Fiber-Reinforced Asphalt Concrete Mixtures Structural Numbers and Pavement Design Considerations

Prepared by

Kamil E. Kaloush, Ph.D., P.E.

Associate Professor

Waleed Zeiada, Ph.D Candidate

Graduate Research Associate

March 2012

NATIONAL CENTER of EXCELLENCE for SMART INNOVATIONS

ARIZONA STATE UNIVERSITY

Fiber-Reinforced Asphalt Concrete Mixtures Structural Numbers and Pavement Design Considerations

Introduction

The AASHTO 1993 design method of flexible pavement is based on identifying the Structural Number (SN) of a multiple layer system to withstand the projected level of axle load traffic. The Structural Number, SN_1 of the Asphalt Concrete (AC) layer is a function of the layer thickness (D_1) and the layer coefficient (a_1) where:

$$SN_1 = a_1 \text{ x } D_1$$

The AC layer coefficient reflects the quality of the material used to construct this layer. The AC layer coefficient can be determined if the elastic modulus of this layer is known at 68 ºF (20 ºC) as shown in Figure 1 (ref. 1).

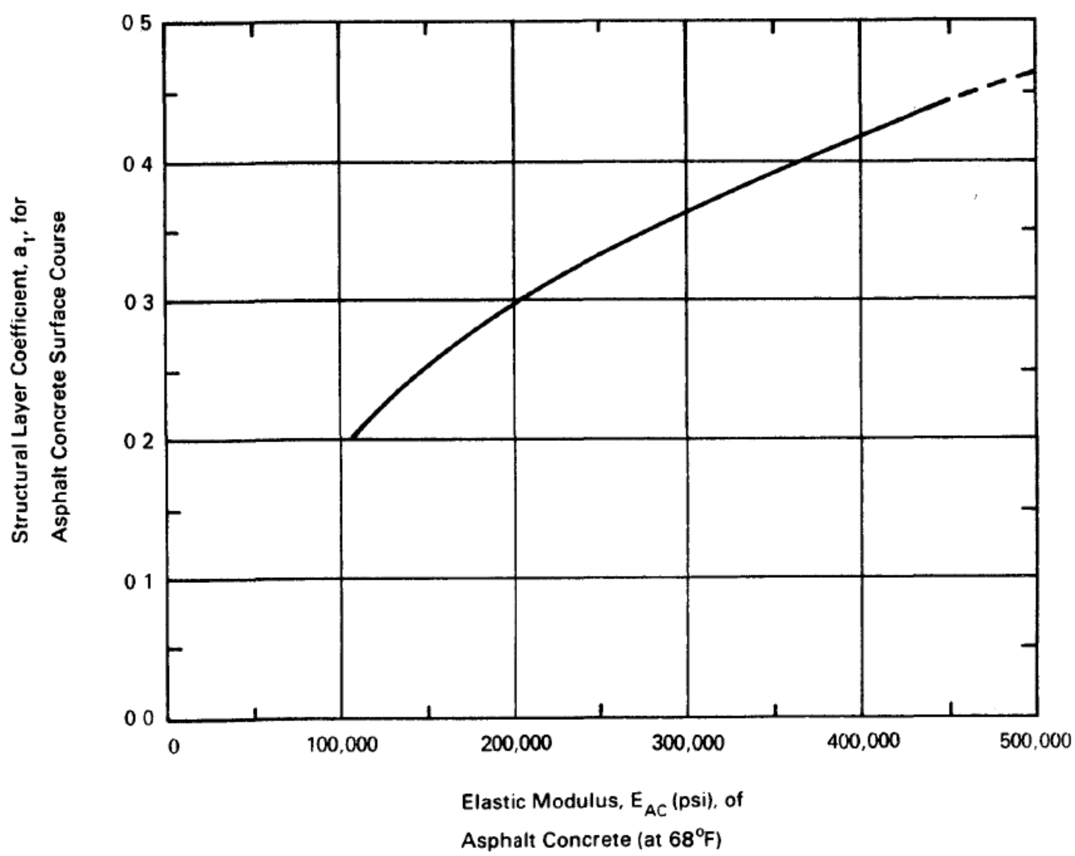

Figure 1 Structural Layer Coefficient of Dense-Grade Asphalt Concrete Bases on Elastic (Resilient) Modulus.

The AASHTO 1993 design method for flexible pavement does not recommend a resilient modulus above 450,000 psi because higher modulus asphalt concretes are stiffer and more susceptible to thermal and fatigue cracking. The maximum a_1 value recommended is 0.44. However, many studies have shown that the actual back calculated a_1 value can be up to 0.85 (ref. 2) by analysis using Falling Weight Deflectometer (FWD). But, using higher a_1 values in pavement design would significantly decrease the AC layer thickness and therefore decrease resistance to fatigue cracking. Fiber-reinforced and polymer-modified mixtures are stiffer than dense-graded mixtures and show better resistance to fatigue cracking. Re-evaluation of the threshold value of a_1 is essential to achieve the benefit of using these modified mixtures in two different approaches. The first approach is to increase the maximum a_1 limit to reduce the thickness, save time and materials. The second approach is to keep the maximum limit of a_1 and use the same thickness as the conventional mixtures, which will lead to longer service life.

Based on this introduction, the following three methods are recommended for design of flexible pavement using fiber-reinforced modified mixtures:

1. Design of New Pavement Layers Using the Mechanistic Empirical Pavement Design Guide (DARWin-ME)

The dynamic modulus property is the key input parameter to determine the pavement performance using DARWin-ME. As the fiber reinforced mixtures enhance the dynamic modulus values, an improvement to the pavement performance predicted by DARWin-ME is expected. A recent study conducted at Arizona State University showed that a fiber-reinforced mixture provided the same performance compared to the conventional mixtures with 30 to 40% reduction in the asphalt pavement layer. (ref. 3) This value varied depending on the traffic level used in the analysis. Table 1 shows typical dynamic modulus values for fiber-reinforced and control mixtures at different test temperatures and frequencies. If only dynamic moduli of the conventional mixture are available for analysis, and based on the modular ratio values shown in Table 1, it is recommended to use an average modular value of 1.44 to calculate the dynamic moduli of the fiber-reinforced mixtures. These modified dynamic moduli can be used as input to determine the pavement performance using DARWin-ME.

Table 1 Typical Dynamic Modulus values for Conventional and Fiber-Reinforced Mixtures

Temp. °F (°C)	Freq. Hz	Dynamic Modulus, MPa - ksi (Test Values)				Modular Ratio (Average 1.44)
		Fiber-Reinforced		Conventional		
14 (-10)	25	7,029	48,463	6,059	41,775	1.16
	10	6,511	44,892	5,587	38,520	1.17
	5	6,279	43,293	5,500	37,920	1.14
	1	5,815	40,090	4,983	34,356	1.17
	0.5	5,577	38,449	4,776	32,926	1.17
	0.1	4,987	34,384	4,212	29,037	1.18
40 (4.4)	25	5,308	36,596	4,191	28,897	1.27
	10	5,132	35,387	4,027	27,768	1.27
	5	4,812	33,178	3,793	26,149	1.27
	1	4,238	29,218	3,204	22,089	1.32
	0.5	3,958	27,289	2,940	20,270	1.35
	0.1	3,325	22,927	2,357	16,247	1.41
70 (21.1)	25	3,197	22,045	2,258	15,566	1.42
	10	2,924	20,160	1,967	13,563	1.49
	5	2,669	18,403	1,760	12,137	1.52
	1	2,119	14,610	1,287	8,870	1.65
	0.5	1,853	12,773	1,108	7,637	1.67
	0.1	1,294	8,920	759	5,230	1.71
100 (37.8)	25	1,786	12,311	1,010	6,960	1.77
	10	1,500	10,341	818	5,641	1.83
	5	1,246	8,589	685	4,723	1.82
	1	814	5,611	442	3,045	1.84
	0.5	641	4,422	360	2,482	1.78
	0.1	315	2,174	235	1,623	1.34
130 (54.4)	25	616	4,249	387	2,668	1.59
	10	466	3,214	294	2,024	1.59
	5	374	2,578	247	1,702	1.51
	1	232	1,596	173	1,194	1.34
	0.5	194	1,335	156	1,076	1.24
	0.1	138	949	130	893	1.06
Average Modular Ratio						**1.44**

2. Design of New Pavement Layers Using the Empirical AASHTO 1993 Design Method

The actual laboratory dynamic modulus test results in Table 1showed that the fiber-reinforced mixture has an average of 44% more stiffness at different test temperatures and frequencies compared to the control mixture. In the absence of similar relationship for the resilient modulus, an assumption is made that the resilient modulus of the fiber-reinforced mixtures is also higher than that of the dense-graded mixture by a similar average value of 44%. This is a reasonable assumption since some research study in the literature showed that both moduli are corellated.

Based on the above, the recommended resilient modulus for the fiber-reinforced mixture at 68º F (20 ºC) is 1.44 x 450,000 = 648,000 psi (1.44 x 3,103 = 4,468 MPa). The limit of the a_1 value for the fiber-reinforced mixture would increase to 0.53 as shown in Figure 2 and reduce the thickness of the AC layer by about 20 %. Note that this value can be higher if a higher modular ratio is considered for the moderate temperature range (20 ºC). This value is lower than the 30-40% reduction value arrived at using mechanistic analysis. This is also due to the empirical pavement desing process in the AASHTO 1993 design method. Nonetheless, a 20 to 40% reduction in pavement thickness is significant.

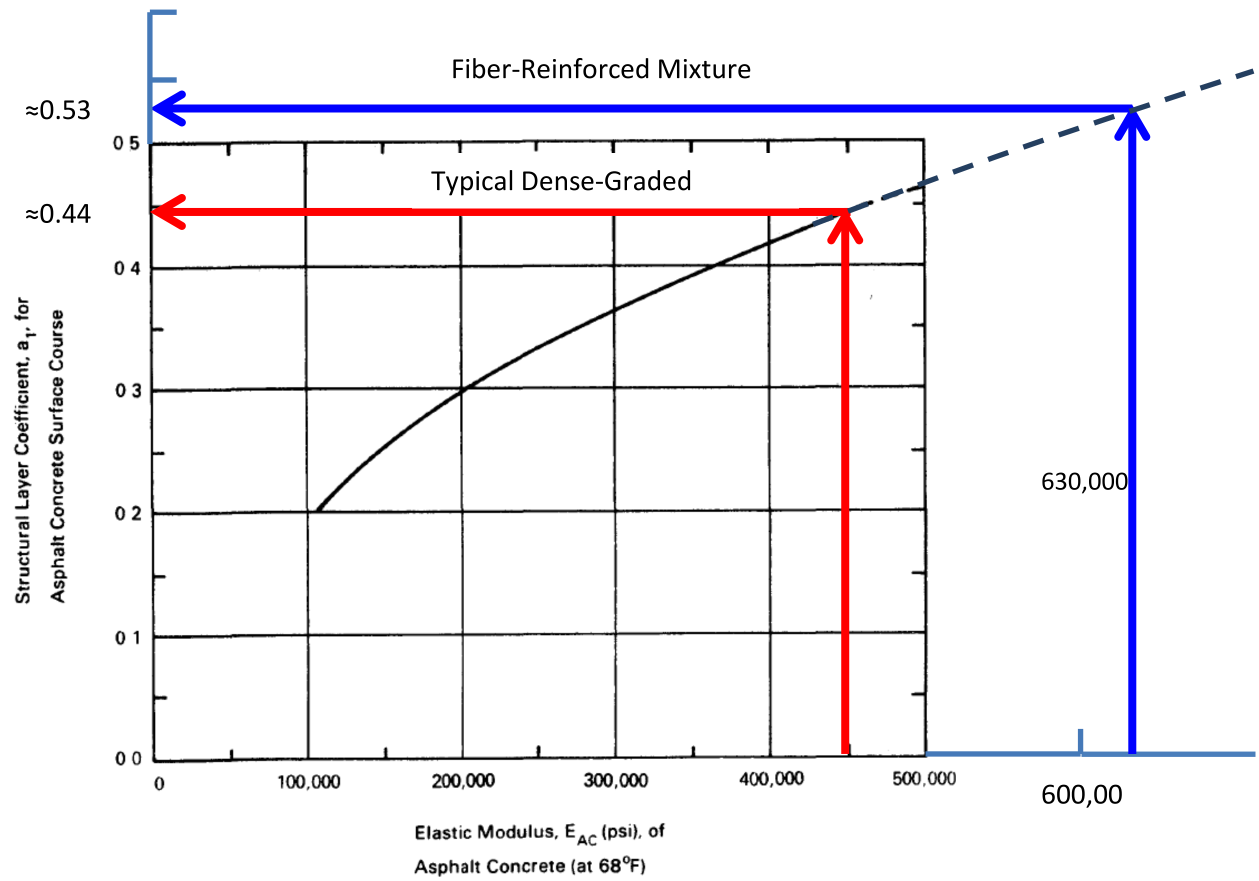

Figure 2 Extrapolated Layer Coefficient of Fiber-Reinforced Asphalt Concrete Mixture

The design of fiber-reinforced HMA pavement follows different scenarios regarding pavement thickness;

Thin Pavements

Use an a_1 value for the fiber-reinforced mixture that is similar to the dense-graded mixture (0.44); this is to avoid an ultra-thin pavement thickness, which is supposed to be more susceptible to fatigue damage. However, the fiber-reinforced asphalt concrete benefit will be in the extra pavement service life due to the higher fatigue endurance limit and enhanced performance of the fiber-reinforced mixture.

Thick Pavements

Use the a_1 value of the fiber-reinforced mixture (0.53). This will reduce the AC layer thickness and decrease the construction cost of this layer without change in the service life.

3. Design of a Pavement Overlay Using the Empirical AASHTO 1993 Design Method.

For re-surfacing of existing pavements, use the current structural number ($SN_{current}$) determined by FWD for the design of a pavement overlay. Follow the process described in AASHTO 1993 pavement overlay design procedure; that is, subtract the $SN_{current}$ before the overlay from the SN_{design} to calculate the $SN_{overlay}$ required.

$$SN_{overlay} = SN_{design} - SN_{current}$$

$$SN_{overlay} = a_1 \text{ x } D_{overlay}$$

The $D_{overlay}$ can be calculated after a_1 is estimated. To estimate a_1, use the two scenarios presented above regarding thin and thick pavements.

References

1. American Association of State Highway and Transportation officials (AASHTO), Guide for Design of Pavement Structures, 1993 (AASHTO Publication: Washington, DC).

2. Michael Pologruto (2006) "Study of In situ Pavement material properties determined from FWD testing " Journal of Transportation Engineering, Vol. 132(9),742-750.

3. Kamil E. Kaloush, Krishna P. Biligiri, Waleed Zeiada, Maria Rodezno, and Jordan Reed, (2010) “Evaluation of Fiber-Reinforced Asphalt Mixtures Using Advanced Material Characterization Tests”, *Journal of Testing and Evaluation, ASTM International*, Volume 38, No. 4.