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Effect of Incorporating Processes of Fumed Silica on Marshall Properties of HMA Concrete

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Abstract: ***Highways play an important role in the economic and social development of societies; therefore, many studies are directed towards modifying pavement properties. In Iraq as well as other countries, pavement surface cracking and rutting are considered as major problems in roads and airports. The main objective of this work is to evaluate the effect of incorporating method of additives on Marshall properties of hot mix asphalt (HMA) concrete (wearing surface layer) using different percentages of additive. OAC of (4.7)% for control mixtures was determined using Marshall mix design. All modified HMA consist of AC of (40-50) penetration grade brought from Al-Duarah refinery, aggregates obtained from AL-Nibaae quarry with NMAS of (12.5) mm, and mineral filler (Portland cement) obtained from Tazloja factory, Additive (Fumed Silica (F.S)) its chemical compositions were tested in the laboratories of General Directorate of Geological survey and Mining. Modified mixtures with (3, 7, 10)% of F.S were prepared based on two methods of incorporating F.S into the HMA concrete are Stirring and Addition methods. They subdivided into the two groups, the first group refers to the addition of F.S as a percentage of the total weight of AC (the weight of modified AC stayed constant), The second group refers to the addition of F.S as a percentage of the total weight of AC (as additional amount) to the weight of AC. Results show that modified specimens prepared based on stirring method and containing (3% + AC) are the best among all mixtures.***

Keywords: Marshall Mix Design, Modified Asphalt Cement, Fumed Silica, Stirring and Addition Processes

1. Introduction

According to previous studies, two methods of incorporating additives into HMA mixtures as will be described. Many researchers was used stirring process of incorporating the additive with hot A.C. It was continued for 45 minutes as a constant blending time. Three percentage of the Silica Fumes (1% - 5%) with a constant increment of 1% by weight of asphalt cement (40-50) have been introduced based on previous work. The produced modified asphalt cement was poured inside the testing mold for furth testing [1]. Asphalt cement of (40-50) penetration grade from Al-Dura refinery was adopted in this study and blended with 2% of Silica Fumes, which was obtained from local market, it is an ultra fine powder consisting of nearly spherical particles around 100 time small than a grain of cement .Other percentages of Silica Fumes were also tried by testing the blend for (penetration, Softening point and Ductility) and 2% of Silica Fume was selected. Soft Asphalt was heated to nearly 25°C, and the Silica Fume was added to the asphalt cement with stirring until homogenous blend was achieved, mechanical blender continued the mixing and stirring for 30 minutes [2]. For the Addition process, addition of additives powder to dry aggregates is the simplest method of incorporating the additive into asphalt mixes. It was first adopted by the State of Georgia in early 1980's. In this method, the additive and mineral filler is incorporated in a drum mixer just after the point at which asphalt is introduced. The additive thus introduced comes in contact with aggregates and directly results in improved bond between aggregate and asphalt. Some portion of additive that fails to come in contact with aggregate will get mixed with asphalt. This result in additive reacting with highly polar molecules in asphalt to form insoluble salts that no longer attract water thus reducing stripping and oxidation potential [3].

2. Framework, Materials and Methods

2.1 Operational and Theoretical Framework

Two steps required to achieve the study objective as shown in Figure 1. The first step is the tests done on mixture components; while second step is the tests done on prepared specimens:

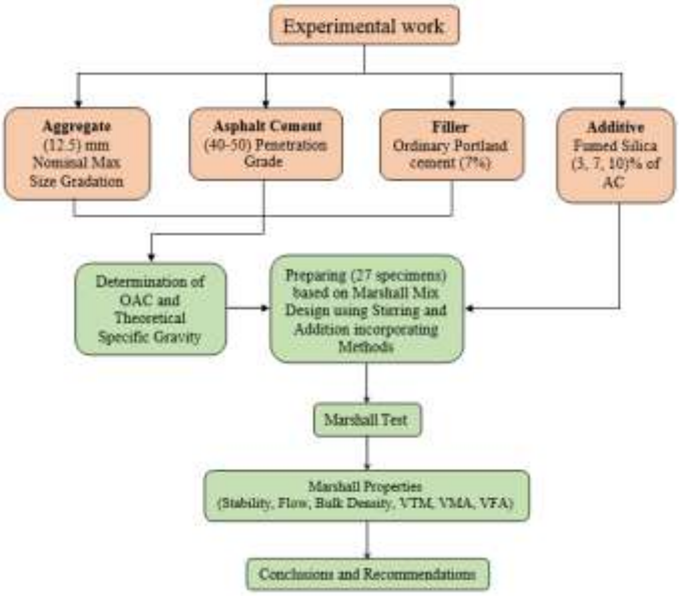

Figure 1: Flow Diagram for Laboratory Analysis Process

2.2 Materials

2.2.1 Asphalt Cement

Asphalt cement of penetration grade (40-50) was used as a binder; it was brought from Al-Dura refinery. Table 1 presents the physical properties of asphalt cement.

Table 1: Physical Properties of Asphalt Cement

Property	*Dura Asphalt Cement*
Penetration (0.01mm)	44
Softening point (°C)	50
Ductility (Cm)	>100

2.2.2 Coarse and Fine aggregate

Crushed coarse aggregate (retained on sieve No.4) was obtained from AL-Nibaae quarry. Crushed sand and natural sand were used as fine aggregate (passing sieve No.4 and retained on sieve No.200), brought from the same source. It consists of hard, tough grains, free from deleterious substances. Table 2 presents the physical properties of aggregate.

Table 2: Physical Properties of Coarse and Fine Aggregate

Property	*Coarse Aggregate*	*Fine Aggregate*
Bulk specific gravity	2.610	2.640
Water absorption (%)	0.448	0.720
Los Angeles Abrasion (%)	22.2	-

The selected gradation in this study followed by [4] specification for wearing course with 12.5 (mm) nominal maximum aggregate size. Table 3 shows the selected aggregate gradation.

Table 3: Physical Properties of Asphalt Cement

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.075
Finer by weight (%)	100	95	83	59	43	13	7
(SCRB 2003) Specification	100	90 - 100	76 – 90	44 - 74	28 – 58	5 – 21	4 – 10

2.2.3 Mineral Filler

Ordinary Portland cement has been used as mineral filler in this study, which is obtained from Tasluga cement factory. The physical properties are shown in table 4.

Table 4: Physical Properties of Mineral filler

Property	*Test Results*
Specific Gravity	2.794
Passing sieve No.200 (0.075mm) (%)	94

2.2.4 Additive

Fumed silica (F.S) as shown in Figure 2 was used for this study. It is produced by a vapor phase hydrolysis process using chlorosilanes such as: silicon tetrachloride in a flame of hydrogen and oxygen. It is supplied as a black, fluffy powder, Chemical compositions and physical properties were tested in the laboratories of General Directorate of Geological survey and Mining and given in Table 5 and 6, respectively.

Table 5: Chemical Components of Fumed Silica

Component	SiO_2	Fe_2O_3	Al_2O_3	TiO_2	CaO	MgO	SO_3	L.O.I
Test Result	99.1	35 ppm	< 0.035	< 0.006	0.03	52 ppm	< 0.07	0.7

Table 6: Physical Properties of Fumed Silica

Property	*Test Results*
surface area (m²/g)	450
Density (kg/m³)	170
Loss of weight when drying at 1000˚c for 2hrs (%)	< 2
Loss of weight (%) when drying at 105˚c for 2 hrs	< 1.5
pH	4.3
Retained on 40 µm sieve (%)	< 0.04
Moisture (%)	0.82

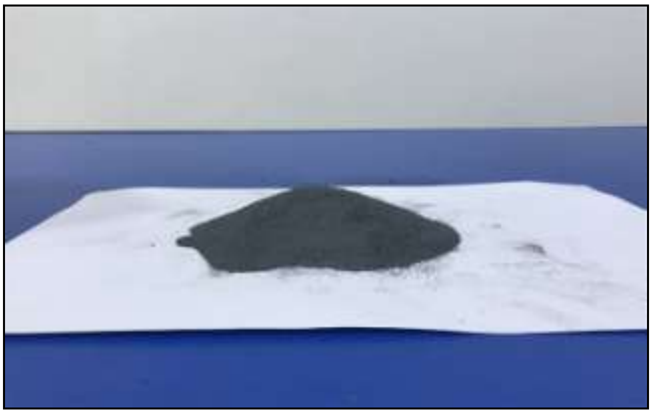

Figure 2: Sample of Fumed Silica

2.3 Methods of Preparing Marshall Specimens and Tests

2.3.1 Preparation of Marshall Specimens

The specimens were prepared in accordance with [5], aggregates and filler were put in the pan, then, the pan was put in the oven and being heated to (160) °C, the pan was charged with the heated aggregates and dry mix thoroughly. Asphalt was heated up to (150) ^{0}C prior to mixing, and it was added to the hot aggregate in the pan. The aggregates and asphalt cement were rapidly mixed using automatic mixer until thoroughly coated and viscosity was (170 ± 20) cSt, and lastly, the mixture was removed from the pan and was ready for compaction process. The procedure begins with recording the mixture temperature and observing until it reaches the desirable compaction temperature. The mold is 4″(10.16 cm) in diameter and 2.5″ ± 0.05 (6.35 cm) in heighten assembly and the face of compaction hammer was cleaned and heated in oven at (120) to (150) ^{0}C, filter paper that was cut into pieces was placed in the bottom of the mold before the mixture is introduced, the mixture that has been prepared is then placed in the mold, and stirred by the spatula or trowel for (15) times around the perimeter and (10) times over the interior, the collar is removed and the surface will be smoothed with the trowel to slightly rounded shape, next, the compaction temperature immediately prior to compaction temperature was (140) ºC and viscosity (280 ± 30) cSt, the collar then will be assembled to the compaction pedestal in the mold holder, the (75) blows of compaction hammer are applied with a free fall of 4.536 kg (10 lb) sliding weight and a free fall of (457.2) mm from the mold base, and the compaction hammer is assured to be perpendicular to the base of the mold assembly, after compaction, the base plate is removed and the same blows are applied to the bottom of the specimen that has been turned around, after that, the collar is lifted from the specimen carefully. Next, the specimen was transferred to smooth surface at room temperature for over-night [6]. The procedure of mixing and compaction are shown in Figure 3

Figure 3: Procedure of Preparing Marshall Specimen

In this study, modified Marshall Specimens were prepared based on the two methods of incorporating the additive (fumed silica) into the HMA concrete as shown later. Three percentage of the fumed silica were added, these are (3, 7, 10)% by weight of asphalt cement, but also the methods of addition subdivided into the two groups:

The first group refers to the addition of F.S as a percentage of the total weight of AC (the weight of modified AC stayed constant) as shown in Table 7. While, the second group refers to the addition of F.S as a percentage of the total weight of AC (as additional amount) to the weight of A.C shown in Table 8.

Table 7: Weights of AC and F.S in the Mixes of First Group

Percentage of F.S (%)	*Asphalt Cement (g)*	*F.S (g)*	*Total Weight of Modified A.C*
3	55.3	1.7	57
7	53	4	57
10	51.3	5.7	57

Table 8: Weights of AC and F.S in the Mixes of Second Group

Percentage of F.S (%)	*Asphalt Cement (g)*	*F.S (g)*	*Total Weight of Modified A.C*
3	57	1.7	58.7
7	57	4	61
10	57	5.7	62.7

2.3.1.1 Preparation of Specimens using Stirring Process

This process was used by many researchers. [1], used this process where the fumed silica was added to the asphalt cement with stirring on the hot plate until homogenous blend was achieved, fabricated mechanical blender continued the mixing and stirring for 30-45 minutes.

In this study, two types of specimens were prepared based on the stirring process. The fumed silica added and mixed on the hot plate with a hot AC for 45 minutes as a constant blending time using manufactured mechanical blender operates with a 2400-2900 rpm on 0.6/0.8A (220V and 50/60Hz) as shown in Figure 4.

Figure 4: Manufactured mechanical blender

18 modified specimens with (3, 7, 10)% of F.S were prepared for this method. 9 of them based on addition of F.S as in first group which mentioned previously represented by (F.S% by wt. of AC), as shown in Figure 5.

Figure 5: Modified Marshall Specimens with (F.S% by wt. of AC)

Another 9 specimens based on addition of F.S as in second group which mentioned previously represented by (F.S% + AC), as shown in Figure 6.

Figure 6: Modified Marshall Specimens with (F.S% + AC)

2.3.1.2 Preparation of Specimens using Addition Process

In this method, the additive and mineral filler is incorporated in a drum mixer just after the point at which asphalt is introduced as used by [3]. 9 modified specimens with (3, 7, 10)% of F.S were prepared for this method based on addition of F.S as in second group which mentioned previously represented by (F.S% AC), as shown in Figure 7.

Figure 7: Modified Marshall specimens with (F.S% AC)

2.3.2 Marshall Test

Procedure of preparing and testing specimens according to this method as shown in Figure 8 is described in [5]. This method covers the measure of the resistance to plastic flow of cylindrical specimens (2.5 in. height and 4.0 in. diameter) of asphalt paving mix loaded on the lateral surface of specimen holder by means of Automatic Marshall apparatus shown below, at a constant rate of (50.8) mm/min until the maximum load was reached. The maximum load resistance and the corresponding strain values were recorded as Marshall stability and flow respectively, at test temperature of (60) °C for (30 to 45) minute in water bath. The entire test was performed within (30) sec after the specimen was removed from water bath. Three specimens for each combination were prepared and average results are reported.

Figure 8: Marshall Test Procedure

3. Results and Discussions

3.1 Optimum Asphalt Content (OAC)

The primary objective of Marshall mix design was to determine the OAC of the designed mixes, with 75-blows compaction using Marshall hammer.

Mixtures with four different asphalt contents (4, 4.5, 5, 5.5)% were prepared and tested. OAC for control mixture of (4.7)% by weight of mixture was obtained by averaging the three values of AC at maximum stability, bulk density and (4)% air voids as shown in Figure 9.

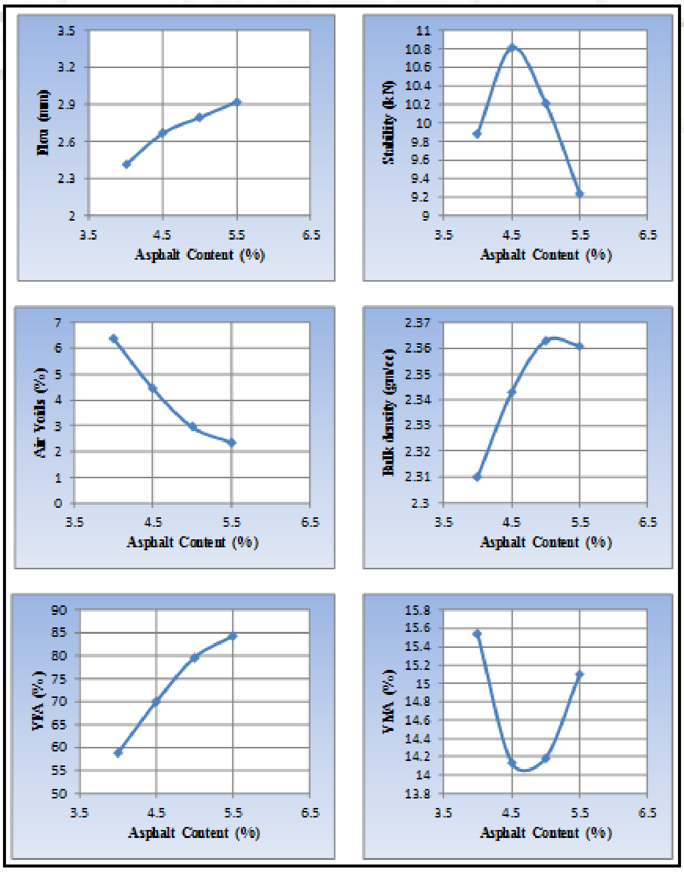

Figure 9 Marshall Test Results for Control Mixture

3.2 Marshall Test

Specimens of Marshall test were prepared by adopting OAC of (4.7)% with (3, 7, 10)% of F.S based on stirring and addition processes of incorporating F.S with AC as mentioned previously, then Marshall properties of these specimens compared with those prepared by OAC alone (control mixes). Data of Marshall Test are mentioned in Table 9.

Table 9: Results of Marshall Test

Asphalt Cement (%)	*F.S (%)*	*Stability (kN)*	*Flow (mm)*	*Bulk Density (g/cc)*	*V.T.M (%)*	*V.M.A (%)*	*V.F.A (%)*
Control Mix	-	10.600	2.720	2.350	3.850	14.725	73.900
F.S% by wt. of AC	3	11.49	2.70	2.330	4.800	15.560	70.260
	7	7.231	0.463	2.266	7.320	17.795	58.917
	10	5.770	0.737	2.252	7.902	18.311	56.855
F.S% + AC	3	14.410	1.213	2.347	4.001	14.851	73.722
	7	6.927	0.613	2.250	7.965	18.368	56.669
	10	6.252	0.933	2.245	8.172	18.551	56.042
F.S% AC	3	10.017	3.303	2.339	4.333	15.146	71.402
	7	8.822	2.870	2.254	7.817	18.236	57.181
	10	10.895	3.590	2.250	7.989	18.389	56.574
SCRB Specification	-	≥ 8	2 – 4	-	3 – 5	≥ 14	70 - 85

3.2.1 Marshall Stability

Results of Marshall Test as mentioned in Table 8 indicated that the stability of mixtures containing (3% F.S by wt. of AC), (3% F.S + AC), and (10% F.S AC) had higher stability values than that of control mixtures by (8.66, 36.31, and 3.06)%, increasing in stability show that stirring method (3% F.S + AC) gives good values, this may be due to the homogenous blend was achieved between F.S and AC. While specimens containing (7, 10% F.S by wt. of AC), (7, 10% F.S + AC), and (3, 7% F.S AC) had lower stability values than those of control mixtures by (31.6, 45.42, 34.43, 40. 86, 5.24, and 16.54)%. Decrease in stability values in the mixture containing additives, may be due to the amount of additives within asphalt cement in the mixture which create loose contact points between the aggregates therefore resulting in lower values of stability.

3.2.2 Marshall Flow

Results of Marshall Test as mentioned in Table 8 indicated that the flow of mixtures containing (3, 7, 10% F.S AC) had significantly higher values than that of control mixtures by (19.69, 3.99, and 30.07)%, results show that addition process gives values more than stirring process. While specimens containing (3, 7, 10% F.S by wt. of AC), and (3, 7, 10% F.S + AC) had lower values than those of control mixtures by (2.17, 83.21, 73.31, 56.04, 77.78, and 66.18)%. Regardless of finding the same amount of asphalt content for all mixtures, but the increase in flow values in the mixture prepared by addition process, may be due to the present of F.S molecules between aggregates which prevent AC to penetrate the spaces easily resulting in higher values of flow.

3.2.3 Bulk Density

Results of Marshall Test as mentioned in Table 8 indicated that the bulk density of mixtures containing (3, 7, 10% F.S by wt. of AC), (3, 7, 10% F.S AC), and (3, 7, 10% F.S + AC) had lower values than those of control mixtures by (0.99, 3.61, 4.22, 0.16, 4.29, 4.50, 0.51, 4.13, and 4.31)%. Mixtures containing (3% + AC) which prepared using stirring process of incorporating F.S with AC, shows that the values of bulk density is lower than control mixtures by (0.16%), which means that this amount of F.S is not effecting significantly the bulk density of modified mixtures, that may be used to improve another property of Marshall properties. While another percentages are significantly influencing the bulk density, this is related to some additives are dispersed less homogeneously when mixed.

3.2.4 Voids in Total Mix (V.T.M)

Results of Marshall Test as mentioned in Table 8 indicated that the VTM of mixtures containing (3, 7, 10% F.S by wt. of AC), (3, 7, 10% F.S + AC), and (3, 7, 10% F.S AC) had higher values than those of control mixtures by (24.74, 90.17, 105.30, 3.96, 106.95, 112.31, 12.58, 103.10, and 107.56)%. Also mixtures containing (3% + AC) which prepared using stirring process of incorporating F.S with AC, shows that the values of VTM is higher than control mixtures by (3.91%), which means that this amount of F.S is not effecting significantly the VTM of modified mixtures, that may be used to improve another property of Marshall properties. While another percentages are significantly influencing the VTM with a high values, this is probably due to the greater surface areas that need to be wetted by binder failing which would lead to an increase in VTM.

3.2.5 Voids in Mineral Aggregate (V.M.A)

Results of Marshall Test as mentioned in Table 8 indicated that the VMA of mixtures containing (3, 7, 10% F.S by wt. of AC), (3, 7, 10% F.S + AC), and (3, 7, 10% F.S AC) had higher values than those of control mixtures by (5.68, 20.86, 24.36, 0.87, 24.75, 25.99, 2.87, 23.85, and 24.89)%. Also mixtures containing (3% + AC) which prepared using stirring process of incorporating F.S with AC, shows that the values of VMA is higher than control mixtures by (0.87%), which means that this amount of F.S is not effecting significantly the VMA of modified mixtures, that may be used to improve another property of Marshall properties. While another percentages are significantly influencing the VMA with a high values. This property is significant in so far as the pavements of hot regions are concerned because asphalt may be prone to bleeding and amounting void ratio could prevent bleeding by providing more spaces for the binder to move into. This was probably due to greater surface areas to be coated.

3.2.6 Voids Filled with Asphalt (V.F.A)

Results of Marshall Test as mentioned in Table 8 indicated that the VFA of mixtures containing (3, 7, 10% F.S by wt. of AC), (3, 7, 10% F.S + AC), and (3, 7, 10% F.S AC) had higher values than those of control mixtures by (5.68, 20.86, 24.36, 0.87, 24.75, 25.99, 2.87, 23.85, and 24.89)%. Also mixtures containing (3% + AC) which prepared using stirring process of incorporating F.S with AC, shows that the values of VFA is higher than control mixtures by (0.87%), which means that this amount of F.S is not effecting significantly the VFA of modified mixtures, that may be used to improve another property of Marshall properties. While another percentages are significantly influencing the VFA with a high values. The increase of VFA indicates an increase of effective asphalt film thickness between aggregates, which will results in decreasing cracking.

4. Conclusions and Recommendations

- Results show that modified specimens prepared based on stirring process and containing (3% + AC) give a good resistance to plastic flow when compared to other types of mixtures.
- It is recommended to evaluate the moisture and temperature susceptibility when using stirring process due to the large variation in temperature range usually practiced in Iraq.
- It is recommended to modify asphalt concrete by using another types of additives such as crumb rubber, fly ash, and etc.
- It is recommended to study the laboratory performance of modified asphalt concrete using paving materials conform to the Superpave mix design requirements.

5. Acknowledgment

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Author Profile

Al-Obaidi was born in Baghdad, Iraq since 1987; received the B.S. in Civil Engineering and M.S. degrees in the field of Roads and Transportation from the Department of Civil Engineering, University of Baghdad in 2009 and 2013, respectively; worked as supervisor engineer with a Turkish Staff (Dec. 2009 - Jan. 2011); Project manager for Dana Al-Rafedain Company (Feb. 2011- June 2011); Supervisor engineer for Tefirom Group Company (July 2011 – Jan. 2012); Project manager for ABT Company (June 2012 – Jan. 2013); Supervising engineer for KAR-PET Company (Jan 2013 – June 2014). He now a faculty member in Al-Farabi University College, Civil Engineering Department, Baghdad, Iraq, since (September 2014). He appointed as a coordinator of the Department for three years ago and now he is a head of the Quality and Accreditation of the Scientific Laboratories of the Civil Engineering Department.