TECH**BRIEF**

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Rutting Strain Index (RSI) Parameter for Asphalt Balanced Mixture Design

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This Technical Brief provides an overview of how to determine the Rutting Strain Index (RSI) parameter using the stress sweep rutting (SSR) test, the Asphalt Mixture Performance Tester (AMPT), and the FlexMAT™ for Rutting analysis tool. It also presents index threshold values for use in asphalt mixture design and construction.

INTRODUCTION

Rutting is one of the key asphalt pavement distresses that affect performance and service life. Rutting is caused by various factors, including conditions like temperature, stress level, and loading time, which all change with pavement depth (Ghanbari et al. 2020). Researchers have studied different approaches to evaluate rutting in asphalt mixtures. The shift model, which is based on viscoplastic theory, allows engineers to incorporate material properties directly into a pavement structural analysis to forecast long-term pavement performance across a broad range of conditions a pavement will experience in the field. The shift model approach is advantageous because it can characterize the broad range of conditions using only four test specimens. Often, however, it is not an option to conduct detailed structural analysis prior to making decisions. Instead, an index parameter that is founded on mechanistic principles and incorporates factors that affect asphalt mixture rutting can aid in decisionmaking. For such situations, and coupled with the strengths of the shift model, the Federal Highway Administration (FHWA) has developed the RSI as an index parameter that can be used as the rutting indicator in balanced mixture design (BMD) (Ghanbari et al. 2020).

THE RSI PARAMETER

The RSI is the average permanent strain (in percent) and is defined as the ratio of the permanent deformation in an asphalt layer to the thickness of that layer at the end of a 20-year period over which 30 million 18-kip equivalent single-axle load (ESAL) repetitions are applied to a standard pavement structure. Note that the period of analysis and number of load repetitions are fixed, which provides a consistent set of external conditions so different asphalt mixtures can be compared. A mixture with lower RSI values has more rutting resistance than a mixture with higher RSI values.

CALCULATING THE RSI OF AN ASPHALT MIXTURE

Engineers can use FHWA's FlexMAT™ for Rutting analysis tool to determine the RSI of an asphalt mixture for a given location.

The calculations require three inputs:

- Data from SSR tests on the asphalt mixture sample.
- Climatic data for the location, which the user selects in FlexMAT™ for Rutting.
- Wheel-load-induced vertical stress data along pavement depth, which are prepopulated in FlexMAT™ for Rutting.

The first step in determining the RSI value of an asphalt mixture is to perform SSR tests specified in TP 134 using 100-mm diameter specimens cored and cut from gyratory-compacted samples, as shown in figure 1 (AASHTO 2019). Field cores also can be used if the specimen dimensions and tolerances specified in R 83 are maintained (AASHTO 2017).

SSR tests are typically performed using an AMPT, as shown in figure 2. Note that other devices can be used to run SSR tests, but the output data need to be formatted for FlexMAT™ for Rutting to use and analyze the results (FHWA 2020).

The SSR test results are then imported and processed in FlexMAT™ for Rutting to calculate the RSI value.

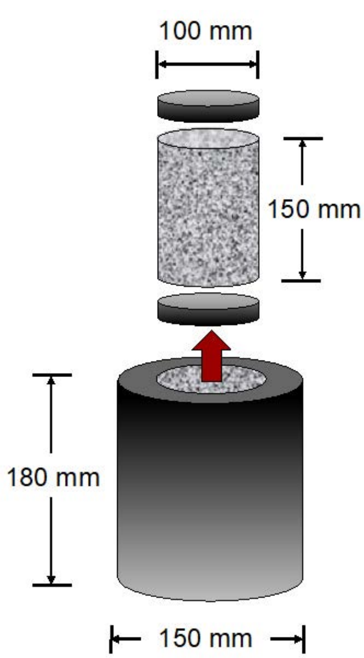
Because permanent deformation in asphalt pavements is a function of temperature, stress level, and loading time, which all change with pavement depth, the research team used FlexPAVE™ to run an array of conditions to develop the underpinnings of the RSI parameter.[1] FlexPAVE™ is a three-dimensional finite-element program that predicts fatigue cracking and rutting performance of asphalt pavements under moving loads using changing temperatures throughout a year. The research team used the FlexPAVE™ simulation results to populate FlexMAT™ for Rutting, so users are not required to run FlexPAVE™ for the RSI calculation.

To calculate the temperature in FlexMAT™ for Rutting, users select a city (in a U.S. territory or State) that is closest to the project location. Then, FlexMAT™ extracts the temperature profile across the entire depth of the pavement structure from a database created using Enhanced Integrated Climatic Model (EICM) simulations that include 20 years of air temperature data

(1996–2015) from the MERRA-2 dataset (NASA 2015).

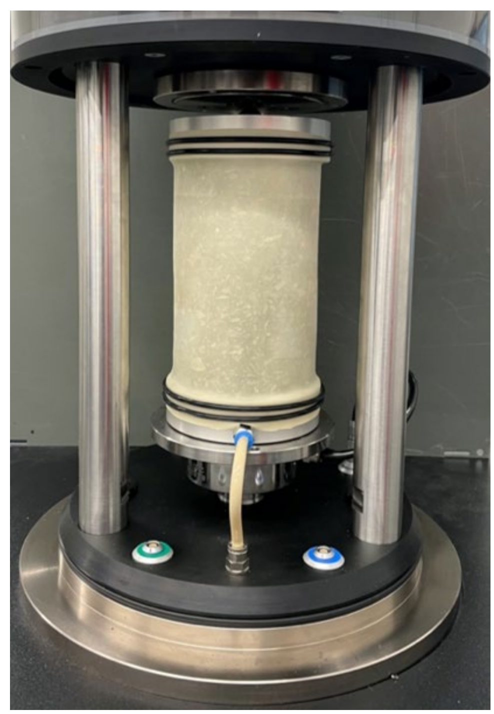
The vertical stresses along pavement depth used to calculate the RSI are prepopulated in FlexMAT™ for Rutting and require no user input. The research team

Figure 1. Illustration. 100-mm diameter specimen cored and cut from a single 150-mm diameter gyratory-compacted sample.



Source: NCHRP.

Figure 2. Photo. SSR test set up in the AMPT.



Source: FHWA.

[1]Information from a forthcoming FHWA report entitled *Development of Asphalt Mixture Performance-Related Specifications.*

analyzed stress distributions in three standard pavement structures (one for each of surface, intermediate, and base course mixtures) under standard ESALs using FlexPAVE™ and used them as fixed inputs. The RSI can be calculated for each asphalt layer (surface, intermediate, and base) based on the mixture category. Users need only import the SSR test data and select a city. FlexMAT™ for Rutting uses the shift model to calculate the permanent strain in each sublayer of asphalt and produces the RSI value within a few seconds.

RSI THRESHOLD VALUES

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 any mixture located in the United States in terms of ESALs.

To determine the RSI threshold values presented in table 1, the research team tested 79 asphalt mixtures with varying percentages of reclaimed asphalt pavement (RAP), different warm-mix asphalt (WMA) technologies, and polymer-modified mixtures. The appendix provides details about these mixtures. They also compared the RSI values of different mixtures to information from State highway agencies and accelerated pavement testing facilities, which included pavement performance observed at test tracks, test roads, and in-service pavements; allowable traffic levels used in agencies' mixture designs; general performance feedback from State highway agencies; and numerical simulations of pavement performance.

Figure 3 shows that the RSI is sensitive to aggregate gradation, binder content, RAP content, and air void content in selected mixtures. These four charts show increased rutting resistance with a coarser gradation, lower asphalt binder content, higher RAP content, and higher compaction density (lower air void content). Note that lowering binder content and increasing the RAP content to improve the mixture's rutting resistance are likely to lower the mixture's resistance to fatigue cracking. Also, note that the RSI values shown in figure 3 depend on the characteristics of the component materials (e.g., aggregate gradation, virgin and RAP binder grades, and other properties).

SUMMARY

In summary, the RSI is an index parameter determined from SSR testing and is based on fundamental engineering principles that are captured by the shift model and presolved pavement analysis. The RSI parameter can account for the effects of changing temperature, stress level, and loading time along pavement depth on the permanent deformation of asphalt pavements using realistic loading and changing climatic conditions. The RSI parameter is also sensitive to mixture factors, such as RAP content, binder content, and volumetric properties. Importantly, the RSI can be employed by agencies as a tool for BMD and quality assurance purposes. If necessary, agencies can further refine the threshold values for local materials and conditions. Finally, the test results generated to determine the RSI value for a given mixture can be used in FlexPAVE™ for long-term pavement performance predictions.

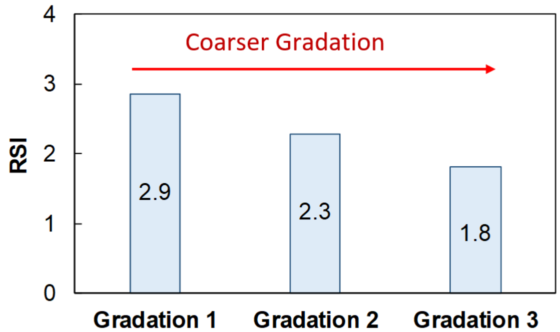
APPENDIX: ASPHALT MIXTURES USED TO DEVELOP THE RSI THRESHOLD VALUES

The RSI threshold values can be used to classify a mixture of interest for the given climatic conditions. Table 2 presents the characteristics of the asphalt mixtures used to develop the RSI threshold values.

Table 1. Recommended threshold values for the RSI index parameter.

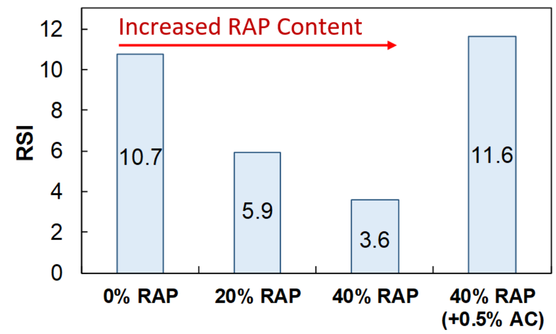
Traffic (Million ESALs)	RSI Limits (%)	Tier	Designation
Less than 10	RSI < 12	Standard	S
Between 10 and 30	RSI < 4	Heavy	H
Greater than 30	RSI < 2	Very Heavy	V
Greater than 30 and slow traffic	RSI < 1	Extremely Heavy	E

Figure 3. Charts. RSI values as a function of four different asphalt mixture factors.



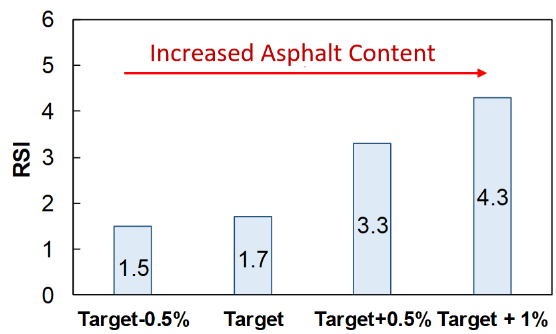
Source: FHWA.

A. RSI values as a function of aggregate gradation with other parameters fixed (NC-PEMD).



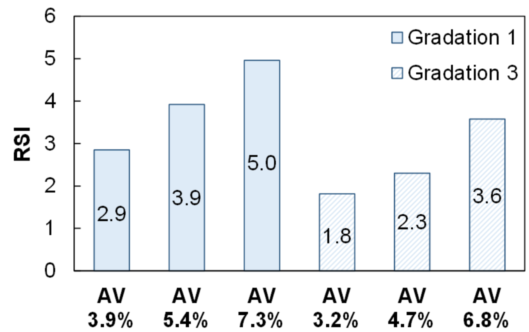
Source: FHWA.

C. RRSI values as a function of RAP content (NH).



Source: FHWA.

B. RSI values as a function of asphalt content with other parameters fixed (ME).



Source: FHWA.

D. RSI values as a function of air void content (NC-PEMD).

Table 2. Characteristics of asphalt mixtures.

Mixture ID	Total[a]	Conventional[a,b]	PMA[a]	WMA[a]	RAP ≥ 40%	Binder PG	NMAS (mm)	Gradation	Remarks
AL (surface)	6	0	2	3[c]	2[c]	67-22, 76-22	9.5, 12.5	Fine OGFC	NCAT test track mixtures, 2009 cycle
AL (intermediate)	6	0	2	3[c]	2[c]	67-22, 76-22	19	Fine	NCAT test track mixtures, 2009 cycle
AL (base)	6	2	0	3[c]	2[c]	67-22	19	Fine	NCAT test track mixtures, 2009 cycle
Canada (surface)	8	3	0	3	2	58-28, 52-34	16	Fine	Mixtures used in Manitoba test road (Kim et al. 2021)
Canada (base)	4	1	0	3	0	58-28	16	Fine	Mixtures used in Manitoba test road
VA-ALF	8	4	2	0	2	58-28, 64-22, 70-22, 70-28, 76-28	12.5	Coarse	Mixtures from ALF(2) (Gibson et al. 2012) and ALF(3) (Li and Gibson 2016) experiments
NH	8	5	0	0	3	58-28, 64-28	12.5	Fine	Mixtures used in Northeast RAP study with various % RAP, % binder, and binder grades
Korea	5	4	1	0	0	64-22, 76-22	19, 25, 40	Fine	Mixtures from Korea Expressway Corp. test road (Kim et al. 2021)
NC	5	4	0	1	0	64-22, 70-22	9.5, 19, 25	Fine	Mixtures commonly used in NC
NC-PEMD	9	9	0	0	0	58-28 (64-22 Pay Grade)	9.5	Fine	Mixtures with different volumetric properties
ME-QA	10	0	10	0	0	64E-28	12.5	Fine	Mixtures sampled from actual paving project for quality assurance
ME	4	4	0	0	0	64-28	12.5	Fine	Mixtures with different binder contents
Total	79	36	17	16	13	NA	NA	NA	NA

[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, which is shown in both the WMA and high RAP columns.
PMA = polymer-modified asphalt; WMA = warm-mix asphalt; RAP = reclaimed asphalt pavement; PG = performance grade; NMAS = nominal maximum aggregate size; AL = Alabama; OGFC = open-graded friction course; NCAT = National Center for Asphalt Technology; VA-ALF = FHWA's Virginia Accelerated Load Facility (mixture); NH = New Hampshire; Corp. = corporation; NC = North Carolina; NC-PEMD = North Carolina performance engineered mixture design; ME-QA = MaineDOT's quality assurance data; ME = Maine; NA = not applicable.

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