Canadian Journal of Civil Engineering

Gradation Characteristics-Based Interlayer Mixture Design Method for Enhanced Rutting Resistance of Asphalt Pavements

Journal:	<i>Canadian Journal of Civil Engineering</i>
Manuscript ID	cjce-2021-0078.R2
Manuscript Type:	Article
Date Submitted by the Author:	05-Jun-2021
Complete List of Authors:	Park, Bongsuk; Purdue University Coconcelli, Cristian; Polyglass USA Inc Chun, Sanghyun; Arkansas Department of Transportation
Keyword:	Interlayer mixture, Rutting performance, Performance-based interlayer mix design, DASR porosity, Asphalt pavement analyzer test
Is the invited manuscript for consideration in a Special Issue? :	Not applicable (regular submission)

SCHOLARONE™
Manuscripts

Gradation Characteristics-Based Interlayer Mixture Design Method for Enhanced Rutting Resistance of Asphalt Pavements

Bongsuk Park*

Lyles School of Civil Engineering
Purdue University
550 Stadium Mall Drive, West Lafayette, IN 47907, U.S.
Phone: (352) 283-5799
E-mail: bongsuk@purdue.edu

Cristian Cocconcelli

Polyglass USA Inc.
1111 W Newport Center Drive, Deerfield Beach, FL 33442, U.S.
Phone: (352) 283-9183
E-mail: cristian.cocconcelli@gmail.com

Sanghyun Chun

System Information and Research Division
Arkansas Department of Transportation
10324 Interstate 30, Little Rock, AR 72209, U.S.
Phone: (352) 672-3972
E-mail: sanghyun.chun@ardot.gov

*Corresponding Author: bongsuk@purdue.edu

**SUBMITTED FOR PUBLICATION IN
THE CANADIAN JOURNAL OF CIVIL ENGINEERING**

Word Count

Abstract:	145
Text:	5,223
Total Words:	5,368
Number of Tables:	4
Number of Figures:	8

1 **ABSTRACT**

2 The major role of interlayer mixtures is to mitigate reflective cracking by absorbing or dissipating
3 concentrated stress, and relatively low-stiffness materials are typically used. However, there is a
4 concern that interlayer mixtures may increase rutting potential due to the low-stiffness materials
5 used. The dominant aggregate size range (DASR) porosity has been successfully applied for
6 structural mixtures to ensure enhanced rutting performance. This study mainly focused on
7 developing the new DASR porosity requirement for interlayer mixtures that ensure acceptable
8 rutting performance in the mix design phase. Ten interlayer mixtures with a broad range of DASR
9 porosities were evaluated using the asphalt pavement analyzer test. Results indicated that the
10 gradation characteristics of interlayer mixtures played an important role in rutting performance.
11 Also, a relationship between DASR porosity and the rutting potential of interlayer mixtures was
12 identified that resulted in the establishment of the preliminary DASR porosity requirements.

13
14 Keywords: Interlayer mixture, Rutting performance, Performance-based interlayer mix design,
15 DASR porosity, Asphalt pavement analyzer test

17 INTRODUCTION

18 Background

19 Interlayer mixtures are typically placed between milled existing pavement and the new overlay to
20 mitigate reflective cracking induced by a stress concentration due to the remained cracks at existing
21 underlying layer after milling (Blankenship et al. 2004; Kim and Buttlar 2002; Lee 2008). The
22 primary role of interlayer mixture in the asphalt pavement system is to absorb or dissipate
23 concentrated stress, so relatively low-stiff materials are typically used (Habbouche et al. 2017). In
24 Florida, the asphalt rubber membrane interlayer (ARMI) which consists of coarse aggregates
25 seated in a thick layer of asphalt rubber binder is the most popular interlayer system. However,
26 when the interlayer (i.e., ARMI) is placed near the pavement surface, the recent field evidence has
27 raised concerns about the increased instability rutting potential likely due to the use of low-stiff
28 material as an interlayer (Chen et al. 2013; Greene et al. 2012). Recent research found that the
29 heavy vehicle simulator (HVS) test sections with the ARMI showed significantly greater rut depth
30 than the section without the ARMI (Greene et al. 2012). This indicated the use of ARMI as a near-
31 surface interlayer technique may cause instability rutting, although it is beneficial for reflective
32 cracking. Therefore, there is a need to design a more suitable interlayer system to resist rutting
33 failure, while mitigating reflective cracking in overlaid or rehabilitated pavement.

34 Several states are currently using specially designed interlayer mixtures to minimize the
35 risk of rutting failure. In New Jersey, the binder rich intermediate course (BRIC) mixture designed
36 with fine gradation along with higher asphalt content has been used as an interlayer mixture
37 (Bennert et al. 2011). The BRIC mixture design requires laboratory tests including asphalt
38 pavement analyzer (APA) test and overlay test to control both rutting and cracking performance.
39 Similarly, the crack attenuating mixture (CAM) is specially designed as an interlayer mixture in

Texas (TxDOT 2014). According to the CAM mixture specification, Hamburg wheel test and overlay test are considered as design requirements to provide acceptable rutting and cracking performance, respectively. However, these laboratory test-based specifications require high labor intensity, time and cost to complete mix design. Therefore, more practical approach is needed to design interlayer mixtures which can mitigate reflective cracking without potential of rutting failure.

The dominant aggregate size range-interstitial component (DASR-IC) theory has been developed to evaluate gradation effects on rutting performance without the need of laboratory tests (Kim et al. 2006). The DASR porosity parameter has been introduced to describe coarse aggregate gradation characteristics of asphalt mixtures, which are mainly responsible for the shear resistance (Kim et al. 2006; Kim et al. 2009). The DASR porosity can be practically applied to design and modify aggregate gradation of asphalt mixtures during mix design stage without any mixture testing. It has been revealed that the DASR porosity well correlated with the rutting performance of field measurements and laboratory testing results (Chun et al. 2018; Greene et al. 2014; Kim et al. 2008; Kim et al. 2009). Even though the DASR porosity concept has been successfully used as a rutting performance indicator to design asphalt mixtures, it is questionable how the DASR porosity works for interlayer mixtures. Since the DASR porosity concept was originally developed for conventional asphalt mixtures (dense-graded structural mixes), further research is needed to determine whether the DASR porosity concept can be used for interlayer mixtures during mix design phase.

In summary, interlayer mixtures may increase instability rutting due to the use of low-shear resistance mixtures. The current specifications for interlayer mixtures consider the laboratory tests as a requirement to ensure acceptable rutting performance. However, incorporating laboratory tests

into mix design process is not practical. Therefore, this study mainly focused on developing the enhanced design methods for interlayer mixtures without the need of laboratory tests, based on a relationship between the DASR porosity and interlayer mixture rutting performance.

Objectives

The primary objective of this study was to establish the new DASR porosity requirements for interlayer mixture design to ensure adequate rutting performance. The detailed objectives of this study are summarized as follows:

- Determine whether the DASR porosity can be used as a performance-based design parameter for interlayer mixtures
- Identify a relationship between the DASR porosity and rutting performance of interlayer mixtures

Scope

Ten interlayer mixtures were designed with two aggregate types widely used in Florida (Georgia granite and Florida limestone) as well as five gradations covering an extensive range of DASR porosity. PG 76-22 polymer-modified asphalt (PMA) binder was used for all interlayer mixtures. The APA test was employed to evaluate interlayer mixture rutting performance as well as to identify a relationship between DASR porosity and interlayer mixture rutting resistance. The APA test is one of the most common laboratory tests for rutting evaluation, and many previous researchers have reported that the APA test can effectively evaluate relative rutting susceptibility of asphalt mixtures (Choubane et al. 2000; Jackson and Baldwin 2000; Kandhal and Mallick 1999). Kandhal and Mallick (1999) reported that the APA test exhibited a sufficient sensitivity to the changes in aggregate gradation and performance grade of binder to assess relative rutting performance for granite and limestone mixtures. In addition, Williams et al. (2004) found that the

APA rut depth was significantly sensitive to the changes in air void contents. Furthermore, it was found to be suitable tool to distinguish between good and poor mixtures in terms of rutting performance, since the APA test exhibited well correlated results with rut depth in the field and test sections (Kandhal and Cooley 2003; Martin and Park 2003). It should be noted that this study mainly focused on rutting performance evaluation. Any concern of cracking potential of evaluated interlayer mixtures was assured by using previously designed mixtures which exhibited satisfactory fracture tolerance to mitigate reflective cracking (Roque et al. 2018; Cocconcelli et al. 2019).

THE DOMINANT AGGREGATE SIZE RANGE-INTERSTITIAL COMPONENT (DASR-IC) THEORY

The structure of aggregate gradation is one of the most important characteristics related to rutting performance of asphalt mixture. Specifically, coarse aggregate gradation primarily provides structural network to resist rutting, which can be described by the dominant aggregate size range-Interstitial component (DASR-IC) theory (Kim et al. 2006; Kim et al. 2009; Roque et al. 2011). In addition, the DASR porosity parameter was developed based on the packing theory and distribution of particle size, and well correlated with rutting performance of dense-graded asphalt mixtures (Vavrik et al. 2001). Details of the DASR-IC theory including the definition and the parameter calculation procedure are described in the following sections.

Dominant Aggregate Size Range (DASR)

According to the DASR-IC theory, the DASR represents the range of coarse aggregates which provide structural interactive network of aggregate to resist shear, as conceptually illustrated in Figure 1. The DASR mainly contributes to interlocking of aggregate in asphalt mixtures, and the DASR particles form the dominant structure to resist shear deformation. The DASR can be

determined using particle interaction analysis based on the packing theory. It should be noted that the DASR can consist of one size or multiple contiguous sizes. Larger particles than the DASR are not play a major role in the aggregate structure because they float in the DASR matrix. On the other hand, particles finer than the DASR, which fill the voids between the DASR particles called the interstitial volume (IV), do not interact with coarser portion in properly designed mixtures. In addition, the combination of fine aggregates, asphalt binder and air voids that exist within the IV is the interstitial components (IC). IC fills DASR voids and binds coarse aggregate.

DASR Porosity

Concept of porosity has been widely used in the field of soil mechanics to dictate the relative ratio of voids to total volume. Less than 50% of porosity for granular materials has been determined to achieve a sufficient contact with each other (Lambe and Whitman 1969). Previous research indicates that the porosity can be used as a criterion for the DASR particles to ensure appropriate interlocking for acceptable resistance to deformation and fracture (Kim et al. 2006). The basic principle used to determine porosity in soils can be extended to asphalt mixtures, since the air voids in the soil is comparable to the void in mineral aggregate (VMA) in asphalt mixtures. The porosity can be obtained for any DASR, when a mixture has certain air void content and effective asphalt binder content for a given gradation. The DASR porosity can be calculated using following equations based on volume of mixture components:

$$\eta_{DASR} = \frac{V_{V(DASR)}}{V_{T(DASR)}} = \frac{V_{ICAGG} + VMA}{V_{TM} - V_{AGG(>DASR)}} \#(1)$$

where, η_{DASR} = DASR porosity, $V_{\text{V(DASR)}}$ = volume of voids within DASR (i.e., IV), $V_{\text{T(DASR)}}$ = total volume available for DASR particles, V_{ICAGG} = volume of IC aggregates, VMA = voids in mineral aggregate, V_{TM} = volume of total mixture, $V_{\text{AGG(>DASR)}}$ = volume of particles greater than DASR.

Even though the 50% of porosity provides adequate interlocking between particles for granular material in the traditional soil mechanics, the specific threshold was not practical to distinguish rutting potential of asphalt mixture. Therefore, for asphalt mixtures, the DASR porosity was categorized into three groups based on rutting performance as follows (Kim et al. 2006; Kim et al. 2009; Roque et al. 2011):

- Group I (Good: $38\% < \eta_{\text{DASR}} < 48\%$): Mixtures within this range of DASR porosity were expected to exhibit good rutting performance in the field.
- Group II (Marginal: $48\% < \eta_{\text{DASR}} < 52\%$): Mixtures within this range of DASR porosity may have a good or poor rutting performance in the field.
- Group III (Poor: $52\% < \eta_{\text{DASR}}$): Mixtures within this range of DASR porosity were expected to have greater rutting potential than mixtures in Group I and II.

INTERLAYER MIXTURE DESIGN

Materials and Aggregate Gradation

The binder and aggregate approved by FDOT were used for interlayer mixtures to avoid any deficiency of materials regarding the rutting performance. PG 76-22 PMA binder widely used to improve rutting performance was used for all mixture types, and it satisfied the FDOT requirements in terms of $G^*/\sin\delta$ and $J_{\text{nr},3.2}$ that are binder properties associated with rutting resistance. At 76°C of testing temperature, the dynamic shear rheometer test results exhibited that the $G^*/\sin\delta$ was 1.33 kPa for unaged binder (minimum 1.0 kPa) and 2.79 kPa for rolling thin film

oven aged binder (minimum 2.2 kPa). In addition, a non-recoverable creep compliance at 3.2 kPa stress level ($J_{nr,3.2}$: 0.44 kPa⁻¹) was lower than maximum requirement of 1.00 kPa⁻¹ at 67°C based on the multiple stress creep and recovery test. For aggregate, Georgia granite and Florida limestone widely used in Florida were used to design interlayer mixtures. Table 1 summarizes information of aggregate sources: (i) coarse aggregate: the #89 stone and S1B stone, (ii) fine aggregate: W-10, M-10, Med. Screening, and (iii) dust: granite and limestone dust. For each aggregate type, five gradations were selected to evaluate extensive range of gradations for identifying appropriate threshold of the DASR porosity. Depending on the gradation, the proportion of coarse and fine aggregate were adjusted, as presented in Table 1. Figure 2 shows all determined blended aggregate gradations: “9.5” denotes 9.5 mm nominal maximum aggregate size (NMAS), and “4.75” denotes 4.75 mm NMAS, “G” and “L” denotes granite and limestone, respectively. Three gradations (A, B and C) were designed as 9.5 mm NMAS and two (D and E) gradations were 4.75 mm NMAS. It should be noted that both granite and limestone had a similar gradation distribution to determine whether aggregate types affect rutting performance.

Design Criteria and Volumetric Properties

Design asphalt binder contents were determined according to reference design criteria used for two existing interlayer mixtures, CAM and BRIC (Bennert et al. 2011; TxDOT 2014). Low target air void contents and less compaction effort were applied to obtain higher asphalt binder content which is beneficial to fracture resistance. In addition, PMA binder was used to achieve better rutting resistance which is a primary concern of interlayer mixtures. Interlayer mix design requirements applied in this study are described below:

- N_{design} : 50 gyrations
- Air void content at N_{design} : 2 %

- The minimum asphalt binder content: 7 %
- The minimum VMA: 17 % for 9.5mm NMAS, 18 % for 4.75 mm NMAS

Table 2 presents volumetric properties of designed interlayer mixtures and all mixtures met the criteria described above. In addition, a consistent filler content (P200) was used for 9.5 mm NMAS and 4.75 mm NMAS mixtures to minimize effects of filler contents, since the filler content was found to be critical for rutting resistance (Hamidi and Motamed 2019). As presented in Table 2, the limestone mixtures generally had higher binder content compared to granite mixtures due to high binder absorption of the Florida limestone except for 4.75 GE mixture which has the greatest binder content. It is important to note that the 4.75 GE mixture was designed with the GA 753 granite to fabricate the finest gradation within the available stockpiles, while other granite mixtures were produced using GA 553 granite. This leads that mix design parameters for 4.75 GE might have been affected by the aggregate characteristics associated with different type of granite aggregate. It should be noted that the reflective cracking resistance of designed interlayer mixtures was assessed using the composite specimen interface cracking (CSIC) test by concurrent studies (Roque et al. 2018; Cocconcelli et al. 2019). The CSIC test specimen consists of existing layer, interlayer, and overlay to simulate realistic condition, and 25.4 mm and 19 mm interlayer thicknesses were used for 9.5 mm and 4.75 mm NMAS interlayer mixtures, respectively. Figure 3 shows that all specimens with interlayer exhibited greater number of cycles to failure than those without interlayer (control). This indicates all designed interlayer mixtures were able to improve reflective cracking resistance. Therefore, this study focused on rutting resistance of interlayer mixtures without any concern of cracking performance, and more details on reflective cracking evaluation for interlayer mixtures can be found elsewhere (Roque et al. 2018; Cocconcelli et al. 2019).

200 **DASR-IC Analysis**

201 DASR-IC analysis was conducted on all interlayer mixtures to calculate the DASR porosity. Table
202 3 presents the DASR porosity values for all mixtures ranged from 41% to 78%. Most of the
203 designed interlayer mixtures had relatively high DASR porosity, since interlayer mixture
204 gradations were designed with finer gradation and higher binder contents compared to the
205 traditional dense-graded asphalt mixture (i.e., structural asphalt mixtures). It is interesting to note
206 that the finer gradation resulted in higher DASR porosity for interlayer mixtures, that is consistent
207 trend observed from structural dense-graded mixtures. Specifically, all 4.75 mm NMAS interlayer
208 mixtures had clearly higher DASR porosity than 9.5 mm NMAS mixtures. In addition, all
209 limestone interlayer mixtures had slightly higher DASR porosity compared to granite interlayer
210 mixtures at a similar gradation except for the finest granite mixture (4.75 GE) which had the
211 greatest binder content presumably due to the use of different aggregate.

212 Furthermore, the interlayer mixtures were categorized based on the original DASR porosity
213 ranges, as presented in Table 3. For granite interlayer mixtures, two mixtures (9.5 GA and 9.5 GB)
214 were associated with Group I (Good), while three mixtures (9.5 GC, 4.75 GD, and 4.75 GE) were
215 in Group III (Poor). For limestone interlayer mixtures, 9.5 mm mixtures have all three Groups and
216 all 4.75 mm mixtures were in Group III (Poor). It should be noted that all designated Groups
217 presented in Table 3 were only used as a reference, since the original DASR categories were
218 developed for structural asphalt mixtures.

219 **APA TEST RESULTS**

220 Asphalt pavement analyzer (APA) test was conducted on interlayer mixtures to evaluate rutting
221 performance. The cylindrical specimens were compacted to 4% air voids using Superpave gyratory
222 compactor, and four replicates for each mix type were tested at 64°C by applying the 8,000 cycles

loading or until a rut depth of 14 mm was reached. Figures 4a and 4b show the APA test setup and APA specimen after completion of test. The maximum APA rut depth of 6 mm was selected as a requirement for sufficient rutting resistance of interlayer mixture, that is consistent with the criterion used for design of BRIC interlayer mixture (Bennert et al. 2011). Furthermore, the rate of rut depth increment was calculated to provide more insight regarding rutting potential of interlayer mixtures.

APA Rut Depth

Figure 5 shows measured APA rut depth for all 10 interlayer mixtures, and the variability in rut depth measurements was low enough to compare each mixture type. It was found that the aggregate gradation appeared to be related to rutting performance, even for finely graded interlayer mixtures. Overall, the coarser gradation was more beneficial to rutting resistance of interlayer mixture compared to finer gradation. For granite mixtures, all 9.5 mm NMAS mixtures satisfied the rut depth requirement (6 mm from Bennert et al. 2011), whereas rut depth of all 4.75 mm NMAS mixtures were greater than 6 mm. Also, all limestone interlayer mixtures exhibited acceptable rut depth (below 6 mm) except for the finest interlayer mixture (4.75 LE). Specifically, the 4.75 GE and LE interlayer mixtures designed by the finest gradation showed clearly greater rut depth than other mixtures, and the 4.75 GE mixture failed before reaching at 8,000 load cycles. This indicates interlayer mixture gradation should be carefully controlled to avoid excessively fine gradation. In addition, limestone interlayer mixtures exhibited better rutting performance than granite mixtures regardless of gradation characteristics. Rougher texture of Florida limestone may provide better shear resistance than Georgia granite at a similar gradation, which is consistent with results reported by previous researchers (Kim et al. 2008). Furthermore, limestone provide better adhesion properties between asphalt binder and aggregates leading to better rutting resistance compared to

the granite mixtures (Guo et al. 2020). This means that aggregate characteristics such as texture and angularity, may also affect interlayer mixture rutting performance. However, consideration of aggregate characteristics for interlayer mixture design may not be practical.

Rate of Rut Depth Increment

Since granite interlayer mixture with the finest gradation (4.75 GE) failed before reaching 8,000 cycles, further interpretation was conducted using the rate of rut depth increment to provide better insight regarding relative rutting performance of each mixture. Figure 6a illustrates determination of the rut depth increment rate from the APA test results. The APA rut depth curve can be separated into two specific behaviors: a non-linear behavior (initial stage) followed by a linear behavior (stabilized stage). In the initial stage, the rut depth rapidly increased, whereas in the stabilized stage, the increment of rut depth is constant. Based on the rut depth curves obtained in this study, the rate of rut depth increment was stabilized before reaching at 2,000 loading cycles for all interlayer mixtures evaluated. Therefore, the 2,000 loading cycles were selected as a criterion to separate the initial and stabilized stages for all interlayer mixtures, and a linear regression method was conducted on the rut depth data in stabilized stage to calculate the rate of rut depth increment. Figure 6b shows that the ranking for rate of rut depth increment was consistent with rut depth results. It is interesting to note that the 4.75 GE mixture exhibited clearly greater rate of rut depth increment compared to the 4.75 LE mixture, while the difference in rut depth between those mixtures was relatively small. This indicates a severity of 4.75 GE mixture hidden by machine limit has been revealed through the rate of rut depth increment analysis. Therefore, for the purpose of relative rutting performance evaluation, the rate of rut depth increment may be a more appropriate parameter than rut depth.

DETERMINATION OF DASR POROSITY REQUIREMENT FOR INTERLAYER MIXTURE

Since the DASR porosity was originally developed for dense-graded structural mixtures, it is necessary to establish the new recommended range of DASR porosity for interlayer mixtures. In this section, the DASR porosity values were compared with APA test results to identify appropriate DASR porosity requirements for interlayer mixture.

Comparison Between DASR Porosity and APA Rut Depth

Figure 7 shows that APA rut depth increased as the DASR porosity increases, indicating the DASR porosity appeared to be related to APA rut depth for interlayer mixtures. For granite interlayer mixtures shown in Figure 7a, both 9.5 GA and 9.5 GB mixtures satisfied rut depth requirement and those mixtures were in Group I (Good) based on the original DAR porosity ranges developed for structural mixtures. In addition, 4.75 GD and 4.75 GE mixtures which were in Group III (Poor), did not satisfy rut depth requirement. However, although DASR porosity (63%) was clearly greater than 52% of the upper limit for Group II (Marginal), the rut depth of 4.75 GD mixture was almost close to the maximum rut depth requirement. On the other hand, even though the DASR porosity of 9.5 GC mixture was slightly higher than 52%, this mixture also exhibited allowable rut depth. As shown in Figure 7b, limestone interlayer mixtures also exhibited similar trend that APA rut depth increased when the DASR porosity increased except for one mixture (4.75 LD). The 4.75 LC and LD mixtures showed good rutting performance, although DASR porosity was in Group III (Poor). Results confirmed that interlayer mixture rutting performance does not well agree with the original DASR porosity categories developed for structural mixtures. Therefore, it is necessary to optimize DASR porosity limits for interlayer mixtures to better represent their rutting performance.

291 **Comparison Between DASR Porosity and Rate of Increment in APA Rut Depth**

292 Figure 8 shows a comparative result between the DASR porosity and increment rate of APA rut
293 depth, and it further confirmed the ability of the DASR porosity predict rutting potential of
294 interlayer mixtures. As the DASR porosity increased, the rut depth increment rate increased that
295 is the same trend with APA rut depth results. Interestingly, the rate of rut depth increment for 4.75
296 GE mixture was greater than for 4.75 LE mixture that was not captured from rut depth results.
297 Since 4.75 GE mixture could not reach 8,000 cycles due to the machine limit, the recorded final
298 rut depth for 4.75 GE appeared to be similar to 4.75 LE mixture. As discussed earlier, the rate of
299 rut depth increment may be more appropriate parameter than final rut depth to compare each
300 mixture type for research purpose, when rut depth value is not measurable. However, the final rut
301 depth is a more practical and preferred parameter to establish a design criterion, since additional
302 procedure and time are required to obtain rut depth increment rate. Furthermore, the final rut depth
303 is more sensitive to the DASR porosity than the rate of rut depth increment at lower DASR
304 porosity, that is more beneficial to distinguish levels of rutting performance. Therefore, the rut
305 depth was selected as a rutting performance indicator to establish recommended DASR porosity
306 range for interlayer mixtures.

307 **Recommended DASR Porosity Requirement for Interlayer Mixtures**

308 Since granite mixtures showed relatively lower rutting resistance compared to limestone mixtures,
309 recommended range of DASR porosity was established based on the results of granite mixtures to
310 be more conservative. Based on the rut depth results from the granite mixtures evaluated in this
311 study, 55% of DASR porosity was recommended as the upper limit for good rutting resistance of
312 interlayer mixtures. The lower limit of DASR porosity for good rutting resistance was selected as
313 the minimum value of DASR porosity (for 9.5 GA) within the range evaluated in this study, which

showed clearly acceptable rutting resistance. For the marginal group, the DASR porosity range between 55% and 63% was recommended based on the 4.75 GD mixture result. The 4.75 GD mixture had 63% of the DASR porosity and its rut depth was slightly greater than the maximum rut depth requirement which is likely marginal rutting performance. In addition, there was one data point (4.75 GE) above 63% DASR porosity that exhibited clearly greater rut depth compared to other mixtures. Therefore, the lower limit for poor group was recommended as 63% to avoid any risk of rutting potential conservatively. Table 4 summarizes recommended DASR porosity range for interlayer mixture, along with original range for structural mixture. As presented in Table 4, the overall DASR porosity range for interlayer mixture is greater than for structural mixture, since interlayer mixture allows higher asphalt content, which may increase rutting resistance.

SUMMARY AND CONCLUSIONS

In this study, interlayer mixtures with extensive DASR porosity range were evaluated using APA test to establish the new DASR porosity requirements for interlayer mixtures. A summary of findings is presented as follows:

- Regardless of aggregate type, coarser interlayer mixture gradation resulted in lower APA rut depth and rate of rut depth increment, indicating that gradation characteristics appeared to be important for fine graded interlayer mixtures to ensure sufficient rutting performance.
- Limestone interlayer mixtures exhibited better rutting performance than granite mixtures due to rougher texture of Florida limestone. This implies that aggregate characteristics, roughness and angularity, may affect interlayer rutting performance. However, consideration of aggregate characteristics for interlayer mixture design may not be practical.

- As the DASR porosity of interlayer mixture increased, APA rut depth and the increment rate of rut depth increased, which is consistent with the trend observed from structural mixture. Therefore, the DASR porosity can be used as a rutting performance indicator to design and evaluate interlayer mixtures.
- Within the range of mixtures evaluated in this study, the DASR porosity of 55% appeared to be the upper limit for good rutting resistance of interlayer mixtures. However, the lower limit for poor rutting resistance was not accurately captured due to the limited data between 63% and 78% DASR porosity range. Therefore, 63% DASR porosity was conservatively selected as the lower limit for poor rutting resistance and the range between 55% to 63% was preliminarily recommended for the marginal group.

In conclusion, the DASR porosity may be used as a performance-based design parameter for interlayer mixture to ensure acceptable rutting performance. The DASR porosity appeared to be closely related to rutting resistance of interlayer mixtures, and a preliminary DASR porosity requirement for interlayer mixtures was established based on the relationship between the DASR porosity and rutting performance. It should be noted that the preliminary DASR porosity requirement was developed based on the laboratory evaluation at mixture level with limited number of mixture type. In particular, a dramatic change in rutting performance was identified between 63% and 78% of DASR porosity. In order to define more accurate DASR porosity ranges for marginal and poor group, evaluation of additional interlayer mixtures belonged to these groups is recommended. In addition, the rutting mechanism of interlayer in the field pavements was not reflected by the APA test, as the APA load was directly applied to the interlayer mixtures.

358 Therefore, field performance evaluation is recommended to further validate the preliminary DASR
359 porosity ranges for interlayer mixtures design determined in this study.

360

Draft

361 ACKNOWLEDGEMENTS

362 The work represented herein was the results of a team effort. The authors would like to
363 acknowledge the FDOT's State Materials Office Pavement Materials Section staff for their
364 assistance with data collection effort and technical advice.

365 REFERENCES

- 366 Bennert, T., Fee, F., Sheehy, E., Blight, R., and Sauber, R. 2011. Implementation of Performance-
367 Based HMA Specialty Mixtures in New Jersey. *Journal of the Association of Asphalt*
368 *Paving Technologists*, **80**: 719-740.
- 369 Blankenship, P., Iker, N., and Drbohlav, J. 2004. Interlayer and Design Considerations to Retard
370 Reflective Cracking. *Transportation Research Record*, **1896**(1): 177-186.
371 doi:10.3141/1896-18.
- 372 Chen, Y., Lopp, G., and Roque, R. 2013. Effects of an Asphalt Rubber Membrane Interlayer on
373 Pavement Reflective Cracking Performance. *Journal of Materials in Civil Engineering*,
374 **25**(12): 1936-1940. doi:10.1061/(ASCE)MT.1943-5533.0000781.
- 375 Choubane, B., Page, G., and Musselman, J. 2000. Suitability of Asphalt Pavement Analyzer for
376 Predicting Pavement Rutting. *Transportation Research Record: Journal of the*
377 *Transportation Research Board*, **1723**: 107-115. doi:10.3141/1723-14.
- 378 Chun, S., Kim, K., Park, B., and Greene, J. 2018. Evaluation of the effect of segregation on coarse
379 aggregate structure and rutting potential of asphalt mixtures using Dominant Aggregate
380 Size Range (DASR) approach. *KSCE Journal of Civil Engineering*, **22**(1): 125-134.
381 doi:10.1007/s12205-017-1372-5.
- 382 Cocconcelli, C., Park, B., Zou, J., Lopp, G., and Roque, R. 2019. Fracture-Tolerant and Shear-
383 Resistant Interlayers for Mitigation of Reflective Cracking. *Transportation Research*
384 *Record*, **2673**(10): 35-46. doi:10.1177/0361198119847622.
- 385 Greene, J., Chun, S., and Choubane, B. 2014. Enhanced Gradation Guidelines to Improve Asphalt
386 Mixture Performance. *Transportation Research Record: Journal of the Transportation*
387 *Research Board*, **2456**: 3-10. doi:10.3141/2456-01.
- 388 Greene, J., Choubane, B., Chun, S., and Kim, S. 2012. Effect of Asphalt Rubber Membrane
389 Interlayer (ARMI) on Instability Rutting and Reflection Cracking of Asphalt Mixture.
390 Florida Department of Transportation.
- 391 Guo, F., Pei, J., Zhang, J., Xue, B., Sun, G., and Li, R. 2020. Study on the Adhesion Property
392 Between Asphalt Binder and Aggregate: A State-Of-the-Art Review. *Construction and*
393 *Building Materials* **256**: 119474. doi:https://doi.org/10.1016/j.conbuildmat.2020.119474.

- 394 Habbouche, J., Hajj, E.Y., Morian, N.E., Sebaaly, P.E., and Piratheepan, M. 2017. Reflective
395 cracking relief interlayer for asphalt pavement rehabilitation: from development to
396 demonstration. *Road Materials and Pavement Design*, **18**(sup4): 30-57.
397 doi:10.1080/14680629.2017.1389080.
- 398 Hamidi, A., and Motamed, A. 2019. The effect of filler type and content on rutting resistance of
399 asphaltic materials. *International Journal of Pavement Research and Technology*, **12**(3):
400 249-258. doi:10.1007/s42947-019-0031-2.
- 401 Jackson, N.M., and Baldwin, C.D. 2000. Assessing the Relative Rutting Susceptibility of HMA in
402 the Laboratory with the Asphalt Pavement Analyzer. *International Journal of Pavement*
403 *Engineering*, **1**(3): 203-217. doi:10.1080/10298430008901706.
- 404 Kandhal, P.S., and Mallick, R.B. 1999. Evaluation of Asphalt Pavement Analyzer for HMA Mix
405 Design. National Center for Asphalt Technology, NCAT Report No. 99-4, Auburn, AL.
- 406 Kandhal, P.S., and Cooley, L.A. 2003. Accelerated Laboratory Rutting Tests: Evaluation of the
407 Asphalt Pavement Analyzer. No. NCHRP Report 508. Transportation Research Board.
- 408 Kim, J., and Buttlar, W.G. 2002. Analysis of Reflective Crack Control System Involving
409 Reinforcing Grid over Base-Isolating Interlayer Mixture. *Journal of Transportation*
410 *Engineering*, **128**(4): 375-384. doi:doi:10.1061/(ASCE)0733-947X(2002)128:4(375).
- 411 Kim, S., Roque, R., Guarin, A., and Birgisson, B. 2006. Identification and Assessment of the
412 Dominant Aggregate Size Range (DASR) of Asphalt Mixture (with discussion). *Journal of*
413 *the Association of Asphalt Paving Technologists*, **75**.
- 414 Kim, S., Guarin, A., Roque, R., and Birgisson, B. 2008. Laboratory Evaluation for Rutting
415 Performance Based on the DASR Porosity of Asphalt Mixture. *Road Materials and*
416 *Pavement Design*, **9**(3): 421-440. doi:10.1080/14680629.2008.9690126.
- 417 Kim, S., Roque, R., Birgisson, B., and Guarin, A. 2009. Porosity of the Dominant Aggregate Size
418 Range to Evaluate Coarse Aggregate Structure of Asphalt Mixtures. *Journal of Materials*
419 *in Civil Engineering*, **21**(1): 32-39. doi:doi:10.1061/(ASCE)0899-1561(2009)21:1(32).
- 420 Lambe, T.W., and Whitman, R.V. 1969. *Soil Mechanics*. John Wiley & Sons.
- 421 Lee, S.J.J. 2008. Mechanical performance and crack retardation study of a fiberglass-grid-
422 reinforced asphalt concrete system. *Canadian Journal of Civil Engineering*, **35**(10): 1042-
423 1049. doi:10.1139/108-049.
- 424 Martin, A.E., and Park, D.-W. 2003. Use of the Asphalt Pavement Analyzer and Repeated Simple
425 Shear Test at Constant Height to Augment Superpave Volumetric Mix Design. *Journal of*
426 *Transportation Engineering*, **129**(5): 522-530. doi:doi:10.1061/(ASCE)0733-
427 947X(2003)129:5(522).

- 428 Roque, R., Chun, S., Zou, J., Lopp, G., and Villiers, C. 2011. Continuation of Superpave Projects
429 Monitoring. Final Report of Florida Department of Transportation, FDOT Contract No.
430 BDK-75-977-06, University of Florida, Gainesville, FL.
- 431 Roque, R., Cocconcelli, C., Zou, J., Park, B., and Lopp, G. 2018. Evaluation of Reflective Cracking
432 Mitigation Treatments Using the Composite Specimen Interface Crack (CSIC) Test, Final
433 Report of Florida Department of Transportation, FDOT Contract No. BDV31-977-39,
434 University of Florida, Gainesville, FL.
- 435 TxDOT. 2014. Standard Specifications for Construction and Maintenance of Highways, Streets
436 and Bridges, Crack Attenuating Mixture. Special Specification 3000.
- 437 Vavrik, W.R., Pine, W.J., Huber, G., Carpenter, S.H., and Bailey, R. 2001. The bailey method of
438 gradation evaluation: the influence of aggregate gradation and packing characteristics on
439 voids in the mineral aggregate (with discussion). *Journal of the Association of Asphalt*
440 *Paving Technologists*, 70, pp. 132-175.
- 441 Williams, R.C., Hill, D.L., Hofmann, K., Zelenock, M., and Bausano, J. 2004. Development of
442 Laboratory Performance Test Procedures and Trial Specifications for Hot Mix Asphalt:
443 Final Report No. RC-1410, Michigan Department of Transportation.
- 444

445 **List of Tables**

446 Table 1. Aggregate Sources Information

447 Table 2. Volumetric Properties of Designed Interlayer Mixtures

448 Table 3. The DASR Porosity for All Interlayer Mixtures

449 Table 4. Recommended DASR Porosity (η DASR) Group

450 **List of Figures**

451 Figure 1. Schematic of the DASR concept

452 Figure 2. Blended aggregate gradations: (a) for granite interlayer mixtures and (b) for limestone
453 interlayer mixtures

454 Figure 3. Reflective cracking resistance of designed interlayer mixtures (Roque et al. 2018): (a)
455 9.5 mm NMAS mixtures with 25.4 mm interlayer thickness, and (b) 4.75 mm NMAS mixtures
456 with 19 mm interlayer thickness

457 Figure 4. APA test: (a) APA testing and (b) completed APA test specimen

458 Figure 5. APA rut depth for all interlayer mixtures evaluated

459 Figure 6. Rate of APA rut depth increment: (a) determination of increment rate for APA rut
460 depth and (b) rate of rut depth increment results

461 Figure 7. Effect of the DASR porosity on APA rut depth: (a) for granite interlayer mixtures and
462 (b) for limestone interlayer mixtures

463 Figure 8. Effect of the DASR porosity on rate of increment in APA rut depth: (a) for granite
464 interlayer mixtures and (b) for limestone interlayer mixtures

465

Table 1 Aggregate Sources Information

Mix Type	Source	Product Name	Pit No.	Percentage
9.5 GA	Georgia Granite	#89 Stone	GA 553	44.5%
		W-10 Screening	GA 553	54.3%
		Dust	GA 553	1.2%
9.5 GB	Georgia Granite	#89 Stone	GA 553	30.0%
		W-10 Screening	GA 553	69.0%
		Dust	GA 553	1.0%
9.5 GC	Georgia Granite	#89 Stone	GA 553	13.0%
		W-10 Screening	GA 553	86.3%
		Dust	GA 553	0.7%
4.75 GD	Georgia Granite	W-10 Screening	GA 553	87.4%
	Local Sand	-	334-LS	10.0%
	Georgia Granite	Dust	GA 553	2.6%
4.75 GE	Georgia Granite	M-10 Screening	GA 753	97.4%
		Dust	GA 553	2.6%
9.5 LA	Florida Limestone	S1B	87090	46.7%
		Med. Screening	87090	52.3%
		Dust	87090	1.0%
9.5 LB	Florida Limestone	S1B	87090	32.1%
		Med. Screening	87090	67.0%
		Dust	87090	0.9%
9.5 LC	Florida Limestone	S1B	87090	11.7%
		Med. Screening	87090	87.7%
		Dust	87090	0.6%
4.75 LD	Florida Limestone	Med. Screening (F21)	87090	15.6%
		Med. Screening (F23)	87090	81.8%
		Dust	87090	2.6%
4.75 LE	Florida Limestone	Med. Screening	87090	97.7%
		Dust	87090	2.3%

Table 2 Volumetric Properties of Designed Interlayer Mixtures

Aggregate Type	Parameters	9.5 mm NMAS			4.75 mm NMAS	
		A	B	C	D	E
Granite	$P_b^{(1)}$	7.9%	8.3%	8.9%	8.4%	12.2%
	$G_{mm}^{(2)}$	2.465	2.456	2.429	2.434	2.264
	VMA	18.9%	19.4%	20.7%	19.6%	28.7%
	P200	4.0%	4.0%	4.0%	6.0%	6.0%
Limestone	P_b	8.9%	9.1%	9.8%	9.6%	11.5%
	G_{mm}	2.244	2.251	2.242	2.265	2.225
	VMA	17.0%	17.6%	19.6%	19.3%	22.1%
	P200	4.0%	4.0%	4.0%	6.0%	6.0%

Note: (1) P_b : Design asphalt binder content (%); (2) G_{mm} : Theoretical maximum specific gravity

Table 3 The DASR Porosity for All Interlayer Mixtures

Aggregate Type	Parameter	9.5 mm NMAS			4.75 mm NMAS	
		A	B	C	D	E
Granite	η_{DASR}	41%	46%	53%	63%	78%
	Group	I (Good)	I (Good)	III (Poor)	III (Poor)	III (Poor)
Limestone	η_{DASR}	43%	48%	56%	66%	75%
	Group	I (Good)	II (Marginal)	III (Poor)	III (Poor)	III (Poor)

475 **Table 4 Recommended DASR Porosity (η_{DASR}) Group**

Group	DASR Porosity (η_{DASR}) Range	
	Structural Mixture (original)	Interlayer Mixture
Group I (Good)	$38\% < \eta_{\text{DASR}} < 48\%$	$41\% < \eta_{\text{DASR}} < 55\%$
Group II (Marginal)	$48\% < \eta_{\text{DASR}} < 52\%$	$55\% < \eta_{\text{DASR}} < 63\%$
Group III (Poor)	$52\% < \eta_{\text{DASR}}$	$63\% < \eta_{\text{DASR}}$

476

477

478

479

480 **Figure 1 Schematic of the DASR concept**

481

(a)

(b)

Figure 2 Blended aggregate gradations: (a) for granite interlayer mixtures and (b) for limestone interlayer mixtures

Figure 3. Reflective cracking resistance of designed interlayer mixtures (Roque et al. 2018):
(a) 9.5 mm NMA mixtures with 25.4 mm interlayer thickness, and (b) 4.75 mm NMA
mixtures with 19 mm interlayer thickness

496

(a)

(b)

Figure 4 APA test: (a) APA testing and (b) completed APA test specimen

497

498

499

500

Figure 5 APA rut depth for all interlayer mixtures evaluated

Figure 6 Rate of APA rut depth increment: (a) determination of increment rate for APA rut depth and (b) rate of rut depth increment results

Figure 7 Effect of the DASR porosity on APA rut depth: (a) for granite interlayer mixtures and (b) for limestone interlayer mixtures

Figure 8 Effect of the DASR porosity on rate of increment in APA rut depth: (a) for granite interlayer mixtures and (b) for limestone interlayer mixtures