Effect of Silica fume on Cold Mix Asphalt Mixture

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Abstract

The cold asphalt emulsion mixture CAEMs is a mixture consisting of asphalt emulsion with aggregate mixed at room temperature. CAEMs is the most preferred layer in recent times as it is most safe in terms of the lack of environmentally friendly and healthy volatile fumes. Many studies have demonstrated that silica fume has significant effects in improving the engineering properties of asphalt binder and mixture. Several requirements were conducted on compacted modified CAEMs with silica fume during the practical program of this research, such as Marshall stability test, density, air voids, indirect tensile strength (exposed to freezing and thawing conditions and not exposed to it and the effect of moisture in addition to non-destructive examination using sound waves). Results of this study prove that using silica fume improved the behavioral properties of cold mix. Higher Marshall Stability (100%) , Higher tensile strength(219%) than the conventional mixture(without additives) and had a positive effect on the resistance to freezing and thawing condition.

Keywords: Cold asphalt emulsion mixture, Silica fume, Indirect tensile, Stability, Open grade.

Effect of Additives on Cold Mix Asphalt

In general, fluoride materials play a major role in the properties of asphalt mixtures, and have a significant impact on the resistance of permanent deformation, hardness, break resistance, and moisture susceptibility of asphalt mixtures [1,2]

1. The Use of SF history

The first silica fume test was conducted on cement produced from Portland cement in 1952. The biggest reason for not discovering the properties of silica is the lack of materials to test it. Early research used an expensive material: smoked silica cement, an amorphous substance obtained from the combustion of silicon tetrachloride in hydrogen-oxygen flame. Silica Fume is a secondary product in the acquisition of silicon and ferro alloys in electric arc furnaces. It consists of spherical particles with a diameter of 150 nm and its main application is pozzolanic for high performance concrete. The silica fume was easily present in the atmosphere. This was in the late 1960s in Europe, in the United States in the mid-1970s. The strict environment laws were enforced in the mid-1970s and the process of collecting silica fume was started and applications were sought. Norway's early work was of great importance because it showed that Portland cement containing silica smoke had high strength and low porosity. Silica fume is one of the world's most valuable additives for concrete products.[3]

2. Properties of silica fume
Silica Fume is a finite material containing spherical particles whose diameter is less than 1 micrometer, and the rate is $0.15 \mu m$. This is why it is 100 times smaller than the rate of cement granules [4,5]. The apparent density of silica fume contains the degree of condensation at hermitage and ranges from (130 to 600 kg / m$^3$). The specific weight of silica fume shall be (2.2-2.3). Calculation and measurement of surface area of silica shall be calculated using the nitrogen absorption method. They usually range from (15,000 to 30,000 m$^2$/kg) [6].

In order to improve cold emulsion asphalt mixtures, many attempts to add additives to cold mixtures were discussed and discussed in the following literature:

Amudhavalli & Mathew [7] studied the effect of silica fume on concrete properties of strength and solidity, the main indicators investigated in this study are M35 with supplementing the amount of cement with different silica fume ratios (0, 5, 10, 15, 20%) and a pilot study of compressive strength. The bending strength at the age of 7 and 28 days and results revealed that silica fume, which has been added to the concrete, has improved the concrete performance of the strength also some of the durability.

Vagelis [8] studied the development of strength, porosity and calcium hydroxide through experiments that add silica fume to the mortar and replaced the cement with silica fume. The combination and switching process gave these regions greater strength than the reference mix.

Abdullah et al.[9] conducted to use silica fume and evaluate its effect on compressive strength, tensile strength and elasticity coefficient of coarse concrete, which is of low quality. Four samples of low value aggregates, lemon, quartz, limestone and slag were prepared. The results showed that the type of aggregate used on the compressive strength and tensile strength and also note the lack of quality lime.

Elsayed [10] Studied the effect of mineral additives on the strength of compression and permeability. These additives are plasticizers and silica fume, which are used in the way of cement substitution by certain percentages (5, 10, 15%). The test was done for the samples and the results were compared with the reference sample. It was found that 10% of the silica that was replaced by the cement place gives a penetration of 12 mm and gives a decrease of 56% in the permeability and increase the compressive strength by 32%. This reduces the permeability. It has high compressive strength in both added ratios and low permeability of water compared to the reference sample.

Ramazan and Gul [11] studied the freezing and melting concrete in addition to fly ash and silica fume by replacing cement with silica fume by 10, 20 and 30% to verify the effect of silica fume. It was observed that fly ash in the mixture provided melting resistance of ice up to 132%. The replacement of plasica with the cement place increased the melting resistance of the ice to 83%. It was concluded that fly ash had a greater effect than silica fume to improve melting resistance.

(Al-Hdabi et al.[12] investigated in the development of cold rolled asphalt (CRA) mixtures via utilize waste fly ash (WFA) and via production silica fume (SF). They utilized (WFA) as modification or conventional filler and (SF) utilized as the additive materials to recover the mechanical and the durability characteristic of (CRA) include (WFA). The outcomes appear that (WFA) boost the mechanical and the durability characteristic of (CRA) significantly, and the accretion of SF ameliorate the elementary strength, the lengthy-duration strength, and the durability of (CRA).
3. Necessities to using SF

The fundamental Rules for a suitable pavement are: dropping using natural incomes, saving energy consumption, lowering greenhouse gas discharges, omission pollutions, Enhancing health And warranty, And hazard Corrective movement. SF due to its spherical shape, higher density and tiny size compared to bitumen, may have an essential potential to improve CAEMs properties. This study concerns in the properties of CAEMs modified with SF[13].

4. Methodology

Silica fume SF was adopted in this study in varies percentages (4, 6, and 8) as alternative from weight of filler used as apart of open grade aggregate which be promoted by the Federal Highway Administration (FHWA) has been mixed with 5% of emulsion asphalt. The methodology was briefly mentioned in Table (1).

| Test                        | Formula                        | Specification       |
|-----------------------------|--------------------------------|---------------------|
| Marshall stability MS       | ------                         | ASTM-D6927[14]     |
| Marshall Stiffness MST      | $MST = Si/(Fi \cdot b)[15]$    | ASTM-D 6927[14]    |
|                             | Si = Mixture’s stability at bitumen content (i) |                      |
|                             | Fi = Mixture’s flow at the same bitumen content (i) |                      |
|                             | b = sample thickness           |                     |
| Indirect Tensile Strength (ITS) | $\sigma_t = \frac{2 \times P_{max}}{\pi H D}$[16] | ASTM-D6931[14]     |
| Tensile Strength Ratio (TSR) | $TSR = (T2 / T1) \times 100$[17] | ASTM D 4867[14]     |
| Ultrasonic Pulse Velocity UPV t | ------                         | ASTM C597[14]      |
| - Freeze-Thaw Cycles        | ------                         | AASHTO T-283       |

5. Results and Discussion

a- Effect of %SF on ITS
The results of ITS are illustrated in Figure(1). There was a significant increase by 33.25% in these results when the percentage of adding 6% of SF at 25°C. A declination in values appears at 40°C accompanied by 50.1% an increase of ITS occurs at 4% SF. This trend due to the effect of SF on the viscosity of the asphalt as indicated by Abutalib [18]. The optimal content for this test is 6%.

b- Effect of %SF on Marshall stability MS
Based on the results obtained and calculate the relationship between Marshall Stability and SF additive ratios shown in Figure (2), it was found that the relationship between them in the addition of SF in different proportions (4%, 6% and 8%) in the case of significant increase by the following percentages respectively (24%, 103% and 106%). This increase matches the research of Mahmood [19]. The optimal content for SF added to this test is 8%.

c- Effect of %SF on Marshall Flow
The flow values of the asphalt emulsion mixtures are shown in Figure(3). It was found that the flow values began to increase by 75% with the addition of SF until reached the maximum value in the highest proportion of SF. High flow values indicate high elasticity which increasing the CAEMs pavement's ability to deform without cracking. This result was compatible with Metwally research [20]. The optimal content for SF added to this test is 8%

d-Effect of %SF on Marshall Stiffness (MST)
Figure (4) shows that the hardness of the mixture increases as the SF content increases by 6% and then decreases. The first increase in hardness gained stability. The figure also shows that the hardness values of the modified mixtures with the addition of SF are greater than those of the conventional mix. The increase was 40% after adding 6% SF while the decrease rate was 11% at 8% SF. This increase and decrease match Metwally research [19]. The optimal content for SF added to this test is 6%

e- Effect of %SF on Tensile Strength Ratio (TSR)
The results of the Tensile Strength Ratio TSR are shown in Figure(5). An increase in the value of TSR versus greater the percentage of replacement Portland cement PC with SF until 6% then decline at 8% SF, so the optimal percentage for the addition of silica filler was 6%. The valuation of moisture damage can be made by calculation TSR. Posolonic material response with calcium hydroxide to produce calcium silicate hydrate (C-S-H) is very comparable to (C-S-H) generated by PC [21].

f- Effect of %SF on TSR Freeze – Thaw
Damage can be assessed by identifying TSR which should be a minimum of 80% [17]. As can be seen in Figure (6) TSR decrease in TSR when increased added SF but still within the allowable value of the standard indicating the continued resistance of the modified cold mix when exposed to freezing and thawing. The best addition percent of SF was 4%.

g-Effect of %SF on Ultrasonic Pulse Velocity Test
There is a small impact of the specimens temperature on the ultrasonic pulse velocity this indicate to that the ultrasonic waves not relies on the viscosity or consistency interchange but rely on the voids in mix when viscosity of asphalt became low, the asphalt seal the voids and raise the impairment in its stiffness with supplying transmission media between aggregate instead air. Density and air voids ratio with viscosity and poison ratio all of them have impact on the specimens dynamic modulus by nondestructive wave's tests. So the temperature has a small impact on mix stiffness. Data obtained from this test as
shown in Figure(7). The results showed a significant increase in the value of ultrasonic wave velocity with an increase in the percentage of SF added. This is evidence of the decrease in air gaps by increasing the additive. The optimal content for SF added to this test is 8%.

**h- Effect of SF% on density**
The results obtained in Figure(8) illustrate a significant increase in density compared to the conventional specimens. This is because of the smoothness of silica and its great ability to fill in the blanks. The rate of increase was 2.7%. These results and the increase matched Mahmood research [19]. The optimal content for SF added to this test is 8%.

**i- Effect of %SF on VMA and VFA**
The results are shown in Figure (9). The results show a steady linear decrease by 10% in the increase of SF, which is expected for the small granules of the additive which achieves ability to nag and fill the blanks significantly. This matches the Metwally research [20]. The optimal content for SF added to this test is 4%.

Figure(9) shows the effect of adding SF on VFA% appearing a significant increase in the increase in the proportion of additives and this indicates that there is enough asphalt to provide durability. The increase is 48%. The optimal content for SF added to this test is 8%.

**g- Effect of %SF on Air Voids**
At Figure(10), the higher the SF filler content leads to slight decline in air void percentage. The rate of decrease is 17.4%. This matches the following Mahmood [19] and Hassan[21] results. The optimal content for SF added to this test is 4%.
Marshall flow.

Figure (5) The effect of %SF on TSR

Figure (6) The effect of %SF on Freeze-Thaw

Figure (7) effect of %SF on Ultrasonic Pulse Velocity

Figure (8) The effect of %SF on density

Figure (9) effect of %SF on VMA and VFA

Figure (10) The effect of %SF on Air Voids

k- Determination of Optimum %SF content

The optimal value of the SF % for cold asphalt mixture was calculated based on the optimal values resulting from the tests conducted by this research. It was found that 6.7 % is the best.

6. Conclusions

1. 6.7% represented the optimal content of the SF % for CAEMs.
2. At 25°C temperature, SF significantly increases ITS of the mixture by 219% at optimum SF content, compared to the conventional mixture. This increase remained high until the fill rate of 6% of SF.

3. At a temperature of 40°C there was an increase in the value of ITS by 525% and a decrease occurred after the optimum rate of additive and this decrease in the value of ITS.

4. 100% was the increase in Marshall stability for prepared modified cold mixtures optimum SF content compared to the conventional mixture.

5. By water damage, TSR of cold mixtures containing, optimum SF content deteriorated by 74.62% but still satisfied the ASTM specification.

6. The modified CAEMs achieved a high increase in Marshall flow. However, it is still remaining within the limits allowed by ASTM standards specifications.

7. Asphalt emulsion mixtures containing optimum SF filler produced higher density with 134.3% and drop in air voids till 37.45%.

8. Although the overall open grade is used, the added filler of the silica fume type filled all the spaces upwards leading to reinforce the open grade and make it more like the dense grade.

9. Ultrasonic Pulse Velocity test has a significant gradual increase in the rate of 132.83% compared to corresponding value at conventional mixture.

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