Evaluation of the Effect of Mixing Conditions of Micro-Silica Modified Asphalt Binder

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Abstract. The aim of this study was to improve an effective approach to the processing of asphalt binder modified with micro-silica particles. Various mixer type (mechanical and high shear), revaluation rates (2000, 4000 and 6000 rpm), and two mixing time (30 and 60 minutes), were adopted. Three micro-silica contents 2%, 4%, and 6% by weight of asphalt cement were added. The asphalt binder was prepared at temperature of 140 °C. Comparisons were made to evaluate the properties of the modified asphalt binder such as penetration grade, softening point temperature, temperature sensitivity, rotational viscosity and ductility. Results of this study showed that the use of micro silica as a modifier was helpful in enhancing the physical properties of the asphalt binder. In general, it was found that the penetration value decreased and softening point temperature, as well as the viscosity value, increased and the temperature sensitivity was improved. Furthermore, high shear mixing was more practical particularly to achieve a good dispersion of micro silica particles into asphalt binder and obtained a homogenous composite binder. Finally, the tested specimens showed 6% of micro silica was adequate to improve the physical properties of asphalt and become more suitable for constructing the highway pavements in hot weather conditions.

1. Introduction

For a long time, asphalt cement is a normally binder material used for flexible pavements construction, due to its unique viscoelastic characteristics [1, 2]. Asphalt cement is a complicated chemical composition, it predominantly displays both viscous and elastic properties which mainly based on loading time and temperature [3, 4]. Actually, higher traffic loads and the numeral of the vehicle together with the adverse environmental circumstances may lead to a quick deterioration of pavement materials. To control these effects, pavement of highway request asphalt binder material with higher performance than normal asphalt binder. Consequently, the construction of flexible pavements needs for modified asphalt binder [5].

Regarding modification method of asphalt binder, various modifiers have been used for improving the mechanical properties of asphalt binder and mixtures. Some of these modifiers were styrene-butadiene-styrene (SBS) [6–9], lime [10, 11], crumb rubber [12] and electronic waste powders [13,14].

Micro Silica powder is very fine amorphous silica, which formed in electrical arc ovens as a by-product material resulted from the manufacturing silicon elements and alloy. Silica powder contains high amorphous silicon oxides content. Micro silica is round particles and typically the diameter is ranged from 0.1 to 0.2 µm [15-17].

Micro silica powder was added to the original asphalt binder PG 64-22 at various percentages to raise viscosity values and decrease the asphalt binder oxidation rate [18].

The present study aims to investigate the effect of mixing conditions on the dispersion of micro silica particle into asphalt binder and the impact of using of various mixers on mixing of micro silica powder where three contents were used ranged (2%, 4%, and 6%). Various tests were conducted to
evaluate the properties of the modified asphalt binder such as penetration grade, softening point temperature, temperature sensitivity, Brookfield rotational viscosity and ductility property.

2. Material Used and Methodology of Research

2.1. Asphalt cement

The base asphalt cement is 60/70 penetration type obtained from the Dora Refinery at the middle region of Iraq. Table 1 shows the physical properties of asphalt binder.

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

2.2. Micro silica powder (mS)

Micro silica is a synthetic non-crystalline of silicon oxide of grey color particles, brought from the local market (china is a source of manufactured) has been used throughout this work. The chemical analysis of micro silica is shown in Table 2, whereas the physical features are shown in Table 3. The results showed that the micro silica powder conforms with the requirements of ASTM C 1240 [15].

| Oxide Composition | Oxide content % | ASTM C1240-15 |
|-------------------|-----------------|---------------|
| SiO₂              | 91.51           | Min. 85%      |
| Fe₂O₃             | 0.44            | < 2.5%        |
| Al₂O₃             | 0.71            | <1%           |
| SO₃               | 0.95            | <1%           |
| K₂O + Na₂O        | 1.38            | <3%           |
| CaO               | 0.90            | <1%           |
| L.O. I            | 4.39            | Max. 6%       |
### Table 3. Micro Silica Particles Physical properties

| Property                  | Result        | ASTM C1240-15 |
|---------------------------|---------------|---------------|
| Size                      | 0.15 µm       | ~0.15 µm      |
| Colour                    | Grey          |               |
| Specific surface area,    | 17000 cm²/g   | ≥ 15000 cm²/g |
| Specific gravity, kg/m³   | 2.2           |               |
| Physical form             | Powder        |               |
| Bulk Density              | 0.6           | 0.5±0.1 kg/liter |
| Moisture                  | 0%            | < 2%          |

Chemical compositions and physical properties were conducted according to manufacture and National Center for Construction Laboratories and Researches.

2.3. Mixer Type

According to the abilities of each mixer, which has a various efficiency of mixing composite materials, the blending circumstances are considered diverse for each of them. So, for each mixer has its special specifications. For instance, due to the constant revolution rate of the mechanical mixer, its blending time is supposed to be adjustable. And the revolution rate of the mixer is considered as variables for a high shear mixer.

2.3.1 Mechanical mixer (M.M)

The conventional mechanical mixer is commonly utilized in laboratory as shown in ‘Figure 1’. This mixer is used to mix various dry fine materials or blend solutions simply mixed together or conjunction a powder material in a solution. This mixer is used considering its time parameter a variable, while its revolution rate is constant in each minute, the composite material need be mixed as long as a homogenized mix is achieved.

2.3.2 Shear mixer (S.M.)

The shear mixer is one of the most appropriate mixers which are used to mix polymer, micro or nanomaterial and other additives with asphalt binder as shown in Figure 1. Revolution rate can be determined based on the type of modifier. Because of, the superior design of the mixer, the mix enter and move quickly through the space between the two very close dishes and leaves it through the space between embedded slots in the external layer. The process makes the mixture of asphalt and micro silica powder more homogeneous.
2.4 Mixing Process of Modified Asphalt Binder
Two mixers were used to mix micro silica particles with asphalt binder. A mechanical mixer can be set at a constant revolution rate (2000) rpm and high shear mixer can be set at various revolution rate (2000, 4000 and 6000) rpm. The blending time parameter is considered as a variable for two mixers ranged (30 to 60) minutes to get a homogeneous composite material. The asphalt binder mixtures were prepared by heating at 140 °C, based on the viscosity of control asphalt binder. Then, gradually adding micro silica particles a weighted 2%, 4% and 6 % (low, medium and high content) to asphalt as shown in Figure 2. Finally, the modifier asphalt examined to evaluate their physical properties.
2.5 Experimental Work
This research was focused on assessing the impact of mixing conditions on the dispersion of micro silica particles into asphalt binder. And determining the optimum content of micro silica particles to evaluate the physical properties of the modified asphalt binder such as penetration grade, softening point temperature, temperature sensitivity, Brookfield rotational viscosity and ductility property.

3. Results and Discussions
Figures 3 and 4 present the relationship of penetration values and softening point temperature respectively, using different mixing process for original and modified asphalt binder. It can be seen that the penetration values decreased and softening point increasing due to the addition of the micro silica content regardless of different mixing processes. The improvement of the stiffness modified asphalt binder may be resulted from the diffusion and the adsorption of the micro silica particles into the asphalt binder. Therefore, is an indicator to decrease oily materials in the maltene phase by absorption of silica powder and convert to the resin materials in the asphalting phase of modified asphalt binder, and the hardness of silica particles is more than the hardness of asphalt binder [25]. Moreover, the large reduction in penetration values and softening point increment observed within the mechanical mixing of modified asphalt indicates that the micro silica particles dispersion was non-homogenous, and the agglomeration was increased, as shown in Figure 10.

![Figure 3. Penetration Value and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 30 Minute.](image-url)
Furthermore, from Figures 5 and 6, it can be seen that the increasing the mixing time of modified asphalt binder improved the physical properties at 60 minutes for high shear mixing type. Also, the long mixing time increasing the stiffness of modified asphalt binder observed within mechanical mixing, due to non-homogenous dispersion and increasing the agglomeration of micro silica particles.

**Figure 4**: Softening Point Temperature and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 30 Minute.

**Figure 5**: Penetration Value and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 60 Minute.
Figure 6: Softening Point Temperature and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 60 Minute.

Figure 7 displayed PI values versus micro silica percent. It can be seen that the PI amount decreased by adding the micro silica content for different mixing processes (i.e. M.M and S.M), at the revolution rate set at 2000 rpm. While the PI values of modified asphalt binder increased by adding the micro silica content for high shear mixing process set at (4000 to 6000) rpm. The conflicting effect by adding the micro silica content for PI values of modified asphalt binder, because of non-homogeneous dispersion and increasing the agglomeration of micro silica particles [26]. Furthermore, in Figure 8, it can be observed the elongated mixing time leads to significant increase in PI value within high shear mixing of modified asphalt which indicates that the micro silica particles dispersion was more homogenous than mechanical mixing [27]. Representing that the rut deformation resistance improves with an addition of micro silica content attributed to an exfoliated structure formed [28]. Nevertheless, the PI quantities still within the standard specifications limits (+2.0 to -2.0), which can be used for paving the highway [29].
Figure 7. Penetration Index and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 30 Minute.

Figure 8. Penetration Index and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 60 Minute.

Figure 9 exhibited the ductility quantities versus micro silica percent. It can be seen that the ductility quantity decreased by adding of the micro silica percent. This might be attributed to the decreasing of light volatiles in the maltene phase. Furthermore, a more reduction in ductility quantity observed within the mechanical mixing, which indicates the non-homogeneous dispersion, and increasing the agglomeration of micro silica particles, as shown in Figure 10.
As well, from Figure 11, it can be seen that the increasing mixing time improved the ductility property at 60 minutes for high shear mixing type, while ductility value decreased observed within mechanical mixing, due to non-homogenous dispersion and increasing the agglomeration of micro silica particles [27].

![Graph showing ductility and various contents of micro silica powder for different types of mixer at mixing duration 30 minute.](image1)

**Figure 9.** Ductility and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 30 Minute.

![Image showing degree of agglomeration of micro silica particles into asphalt binder for various mixer.](image2)

**Figure 10.** The degree of Agglomeration of Micro Silica particles into Asphalt Binder for Various Mixer (Mechanical Mixer at Left Side and High Shear Mixer at Right Side).
Figure 11. Ductility and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 60 Minute.

Figures 12-15 presents the rotational viscosity values against micro silica percent at a temperature of 135 to 165°C. As can be seen that the viscosity increased by the addition of micro silica percent. It may be attributed to the increase the in diffusion and adsorption of micro silica particles into modified asphalt binder. Furthermore, the large increment of viscosity value observed within mechanical mixing of modified asphalt at 60 minutes which indicates that the non-homogeneous dispersion and increasing the agglomeration of micro silica particles, as shown in ‘figure 10’ [25, 26].

Figure 12. Viscosity Value and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 30 Minute.
Figure 13. Viscosity Value and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 60 Minute.

Figure 14. Viscosity Value and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 30 Minute.
4. Conclusions
The main purpose of this study is to assess the effect of two different mixing techniques (conventional mechanical mixer and high shear mixer) of micro silica powder with asphalt binder based on the physical and testing. From the research results and analyses, the following conclusions can be drawn:
1. The penetration value of modified asphalt was reduced, whilst increased the softening point temperature by adding the micro silica content. It is an indication to improve the stiffness of the modified asphalt.
2. Regarding temperature sensitivity (PI) of modified asphalt binder is decreased by addition the micro silica content for different mixing processes, which was at the revolution rate set at 2000 rpm. While the PI values increased by adding the micro silica content for high shear mixing processes set at (4000 to 6000) rpm. It is an indication of improves the rut deformation resistance.
3. The ductility value is decreased by adding the micro silica content observed within mechanical mixing of modified asphalt binder.
4. Long mixing time improved the ductility property at 60 minutes for high shear mixing type, while ductility value decreased observed within mechanical mixing which indicates that non-homogenous dispersion and increasing the agglomeration of micro silica particles.
5. The viscosity value is increased by adding the micro silica content. It is an indication to improve the stiffness of modified asphalt binder.
6. High shear mixer set at (4000 to 6000) rpm for mixing time fixed (30) minutes at 140°C mixing temperature was adequate to achieve a good dispersion of micro silica particles into asphalt binder and obtained a homogenous composite binder. Also, it can be seen that elongated mixing time reached (60) minutes may be an impact in a little development of a good dispersion of micro silica, but it is supposedly more consumption of energy and more costly.
7. The high shear mixing was more practical particularly in this field was found to achieve a good dispersion of micro silica particles into asphalt binder and obtained a homogenous composite binder. In contrast to the conventional mechanical mixing process.
8. Based on the physical properties of the tested specimens, the 6% of micro silica by asphalt binder weight was adequate to improve the physical properties, and became more suitable for construction the highway pavements in the hot weather.

![Figure 15. Viscosity Value and Various Contents of Micro Silica Powder for Different Types of Mixer at Mixing Duration 60 Minute.](image-url)
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