Evaluation silica fume addition on some properties of cold bitumen emulsion mixtures (CBEMs).

To cite this article: H H Joni and M Sh Hashim 2018 IOP Conf. Ser.: Mater. Sci. Eng. 433 012021

View the article online for updates and enhancements.
Evaluation silica fume addition on some properties of cold bitumen emulsion mixtures (CBEMs).

H H Joni¹, M Sh Hashim²³

¹ Asst. Professor, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.
² M.Sc. Transportation Engineering, Building and Construction Engineering Department, University of Technology, Baghdad, Iraq.
³ University of Kerbala, Kerbala, Iraq.

Abstract: Cold mix asphalt is an alternative to hot mix asphalt that consists of aggregate and filler with asphalt emulsion as a binder material rather than asphalt cement. It has many benefits such as save energy and less emissions. The major objective of this paper is determining the effects of adding silica fume on some properties of cold bitumen emulsion mixtures (CBEMs). This was done by adding three proportions of silica fume (1, 2, and 3%) as a replacement for limestone dust and then conducting tests including indirect tensile strength, compressive strength, Marshall stability, flow test, bulk specific gravity (Gmb), and air voids. The mixtures were also evaluated for moisture sensitivity by means of their tensile strength ratios, retained Marshall stability, and a double punch shear test.

The results showed that the addition of silica fume increased the indirect tensile strength, compressive strength, Marshall stability, and bulk specific gravity (Gmb) by (18.5, 68, 78.4, and 0.4) %, respectively, and decreased the flow values and air voids to about (13.5 and 6.6) %, respectively for 3% of replacement. Moreover, the addition of silica fume gave different behaviours in terms of moisture resistance; in general, there was an improvement in moisture resistance compared to that seen in the control mix.

Keywords: Emulsified asphalt, Cold mix asphalt, Silica Fume, Double Punch Shear, Compressive Strength.

1. Introduction

The production of cold bituminous emulsion mixtures is done by mixing asphalt emulsion with aggregate and filler at ambient temperature. Currently, the expansion in the employment and approval of such practices in sustainable pavement design has occurred as a result of multitudinous attempts to reduce emissions during applications of asphalt paving and save energy, the use of cold bitumen emulsion mixtures is one of these practices [1]. Cold bitumen emulsion mixtures (CBEMs) offer many features such as requiring less energy, being more cost effective, and producing pavement with less impact on the environment when applied as alternatives to traditional hot mix asphalt [2]. The use of CBEMs resultant mix has low early strength, however, and thus has been used in limited applications such as low/medium low trafficked roads, footways, and reinstatements [3, 4]. Many asphalt mixture properties, such as stiffness, resistance to fracture, resistance to permanent deformation, and moisture susceptibility, are affected by the type of filler used, however, and thus filler plays a prime in enhancing the engineering characteristics of asphalt mixtures [5, 6]. Many attempts have been investigated to improve cold mixes,[7] studied the durability, microstructure, and mechanical properties of cold asphalt emulsion mixtures by using different types of filler, including using ground granulated blast furnace slag (GGBS) and fly ash (FA) to create binary blended fillers (BBF); to obtain ternary blended fillers (TBF), silica fume was added to BBF. The results of durability and mechanical properties indicated that the use of TBF was more appropriate than BBF in the production of CBEMs,[8] used by-product and waste materials as fillers and/or activators in CBEMs. Paper Sludge Ash (PSA), silica fume (SF), and other materials were used to develop the durability and the mechanical properties of CBEMs, and the
results showed that the silica fume added further improvements to CBEMs comprised of OPC or PSA. It played a major role in activating the PSA within the mix and accelerating the hydration process, and in addition, a significant improvement in the mechanical and durability properties of CBEMs was shown when a low percentage of silica fume was added.

2. Experimental Program

2.1. Materials Properties

The aggregate utilized in this research is crushed gravel quartz, it is brought from local asphalt concrete mix plant, in Jurf Alnaddaf which was collected from Al-Nibaay quarry. Table 1 illustrates the physical properties of the aggregate, and the chemical composition of the aggregate is presented in table 2. The nominal maximum aggregate size selected for the cold mixes was 19.0 mm, this gradation is within the specification limits recommended by the State Corporation for Roads and Bridges in Iraq (SCRB) for binder course. The mineral filler in the control mixture was limestone dust from a local market; the specific gravity for the limestone of filler was (2.72). In this study, silica fume (SF) was used as a partial replacement for the traditional filler at 1%, 2%, and 3%. The specific gravity for this SF is (2.42). The particle size of silica fume is very small, the surface area is very large (15000-30000) m²/kg. The chemical composition of the limestone dust and silica fume are shown in table (2), and the size distribution of silica fume is presented in figure 1. To produce a dense–graded mixture, a slow setting cationic emulsified asphalt of low viscosity type (Css-1) with 53.1% residue from MEGA INSAAT (a Turkish company) was used in this study, because of its compatibility with a wider range of aggregates and its common utilization all over the world, the properties of emulsified asphalt are shown in table 3.

| Laboratory Test                  | ASTM Specification | Results                      |
|----------------------------------|--------------------|------------------------------|
| Specific gravity                 | Coarse aggregate   | ASTM C127                   |
| Bulk Gs                          | 2.621              | 2.657                        | 0.5%                        |
| App. Gs                          | 2.657              | 2.691                        | 0.4%                        |
| Absorption%                      |                    |                              |                             |
| Fine agg.                        | ASTM C128          | Crashed sand (<#4)           |
| Bulk Gs                          | 2.663              | 2.691                        | 0.4%                        |
| App. Gs                          | 2.691              |                              |                             |
| Angularity*                      | ASTM D5821         | Min 90%                      | 93%                         |
| Min 90%                          |                     |                              |                             |
| Flat & Elongation for coarse agg*| Flat Elongation    | ASTM D4791                   |
| Flat                             | Max 10%            |                              | 0 %                         |
| Elongation                       |                    |                              | 0 %                         |
| Soundness*                       | ASTM C88           | 12% Max                      | 4.3%                        |
| Flat                             |                     |                              |                             |
| Aggregate Size < 25 mm           | Aggregate Toughness| ASTM C131                    |
| 35% Max                          |                     |                              | 21.1%                       |
| Equivalent sand for fine agg. (clay content)* | ASTM D2419 | Min 45%                      | 96%                         |

*Tests were conducted by the National Center for Construction Laboratories and Researches (NCCLR).
Table.2 Results of Chemical Composition

| Chemical Composition       | Dust* | SF* | Coarse** | Agg |
|---------------------------|-------|-----|----------|-----|
| Silica, SiO₂              | 4.06  | 90.04 | 80.73    |     |
| Lime, CaO                 | 47.48 | 1.9  | 6.77     |     |
| Magnesia, MgO             | 0.91  | 0.01 | 0.63     |     |
| Sulfuric Anhydride, SO₃  | 5.4   | 0.24 | 2.3      |     |
| Alumina, Al₂O₃            | 1.02  | 1.03 | 0.66     |     |
| Ferric Oxide, Fe₂O₃       | 3.02  | 0.01 | 0.98     |     |
| Loss on Ignition          | 37.07 | 2.86 | 6.3      |     |

*Tests were conducted by the Iraq Geological Survey
**Test was conducted by Directorate of Materials Research.

Figure.1 Size Distribution of Silica Fume

Table.3 Physical Properties of Cationic Slow Setting Low Viscosity Emulsified Asphalt (CSS-1)

| Test                              | ASTM Designation (D244) | Test Result | Specification Limits (D2397) for CSS-1 |
|----------------------------------|-------------------------|-------------|---------------------------------------|
| Particle Charge Test *           | D244                    | Positive    | Positive                              |
| Viscosity, Saybolt Furol at 25°C (77°F) | D244                   | 24          | 20 100                                |
| Residue by Distillation, %       | D6997                   | 53.1        | 57 50 70                              |
| Residue By Evaporation           | D6934                   | 52.7        | 50 70                                 |
| Sieve Test, %                    | D6933                   | 0.06        | 0.10                                  |
| Cement mixing test, %            | D6935                   | 0.732       | 2 0                                   |
| Settlement Test, 5day, %         | D6930                   | 0.4         | 0 1                                   |
| 1 Day Storage stability test, %  | D6930                   | 0.2         | 0 1                                   |
| Tests on Residue                 |                         |             |                                       |
| Penetration, 25°C (77°F), 100 g, 5 s | D5                    | 140         | 100 250                               |
| Ductility, 25°C (77°F), 5 cm/min, | D113                   | 105         | 40 40       |
| Solubility in trichloroethylene, %** | D2042                 | 99          | 97.5 97.5 |
| Specific Gravity at 25°C **     | D70                     | 1           | 1 1        |

* Test was conducted by the Manufactures Laboratory (MEGA INSAAT Company) of Asphalt Emulsion.
** Test was conducted by the National Center for Construction Laboratories and Researches (NCCLR).
2.2. Mixture Production
Mixture design and testing procedures vary between road authorities, research institutions, and asphalt researchers; the design procedure followed by this paper used the Superpave mix design method. Generally, the design procedures include the following steps:

2.2.1 Determination of aggregate gradation: The Superpave mix design procedure was used to select the aggregate gradation, and three trial blends were selected in this study: coarse, mid, and fine. These blend gradations were within the specification limits recommended by the State Corporation for Roads and Bridges in Iraq (SCRB) and (AASHTO M323, 2012), as shown in Figure 2.

2.2.2 Estimation of Initial Residual Content and Initial Emulsion Content (IEC): For the three blends, the residual asphalt content was initially estimated using the empirical formula offered by the Asphalt Institute as shown below:

\[
P = (0.05 A + 0.1 B + 0.5 C) \times (0.7)
\]

where \( P \) = % initial residual content by weight of dry aggregate, \( A \) = % of retained aggregate on sieve 2.36 mm, \( B \) = % of passing aggregate for sieve 2.36 mm and retained in 0.075 mm, and \( C \) = % of passing aggregate for sieve 0.075 mm.

To compute the initial emulsion content (IEC) applied to produce the mixtures, the empirical formula from the Asphalt Institute was used, as shown below:

\[
IEC = \frac{P}{X} \times 100\%
\]

where \( P \) = % Initial Residual Bitumen Content and \( X \) = % residue content of the emulsion (53.1%). From the above equations, the initial emulsion content (IEC) for the three blends were calculated and the results were 7.62%, 8.36%, and 6.85% of the total weight of aggregate for blend (1), blend (2), and blend (3), respectively.

According to the above calculations, the IECs were 7.62, 8.36, and 6.8; however, IECs at (5%, 5.5%, 6%, 6.5%, and 7%) of total weight of aggregate are more suitable [9, 10], so those values of the total weight were adopted in this study for each trial mix.
2.2.3 Select the Design Asphalt Emulsion Content: A Superpave mix design procedure was used and the mixture was prepared at ambient temperature by manual blending the initial emulsion content with aggregate and filler for 2 to 5 minutes until a good coating obtained without pre-wetting as in previous studies [9, 10]. For the maximum theoretical specific gravity calculation, samples were prepared and kept for 24 hours at room temperature before they were tested in accordance with (ASTM D2041) [10]. For gyratory testing, the samples were prepared immediately after mixing and compacted using the Superpave Gyratory Compactor; after each sample was compacted for 160 cycles, it was extruded from the mould and rested for 10 minutes before being transferred and allowed to cure for 24 hours at ambient temperature. The specimens were then transmitted to an oven at 40 °C and left for 24 hours. To determine the bulk specific gravity, samples were cooled for 2 to 4 hours at room temperature, and then the bulk specific gravity was calculated according to (ASTM D 2726). After that, using the SGC software archive, the volumetric properties were checked, data gathered, and the percentage air voids (Va %), voids filled with asphalt (VFA%), voids in mineral aggregate (VMA%), and percent G_{mm} were calculated. The results obtained were compared with the requirements of the Superpave volumetric mix design criteria; based on this, blend three at 5.5% initial emulsion content (IEC) with 3.41% estimated residual asphalt content was selected to be the design blend because it best met the requirements of the Superpave mix design. According to the Superpave mix design method, after the structure of aggregate with estimated asphalt content was selected, the design asphalt emulsion content was chosen using specimens at varying emulsion contents (estimated residual asphalt content %, estimated residual asphalt content ±0. 5%, and estimated residual asphalt content +1%) and the prior steps of mixing, compaction, curing, and evaluation of mixture properties were repeated. Figures of the volumetric properties of different asphalt emulsion contents were then drawn and the design emulsion content with 4% air voids selected. The design asphalt emulsion content used in this paper was thus 6.37% of the total weight of aggregate.

Figure.2 Trail Gradations for 19 mm Nominal Maximum Size
3. Testing program

Many mixtures were prepared, with limestone dust to act as control mix, alongside those with different percentages of silica fume. All mixtures were evaluated in terms of their properties such as indirect tensile strength, Marshall stability, compressive strength, flow test, $G_{mb}$, and Va. All mixtures were also evaluated for moisture damage based on tensile strength ratio, retained Marshall Stability, and a double punch test. These tests were conducted for all specimens after a curing protocol that rested them for one day at ambient temperature (in the mould for Marshall Specimens and in a room for Superpave specimens), then 24 hours in an oven @ 40 °C.

3.1. Compressive strength

This test method was used to measure the maximum compressive strength for compact bituminous mixtures; it was conducted for all prepared mixtures. Three specimens were prepared according to standard specifications (ASTM D 1074) for each type of mixture with batch weights of 1850 gm. A Superpave gyratory compactor and the second type of SGC mould (100 mm in diameter and 100 mm height) were utilized to produce testing specimens. The compressive strength of specimens was determined after storing them in a water bath for 2 hours at 25.0 ± 1 °C.

3.2. Indirect Tensile Strength

The cylindrical specimens (150 mm diameter and 115 mm height with 7% ± 0.5 air voids) were prepared by utilized a Superpave gyratory compactor. Six specimens were used for each type of mixture. The first three specimens were tested for indirect tensile strength without any conditioning after being cured at room temperature, while the other three specimens were subject to partial vacuum saturation (55-80) %, followed by a single freeze-thaw (F–T) cycle prior to being tested. Two diametrically opposed rigid platens were used along the diametric vertical axis of the test specimen and the compressive load was applied to induce tensile stress; the tensile strength determined by recording the maximum compressive load on the sample.

3.3. Bulk Specific Gravity ($G_{mb}$)

This was calculated for compact samples of all types of mixtures after a curing protocol outlined in (ASTM D 2726) as mentioned by the Asphalt Institute (MS 14).

3.4. Air Voids (Va)

Air voids are the trapped air between aggregate particles coated with asphalt in an asphaltic concrete pavement; these were calculated for all type of mixtures.

3.5. Marshall Stability and Flow

The resistance to plastic flow of designed asphalt mixture samples was measured by means of Marshall Apparatus and carried out according to (AASTHO T245-08). For each type of mixtures, six specimens were prepared, and a 1,200 gm batch weight was used to produce samples using the same method of mixing used to produce the design mixture, compacted by means of a Marshall compactor with 75 (SCRB/R9, 2003) blows on each face for heavy traffic. Three samples were prepared for determination of an average dry stability value, and the samples were immersed for 30 minutes in a water bath at 25 °C (Asphalt Institute MS-14) rather than the 60 °C used in HRM. The other three samples were used for determination of average soaked stability, and these were water conditioned. In this test, each compacted specimen was soaked to half thickness in water for 24 hours at room temperature. The specimens were then inverted and soaked for a further 24 hours on the other half [4, 9]. The specimens were subsequently to well dried, then tested for Marshall Stability at room temperature.
3.6. Evaluate of moisture damage

3.6.1. Double Punch Test: The double punch test was advanced at the University of Arizona by Jimenez to measure the stripping of binder from aggregates and falls in the category of those that include measuring mix mechanical properties. The severity of this test by comparing predictions on similar mixtures using the immersion–compression test [11]. Some numerous studies have used this test [10, 12-15]. The same procedure used to prepare specimens for retained Marshall stability was used to prepare samples for this test. After curing, the samples were conditioned for 30 minutes in a water bath at 25 °C, before being tested; then, the compacted cylinder specimens were placed between two steel rods, each of 2.54 cm in diameter, held in a punching configuration at the end of the specimen. The specimen was fixed between the steel rods, aligning one over the other, and the punching strength was calculated by measuring the maximum load applied to the specimen, Marshall apparatus was used to apply loading at a rate of 2.54 cm/min.

3.6.2. Tensile Strength Ratio (TSR): The ratio of the average indirect tensile strength of the wet specimens to the dry specimens is called the tensile strength ratio, and represents a reduction in mixture safety due to moisture damage. As a failure criterion, a minimum of 80% TSR is recommended according to Superpave mix design criteria. The condition of wet specimens was as described previously in 3.2. The sensitivity to moisture or stripping can be estimated by utilizing the indirect tensile strength test [16].

3.6.3. Retained Marshall Stability (RMS):- the ratio of wet to dry stability [3, 17]. [4] stated that a minimum of (50%) RMS can be achieved for cold bituminous emulsion mixtures, whereas [3] regarded a value of more than (75%) RMS as acceptable.

4. Result and Discussion

4.1 Effects of Adding Silica Fume on Compressive Strength. Figure 3 presents the results of compressive strength, showing that as the proportion of silica fume increases, the value of compressive strength also increases. This can be attributed to the high fineness of silica fume which can thus fill the small pores between the aggregate and limestone dust.

4.2 Effects of Adding Silica Fume on Indirect Tensile Strength (ITS). The results demonstrate that the ITS value for both dry and wet conditioned samples was increased with increased SF content, as shown in Figure 4. This may be due to an increase in viscosity of the binder due to impact of silica fume, as mentioned by [18].
Figure.3 Relationship between Compressive Strength and Type of Mixtures

Figure.4 Relationship between Indirect Tensile Strength and Type of Mixtures.

4.3 Bulk Specific Gravity ($G_{mb}$)
Figure 5 shows the results of $G_{mb}$ for dry Marshall specimens for silica fume replacement. The $G_{mb}$ value increases as the silica fume content increases; this behaviour is expected because of the high fineness of silica fume compared with limestone dust, which fills the voids between the aggregate particles.

4.4 Air voids ($V_a$)
The air voids results presented in Figure 6 show that a slight decline in air void percentage for dry Marshall specimens occurs as the percent of silica fume increases; this is due to the high fineness of silica fume.

4.5 Effect of Adding Silica Fume on Marshall Stability and Flow.
The results of Marshall stability testing showed an increase with the increase the silica fume content for dry and wet results, as shown in Figure 7. This increase reached up to 78.4% at 3% replacement with silica fume, compared with the control mix. This may be due to the increase of $G_{mb}$ and the reduction of air voids. On the other hand, a reduction in flow values was seen as the content of silica fume was increased, as shown in Figure 8.
**Figure 5** Relationship between Bulk Specific Gravity and Type of Mixtures.

**Figure 6** Relationship between Air Voids and Type of Mixtures.

**Figure 7** Relationship between Marshall Stability and Type of Mixtures.
4.6 Effect of Adding Silica Fume on Punching Strength.
The results of the double punching shear test are shown in Figure 9. There was a slight decrease in punching strength value with the increase of the silica fume content, but it remained higher than in the control mix for all additions. Silica fume plays a role as an activator and requires hydraulic products to give good results; this conforms with [8], there was no hydraulic products for the limestone dust as a mineral filler, so the silica fume did not react and leads to reduction in punching value.

4.7 Effect of Adding Silica Fume on Tensile Strength Ratio (TSR).
The results of tensile strength ratio (TSR) are shown in Figure 10. The results demonstrated a slight increase in TSR value as the percent of replacement for silica fume was increased, this increased up to about (6%) for 3% replacement of silica fume.

4.8 Effect the Adding of Silica Fume on Retained Marshall Stability (RMS).
Figure 11 demonstrates the results of retained Marshall Stability testing. It can be clearly noted that there was an increase in the RMS value followed by a decrease with increasing silica fume content. This may be due to the high increase in value of dry Marshall stability in comparison with the wet value. However, these values of RMS are all above those seen in the control mix and above the values recommended by Thanaya and Read and Whiteoak.
5. Conclusions

On the basis of the experimental results, the following conclusions can be drawn:

- Using silica fume as a replacement for limestone dust leads to an increase in bulk specific gravity and a reduction in air voids.
- Silica fume in cold mix asphalt improves the compressive strength, indirect tensile strength, and Marshall Stability at 3% replacement to around (68, 18.5, and 78) %, respectively. It also reduces the flow values to around 13.5%.
- Mixtures containing silica fume as a replacement didn’t give good results for moisture resistance because there was no hydraulic products to reacts with silica fume.
- Sample products by using the Superpave gyratory compactor (SGC) performed better than those produced using a Marshall Hammer based on air void content.

6. References

[1] Dulaimi A, Al Nageim H, Ruddock F and Seton L 2016 New developments with cold asphalt concrete binder course mixtures containing binary blended cementitious filler (BBCF) Constr. Build. Mater. 124 414–23
[2] Al-Busaltan S, Al Nageim H, Atherton W and Sharples G 2012 Mechanical Properties of an
Upgrading Cold-Mix Asphalt Using Waste Materials *Journal of Materials in Civil Engineering* vol 24 pp 1484–91

[3] Read J and Whiteoak D 2003 *The shell bitumen handbook* (Thomas Telford)

[4] Thanaya I N A 2003 *Improving the performance of cold bituminous emulsion mixtures (CBEMs): incorporating waste*

[5] Kim Y-R, Little D and Song I 2003 Effect of Mineral Fillers on Fatigue Resistance and Fundamental Material Characteristics: Mechanistic Evaluation *Transp. Res. Rec.* 1832 1–8

[6] Kim Y-R, Lutfi J S, Bhasin A and Little D N 2008 Evaluation of Moisture Damage Mechanisms and Effects of Hydrated Lime in Asphalt Mixtures through Measurements of Mixture Component Properties and Performance Testing *Journal of Materials in Civil Engineering* vol 20 pp 659–67

[7] Nassar A I, Mohammed M K, Thom N and Parry T 2016 Mechanical, durability and microstructure properties of Cold Asphalt Emulsion Mixtures with different types of filler *Constr. Build. Mater.* 114 352–63

[8] Al-Busultan S F S 2012 Development of New Cold Bituminous Mixtures for Road and Highway Pavements *Sch. Built Environ. PhD thesis*

[9] Al-Mishhadani S A and H.H.Al-Baid 2014 Some Properties of Emulsified Asphalt Paving Mixture at Iraqi Environmental Conditions *Tikrit J. Eng. Sci.* 21–1

[10] Mohsin F A 2016 *Laboratory Study on the Properties of Cold and Hot Recycled Asphalt Paving Mixtures* (University of Technology)

[11] Jimenez R A 1974 Testing for Debonding of Asphalt from Aggregates *Transp. Res. Rec.* 1–17

[12] Mashkoor O G 2015 *Durability evaluation of polymer modified open graded hma mixtures based on experimental work and FE modeling* (College of Engineering : AL-Mustansiriya University )

[13] Sarsam S I and Alwan A H 2014 Impact of Moisture Damage on Rutting Resistance , Shear and Tensile Properties of Asphalt Pavement *Int. J. Sci. Res. Knowl.* 2 453–62

[14] Solaimanian M, Harvey J, Tahmoressi M and Tandon V 2003 Test methods to predict moisture sensitivity of hot-mix asphalt pavements *Moisture Sensitivity of Asphalt Pavements-A National Seminar*

[15] Turos M I 2010 Determining the flexural strength of asphalt mixtures using the Bending Beam Rheometer

[16] Santucci L 2002 Moisture sensitivity of asphalt pavements *Tech Top.*

[17] I Nyoman Arya Thanaya 2007 *Review and Recommendation of Cold Asphalt Emulsion Mixtures Caems Design Civ. Eng. Dimens.* 9 49–56

[18] Abutalib N, Fini E H, Aflaki S and Abu-Lebdeh T M 2015 Investigating Effects of Application of Silica Fume to Reduce Asphalt Oxidative Aging *Am. J. Eng. Appl. Sci.* 8 176–84

**Acknowledgements**

The authors would like to thank Dr Riyad Al Anbari and the staff of the Building and Construction Engineering Department, University of Technology, particularly those working in the Asphalt Laboratory, for their help in accomplishing this research.