The Effect of Super fine Materials on Some Properties of Hot Mix Asphalt Concrete

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Abstract

The super fine materials constitute that portion of mineral filler finer than 10 microns. The effectiveness of these materials comes from their relation with asphalt film thickness. Asphalt cement grade (40-50) has been used. Nibaay course aggregate and Thmail fine aggregate were combined to achieve the aggregate gradation confirms with the Iraqi Standard Specifications for dense graded mix. Six different types of filler from five locally different sources in Iraq had used and subjected to grain size distribution, specific gravity and chemical composition tests. To study the effect of super fine materials on the performance of HMA mixture, Marshall stiffness, Indirect tensile strength, Moisture susceptibility and Creep tests have been made. Statistical analysis for results has been made. The conclusions referred to the importance of super fine materials due to their effect on HMA concrete properties.

Key Words: Superfine Materials, Hot mix asphalt

تأثير المواد بالغة النعومة على بعض خواص خرسانة الخلطات الاسفلتية الحارة

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الخلاصة

ندرس في هذا البحث الاهتزازات الحرة لعتبة مرنة تحت تأثير حركة كلية ثنائية البعد. نُمذجت العتبة باستخدام نظرية عتبة أويلر-برنولي. حُصِّلَ حل مضبوط للاهتزازات الطبيعية و ما يقارنها من أشكال الأنماط لهذه العتبة. يمكن توسيع النموذج الى عتبات واقعة تحت تاثير حركات ثلاثية الأبعاد.

1. Introduction

The superfine materials constitute that portion of mineral filler finer than 10 microns [1]. The effectiveness of these materials comes from their relation with asphalt film thickness. Many studies have been made to study the effect of film thickness, and most of them referred to that, asphalt film thickness of HMA concrete is about 10 microns [2, 3, 4]. So, if the size of the mineral filler particles is smaller than 10 microns, the filler acts as an extender of the asphalt cement because as mentioned, the thickness of most asphalt films in dense-graded HMA is less than 10 microns, but if the mineral filler size is larger than 10 microns, then it will be act like an aggregate [5].

The symbol P10 will be taken to refer the amount of super fine materials while studying their effect on HMA concrete.

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2. Materials

2.1 Asphalt Cement

One grade of (40-50) asphalt cement from Nasiria Refinery has been tested. The physical properties of this type are illustrated in Table 1.

Table 1. Physical properties of Nasiria asphalt cement.

Property	Symbol	ASTM Designation No.	Test condition and units	Results	Specification limits
Penetration	Pe	D-5	25°C,100 gm, 0.1 mm	46	40-50
Softening point	SP	D-36	Ring & ball, °C	51	-
Ductility	D	D-113	25°C, 5cm/min, cm	+100	+100
Specific gravity	Gs	D-70	25°C	1.028	-
Flash point	FP	D-92	Cleveland open cup, °C	+246	+246
Solubility	S	D-2042	Trichloroethylene Solvent, %	99	+99 %

2.2 Aggregate

Two types of aggregate were used in this study:

1- Nibaay course aggregate (passing sieve 3/4 inch and retained sieve No. 4) with 100% crushed particles, brownish in colour, quartzite mineral composition with angular faces.

2- Thmail fine aggregate (passing sieve No.4 and retained sieve No. 200) with rounded faces particles, orange in colour, quartzite mineral composition. The materials retained on sieve No. 8 consist of 50% Nibaay crashed aggregate and 50% Thmail fine aggregate.

Figure 1 shows the midline gradation of the aggregate used in the mix design. The aggregate gradation confirms with Iraqi Standard Specification for Roads and Bridges for 19 mm (3/4 inch) maximum size for surface course type III/A [8].

2.3 Fillers

Six different types of filler have been used from five locally sources in Iraq, which they are:

1- Silica powder (Si), from Arthuma quarry, about 260 Km to the north west of Ramadi city. It is used in glass industry due its high purity.

2- Sulaimania Marble powder (SM), from Sulaimania quarries for marble and tile mortar production about 300 Km to the north east of Baghdad.

3- Mosul Rock powder (MR), from Mosul quarries for rock plates and tile mortar (lime stone powder), about 260 Km to the north west of Baghdad.

4- Limestone dust (Li), from Karbala lime factory, about 180 Km to the west south of Baghdad.

5- Cement Kiln dust (Ki), is a bypass of cement production, from Kubaisa cement factory, about 95 Km to the north west of Ramadi city.

6- Portland cement (Ce), from Kubaisa cement factory, about 95 km to the north west of Ramadi city.

The laboratory tests have been conducted in order to evaluate the properties of each type of filler especially the grain size distribution, the specific gravity and chemical composition.

Hydrometer analysis was conducted on each type of the filler according to ASTM D-422 to obtain the grain size distribution for each type of filler as shown in Figure 2, which will be used to obtain the values of P10. All types of the filler are passing the sieve No. 200 (0.075 mm).

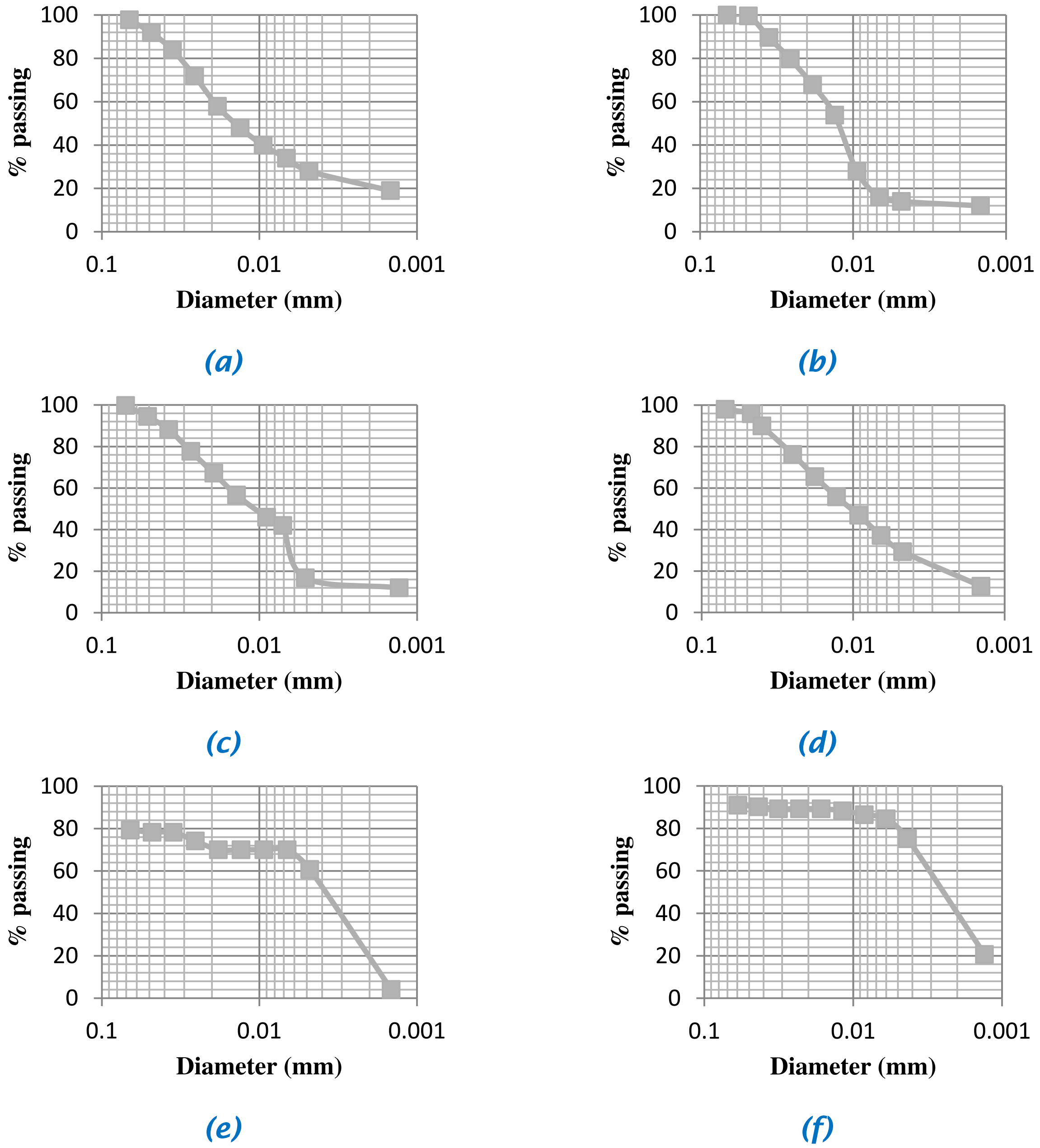

Figure 2. Grain size distribution for each type of filler. (a) SM, (b) MR, (c) Si, (d) Li, (e) Ki, and (f) Ce.

Table 2 illustrates the chemical composition of fillers, while the properties of each type of filler are shown in Table 3.

Table 2. The chemical composition of each type of filler.

Filler type		Oxides Percentage (%)						
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I
	MR	2.52	1.2	0.32	43.8	2.63	15.55	33.14
	Li	2.36	0.17	0.27	52.56	0.92	1.22	42.19
	Si	91.02	3.4	2.04	0.97	0.98	0.43	0.69
	SM	36.44	2.07	6.73	5.17	20.15	0.16	16.44
	Ki	14.82	5.25	1.98	49.65	3.35	6.33	9.77
	Ce	22.58	5.46	3.05	61.62	2.85	2.43	1.38

Table 3. The properties of each type of filler.

properties	Filler type					
	Si	SM	Li	MR	Ce	Ki
Specific gravity(Gs)	1.785	2.657	2.763	2.668	3.1	2.512
Passing 10 microns(P10)	48.5	42.00	49	32	88	70.04

3. Hot Asphalt Concrete Mixture Tests and Results

To study the effect of super fine materials on the performance of HMA mixture, several tests were made to investigate how these properties would affect.

3.1. Preparation of Marshall Mixture

The preparation of Marshall mixtures was made in accordance to ASTM D-1559 specification. Marshal specimens were made to determine the resistance to plastic flow and indirect tensile strength.

The properties of HMA concrete for each type of filler according to a series of tests for Marshall stability, flexibility (flow) and durability (density-voids analysis) was carried out on each type of filler mixtures for selecting the optimum asphalt content OAC and the determination of Marshall test parameters. Table 4 shows the parameters of Marshall test for each type of filler.

Table 4. Parameters of Marshall test for each type of filler.

Filler type	Stiffness, kN/mm	Flow, mm	Stability, kN	AV, %	Density, gm/cm^3
SM	3.42	4.27	14.60	2.60	2.425
MR	4.37	3.25	14.19	3.01	2.412
Si	4.64	3.57	16.54	2.87	2.419
Li	4.76	2.77	13.17	2.86	2.431
Ki	3.80	4.00	15.50	4.00	2.368
Ce	2.49	3.80	10.83	4.00	2.397

3.2 Indirect Tensile Strength (ITS) Test

The method covers the procedure of preparing specimens in the same method described for Marshall method and tested for ITS according to ASTM D-4123. The specimens were left to cool for 24 hours at room temperature, then were immersed in water bath at two different test temperatures (25 ºC and 60 ºC) for 30 minutes, and were tested for ITS at rate of 50.8 mm/min. (2 in./min) in Marshall compression machine until recording the ultimate load resistance. Table 5 shows the results of tests, it also consists of the results of temperature susceptibility (TS), which can be obtained as follows:

$$TS=\frac{ITS\ @\ 25-ITS\ @\ 60}{t1-t2}\ [6] \quad (1)$$

where: $t1$= 60 °C (Test temperature)

$t2$= 25 °C (Test temperature)

3.3 Indirect Retained Strength (IRS) (Temperature Susceptibility) Test

This method determines the stripping potential of asphalt cement from aggregate in asphalt concrete mixtures which is a function of the affinity between aggregate and the bitumen and its consequent ability the displacing effect of water [7]. The test was conducted according to ASTM D-4867 through which two subsets of triple specimens were prepared in the same method described for Marshall method. The results of test are shown in Table 5. Also, the table shows the results of ITS for conditioned sub set after immersing in water bath of 60 °C for 24 hours.

Table 5. The results of ITS and IRS tests.

Filler type	ITS at 25 °C	ITS at 60 °C	TS	ITS after 24 hr.	IRS
SM	1131.67	171.32	27.44	818.78	72.00
MR	1158.80	180.78	27.94	808.05	70.00
Si	1105.31	174.80	26.59	623.33	56.00
Li	1053.09	152.96	25.72	724.84	69.00
Ki	1071.75	174.33	25.64	921.48	86.00
Ce	990.90	155.41	23.87	916.64	92.50

Resistance to Permanent Deformation (Creep) Test

Diametrical indirect tensile creep test has been used to evaluate the effect of filler type on the permanent deformation tendency of HMA mixtures using different types of filler at two test temperatures 25 °C and 40 °C. Table 6 shows the results of test consisting of the values of initial stiffness instant of loading (μo) and the permanent deformation (ε_p) at the end of unloading case after 120 minutes of test.

Table 6. The results of Creep test

Filler type	μo @ 25	μo @ 40	ε_p @ 25	ε_p @ 40
SM	6.34	4.95	2.19	3.09
MR	33.83	22.67	1.30	1.72
Si	9.02	4.85	0.96	2.88
Li	7.95	7.83	2.65	2.87
Ki	9.00	8.91	1.15	1.42
Ce	22.56	16.92	1.39	1.93

4. Statistical Analysis

A simple linear regression model with a significant level of 0.05 was used to represent the relations between the properties of HMA concrete and the super fine materials percentage (P10).

Although the P10 has no effect on creep test parameters, it has a pronounced effect on ITS test parameters that are ITS at 25 ºC and TS (for a significant level up to 0.1 the P10 also affect on IRS), with a single effect on the AV in Marshall test parameters as shown in Tables 7 to 9.

Table 7. Shows the effect of P10 on Creep test parameters.

Independent	Dependant	R^2	P-value
P10	μo @25	0.005	0.893
	μo @40	0.002	0.933
	ε_p @25	0.060	0.640
	ε_p @40	0.165	0.424

Table 8. Shows the effect of P10 on ITS test parameters.

Independent	Dependant	R2	P-value
P10	**ITS @25**	**0.814**	**0.014**
	ITS @60	0.277	0.283
	TS	**0.891**	**0.005**
	ITS @25 after 24hr	0.475	0.130
	IRS	**0.624**	**0.062**

Table 9. Shows the effect of P10 on Marshall test parameters.

Independent	Dependant	R^2	P-value
P10	Stiffness	0.501	0.116
	Flow	0.096	0.550
	Stability	0.271	0.290
	% AV	**0.757**	**0.024**
	Density	0.395	0.181

As mentioned previously, the P10 refers to materials finer than 10 microns in diameter, which are called super finer materials. This factor was used to study the effect of materials with diameter less than 10 microns taking in consideration that the film thickness of asphalt is 10 microns [5]. This portion of filler(less than 10 microns) will be within the asphalt film and acts like an extender [3].

Excessive amount of super fine materials P10 has an adverse effect on the function of filler as completion of aggregate gradation. This will create lesser dense mix and increasing air voids (AV), to be so obvious in Ce and Ki due to their high P10 values. The existence of these AV due to the missing of fractions in an aggregate gradation will reduce the contact between aggregate particles and asphalt because most of filler particles are within the asphalt film leading to a loss on adhesion between them and at last the cohesion of hall mix. The ITS test refers to that cohesion of mix and the adverse effect of high values of P10 of Ce and Ki on ITS values at all test temperature compared to SM can be seen

But the existence of large amount of filler within asphalt film will make it behave like an extender to provide more stiffness to the film to resist water attack and that can be expressed in high values of IRS for Ce and Ki compared to Si and SM.

It can be seen that the P10 has an inverse relation with TS because the increase of super fine materials within the asphalt film will increase the stiffness of the film. That will decrease the susceptibility of asphalt mastic of film to variation in temperature as in Ce and Ki.

5. Conclusions

1- The super fine materials P10 parameter shows highly effect on the HMA mixture properties and can explain the effect of filler on these properties and also can be used to back up the theory that the asphalt film thickness is 10 microns.
2- The increasing in P10 will increase the %AV of mix and reduce density.
3- The increasing in P10 will decrease the cohesion of the mix which representing by indirect tensile strength ITS values.
4- The increasing in P10 will reduce the effect of moisture damage which representing by increasing in indirect retained strength IRS values
5- The increase in P10 will decrease the effect of the increase of temperature on the cohesion of the mix associated by decrease of temperature susceptibility TS values.

6. Recommendations

Due to the previous, it is important to evaluate the super fine materials amount P10 in the filler according to ASTM D-422 using Hydrometer analysis to be added to the tests of filler.

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