TechBrief

The Pavements Program is an integrated national effort to improve the durable long-term performance and cost effectiveness of asphalt and concrete pavements. Managed by the Federal Highway Administration through partnerships with state highway agencies, industry and academia, the program's primary goals are to build safe, durable, and cost-effective pavements. The program was established to develop and implement guidelines, methods, procedures and other tools for use in pavement materials selection, mixture design, testing, construction and quality assurance.

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Cyclic Fatigue Index Parameter (S_{app}) for Asphalt Performance Engineered Mixture Design

This Technical Brief provides an overview of how to determine the cyclic fatigue index parameter using the Asphalt Mixture Performance Tester. It also presents index threshold values for use in asphalt mixture design and construction.

Introduction

Fatigue resistance is an important characteristic of asphalt mixtures. Researchers have proposed many approaches to characterize this property, one of which is the simplified viscoelastic continuum damage (S-VECD) model. This model is founded on mechanistic theories that allow engineers to incorporate material properties directly into pavement structural analysis and long-term performance predictions. However, situations may occur where engineers do not need detailed structural analysis to make effective decisions, and instead, merely require an index parameter that relates to the fatigue characteristics of the asphalt mixtures. To support such situations and still retain many of the benefits of S-VECD analysis, FHWA has developed the S_{app} parameter.

S_{app} accounts for the effects of a material's modulus and toughness on its fatigue resistance and is a measure of the amount of fatigue damage the material can tolerate under loading. Higher S_{app} values indicate better fatigue resistance of the mixture. The S_{app} value of an asphalt mixture can be obtained via cyclic fatigue tests using 100-mm diameter specimens (AASHTO TP 107) or 38-mm diameter small specimens (AASHTO TP 133) cored and cut from gyratory-compacted samples (Figure 1). These tests are commonly performed using an Asphalt Mixture Performance Tester (Figure 2). The test results can be imported to and processed by the FlexMAT™ program (available from FHWA) to calculate the S_{app} value. The S_{app} parameter can be used as the fatigue cracking indicator in a performance engineered mixture design (PEMD).

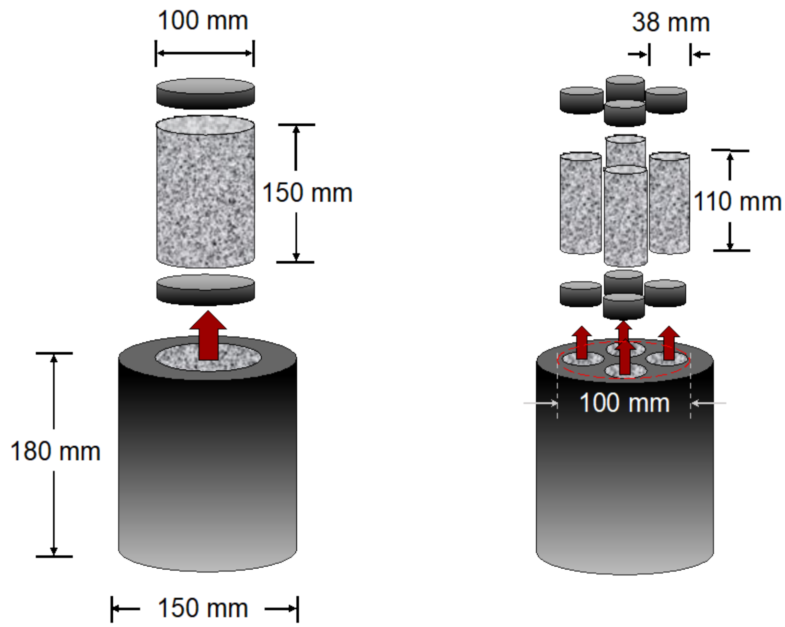

Figure 1. 100-mm diameter specimen (left) and four 38-mm diameter specimens (right), each cored and cut from a single 150-mm diameter gyratory compacted sample.

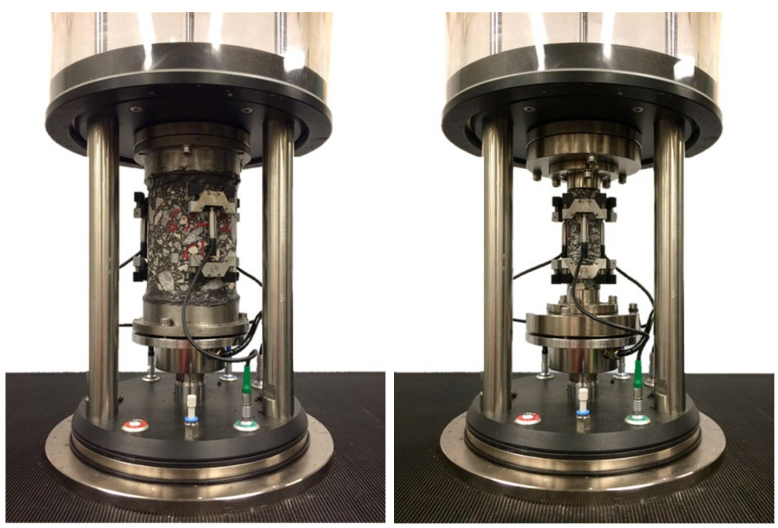

Figure 2. Cyclic Fatigue Test Setup in Asphalt Mixture Performance Tester with 100 mm diameter test specimen (left) and 38 mm diameter test specimen (right).

The S_{app} value is determined at the average temperature of the high and low performance grades, as given in LTPPBind Online at the location for the project of interest, minus three degrees Celsius. The S_{app} threshold values, presented in Table 1, were determined using 105 mixtures that include hot-mix asphalt mixtures with varying percentages of reclaimed asphalt pavement (RAP), warm mix asphalt (WMA) mixtures with different technologies, and polymer-modified mixtures. Details about these mixtures can be found in the appendix. The threshold values shown in Table 1 apply to surface, intermediate, and base course mixtures and can be used to estimate the allowable traffic level for the mixture in terms of equivalent single-axle loads (ESALs). These threshold values were determined by comparing the mixtures' S_{app} values with the information gathered from state highway agencies and accelerated pavement testing facilities, which includes the pavement performance observed at test tracks, test roads, and in-service pavements, allowable traffic levels used in agencies' mix designs, general performance feedback from state highway agencies, and numerical pavement performance simulations. Although the threshold values in Table 1 were determined from a wide range of mixtures, they can be further refined for local materials and conditions.

Table 1. Recommended Threshold Values for the S_{app} Fatigue Index Parameter.

Traffic (million ESALs)	S_{app} Limits	Tier	Designation
Less than 10	$S_{app} > 8$	Standard	S
Between 10 and 30	$S_{app} > 24$	Heavy	H
Greater than 30	$S_{app} > 30$	Very Heavy	V
Greater than 30 and slow traffic	$S_{app} > 36$	Extremely Heavy	E

Figure 3 shows the S_{app} value changes as a function of aggregate gradation, binder content, air void content, RAP content, binder grade, type of binder modifier, and laboratory oven-aging time. The charts generally show greater fatigue resistance with finer gradation, increased asphalt binder content, higher compaction density, and less RAP. Specific binder modifiers (crumb rubber-terminal blend (CR-TB), Terpolymer, and SBS polymer) also increase fatigue resistance, while aging of the mixture reduces fatigue resistance.

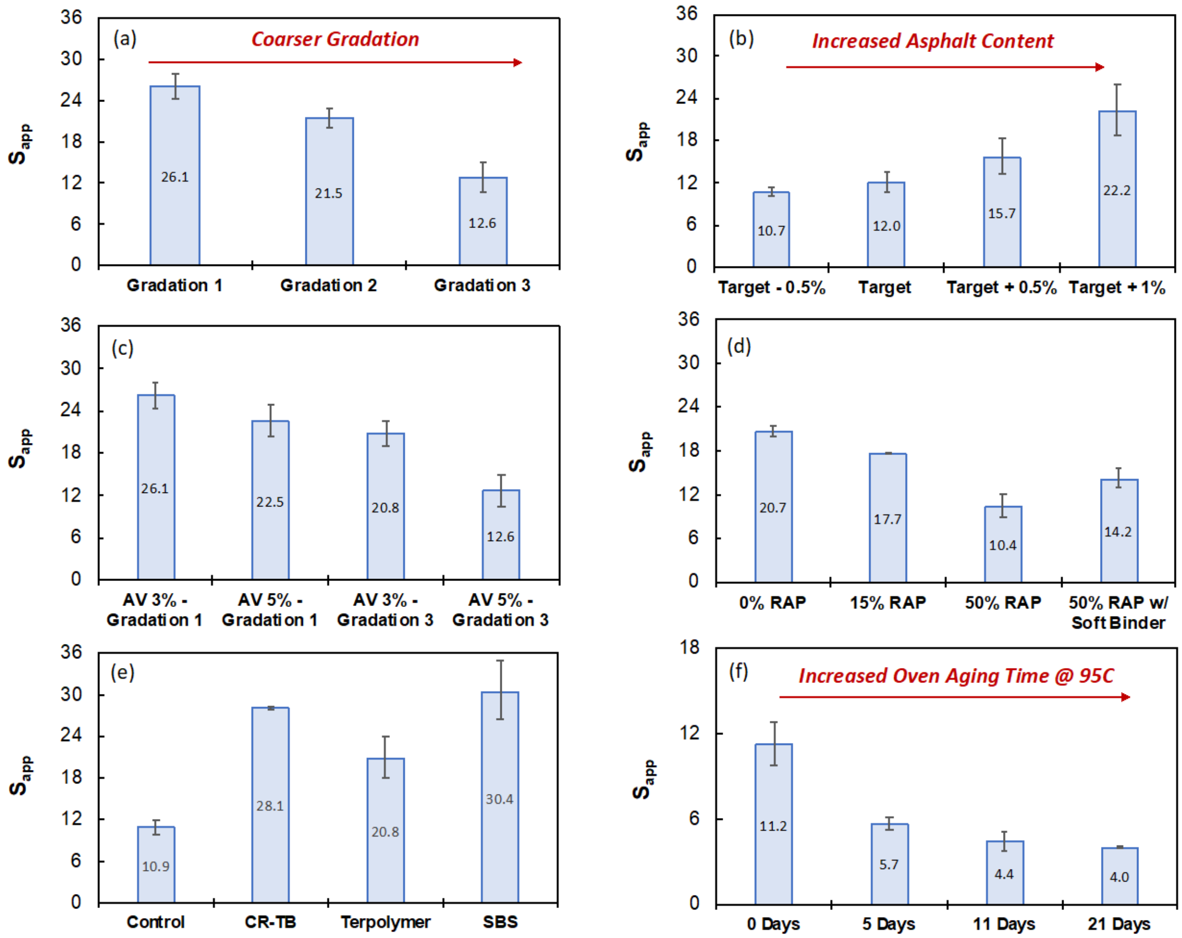

Figure 3. S_{app} values as a function of (a) aggregate gradation (NC-PEMD), (b) binder content (ME), (c) air void content (NC-PEMD), (d) RAP content (NH), (e) binder modifier (VA-ALF), and (f) laboratory oven-aging time (AL-aged) Note: Error bars represent ± one standard deviation.

In summary, S_{app} is a fatigue cracking index parameter that is based on mechanistic S-VECD theory. The S_{app} value was found to be sensitive to mixture factors (e.g., aggregate gradation, binder content, RAP content, binder grade, type of binder modifier), compaction, and aging and meets general expectations with respect to the effects of these parameters on fatigue cracking performance. S_{app} can be used to compare many different types of mixtures and determine if the material is suitable for the layer, traffic, and project location under consideration. S_{app} values derived from 105 mixtures were used to develop the threshold values for allowable traffic levels, which can be further refined using local materials and conditions. Finally, the test results generated to determine the S_{app} value for a given mixture can be used in FlexPAVE^{TM} for long-term pavement performance prediction.

Appendix

Mixture ID	Total[a]	Conventional[a,b]	PMA[a]	WMA[a]	RAP≥ 40%[a]	Binder PG	NMAS	Gradation Type	Remarks
AL (surface)	6[d]	0	2	3[c]	2[c]	67-22, 76-22	9.5, 12.5 mm	Fine OGFC	NCAT test track mixtures, 2009 cycle, includes 1 polymer-modified OGFC mixture
AL (bottom)	5[d]	1	0	3[c]	2[c]	67-22	19 mm	Fine	NCAT test track mixtures, 2009 cycle
AL (aged)	4[e]	0	0	0	4	67-22	19 mm	Fine	50% RAP mixtures at different aging levels
Canada (surface)	8[d]	3	0	3	2	58-28, 58-34	16 mm	Fine	Mixtures used in Manitoba test road
Canada (base)	4[d]	1	0	3	0	58-28	16 mm	Fine	Mixtures used in Manitoba test road
VA-ALF	7[d]	3	2	0	2	58-28, 64-22, 70-22, 70-28, 76-28	12.5 mm	Coarse	ALF mixtures used in 2003 and 2013 tests
VA-PEMD	10[d]	10	0	0	0	64-22	12.5 mm	Coarse	Mixtures designed for different volumetric properties
NH	9[d]	6	0	0	3	58-28, 64-28	12.5 mm	Fine	Mixtures used in Northeast RAP study with various %RAP, %binder, and binder grades
Korea	2[d]	1	1	0	0	64-22, 76-22	19 mm	Fine	Surface mixtures from S. Korea test road
NC (aged)	4[e]	4	0	0	0	58-28 (64-22 Pay Grade)	9.5 mm	Fine	Surface mixtures at different aging levels
NC	7[e]	6	1	0	0	64-22, 70-22, 76-22	9.5, 19, 25 mm	Fine	Mixtures commonly used in North Carolina
NC-PEMD	9[e]	9	0	0	0	58-28 (64-22 Pay Grade)	9.5 mm	Fine	Mixtures with different volumetric properties
ME-QA	10[e]	0	10	0	0	64E-28	12.5 mm	Fine	Mixtures sampled from actual paving project for quality assurance
ME	4[e]	4	0	0	0	64-28	12.5 mm	Fine	Mixtures with different binder contents
GA	16[e]	14	2	0	0	64-22, 67-22, 76-22	9.5, 12.5, 19, 25 mm	Fine, Coarse	Paving mixtures commonly used in Georgia
Total	105	62	18	12	15	NA[f]	NA[f]	NA[f]	NA[f]

Note: [a] Number of mixtures; [b] Conventional mixtures without polymer or WMA additives; [c] One mixture from each row of the NCAT mixtures is a WMA mixture with high RAP content. This mixture is shown in both the WMA and high RAP columns; [d] 100 mm diameter specimens tested; [e] 38 mm diameter specimens tested; [f] Not Applicable.

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Key Words — asphalt, mix design, index parameter, S_{app}, cyclic fatigue test, AMPT, performance, simplified viscoelastic continuum damage (S-VECD) model

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