Effect of Fine Aggregate Composition on Moisture Susceptibility of Hot Mix Asphalt

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Abstract This paper discusses how the moisture susceptibility is influenced by the angularity characteristic and the composition of the fine aggregates. The results indicate that the composition of fine aggregate affects the moisture susceptibility of asphalt mixture in certain degree. By reviewing the results of the split strength ratio of bituminous mixture, the mass (in percent %) of natural sand in the fine aggregate (N/FA) ratio has an optimal value. This value is propitious to improve the workability of the asphalt mixture and enhance the compaction of mixture, and thus reduce the percent of air voids in asphalt mixture and reduce the moisture susceptibility. From the study, it was found that the optimal value of N/FA is 30 %, approximately being equal to 13 % (in weight) of the total weight of the mineral aggregates. Further increase in N/FA ratio may cause a lower adhering ability between the bitumen and aggregate. Furthermore it is considered that by viewing the FAA alone is not sufficient to justify or conclude on the possible performances of the subsequent bituminous mixtures formed.

Keywords Hot mix asphalt (HMA) · Moisture susceptibility · Fine aggregate angularity (FAA) · Split strength

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1 Introduction

The fine aggregates (i.e. 0.075 mm to 2.36 mm) used in the paving asphalt mixtures are usually consisted of stone chips, natural sand, or crushed sand. It is typically considered that the characteristics of the fines aggregate are influential to the performance of asphalt mixtures, especially on the rutting performance of the materials. Around the world, different researches drew different conclusions on this which leads to different emphasis on the material specifications. For example, (1) The specification of JTJ 032-94 (China) regulates that the fine aggregates of hot mix asphalt should be consisted of superior quality natural sands or crushed sands, of which the dosage of stone chips used in topping course or wearing course of the asphalt concrete of the expressway, first-grade highway should not exceed that of natural sands (2). The Asphalt Pavement Guide of Japan also rules that the dosage of stone chips should not exceed the dosage of natural sands in the design of mixtures (3). The Federal Highway Administration of America (FHWA) regulates that the dosage of natural sands in the total fine aggregates is 20 % approximately and also many highway authorities in the US require minimum values of FAA (43–45 %) to be used in bituminous mixtures on high traffic roads (4). In addition, the Superpave asphalt mixtures design method indicates the fine aggregates angularity (FAA) as the criteria for controlling the quality of fine aggregates (5). However, some scholars considered that, under different testing content or testing conditions, the value of FAA is not always the important factor that affects the performance of asphalt mixtures. (6) However, the Hong Kong specification does not put emphases on the properties of the fine aggregates other than specifying the requirements on gradations.

On the basis of the different viewpoints mentioned above, this study reviews the effects on the property of the asphalt mixture (i.e. moisture susceptibility) by varying the component proportion of fine aggregates (thus changing the value of FAA) by the adoption of the freeze-thaw splitting test of asphalt mixtures.

2 Experiment

2.1 Materials

The bitumen used in the study is SK-AH-70 obtained from China and the technical specifications of the material are shown in Table 1. The crushed

Table 1 Main technical specification of asphalt

Specification	Tested value
Penetration (10^{-1} mm)	69
15 °C Ductility (cm)	>200
Soften point (°C)	46
Density (g/cm^3)	1.018

gritsand was used as the coarse aggregates and its bulk specific gravity of coarse aggregate is 2.692. The fine aggregates composed of limestone chips and natural river sand. The two types of fine aggregates were mixed together according to different mass percentages to form different natural sand to total fine aggregates ratio (N/FA). The corresponding specific gravities of the different fine aggregates are shown and the associated FAAs (6) as tested based on ASTM C1252 are shown in Table 2. The mineral filler used in the mixtures was limestone powder and its apparent specific gravity was 2.720. A dense-grade aggregates gradation was selected for mixture design, and the associated gradation of the material is shown in Table 3.

2.2 Determination of Asphalt Content of Mixtures

Based on the aggregates gradation shown in Table 3, the bitumen content of mixtures were determined according to the composed proportion of the two fine aggregates, with the two boundary levels of 10 and 50 % of N/FA ratio (being the lower and upper limits respectively). The mixtures samples were formed by the Marshall compaction method. The Marshall test results (stability, percent air voids, flow value and percent of the voids in mineral aggregate that are filled with asphalt of bituminous mixtures) indicate that the optimum asphalt aggregate ratio of 4.7 % was achieved at the level of 10 % N/FA, and 4.6 % was obtained at the level of 50 % N/FA. Finally the asphalt aggregate ratio of 4.7 % was selected for all experiments under this study.

Table 2 Bulk specification gravity and FAA value of fine aggregates

N/FA (%)	Bulk specification gravity (g/cm^3)	FAA value (%)
10	2.713	47.1
20	2.715	46
30	2.630	44.1
40	2.667	42.8
50	2.658	40.3

Table 3 Aggregate gradation of asphalt concrete mixtures

Sieve size (mm)	16.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Percent passing (%)	100	97	76	50	32	22	15	11	7	5

2.3 Testing of Volume Specification

By keeping the composition of the coarse aggregates (sizes from 4.75 to 13.2 mm) the same, the proportions of the fine aggregates were adjusted in five levels, being from 10 to 50 % (i.e. with 10 % interval). The ratios of mineral aggregates are shown in Table 4. Two batches of Marshall samples were made at each level, of which the asphalt aggregate ratio of 4.7 % was adopted for all the samples of the mixtures. The bulk specific gravity of samples was obtained according to ASTM D 1188-96 (7), the percentage air voids (VV), percentage of the voids in mineral aggregate (VMA) were also pursued and the results are shown in Table 5.

2.4 Freeze and Thaw Split Tests

A series of freeze-thaw split tests were conducted (3 nos. samples were adopted for each test). One of the two batches samples was pre-conditioned according to ASTM D4867/D4867 M-96 (8), of which the samples were frozen under the condition of −18 °C for 16 h ± 1 h and thawed at 60 °C ± 0.5 °C for 24 h. Another batch of samples (control samples) was placed under the condition of room temperature. The moisture susceptibility was evaluated based on the ratio of freeze-thaw split strength (TSR). The splitting tests were conducted at the temperature of 25 °C and the loading rate was set as 50 mm/min. The results of freeze-thaw split tests are shown in Table 6.

Table 4 Mineral aggregate composing ratios

d (mm)		13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075	<0.075
Ratio (%)		3.0	20.7	26.3	18.0	10.0	7.0	4.0	3.3	2.1	5.6
N/FA (%)	10	3.0	20.7	26.3	1.8[a]	1.0	0.7	0.4	0.3	0.2	5.6[b]
					(16.2)	(9.0)	(6.3)	(3.6)	(3.0)	(1.9)	
	20	3.0[(2)]	20.7	26.3	3.6	2.0	1.4	0.8	0.7	0.4	5.6
					(14.4)	(8.0)	(5.6)	(3.2)	(2.6)	(1.7)	
	30	3.0	20.7	26.3	5.4	3.0	2.1	1.2	1.0	0.6	5.6
					(12.6)	(7.0)	(4.9)	(2.8)	(2.3)	(1.5)	
	40	3.0	20.7	26.3	7.2	4.0	2.8	1.6	1.3	0.8	5.6
					(10.8)	(6.0)	(4.2)	(2.4)	(2.0)	(1.3)	
	50	3.0	20.7	26.3	9.0	5.0	3.5	2.0	1.7	1.1	5.6
					(9.0)	(5.0)	(3.5)	(2.0)	(1.6)	(1.0)	

[a]In the cell, the above datum was the mass percent of nature sand against total mass of mineral aggregate, the inferior datum was the mass percent of stone chip with same dimension against total mass of mineral aggregate

[b]The ratio of the coarse aggregates (≥4.75 mm) and mineral powder (<0.075 mm) against total quantum of mineral aggregate kept constant when the N/FA varied

Table 5 Volume specification of marshall samples

N/FA (%)	FAA (%)	VV (%)	VMA (%)
10	47.1	5.3	15.8
20	46.0	6.3	16.7
30	44.1	5.5	15.9
40	42.8	5.0	15.5
50	40.3	5.1	15.6

Table 6 Testing results of freeze-thaw split

N/FA (%)	FAA (%)	R_{T1}^{a} (MPa)	R_{T2}^{b} (MPa)	TSR = R_{T2}/R_{T1} (%)
10	47.1	1.429	0.945	66.2
20	46.0	1.377	0.916	66.5
30	44.1	1.377	1.026	74.5
40	42.8	1.287	0.942	73.2
50	40.3	1.203	0.855	71.0

[a]The split strength of samples that did not endure the freeze-thaw precondition
[b]The split strength of samples that endured the freeze-thaw precondition

2.5 *Test Results*

Based on the test results as shown in Table 5, the effects of N/FA on the volume properties are plotted in Figs. 1 and 2. The data indicates that, by varying the values of N/FA, the two volume properties of VV and VMA tend to vary considerably and when N/FA value is approximately at the level of 20 %, VV and VMA of samples appear to be the highest.

Based on the results of the freeze-thaw split tests, the ratio of split strength of the samples obtained under the freeze-thaw conditioning against the split strength of the control samples are demonstrated in Table 6 according to different N/FA ratios. Figures 3, 4, 5 and 6, respectively, illustrate how the FAA values, split strengths (R_T), and TSR(s) were affected by varying the N/FA ratio. In the meanwhile, the effects of FAA on R_T and TSR are shown in Figs. 6 and 7 respectively.

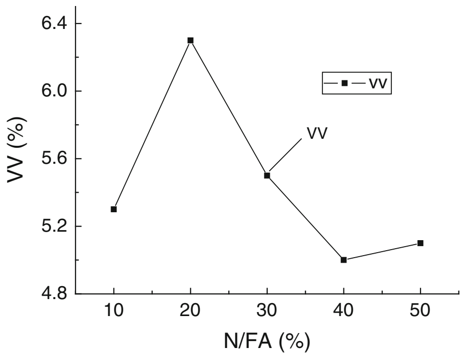


Fig. 1 N/FA versus the percent air voids in asphalt mixtures (VV)

Fig. 2 N/FA versus the total voids in mineral aggregate (VMA)

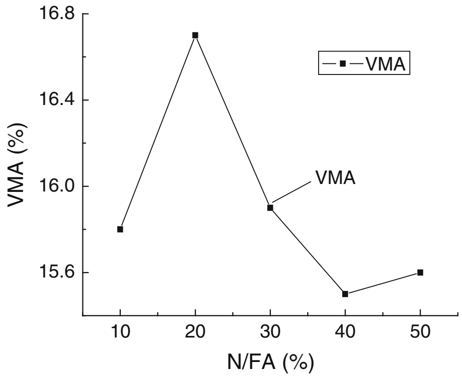


Fig. 3 N/FA versus FAA FAA

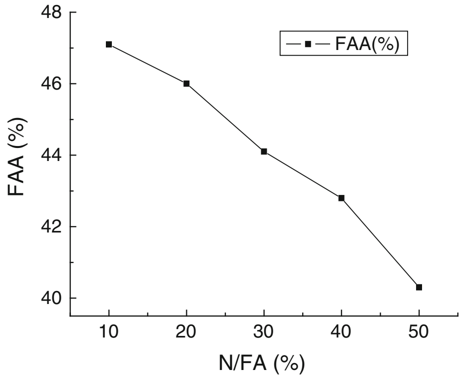
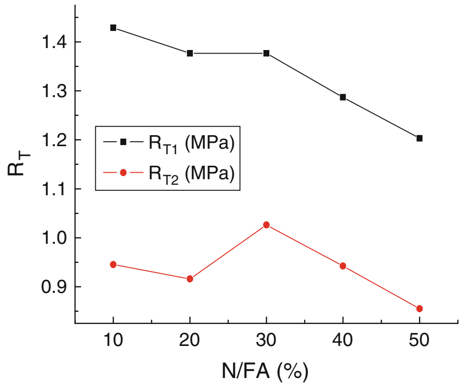


Fig. 4 N/FA versus R_T



Several important trends from the results are observed, firstly, the FAA of the fine aggregates reduces considerably when the N/FA ratio increases and this trend is well expected as the increasing content of sand (with more rounded shapes) would

Fig. 5 N/FA versus TSR

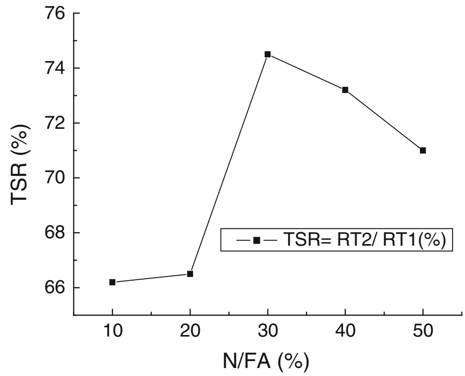


Fig. 6 FAA versus R_T

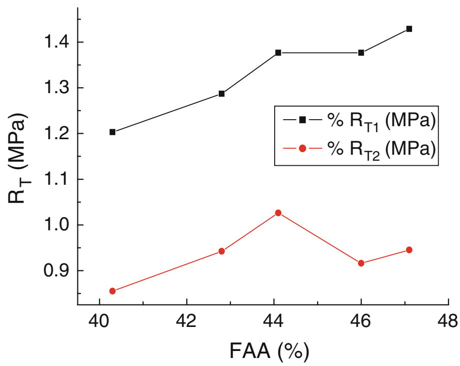
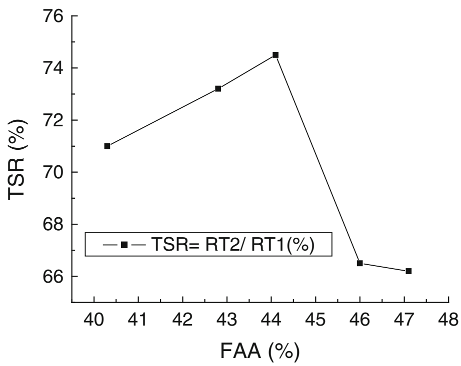


Fig. 7 FAA versus TSR



reduce the overall angularity of the mixed fine aggregates. Secondly the split strengths (R_{T1} and R_{T2}) and TSRs of the test samples varied significantly with the change in N/FA ratio, and it is shown that the optimum TSR (74.5 %) tends to be at the N/FA ratio of approximately 30 %, which corresponds to the ratio of natural sand to total mineral aggregates of about 13.2 % and the associated FAA value is 44.1. Thirdly, the increase in FAA seems to enhance the split strengths (in a rather vague extent) but it shows the inability of enhancing the TSRs and subsequently the moisture susceptibility. Hence it is opined that the FAA is only a general indicator used to qualify the macro physical characteristic of fine aggregates, as there may be many other factors that may contribute to the behavior of the bituminous mixtures. The story is further complicated if different components are present (i.e. more angular aggregates and sand which is less angular).

2.6 Interpretation

The shape of natural sand is generally rounder and the surface is usually smoother than the fine aggregates that are all composed of stone chips, so by varying the content of natural sand within the fine aggregates, the workability of the asphalt mixtures are expected to change accordingly. The most important factor of influencing the moisture susceptibility of asphalt mixtures, have been well recognised to be the (1) percent air voids in bituminous mixture which is affected by the workability of fresh-mix asphalt mixtures and (2) the adhering capacity between the bitumen and the aggregates.

A lower N/FA ratio is expected to produce a higher FAA, and the compaction of the bituminous mixtures would become difficult because of the poor workability, and the associated air void content is rather high and hence the TSR is rather low. With the increase in the value of N/FA ratio, the workability of the mixture would be higher and the compaction of the mixture could be correspondingly improved and thus the density of mixture would increase. Under such a condition, the volume of voids of the mixture would decrease and thus TSRs would increase correspondingly. When the N/FA ratio continually to increase, the workability of mixture would become higher and higher and finally it reaches a point that further increase in workability does not significantly reduce the Volume of Voids (i.e. change in VV (%) becomes steady and small) of the bituminous mixtures. At that point the TSR value would achieve the maximum value. Further decrease in air voids (i.e. due to the increase in workability) may not significantly affect the TSRs. Within such a range, the effect of varying air voids of mixture on changing the TSR value of mixture would not be significant. Whereas because of the increased content of the natural sand, and due to the relatively high overall roundness and smoothness of fine aggregates increase and thus it causes a reduction in the sorption of asphalt to the aggregates (last column of Table 5 refers). In the consequence of this, the proportion of adsorbed asphalt is reduced and in the meantime, the proportion of the free asphalt is increased correspondingly. As the bounding capacity of asphalt binder reduces, thus the moisture susceptibility becomes higher and hence the TSR decreases.

3 Conclusions and Recommendations

Several conclusions can be drawn after this study:

1. The composition of fine aggregates has apparent influence on the compaction characteristic of the bituminous mixture. The compacted characteristic and cohering characteristic of mixture that result from the variety of fine aggregate composition reduced the change of volume performance.
2. The existence of natural sand in the fine aggregates obviously cause variations on the FAA. However, it is considered that by viewing the FAA alone is not sufficient to justify or conclude on the possible performances of the subsequent bituminous mixtures formed (the moisture susceptibility is one example of the performance criteria under the study). Moreover, FAA may have different influences on the different performance criterion (rutting/fatigue, etc.) of the bituminous mixtures.
3. The composition of fine aggregate affects the moisture susceptibility of asphalt mixture in some degree. In a determined range, corresponding to the ratio of split strength of bituminous mixture, the N/FA ratio has an optimal value. This value is propitious to improve the workability of asphalt mixture and enhance the compacting degree of mixture, thus decrease the percent of air voids in asphalt mixture and reduce the moisture susceptibility. Further increase in N/FA ratio may cause a lower adhering ability between the bitumen and aggregate. For this study, the optimal value of N/FA is 30 %, approximately reach the 13 % in the total mineral aggregate.

The authors opine more detailed investigations are needed and worthwhile for further recommendations on the additional requirements of the fine aggregates (apart from gradation) used within the bituminous mixtures for construction of road pavement in Hong Kong.

Bibliography

ASTM C1252-06 (2006), Standard Test Methods for Uncompacted Void Content of Fine Aggregate.

ASTM Designation D 1188-96 (2002), Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Coated Samples. American Society for Testing and Materials.

ASTM Designation D4867/D4867 M-96 (2002), Standard Test Method for Effect of Moisture on Asphalt Concrete Paving Materials. American Society for Testing and Materials.

E.T. Harrigan, R.B. Leahy and J.S. Youtcheff. (1994), SHRP -A-379, The SUPERPAVE Mix Design System - Manual of Specifications, Test Methods, and Practices. Strategic Highway Research Program Strategic Highway Research Program, National Research Council, Washington, DC.

Jose Leomar fernandes, Reynaldo Roque, Mang Tia, etc (2000), Evaluation of Uncompacted Void Content of Fine Aggregate as A Quality Indicator of Materials used in Superpave Mixtures. Transportation Research Board 79th Annual Meeting. Washington, D.C.

Reed B. Freeman, Chun-Yi Kuo (1999), Quality Control for Natural Sand Content of Asphalt Concrete, Reed B. Freeman, Chun-Yi Kuo, Journal of Transportation Engineering.

The Specification of Construction Technique of Highway Asphalt Pavement (1994), People's Traffic Publishing Company, Beijing.

The Specification of Construction and Acceptance of Highway Asphalt Pavement (1994), People's Traffic Publishing Company, Beijing.