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Research paper

Influence of Micro- Size Silica Powder on Physical and Rheological Characteristics of Asphalt Binder

[1]Hussein H. Zghair* **[1]Hasan H. Joni,** **[1] Maan S. Hassan**

[1] Civil Engineering Department, University of Technology, 10066, Baghdad, Iraq.
**E-mail address: 11539@uotechnology.edu.iq*

Abstract

During the last years, the use of by-product materials, such as micro silica, mS, especially in the area of highway pavement materials has received increasing interest. The experimental work of this research focused on the investigation of the potential use of micro silica powder to enhance the rheological properties of asphalt cement binder. To achieve this aim, mixtures with various contents of micro silica and asphalt were prepared. The asphalt cement and micro silica were first tested. The micro silica powder has been mixed with the asphalt cement at a temperature of 140 °C by conventional mechanical mixer at 2000 rpm. Two mixing time durations were implemented to produce the modified asphalt mixtures: 30 and 60 minutes. The mS modified asphalt was then evaluated for the empirical physical and rheological properties including penetration value, softening point temperature, temperature susceptibility, Brookfield Rotational viscosity and ductility. The experimental work results showed that micro silica powder reduces penetration value and increases softening point temperature. Progressive increases in mS content were found to increase Brookfield Rotational Viscosity (RV) and tend to decrease the ductility of the studied specimens. The negative effects of added mS were more pronounced at values more than 4%. Finally, the increase in mixing time duration may slightly lead to good micro silica powder dispersion into the asphalt matrix, but it is the consumption of energy and cost.

Keyword: *Asphalt binder properties, micro silica, modification process*

1. Introduction

Asphalt cement is a complex chemical composition, often it shows both viscous and elastic behaviors which largely based on temperature and loading time **[1, 2]**. Asphalt cement is generally known as common binder material used to the construction of flexible pavements, because of its unique viscoelastic characteristics **[3, 4]**. However, higher traffic loads globally together with the variation of weather conditions leads to quick deterioration of highway pavement materials. To control these effects, pavement of highway request binder material with higher performance than normal grade asphalt cement. Consequently, nowadays the construction of flexible pavements needs for modified asphalt cement **[5]**.

In the process of asphalt cement modification, different materials have been used for modifying the base asphalt cement and to improve the mechanical performance of asphalt binder material and mixtures. These materials include the styrene-butadiene-styrene (SBS) **[6–9]**, lime **[10, 11]**, crumb rubber **[12]** and electronic waste powders **[13-14]**.

Micro Silica is ultra-fine non-crystalline silica which produced in electrical arc ovens as a waste material from the production of silicon elements. The silica fume has the high content of non-crystalline silicon oxides. The shape of micro silica is round particles, diameter typically closed to 0.1 to 0.2 µm [**15-17**].

Micro silica was added to the control asphalt binder PG 64-22 at different contents to increase viscosity values and reduce the oxidation rate of asphalt binder can be obtained by addition of micro silica to the control asphalt binder **[18].**

The object of this research is to investigate the impact of micro silica particles on the empirical physical and rheological properties of asphalt cement binder including penetration value, softening point temperature, temperature sensitivity (penetration index), Brookfield rotational viscosity and ductility value by three various percentages (2%, 4% and 6%) of micro silica powder. As well, studying the impact of mixing time duration on the distribution of micro silica powder in asphalt cement binder, it was also conducted to evaluate the mS modified asphalt binder properties.

2. Research methodology and experimental program

2.1 Material used

2.1.1Asphalt cement

This research has used asphalt cement 60/70 penetration type Brought from the Dora refinery at the middle region of Iraq. Table 1 shows rheological properties of asphalt cement binder**.**

2.1.2 Micro silica powder

Micro silica is a non-crystalline of silicon oxide. Chemical analysis of micro silica used is tabulated in Table 2, whereas the physical features are shown in Table 3. Results showed the micro silica powder conforms to requirements of **ASTM C 1240 [15]**.

Table 1: Physical characteristics of asphalt cement used in this work

Test	Test Conditions	Standard	Results	Standard Limits of Iraqi Specification (SCRB/ R9, 2003)[24]
Penetration	(0.1mm)	ASTM D5[19]	66	60-70
Ductility	cm	ASTM D113 [20]	130	>100
Flash point Fire point	…..	ASTM D92 [21]	Flash 302°C	> 232 °C
			Fire 310°C	---
Thin – film oven test	163 °C, 50gm, 5 hr.	0.222<1 Mass loss	Pen. 89.9	>52
			Duc. 120	>50
Rotational Viscosity	Pa. sec	ASTM D4402 [22]	@ 135 °C 430 @ 165 °C 128	---
Softening point	…..	ASTM D36 [23]	49.5	----
Penetration index	…..	ASTM D36 [23]	-0.665	---

Table 2: Chemical Analysis of Micro Silica Compostions*

Oxide Composition	Oxide content %	ASTM C1240-15
SiO2	91.51	Min. 85%
Fe2O3	0.44	< 2.5%
Al_2O_3	0.71	<1%
SO_3	0.95	<1%
$K_2O + Na_20$	1.38	<3%
CaO	0.90	<1%
L.O. I	4.39	Max. 6%

Table 3: Physical Characteristics of Micro Silica Particles *

Property	Result	ASTM C1240-15
Size	0.15	~0.15 µm
Color	Grey	_
Specific surface area,	17000	≥ 15000 cm^2/g
Specific gravity, kg/m³	2.2	_
Physical form	Powder	_
Bulk Density	0.6	0.5±0.1kg/liter
Moisture	0%	< 2%

* Chemical and physical analysis were conducted according to manufacture and National Center for Construction Laboratories and Researches.

2.2 Modification process

Micro silica (mS) modified asphalt specimens were prepared by heating the asphalt cement at 140 °C, based on the viscosity of base asphalt binder. At 140 °C asphalt cement sufficiently turns into a liquid. Then, micro silica powder a weighted 2%, 4% and 6 %(low, medium and high percent) gradually added to asphalt cement weight. The mS modified asphalt binder was mixed using a desktop conventional mechanical mixer at the rate of 2000 rpm to obtain a homogeneous composite material and reduce the agglomeration, for different mixing time ranged (from 30 to 60) minutes as shown in the plate 1.

Plate 1: Process of mixing of micro silica with asphalt cement under control temperature by using the electronic oven.

2.3 Experimental Tests

This study was focused on the determination the optimum content of micro silica powder by physical and rheological properties (penetration value, softening point temperature, temperature sensitivity (PI), ductility value and rotational viscosity) for original and mS modified asphalt. Tests were achieved according to the standard specifications such as ASTM-D5, ASTM-D36, ASTM D4402 and ASTM-D113 respectively.

3. Results and discussion

The most important tests that are used to determine the physical and rheological characteristics of asphalt binder are the penetration value and the softening point temperature, they are conducted to original and mS modified asphalt binder. Figures 1&3, present the results of penetration value and softening point temperature for original and mS modified asphalt binder. From these figures, it can be seen that the penetration value of mS modified asphalt binder is decreased with increasing of softening point to adding the micro silica particles. Attributed to increase the hardness at moderate temperatures by diffusion and adsorption of micro silica powder in asphalt cement leads to absorption of oily material in the maltene phase and transform to the resin in the asphaltene phase of asphalt cement. Also, the micro silica particles are stiff and more than asphalt binder's stiffness **[25].** Micro silica powder had a significant effect on the rheological characteristics of asphalt binder based on the obtained results. As can be seen in Figures 2&4**,** increasing of mixing time duration of modified asphalt improves the rheological properties of asphalt cement until 60 minutes, but elongated mixing time may slightly lead to a good distribution of micro silica and it is more energy consumption and less economical cost.

The asphalt binder behavior to different temperature can be predicted in the application of pavement based on penetration index and it is a quantitative measure **[26]**. PI values were calculated from the relationship between penetrations value and softening point temperatures. Figure(5)**,** presented PI values versus micro silica content, as seen that the PI values of mS modified asphalt binder decrease with increasing of the micro silica content. This indicates that the micro silica powder has been adversely affecting on temperature susceptibility of the mS modified asphalt binder. But all values of PI were within the range of the standard specifications (-2 to +2) and can be used to the construction of pavements **[26]**.

Figure 6, shows ductility value of mS modified asphalt binder was reduced by increasing micro silica powder content, due to reduce the oily materials (absorption of the light volatiles) in maltene phase and lead to increase the stiffness of mS modified asphalt binder. Also, the longer mixing time leads to decrease ductility of mS modified asphalt as shown in Figure 7, the result is attributed to decrease the homogeneity and increases the stiffness of mS modified asphalt resulting from micro-silica modification **[27].**

The desired workability of asphalt binder at high temperatures (during mixing and compaction) are determined by Brookfield rotational viscosity test. Figures 8 to11, presented the viscosity values for the original and mS-modified asphalt binder at a temperature range of 135–165ºC**.** From these figures, it can be seen that the added mS content increases the viscosity of asphalt binder. Attributed to increase surface area and reactivity by diffusion and adsorption of micro silica powder in asphalt binder **[28]**. The high viscosity of asphalt binder is suitable for paving and maintenance of road pavement which bearing heavy traffic load. Superpave specification obligates that used asphalt binder viscosity must not be more than 3000 mPa s. However, all the modified binders conform to this requirement.

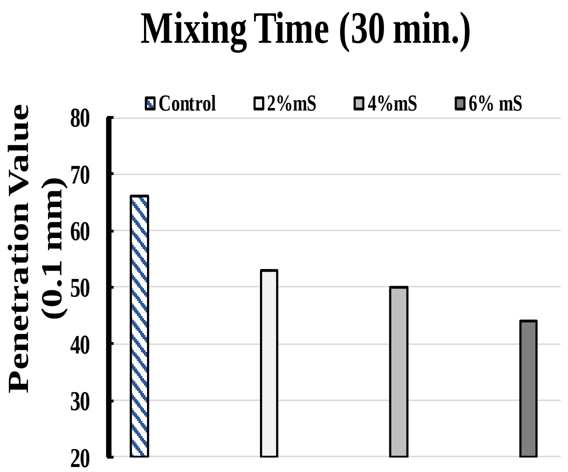

Fig. 1: Penetration Value of Original Asphalt and mS-Modified asphalt at Mixing Time 30 Minute.

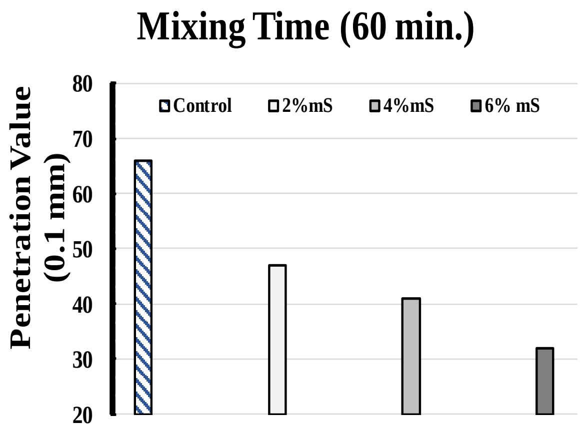

Fig. 2: Penetration Value of Original Asphalt and mS-Modified asphalt at Mixing Time 60 Minute.

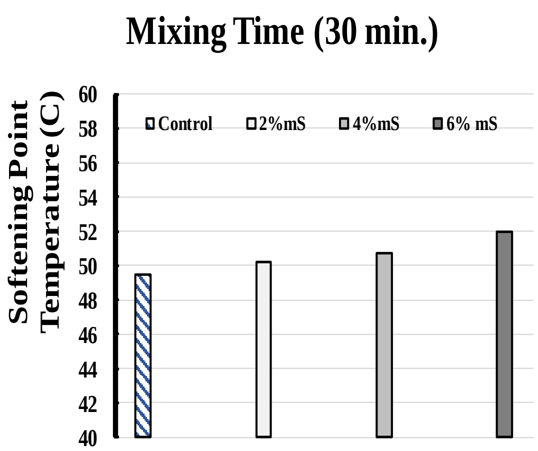

Fig.3: Softening Point of Original Asphalt and mS-Modified asphalt at Mixing Time 30 Minute.

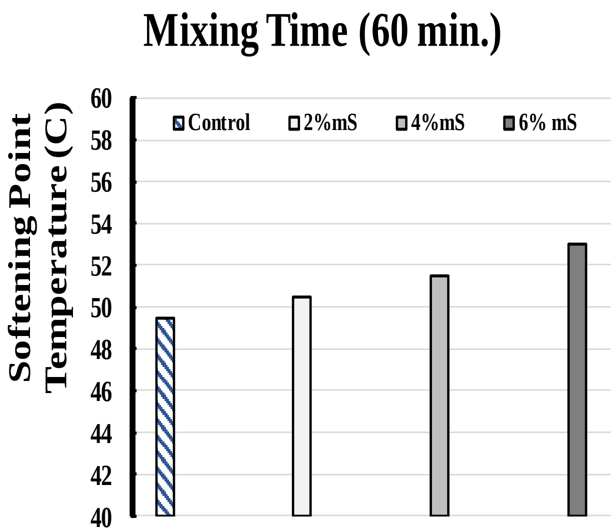

Fig.4: Softening Point of Original Asphalt and mS-Modified asphalt at Mixing Time 60 Minute.

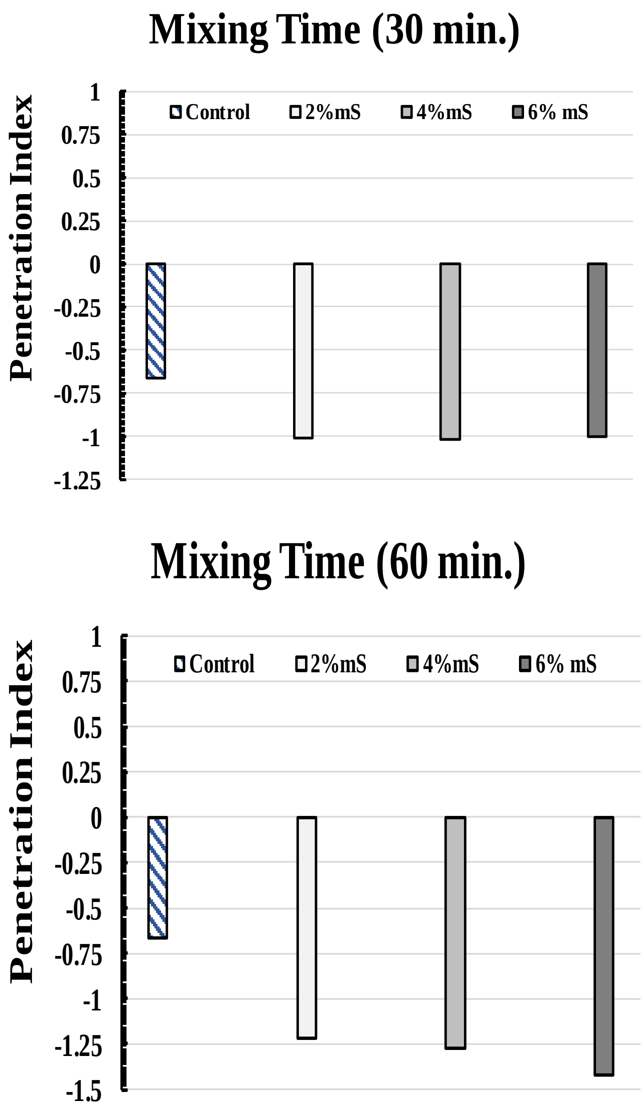

Fig.5: Penetration Index of Original Asphalt and mS-Modified asphalt at Mixing Time 30 & 60 minutes.

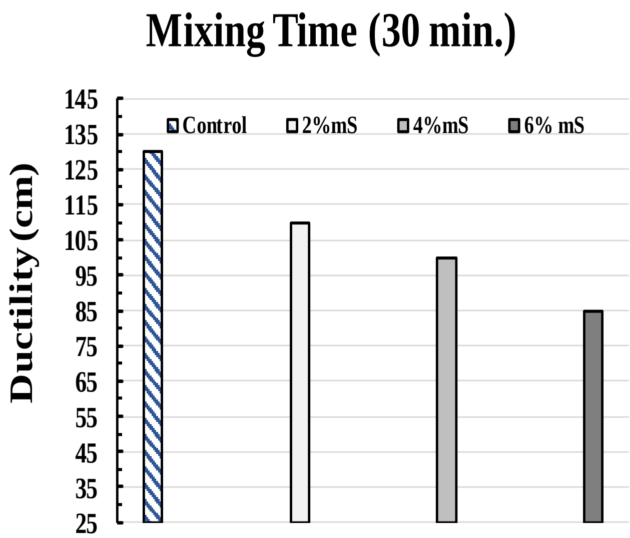

Fig.6: Ductility of Original Asphalt and mS-Modified asphalt at Mixing Time 30 minute.

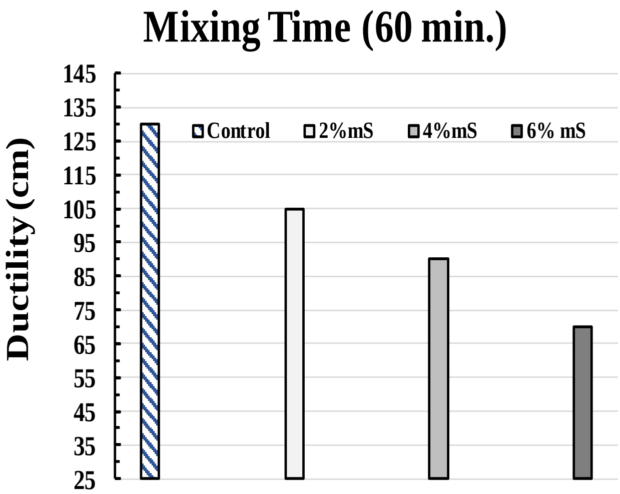

Fig.7: Ductility of Original Asphalt and mS-Modified asphalt at Mixing Time 60 minute.

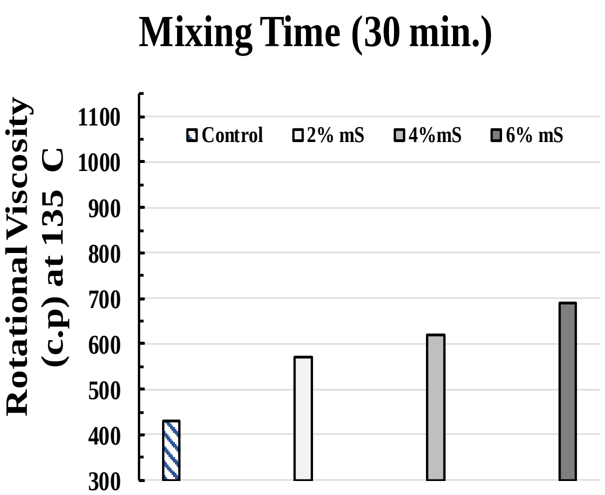

Fig.8: A viscosity of Original Asphalt and mS-Modified asphalt at Mixing Time 30 minute.

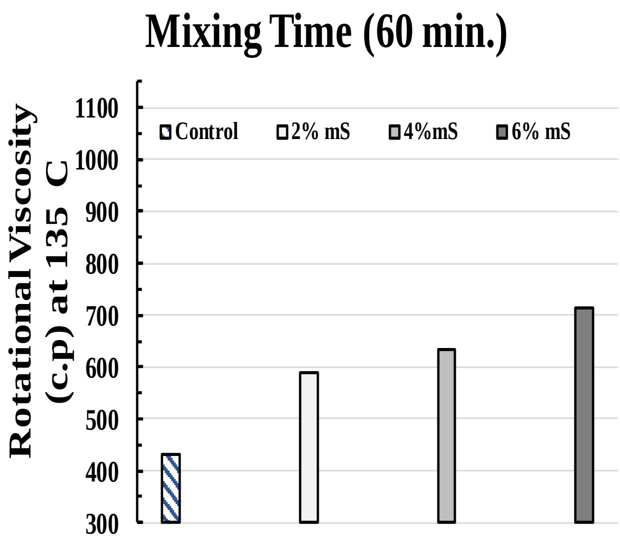

Fig.9: A viscosity of Original Asphalt and mS-Modified asphalt at Mixing Time 60 minute.

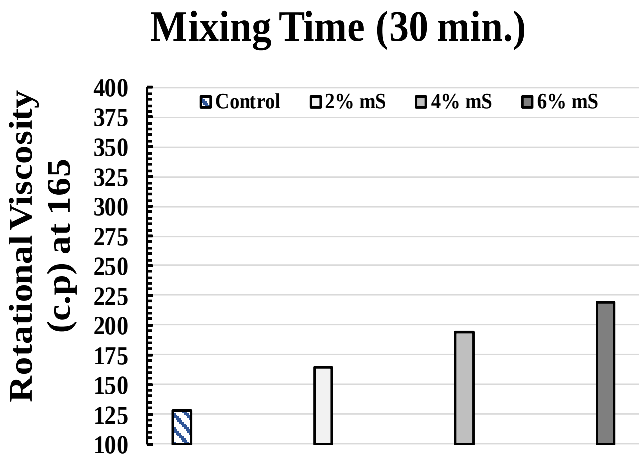

Fig.10: A viscosity of Original Asphalt and mS-Modified asphalt at Mixing Time 30 minute.

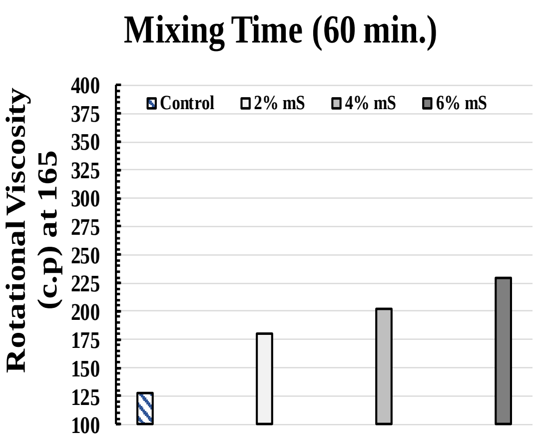

Fig.11: A viscosity of Original Asphalt and mS-Modified asphalt at Mixing Time 60 minute.

4. Conclusions

The main object of this work was to describe the physical and rheological properties of mS modified asphalt cement. Using modifier as micro silica powder had the positive effect on the physical and rheological characteristics of asphalt cement. Based on experimental work results were conducted on the asphalt cement with various micro silica percentages, the results were analyzed and compared with standard specification. The following point can be concluded:

1. mS modified asphalt increased the softening point temperature, whilst penetration value decreased by increasing the micro silica content, due to a stiffness of the micro silica particles are stiffer than the asphalt binder.
2. Viscosity values of mS modified asphalt binder increase with the added micro silica content and all viscosity values were within the standard specifications.
3. Temperature susceptibility (PI) of mS modified asphalt binder was reduced by increasing the content of micro silica, indicating that the micro silica has adversely effect on the temperature susceptibility of the mS modified asphalt binder. But all values of PI were within the range of the specifications (-2 to +2) and can be used in the pavements construction.
4. When using the conventional mechanical mixer at 2000 rpm for mixing time about (60) minutes may slightly lead to a good distribution of micro silica powder in the asphalt matrix, but it is energy-consuming and economically inefficient.
5. A 6% micro silica by asphalt weight enhanced the rheological properties of the mS modified asphalt cement. The mS modified asphalt cement became more proper for construction of pavements in hot weather conditions. This indicates that the lower penetration value, the higher softening point temperature, and viscosity.
6. The adverse effects of added mS were more pronounce at values more than 4% on the asphalt binder characteristics such as ductility, attribution to decrease the homogeneity and increase the stiffness of the mS modified asphalt cement.

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