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Effect of Adding Steel Filings Aggregates on The Properties of Hot Mix Asphalt

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ABSTRACT

Hot Mix Asphalt (HMA), which are used in road's courses and flexible pavement structures, consisting of fine and coarse aggregates, filler, and binder(asphalt) ,mixed together in percent's according to a specific specifications.
The main objective of this study is to investigate experimentally the effect of adding Steel Filing Aggregate (SFA) on the properties of Hot Mixtures Asphalt for surface layers.
Steel filing Aggregate is a product of filing, drilling, and cutting of steel industry which, can be used as a partial replacement for fine aggregate in the creating Hot Asphalt Mixtures, for economical , environmental, and improvement purposes.

The proposed mix designs specimens test of HMA for surface layer were prepared using : obtained Optimum Asphalt Content (OAC) (where the asphalt of penetration grade 40 was provided from Begi Oil Refinery, which was determined to be equaled 5.07 % (of the total weight mix) , ordinary portland cement as the mineral filler by 5 % (of the total weight of aggregates) and locally aggregates, and then tested according to Marshall test method (ASTM- D-1559&MS-2).

Steel Filling Aggregates (SFA), which were passing through the sieve No.4 (4.75 mm) were added to the above HMA samples in three different percentages which were 5 % , 10 % and 20 % (of the total weight of mix) in order to evaluate their effects on some of the Marshall test properties of HMA .

The experimental results and calculations for Marshall Tests on mix designs specimens test of HMA showed that adding SFA by above percentages on HMA, satisfy the requirements of the Iraqi General Specification for Roads & Bridges (SORB/2003) and has given significant improvement .The results also showed that 10% of SFA (of the total weight of mix) is the optimum percent .

Keywords:

First keyword; Second keyword; Third keyword; Fourth keyword; Fifth keyword; Sixth keyword.

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1. INTRODUCTION

Hot Mix Asphalt(H.M.A.)created from materials and the asphalt act to adhere to the aggregates. Because the characteristic of asphalt is the "glue" that will cause to hold the pavement together, pavement failuremay be expected if the asphalt cannot adhere the mixtureasphalt together . HMA is commonly motioned referring to the bound courses of flexible paving structures, which used in the surface course, base course of roads and airfield pavements. The design of asphalt paving mix, similar to the design of other materials of engineering is widely a matter of selecting and percent's of constituent materials to obtain the desired properties in roads and pavement structure. Commonly, in most applications, the asphalt concrete materials is mixed in high temperatures, placed as HMA then compacted at atmosphere temperature. HMA is typically layered for surface layer and binder course in 10-20 cm. thick corresponding on the design limits. The aggregates in the top layer (which known as the friction or surface layer) are selected for their durability and friction properties, while the aggregates in the lower layer (which known as the binder course) are selected to prevent rutting and failure. Designing HMA for specific road or pavement, the selected aggregates must be durable, strong, and have a good angular shape to prevent rutting. Mineral filler is selected to fill in the voids between the coarse particles, this property leading to increasing the bulk density of the asphalt concrete or HMA and produce load transfer between the particles of layer. The percent of asphalt is selected to satisfy a specific specification between (4- 6) % (of the total weight of mix).

Waste steel filling aggregate is a kind of industrial waste which generated during steelmaking can be used as a part of fine aggregate in producing hot asphalt mixtures for the construction of pavements due to the two great benefits may be gained, firstly in reducing the amount of aggregates, secondly in disposal problem.

2 - BACKGROUND LITERATURE REVIEW :

Majority of research workers had inspected the addition of steel slag and Steel Filing Aggregate (SFA) in HMA .The early investigations were preformed on the addition of SFA on Hot Mixture Asphalt with varying percentages of SFA. Most of them were concerned with the addition of steel filing aggregate in H.M.A as a replacement of the fine aggregate.

Csanyihad explained the functions of fillers. The "Filler Theory" presumes that particles coated with asphalt and fill the voids in the aggregate." Mastic Theory" presumes that the filler and asphalt combine together to form the mastic which fills the voids and binds the particles of aggregates.[1].

Al-Qaisiinvestigated the effect of filler type and their percentages on the properties of HMA. He claimed that the ratio of filler/asphalt (F/A) which required to provide the desired properties of HMA influenced by the filler type used[2].

Prithviinvestigated the effect of adding Waste Materials in Hot Mix of on properties of asphalt mixtures. He found that mixing filler with asphalt before mixing with aggregate produce a higher stability and more uniform mix than using the conventional method of mixing and suggested to test this method (premixing of asphalt) at site construction as a mean of instituting tighter control over the critical F/A ratio[3].

Yue Xiaoevaluated the effect of Steel slag powder as filler on the crack resistance of asphalt mixtures and results suggested that the particles in steel slag powder and limestone powder possess both obvious edges , corners and coarse surface textures[4].

Theexperimental results and calculations for Marshall Test on mixtures designs specimens of HMA for the surface layers showed that, adding SFA on the HMA by 10% (of the total weight of mix) has a obvious improvement on the properties of(H.M.A.) , comparing with other used percentages of (SFA) .

3-METHODOLOGY AND MATERIALS :

The Roads Laboratory in Civil Engineering Department / Mosul University , the Marshall Stability and Flow apparatus test had been used in this research .

In Marshall stability test method of hot-mix asphalt paving mixtures design with five percentages of asphalt contents of 4% , 4.5% , 5% , 5.5% and 6% (of total weight of mix) ,three compacted specimens test for each of these percentages of asphalt contents are prepared using the: selected gradation of aggregates as shown in Table (3) ,ordinary portland cement by 5 % (of the total weight of mix) as the mineral filler, and tested according to (ASTM-D-1559 & MS-2) .The results of testing are calculated and formulated as shown in Table No.(8), then drawn graphically in six curves with percent of asphalt content on thex-axis and the following properties on the y-axis

All materials which were used in this studywere locally obtained and then tested as follows :

3-1 Asphalt:

The terms of asphalt and bitumen are often referring to the mean of natural and manufactured forms of the substance. Asphalt term is commonly used for the refined residue from the distillation process of oils, while bitumen term used for the naturally occurring variety. Asphalt or bitumen is a black in color, sticky and highly viscous liquid. The asphalt is commonly used in pavements as the binder or the glue, due to itsexcellentcharacteristicengineering such as elasticity, adhesion, and water resistance

Asphalt grade (40-50) from Begi Refinery was brought and used in this study. Such grade is widely used in pavements and Roads construction projects.The relative characteristic indexes were testedaccordingto the Specifications of organization of Roads and Bridges (SORB2003) , and the physical properties of this asphalt used are shown in Table (1)[5] .

3-2 Aggregate:

Aggregates are dominant granular materials such as sand, gravel, slag, recycled concrete, and broken stone. Aggregates are using in preparing asphalt mixtures, when mixing with asphalt to form asphalted concrete, in order to give volume, stabilizer for base and sub base courses in roads construction, and resistance to wear.

Aggregates can be classified depending upon their mineral size, chemical and physical properties into fine and coarse aggregates .Fine aggregates or as its called sand are those which has the particle size between 2 mm - 4.75 mm .

Coarse aggregates are those which have particle size more than 4.75 mm. The physical properties of fine and coarse aggregates are listed in Table (2).

Thecombined aggregates gradation was selected approximately to satisfy the job mix limits of the gradation. Aggregate gradation was specified by the (SORB/2003) for graded dense and paving mixtures for wearing course. The coarse and fine aggregates were sieve analyzed and decomposedin the laboratory to give almost similar controlled gradation and to satisfy the selected aggregate grading (design grading) of HMA for wearing coursewhich was used in this study shown in Table (3) .

3-3 Mineral filler:

A mineral filler is the smallest particles i.e. a fine aggregate which used in asphalt mixtures and passed through the sieve number 200 (0.075mm).Ordinary Portland cement and limestone powder are the most commonly manufactured mineral filler used in HMA.

In this study, only ordinary Portland cement was used of 5 % (of the total weight of aggregates).The physical properties for this mineral filling and Steel filling aggregates (SFA) are shown in Table (4).

3-4 Steel filingsaggregate:

Waste Steel Filings Aggregates (SFA) were collected from Mosul Industry Zone to be use in this research and crushed and ground to pass the standard sieves as shown in Table (6). The SFA were added to replace fine aggregate in proportion of 5%, 10% and 20% (by total weight of mix) in Hot Mix Asphalt (HMA).

SFA must be "clean", without absorbed chemicals, clay coatings and other fine materials in concentrations that could alter the hydration and bond of the cement paste.The chemical composition of SFA is different referring to the steel making practice and the quality of steel being produced. However, in accordance with the description from Federal Highway Administration (FHWA) [6].

The chemical composition of steel filling aggregate is usually include four main oxides, which are lime, silica, alumina, and magnesia. Other elements include, iron, alkalis, manganese, trace, sulfur and some others. Table (7) shows the list of different ranges of compound includes in S.F.A.

There were many grades of steel filling that can be produced, and the properties of the steel filing can change significantly medium , and low, depending on the carbon content of the steel, High-grade steels had high carbon content . To reduce the amount of carbon in the steel, greater oxygen levels were required in the steel-making process [7].

3-5 Mechanical propertiesof steel filing aggregate:

The processed steel filing according to the F.H.W.A has suitable mechanical properties for general use as partial replacement of fine aggregate in construction. Due to the advantages which may produce as good abrasion resistance and high bearing strength. These properties greatly improve the performance of asphalt mixes which using in pavement allowing it to produce better skid resistance than the natural aggregate. SFA has a higher degree of internal frictionand higher shear strength comparing with natural aggregate[6]. FHWA has generated the mechanical properties of steel filing aggregate as shown in Table (7).

3-6 Marshal method for mix design of asphalt concrete :

Asphalt mixtures are used commonly in the wearing and base courses of pavements. The asphalt mix usually consists of aggregates ,mineral filler and asphalt binder .The asphalt mix design for pavements was commonly denoted by selecting and proportioningtheconstituent materials to satisfy the required specification for the desire road .

3-7 Procedure of marshal test method for preparation the mix design specimens of asphalt concrete:

Marshall Stability test method of mix design was used with five percentages of asphalt contents.For each of these percentages three cylindrical specimens of testing were prepared, compacted, and tested according to (ASTM-D-1559 & MS-2) in order to obtain the optimum asphalt content (O.A.C).

3-8 Preparation marshal test method for mix design of asphalt concrete:

Sample for each mix design was prepared using the selected coarse aggregate, fine aggregate, the mineral filler and percentage of asphalt content according to (ASTM-D-1559 & MS-2) and the requirements of the Organization of Roads and Bridges Specifications (SORB 2003) as listed in Table (3).

3-9 Parameters ofstability and flow tests:

In conducting the stability and flow test, the specimen is immersed in a water bath at a temperature of 60˚C for 30 minutes. Then, the specimen placed in the Marshall Stability and Flow Test Apparatus and loaded at a constant load rate of 5 mm per minute until failure of the specimen occurred .The obtained maximum load in KN (which causes the failure of the specimen) is recorded as **Marshall Stability value** . The Stability value is corrected for the height of specimen using Stability correlation ratios. The total amount of deformation of units of 0.25 mm that occurs at maximum load is recorded as **Flow value**. The total amount of time between removing the specimen from the water bath and completion of the test should not exceed 30 second [8].

3-10 The Bulk Specific Gravity of (G_{mb}) :

The bulk specific gravity of the compacted specimen (G_{mb}) calculated as follow:

$$G_{mb}=\frac{A}{B-C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where:

G_{mb} = bulk specific gravity of the compacted specimen.

A= dry weight of the compacted specimen (g).

B=(SSD)weight of the compacted specimen (g).

C=submerged weight of the compacted specimen (g).[9]

3-11 Theoretical density and maximum specific gravity (G_{mm}) / AASHTO T209 :

TheTheoretical Maximum Specific Gravity of Hot Mix Asphalt Paving Mixtures(G_{mm}) / AASHTO T209 calculated as follow:

$$(G_{mm}) = \frac{A}{A+D-E} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

G_{mm} =The Theoretical Maximum Specific Gravity of the asphalt mixture sample . A = weight of dry sample in air.

D = weight of pycnometer filled with water at test temperature.

E = weight of pycnometer filled with the sample and water at test temperature [10].

3-12 The Bulk Specific Gravity of aggregate(G_{sb}):

When the total aggregate consists of separate fractions, the bulk specific gravity of coarse aggregate, fine aggregate , mineral filler , and SFA with different specific gravities, the of the total aggregate is computed as follows :

$$Gsb=\frac{P_1+P_2+\ldots.P_n}{\frac{P_1}{G_1}+\frac{P_2}{G_2}+\ldots..\frac{P_n}{G_n}} \quad \ldots\ldots\ldots (3)$$

Where :

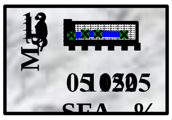
Gsb =Bulk Specific Gravity of aggregate.

P_1 = Percent by weight of aggregate 1, etc. ,

G_1 = Bulk specific gravity of aggregate 1 , etc[11].

3-13 Air voids in compacted mineral aggregate (VMA):

The air voids in the mineral aggregate (VMA) are the void spaces between the aggregate particles of the compacted mix. This void space includes the air voids and the effective asphalt content .VMA is computed as follows:

VMA =100 -  ………..(4)

Where:

VMA = Voids in mineral aggregate, in percent of bulk volume,

Gsb = Bulk specific gravity of the aggregate ,

G_{mb} = Bulk specific gravity of compacted mix ,

Ps = Aggregate percent by total weight of mix [11].

3-14 Air voids in compacted mixture (Va) :

The air voids in compacted mixture are small pockets or airspaces of air that take place between the coated aggregate particles by asphalt in the final compacted mixture. A correct percentage value of air voids is necessary in roads mixes although which small amounts of asphalt can flow during compaction operation. The allowable percentage of airvoids (in laboratory specimens) is between 2% - 4% for most wearing layer mixes or as specified by the designer. The durability of an asphalt concrete pavement is a function of the air value content .Va is calculated as follow:

$$Va=\left[\frac{G_{mm} - G_{mb}}{G_{mm}}\right]\times 100 \quad \ldots\ldots\ldots\ldots\ldots (5)$$

Where :

Va = Percent of air voids in compacted mixture,

G_{mm} = Theoretical maximum specific gravity of the compacted paving mixture ,

G_{mb} = bulk specific gravity of the compacted mixtures [12].

3-15Voids filled with asphalt (VFA):

VFA can also specify the percent of the volume of the VMA that is filled with asphalt cement. Voids Filled with Asphalt is calculated as follow:

$$VFA=100\times\frac{VMA-Va}{VMA} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where :

VFA = The percent of Voids Filled with Asphalt (VFA).

VMA = The percent voids in the mineral aggregate .

Va = The percent air voids of the total mix volume (CT 367) [13].

3-16 Optimum asphalt content:

The main objectives of a mix design are to select the Optimum Asphalt Content for a given aggregate source, binder source and the optimum aggregate gradation.

In Marshall test, the stability and the flow was measured in loading rate of (0.25) mm /min, and then the results of testing are drawn graphically in six curves with percent of asphalt onthe x-axis and the following properties on the y-axis:

1- Marshall stability, KN.

2- Marshall Flow, mm.

3- Unit weight, (Bulk Specific Gravity, Density) ,G_{mb} , g/cm^3 .

4-The percent of air Voids in Total compacted Mixture, (Va ,VTM) , % .

5-The percent of Voids in compacted Mineral Aggregate (VMA) ,% .

6- The percent of Air Voids Filled with Asphalt, (VFA) , % .

The value of (OAC) is chosen as the average percent of asphalt content for the maximum stability, maximum density and specified percent of air voids in mixture (Va), Thus:

$$A_O= \frac{A1+A2+A3}{3} \text{ ……………………… (7)}$$

Where : A_O = Optimum Asphalt Content ,

A_1 = percent of asphalt content at maximum stability,

A_2 = percent of asphalt content at maximum density , G_{mb},

A_3 = percent of asphalt content at specified air voids in mixture, Va[8].

4-RESULTS AND DISCUSSIONS:

Marshall stability test method of hot-mix asphalt paving mixtures design was followed with five percentages of asphalt contents of 4% , 4.5% , 5% , 5.5% and 6% (of total weight of mix) ,three compacted specimens test for each of these percentages of asphalt contents are prepared and tested according to (ASTM-D-1559 & MS-2) .The results of testing are calculated and formulated as shown in Table No.(8) , then drawn graphically in six curves with percent of asphalt content on thex-axis and the following properties on the y-axis : Marshall Stability, Marshall Flow, (G_{mb}) , (VMA) , (Va) and (VFA), as shown in Figures (5.1 to 5.6) .

The value of Optimum Asphalt Content (OAC) was obtained using the Curves in Figures (5.1, 5.3 and 5.5) as the average percent of asphalt content at the maximum stability, the maximum density (Gmb) and specified percent of air voids in total mixture (Va) .

Thus OAC= **5.07 %** (of the total weight of mix).

In Marshall stability test method of hot-mix asphalt paving mixtures design with the obtained OAC of asphalt contents of 5.07 % (of total weight of mix) and with three percentages of Steel Filing Aggregate (SFA) of 5% , 10% and 20% (of total weight of mix) , three compacted specimens test for each of these percentages of (SFA) are prepared and tested according to (ASTM- D-1559&MS-2) . The results of testing are calculated and formulated as shown in Table No. (10), then drawn graphically in six curves with percent's of SFA onx-axis and the following on y-axis: Marshall Stability, Marshall Flow, (G_{mb}), (VMA), (Va) and (VFA) as shown in Figures (from 5.7 to 5.12) in order to evaluated the addition of SFA in the Hot Asphalt Mixtures.

5- CONCLUSIONS AND RECOMONDATIONS :

5 -1 Conclusions:

From the studies on the addition of SFA on HMA described in this study , thefollowing conclusions can be summarized as follow :

1 - The value of optimum asphalt Content (OAC) was determined as equal to **5.07 %** (of the total weight of mix).

2-Using theresults in table no. (10), the value of the optimum percent of SFA to be added on the HMA, was chosen as equal to 10%(of the total weight of mix which led best improvement in Marshal properties, comparing with other percent's values of SFA used in this study.

3 -The experiential results of Marshall properties tests on the mix design of HMA for wearing course using the obtained OAC and with the addition of SFA by 10% % (of total weight of mix) showed that satisfy the requirements of the Iraqi SBRO/2003 as shown in table no.(11) .

4 - Referring to the results in table no. (10) , its observed that adding SFA by 10 % (of total weight of aggregate) on the Hot Asphalt Mixture leading to increase the Marshall stability by 4.94 %, and the bulk density by 8.4 % .While, to decrease the VMA by 5.0 % and VTM by 9.33 %, in comparison to the conventional mixtures.

5 -The addition of SFA to the asphalted concrete mixtures to the surface layer mixtures can produce many advantages such as ; excellent wheel tracking , skid resistance , good wear resistance and the high stability and consequently rutting resistance is an important asset ; winter patching . Therefore using steel filling aggregate in surface treatments that should be developed to take advantage of its skid resistance , quickly achieved stability and greater cohesive strength compared to conventional mixture.

6- SFA may improve the pores continuity in the water permeability in asphalt mixes and the adhesion with asphalt ,when the problem of stripping and moisture related damage to pavement may generated

5-2 **Recommendations:**

The recommendations may be summarized for further studies as follow:

1) The optimum Asphalt Content (OAC) is the most important criterion in preparing the Marshal specimen tests .This is because any error in obtaining the OAC value will definitely influence the test results.

2) Using the Steel Filing Aggregate, (SFA) as a replaced by the fine aggregate should be added by **10** % (of total weight of aggregate) ,when taken the Marshall stability as the first favors choice, leading to produce asphalt concrete mixtures with higher Marshall Stability, lower voids in compacted mineral aggregate (VMA) ,voids in compacted mixture (VTM) comparing without adding SFA .

3) This research was executed by using petroleum asphalt of penetration 40 was provided from Begi Oil Refinery), and the OAC was determined to be equaled 5.07 % (of the total weight mix).

4) The difference between Gmm and Gmb is the volume. Because, the weights are the same, but the compacted HMA . So the following relationship between them is always true:

Gmm ≥ Gmb

5) From an economical and environmental scopes, investigating should be taken in account for other local waste materials could be used as mineral fillers inasphalted mixtures, such as, steelfibers, steel-slag, which might be produced from lathe machines due to cutting and drilling process of steel, which can be used as a partial substitute for fine aggregate in the production of Hot Mixtures Asphalt in improvement purposes.

6) Finely, It is recommended that SFA be used as a fine aggregate replacement for sustainable development in highway constructio

Table(1)The physical properties of asphalt cement used (Grade 40-50) *:

Properties	Unit	Specification of Test	Results of Test	Specification Limits for Grade 40
Penetration 1/10 mm at 25°C, 100g , 5 sec.	0.1 mm	ASTM D-D5	46	40-50
Ductility at 25°C, 5 cm/min	cm	AASHT D -113	108	100 min.
Softening Point (R. and B.)5 C°/min	C°	ASTM D -36	57	51-62
Flash Point (Cleveland Open Cup)	C°	ASTM D -92	241	232 min.
Specific Gravity at 25 °C	-	ASTM D-70	1.04	NA
Thin Film Oven Test : Loss in mass Related Penetration of original Ductility at 25°C , 100g , 5 sec.	 % % cm	ASTM D -1754	 0.70 >55 >25	 0.75 max. 55 min. 25 min.

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

Table(3)The Aggregate specification

Sieve Size		Percentage by Passing Weight %			
Inch	mm	Job Mix limits for Wearing Course	Average limits of Job Mix	Specification Limits of SORB / R9 for Wearing Course	Average Specification Limits of for SORB / R9
1"	25	100	100	100	100
3/4"	19.0	100	100	100	100
1/2"	12.5	89.3 - 99. 7	94.5	90-100	95
3/8"	9.5	73.8 - 88.5	81.2	76-90	83
No.4	4.75	44.8 – 59.8	52.3	44-74	59
No.8	2.36	34.1 - 43.6	38.9	28-58	43
No.50	0. 3	10.3 - 19.6	15.0	5-21	13
N 200	0.075	4.9 - 9.3	7.1	4-10	7
Asphalt (% of the total weight of aggregates in mixture		4 - 6		4 - 6	

*Tested in Roads laboratory of Civil Eng. Dept. /University of Mosul

Table (2) The Physical Properties of Aggregates used*:

Properties	Type of Aggregate	
	Fine Aggregates (ASTM D-1073)	Coarse Aggregates (ASTM D-692)
bulk Specific Gravity , (gm/ cm³)	2.53	2.64
L.A. Abrasion (AASHTO T 96)	16.8	19.7
Water Absorption, (%)	0.43	0.67

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

Table (4) The Chemical Composition of the SFA used:

Component	Open Hearth Steel Filing	Basic Oxygen Steel Filing
Calcium oxide (CaO)	25.6	41.1
Silicon dioxide (SiO_2)	16.3	15.4
Iron (Fe or Fe_2O_3)	25.6	19.8
Magnesium oxide (MgO)	9.8	6.8
Manganese oxide (MnO)	11.1	8.7
Aluminum oxide (Al_2O_3)	2.5	2.1
Titanium dioxide (TiO_2)	0.9	0.4
Free lime (free CaO)	2.3	3.4

Table (5) The Sieve Analysis of Steel Filing Aggregate and Mineral Filler

Material	Specific Gravity (g/cm^3)	Passing percent weight through sieve No.200
O.P.C	3.15	95
Steel Filing Aggregate , SFA	7.38	11

Table (6) The Sieve Analysis of (SFA)*

Sieve Size		Percentage of Passing Weight %
Inch	mm	------
3/8"	9.4	100
No.4	4.75	100
No.8	2.36	97
No.16	1.18	94
No.30	0.6	59
No.50	0.3	20
No.100	0.1475	14
N o.200	0.075	8

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

(7) The Mechanical Properties of Steel Filing Aggregate used :

Property	Value
Los Angeles abrasion (ASTC131)	20% -25%
Sodium sulfate soundness loss (AST C88)	<12%
Angle of internal friction	40° - 50°
Hardness (measured by Moh's scale of mineral hardness)	6% - 7%
(CBR) California Bearing Ratio, top size 19mm	up to 300

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

Table (8) Marshall Properties determination of the Optimum Asphalt Content(OAC)*

Properties \ Asphalt percent	4%	4.5%	5%	5.5%	6%
Marshall **Stability** (ASTM D159) , KN	8.264	9.154	**9.938**	9.106	8.043
Marshall **Flow** value ,(in 0.25 mm unit), mm	2.134	2.388	2.794	3.302	3.937
Bulk Specific Gravity (G_{mb}) , g/cm^3	2.298	2.316	**2.342**	2.314	2.296
Percent Voids in compacted mineral aggregate , (**VMA**) , %	15.541	15.322	14.820	16.281	17.372
Percent of Air Voids in compacted mixture , (**Va**,VTM) , %	5.510	4.691	4.213	3.784	3.529
Percent of Air Voids Filled with Asphalt, (**VFA**) , %	64.543	69.384	71.572	76.758	79.686

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

Table (9) The Marshall Properties at OAC

Marshall Properties	Value at O.A.C.	Specification Limits of (S.O.R.B./R9) for Wearing course
Marshall **Stability** (Number of blows = 2×75), (KN)	9.202	8 KN (min.)
Marshall **Flow** value , (in 0.25 mm unit)	2.802	2 – 4(mm)
Bulk Specific Gravity, (G_{mb}) , gm/cm^3	2.308	---------
Percent Voids in compacted mineral aggregate,(**VMA**) ,%	16.086	14 % min
Percent Air Voids in compacted mixture , (**Va**,VTM) , %	4.203	3% – 5%
Air Voids Filled with Asphalt,(**VFA**), %	69.278	60% - 80%
Index Retained Strength, %	74.000	70 (min.)
Optimum Asphalt Content,(**O.A.C**)	5.070	4 – 6 (%)

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

Table (10) Marshall Properties with Different percent of SFA at O.A.C*

Properties \ SFA	0 %	5%	10%	20%
Marshall **Stability** (ASTM D159) , KN	8.739	9.106	9.171	9.022
Marshall **Flow** value, (in 0.25 mm unit), mm	2.057	2.083	2.159	2.032
Bulk Specific Gravity(G_{mb}) , g/cm^3	2.297	2.390	2.490	2.710
Percent of Voids in compacted mineral aggregate , (**VMA**) ,%	16.454	16.094	15.670	14.899
Percent of Air Voids in compacted mixture , **Va** ,VTM) , %	3.609	3.434	3.301	3.214
Percent of Air Voids Filled with Asphalt, VFA, %	78.066	78.663	78.934	78.428

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

Table (11) The comparison of Marshall Properties at OAC before and after adding SFA by 10% with SORB/2003 specifications :

Properties	Ordinary mix at O.A. **C**	S.F.A mix with 10 %	Specification of S.O.R.B
Marshall **Stability** (ASTM D159) , KN	9.202	9.171	8 KN (min.)
Marshall **Flow** value, mm	2.802	2.159	2 – 4(mm)
Bulk Specific Gravity(G_{mb}) , g/cm^3	2.308	2.490	---------
Percent of Voids in compacted mineral aggregate , (**VMA**) , %	16.086	15.670	14 % min
Percent of Air Voids in compacted mixture , **Va** ,VTM) , %	4.203	3.301	3% – 5%
Percent of Air Voids Filled with Asphalt, **VFA**, %	69.278	78.934	60% - 80%

*Tested in Roads laboratory of Civil Eng. Dept. / University of Mosul

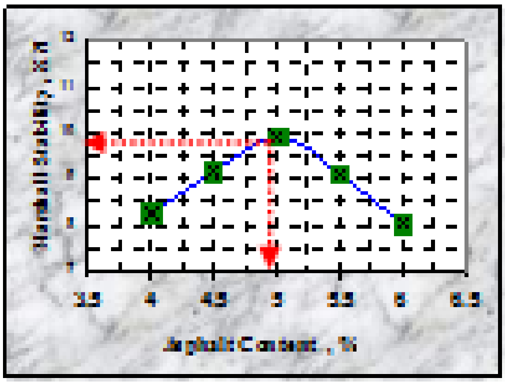


Fig.(5.1) The relationship between Marshall Stabillity and Asphalt percentage.

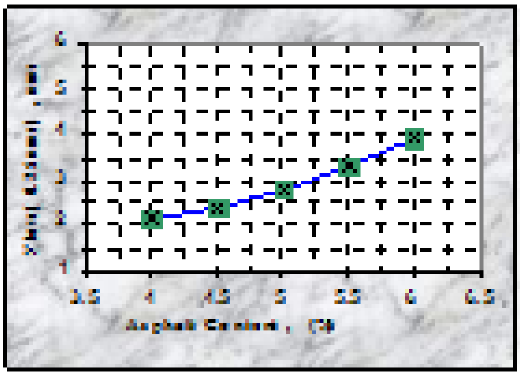


Fig.(5.2) The relationship between Flow and Asphalt percentage .

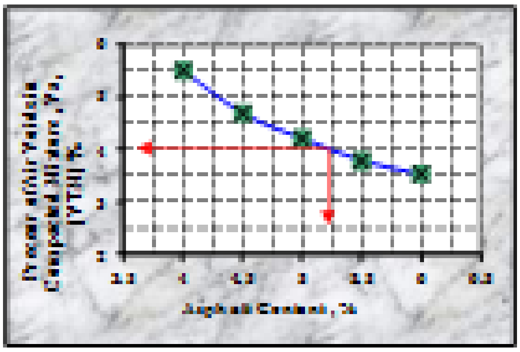


Fig.(5.3) The relationship between Bulk Density (G.m.b and Asphalt percentage.

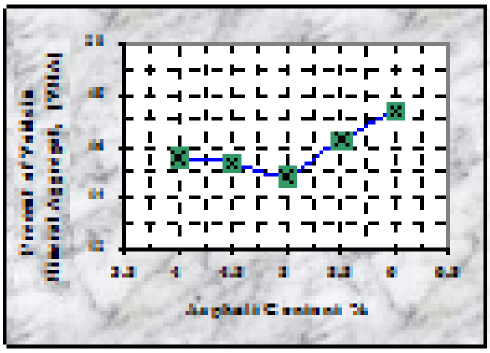


Fig.(5.4) The relationship between (VMA) and Asphalt percentage.

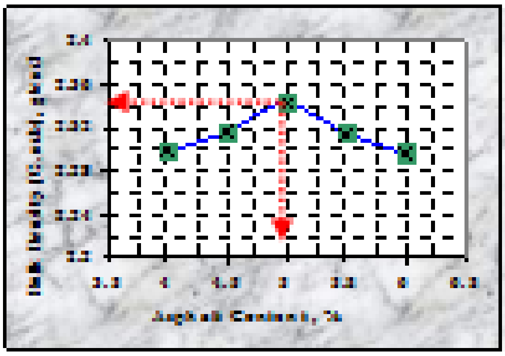


Fig.(5.5) The relationship between (Va, VTM) and Asphalt percentage.

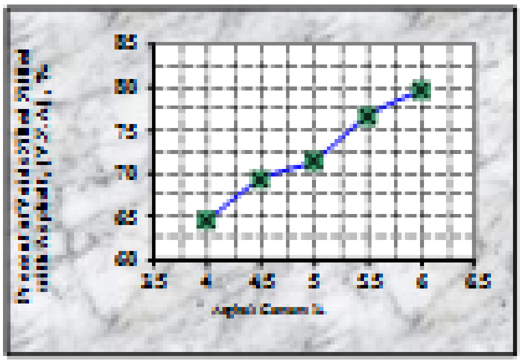


Fig.(5.6) The relationship between (V.F.A) and Asphalt percentage .

The relationships between Marshall Properties of HMA and Asphalt percentages

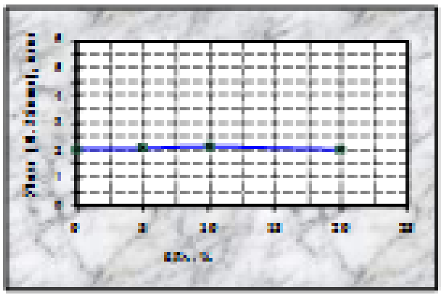


Fig.(5.7) The relationship between percentage Flow and SFA percentage

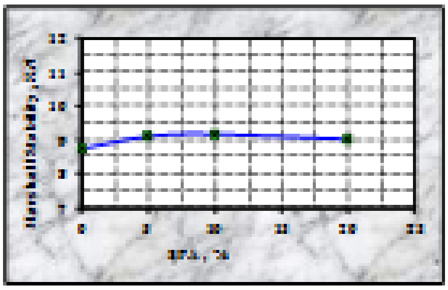


Fig.(5. 8) The relationship between Marshall Stability and SFA

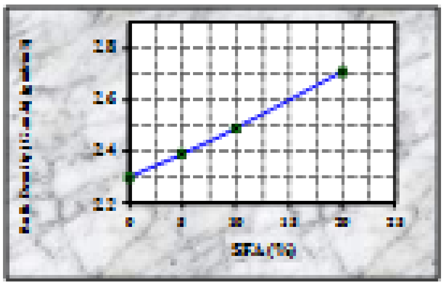


Fig.(5.9) The relationship between Bulk Density (G.m.b) and SFA percentage

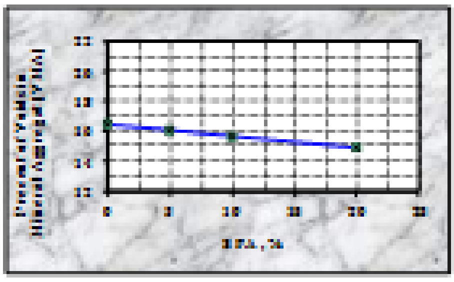
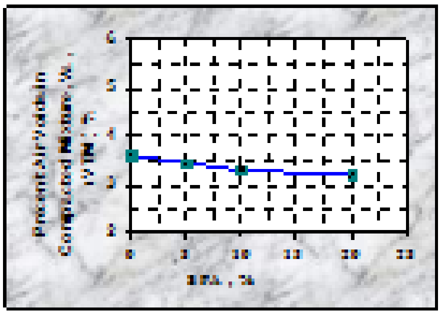


Fig.(5.10) The relationship between (VMA) and SFA percentage



g.(5.11) The relationship between (Va, VTM) and SFA percentage

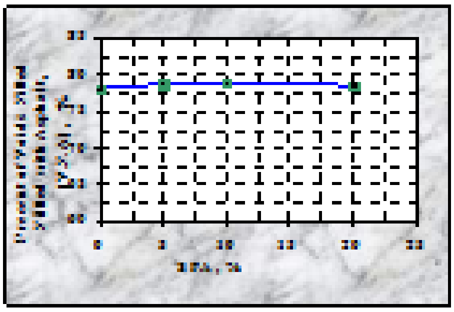


Fig (5.12) The relationship between (VFA) and SFA percentage

The relationships between Marshall Properties of HMA and Percent of SFA

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تأثير إضافة ركام برادة الحديد على خواص الخلطات الخرسانية الإسفلتية الساخنة

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المستخلص

الخرسانة الإسفلتية أو الخلطة الإسفلتية الساخنة (HMA) هي مادة مركبة تستعمل كثيرا في مشاريع الرصف المرن منها الطرق والمطارات , تتألف من ركام خشن , ركام ناعم , مادة مالئة ; والإسفلت (الذي يستعمل فيها كمادة رابطة) تمزج مع بعضها البعض بنسب وزنية وفقا لمواصفات قياسية معينة , وذلك في أفران ساخنة لمعامل خاصة بإنتاجها .

الهدف الأساس من هذا البحث هو إعداد دراسة نظرية ومختبرية حول تقييم تأثير إضافة ركام برادة الحديد على الخواص الفيزيائية للخلطات الإسفلتية الساخنة للطبقة السطحية.

ركام برادة الحديد هي تلك المادة الصناعية الناتجة من بقايا عملية البرادة والتثقيب والقطع للحديد الصناعي في بعض الورش والمعامل الصناعية والتي يمكن استخدامها كبديل جزئي عن الركام الناعم المستخدم في إنتاج الخلطات الخرسانية الإسفلتية الساخنة وذلك لأسباب بيئية (من جراء التخلص من هذه النفايات) واقتصادية (من حيث تقليل كلفة الإنتاج) ,هذا فضلا عن تعزيزها لبعض الخصائص الايجابية للخلطات الإسفلتية الساخنة.

تم إعداد مختبري عدة نماذج فحص قياسية لتمثل خلطات إسفلتية ساخنة للطبقة السطحية , وذلك باستخدام نسبة الإسفلت (بدرجة نفاذية 40-50 الوارد من مصفاة بيجي) المثالية (OAC) لكل خلطة التي تم التوصل إليها بتحليل ورسم نتائج الاختبار المختبرية بيانيا, وكانت بمقدار5.07 % (من الوزن الكلي للمزيج) , وباستخدام الإسمنت البورتلندي العادي كمادة مالئة بنسبة5 % (من الوزن الكلي للمزيج) ,وركام محلي .

أضيف ركام برادة الحديد(SFA) العابر من المنخل القياسي رقم 4 (4.75 ملم) الى نماذج الخلطات الإسفلتية الساخنة للطبقة السطحية أعلاه, بثلاث نسب وزنية مختلفة وهي 5 %, 10 % و 20% (من الوزن الكلي للركام), وذلك لتقييم مدى تأثيرها على خصائص فحص مارشال لها.

أظهرت نتائج الاختبارات بإضافة ركام برادة الحديد(SFA) للخلطات الإسفلتية الساخنة بهذه النسب الثلاثة وهي:5 % , 10 %, و 20 % (من الوزن الكلي للمزيج) ان خصائص فحص مارشال لها تقع ضمن حدود المواصفات العامة للطرق والجسور العراقية للطبقة السطحية بصورة عامة ,واعطت هذه الاختبارات تحسنا ايجابيا عليها من حيث زيادة الكثافة والثباتية, وتقليل الزحف وحجم الفراغات الهوائية, وكانت أفضل النتائج هي عند إضافة ركام برادة الحديد بنسبة10 % مقارنة مع بقية نسب الإضافة الباقية.