Technical Note

ISSN 1997-1400 Int. J. Pavement Res. Technol. 3(3):156-159
Copyright @ Chinese Society of Pavement Engineering

Modification of Full Asphalt Content Asphalt Concrete Design Method

Zhe-Sheng Ge[1+] and Xiao-Ning Zhang[2]

Abstract: This technical note presents the research work that investigated the issues of the current full asphalt content (FAC) asphalt concrete design method. These issues include the discrepancy between the actually measured volume of air voids and the targeted or designed one in FAC mixtures, the lack of good control on voids in mineral aggregate (VMA) in FAC mixtures, and no consideration on the asphalt absorbed by aggregates in a mixture design. The causes of these problems are discussed and possible improvements are suggested through mixtures volume-balance-equation analysis and modification. The suggested improvement is validated through laboratory tests that include Marshall testing, soggy Marshall testing, freezing-melting testing, and rut testing. The results indicate that the properties of designed FAC asphalt concrete satisfy the Chinese National technical specifications for construction of highway asphalt pavement. Consequently, the improved method can be recommendable to design close-discontinuous gradation asphalt mixtures such as FAC, stone mastic asphalt (SMA), and open-graded friction courses (OGFC) mixtures.

***Key words**: Asphalt cement; Designing method; Full asphalt content asphalt concrete; Pavement engineering.*

Introduction

A good asphalt mixture design should accommodate various property or performance requirements imposed by modern heavy traffic loadings and has to make a balance among them, even on contradicting ones such as between the rut resistance at high temperature and contract cracking resistance at low temperatures. The FAC, as proposed and engineered in the early 1990s, has shown promising results as indicated by the performance of testing sections in northeastern and southern China [1-3]. Asphalt mixtures designed by this method have a dense-framework structure similar to SMA with the excellent performance of impermeability, antiskid property, and fatigue and rut resistance [4-7]. Specifically as compared with SMA, FAC has no need for fibers, reduced asphalt content by 15%, similar in impermeability and somehow is inferior to SMA in the antiskid property but still better than many other asphalt mixtures allowed by Chinese specifications.

FAC use the coarse aggregate void filling (CAVF) method in its design process with both the interlocking of coarse aggregate and the filling and cohesion of fine aggregate being materialized [1, 2], resulting in good mixture performances. For example, in the rehabilitation project of the northern city loop at Guang Zhou, China, the existing Portland cement concrete pavement was overlaid with 9*mm* FAC in the December of 2000. The average daily traffic of the highway is about 190,000 vehicles with 60% truck traffic. So far the performance of the pavement has met the requirement of original design with no reflective cracking and rutting occurrence.

Although the application of FAC has achieved some good results, it is discovered through the authors' engineering practice that there are still some unsolved issues that need to be further studied. In this technical note, these problems and their causes are investigated and explored so that effective measures can be taken to improve the CAVF designing method.

The CAVF Method and its Problems

The volume control or compatibility is a critical issue in the CAVF method. In general, the volume of total air void in coarse aggregates is equal to the sum of the volumes of fine aggregates, asphalt, filler, and remaining air void that an asphalt mixture contains. In other words, the fine aggregate-filler-asphalt mixture is the filler of coarse aggregates. The fine aggregate should not be too big to avoid the aggregate interference, with aggregates of 0～2.36 or 0～1.18*mm* usually used as good fillers.

According to the volume compatibility relation, the following equations of CAVF can be obtained:

$$q_c + q_f + q_p = 100 \tag{1}$$

$$\frac{q_c}{100\gamma_s}\left(VCA_{DRC} - VV_s\right) = \frac{q_f}{\gamma_f} + \frac{q_p}{\gamma_p} + \frac{q_a}{\gamma_a} \tag{2}$$

where,

q_c, q_f, q_p = mass percentages of coarse and fine aggregate, and filler, %;
q_a =asphalt-aggregate ratio, %;
VCA_{DRC} = void in compacted coarse aggregate, %;
VV_S = target volume of air voids in asphalt mixture, %;
γ_s = specific density of tightly mixed coarse aggregate ;
γ_f, γ_p = apparent specific densities of fines aggregate and filler; and
γ_a = specific density of asphalt.

The densities and VCR_{DRC} can be obtained through tests such as the methods specified by AASHTO T19 or ASTM C29. Among the five variables in Eq. (1) and (2), three of them will be the input parameters predetermined by designers and the other two variables, usually q_c and q_f, can be calculated.

It is convenient and simple to use the CAVF designing method, but the authors' experience indicates that for FAC mixtures designed by the CAVF, some issues need to be studied further, including:

---

[1] Senior Engineer, South China University of Technology Road Research Institute, Guangdong, China.
[2] Professor, South China University of Technology Road Research Institute, Guangdong, China.
[+] Corresponding Author: E-mail zsge@scut.edu.cn

Note: Submitted June 27, 2009; Revised December 25, 2009; Accepted January 24, 2010.

1. The difference between actually measured volume of air void VV_{mix} and target VV_s should be evaluated, which means that actual asphalt mixture may perform differently from the designed one;
2. A suitable method should be studied to make VMA of FAC mixtures in control;
3. Asphalt absorbed by aggregates should be considered and its influence on asphalt mixture design should be accounted.

Table 1. V_{be} of Asphalt Mixtures.

Gradation Type	AC25	AC20	AC16	AC13	SMA
V_{be}, %	8	9	9.5	10	12~14

Reasons for Difference in Volume of Air Void and Revision

Reasons on the difference between actual VV_{mix} and target VV_s can be understood by analyzing the mixture volume-balance-equation:

$$\left(\frac{q_f}{\gamma_f}+\frac{q_p}{\gamma_p}+\frac{q_a}{\gamma_a}\right)M=\frac{V_{mix}}{100}\left(VCA_{mix}-VV_{mix}\right) \tag{3}$$

where,
M = total mass of the mineral, *kg*;
V_{mix} = total volume of the mixture, m^3;
VCA_{mix} = void in coarse aggregate of asphalt mixture, %; and
VV_{mix} = actual VV in asphalt mixture, %.
Assume:

$$V_{mix}\left(VCA_{mix}-VV_{mix}\right)=V_{DRC}\left(VCA_{DRC}-VV_s\right) \tag{4}$$

where,
VCA_{DRC} = $(1-\gamma_s/\gamma_c)*100$;
V_{DRC} = volume of tightly mixed coarse aggregate, m^3;
γ_c = bulk specific density of coarse aggregate; and
$V_{DRC} = q_c\, M/\gamma_s$.
Eq. (2) can be obtained by submitting the above expression of V_{DRC} and Eq. (3) into Eq. (4).

According to the CAVF theory, the following essential conditions exist for coarse aggregates interlocked:

$$V_{DRC} \ge V_{mix}\ ,\ VCA_{DRC} \ge VCA_{mix}\ 。$$

Submitting them into Eq. (4), it can be obtained that:

$$VV_S \ge VV_{mix}$$

This means that for a given target VV_s, the actual VV_{mix} can be different values as long as the above conditions are met, depending on the interference level of fine aggregate and fillers on the coarse aggregate structure. To account for such unavoidable interaction among aggregates, a new interference coefficient, α, is introduced as:

$$\alpha=\frac{VCA_{mix}}{VCA_{DRC}}$$

This interference coefficient can divide asphalt mixtures into different groups. For continuous gradation asphalt mixtures, α, is between 1.0 and 1.4, but for FAC, SMA and other close-discontinuous gradation asphalt mixtures, α = 09-0.95 [8]. In addition, there are substantial differences in the values of γ_s and VCA_{DRC} measured by different methods, which can lead to different values in α. A research indicates that values determined by the methods specified by AASHTO T19 or ASTM C29 are the closest ones to the real values of actual mixtures [2].

The original design method can be improved by replacing VCA_{DRC} with VCA_{mix} on the right side of Eq. 4 and requiring that $V_{mix} = V_{DRC}$, $VV_s = VV_{mix}$, as indicated by Eq. (5). Eq. (5) can be used for the general design purpose:

$$\frac{q_c}{100\gamma_s}\left(\alpha VCA_{DRC}-VV_s\right)=\frac{q_f}{\gamma_f}+\frac{q_p}{\gamma_p}+\frac{q_a}{\gamma_a} \tag{5}$$

Introducing V_{be} to Control *VMA*

There is a problem in Eq. (3) that the volume of asphalt absorbed by aggregates is not included or considered. Therefore, a more accurate volume-balance-equation is suggested as in Eq. (6).

$$\left(\frac{q_f}{\gamma_f}+\frac{q_p}{\gamma_p}\right)M=\frac{V_{mix}}{100}\left(VCA_{mix}-VV_{mix}-V_{be}\right) \tag{6}$$

where,
V_{be} = volume of effective asphalt binder, %.
With the conditions that:

$$V_{mix}=V_{DRC}=\frac{q_c M}{\gamma_s}\ ,\ \ \alpha VCA_{DRC}=VCA_{mix}\ ,\ \ VV_s=VV_{mix}$$

Eq. 6 can be rewritten as:

$$\frac{q_f}{\gamma_f}+\frac{q_p}{\gamma_p}=\frac{q_c}{100\gamma_s}\left(\alpha VCA_{DRC}-VV_s-V_{be}\right) \tag{7}$$

Since $VMA = VV_s + V_{be}$, the control of VMA becomes the control of VV_s and V_{be} instead. V_{be} can be determined using the value given in Table 5.3.3-1 and Table 5.3.3-3 of the Chinese Technical Specifications for Construction of Highway Asphalt Pavements (JTG F40-2004) [9], as shown in Table 1.

For the FAC asphalt mixture, mass percentages of coarse and fine aggregate can be calculated using Eqs. (1) and (7), and then q_a can be obtained by back-calculation using the following equations:

$$q_{be}=\frac{V_{be}\gamma_a}{\left(1-0.01VMA\right)\gamma_{sb}} \tag{8}$$

$$q_{ba}=\left(\frac{1}{\gamma_{sb}}-\frac{1}{\gamma_{se}}\right)\gamma_a\times 100 \tag{9}$$

$$q_a=q_{ba}+q_{be} \tag{10}$$

Table 2. Gradation Composition of Aggregate.

Minerals	Passing Percentage of the Sieve (*mm*) Below,%										
	19	16	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Coarse Aggregate	100	90	40	2	0	0	0	0	0	0	0
Fine Aggregate	100	100	100	100	100	85	70	40	25	10	1
Filler	100	100	100	100	100	100	100	100	100	94.9	92.1
Composted Gradation	100	92	54	24	23	20	18	13	10	7	6

Table 3, Marshall Testing Results.

q_a ,%	VV,%	VMA ,%	VFA,%	Stability, *kN*	Flow Value, 0.1*mm*
4.0	5.5	14.5	62.1	13.6	30.8
4.5	4.8	14.8	67.6	13.8	33.1
5.0	4.0	15.0	73.3	14.3	35.2
5.5	3.6	15.6	76.9	13.5	38.5
6.0	3.0	16.0	81.3	12.6	40.3

Table 4. Soggy Marshall Testing Results.

q_a %	Stability *kN*	Immersion Stability, *kN*	Residual Stability, %	Requirement %
5.0	13.12	12.12	92.4	≥ 85

Table 5. Freezing-Melting Test Results.

q_a %	Cleavage Strength *MPa*	Cleavage Strength of Freeze and Split Test, *MPa*	TSR %	Requirement %
5.0	1.328	1.162	87.45	≥ 80

Table 6. Rut Testing Results.

q_a /%	DS/(time·mm^{-1})				
	1	2	3	Average	Requirement
5.0	3128	3900	3516	3515	≥ 3000

Table 7. Small Girder Bending Test Results.

Sample	L *mm*	H *mm*	Midst Deflection *mm*	Breaking Strain με	Requirement με
1	200	35	0.77	4042	≥ 2000
2	200	35	0.81	4252	
3	200	35	0.74	3885	
Average	200	35	0.77	4060	

where,

q_{be} = effective asphalt-aggregate ratio, %;

q_{ba} = absorbed asphalt-aggregate ratio, %;

γ_a = specific density of asphalt;

q_a = asphalt-aggregate ratio, %;

γ_{se} = effective specific density of composite mineral; and

γ_{sb} = bulk specific density of composite mineral.

Design Example

The gradation of coarse aggregate was empirically designed with the gradation of fine aggregate having the Talbol index of 0.5. The composite gradation of aggregates is presented in Table 2.

The apparent specific densities of coarse aggregate, fine aggregate, and filler are 2.635, 2.623, and 2.682, respectively. The bulk specific density of coarse aggregate is 2.621; the specific density of asphalt is 1.028, and the density of tightly mixed coarse aggregate is 1.654g/cm^3. Therefore, VCA_{DRC} = (1-1.654/2.621) = 36.89%.

Assume q_p = 6%, V_{be} = 11%, VV_s = 4.0%, and α = 0.9. From Eq. (1) and (7), the mass percentages of coarse and fine aggregates can be obtained as q_c = 77.5%, q_f = 16.5%. Also if γ_{sb} = 2.625, γ_{sa} = 2.636, and γ_{se} = 2.626, from Eqs.(8) to (10), the asphalt-aggregate ratio can be obtained as q_a =5.1%. The Marshall tests were conducted on FAC specimens with the composite gradation given in Table 2 and different asphalt-aggregate ratios. The results are presented in Table 3, which indicates that the calculated asphalt-aggregate ratio 5.1% is generally in the reasonable range of the testing results obtained. The indexes and mechanical properties of asphalt mixtures presented from Tables 4 to 7 satisfy the requirements of Chinese Technical Specifications for Construction of Highway Asphalt Pavements (JTG F40-2004) [9].

Conclusions

This paper presents the research work that investigated the problems of current FAC design methodology with suggestions for its improvements as follows:

1. The interference coefficient α as defined in this paper should be added to the original design equation to improve its capability to assure FAC mixtures to have the targeted volume of air voids, VV_s, in asphalt mixtures.
2. The volume of effective asphalt binder, V_{be}, should be added to the volume equilibrium equation so that a better control of *VMA* in asphalt mixtures can be achieved and then the optimum asphalt-aggregate ratio can be obtained by back-calculation.

The laboratory results presented in this paper indicate that FAC mixtures designed with the improved method have met the technical requirements set by the Chinese National Specifications. Similarly, for other close-discontinuous gradation asphalt mixtures, such as

SMA and OGFC mixtures, the improved method can also be recommendable to their mixtures design since they are also required to satisfy Eqs. (1) and (2) to secure both the interlocking of coarse aggregates and the filling of fine aggregates.

References

1. Zhang, X.N., Wang, S. H., Wu, K.H., and Wang, D.Y., (2001). The CAVF Method for Design Asphalt Mixture, *Highway*, Vol. 12, pp.17-21. (in Chinese).
2. Zhang, X. N., Guo, Z.X., and Wu, K.H., (1995). Volume Method of Bituminous Mixture Design, *Journal of Harbin University of Civil Engineering and Architecture*, Vol. 2, pp.28-36. (in Chinese).
3. Zhou, G. L., Zhang, X. N., Wang S. H., and Wang, D.Y., (2002). Design of Full Asphalt Mixture by CAVF Method, *Highway*, Vol. 3, pp. 76-79. (in Chinese).
4. Zhang, X. N., (1999). Traffic Safety and the Progress of the Asphalt-Paving Technique, *Journal of Harbin University of Civil Engineering and Architecture*, Vol. 2, pp. 93-98. (in Chinese).
5. Wang, S. H., Zhang, X.N., and Wu, K.H., (1994). Designing Gradation Composition of Bituminous Mixture on the Aggregate Volume, *Journal of South China Construction University*, Vol. 2, pp. 27-30. (in Chinese).
6. Yang, Y. L., Zhang, X. N., Wang, S. S., and Zhang, H. W., (2003). On Design and Property of Semi-Flexible Asphalt Mixture, *Journal of Jinan Communications College*, Vol. 3, pp. 32-41. (in Chinese).
7. Zhang, X.N., Wang, S. H., and Wu, B. S., (2002). Research on the Overlay in the Test Road of Guangzhou North Ring Freeway, *Journal of Foreign Highway*, Vol. 2, pp. 10-15. (in Chinese).
8. Yu, J. M., (2005). *The Fatigue Performance of Asphalt Mixes*, Guangzhou, South China University of Technology. (in Chinese).
9. Ministry of Communications of the People's Republic of China. (2004). *Technical Specifications for Construction of Highway Asphalt Pavements*, *JTG F40-2004*, People's Communication Press, pp. 28-30, Beijing, China. (in Chinese).