

2. RESEARCH METHODOLOGY

I. Materials properties

Control asphalt cement has a penetration grade of 60/70 supplied by the Durah refinery in Iraq. Features of used control asphalt are shown in Table (1).

TABLE I: Physical tests of used control asphalt.

Property	ASTM	Result	Specification Limits [24]
Penetration value 100 gm, 25°C, 5 sec., (0.1mm)	D-5[19]	66	60-70
Ductility value	D-113 [20]	130	>100
Flashpoint	D-92 [21]	Flashpoint 302 °C	> 232 °C
Fire point		Fire point 313°C	-----
Dynamic Rotational Viscosity (cP)	D-4402 [22]	430@135 °C 128@ 165 °C	-----
Penetration index	-----	-0.665	-----
Softening point temperature	D--36 [23]	49.5	-----

There are two types of particle size as micro and nano silica powder. Micro silica (mS) powder is grey color and a synthetic amorphous silica, obtained from the local market which been used throughout this study as shown in Figure 1. Chemical examination of the micro silica are in Table (2), and Table (3), showing physical properties which conform to the requirements of specifications [25].

TABLE II: Chemical compositions of used micro silica (mS) filler.

Oxides	content, %	Limits of specification[25]
Al2O3	0.71	<1%
SiO2	91.51	> 85%
Fe2O3	0.44	< 2.5%
K2O + Na20	1.38	<3%
L.O. I.	4.38	Max. 6%
SO3	0.95	<1%
CaO	0.89	<1%

TABLE III: Physical features of used micro silica (mS) filler.

Feature	Results	Limits of specification [25]
Specific surface area,	17	≥ 15 m2/g
Size	0.15	~0.15 µm
Specific gravity, kg/m³	2.21	---
Color	Grey	---
Moisture	---	< 2%

Nano silica (nS) filler is a white powder, a synthetic amorphous silica imported from AEROSIL Company at North America and presented in Figure (1). Characteristics of physical & chemical analysis are shown in Table (4) and Table (5).

TABLE IV:Physical Properties of Nano SiO_2 (nS) filler.

Property	Result
Size	11- 12nm.
Specific surface area, m2/g	200
Physical form	Powder
Density (gr/cm3)	0.1<
Color	White

TABLE V: Chemical Analysis of Nano SiO2 filler.

Property		Result
PH	---	3.7-4.5
SiO_2	wt.%	99.8

Figure 1: Nano and micro size of silica fillers.

3. Modification Methods of Asphalt Cement by Micro Silica (mS) and Nano Silica (nS)

The conventional mechanical blender was used to mix the control asphalt with nano and micro silica particles. The blender can be fixed at 2000 rpm, for various mixing period ranged between (30 to 60) minutes at a temperature of 140 °C and the capacity of the blender is 1.5 L [29&30], as shown in Figure (2). After heating the asphalt binder and transforms too sufficiently fluid, gradually addition of nano and micro silica powder to the asphalt binder by weight at contents of (2%, 4% and 6%) to attain a homogeneous composite binder. Then, tested to evaluate the features of the asphalts modified with silica.

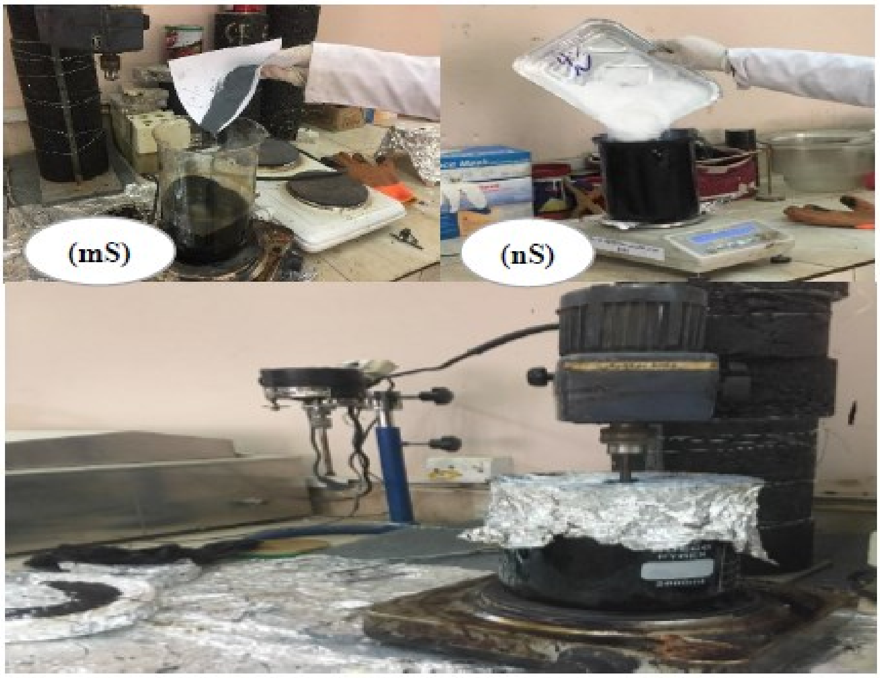

Figure 2: Method of modification of used asphalt by micro silica (mS) and nano silica (nS) at University Of Technology.

4. Laboratory Examinations of Modified Asphalt with Silica Fillers

To assess the impact of particle size of silica fillers on the asphalt cement physical tests; including softening point, penetration grade, penetration index, ductility, and viscosity were carried out on control asphalt and asphalt modified by various contents of silica fillers. All tests were attained based on the standard specifications. Although penetration is an empirical test, it is still used to estimate the asphalt stiffness, and softening point value that represents the flow of asphalt. Currently, the dynamic viscosity is usually used to assess the asphalt viscosity. Also, the susceptibility of temperature (Penetration index) for asphalt cement can be an estimate according to the relationship between penetration and softening point results (SP./pene.) [26].

5. Results and Discussions

The greatest significant test that was used to assess the rheological features of asphalt are penetration grades and softening point tests carried out on control and modified asphalts by several contents of silica powder. Figures (4 and 5) shows the results of penetration grade and softening point for control and modified asphalts at mixing period of 30 min. It can be observed that the values of penetration for the modified asphalts is reduced while the softening point increased by the addition of the silica content, due to the improvement of hardness of modified asphalt by distribution of silica powder in asphalt.

Also, indications to reduce oil materials in maltene level by absorption of silica particles and alter to the resin in asphaltene level of modified asphalts, as agreed with references [27&28]. Further, the larger decrease in penetration value and increase in softening point temperature noticed within nano silica modified asphalt indicates that nano silica powder addition makes the binder to be more consistent and firmer than the micro silica modified asphalt binder. Also, from Figures (6&7), it can be observed that the longer mixing period of modified asphalts enhancement of the rheological characteristics until 60 minute for all the tested specimens of modified asphalt, and based on ductility test .

Figures (8& 9) shows PI values against silica powder content. It can be noticed that the PI value of modified asphalts with micro silica was reduced by addition of the micro silica percent. While the PI values of modified asphalts with nano silica is decreased in an incompatible trend. References show that PI values ranging from (-3), represent very susceptible temperature to (+7), represent little susceptible temperature in asphalt binder [26]. However, the addition of silica powder have been the incompatible influence on temperature susceptibility of modified asphalts. Nevertheless, the PI values are still in the standard specifications range of (-2.0 to +2.0) which can be used for the construction of highway pavements [26].

Figure (10) displays the ductility values in contrast to silica powder percent. It can be noted that the ductility values of modified asphalts is reduced with the addition of the silica powder percent. This phenomenon could be endorsed to the reduction of the light volatile materials in the maltene level as well as the hardness of silica powder higher than the hardness of the asphalt, in agreement with references [27&28]. Also, a huge decrease in the ductility value observed within nano silica modified asphalt indicates that nano silica powder addition makes the binder to be firmer than the micro silica modified asphalt binder, and agglomeration phenomenon of nano silica into modified asphalt as presented in Figure 3. Also, from the Figure (11), it can be observed that the longer mixing period of the modified asphalts reduction of the ductility values for all the tested specimens, these results are recognized to decrease the homogeneity of modified asphalt and cumulative agglomeration of silica powder [28,29&30].

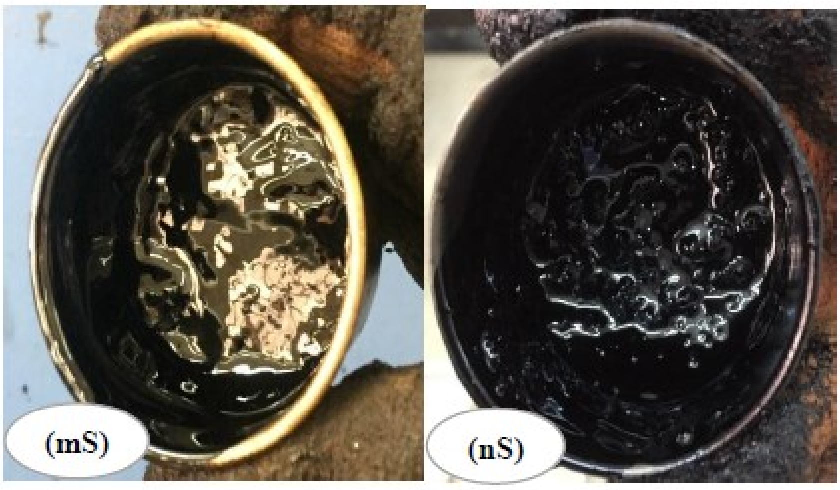

Figure 3: The degree of agglomeration of modified asphalt binders.

Figures (12&13) show the dynamic rotational viscosity values versus silica powder content at a temperature of 135°C. As can be observed, the addition of silica content increases the viscosity of the modified asphalt binders, due to increase of the modified asphalt stiffness and increase of dispersion of silica powder in modified asphalts. Also, a great increase in viscosity value detected within nano silica modified asphalts indicates that nano silica powder has a huge surface area by distribution into modified asphalt binders [31, 32 &33].

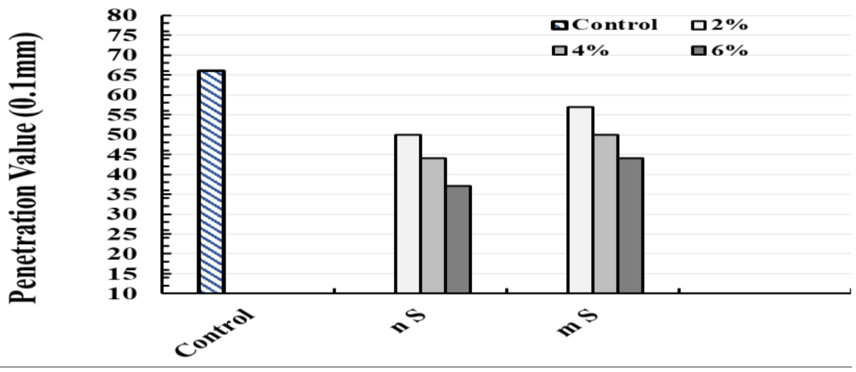

Figure 4: Penetration values for control and modified asphalts with silica fillers at mixing period of 30 minutes

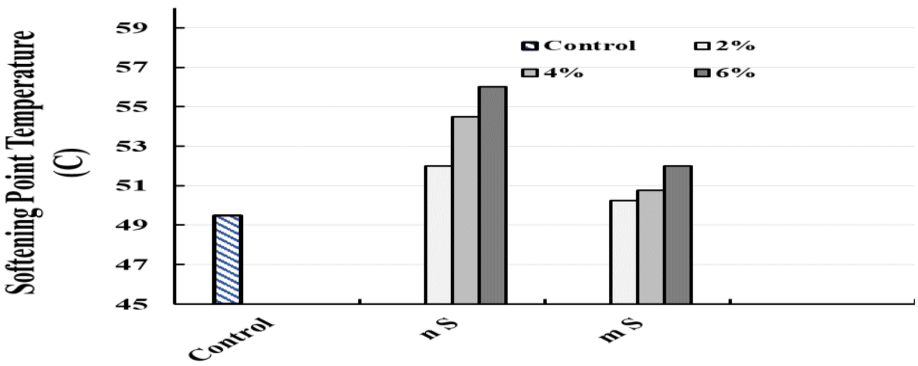

Figure 5: Softening point values for control and modified asphalts with silica fillers at mixing period of 30 minutes

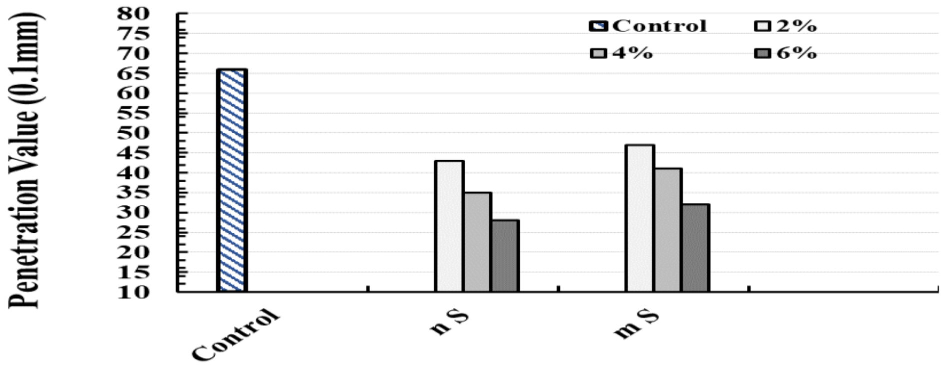

Figure 6: Penetration values for control and modified asphalts with silica fillers at mixing period of 60 minutes

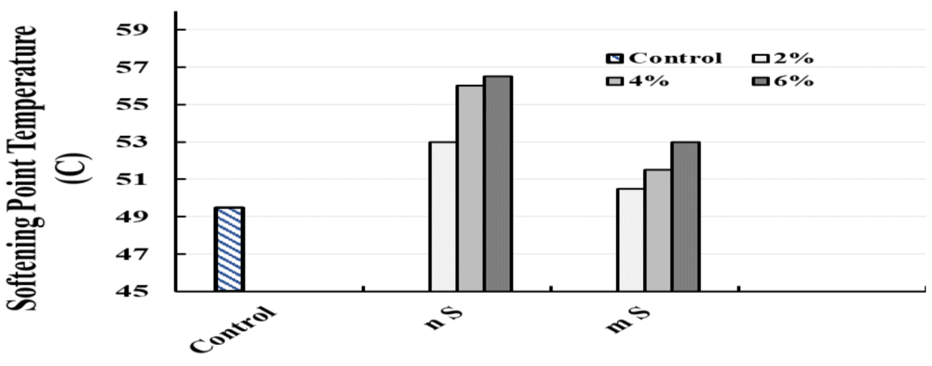

Figure 7: Softening point values for control and modified asphalts with silica fillers at mixing period of 60 minutes

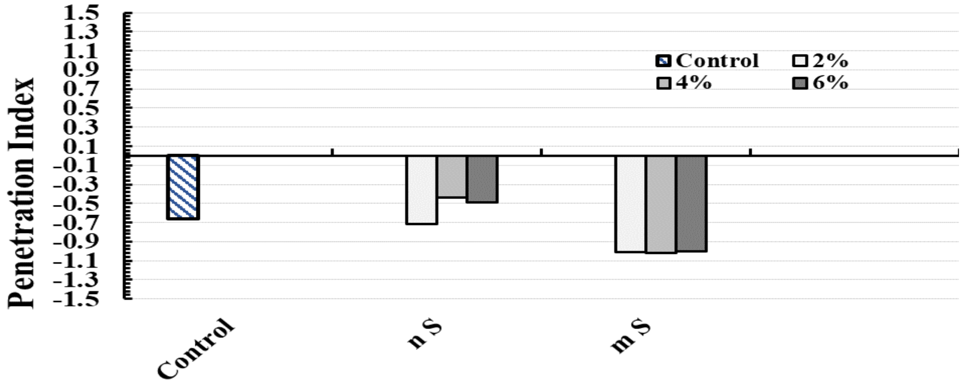

Figure 8: Penetration Index values values for control and modified asphalts with silica fillers at mixing period of 30 minutes

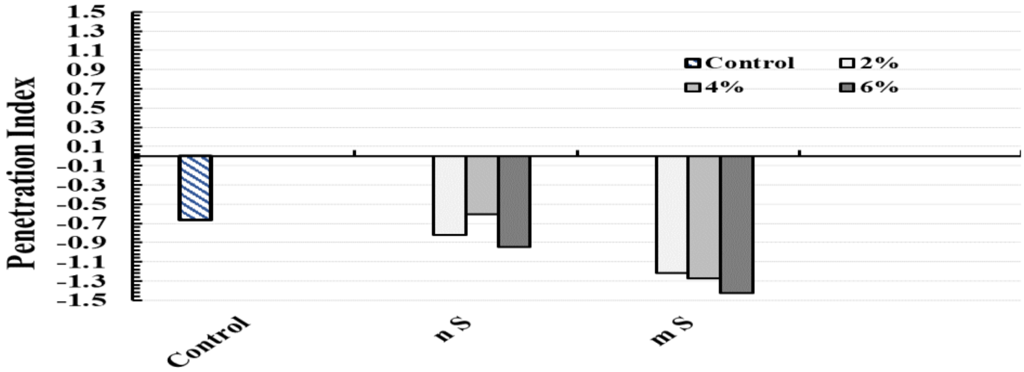

Figure 9: Penetration Index values values for control and modified asphalts with silica fillers at mixing period of 60 minutes

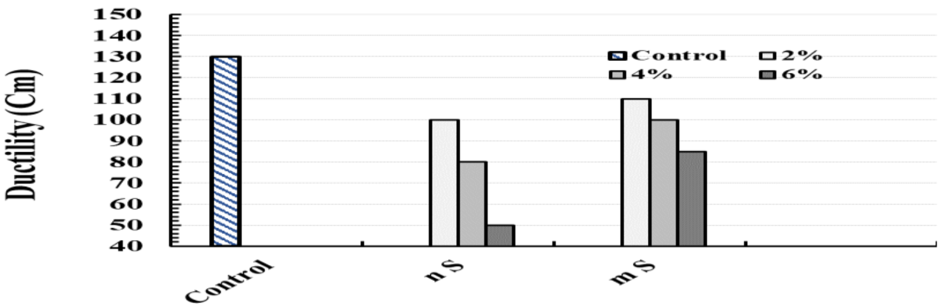

Figure 10: Ductility values for control and modified asphalts with silica fillers at mixing period of 30 minutes

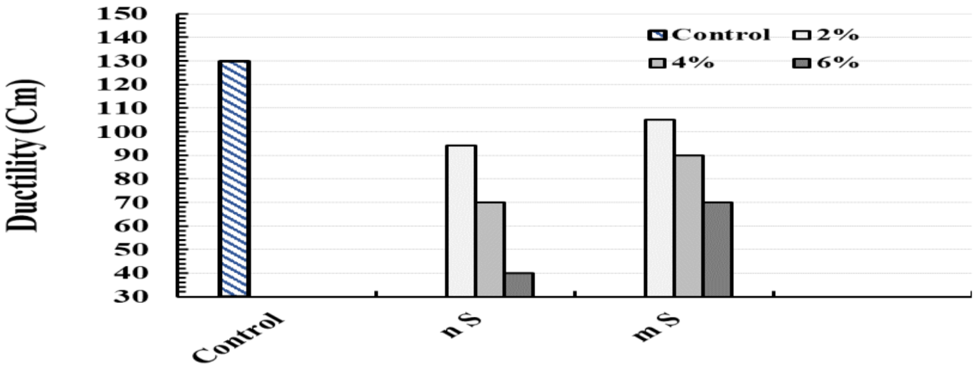

Figure 11: Ductility values for control and modified asphalts with silica fillers at mixing period of 60 minutes

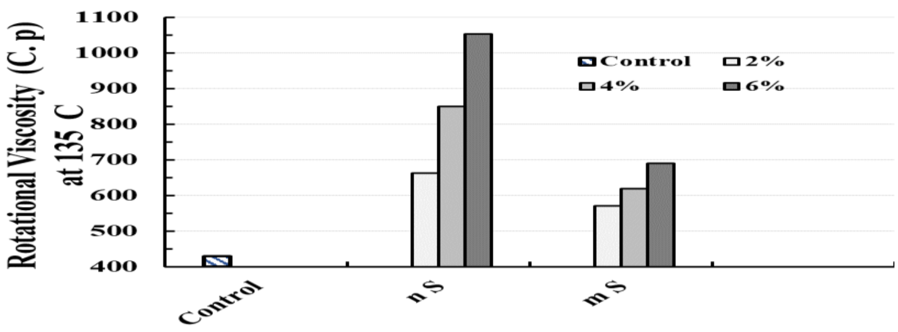

Figure 12: Viscosity values for control and modified asphalts with silica fillers at mixing period of 30 minutes

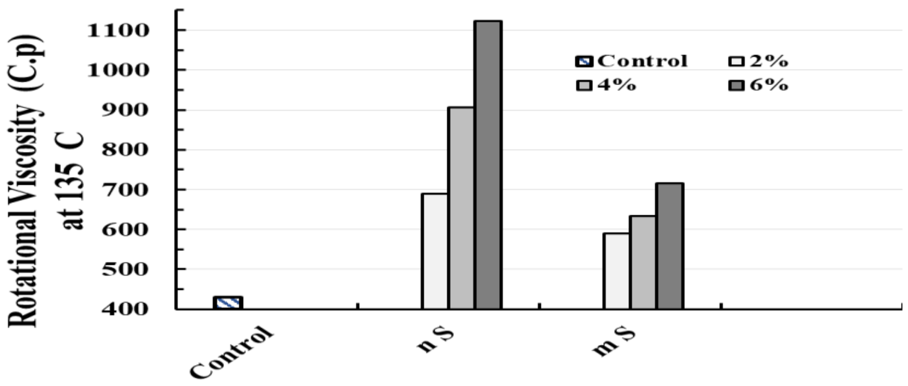

Figure 13: Viscosity values for control and modified asphalts with silica fillers at mixing period of 60 minutes

6. Conclusions

The significant objective of this experimental work is to exhibit the physical characteristics of the modified asphalt binder. According to the results of this experimental work, these conclusions have been drawn:

1) Penetration of modified asphalt decreased, whilst increasing the softening point by increasing the silica powder percent.
2) Temperature susceptibility (penetration index) of modified asphalts reduces with the addition of the silica content, specifies that the silica has been undesirably effecting on susceptibility of temperature. Nevertheless, the PI was within the limitations of the standard specifications (-2 to +2) which can be used for the construction of highway pavements.
3) It has been observed that the addition of silica content increases the viscosity of the modified asphalt binder. Therefore, a great increase in viscosity was detected within nano silica modified asphalt indicating that nano silica powder has a huge surface area by dispersion in modified asphalt binder.
4) The ductility property of the modified asphalt binder is decreased with the increasing of the silica powder content. Moreover, the large decrease in ductility value seen within nano silica modified asphalt indicates that added nano silica powder makes the binder to be stiffer than the modified asphalt with micro silica powder. Besides the agglomeration phenomenon of nano silica particles into modified asphalt binder.
5) Mechanical blender set at (2000) rpm, for period of mixing reached (30) min. at a temperature of 140°C was sufficient to achieve a reasonable distribution of silica powders for all the tested specimens of modified asphalt, and based on ductility test.
6) According to the characteristics of modified asphalt binders (lower penetration value, higher softening point temperature, and viscosity), the 6% of micro silica (mS) and 4 % of nano silica (nS) by asphalt weight were reasonable to develop these physical characteristics.

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