Optimizing the Performance of Item 404-Low Volume Traffic Mixes

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16. Abstract

Most local public agencies (LPAs) in Ohio follow the Ohio Department of Transportation (ODOT) specifications for designing asphalt mixtures placed on low-volume roads, with the majority of these agencies using Type 1 surface mixes prepared using PG 64-22 asphalt binders. As an alternative, some LPAs use a mix known as 404LVT, which is a fine-graded recipe mix that is rich in asphalt binder and can be placed at a thickness of 1 inch to correct minor surface distresses. The main goal of this study was to optimize the 2015 404LVT specifications developed by Flexible Pavements of Ohio (FPO) for use by LPAs in Ohio on low-volume local roads. To achieve this objective, information was collected about the current state-of-the-practice for using 404LVT mixes in Ohio. In addition, a laboratory testing plan was designed and executed using materials collected from different asphalt plants across Ohio. This research project also involved evaluating the field condition of pavement sections constructed using 404LVT mixes. Based on the outcome of the laboratory test plan and the pavement condition evaluations, several recommendations were made to improve the performance of 404LVT mixes. In addition, recommendations were made to modify the 404LVT specifications in order to make the mix more cost-effective without compromising its performance.

17. Keywords

Asphalt mixture, asphalt binder, mix design, low-volume roads, cracking, rutting

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1. Project Background

Most local public agencies (LPAs) in Ohio follow the Ohio Department of Transportation (ODOT) specifications for designing asphalt mixtures placed on low-volume roads. Current ODOT mix design specifications for asphalt overlays placed on roads with low traffic are based on the Marshall mix design method, and Type 1 surface mixes (prepared using PG 64-22 asphalt binders) are typically used for this purpose (ODOT 2023). As an alternative, some LPAs use 404LVT (Low Volume Traffic), a recipe mix based on ODOT Item 404, which was used by ODOT for several decades before being removed from its Construction and Material Specifications (CMS) in 2002. This recipe mix was modified and reintroduced by Flexible Pavements of Ohio (FPO) in 2008 for use in thin asphalt overlays to correct minor surface distresses (Crago and Surber 2021). Subsequent modifications were made by FPO in later years that led to the development of a revised Item 404LVT specification (Table 1), which was published in 2015 (FPO 2015).

The 2015 404LVT asphalt mixture is a recipe mix that is rich in asphalt binder, fine textured, and nonrestrictive in aggregate shape and type, with strict limits on the amount of reclaimed asphalt pavement (RAP) that can be incorporated into the asphalt mixture. This mix is recommended for use on low-volume roads with a maximum average daily traffic (ADT) of 2,500 vehicles per day, and it can be produced as either a hot mix asphalt (HMA) or a warm mix asphalt (WMA). The 2015 404LVT specifications allow for using PG 64-22 or PG 58-28 asphalt binders. The amount of reclaimed asphalt pavement (RAP) that is incorporated in the mix is limited to 10% when using PG 64-22 and to 20% when using PG 58-28. The total asphalt binder content is specified based on the type of the coarse aggregates used in the mix (6.8% for limestone coarse aggregates, 6.6% for gravel coarse aggregates, and 6.7% for gravel/limestone coarse aggregate blends), which is approximately 0.5% higher than the binder content commonly used in ODOT Type 1 surface mixes.

The predominant type of distress on asphalt pavements on local roads is caused by long-term cracking from environmental factors, as opposed to rutting from heavy truck traffic. The higher asphalt binder content in the 2015 404LVT mixes is expected to make these mixes more durable and more resistant to cracking. Another advantage of 404LVT mixes is that they contain smaller aggregate particles, which would allow placing an asphalt overlay at a thickness of 1 inch (as compared to 1.25 inches or 1.5 inches, which are typically used for ODOT Type 1 surface mixes).

Table 1. 2015 404LVT Mix Design Specifications (FPO 2015).

Aggregate gradation	100% passing the ½-inch sieve 90 to 100% passing the ⅜-inch sieve 72% passing the No. 4 sieve 42 to 60% passing the No. 8 sieve 27 to 45% passing the No. 16 sieve 10 to 22% passing the No. 50 sieve 0 to 8% passing the No. 200 sieve
Virgin fine aggregate	A minimum of 50% of virgin fine aggregate must consist of natural sand (per ODOT CMS Item 703.05)
Total binder content (% by weight of mix)	6.6% for gravel coarse aggregate[1,2] 6.8% for limestone coarse aggregate[1,2] 6.7% for gravel/limestone coarse aggregate blends[1,2] For slag aggregate blends, the percentage as determined by the Marshall mix design process for medium traffic, with binder content selection at 2.5% air voids. [1] Increase binder content by 0.2% for coarse aggregate having absorption ≥ 4.0 [2] The engineer may adjust the binder content; compensation will be made according to 404LVT.22
Virgin binder minimum (% by weight of mix)	5.6% for gravel coarse aggregate 5.8% for limestone coarse aggregate
Traffic volume (ADT)	Maximum of 2,500 vehicles per day
Binder grades	PG 58-28 or PG 64-22
Limits for reclaimed asphalt pavement (RAP) (% by weight of mix)	Maximum of 20% for PG 58-28 Maximum of 10% for PG 64-22

Several LPAs in Ohio currently use the 404LVT mix (e.g., Fayette County, Miami County, and Darke County) and are generally satisfied with its performance. The LPAs in these counties have made significant efforts to select a material combination for this mix that will provide good cracking resistance for asphalt overlays on their low-volume roads. However, it is recognized that the specification could be improved through a more comprehensive effort to optimize the 404LVT material selection and mix design. The optimization of this mix is expected to not only result in more cost-effective, longer lasting low-volume roads but also provide the data needed to support the wider use of 404LVT mixes on low-volume local roads across Ohio.

2. Research Context

2.1 Objectives of the Study

The main goal of this study is to optimize 404LVT specifications for use by LPAs in Ohio on low-volume local roads. The specific objectives of this study include:

- Examine the effect of different mix design factors (such as asphalt binder type, asphalt binder content, coarse aggregate type, fine aggregate type, and RAP content) on the performance and durability of 404LVT mixes.
- Improve the performance of 404LVT mixes with regard to long-term cracking due to environmental conditions.
- Recommend changes to the 2015 404LVT specifications to make the mix more cost-effective without compromising its performance.

2.2 Research Tasks

To achieve the previous objectives, the following research tasks were conducted as part of this project:

- Task 1: Summarize background information about 404LVT specifications
- Task 2: Collect information about the current state-of-the-practice for using 404LVT mixes in Ohio
- Task 3: Develop a laboratory testing plan
- Task 4: Conduct laboratory testing and analyze test results
- Task 5: Compare the cost-effectiveness of 404LVT mixes to ODOT Type 1 surface mixes
- Task 6: Prepare final report and present findings

2.3 Background Information about 404LVT Specifications

Over the past 25 years, significant changes have been made to the mix design specifications for Item 404. Table 2 presents the aggregate gradation limits that were listed in the ODOT 1997

CMS book for this item. As mentioned earlier, this item was removed from the ODOT 2002 CMS book, but it was later modified and reintroduced by the industry in 2008 for use by LPAs in Ohio. A tighter control on the gradation limits for Sieve No. 4 was proposed in 2008 with a percent passing of 60% to 70% (Crago 2009, Crago and Surber 2021). The aggregate gradation limits for this sieve size were modified again in 2011 to fall within the range of 65% to 75% (Crago and Surber 2021). A further change to the aggregate gradation limits was proposed by FPO in 2015 with a single target value of 72% specified for Sieve No. 4 (Table 3). In addition, the 2015 404LVT specifications stipulated that a minimum of 50% of the virgin fine aggregate must be natural sand.

Table 2: Aggregate Gradation Limits for Item 404 in the ODOT 1997 CMS Book.

Sieve Size	Percent Passing (%)
½”	100
⅜”	90 – 100
No. 4	45 – 75
No. 16	15 – 45
No. 50	3 – 22
No. 200	0 – 8

Table 3: Aggregate Gradation Limits for 404LVT Mixes in the 2015 FPO Specifications.

Sieve Size	Percent Passing (%)
½”	100
⅜”	90 – 100
No. 4	72
No. 8	42 – 60
No. 16	27 – 45
No. 50	10 – 22
No. 200	0 – 8

A comparison between the aggregate gradation limits for the 1997 ODOT Item 404 and the 2015 404LVT asphalt mixes is presented in the 0.45 power gradation graph in Figure 1. As can be noticed from this figure, in addition to the tighter control on the percent passing for Sieve No. 4, the lower percent passing limits for Sieve Nos. 16 and 50 were increased, resulting in a strictly finer gradation for the aggregate blend. By comparing the 1997 ODOT Item 404 and the 2015 404LVT aggregate gradation limits to the maximum density line in Figure 1, it can also be observed that the 2015 specification limits are closer to the maximum density line than the 1997 ODOT specification limits.

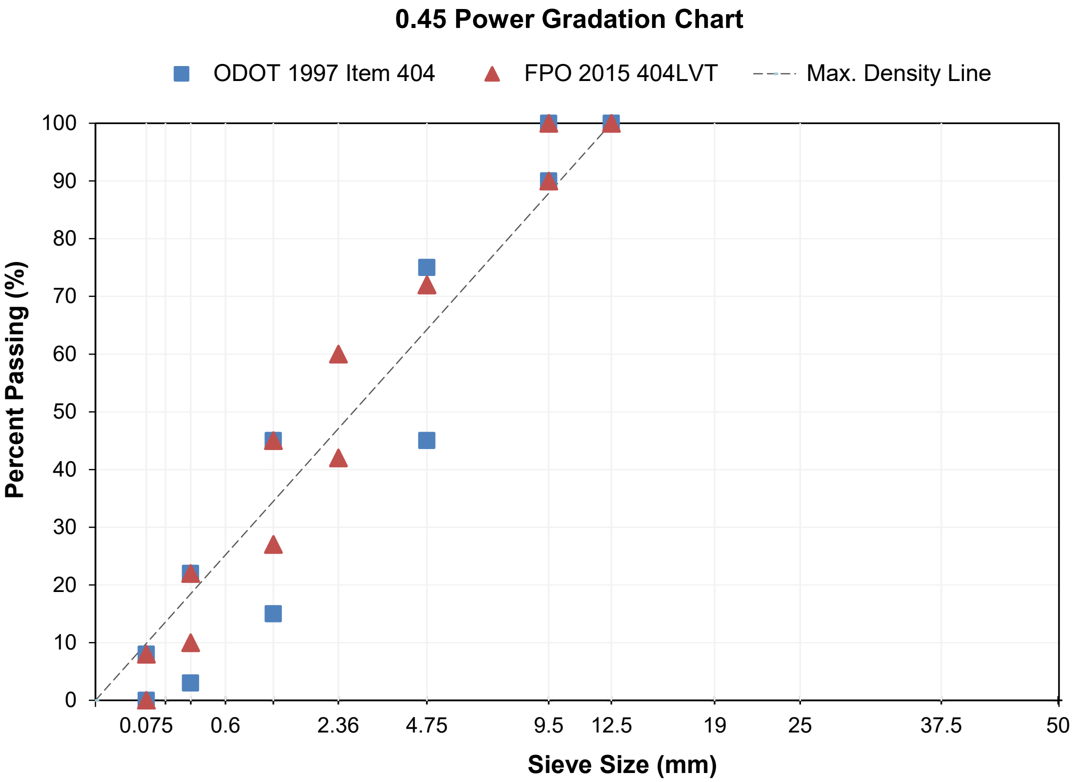


Figure 1. Comparison of Aggregate Gradation Limits
for ODOT 1997 Item 404 and 2015 404LVT Asphalt Mixes.

Along with the modifications to the aggregate gradation, significant changes were also made to the asphalt binder type and the asphalt binder content in the various Item 404 specifications. An AC-20 viscosity-graded asphalt binder was generally used for ODOT 1997 Item 404 (Crago and Surber 2021). Following ODOT's transition to the Superpave asphalt binder grading system at the end of the 1990s/beginning of 2000s, a performance-graded asphalt binder was specified in subsequent Item 404 specifications. A PG 64-22 asphalt binder was proposed in the 2008 404LVT specifications with an allowable RAP content of 30% without change to the asphalt binder type and 40% if a polymer-modified asphalt binder is used (Crago 2009). The 404LVT specifications revised by FPO in 2015 allow for using PG 58-28 (with a maximum RAP content of 20%) or PG 64-22 (with a maximum RAP content of 10%) asphalt binders. The total asphalt binder content specified for this recipe mix increased over time to account for the use of a finer aggregate blend. A total asphalt binder content of 6.0% was typically used for Item 404 mixes with limestone coarse aggregates and 5.8% for mixes with gravel coarse aggregates in the ODOT 1997 specifications. The total asphalt binder content was increased to 6.4% for mixes with limestone coarse aggregates and 6.2% for mixes with gravel coarse aggregates in 2008. The 2015 404LVT specifications call for using 6.8% total asphalt binder content for mixes with limestone coarse aggregates and 6.6% for mixes with gravel coarse aggregates. A minimum virgin asphalt content of 5.8% is also specified in the 2015 404LVT specifications for mixes with limestone coarse aggregates and 5.6% for mixes with gravel coarse aggregates.

2.4 Current State-of-the-Practice for the Use of 404LVT Asphalt Mixes

A survey was conducted in this study to document the current state-of-the-practice by LPAs in Ohio regarding the use of 404LVT asphalt mix design specifications for low-volume local roads. The survey was implemented in Qualtrics and was sent out at the end of September 2021 (with a deadline of October 29, 2021). A total of 26 responses to the survey were received. Below is a summary of these responses. More detailed information about the online survey and the responses to the survey are available in Appendix A.

Survey respondents from five counties and ODOT District 6 indicated that they are currently using 404LVT mix design specifications for resurfacing roads under their jurisdictions. Four of the respondents indicated that their agencies first started using the 404 LVT mix between 5 and 10 years ago, and two indicated that their agencies first started using the mix within the past five years. The 404LVT mix is used extensively in two counties and often by two additional counties. Respondents in four counties indicated that they were “very satisfied” with the performance of the mix, while the remaining county and ODOT District 6 reported that they were “somewhat satisfied” with the mix performance.

A total of 12 respondents from the 16 agencies that have never used 404LVT mixes reported using ODOT Item 441 (Medium Traffic). Other mixes used included ODOT Item 441

(Medium Traffic) with some modifications (as per plan), ODOT Supplemental Specification 823 (Low Traffic), and a recipe mix design that was developed in-house. When asked if their agency would consider using an optimized 404LVT mix (i.e., a mix containing smaller aggregate particles that could be placed at a thickness as low as 1 inch), six respondents indicated “Yes,” eight indicated “Maybe,” and two indicated “No.”

Four survey respondents indicated that their agency used this mix type in the past but no longer use it. Of these respondents, three reported that they are currently using ODOT Item 441 (Medium Traffic), while one is using ODOT Supplemental Specification 823 (Low Traffic). When asked why they no longer use 404LVT mixes, a respondent from one county reported that the 404LVT mix is not available from local asphalt plants. Another county respondent indicated that it was not cost-effective to use, as the single bidder for asphalt projects had provided a bid price for the 404LVT mix that was equal to or above the cost for ODOT Item 441 mix. A third county agency reported that they received complaints about cracking in the placed mixture within 4 months of installation.

3. Research Approach

A laboratory testing plan was developed and implemented in this study to examine the effects of various mix design factors – such as asphalt binder type, asphalt binder content, RAP content, coarse aggregate type, fine aggregate type, and aggregate source – on the performance and durability of 2015 404LVT mixes. As can be noticed from Figure 2, the laboratory testing plan included two asphalt binders (PG 58-28 and PG 64-22), two types of coarse aggregates (limestone and gravel as well as a limestone-gravel blend), and two types of fine aggregates (natural sand and limestone sand). The total asphalt binder content specified in the 2015 404LVT specifications (6.8% for limestone, 6.6% for gravel, and 6.7% for the limestone/gravel blend) as well as lower and higher percentages of asphalt binder (−0.3% and +0.3%) were evaluated in this study. The research team also examined the effect of using a higher percentage of RAP on the performance of 404LVT mixes. Aggregate blends prepared using varying percentages of limestone No. 8 (LS8), gravel No. 8 (GR8), natural sand (NS), and limestone sand (LSS) as well as aggregates from different sources collected from asphalt plants in different counties were also included in the laboratory testing plan. Detailed information about the materials used in the different asphalt mixes evaluated in this study is provided in Appendix B.

Laboratory Testing Plan

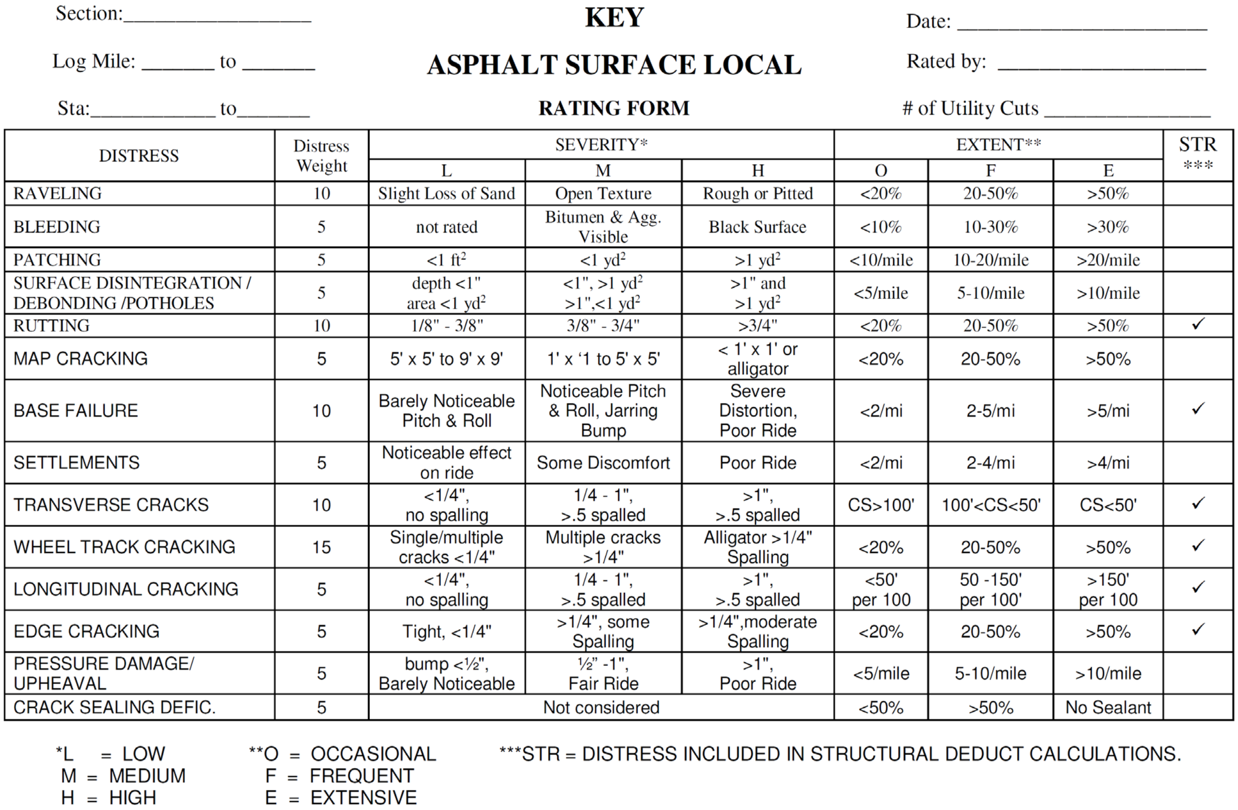
- Effect of Binder Type
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
  - 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22
  - 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 64-22
- Effect of Binder Content
  - 24% LS8 + 56% NS + 20% RAP @ 6.5%, 6.8%, and 7.1% PG 58-28
  - 23% GR8 + 57% NS + 20% RAP @ 6.3%, 6.6%, and 6.9% PG 58-28
  - 30% LS8 + 60% NS + 10% RAP @ 6.5%, 6.8%, and 7.1% PG 64-22
  - 30% GR8 + 60% NS + 10% RAP @ 6.3%, 6.6%, and 6.9% PG 64-22
- Effect of RAP Content
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
  - 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28
  - 21% LS8 + 54% NS + 25% RAP @ 6.8% PG 58-28
  - 21% GR8 + 54% NS + 25% RAP @ 6.6% PG 58-28
  - 30% LS8 + 60% NS + 10% RAP @ 6.8% PG 64-22
  - 30% GR8 + 60% NS + 10% RAP @ 6.6% PG 64-22
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22
  - 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 64-22
- Effect of Coarse Aggregate Type
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
  - 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28
  - 12% LS8 + 12% GR8 + 56% NS + 20% RAP @ 6.7% PG 58-28
- Effect of Fine Aggregate Type
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
  - 24% LS8 + 28% LSS + 28% NS + 20% RAP @ 6.8% PG 58-28
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22
  - 24% LS8 + 28% LSS + 28% NS + 20% RAP @ 6.8% PG 64-22
- Effect of Aggregate Sources
  - 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28 (Fayette County)
  - 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28 (Fayette County)
  - 24% LS8 + 26% LSS + 30% NS + 20% RAP @ 6.8% PG 58-28 (Darke County)
  - 28% GR8 + 20% LSS + 32% NS + 20% RAP @ 6.6% PG 58-28 (Miami County)
  - 25% LS8 + 27% LSS + 28% NS + 20% RAP @ 6.8% PG 58-28 (Madison County)
  - 22% GR8 + 29% LSS + 29% NS + 20% RAP @ 6.6% PG 58-28 (Athens County)
  - 27% SLAG8 + 20% SLAGS + 33% NS + 20% RAP @ 6.8% PG 58-28 (Cuyahoga County)
  - 26% LS8 + 20% LSS + 34% NS + 20% RAP @ 6.8% PG 58-28 (Richland County)
  - 25% GR8 + 20% LSS + 35% NS + 20% RAP @ 6.6% PG 58-28 (Richland County)

Figure 2. Laboratory Testing Plan.

To support the goals and objectives of this research project, balanced mix design concepts were utilized in evaluating the effect of the different modifications to the 2015 404LVT mix design. Several laboratory tests were used to evaluate the performance of the various asphalt mixtures. The indirect tension asphalt cracking test (IDEAL-CT) was used to evaluate the cracking resistance of the asphalt mixtures at intermediate temperatures. The modified Lottman test (AASHTO T 283) was used to evaluate the durability of the asphalt mixtures and their resistance to moisture-induced damage. The Hamburg wheel tracking device (HWTD) was used to evaluate the susceptibility of the asphalt mixtures to permanent deformation (or rutting). The asphalt concrete cracking device (ACCD) was used to evaluate the resistance of the asphalt mixtures to low-temperature (thermal) cracking. Detailed information about these tests is provided in Appendix C, and a summary of the laboratory test results is provided Appendix D. It is noted that even though balanced mix design concepts were utilized in the laboratory testing plan, the emphasis in this study was on providing an optimized recipe mix design that does not involve performing any of the previous laboratory tests as part of the mix design process for 404LVT mixes.

As part of this project, the research team also evaluated the field condition of different pavement sections constructed using 404LVT mixes in Fayette County, Darke County, and Miami County, where this type of mixture is widely used. Pavement sections constructed from 2015 to 2017 were primarily targeted by the research team. However, as Darke County did not start using 404LVT mixes on a wide scale until 2017, only sections constructed in 2017 and 2018 were included in the pavement condition evaluation for this county. Information about the mix designs of the 404LVT mixes used in the construction of the different pavement sections was collected from the three counties. In addition, traffic information for the different pavement sections was obtained from ODOT Transportation Information Mapping System (TIMS) and supplemented with truck traffic information obtained from the three counties. Photographs and videos of the pavement surface were also collected for future reference to document the condition of the pavements in the three counties.

The pavement condition evaluation was conducted according to the ODOT Pavement Condition Rating (PCR) Manual for local roads surfaced with asphalt using the rating form presented in Figure 3. As can be noticed from this figure, pavement distresses typically encountered on local asphalt roads are rated in terms of severity (Low, Medium, or High) and extent (Occasional, Frequent, or Extensive). It is noted that the primary objective of the pavement condition evaluations conducted in this study was not to obtain a PCR rating for the various pavement sections, but rather to identify the main distresses encountered for 404LVT mixes and the corresponding severity and extent levels four to seven years after construction. Appendix E presents a summary of the pavement condition evaluations conducted in Fayette County, Darke County, and Miami County. Main distresses noted for these pavement sections are included in this appendix. This appendix also includes a discussion of the effect of the mix composition of the 404LVT mixes and the prevailing traffic level on the performance of the various pavement sections.



Section:__________________

Log Mile: _______ to _______

Sta:____________ to_______

KEY

ASPHALT SURFACE LOCAL

RATING FORM

Date: ________________________

Rated by: ____________________

# of Utility Cuts ________________

DISTRESS	Distress Weight	SEVERITY*			EXTENT**			STR ***
		L	M	H	O	F	E	
RAVELING	10	Slight Loss of Sand	Open Texture	Rough or Pitted	<20%	20-50%	>50%	
BLEEDING	5	not rated	Bitumen & Agg. Visible	Black Surface	<10%	10-30%	>30%	
PATCHING	5	<1 ft^2	<1 yd^2	>1 yd^2	<10/mile	10-20/mile	>20/mile	
SURFACE DISINTEGRATION / DEBONDING /POTHOLES	5	depth <1" area <1 yd^2	<1", >1 yd^2 >1",<1 yd^2	>1" and >1 yd^2	<5/mile	5-10/mile	>10/mile	
RUTTING	10	1/8" - 3/8"	3/8" - 3/4"	>3/4"	<20%	20-50%	>50%	✓
MAP CRACKING	5	5' x 5' to 9' x 9'	1' x ‘1 to 5' x 5'	< 1' x 1' or alligator	<20%	20-50%	>50%	
BASE FAILURE	10	Barely Noticeable Pitch & Roll	Noticeable Pitch & Roll, Jarring Bump	Severe Distortion, Poor Ride	<2/mi	2-5/mi	>5/mi	✓
SETTLEMENTS	5	Noticeable effect on ride	Some Discomfort	Poor Ride	<2/mi	2-4/mi	>4/mi	
TRANSVERSE CRACKS	10	<1/4", no spalling	1/4 - 1", >.5 spalled	>1", >.5 spalled	CS>100'	100'<CS<50'	CS<50'	✓
WHEEL TRACK CRACKING	15	Single/multiple cracks <1/4"	Multiple cracks >1/4"	Alligator >1/4" Spalling	<20%	20-50%	>50%	✓
LONGITUDINAL CRACKING	5	<1/4", no spalling	1/4 - 1", >.5 spalled	>1", >.5 spalled	<50' per 100	50 -150' per 100'	>150' per 100	✓
EDGE CRACKING	5	Tight, <1/4"	>1/4", some Spalling	>1/4",moderate Spalling	<20%	20-50%	>50%	✓
PRESSURE DAMAGE/ UPHEAVAL	5	bump <½", Barely Noticeable	½" -1", Fair Ride	>1", Poor Ride	<5/mile	5-10/mile	>10/mile	
CRACK SEALING DEFIC.	5	Not considered			<50%	>50%	No Sealant	

*L = LOW
M = MEDIUM
H = HIGH

**O = OCCASIONAL
F = FREQUENT
E = EXTENSIVE

***STR = DISTRESS INCLUDED IN STRUCTURAL DEDUCT CALCULATIONS.

Figure 3. ODOT PCR Form for Asphalt Pavements on Asphalt Local Roads.

4. Research Findings and Conclusions

Based on the laboratory test results and the pavement condition evaluations conducted in Fayette County, Darke County, and Miami County for pavement sections constructed using 404LVT mixes, the following conclusions can be made:

- Binder type: The 2015 404LVT specifications allow for using either PG 58-28 or PG 64-22 asphalt binders. For a specific aggregate type, the same total asphalt binder content is specified for both binders. However, a maximum of 20% RAP is permitted when using PG 58-28 as compared to 10% RAP when using PG 64-22. In this study, the laboratory test results for 404LVT mixes prepared using PG 58-28 showed better resistance to low-temperature cracking and fatigue cracking than those prepared with PG 64-22, while 404LVT mixes prepared using PG 64-22 showed better resistance to permanent deformation (or rutting). Comparable resistance to moisture-induced damage was obtained for 404LVT mixes prepared with both binders. The field evaluations conducted in Fayette County, Darke County, and Miami County revealed that low-temperature cracking and longitudinal cracking are the two dominant distresses encountered for 404LVT mixes in the field and that permanent deformation (or rutting) is not a common distress. Therefore, it is recommended to use PG 58-28 asphalt binders for 404LVT mixes rather than PG 64-22.
- Binder content when using gravel, limestone, or gravel/limestone coarse aggregates: The 2015 404LVT specifications called for a total asphalt binder content of 6.8% when using limestone coarse aggregates, 6.6% when using gravel coarse aggregates, and 6.7% when using gravel/limestone coarse aggregate blends. In general, increasing the total asphalt binder content in an asphalt mixture is expected to improve the resistance of the asphalt mixture to fatigue cracking and reduce its resistance to permanent deformation (or rutting), while reducing the total asphalt binder content is expected to have the opposite effect for both permanent deformation (or rutting) and fatigue cracking. In this study, several 404LVT asphalt mixes prepared using coarse aggregates collected from asphalt plants in different counties across the state were produced using the total asphalt binder contents specified in the 2015 404LVT specifications and were evaluated for resistance to fatigue cracking and permanent deformation (or rutting). The laboratory test results revealed that the total asphalt binder contents specified in the 2015 404LVT specifications are relatively close to the optimum for fatigue cracking and are slightly higher than the optimum for permanent deformation (or rutting) for some of the mixes. Therefore, it is recommended to continue to use a total asphalt binder content of 6.8% for coarse limestone aggregates, 6.6% for gravel coarse limestone aggregates, and 6.7% for gravel/limestone coarse aggregate blends. The field condition evaluations revealed that permanent deformation (or rutting) is not a concern provided that the total number of trucks is

fewer than 100 trucks per day. Therefore, to ensure that permanent deformation (or rutting) will not be an issue for roads where this mix is placed, it is recommended to specify a maximum truck traffic of 100 trucks/day.

- Binder content when using slag aggregates: The 2015 404LVT specifications called for using the Marshall mix design process for medium traffic with a target air voids level of 2.5% when using slag aggregates. The laboratory testing plan involved evaluating the performance of a single 404LVT mix that was prepared using 27% slag No. 8, 20% slag sand, 33% natural sand, and 20% RAP. A total asphalt binder content of 6.8% was used for the slag mix (similar to 404LVT mixes containing limestone coarse aggregates). The laboratory test results for the slag mix showed good resistance to permanent deformation (or rutting) but low resistance to fatigue cracking. Therefore, to improve the resistance of the slag mix to fatigue cracking, it is recommended to increase the total asphalt binder content to 7%.
- Binder content when using aggregates with high absorption: The 2015 404LVT specifications require increasing the total asphalt binder content by 0.2% for coarse aggregates having an absorption greater than 4.0%. By reviewing the absorption values for coarse aggregates across the state, it was observed that the vast majority of coarse aggregates have an absorption of less than 3.5% and that only one coarse aggregate has an absorption exceeding 4%. Given that a recipe mix design is used for 404LVT mixes, it is imperative to control as many variables as possible to prevent premature failure of the asphalt mixture. Therefore, it is not recommended to use coarse aggregates with an absorption greater than 3.5%.
- Coarse aggregate type: Limestone and gravel are the two most commonly available coarse aggregates in Ohio. Limestone and gravel as well as gravel/limestone blends can be used as coarse aggregates for 404LVT mixes. In this study, comparable laboratory test results were obtained for 404LVT mixes prepared using limestone No. 8, gravel No. 8, and a blend of gravel No. 8 and limestone No. 8 coarse aggregates. However, pavement sections constructed using 404LVT mixes in Fayette County, Darke County, and Miami County showed better performance with regard to raveling and transverse cracking for 404LVT mixes produced using limestone coarse aggregates as compared to those produced using gravel coarse aggregates or gravel/limestone coarse aggregate blends. Therefore, it is recommended to consider using limestone coarse aggregates when available in the production of 404LVT

mixes. As limestone aggregates have higher angularity than gravel aggregates, they may also provide better resistance to permanent deformation (or rutting).

- Fine aggregate type: According to the 2015 404LVT specifications, a minimum of 50% of the virgin fine aggregates in the 404LVT mix must consist of natural sand. Mix design packets obtained from different asphalt contractors or the three counties mentioned earlier showed that some 404LVT mixes were produced using natural sand as 100% of the virgin fine aggregates, while other mixes contained approximately 50% to 65% of the virgin fine aggregates as natural sand and the remaining portion as limestone sand. Incorporating limestone sand along with natural sand in 404LVT mixes was found to improve their resistance to fatigue cracking and rutting. Therefore, it is recommended to use limestone sand in addition to natural sand in 404LVT mixes.
- RAP content: The 2015 404LVT specifications allow for using a RAP content of 20% with PG 58-28 asphalt binder and a RAP content of 10% with PG 64-22. The laboratory testing plan evaluated the effect of increasing the RAP content by 5% for PG 58-28 and by 10% for PG 64-22. The higher RAP content did not seem to negatively impact the performance of the resulting asphalt mixtures. Therefore, along with using PG 58-28 asphalt binder for 404LVT mixes, as recommended earlier, it is suggested to use a maximum allowable RAP content of 20% for Method 1 RAP and 25% for Method 2 RAP (similar to ODOT CMS Item 441 Type 1 surface mixes). Based on information provided by the different counties, the cost of 404LVT mixes in 2021 was approximately ~$85/ton (as compared to ~$80/ton for Item 441 surface mixes). Therefore, allowing for a higher RAP content in 404LVT mixes is expected to offset a portion of the price difference between 404LVT and Item 441 surface mixes. Another advantage of 404LVT mixes is that they can be placed at a compactable lift thickness of 1”, making them more cost effective than Item 441 surface mixes, which are typically placed at a thickness of 1.25 inches or 1.5 inches. A comparison between the costs of asphalt overlays constructed using 404LVT mixes (assuming 1 inch thickness) and Item 441 Type 1 surface (assuming 1.5 inch thickness) is presented in Appendix F.
- Aggregate gradation: One of the main differences between the 2015 404LVT specifications and the previous specifications for this asphalt mixture is aggregate gradation. The 2015 404LVT specifications call for using 72% passing for Sieve No. 4. A tighter control was also placed on the upper and lower limits of the percent passing for the other sieves. In this study,

it was observed that several aggregate blends barely met the lower control point for Sieve No. 50. Therefore, it is recommended to reduce the percent passing for this lower limit from 10% to 8%. Given that a recipe mix design is used for 404LVT specifications, it is also advantageous to have stricter control on the aggregate gradation. Therefore, it is recommended to increase the lower limits for Sieve No. 8 from 42% to 47% and increase the lower limits for Sieve No. 16 from 27% to 32% to ensure a strictly finer mix gradation that is comparable to the aggregate gradations that have been used in Fayette County, Darke County, and Miami County.

- <u>Traffic level:</u> A maximum traffic of 2,500 vehicles/day is specified in the 2015 404LVT specifications for roadways where this mix will be placed. The notes to the designers provided by FPO in 2015 indicated that this mix shall only be used on roads where heavy, slow-moving trucks are not commonly encountered. However, the actual specifications do not stipulate what constitutes heavy traffic. In this study, better field performance of 404LVT mixes was observed for pavement sections that have fewer than 100 trucks/day. Therefore, in addition to the maximum traffic requirement of 2,500 vehicles/day, it is recommended to specify a maximum of 100 trucks/day in the 404LVT specifications.
- <u>Mix production and placement:</u> Common practices and traditional paving equipment can be used for the production and placement of 404LVT mixes. The 2015 404LVT specification document refers to several ODOT specifications that are used for this purpose. No changes are proposed to these specifications.
- <u>Quality control limits:</u> According to the 2015 404LVT specifications, the asphalt binder content and the aggregate gradation in the mix shall be determined for the first 100 tons and every 400 tons thereafter for each production day. During production, the contractor shall investigate and correct any deviation from the job mix formula that exceeds ± 4% for percent passing Sieve No. 4 or ± 0.3% for total asphalt binder content. Production shall cease until corrections are made when the deviation from the job mix formula exceeds ± 6% for percent passing Sieve No. 4 or ± 0.5% for total asphalt binder content. These deviation limits are similar to those specified by ODOT in CMS Item 403 for the quality control of Type 1 surface mixes. Therefore, no changes to these deviation limits are proposed.
- <u>Mix acceptance:</u> According to the 2015 404LVT specifications, mix acceptance is determined based on the mean of the quality control test results for each production day. The pavement owner is responsible for verification testing according to ODOT CMS Item 403.06. The mix

is considered acceptable if the average asphalt binder content is within ± 0.5% and the average percent passing Sieve No. 4 is within ± 6% from the job mix formula. If the mix does not meet these requirements, the Engineer will determine whether or not the deficient work will be accepted and will remain in place. If accepted, payment will be equal to 90% of the bid item cost for deviations related to aggregate gradation and 70% for deviations related to asphalt binder content. The 2015 404LVT specification is more lenient than ODOT CMS Item 448 specification that calls for removing and replacing the asphalt mixture if the deviation in the average asphalt binder content exceeds ± 0.5% from the job mix formula. However, the 2015 404LVT specification does allow the Engineer to make the decision on whether or not the mix will be accepted and will remain in place. Therefore, no changes are proposed to the 2015 404LVT specifications with regard to mix acceptance.

5. Recommendations for Implementation

The 2015 404LVT specifications were modified based on the findings and conclusions mentioned in the previous section. The revised 404LVT specifications are presented in the following pages. It is emphasized that 404LVT asphalt mixes should only be used for low-volume roads with low truck traffic where heavy, slow-moving trucks are not commonly encountered. The 404LVT mix is intended for use in rehabilitating low-volume roads where the ride quality has been compromised. It should not be used for roads that do not have sufficient remaining structural capacity to last for the service life of the 404LVT application. In addition, it is not recommended to use 404LVT for roads with excessive fatigue cracking, roads with rutting that exceeds ¼ inch in depth, or roads where the base of the pavement has failed. Roads that may benefit from the use of 404LVT include pavements with raveling, where the loss of surface aggregates can lead to reduced skid resistance and a rougher road surface. Roads with cracks that may be too small for crack sealing applications or have already been treated using chip seals/cape seals but are losing aggregate or exhibiting surface delamination are also good candidates for treatment with 404LVT.

ITEM 404LVT (Low Volume Traffic) ASPHALT CONCRETE

404LVT.01 Description.

This work consists of constructing a 1-inch-thick surface course or variable depth intermediate course of aggregate and asphalt binder for use in low-volume traffic applications.

Mix aggregate and asphalt binder in a central plant and spread and compact on a prepared surface according to these specifications and in reasonably close conformity with the lines, grades and typical sections shown on the plans or established by the Engineer.

All specification references herein are to the Ohio Department of Transportation, 2023 Construction & Materials Specifications.

The requirements of specification 401, 402, and 403 do not apply except where noted.

Asphalt concrete mix pavement thickness shown on the plans or stated in the proposal is for exclusive use in calculating the weight required to be placed per unit of surface area.

Section .19 includes a pay adjustment mechanism for mix that deviates from the job mix formula. Mixes having binder content below the job mix formula, but within specification tolerances, will receive an adjustment commensurate with the reduction in the amount of binder. No payment is made for binder content in excess of the job mix formula.

404LVT.02 Composition.

Establish a Job Mix Formula (JMF) by combining coarse aggregate, fine aggregate, reclaimed asphalt pavement (RAP) and asphalt binder in proportions that result in an asphalt mixture meeting the blend limits in Table 1.

Table 1

<table>
<tr><th colspan="3">Mixture Proportions</th></tr>
<tr><th>Sieve</th><th colspan="2">Total Percent Passing</th></tr>
<tr><td>1/2 inch</td><td colspan="2">100</td></tr>
<tr><td>3/8 inch</td><td colspan="2">90 to 100</td></tr>
<tr><td>No. 4</td><td colspan="2">72</td></tr>
<tr><td>No. 8</td><td colspan="2">47 to 60</td></tr>
<tr><td>No. 16</td><td colspan="2">32 to 45</td></tr>
<tr><td>No. 50</td><td colspan="2">8 to 22</td></tr>
<tr><td>No. 200</td><td colspan="2">0 to 8</td></tr>
<tr><td>Total binder content [1,2,3]
(% by weight of mix):</td><td colspan="2">Gravel coarse aggregate: 6.6%
Limestone coarse aggregate: 6.8%
Gravel/Limestone coarse aggregate blends: 6.7%
Slag coarse aggregate: 7.0%</td></tr>
<tr><td>Minimum virgin binder content
(% by weight of mix):</td><td colspan="2">Gravel coarse aggregate: 5.4%
Limestone coarse aggregate: 5.6%
Gravel/Limestone coarse aggregate blends: 5.5%
Slag coarse aggregate: 5.8%</td></tr>
<tr><td>Traffic volume</td><td colspan="2">Average daily traffic (ADT):
Maximum 2,500 vehicles per day
Average daily truck traffic (ADTT):
Maximum 100 trucks per day</td></tr>
<tr><td>Binder Grade</td><td colspan="2">PG 58-28</td></tr>
<tr><td>Limits for RAP
(% by weight of mix):</td><td>Method 1
20% max.</td><td>Method 2
25% max.</td></tr>
</table>

Note 1: A minimum of 50% of the virgin fine aggregate must be natural sand, 703.05. It is also recommended to use limestone sand or slag sand at a percentage of at least 30% of the virgin fine aggregate or 20% of the total blend.

Note 2: Do not use any aggregate that has an absorption greater than 3.5%.

Note 3: The engineer may adjust binder content. Compensation will be made according to 404LVT.19.

404LVT.021 Quality Control

Ensure quality control personnel, testing devices, and facilities meet the requirements of Supplement 1041. Meet the requirements of Item 403 except 403.06.

Calibrate asphalt content nuclear gauges according to Supplement 1043. Perform quality control testing according to the frequency provided in Table 2.

Obtain mix samples at the mixing plant.

Table 2

Quality Control Testing Schedule		
Daily Frequency	**Tests**	**Sample Type**
Within first 100 tons	binder content, gradation	completed mix
Each 400 tons thereafter	binder content, gradation	completed mix

During production investigate and correct variation from the JMF, as shown by the quality control analysis, of plus or minus 4 percent passing the No. 4 sieve or plus or minus 0.3 percent binder.

If variation exceeds the limits in Table 3 immediately cease production until the cause for variation is determined and corrections made. Notify the Engineer.

Table 3

Deviation from the Design		
Mix Characteristic	**From the Design**	**Range**
Binder Content	± 0.5 percent	1.0
No. 4 Sieve	± 6 percent	12

404LVT.03 Materials. Furnish materials conforming to Table 4.

Table 4

Material	Specification
Asphalt binder	702.01
Aggregate	703.05[4]
Mineral filler	703.07
Polymer	702.14

Note 4: Do not apply the gradation requirements for fine aggregate.

404LVT.04 Equipment. Apply the requirements of 401.03

404LVT.05 Notification. Apply the requirements of 401.04

404LVT.06 Weather Limitations. Apply the requirements of 401.05

404LVT.07 Conditioning Existing Surface. Apply the requirements of 401.06

404LVT.08 Hauling. Apply the requirements of 401.07

404LVT.09 Placement Operation.

Ensure spreading operations result in a mat texture that is uniform and free of deficiencies such as tears, drags or other blemishes. Remove and replace areas of deficient mat texture.

Apply the requirements of 401.08

404LVT.10 Asphalt Binder Compatibility. Apply the requirements of 401.09

404LVT.11 Surface Tolerances. Apply the requirements of 401.10

404LVT.12 Opening to Traffic. Apply the requirements of 401.11

404LVT.13 Method of Measurement. Apply the requirements of 401.12

404LVT.14 Mixing Plants. Apply the requirements of 402.02

404LVT.15 Plant Calibration. Apply the requirements of 402.03

404LVT.16 Use of Reclaimed Asphalt Pavement

Process recycled asphalt pavement such that it passes a 9/16-inch sieve and when incorporated ensures a one-half inch maximum aggregate size.

404LVT.17 Mixing and Production

Apply the requirements of 402.07. Asphalt mixtures may be produced using the warm mix asphalt method according to 402.05.

404LVT.18 Asphalt Binder Price Adjustment.

Apply the requirements of ODOT proposal note 534

404LVT.19 Acceptance and Basis of Payment.

Acceptance for gradation and binder content will be based upon the mean of the results of all required quality control tests performed during a day's production.

The pavement owner is responsible for verification testing according to 403.10.

Production will be considered acceptable if the tolerances shown in Table 3 are not exceeded.

In the event material does not meet these requirements but that reasonably acceptable material has been produced, the Engineer will make a determination if the deficient work will be accepted and remain in place. If accepted, payment will equal 90 percent of the bid item cost for deviations related to aggregate gradation and 70 percent for binder deviations.

Payment for accepted quantities, complete in place, will be based on the following formula: $CY \text{ X } [\text{Unit Price} + 2BI(B_{ADJUST} - BC)]$

Where CY = cubic yards of asphalt concrete

Unit Price = unit price bid for the item

BC = Binder Correction factor.

$BC = B_{JMF} - B_{ACTUAL}$ if $B_{JMF} > B_{ACTUAL}$

$BC = 0$ if $B_{JMF} < B_{ACTUAL}$

B_{ACTUAL} = Mean binder content of material placed, excluding deficient material removed or accepted at reduced pay

B_{ADJUST} = (%) binder adjustment (Table 1, Note 3)

B_{BID} = specified binder content (%)

$B_{JMF} = B_{BID} + B_{ADJUST}$

BI = Bidding Index

Pay Items	**Unit**	**Description**
404LVT	Cubic Yard	404LVT, Asphalt Concrete, PG 58-28

6. References

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Zhou, F., S. Im, L. Sun, and Scullion, T. (2017). "Development of an IDEAL-CT Cracking Test for Asphalt Mix Design and QC/QA." *Journal of Association of Asphalt Paving Technologists* (AAPT), Vol. 86, pp. 549–578.

Appendix A
Survey Questionnaire

A.1 Introduction

A survey was conducted in this study to document the current state-of-the-practice by LPAs in Ohio regarding the use of 404LVT (Low Volume Traffic) asphalt mix design specifications for local public roads. A draft survey questionnaire was prepared by the research team and sent to the Technical Advisory Committee (TAC) for review in the middle of September of 2021. Modifications were made based on comments received from the advisory committee, and the revised survey was implemented in Qualtrics by the research team. The survey invitations were sent out by ODOT Local Technical Assistance Program (LTAP) to Ohio LPAs on September 30, 2021, with a due date of October 15, 2021, which was later extended to October 29, 2021, to give invitees more time to respond to the survey.

A.2 Survey Organization

A copy of the survey questionnaire is provided at the end of this appendix. As can be noticed from this questionnaire, the survey included four sections. The first section included one general question: "Does your agency use 404LVT mix design specifications for roadway resurfacing?" (Question 1). Each respondent was directed to one of the three remaining sections (Sections 2 through 4) based on their response to Question 1. In the second section, respondents who indicated that they currently use 404LVT mixes for resurfacing low-volume roads were asked how long they have used these mixes, to what extent they use these mixes, and how satisfied they are with the mixes. The third section was designed for respondents who had replied, "We used this mix type in the past, but we no longer use it" to Question 1. The questions in the third section sought information on the specific mix design specifications that are currently used by the respondent's agency for resurfacing low-volume roads and why their agency no longer uses 404LVT mixes. In the fourth section, the respondents who indicated that they had never used 404LVT mixes were asked which mix design specifications they are currently using for road resurfacing and if their agency would consider using an optimized 404LVT mix in the future. At the end of the survey, respondents were asked for their permission to be contacted by the research team if the researchers have any questions regarding their survey responses.

A.3 Survey Results

A total of 26 responses to the survey were received: one from an ODOT district representative and 25 from local agency representatives (representing seven cities, 16 counties, one township, and one village, all in Ohio). Below is a summary of the responses to the survey questionnaire:

- General Information (Question 1): When asked if their agency uses 404LVT mix design for roadway resurfacing, the majority of respondents (16 out of 26, or 62% of agency representatives) indicated that their agency has never used this mix type. Four respondents (25%) indicated that their agency had used this mix type in the past but are no longer using it. Six respondents (23%) indicated that they are currently using this mix design specification for resurfacing roads under their jurisdiction; these respondents were from Fayette County, Darke County, Muskingum County, Miami County, Madison County, and ODOT District 6.

The following three questions were asked of the respondents who indicated that their agency currently uses 404LVT mixes for road resurfacing:

- Duration of Use (Question 2): Respondents were asked when their agency first started using the 404LVT mix design for roadway resurfacing. The respondants from Fayette County, Miami County, Madison County, and ODOT District 6 replied that their agencies first started using the 404LVT mix between 5 and 10 years ago. The respondant from Darke County and Muskingum County reported that the agency first started using this mix within the past five years.
- Extent of Use (Question 3): Respondents were asked to what extent their agency uses the 404LVT mix design for roadway resurfacing. The 404LVT mix is used “extensively” in Fayette County and Darke County. The respondents from Miami County and Madison County indicated that the mix is “often” used by their agencies, while the respondent from Muskingum County indicated that the mix is “sometimes” by their agency. ODOT District 6 indicated that the mix is rarely used.
- Performance of the mix (Question 4): Respondents were asked how satisfied they are with the performance of the 404LVT mix. Respondents in Fayette County, Darke County, Muskingum County, and Madison County reported that they were “very satisfied” with the performance of

the mix, while respondants at ODOT District 6 and Miami County reported that they were "somewhat satisfied" with the mix performance.

- Final thoughts: Respondents were also asked for their final thoughts or comments that might benefit the research project. The respondent from ODOT District 6 indicated, "We do not personally use 404LVT but the Fayette County Engineer uses it to pave some of his county roads that are funded by Federal funds. We review and approve his plans."

The following question was asked of the respondents who indicated that their agency has never used 404LVT mixes:

- Mix design specification that is used for resurfacing low-volume roads: Respondents were asked which mix design specifications are currently used by their agencies for roadway resurfacing of low-volume local roads. The vast majority of the respondents (85%) indicated that they use ODOT Item 441 (Medium Traffic) with or without modifications. Two respondents (the Village of Grafton and the City of Beavercreek) reported that they use ODOT Item 441 (Medium Traffic) with some modifications (as per plan), while Defiance County uses ODOT Supplemental Specification 823 (Low Traffic), and Knox County uses a recipe mix design developed in-house. One respondent did not indicate the mix design specification.

The four respondents who indicated that their agency used this mix type in the past but no longer use it were asked to provide additional information:

- Experience with 404LVT mix: Respondents were asked to provide more information about their agency's experience with the 404LVT mix and why it is no longer used for road resurfacing. The respondent from Defiance County reported, "Not available from the local asphalt plants." The respondent from Washington County included the following response: " I only have a single hot mix supplier and a single bidder on asphalt projects. The bid price was equal to or above ODOT 441. It was not cost effective to continue but remains an option that I want to return to." The respondent from Licking County indicated, "Had complaints about cracking less than 4 months after installation." The respondent from the City of Pickerington did not provide further details.

The following question was asked of 16 respondents who indicated that their agency has never used the 404LVT mix:

- Interest in using 404LVT mix in the future: Respondents were informed of the possible advantages of 404LVT mixes (i.e., that these mixes contain smaller aggregate particles, which would allow the placement of the asphalt overlay at a thickness as low as 1 inch), and they were asked if their agency would be interested in using an optimized 404LVT mix for roadway resurfacing in the future. Six respondents indicated "Yes," eight indicated "Maybe," and two indicated "No."

Introduction

Optimizing 404LVT (Low Volume Traffic) Mix Designed for Ohio's Local Roadways

This survey is conducted for the Ohio's Research Initiative for Locals (ORIL) program to collect information regarding the use of Item 404LVT (Low Volume Traffic) mixes for roadway resurfacing.

Please complete the survey regardless of whether your agency uses Item 404LVT mixes or not, as additional information is collected regarding the asphalt mixture used by your agency for resurfacing roadways with low volume traffic.

The survey should take less than 5 minutes to complete. Please complete the survey by October 15, 2021.

To view the survey questionnaire as a pdf file, please click: survey file.

For questions about this survey, please contact:
Dr. Ala R. Abbas
Department of Civil Engineering
The University of Akron
Email: abbas@uakron.edu

Contact Information

Contact Information: *

Name:	
Position:	
Agency:	
Email address:	
Phone number:	

Type of local public agency that you work for: *

○ City
○ County
○ Township
○ Village
○ Other. Please specify: ____

General

Q1: Does your agency use Item 404LVT (Low Volume Traffic) mix design specification for roadway resurfacing? *

- ○ Yes, we currently use Item 404LVT mixes for roadway resurfacing.
- ○ We used this mix type in the past but we no longer use it.
- ○ No, we never used this mix type.

If “Yes, we currently use Item 404LVT mixes for roadway resurfacing.” is selected for Q1.

When did your agency first start using Item 404LVT asphalt mixes for roadway resurfacing?

○ Within the past 5 years.
○ Between 5 and 10 years ago.
○ More than 10 years ago.

To what extent do you use Item 404LVT mixes for roadway resurfacing?

○ Extensively
○ Often
○ Sometimes
○ Rarely

How satisfied are you with the performance of Item 404LVT mixes?

○ Very satisfied
○ Somewhat satisfied
○ Not satisfied

Any final thoughts or comments that you would like to provide that may benefit this research project?

If “We used this mix type in the past but we no longer use it.” is selected for Q1.

Which mix design specification do you currently use for roadway resurfacing on low-volume roads?

○ ODOT Item 441 (Medium Traffic)
○ ODOT Supplemental Specification 823 (Low Traffic)
○ ODOT Item 441 (Medium Traffic) with some modifications (as per plan)
○ ODOT Supplemental Specification 823 (Low Traffic) with some modifications (as per plan)
○ Recipe mix design developed in-house
○ Other. Please specify:

Please provide more information about your experience with Item 404LVT mixes and why you stopped using this type of mix for roadway resurfacing?

If “No, we never used this mix type.” is selected for Q1.

Which mix design specification do you currently use for roadway resurfacing on low-volume roads?

○ ODOT Item 441 (Medium Traffic)
○ ODOT Supplemental Specification 823 (Low Traffic)
○ ODOT Item 441 (Medium Traffic) with some modifications (as per plan)
○ ODOT Supplemental Specification 823 (Low Traffic) with some modifications (as per plan)
○ Recipe mix design developed in-house
○ Other. Please specify: ☐

One of the advantages of Item 404LVT mixes is that they contain smaller aggregate particles, which would allow the placement of the asphalt overlay at a thickness as low as 1 inch. Would your agency be interested in using an optimized Item 404LVT mix for roadway resurfacing in the future?

○ Yes
○ No
○ Maybe

Permission to Contact

Do we have your permission to contact you for more information regarding your responses in the future (if needed)? *

○ Yes

○ No

Appendix B

Material Information

B.1 Introduction

This appendix presents information on the materials used to prepare the asphalt mixtures included in the laboratory testing plan that was presented in Section 3 (Research Approach) of the main report. The mix compositions for these asphalt mixtures are presented in Tables B.1, B.2, B.3, and B.4. For each asphalt mixture, Table B.1 provides information about the mix blend represented using a Blend ID as well as information about the asphalt binders used in the preparation of the asphalt mixtures. Details about each blend are presented in Table B.3. This table also includes information about the aggregate source and the aggregate absorption. The particle size distributions for all mix blends are presented in Figures B.1 through B.15. As can be seen from Table B.1, three PG 58-28 and one PG 64-22 asphalt binders were used in this study. The viscoelastic properties for the PG 58-28 asphalt binders are presented in Table B.3, and those for the PG 64-22 asphalt binder are presented in Table B.4.

Table B.1. Mix Composition of Asphalt Mixtures Included in the Laboratory Testing Plan.

Testing Matrix	Blend ID	Binder Type
• Effect of Binder Type		
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28	Blend 1	PG 58-28 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28	Blend 2	PG 58-28 (A)
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22	Blend 1	PG 64-22 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 64-22	Blend 2	PG 64-22 (A)
• Effect of Binder Content		
– 24% LS8 + 56% NS + 20% RAP @ 6.5%, 6.8%, and 7.1% PG 58-28	Blend 1	PG 58-28 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.3%, 6.6%, and 6.9% PG 58-28	Blend 2	PG 58-28 (A)
– 30% LS8 + 60% NS + 10% RAP @ 6.5%, 6.8%, and 7.1% PG 64-22	Blend 3	PG 64-22 (A)
– 30% GR8 + 60% NS + 10% RAP @ 6.3%, 6.6%, and 6.9% PG 64-22	Blend 4	PG 64-22 (A)
• Effect of RAP Content		
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28	Blend 1	PG 58-28 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28	Blend 2	PG 58-28 (A)
– 21% LS8 + 54% NS + 25% RAP @ 6.8% PG 58-28	Blend 5	PG 58-28 (A)
– 21% GR8 + 54% NS + 25% RAP @ 6.6% PG 58-28	Blend 6	PG 58-28 (A)
– 30% LS8 + 60% NS + 10% RAP @ 6.8% PG 64-22	Blend 3	PG 64-22 (A)
– 30% GR8 + 60% NS + 10% RAP @ 6.6% PG 64-22	Blend 4	PG 64-22 (A)
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22	Blend 1	PG 64-22 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 64-22	Blend 2	PG 64-22 (A)
• Effect of Coarse Aggregate Type		
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28	Blend 1	PG 58-28 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28	Blend 2	PG 58-28 (A)
– 12% LS8 + 12% GR8 + 56% NS + 20% RAP @ 6.7% PG 58-28	Blend 7	PG 58-28 (A)

Table B.1. Mix Composition of Asphalt Mixtures Included in the Laboratory Testing Plan (Continued).

• Effect of Fine Aggregate Type		
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28	Blend 1	PG 58-28 (A)
– 24% LS8 + 28% NS + 28% LSS + 20% RAP @ 6.8% PG 58-28	Blend 8	PG 58-28 (A)
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22	Blend 2	PG 64-22 (A)
– 24% LS8 + 28% NS + 28% LSS + 20% RAP @ 6.8% PG 64-22	Blend 8	PG 64-22 (A)
• Effect of Aggregate Sources		
– 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28 (Fayette County)	Blend 1	PG 58-28 (A)
– 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28 (Fayette County)	Blend 2	PG 58-28 (A)
– 24% LS8 + 26% LSS + 30% NS + 20% RAP @ 6.8% PG 58-28 (Darke County)	Blend 9	PG 58-28 (A)
– 28% GR8 + 20% LSS + 32% NS + 20% RAP @ 6.6% PG 58-28 (Miami County)	Blend 10	PG 58-28 (A)
– 25% LS8 + 27% LSS + 28% NS + 20% RAP @ 6.8% PG 58-28 (Madison County)	Blend 11	PG 58-28 (B)
– 22% GR8 + 29% LSS + 29% NS + 20% RAP @ 6.6% PG 58-28 (Athens County)	Blend 12	PG 58-28 (B)
– 27% SLAG8 + 20% SLAGS + 33% NS + 20% RAP @ 6.8% PG 58-28 (Cuyahoga County)	Blend 13	PG 58-28 (C)
– 26% LS8 + 20% LSS + 34% NS + 20% RAP @ 6.8% PG 58-28 (Richland County)	Blend 14	PG 58-28 (C)
– 25% GR8 + 20% LSS + 35% NS + 20% RAP @ 6.6% PG 58-28 (Richland County)	Blend 15	PG 58-28 (C)

Table B.2. Blend Composition and Aggregate Information.

Blend ID	% Blend	Material Type	Agg. Source	Agg. Absorption
Blend 1 (Fayette County)	24%	Limestone No. 8	Melvin Stone-Melvin	2.29%
	56%	Natural Sand	Melvin Stone-Circleville	1.93%
	20%	RAP	N/A	N/A
Blend 2 (Fayette County)	23%	Gravel No. 8	Melvin Stone-Circleville	2.16%
	56%	Natural Sand	Melvin Stone-Circleville	1.93%
	20%	RAP	N/A	N/A
Blend 3 (Fayette County)	30%	Limestone No. 8	Melvin Stone-Melvin	2.29%
	60%	Natural Sand	Melvin Stone-Circleville	1.93%
	10%	RAP	N/A	N/A
Blend 4 (Fayette County)	30%	Gravel No. 8	Melvin Stone-Circleville	2.16%
	60%	Natural Sand	Melvin Stone-Circleville	1.93%
	10%	RAP	N/A	N/A
Blend 5 (Fayette County)	21%	Limestone No. 8	Melvin Stone-Melvin	2.29%
	54%	Natural Sand	Melvin Stone-Circleville	1.93%
	25%	RAP	N/A	N/A
Blend 6 (Fayette County)	21%	Gravel No. 8	Melvin Stone-Circleville	2.16%
	54%	Natural Sand	Melvin Stone-Circleville	1.93%
	25%	RAP	N/A	N/A
Blend 7 (Fayette County)	12%	Limestone No. 8	Melvin Stone-Melvin	2.29%
	12%	Gravel No. 8	Melvin Stone-Circleville	2.16%
	56%	Natural Sand	Melvin Stone-Circleville	1.93%
	20%	RAP	N/A	N/A
Blend 8 (Fayette County)	24%	Limestone No. 8	Melvin Stone-Melvin	2.29%
	28%	Limestone Sand	Melvin Stone-Melvin	0.94%
	28%	Natural Sand	Melvin Stone-Circleville	1.93%
	20%	RAP	N/A	N/A
Blend 9 (Darke County)	24%	Limestone No. 8	Walls Materials-Fort Jefferson	2.04%
	26%	Limestone Sand	Walls Materials-Fort Jefferson	0.98%
	30%	Natural Sand	Watson SD&GR-Middletown	1.12%
	20%	RAP	N/A	N/A

Table B.2. Blend Composition and Aggregate Information (Continued).

Blend ID	% Blend	Material Type	Agg. Source	Agg. Absorption
Blend 10 (Miami County)	28%	Gravel No. 8	Martin Marietta-Spring Valley	1.80%
	20%	Limestone Sand	Melvin Stone-Melvin	0.94%
	32%	Natural Sand	Martin Marietta-Spring Valley	1.87%
	20%	RAP	N/A	N/A
Blend 11 (Madison County)	25%	Limestone No. 8	Shelly Materials-Columbus	2.26%
	27%	Limestone Sand	Shelly Materials-Columbus	1.94%
	28%	Natural Sand	Mar-Zane Mat.-Zanesville	0.89%
	20%	RAP	N/A	N/A
Blend 12 (Athens County)	22%	Gravel No. 8	Mar-Zane Mat.-Logan	2.25%
	29%	Limestone Sand	Shelly Materials-Columbus	1.94%
	29%	Natural Sand	Mar-Zane Mat.-Haydenville	1.35%
	20%	RAP	N/A	N/A
Blend 13 (Cuyahoga County)	27%	Slag No. 8	Stein/Cleveland Slag	2.43%
	20%	Slag Sand	Stein/Cleveland Slag	0.90%
	33%	Natural Sand	Lakeside S&G-Shalersville	1.16%
	20%	RAP	N/A	N/A
Blend 14 (Richland County)	26%	Limestone No. 8	Olen-Upper Sandusky	1.85%
	20%	Limestone Sand	Olen-Upper Sandusky	0.60%
	34%	Natural Sand	Olen-Fredericktown	1.65%
	20%	RAP	N/A	N/A
Blend 15 (Richland County)	25%	Gravel No. 8	Olen-Fredericktown	2.21%
	20%	Limestone Sand	Olen-Upper Sandusky	0.60%
	35%	Natural Sand	Olen-Fredericktown	1.65%
	20%	RAP	N/A	N/A

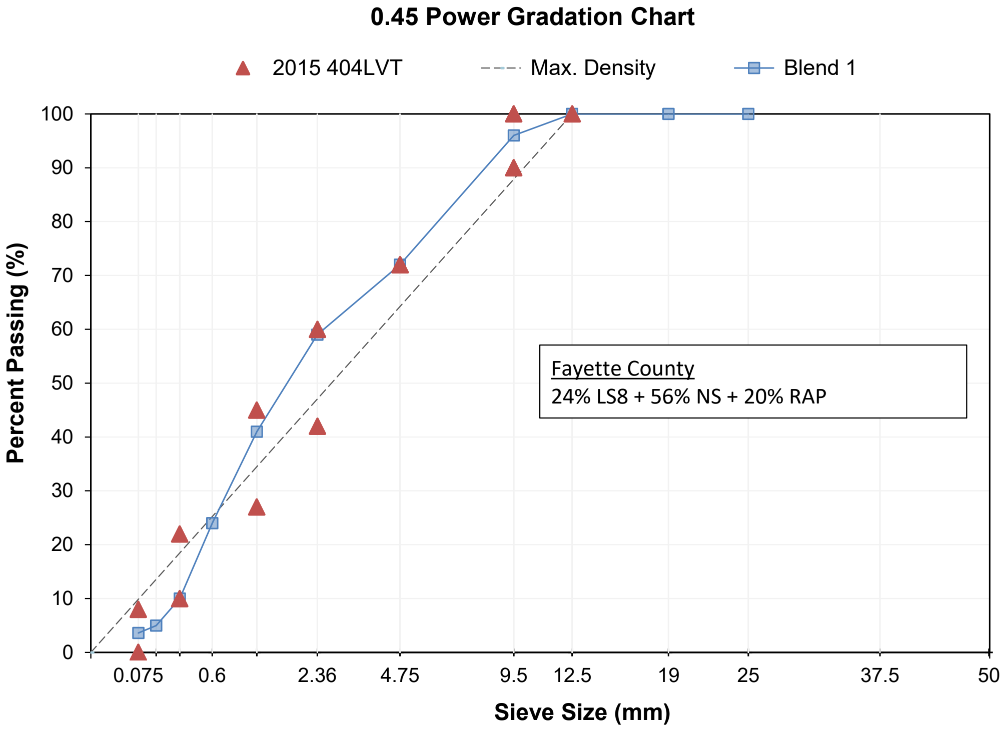

Figure B.1. Particle Size Distribution of Blend 1.

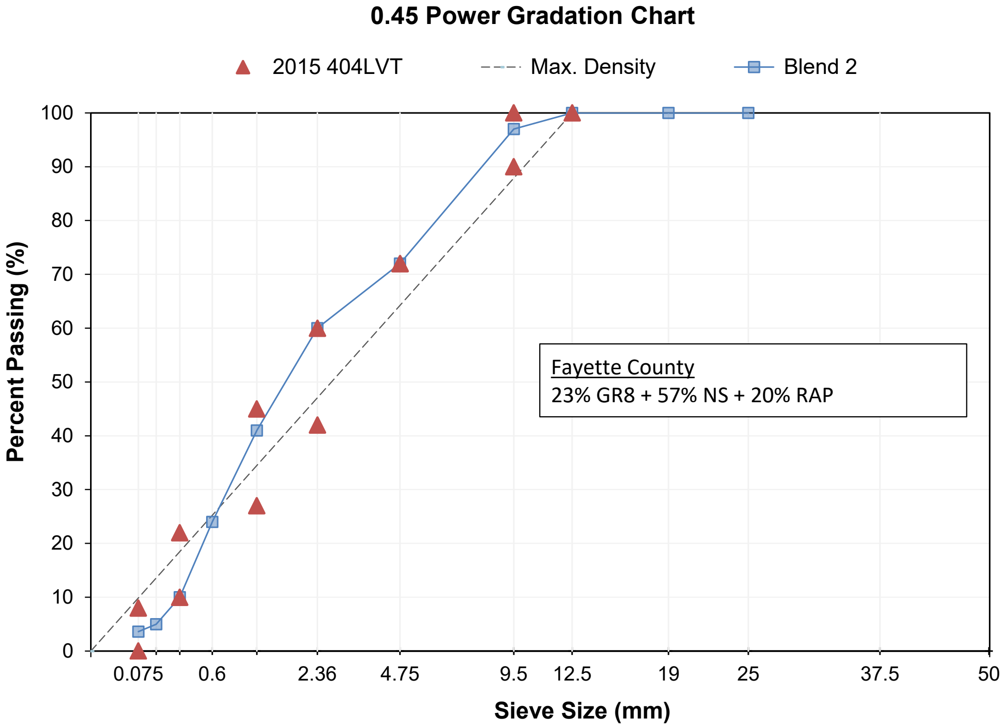

Figure B.2. Particle Size Distribution of Blend 2.

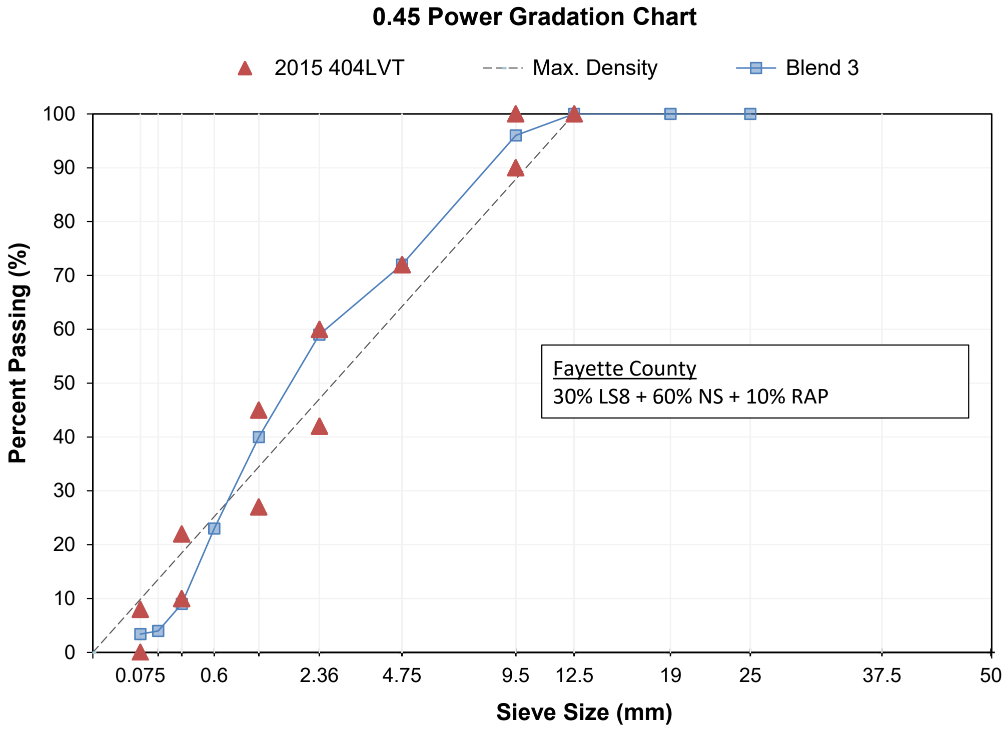

Figure B.3. Particle Size Distribution of Blend 3.

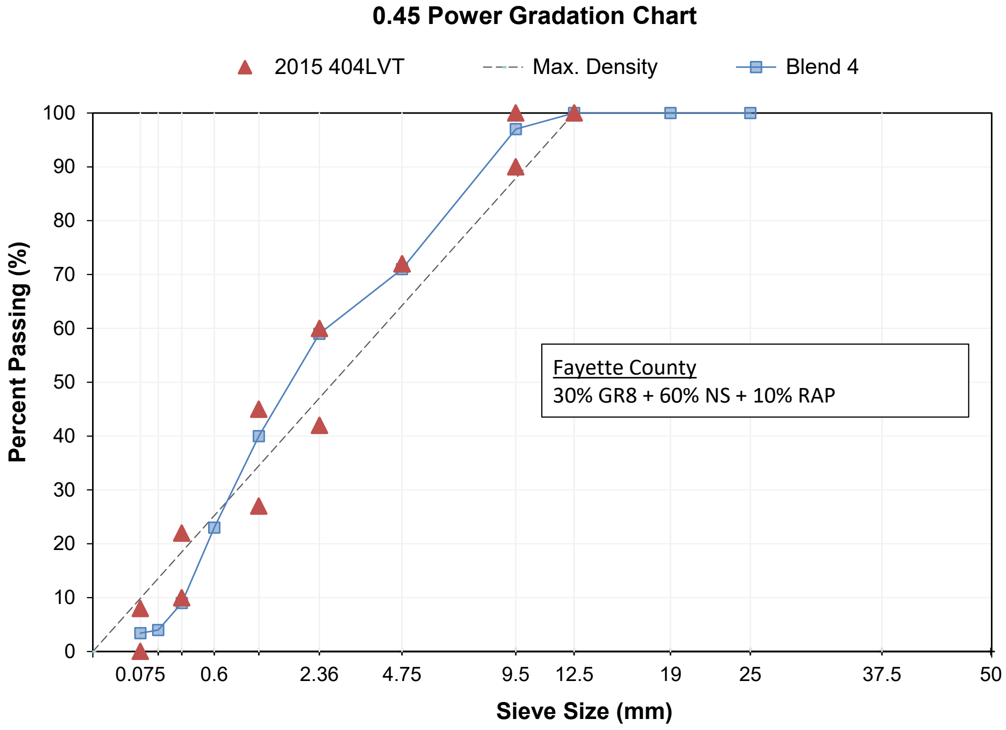

Figure B.4. Particle Size Distribution of Blend 4.

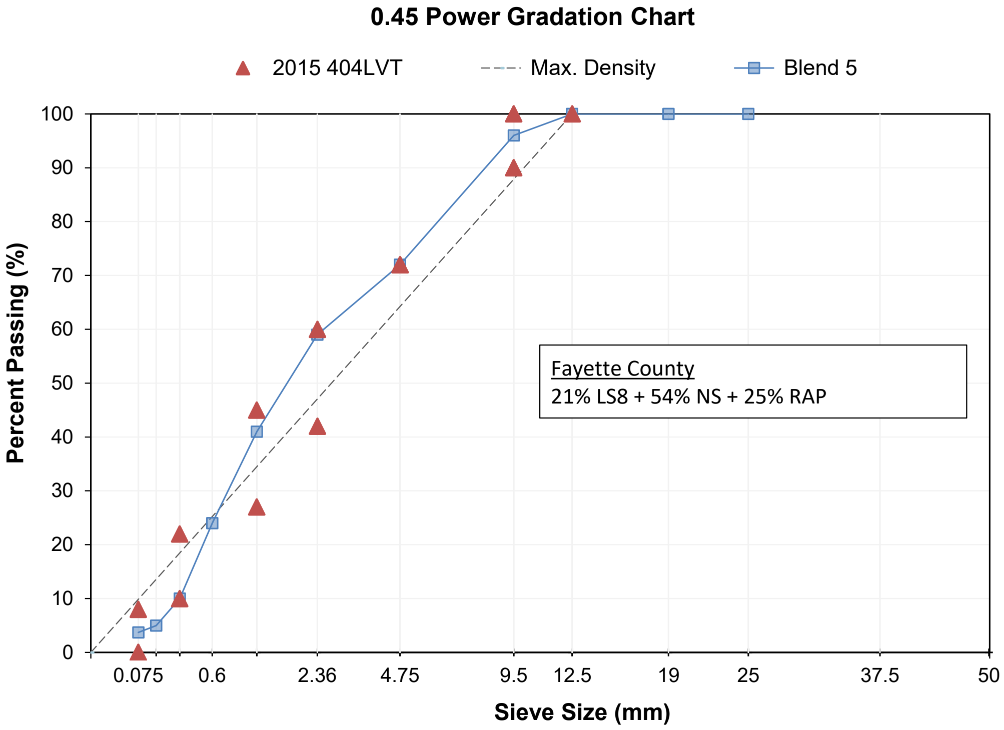

Figure B.5. Particle Size Distribution of Blend 5.

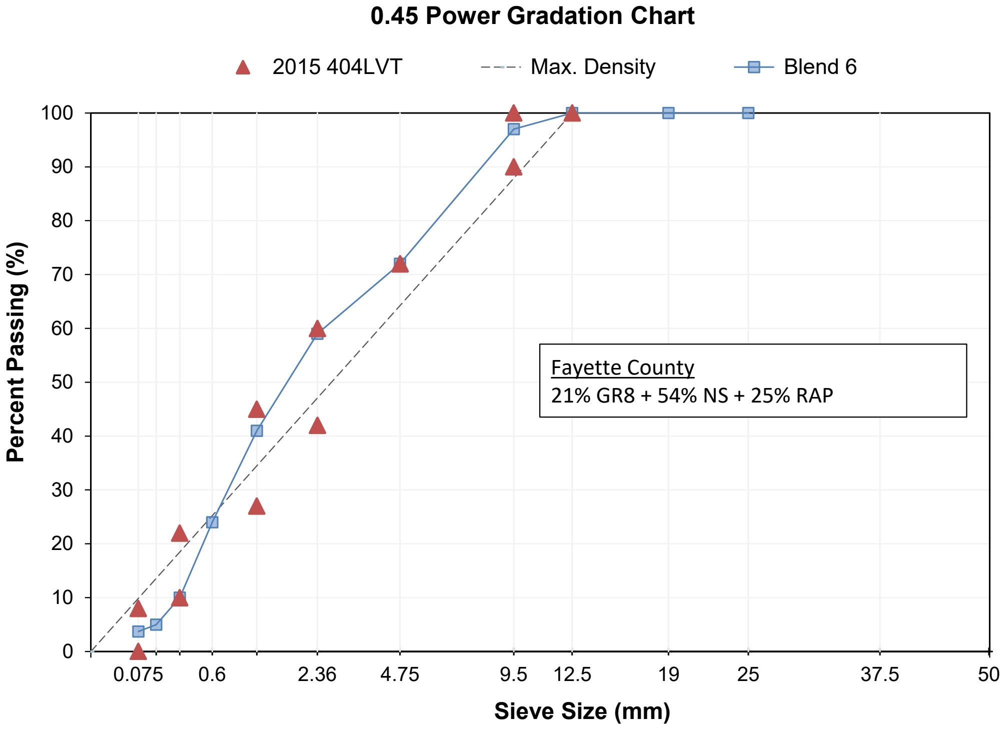

Figure B.6. Particle Size Distribution of Blend 6.

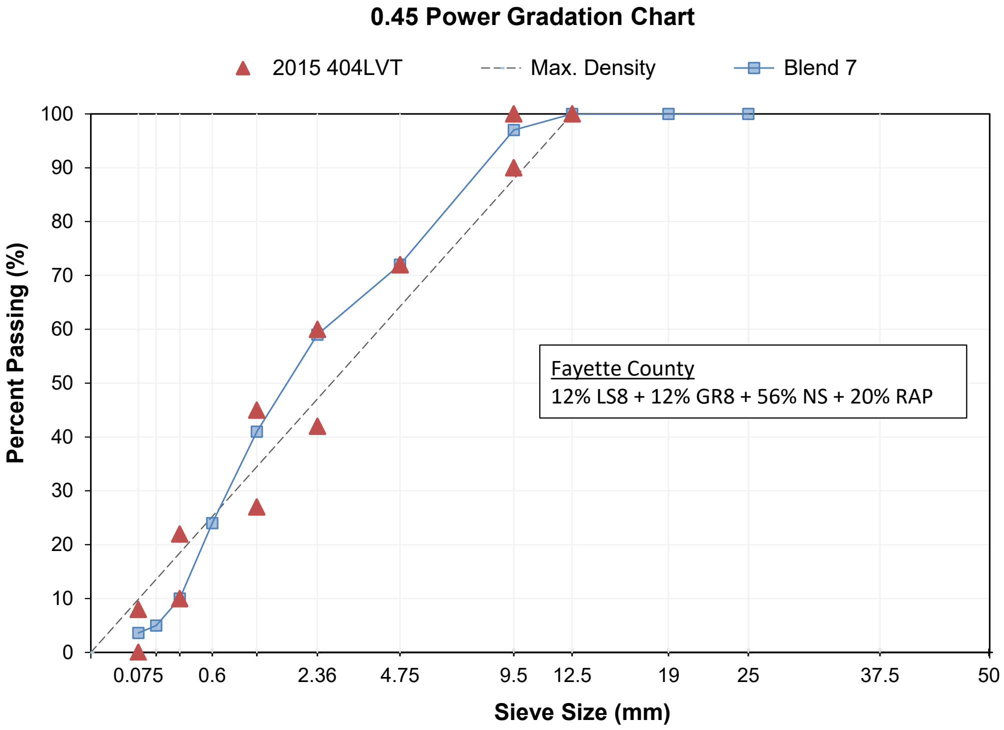

Figure B.7. Particle Size Distribution of Blend 7.

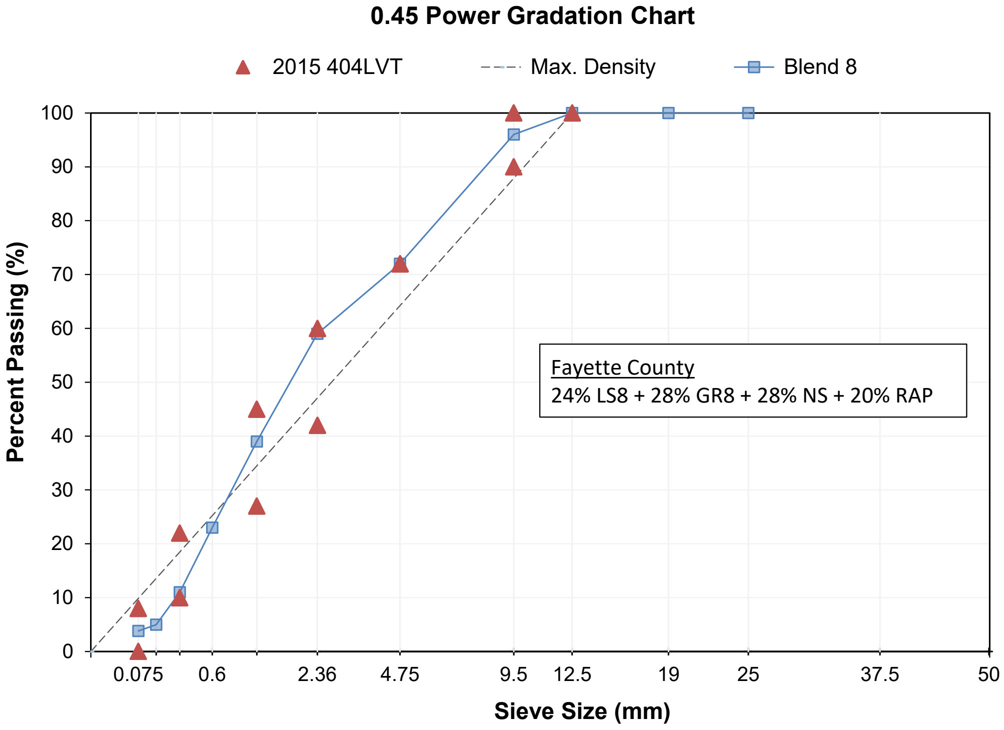

Figure B.8. Particle Size Distribution of Blend 8.

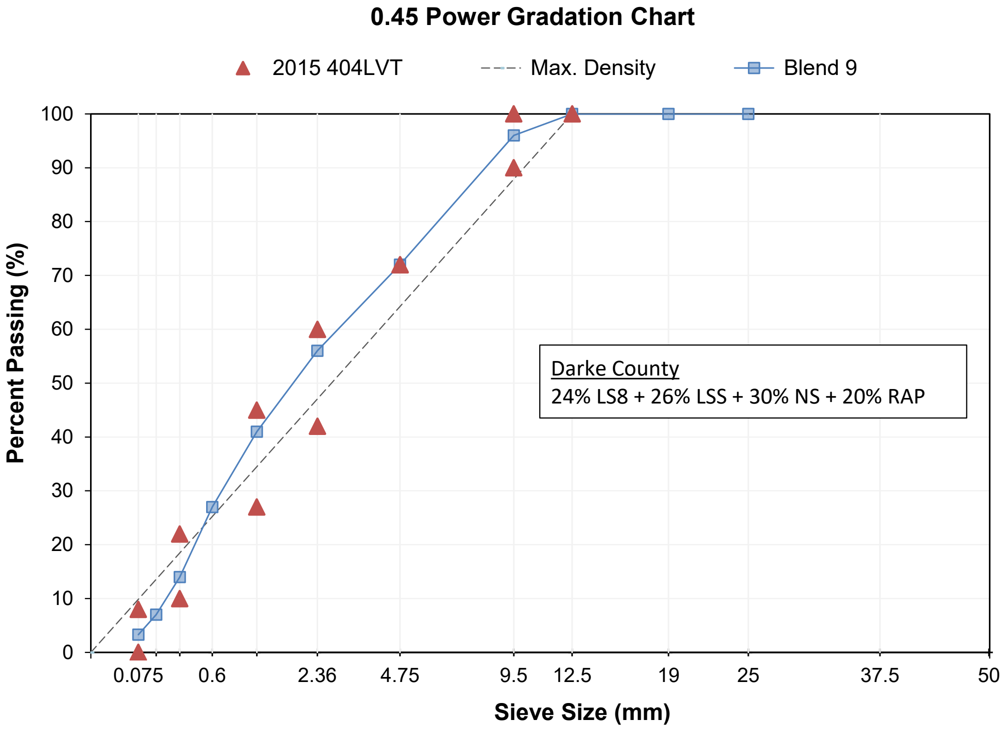

Figure B.9. Particle Size Distribution of Blend 9.

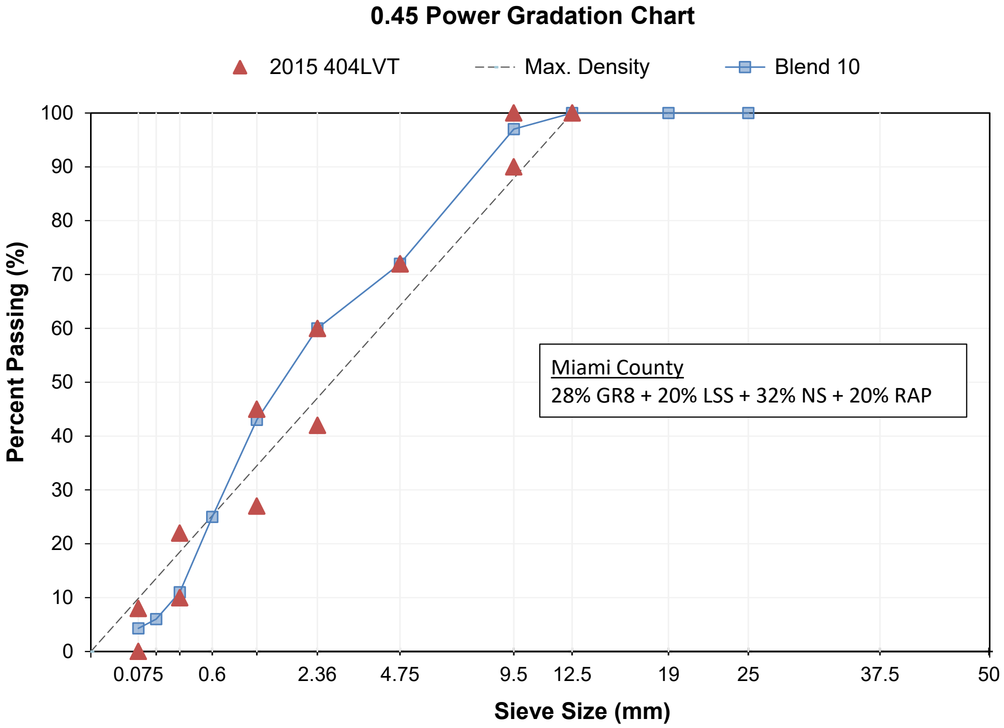

Figure B.10. Particle Size Distribution of Blend 10.

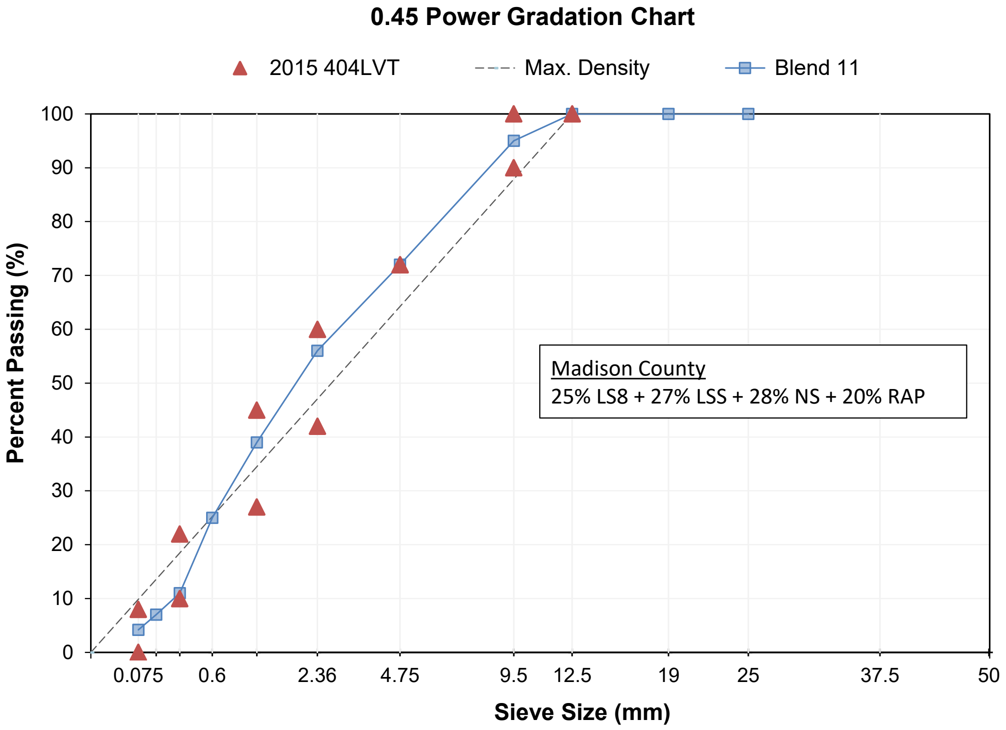

Figure B.11. Particle Size Distribution of Blend 11.

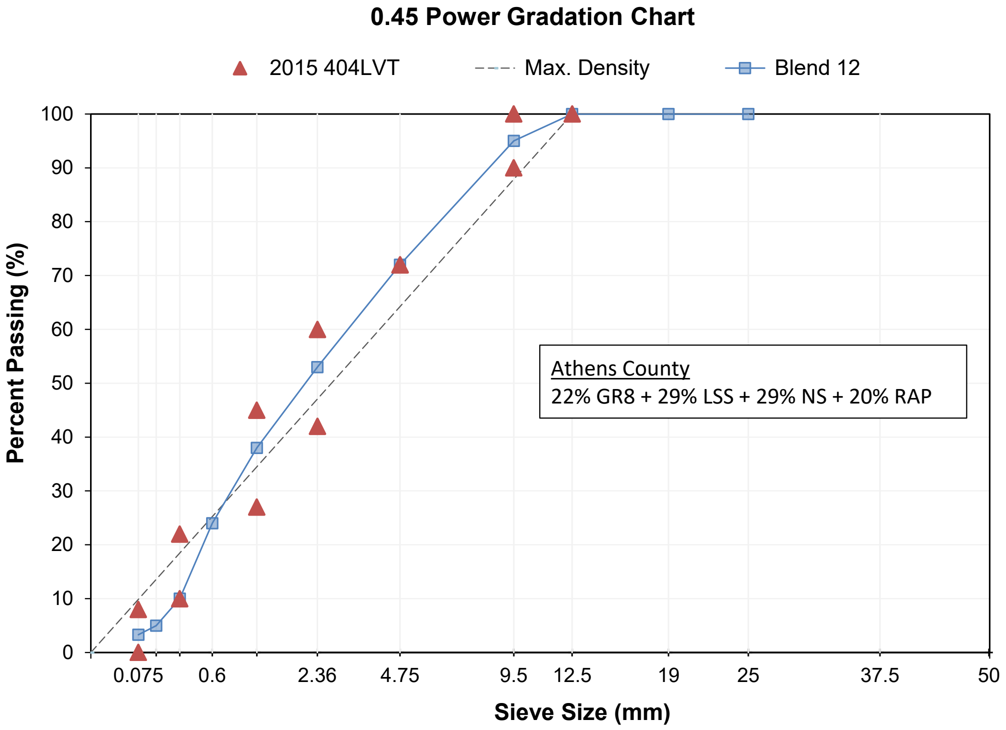

Figure B.12. Particle Size Distribution of Blend 12.

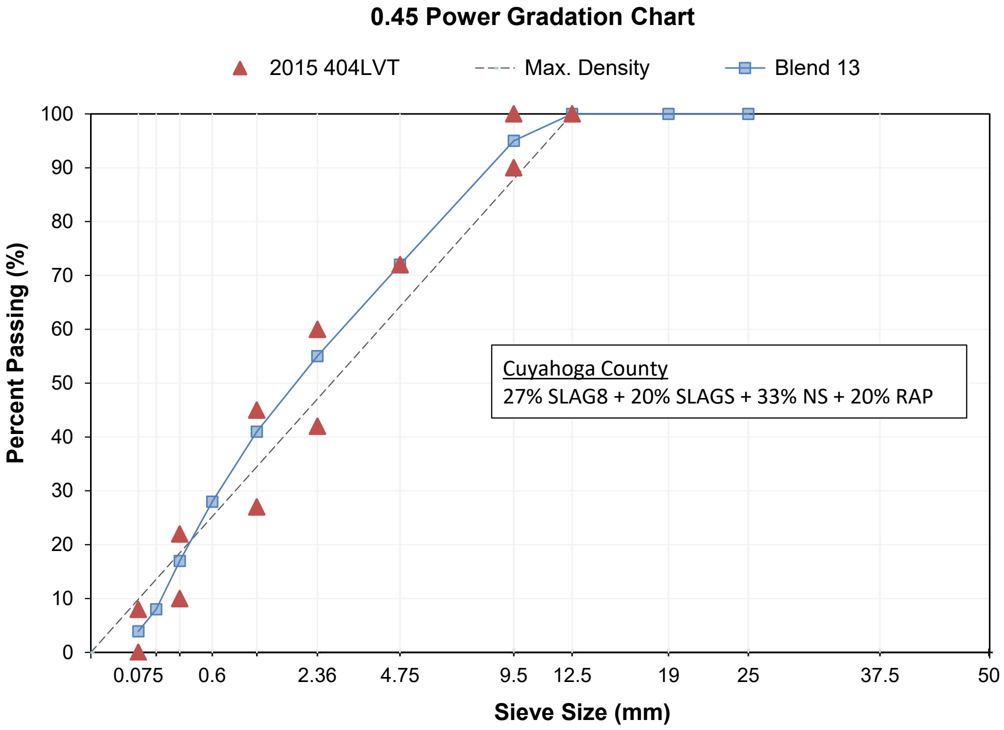

Figure B.13. Particle Size Distribution of Blend 13.

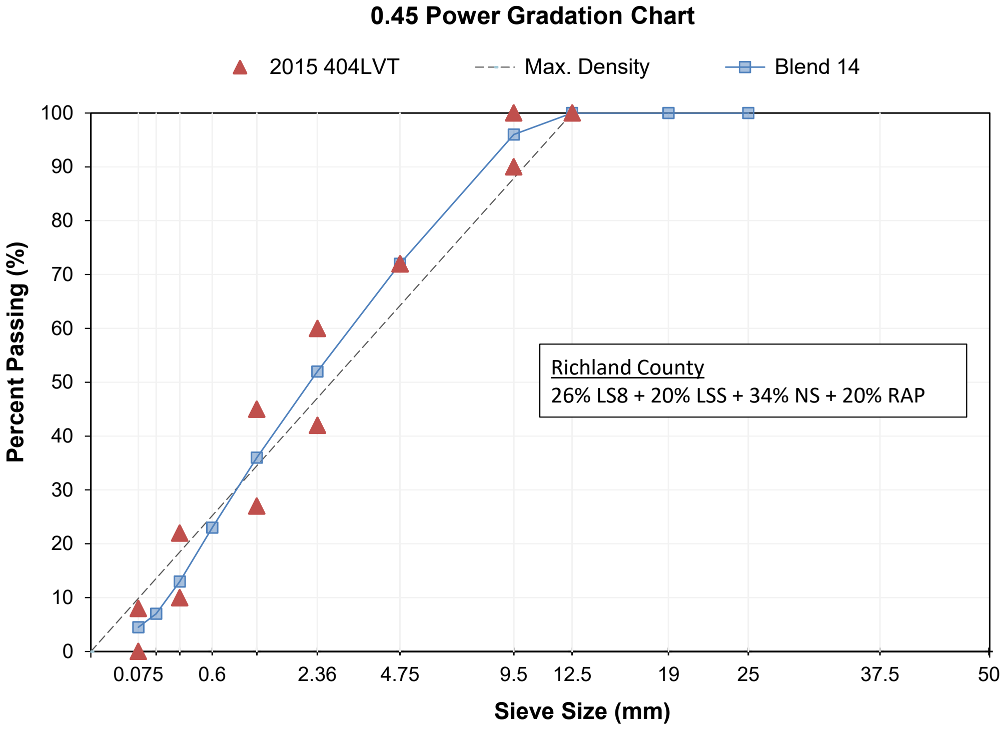

Figure B.14. Particle Size Distribution of Blend 14.

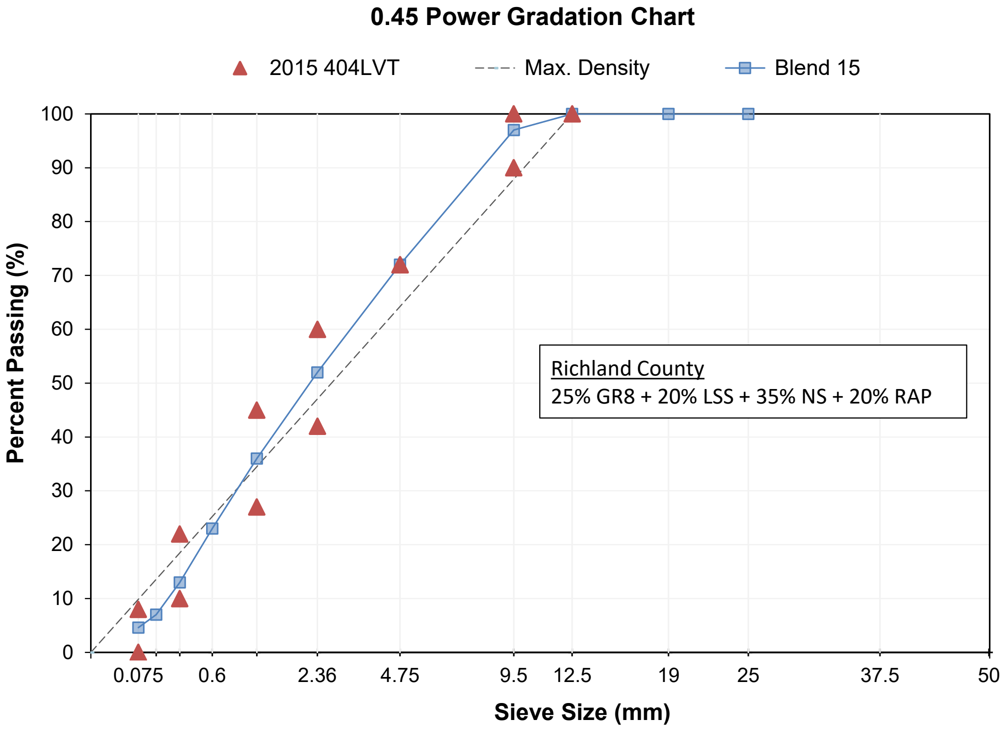

Figure B.15. Particle Size Distribution of Blend 15.

Table B.3: Viscoelastic Properties of the PG 58-28 Asphalt Binders.

Binder Property	Binder Grade		
	PG 58-28 (A)	PG 58-28 (B)	PG 58-28 (C)
Viscosity @ 135°C, Pa.s	0.28	0.30	0.29
Original DSR, G*/sinδ, kPa	1.21 @ 58°C	1.50 @ 58°C	1.15 @ 58°C
RTFO DSR, G*/sinδ, kPa	3.83 @ 58°C	3.55 @ 58°C	3.03 @ 58°C
PAV DSR, G*sinδ, kPa	3,290 @ 19°C	4,655 @ 19°C	4,370 @ 19°C
PAV BBR Stiffness, MPa	171 @ -18°C	235 @ -18°C	219 @ -18°C
PAV BBR m-value	0.319 @ -18°C	0.321 @ -18°C	0.308 @ -18°C

Table B.4: Viscoelastic Properties of the PG 64-22 Asphalt Binder.

Binder Property	Binder Grade
	PG 64-22 (A)
Viscosity @ 135°C, Pa.s	0.426
Original DSR, G*/sinδ, kPa	1.27 @ 64°C
RTFO DSR, G*/sinδ, kPa	4.29 @ 64°C
PAV DSR, G*sinδ, kPa	3,720 @ 25°C
PAV BBR Stiffness, MPa	150 @ -12°C
PAV BBR m-value	0.302 @ -12°C

Appendix C
Laboratory Testing Plan

C.1 Introduction

This appendix presents a summary of the test procedures for the indirect tension asphalt cracking test (IDEAL-CT), the modified Lottman test (AASHTO T 283), the Hamburg wheel tracking device (HWTD), and the asphalt concrete cracking device (ACCD) that were included in the laboratory testing plan for this project (please refer to Section 3 in the main report).

C.2 Indirect tension asphalt cracking test (IDEAL-CT)

The IDEAL-CT test is an indirect tensile strength test that is used to determine the cracking resistance of asphalt mixtures at moderate temperatures (Figure C.1). Similar to the traditional indirect tensile strength test, a cylindrical specimen is vertically loaded along its diameter at a constant loading rate until the specimen breaks and the measured load drops to nearly zero. The IDEAL-CT test is performed at 25 ± 1°C using a loading rate of 50 ± 2 mm/min. The height of the Superpave gyratory-compacted specimen required for this test is 62 ± 3 mm for surface mixtures, with a target air void level of 7.0% ± 0.5%. In this study, the loose asphalt mixture used in the preparation of the IDEAL-CT specimens was short-term aged for a period of 4 hours at 275°F (135°C) before being compacted in the Superpave gyratory compactor.

Load and deformation measurements are recorded during the IDEAL-CT test and used in obtaining a cracking parameter called the cracking tolerance index, CT_{index}, which can be used to identify brittle asphalt mixtures that may be prone to premature cracking (Figure C.2). Equation C.1 was suggested by Zhou et al. (2017) for the calculation of the CT_{index}.

$$CT_{index} = \frac{t}{62} \times \frac{G_f}{|m_{75}|} \times \frac{l_{75}}{d} \tag{C.1}$$

where,

G_f = work of fracture which is the total area under load versus displacement curve (J/m^2)

D = sample diameter (mm)

t = sample thickness (mm)

l_{75} = displacement corresponding to the 75 percent of the peak load in the post-peak stage (mm)

m_{75} = slope in the post-peak stage (kN/mm), which is calculated as follows (refer to Figure C.3):

$$m_{75} = \frac{P_{85} - P_{65}}{l_{85} - l_{65}} \tag{C.2}$$

where,

P_{85} = 85 percent of the peak load in the post-peak stage (kN)
P_{65} = 65 percent of the peak load in the post-peak stage (kN)
l_{85} = displacement corresponding to 85 percent of the peak load in the post-peak stage (mm)
l_{65} = displacement corresponding to 65 percent of the peak load in the post-peak stage (mm)

Figure C.1. Indirect Tension Asphalt Cracking Test Setup.

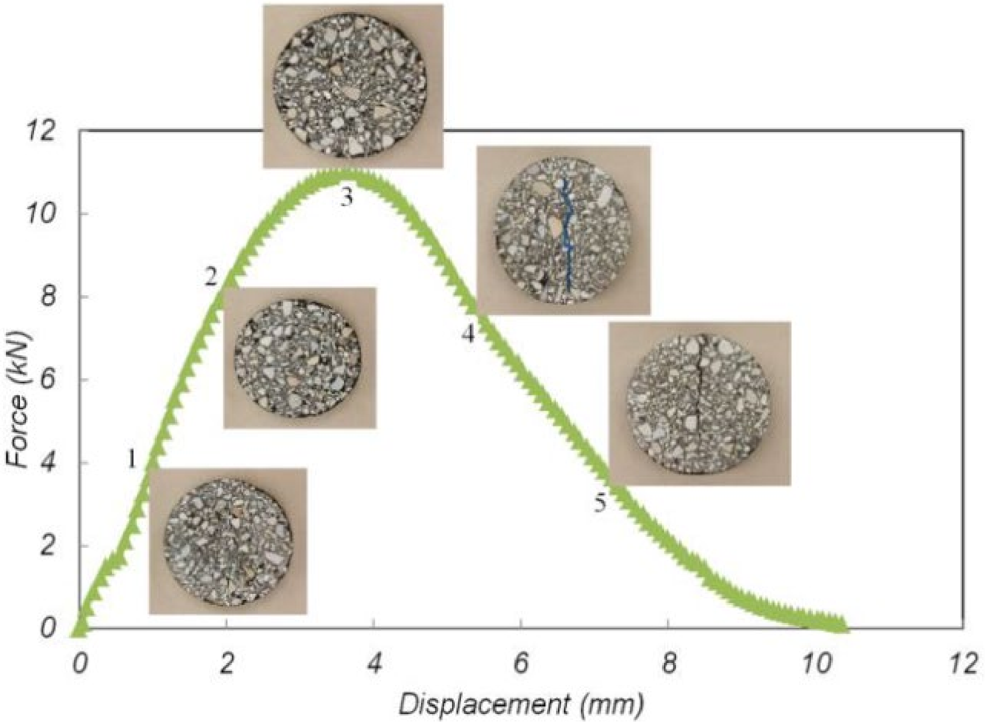

Figure C.2: Example Load versus Displacement Curve
Obtained using the IDEAL-CT Test (after Zhou et al. 2017).

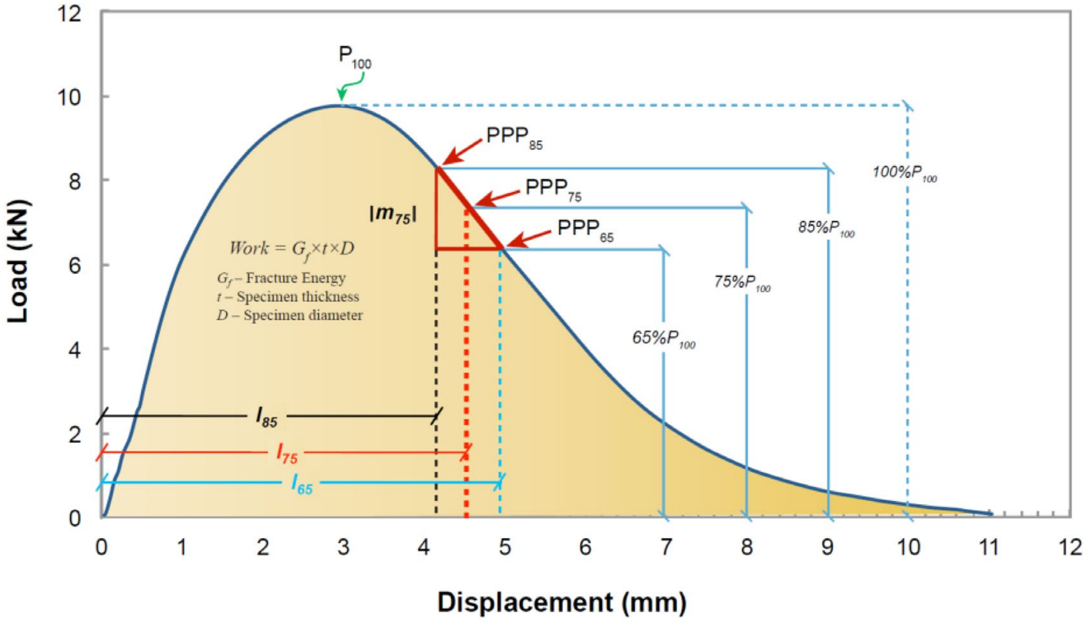

Figure C.3: Determination of $|m_{75}|$ for the Calculation of CT_{index} (after Zhou et al. 2017).

C.3 Modified Lottman test (AASHTO T 283)

The modified Lottman test was conducted according to AASHTO T 283 (Standard Method of Test for Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage) and ODOT Supplement 1051 (Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage). In this test, six Superpave gyratory-compacted specimens were prepared for each asphalt mixture. The six specimens were divided into two subsets. One subset was wrapped and stored at room temperature for later testing under dry conditions (unconditioned), while the other subset was subjected to moisture conditioning followed by one cycle of freezing and thawing before testing (conditioned). The conditioning procedure involved partially saturating the samples (with a target degree of saturation of 70% to 80%) and wrapping them in a plastic film before placing them in a plastic bag containing 10 ± 0.5 mL of water. The plastic bag was then sealed and placed in a freezer maintained at a temperature of −18 ± 3°C (0 ± 5°F) for a minimum of 16 hours. At the end of the freezing cycle, the samples were removed from the plastic bag and placed in a warm water bath at 140 ± 1°F (60 ± 0.5°C) for 24 ± 1 hours. The samples were then placed in a 77 ± 1°F (25 ± 0.5°C) water bath for 2 hours ± 10 mins before being tested in the indirect tension test.

The unconditioned and conditioned indirect tensile strength (ITS), calculated using Equation C.3, along with the tensile strength ratio (TSR), calculated using Equation C.4, were used to evaluate the durability of the asphalt mixtures and their susceptibility to moisture-induced damage.

$$ITS = \frac{2P}{\pi D t} \tag{C.3}$$

where,

P = peak load

D = specimen diameter

t = specimen thickness

$$TSR = \frac{ITS_{Conditioned}}{ITS_{Unconditioned}} \tag{C.4}$$

where,

$ITS_{Conditioned}$ = average indirect tensile strength of the conditioned samples

$ITS_{Unconditioned}$ = average indirect tensile strength of the unconditioned samples

C.4 Hamburg Wheel Tracking Device

The Hamburg wheel tracking device (HWTD), shown in Figure C.4, was used to evaluate the compressibility of the asphalt mixtures and their susceptibility to permanent deformation (or rutting). This test was conducted according to AASHTO T 324 (Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Asphalt Mixtures). In this test, a loaded steel wheel tracks over the samples in a heated water bath, and the deformation is observed versus the number of loading passes (Figure C.5). The compacted samples are conditioned at 50°C for 90 minutes prior to the beginning of the test and are kept submerged under water at that temperature throughout the duration of the test. In this study, the loose asphalt mixture used in the preparation of the Hamburg test specimens was short-term aged for a period of 4 hours at 275ºF (135ºC) before being compacted in the Superpave gyratory compactor.

Figure C.4. Hamburg Wheel Tracking Device.

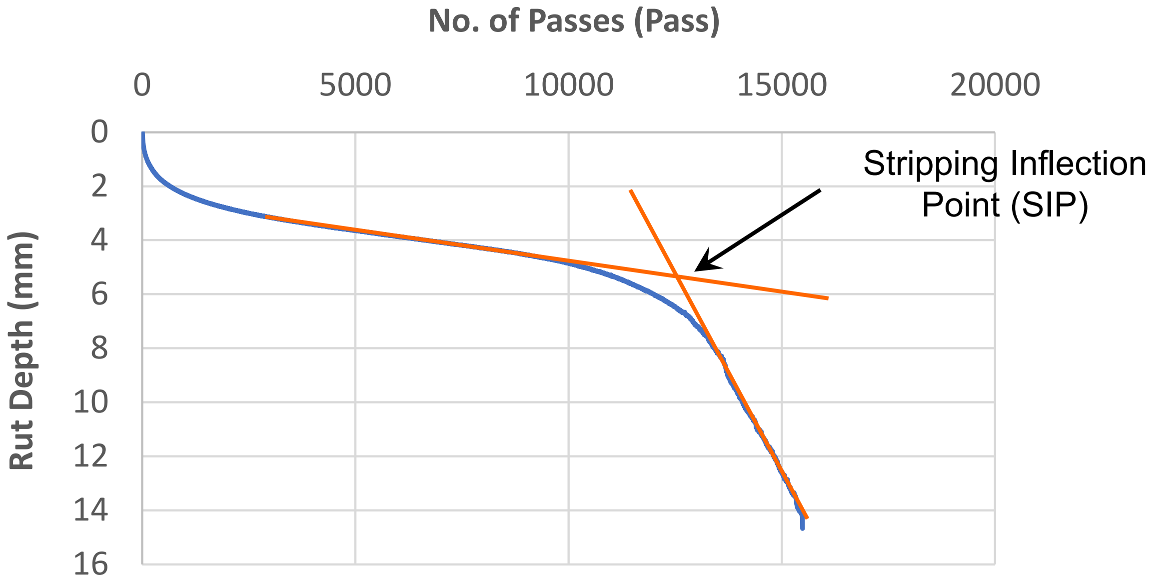

Figure C.5: Example Rut Depth versus Number of Passes Data Obtained using the Hamburg Wheen Tracking Device.

Table C.1 presents a summary of the temperature and performance criteria used by different state highway agencies for the Hamburg wheel tracking device. As can be noticed from this table, in addition to specifying a maximum allowable rut depth after a certain number of cycles, the stripping inflection point (SIP) has been utilized in evaluating the moisture susceptibility of asphalt mixes. The SIP represents the number of load cycles at which a sudden increase in rut depth occurs, which typically happens when the asphalt binder is stripped from the aggregate. A maximum rut depth of 12.5 mm at 10,000 passes and a minimum SIP of 10,000 passes have been used by several agencies for softer asphalt binders, such as PG 58-28. Therefore, it was decided to use these criteria in this study to evaluate the performance of the various 404LVT asphalt mixes.

Table C.1. Summary of Hamburg Wheel Tracking Device Criteria used by State Highway Agencies (Yin et al. 2020).

State	Binder/mixture type	Temperature	Criteria
California	PG 58-xx	50°C	Min. 10,000 passes at 12.5 mm rut depth
	PG 64-xx		Min. 15,000 passes at 12.5 mm rut depth
	PG 70-xx		Min. 20,000 passes at 12.5 mm rut depth
	PG 76-xx		Min. 25,000 passes at 12.5 mm rut depth
Colorado	PG 58-xx	45°C	Max. 4.0 mm rut depth at 10,000 passes
	PG 64-xx	50°C	
	PG 70-xx, 76-xx	55°C	
Georgia	4.75 mm and 9.5 mm SP mixes	50°C	Max. 12.5 mm rut depth at 15,000 passes with min. SIP of 15,000 passes
	12.5 mm, 19 mm, and 25 mm SP mixes, and all mixes with PG 76-22 binder		Max. 12.5 mm rut depth at 20,000 passes with no SIP
Iowa	PG 58-xx	40°C	Max. 8.0 mm rut depth at 8,000 passes Min. 10,000 or 14,000 passes with no SIP
	PG 64-xx (or higher)	50°C	
Illinois	PG 58-xx (or lower)	50°C	Max. 12.5 mm rut depth at 5,000 passes
	PG 64-xx		Max. 12.5 mm rut depth at 7,500 passes
	PG 70-xx		Max. 12.5 mm rut depth at 15,000 passes
	PG 76-xx (or higher)		Max. 12.5 mm rut depth at 20,000 passes
Louisiana	Level 1 high traffic	50°C	Max. 6.0 mm rut depth at 20,000 passes
	Level 2 medium/low traffic		Max. 10.0 mm rut depth at 20,000 passes
Maine	All	50°C	Max. 12.5 mm rut depth at 20,000 passes Min. 15,000 passes with no SIP
Massachusetts	All	45°C	Max. 12.5 mm rut depth at 20,000 passes Min. 15,000 passes with no SIP
Montana	PG 58-xx	44°C	Max. 13.0 mm rut depth at 15,000 passes
	PG 64-xx	50°C	
	PG 70-xx	56°C	
Oklahoma	PG 64-xx	50°C	Min. 10,000 passes at 12.5 mm rut depth
	PG 70-xx		Min. 15,000 passes at 12.5 mm rut depth
	PG 76-xx		Min. 20,000 passes at 12.5 mm rut depth
Texas	PG 64-xx	50°C	Min. 10,000 passes at 12.5 mm rut depth
	PG 70-xx		Min. 15,000 passes at 12.5 mm rut depth
	PG 76-xx		Min. 20,000 passes at 12.5 mm rut depth
Utah	PG 58-xx	46°C	Max. 10.0 mm rut depth at 20,000 passes
	PG 64-xx	50°C	
	PG 70-xx	54°C	
Washington	All	50°C	Max. 10.0 mm rut depth at 15,000 passes Min. 15,000 passes with no SIP

C.5 *Asphalt Concrete Cracking Device (ACCD)*

The ACCD test was used to evaluate the resistance of the asphalt mixtures to low-temperature (thermal) cracking (Figure C.6). This test uses a metal ring made of Invar steel to induce tensile stresses in an asphalt mixture sample as the temperature is lowered. In this test, a 6-inch-diameter (150-mm) Superpave gyratory specimen is compacted to a height of 4.3 inches (110 mm). The specimen is then cut to produce two ACCD specimens with a thickness of 2 inches (50 mm). An inner core of 2.3 inches (6 mm) is extracted from the center of each specimen and replaced with the Invar steel ring. A 0.88-inch (22.4-mm) long-notch is introduced at the outer surface of the specimen to control the location of the crack as the temperature is lowered at a rate of 10°C per hour during the test. The temperature and strain of each ACCD ring are continuously recorded until failure. The temperature corresponding to the maximum slope of the strain versus temperature curve is considered as the onset of thermal cracking. The ACCD cracking temperature is defined as the temperature corresponding to eighty percent of the maximum slope (Figure C.7).

It is noted that not all laboratory tests needed to be performed to evaluate the effect of every mix design factor on the performance of 404LVT mixes. For example, it is generally held that asphalt binder content has little effect on the resistance of an asphalt mixture to low-temperature cracking as measured using the ACCD test. Therefore, there was no need to include the ACCD test in the portion of the laboratory testing plan that examined the effect of the asphalt binder content on the performance of 404LVT mixes.

Figure C.6. Asphalt Concrete Cracking Device Test Setup.

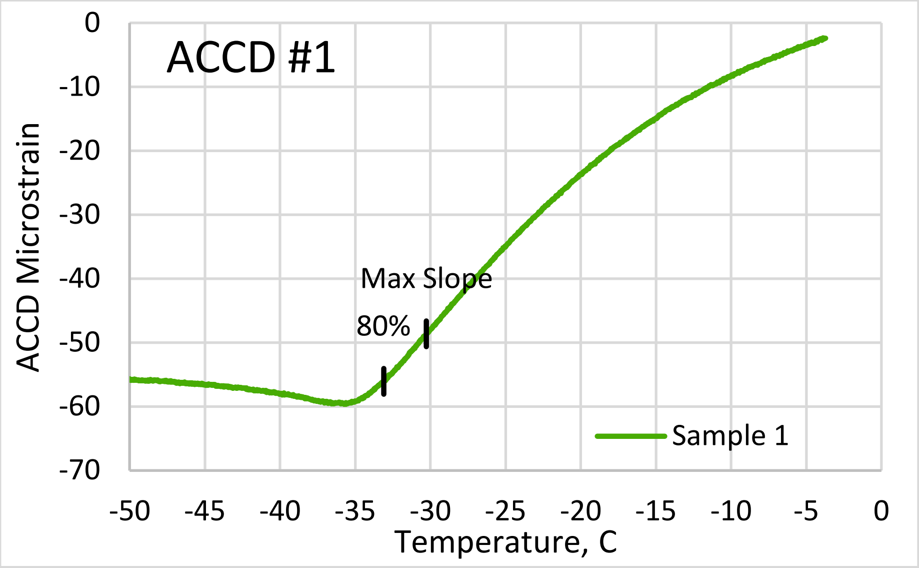

Figure C.7. Example ACCD Test Results.

Appendix D
Laboratory Test Results and Discussion

D.1 Introduction

This appendix presents a summary of the laboratory test results for the various 404LVT mixes that were included in the laboratory testing matrix, which was presented in Table B.1. As discussed in Section 3 (Research Approach) of the main report, the laboratory testing matrix included different 404LVT mixes prepared using two asphalt binders (PG 58-28 and PG 64-22), two types of coarse aggregates (limestone and gravel as well as a limestone-gravel blend), and two types of fine aggregates (natural sand and limestone sand). The total asphalt binder content specified in the 2015 404LVT specifications (6.8% for limestone, 6.6% for gravel, and 6.7% for the limestone/gravel blend) as well as lower and higher percentages of asphalt binder (−0.3% and +0.3%) were evaluated in this study. The research team also examined the effect of using a higher percentage of RAP on the performance of 404LVT mixes. Aggregate blends prepared using varying percentages of limestone No. 8 (LS8), gravel No. 8 (GR8), natural sand (NS), and limestone sand (LSS) as well as aggregates from different sources collected from asphalt plants in different counties were also included in the laboratory testing plan.

As discussed in Appendix C (Laboratory Test Procedures), several laboratory tests were utilized to evaluate the performance of the various 404LVT mixes. The indirect tension asphalt cracking test (IDEAL-CT) was used to evaluate the cracking resistance of the asphalt mixtures at intermediate temperatures. The modified Lottman test (AASHTO T 283) was used to evaluate the durability of the asphalt mixtures and their resistance to moisture-induced damage. The Hamburg wheel tracking device (HWTD) was used to evaluate the susceptibility of the asphalt mixtures to permanent deformation (or rutting). The asphalt concrete cracking device (ACCD) was used to evaluate the resistance of the asphalt mixtures to low-temperature (thermal) cracking. The laboratory test results are presented in the following sections in the same order of the different mix design factors listed in Table B.1 for all test results except those for the ACCD test, which are presented at the end of this appendix.

D.2 Effect of Binder Type

Four asphalt mixtures were used to evaluate the effect of the binder type on the performance of 404LVT mixes:

- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
- 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28
- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22
- 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 64-22

Two mixtures were prepared using limestone coarse aggregates and the other two were prepared using gravel coarse aggregates. For each aggregate type, two different asphalt binder types (PG 58-28 and PG 64-22) were used. The total binder contents specified in the 2015 404LVT specifications for limestone and gravel coarse aggregates were used for the preparation of the four asphalt mixtures.

The indirect tensile strength (ITS), fracture energy (G_f), displacement corresponding to 75% of the peak load in the post-peak portion of the load versus displacement curve (L), post-peak slope (S), and CT_{index} obtained using the IDEAL-CT test for the four asphalt mixtures are presented in Figures D.1 to D.5, respectively. It can be noticed from these figures that asphalt mixtures prepared using PG 64-22 exhibited higher ITS, G_f, and S values; slightly lower L values; and lower CT_{index} values than those prepared using PG 58-28. This indicates that PG 58-28 might result in an asphalt mixture with a better resistance to cracking than PG 64-22. The aggregate type did not seem to affect the test results.

The tensile strength ratio (TSR) values obtained using the modified Lottman (AASHTO T 283) test for the four asphalt mixtures are presented in Figure D.6. As can be noticed from this figure, all mixtures met the minimum TSR requirement of 70% (which is typically used for low-volume mixes). This was the case for mixtures prepared using PG 58-28 as well as mixtures prepared using PG 64-22. This suggests that moisture-induced damage is not a major concern for 404LVT mixes.

The average number of passes needed to reach the stripping inflection point (SIP) and the average rut depth after 10,000 passes obtained using the HWTD for the four asphalt mixtures are presented in Figures D.7 and D.8, respectively. As can be noticed from these figures, the average number of passes needed to reach the SIP was higher than 10,000 passes for asphalt mixtures prepared using PG 58-28 and it was not even reached for those prepared using PG 64-22. Asphalt mixtures prepared using PG 64-22 also exhibited lower average rut depths at 10,000 passes in comparison to those prepared using PG 58-28. This suggests that PG 64-22 might result in an asphalt mixture with better resistance to permanent deformation (or rutting) than PG 58-22. Nonetheless, the average rut depths at 10,000 passes for all mixtures were less than the maximum permitted rut depth of 12.5 mm.

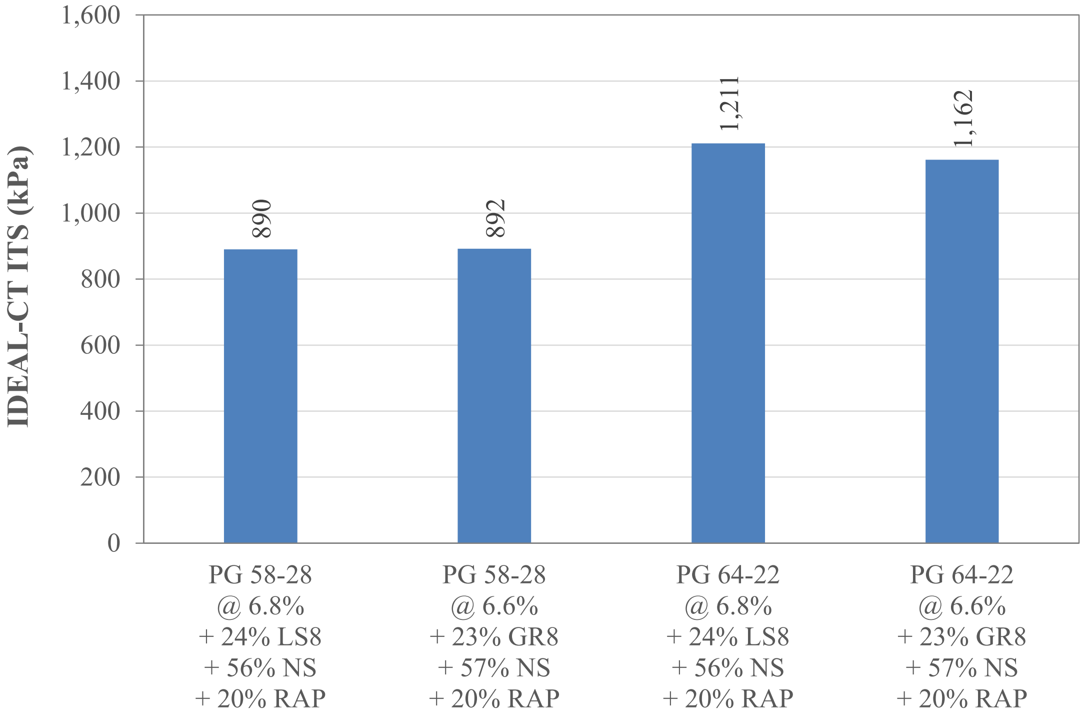

Figure D.1. Effect of Binder Type on ITS.

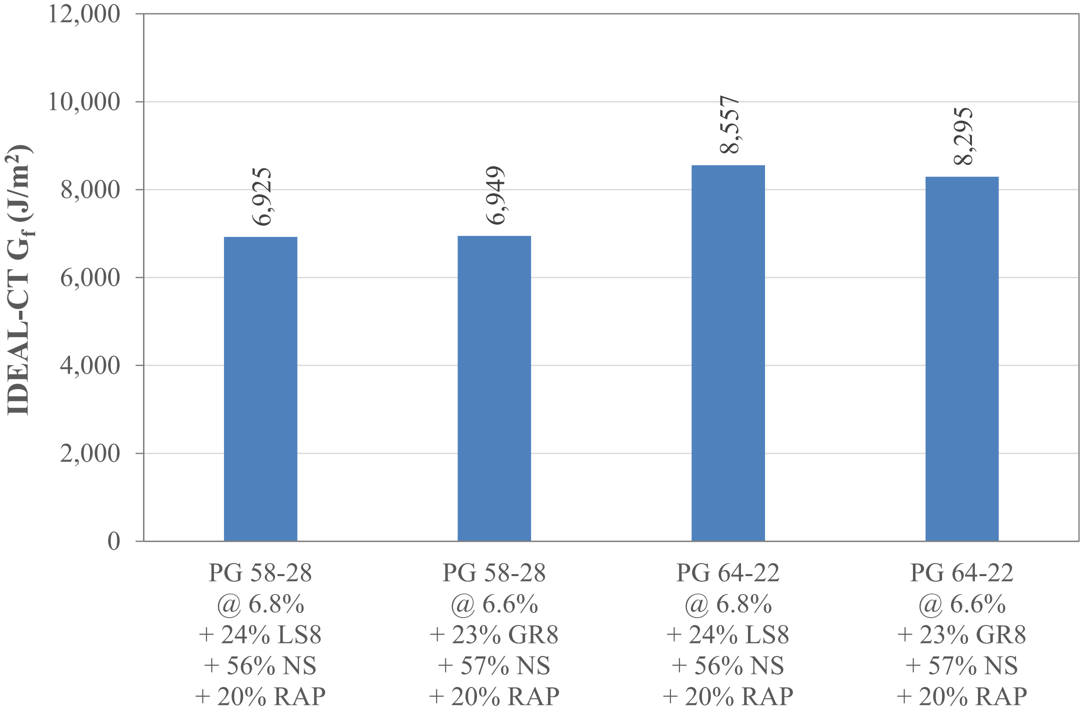

Figure D.2. Effect of Binder Type on G_f.

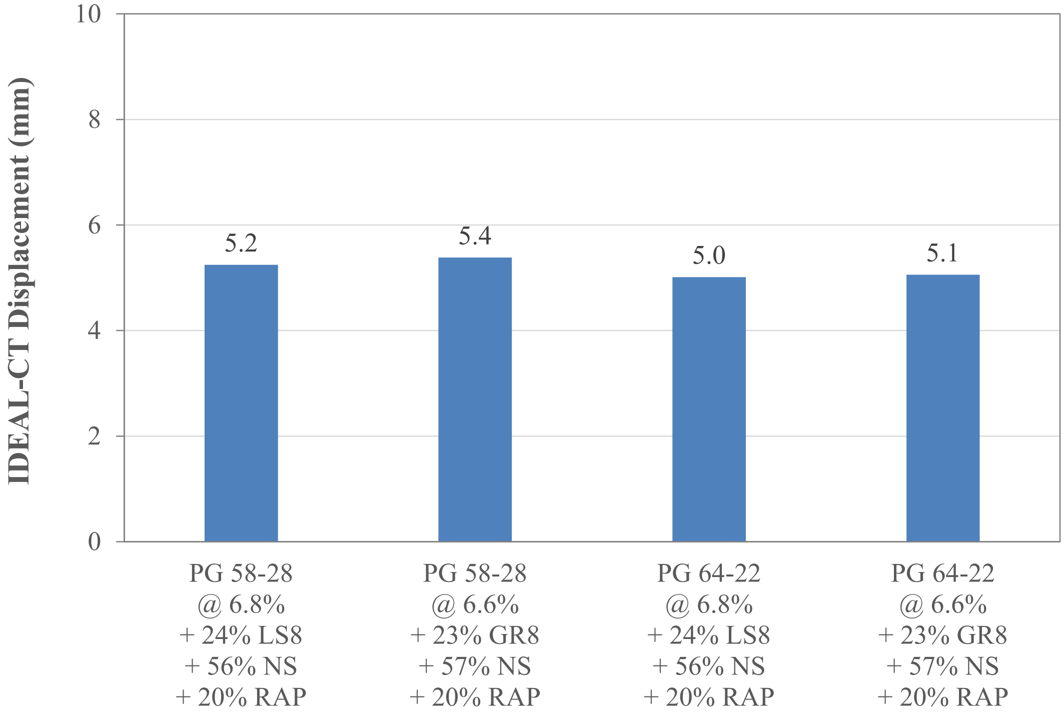

Figure D.3. Effect of Binder Type on L.

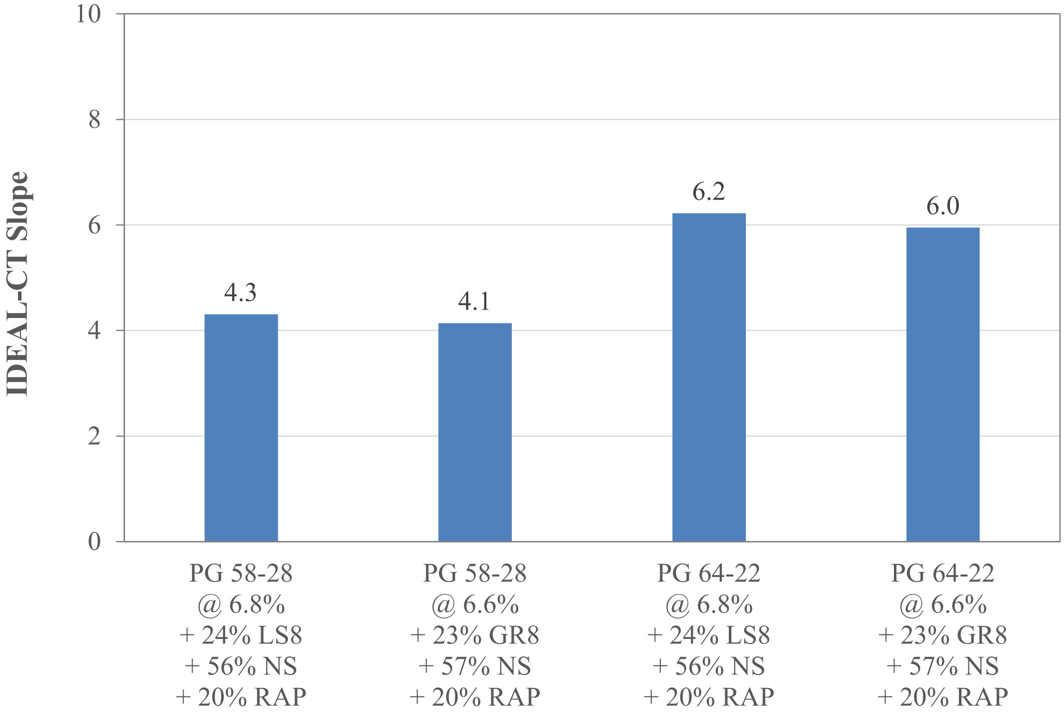

Figure D.4. Effect of Binder Type on S.

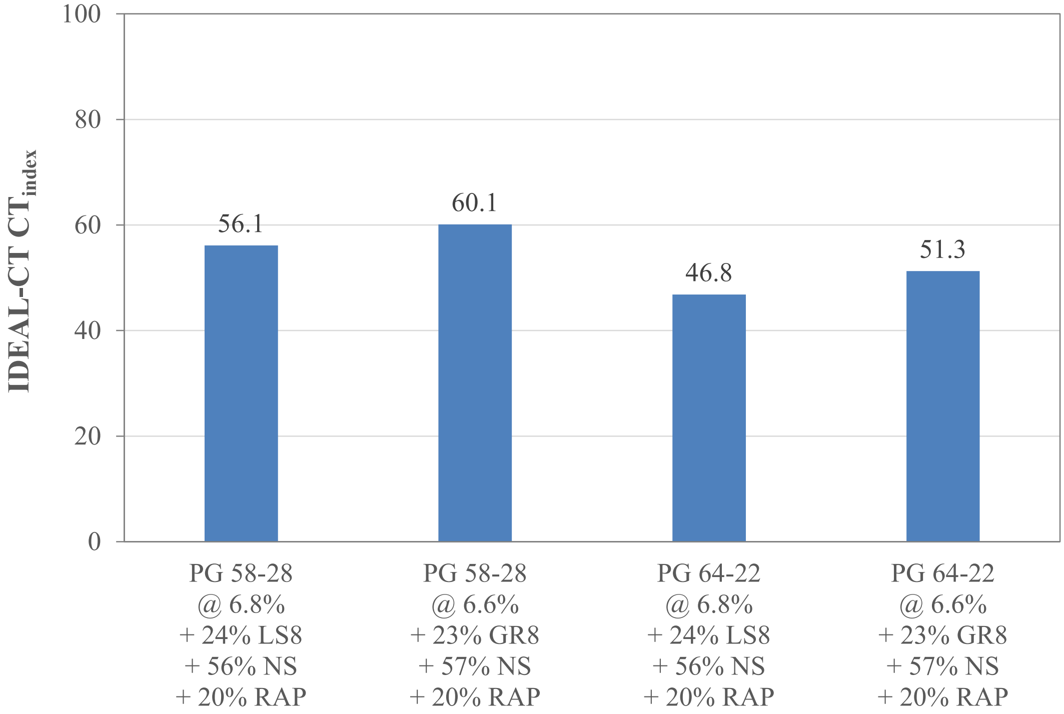

Figure D.5. Effect of Binder Type on CT_{index}.

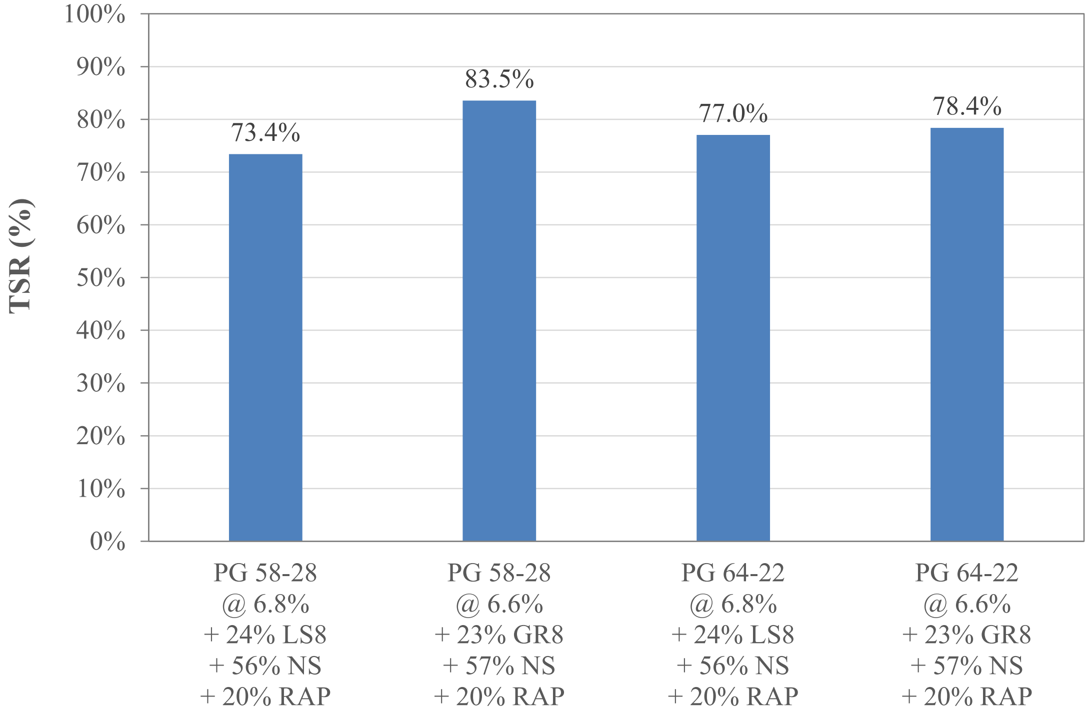

Figure D.6. Effect of Binder Type on TSR.

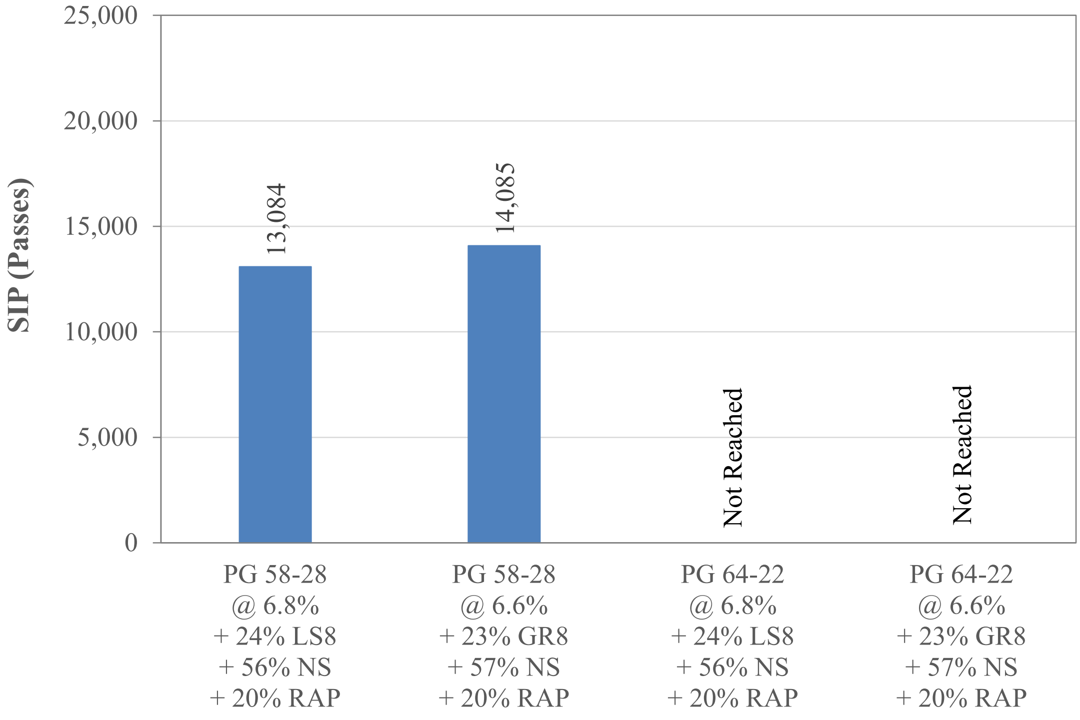

Figure D.7. Effect of Binder Type on SIP.

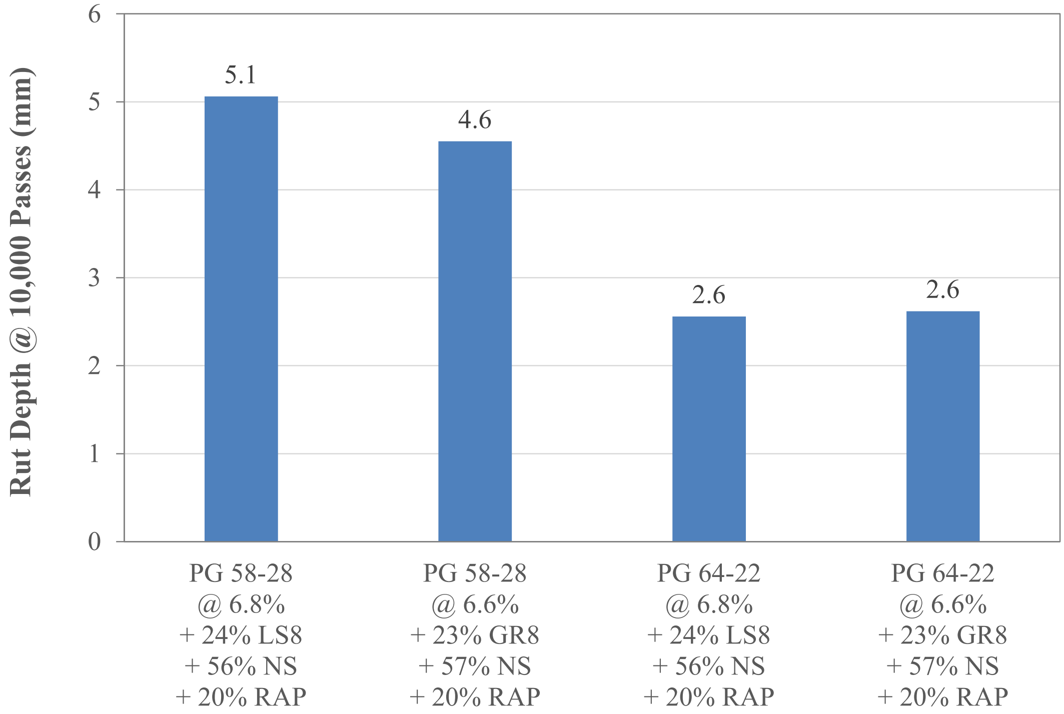

Figure D.8. Effect of Binder Type on Rut Depth after 10,000 Passes.

D.3 Effect of Binder Content

Twelve asphalt mixtures were used to evaluate the effect of the binder content on the performance of 404LVT mixes:

- 24% LS8 + 56% NS + 20% RAP @ 6.5%, 6.8%, and 7.1% PG 58-28 (Three Mixes)
- 23% GR8 + 57% NS + 20% RAP @ 6.3%, 6.6%, and 6.9% PG 58-28 (Three Mixes)
- 30% LS8 + 60% NS + 10% RAP @ 6.5%, 6.8%, and 7.1% PG 64-22 (Three Mixes)
- 30% GR8 + 60% NS + 10% RAP @ 6.3%, 6.6%, and 6.9% PG 64-22 (Three Mixes)

The twelve asphalt mixtures were prepared by mixing four different aggregate blends with asphalt binders at three different binder contents (specified −0.3%, specified, and specified +0.3%). Six of the asphalt mixtures were prepared using PG 58-28, and the remaining six mixes were produced using PG 64-22. Half of the mixtures were produced using limestone coarse aggregates and the other half were produced using gravel coarse aggregates. As specified in the 2015 404LVT specifications, the six asphalt mixtures produced using PG 58-28 contained 20% RAP and the mixtures produced using PG 64-22 contained 10% RAP.

The indirect tensile strength (ITS), fracture energy (G_f), displacement corresponding to 75% of the peak load in the post-peak portion of the load versus displacement curve (L), post-peak slope (S), and CT_{index} obtained using the IDEAL-CT test for the four asphalt mixtures are presented in Figures D.9 to D.13, respectively. As can be noticed from these figures, increasing the binder content resulted in slightly lower ITS, slightly higher G_f, slightly higher L, lower S, and higher CT_{index} values for all mixtures. This indicates that increasing the binder content in an asphalt mixture increases its ductility and makes it more resistant to cracking. These figures also show that mixtures prepared using PG 64-22 are more sensitive to the binder content than those prepared using PG 58-28. This trend is clear from the relative magnitudes of S and CT_{index} in Figures D.12 and D.13, respectively.

The tensile strength ratio (TSR) values obtained using the modified Lottman (AASHTO T 283) test for the twelve asphalt mixtures are presented in Figure D.14. As can be noticed from this figure, no clear trend is observed for the effect of the binder content on the TSR value for the different asphalt mixtures.

The average number of passes needed to reach the stripping inflection point (SIP) and the average rut depth after 10,000 passes obtained using the HWTD for the twelve asphalt mixtures are presented in Figures D.15 and D.16, respectively. As can be noticed from these figures, the average number of passes needed to reach the stripping inflection point (SIP) exceeded 10,000 passes for all mixtures, with no clear trend regarding the effect of the binder content. On the other hand, a clear trend can be observed regarding the effect of the binder content on the average rut depth after 10,000 passes. Figure D.16 shows that increasing the binder content resulted in higher average rut depths after 10,000 passes for all mixtures. This is expected, as asphalt mixtures become more susceptible to permanent deformation (or rutting) with the increase in binder content. However, the average rut depths at 10,000 passes for all mixtures were less than the maximum permitted rut depth of 12.5 mm.

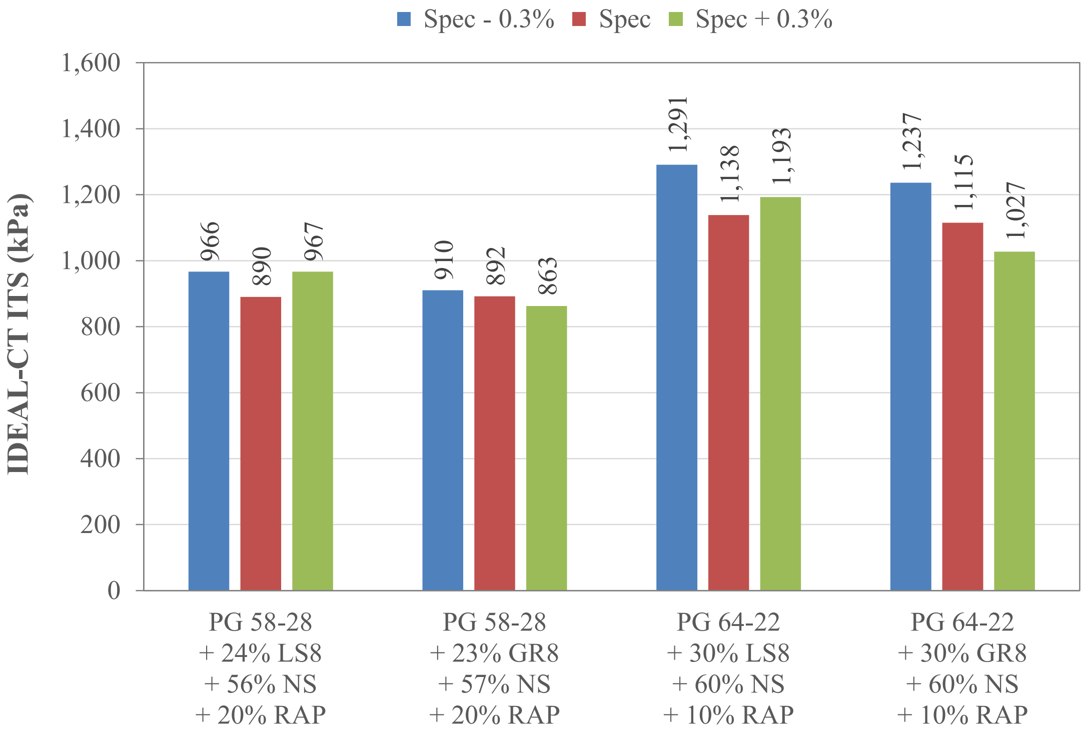

Figure D.9. Effect of Binder Content on ITS.

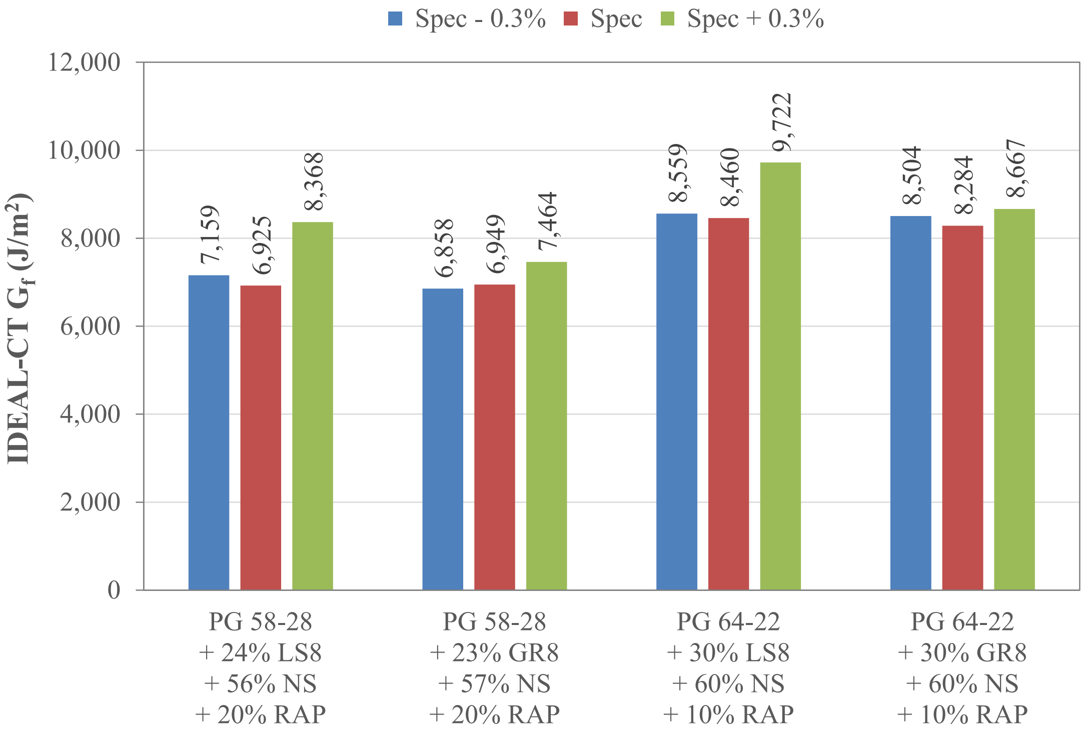

Figure D.10. Effect of Binder Content on G_f.

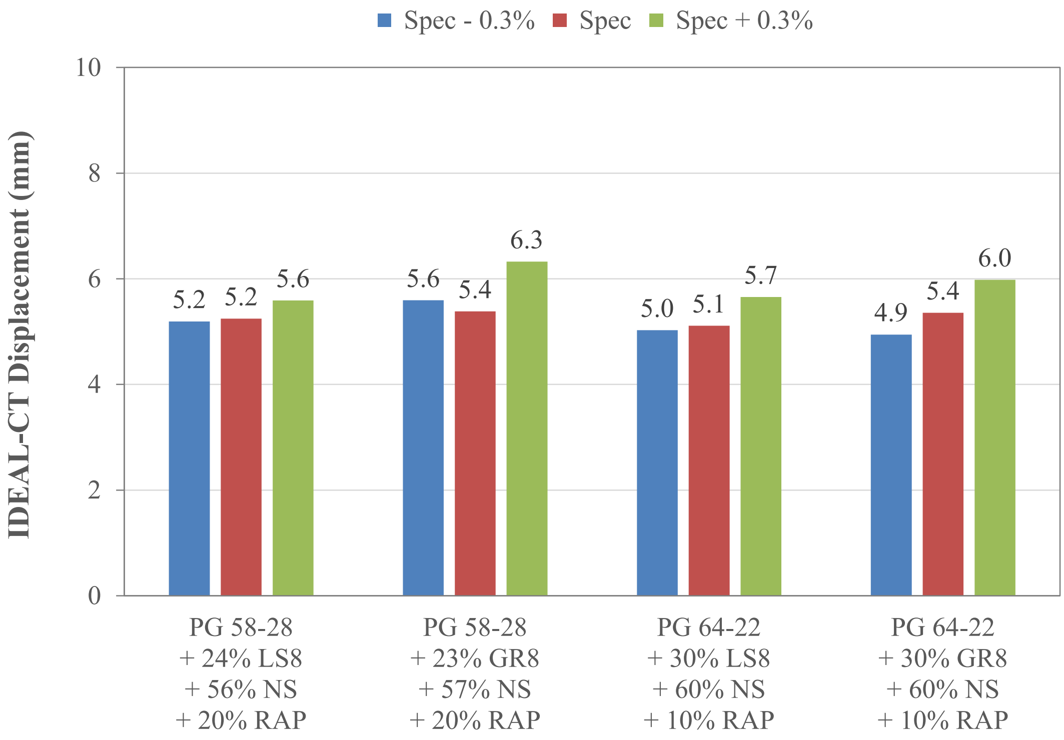

Figure D.11. Effect of Binder Content on L.

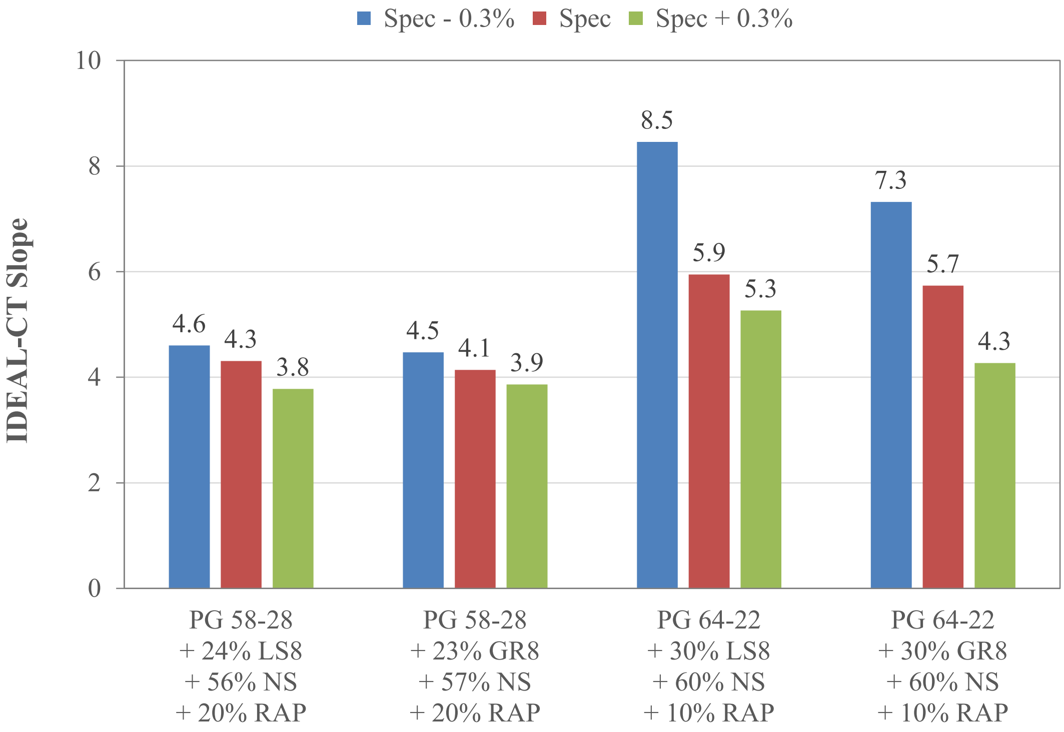

Figure D.12. Effect of Binder Content on S.

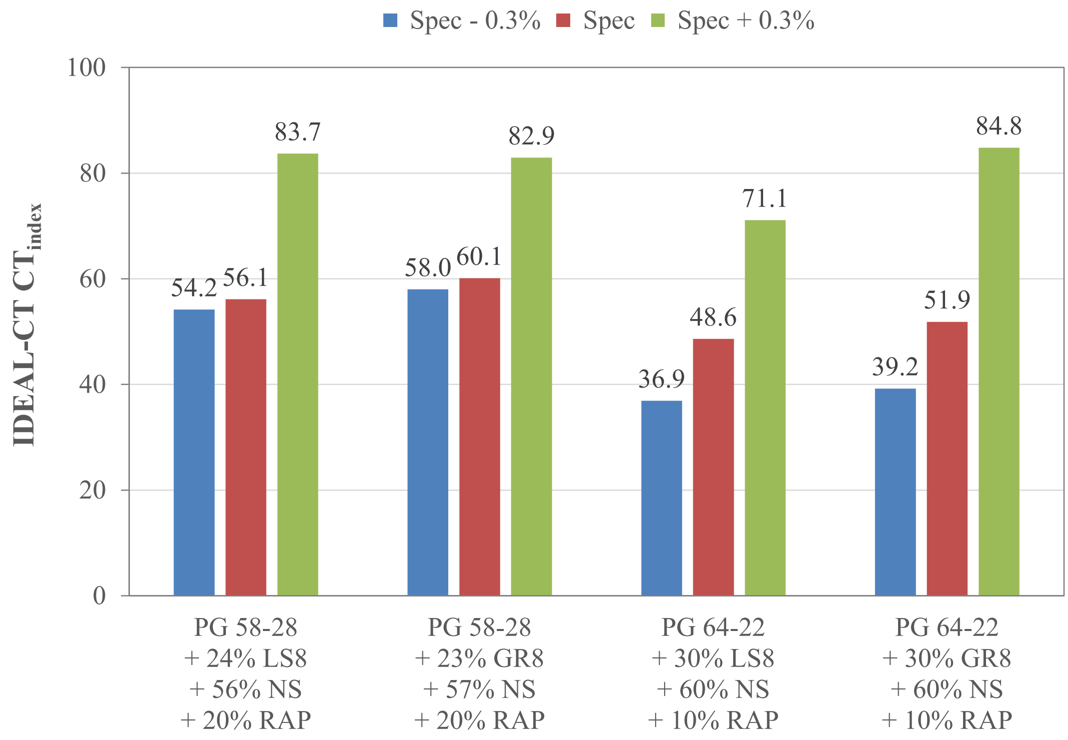

Figure D.13. Effect of Binder Content on CT_{index}.

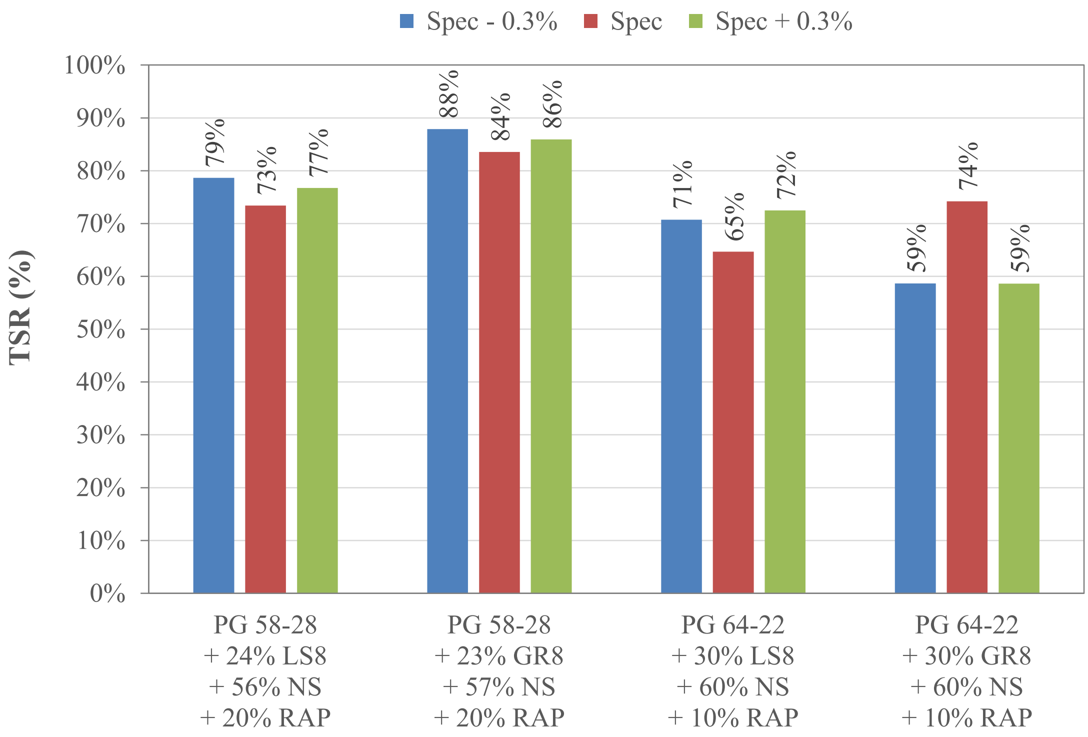

Figure D.14. Effect of Binder Content on TSR.

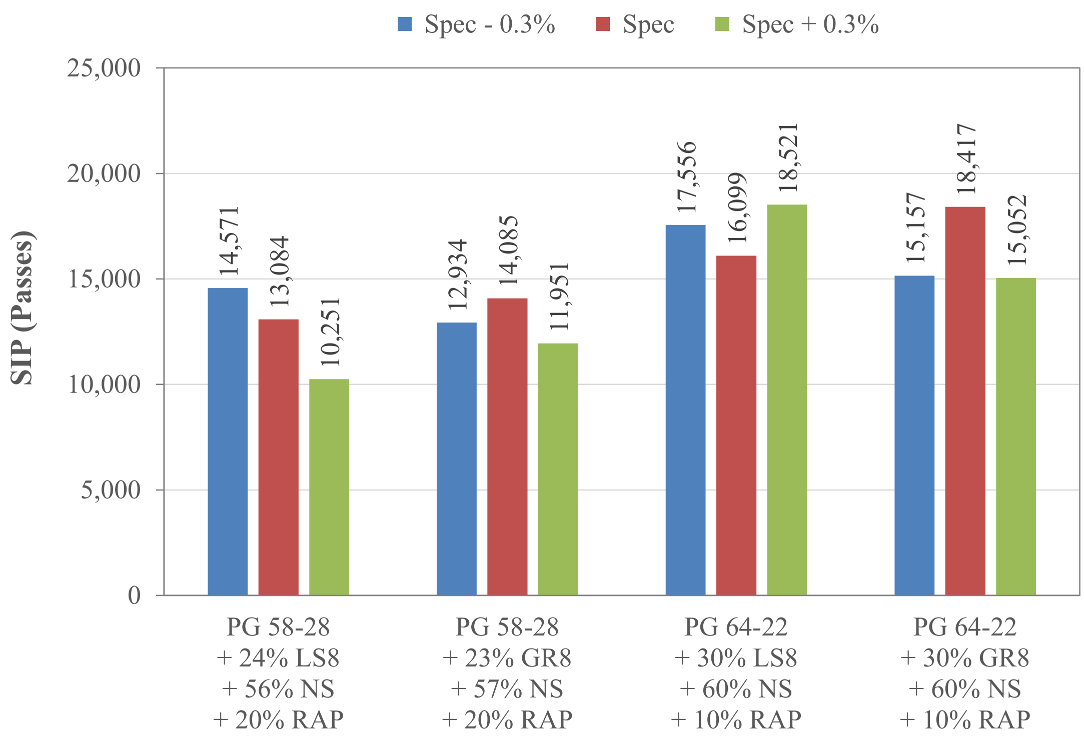

Figure D.15. Effect of Binder Content on SIP.

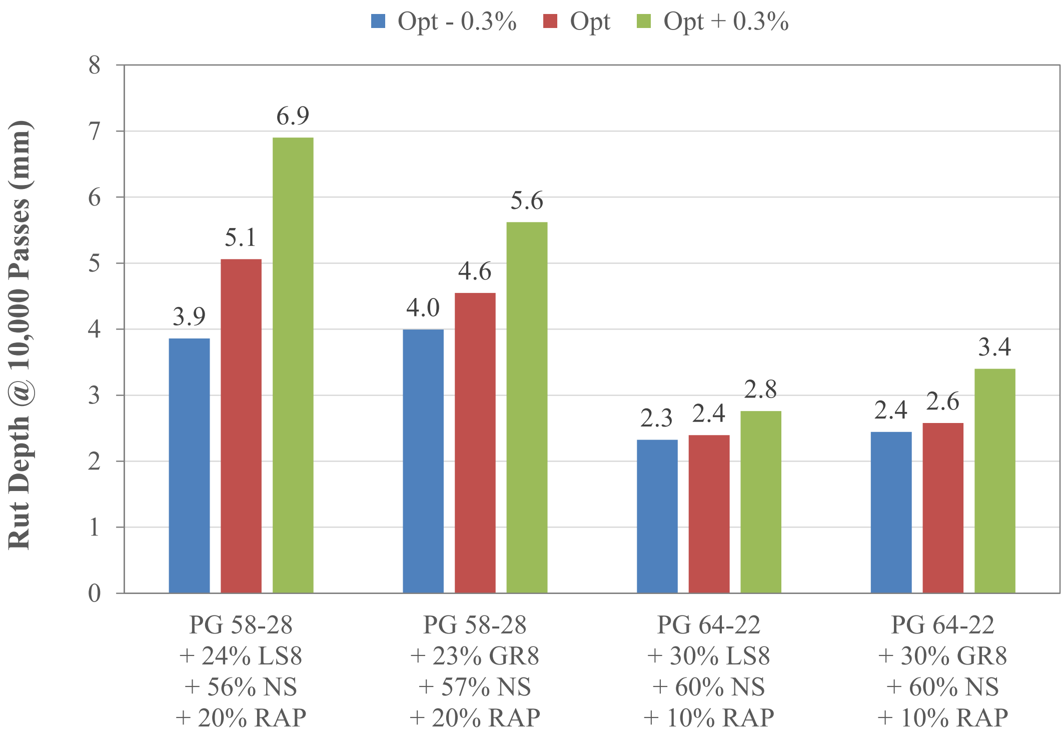

Figure D.16. Effect of Binder Content on Rut Depth after 10,000 Passes.

D.4 Effect of RAP Content

Eight asphalt mixtures were used to evaluate the effect of the RAP content on the performance of 404LVT mixes:

- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
- 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28
- 21% LS8 + 54% NS + 25% RAP @ 6.8% PG 58-28
- 21% GR8 + 54% NS + 25% RAP @ 6.6% PG 58-28
- 30% LS8 + 60% NS + 10% RAP @ 6.8% PG 64-22
- 30% GR8 + 60% NS + 10% RAP @ 6.6% PG 64-22
- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22
- 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 64-22

Four of the eight mixtures were prepared using PG 58-28 asphalt binder and the other four were prepared using PG 64-22. RAP contents of 20% and 25% were used for the asphalt mixtures prepared using PG 58-28, and RAP contents of 10% and 20% were used for the asphalt mixtures prepared using PG 64-22.

The indirect tensile strength (ITS), fracture energy (G_f), displacement corresponding to 75% of the peak load in the post-peak portion of the load versus displacement curve (L), post-peak slope (S), and CT_{index} obtained using the IDEAL-CT test for the asphalt mixtures prepared using PG 58-28 asphalt binder are presented in Figures D.17 to D.21, respectively. The IDEAL-CT test results for the asphalt mixtures prepared using PG 64-22 asphalt binder are presented in Figures D.25 to D.29. For asphalt mixtures prepared using PG 58-28, it can be noticed from these figures that increasing the RAP content resulted in slightly higher ITS, slightly higher G_f, negligible effect on L, negligible effect on S, and negligible effect on CT_{index}. As for mixtures prepared using PG 64-22, increasing the RAP content resulted in slightly higher ITS, slightly higher G_f, slightly lower L, slightly higher S, and negligible effect on CT_{index}. These results suggest that increasing the RAP content by 5% (from 20% to 25%) for mixtures prepared using PG 58-28 and by 10% (from 10% to 20%) for mixtures prepared using PG 64-22 will have a negligible effect on the resistance of the 404LVT mixes to cracking.

Figure D.22 shows the TSR values for the 404LVT mixes prepared using PG 58-28, and Figure D.30 shows the TSR values for the 404LVT mixes prepared using PG 64-22. These figures also show that all mixes met the minimum TSR requirement of 70%, with no clear trend observed regarding the effect of the RAP content on the TSR value.

The average number of passes needed to reach the stripping inflection point (SIP) and the average rut depth after 10,000 passes obtained using the HWTD test for the asphalt mixtures prepared using PG 58-28 are presented in Figures D.23 and D.24, respectively. The HWTD test results for the asphalt mixtures prepared using PG 64-22 are presented in Figures D.31 and D.32. For the asphalt mixtures prepared using PG 58-28, Figure D.24 shows comparable average numbers of passes needed to reach the SIP (which are greater than 10,000 passes) for all mixes. It can also be noticed from Figure D.25 that mixes with higher RAP contents had lower rut depths at 10,000 passes. As for mixtures prepared using PG 64-22, increasing the RAP content resulted in a higher number of passes needed to reach the SIP (Figure D.31) and a negligible effect on the rut depths at 10,000 passes (Figure D.32).

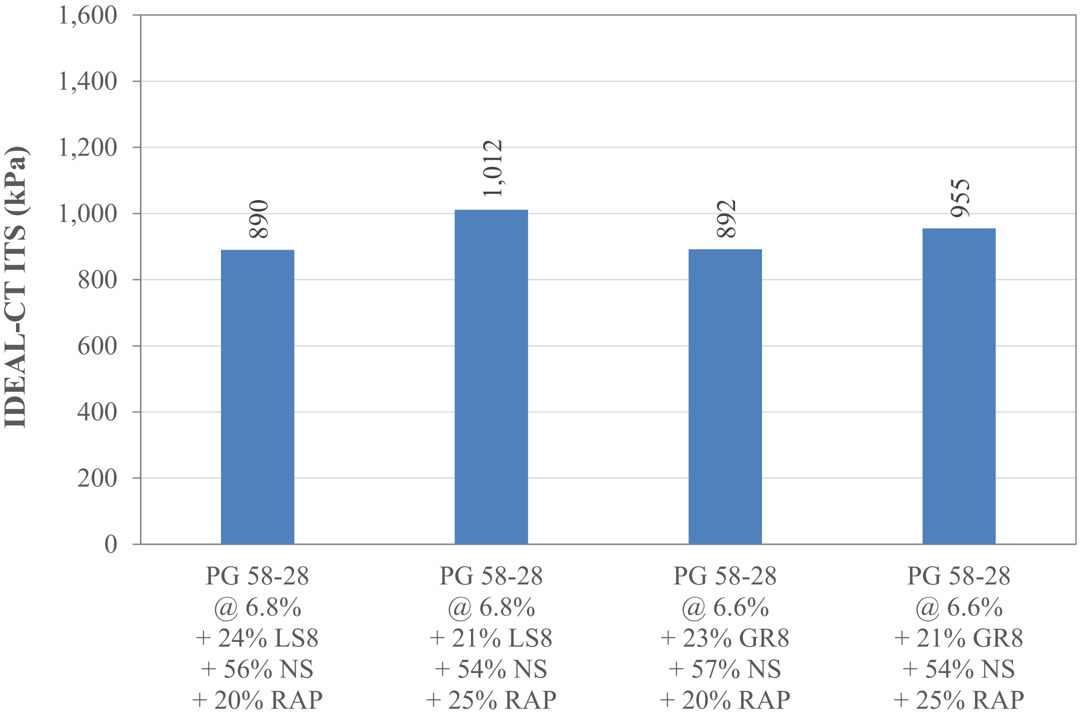

Figure D.17. Effect of RAP Content on ITS for the PG 58-28 Mixes.

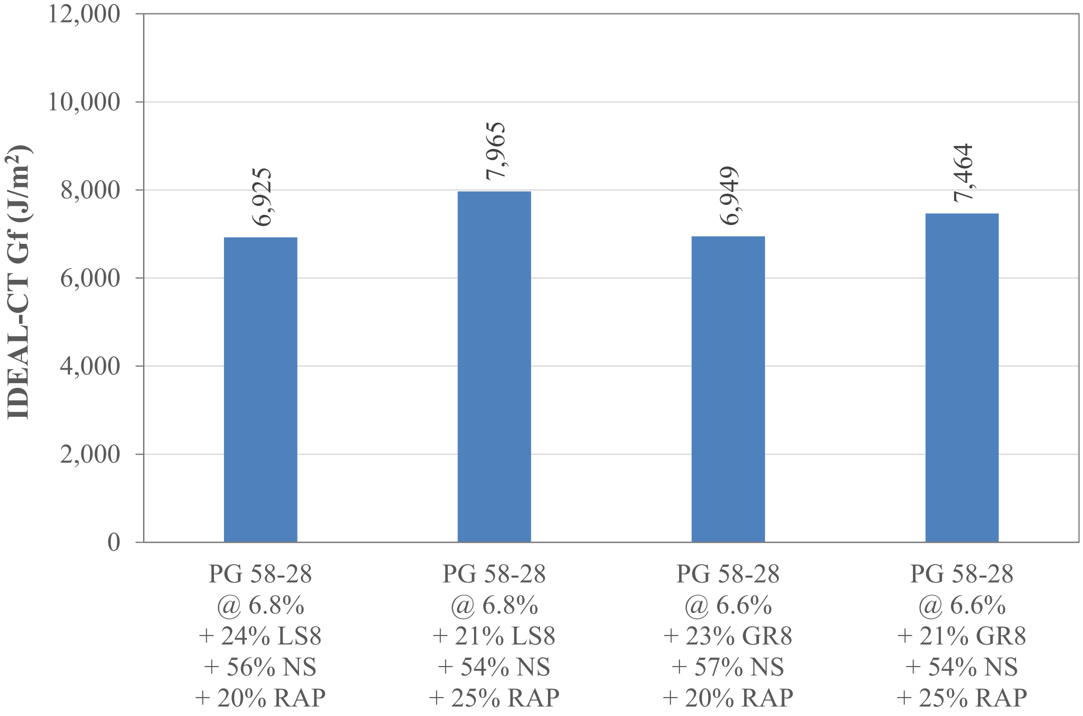

Figure D.18. Effect of RAP Content on G_f for the PG 58-28 Mixes.

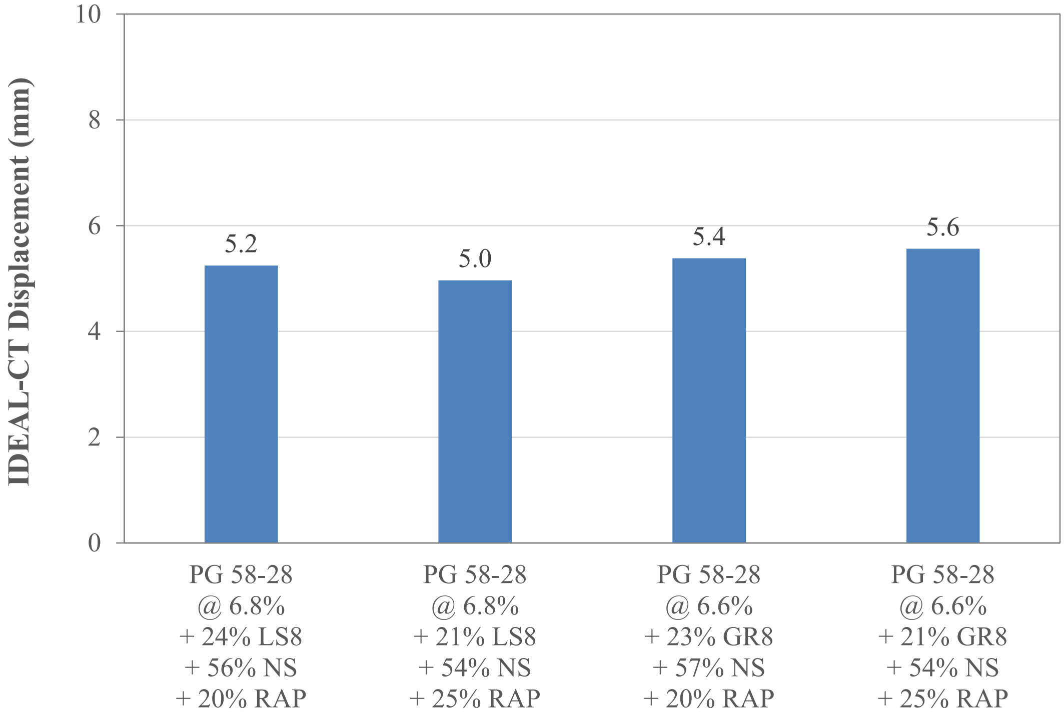

Figure D.19. Effect of RAP Content on L for the PG 58-28 Mixes.

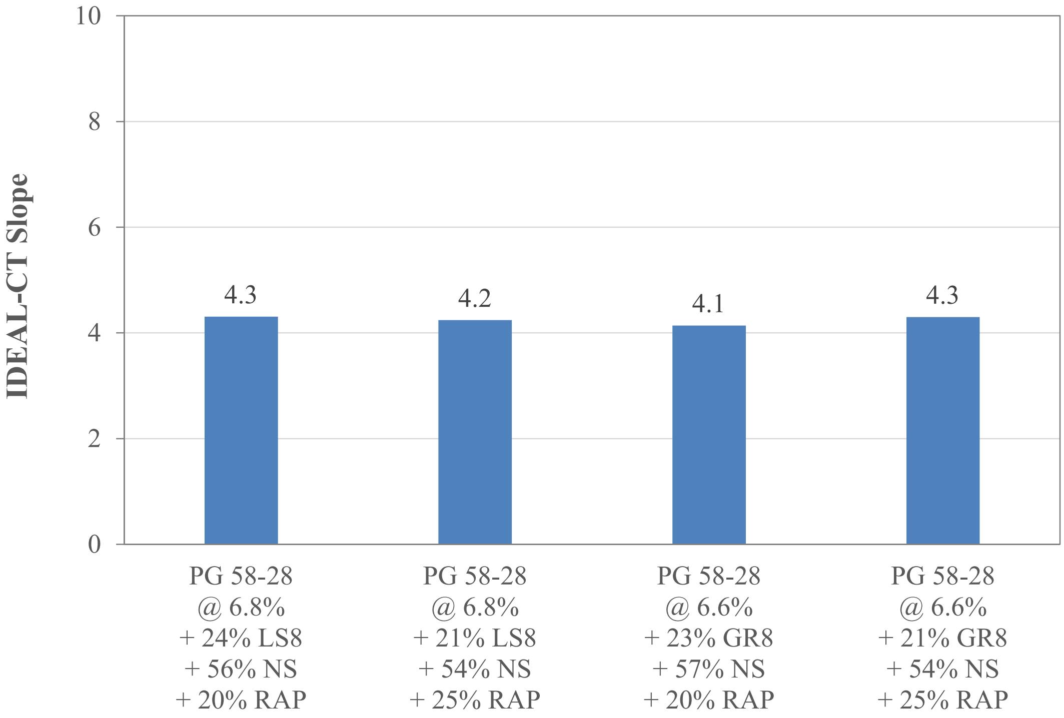

Figure D.20. Effect of RAP Content on S for the PG 58-28 Mixes.

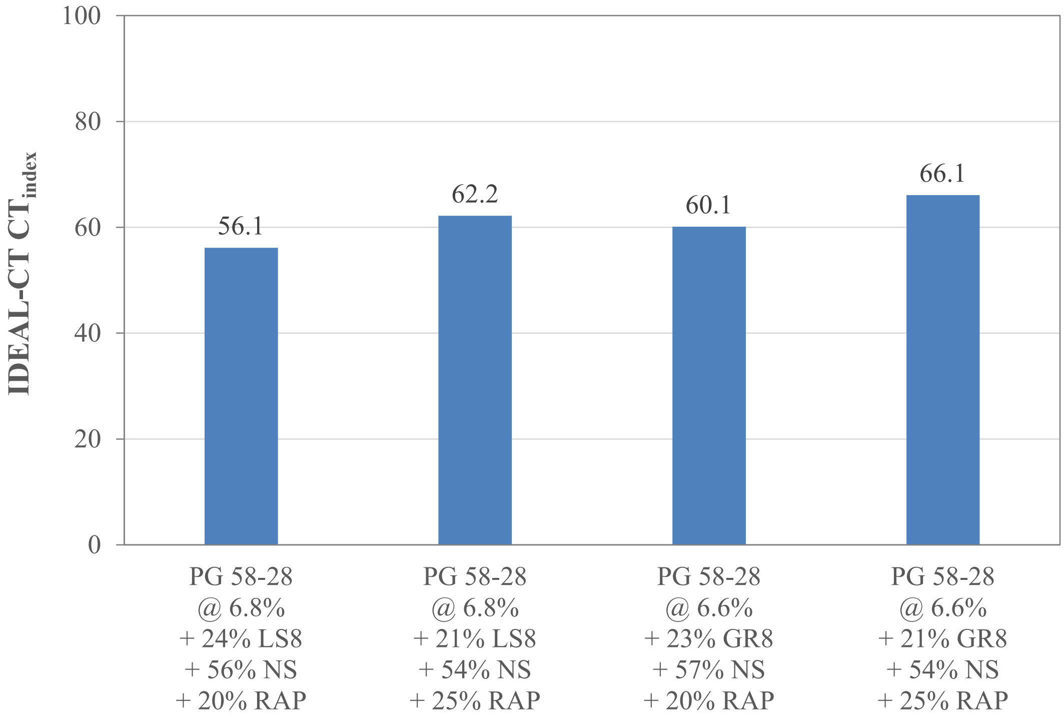

Figure D.21. Effect of RAP Content on CT_{index} for the PG 58-28 Mixes.

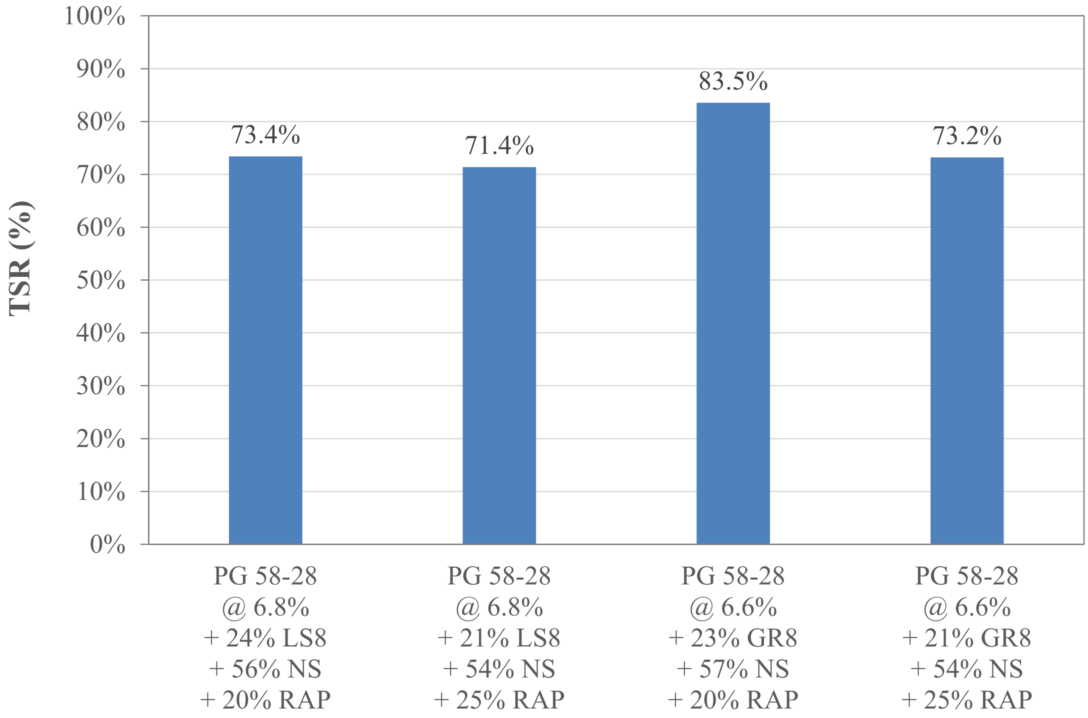

Figure D.22. Effect of RAP Content on TSR for the PG 58-28 Mixes.

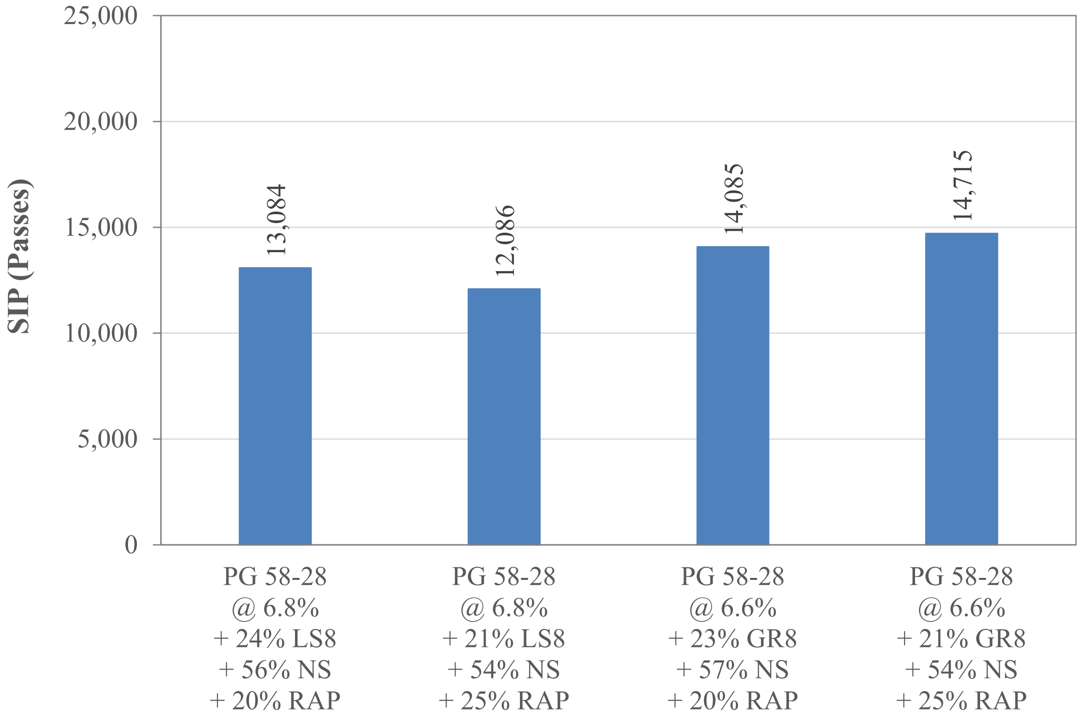

Figure D.23. Effect of RAP Content on SIP for the PG 58-28 Mixes.

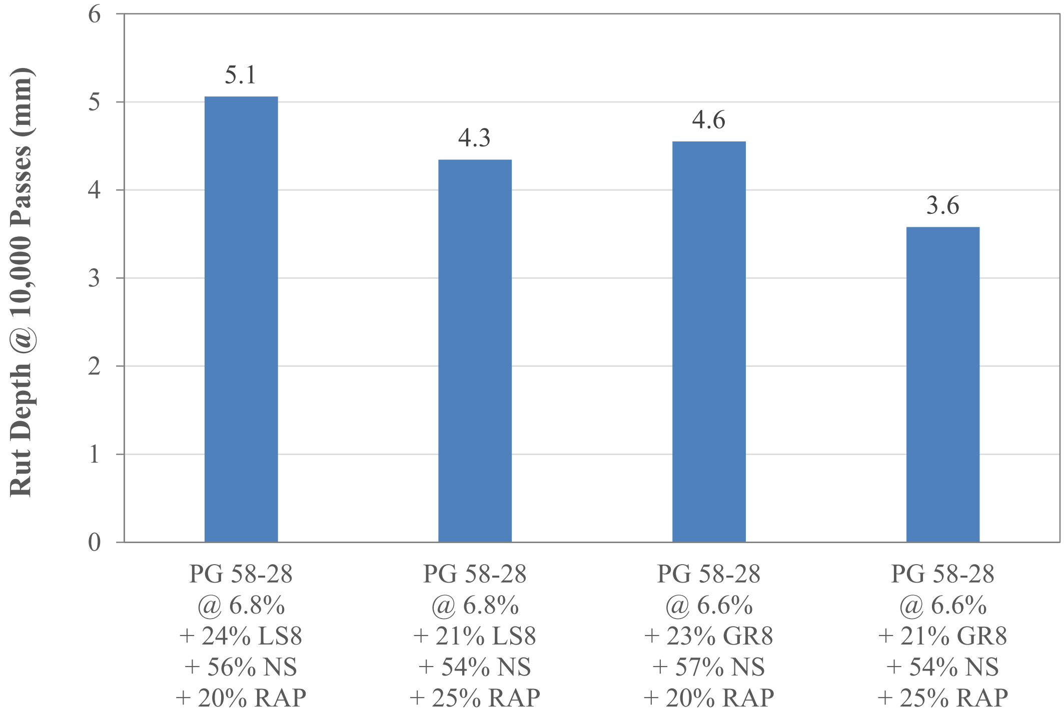

Figure D.24. Effect of RAP Content on Rut Depth after 10,000 Passes for the PG 58-28 Mixes.

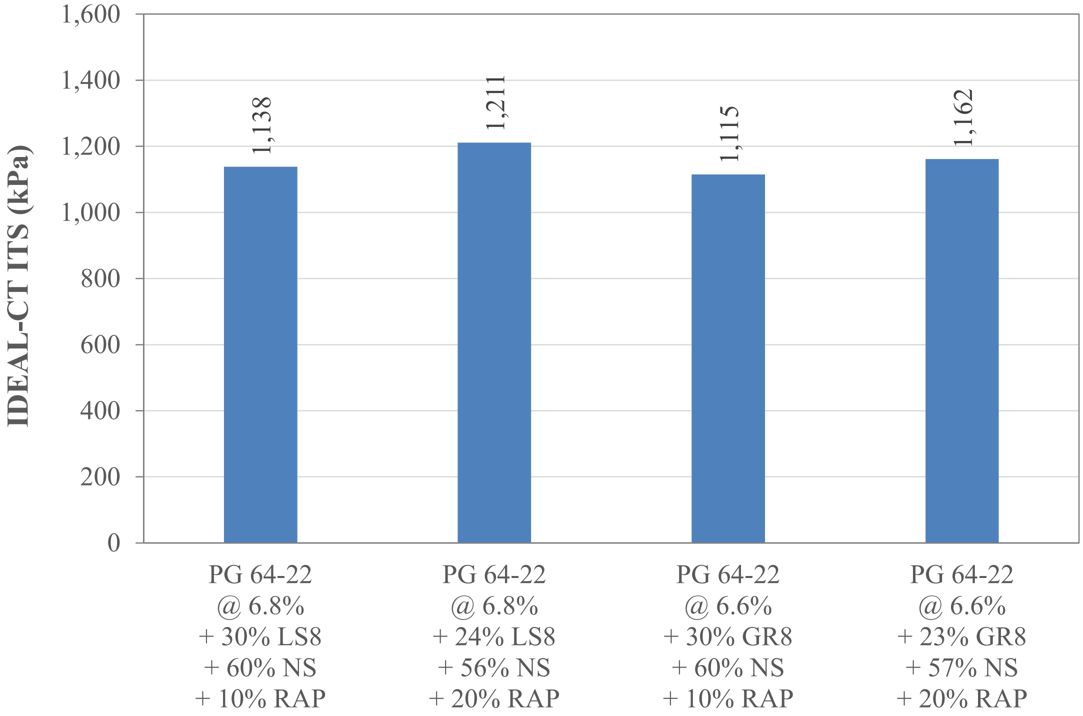

Figure D.25. Effect of RAP Content on ITS for the PG 64-22 Mixes.

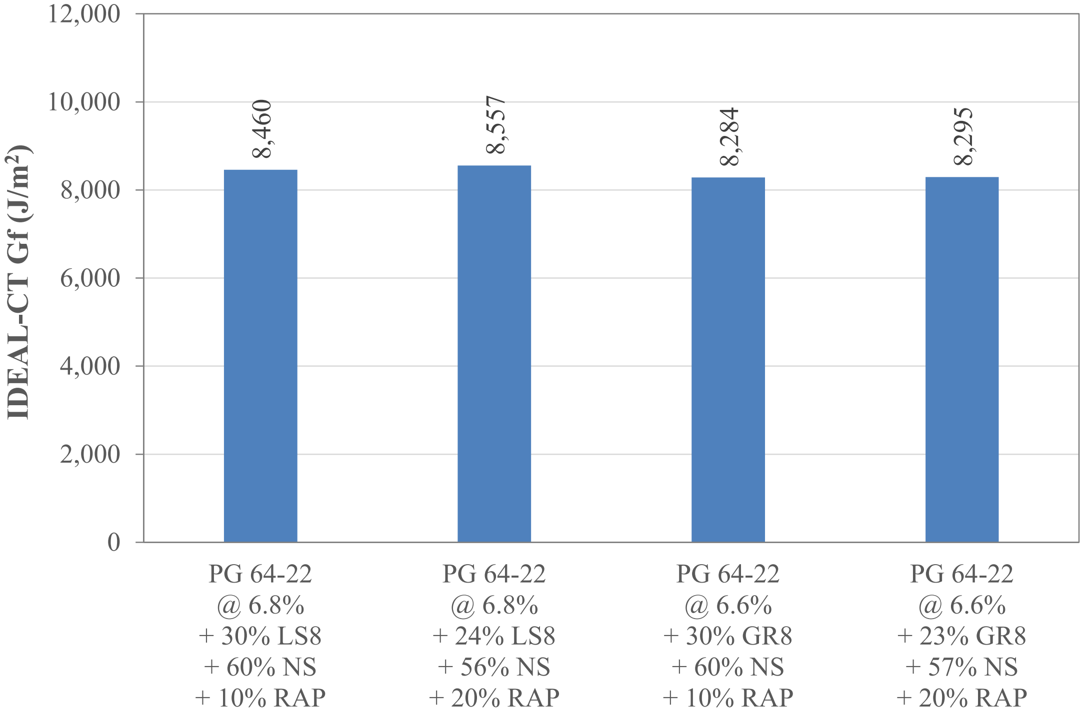

Figure D.26. Effect of RAP Content on G_f for the PG 64-22 Mixes.

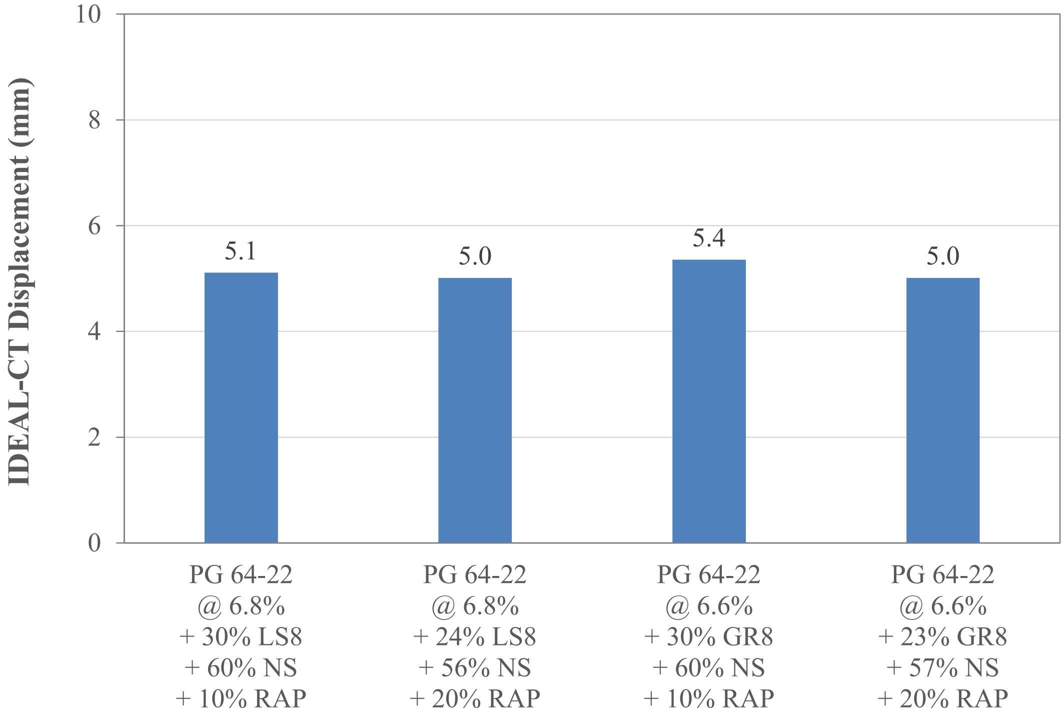

Figure D.27. Effect of RAP Content on L for the PG 64-22 Mixes.

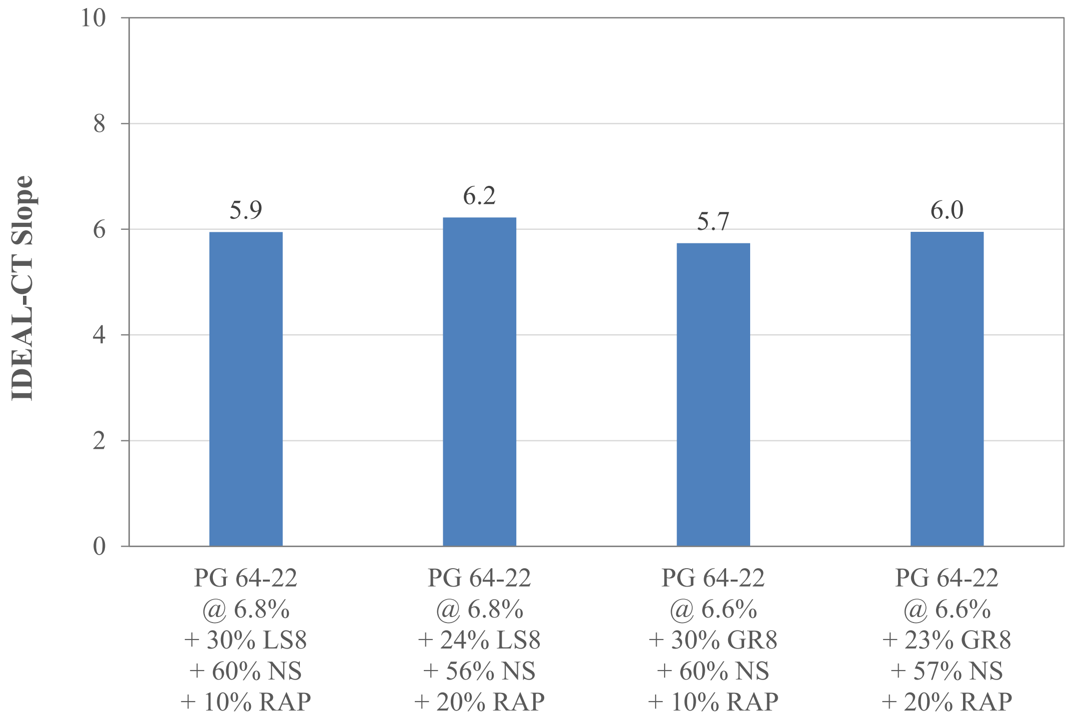

Figure D.28. Effect of RAP Content on S for the PG 64-22 Mixes.

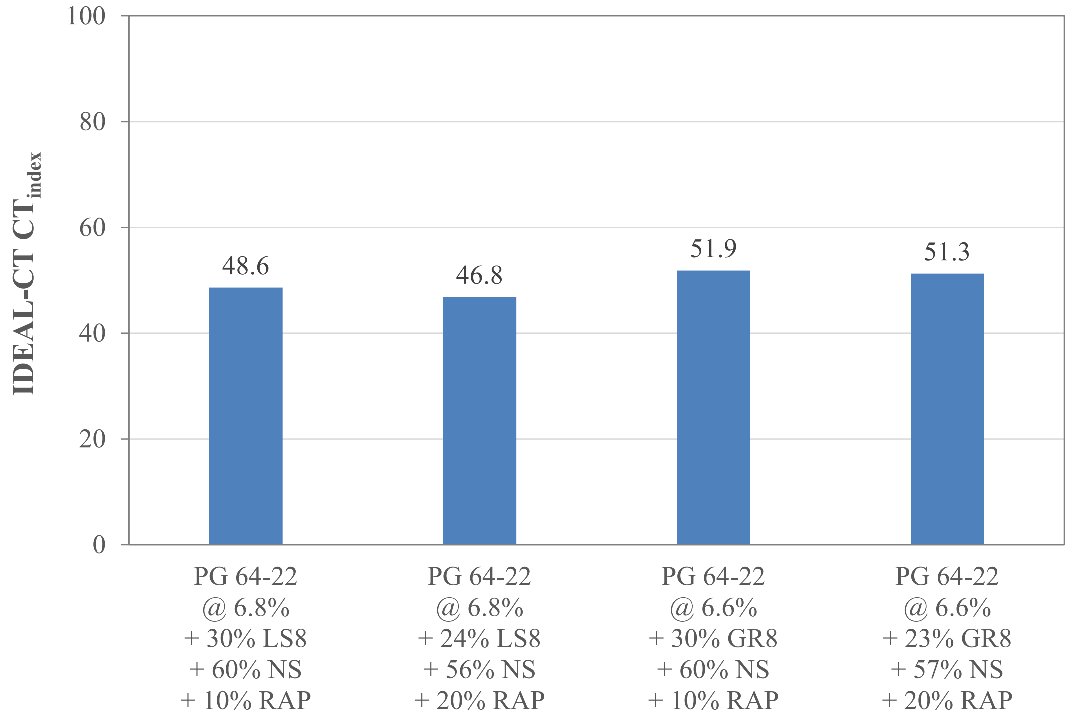

Figure D.29. Effect of RAP Content on CT_{index} for the PG 64-22 Mixes.

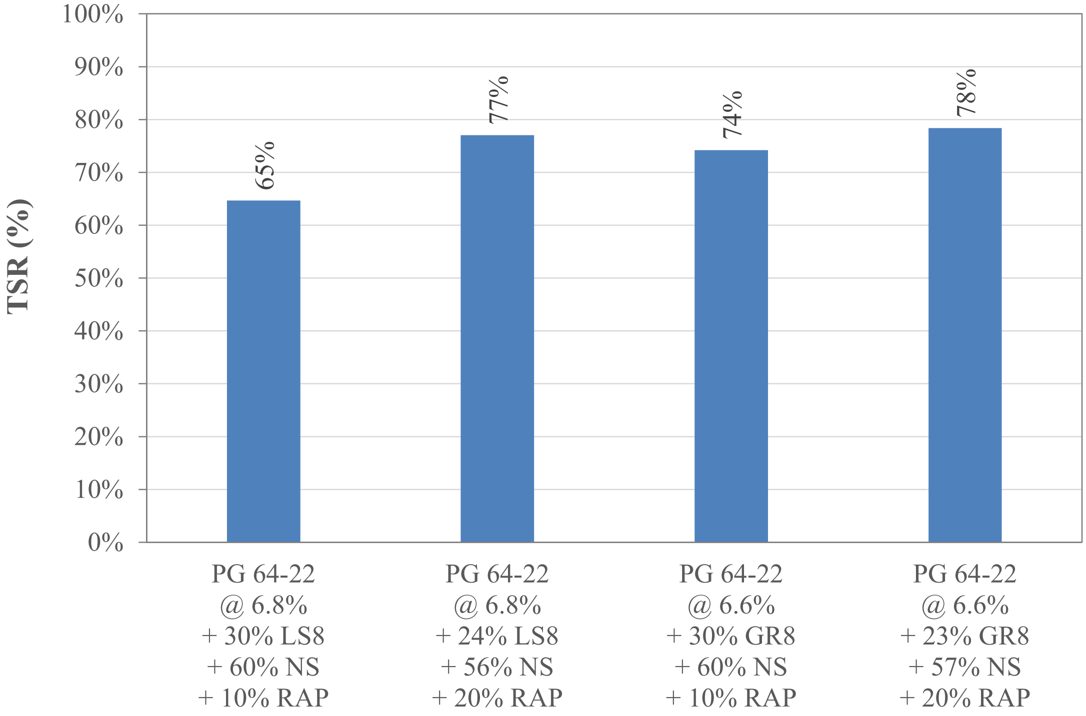

Figure D.30. Effect of RAP Content on TSR for the PG 64-22 Mixes.

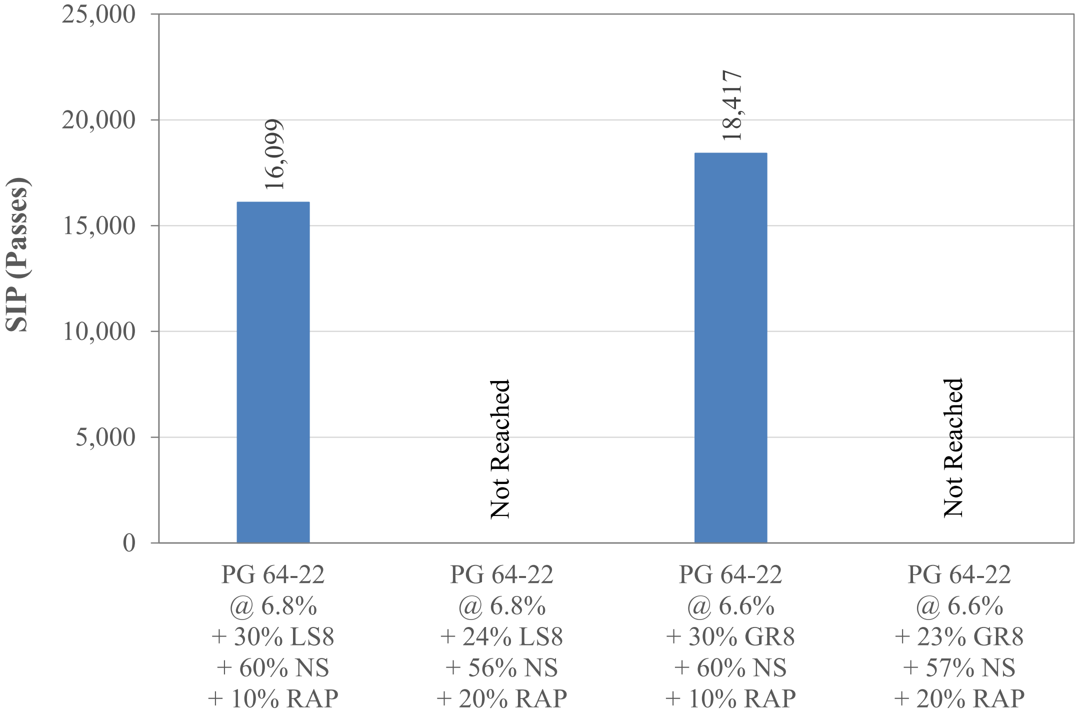

Figure D.31. Effect of RAP Content on SIP for the PG 64-22 Mixes.

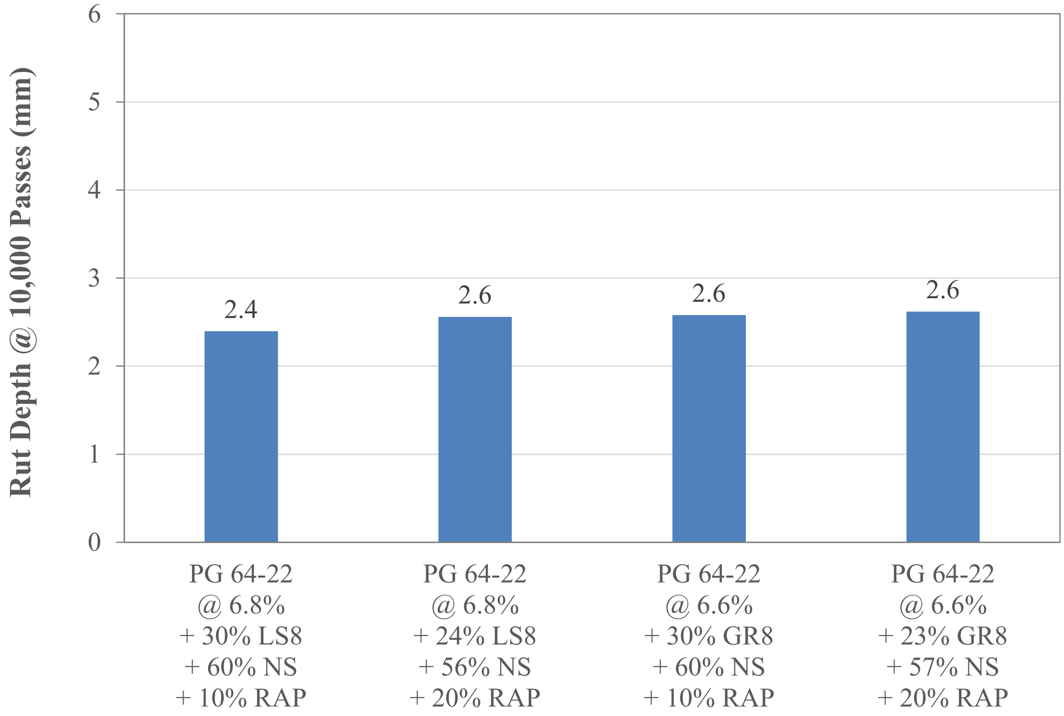

Figure D.32. Effect of RAP Content on Rut Depth after 10,000 Passes for the PG 64-22 Mixes.

D.5 Effect of Coarse Aggregate Type

Three asphalt mixtures were used to evaluate the effect of the coarse aggregate type on the performance of 404LVT mixes:

- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
- 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28
- 12% LS8 + 12% GR8 + 56% NS + 20% RAP @ 6.7% PG 58-28

The first mixture was prepared using limestone as coarse aggregate, the second one was prepared using gravel as coarse aggregate, while the third mixture was prepared using a blend of limestone and gravel as coarse aggregates.-The total binder contents specified in the 2015 404LVT specifications were used for the preparation of the three asphalt mixtures.

The indirect tensile strength (ITS), fracture energy (G_f), displacement corresponding to 75% of the peak load in the post-peak portion of the load versus displacement curve (L), post-peak slope (S), and CT_{index} obtained using the IDEAL-CT test for the three asphalt mixtures are presented in Figures D.33 to D.37, respectively. As can be noticed from these figures, the coarse aggregate type had little effect on the IDEAL-CT test results.

The tensile strength ratio (TSR) values obtained using the modified Lottman (AASHTO T 283) test for the three asphalt mixtures are presented in Figure D.38. It can be noticed from this figure that all mixes met the minimum TSR requirement of 70%, with no clear trend regarding the effect of the coarse aggregate type on the TSR results.

The average number of passes needed to reach the stripping inflection point (SIP) and the average rut depth after 10,000 passes obtained using the HWTD for the three asphalt mixtures are presented in Figures D.39 and D.40, respectively. As can be noticed from these figures, comparable number of passes needed to reach the SIP and comparable rut depths at 10,000 passes were obtained for all mixtures. The number of passes needed to reach the SIP exceeded 10,000 passes for all mixtures and the average rut depths at 10,000 passes were lower than 12.5 mm.

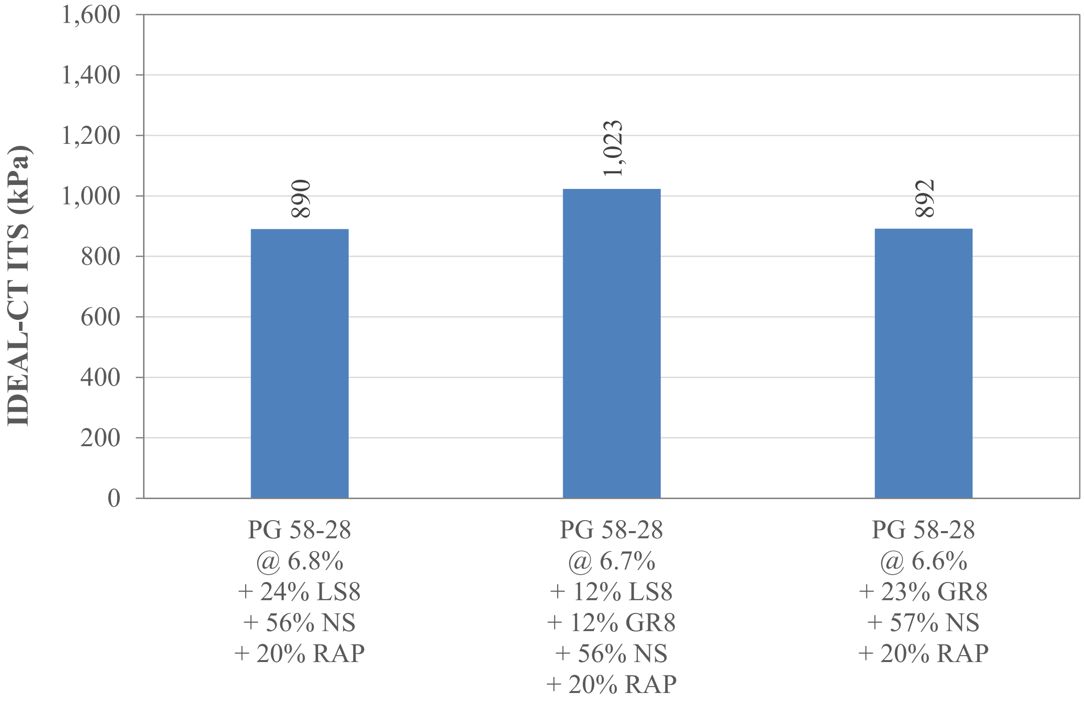

Figure D.33. Effect of Coarse Aggregate Type on ITS.

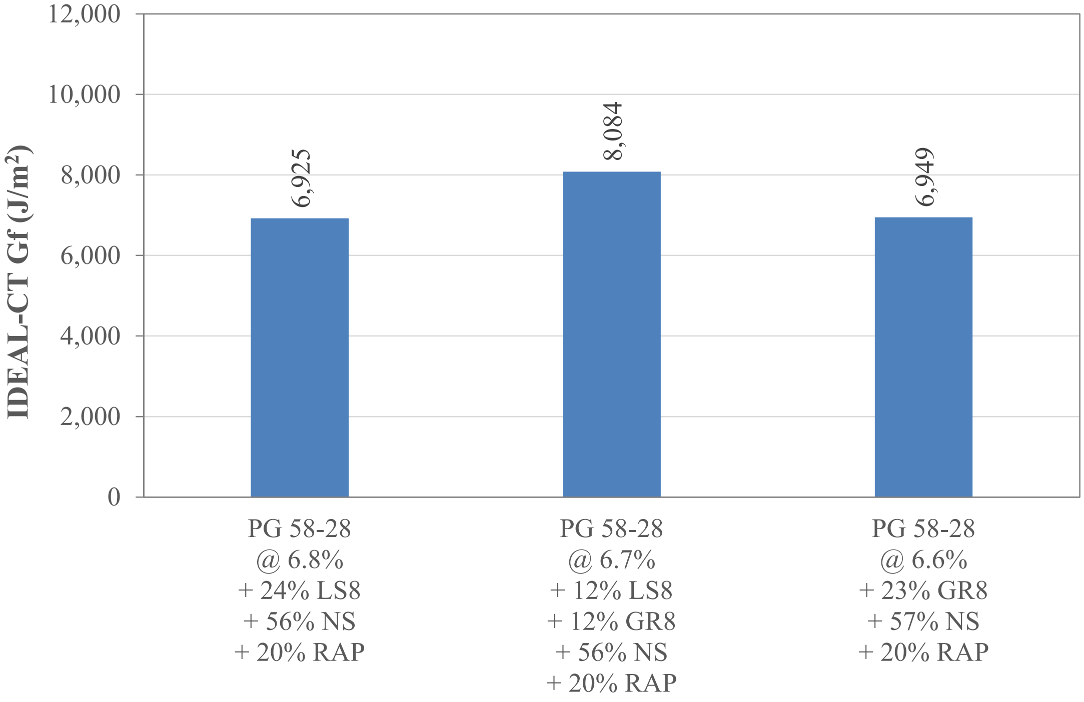

Figure D.34. Effect of Coarse Aggregate Type on G_f.

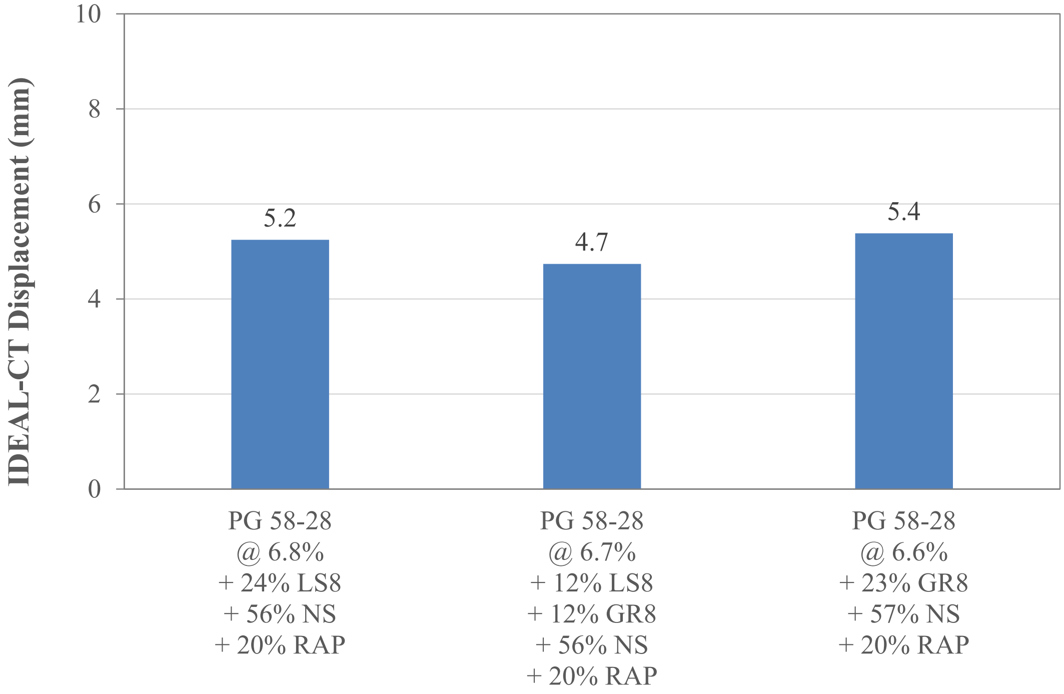

Figure D.35. Effect of Coarse Aggregate Type on L.

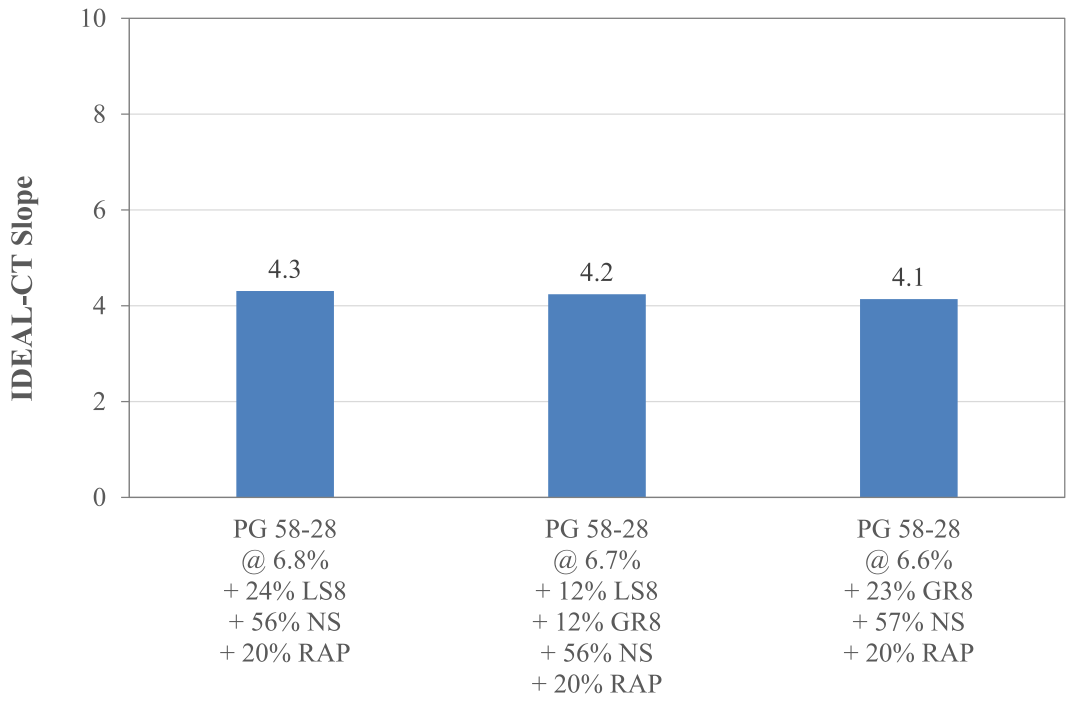

Figure D.36. Effect of Coarse Aggregate Type on S.

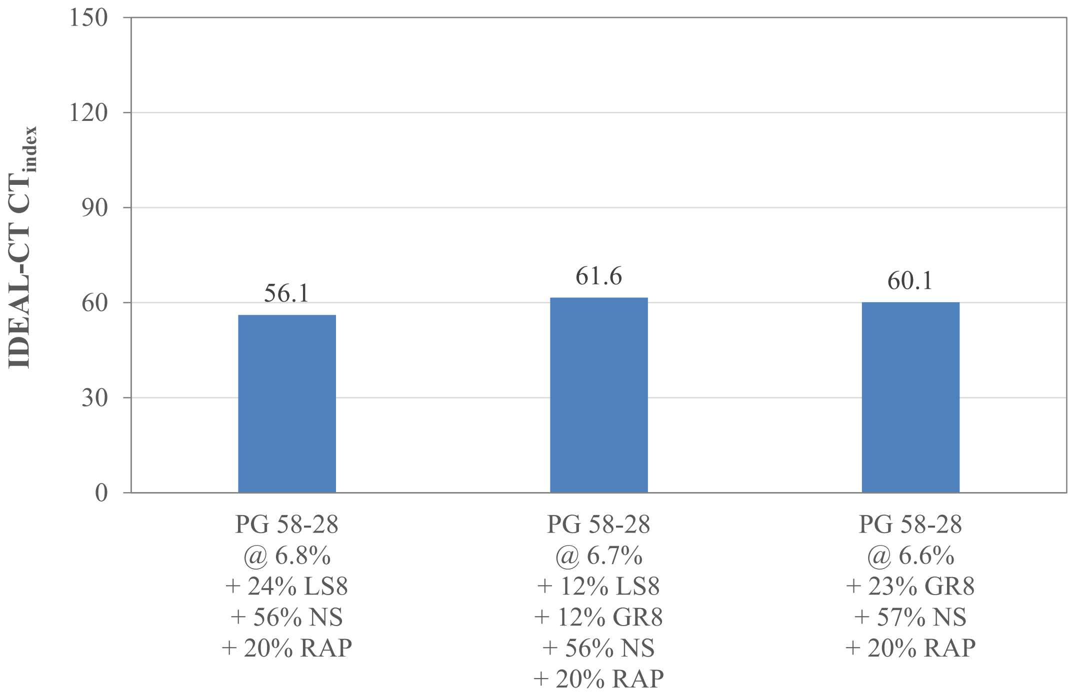

Figure D.37. Effect of Coarse Aggregate Type on CT_{index}.

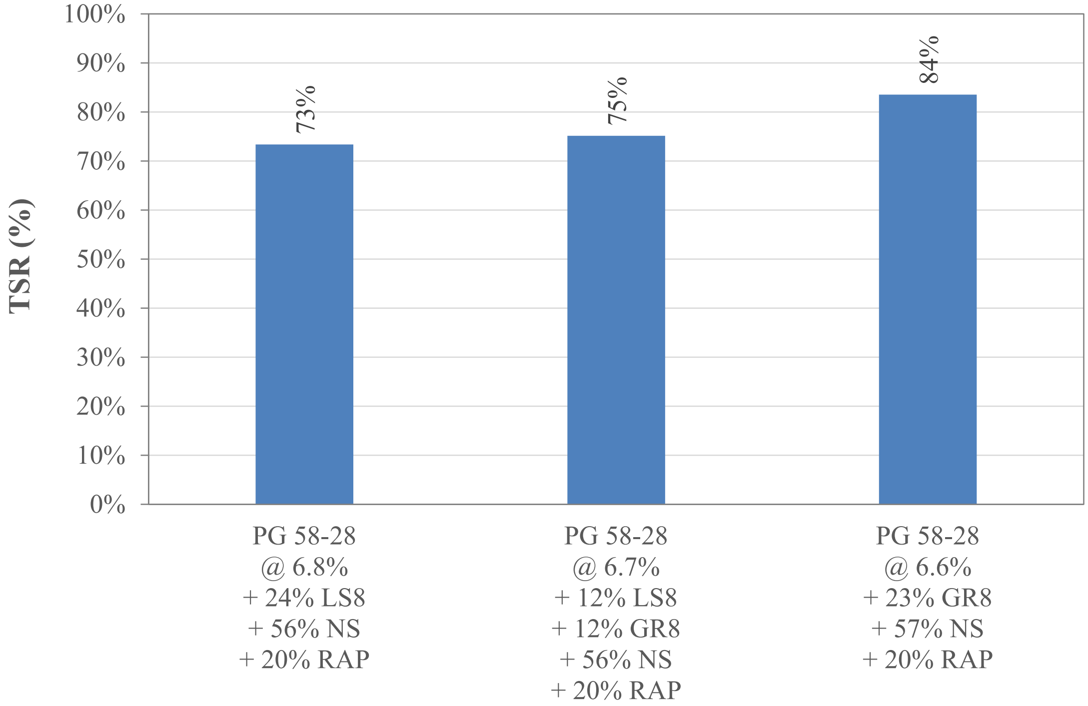

Figure D.38. Effect of Coarse Aggregate Type on TSR.

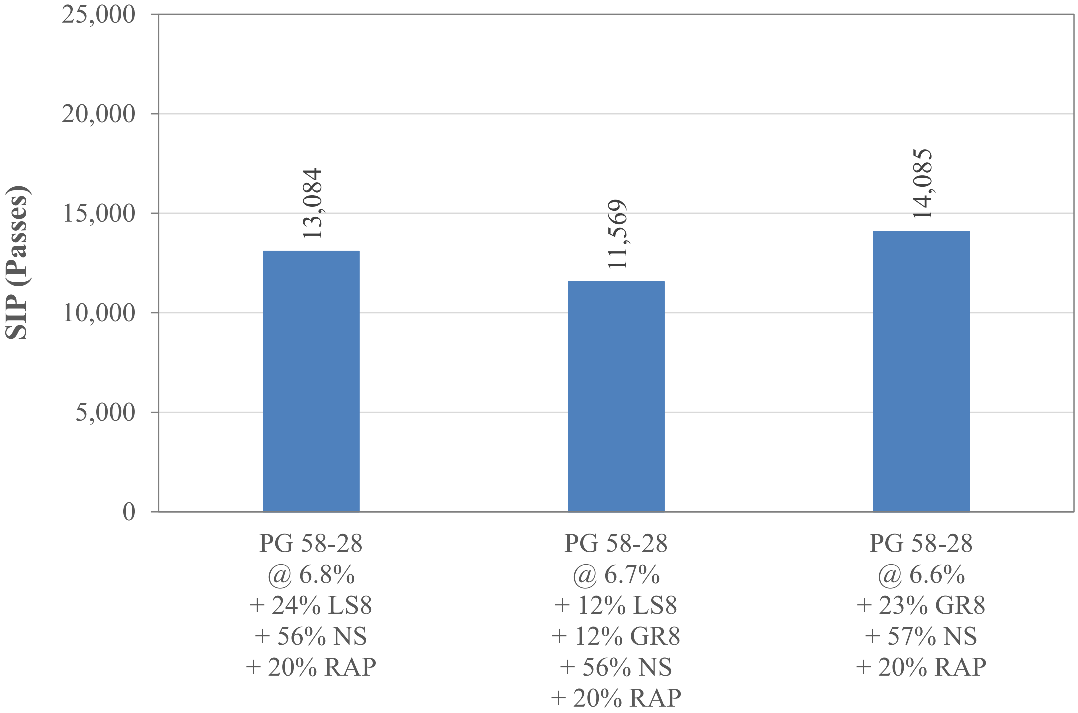

Figure D.39. Effect of Coarse Aggregate Type on SIP.

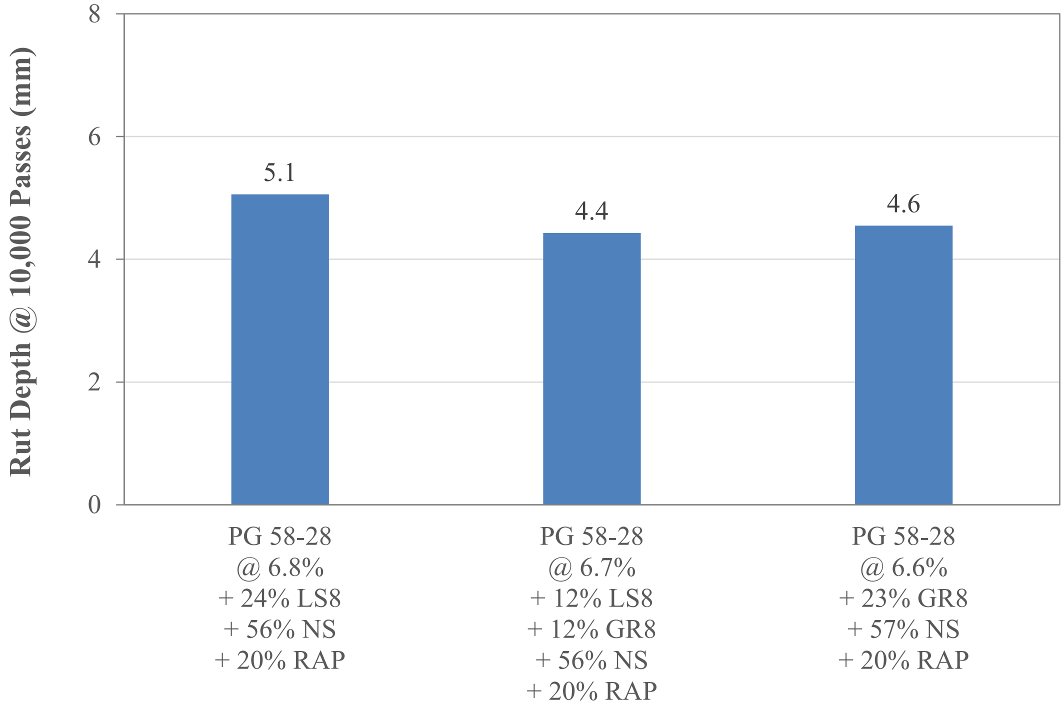

Figure D.40. Effect of Coarse Aggregate Type on Rut Depth after 10,000 Passes.

D.6 Effect of Fine Aggregate Type

Four asphalt mixtures were used to evaluate the effect of the fine aggregate type on the performance of 404LVT mixes:

- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28
- 24% LS8 + 28% NS + 28% LSS + 20% RAP @ 6.8% PG 58-28
- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 64-22
- 24% LS8 + 28% NS + 28% LSS + 20% RAP @ 6.8% PG 64-22

Two of the four mixtures were prepared using only natural sand as the fine aggregates, while the remaining two mixtures were prepared using limestone sand in addition to natural sand as the fine aggregates.

The indirect tensile strength (ITS), fracture energy (G_f), displacement corresponding to 75% of the peak load in the post-peak portion of the load versus displacement curve (L), post-peak slope (S), and CT_{index} obtained using the IDEAL-CT test for the four asphalt mixtures are presented in Figures D.41 to D.45, respectively. It can be noticed from these figures that asphalt mixtures containing limestone sand exhibited higher ITS and G_f values and slightly lower L values for both PG 58-28 and PG 64-22. As for S and CT_{index}, incorporating limestone sand into the asphalt mixture resulted in comparable S values and higher C_{Tindex} values for mixtures prepared using PG 58-28 and higher S values and lower higher C_{Tindex} values for mixtures prepared using PG 64-22. This suggests that the effect of the fine aggregate type is also dependent on the binder type used in the mixture.

The tensile strength ratio (TSR) values obtained using the modified Lottman (AASHTO T 283) test for the four asphalt mixtures are presented in Figure D.46. As shown in this figure, all mixes met the minimum TSR requirement of 70%, with no clear trend regarding the effect of the fine aggregate type on the TSR results.

The average number of passes needed to reach the stripping inflection point (SIP) and the average rut depth after 10,000 passes obtained using the HWTD for the four asphalt mixtures are presented in Figures D.47 and D.48, respectively. As can be noticed from these figures, the average number of passes needed to reach the SIP for asphalt mixtures containing limestone sand was comparable to those prepared using only natural sand as fine aggregates. However, lower rut depths at 10,000 passes were obtained for mixtures containing limestone sand, which suggests that incorporating limestone sand into the asphalt mixture is expected to improve its resistance to permanent deformation (or rutting).

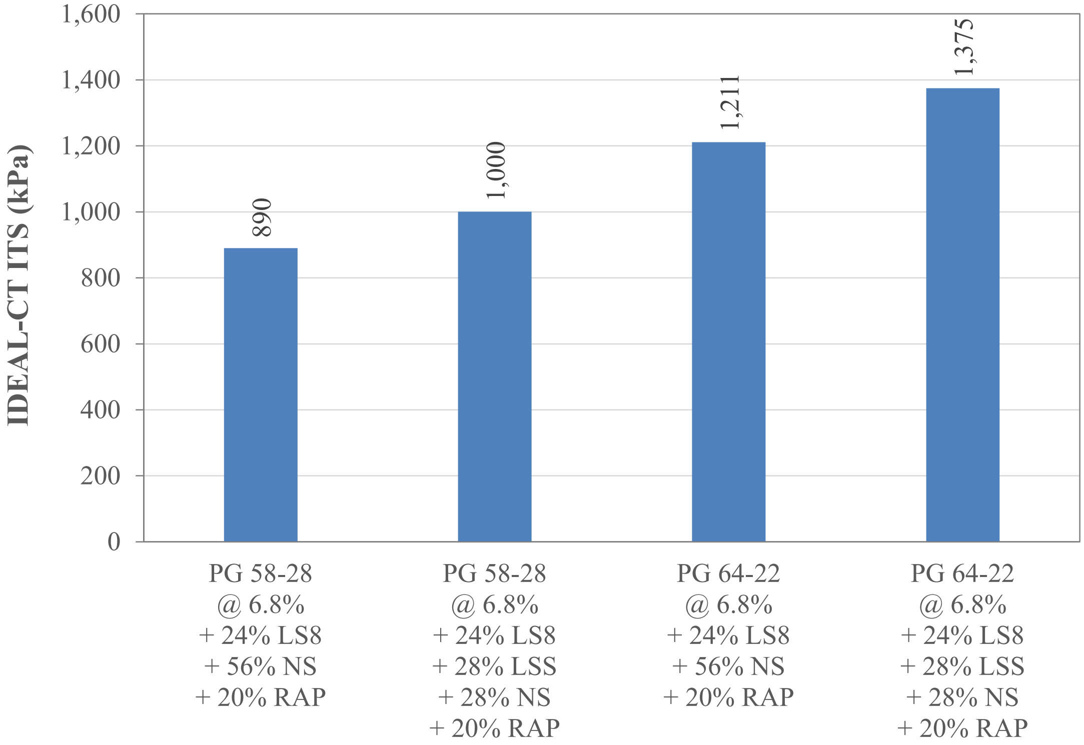

Figure D.41. Effect of Fine Aggregate Type on ITS.

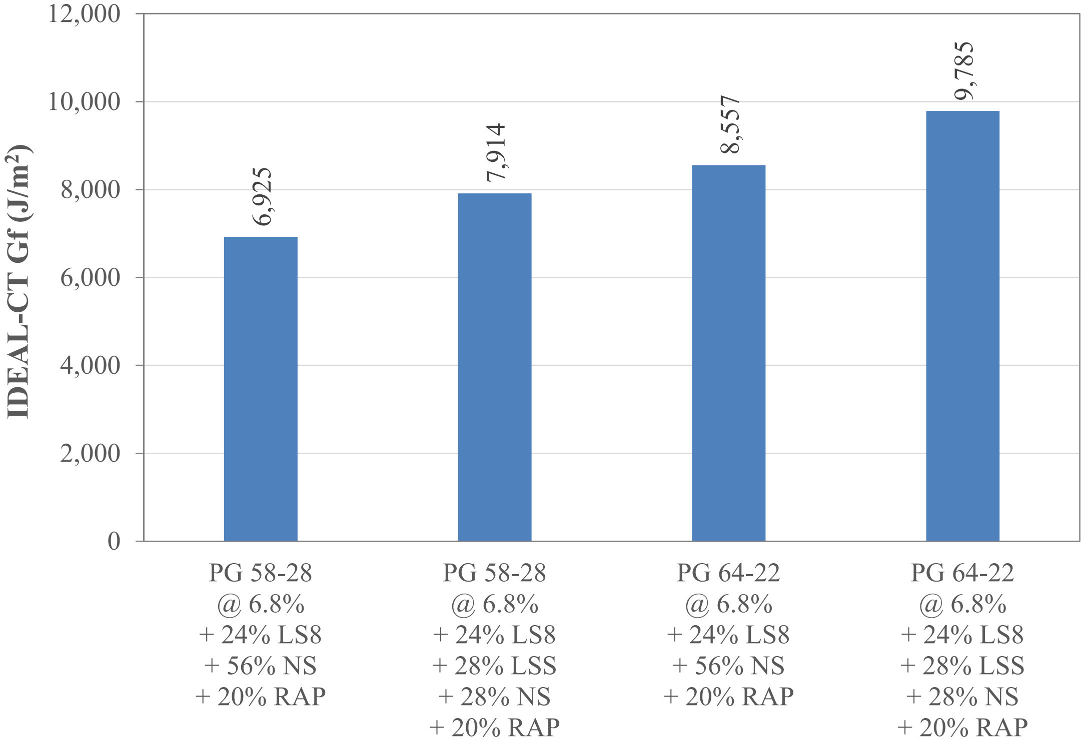

Figure D.42. Effect of Fine Aggregate Type on G_f.

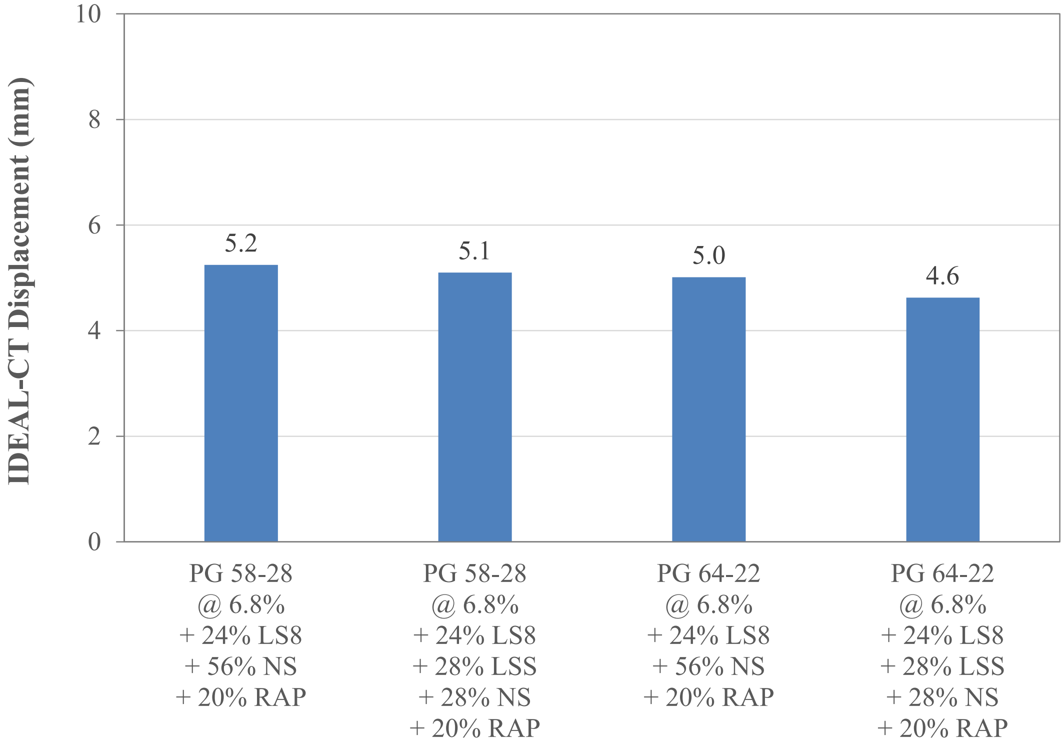

Figure D.43. Effect of Fine Aggregate Type on L.

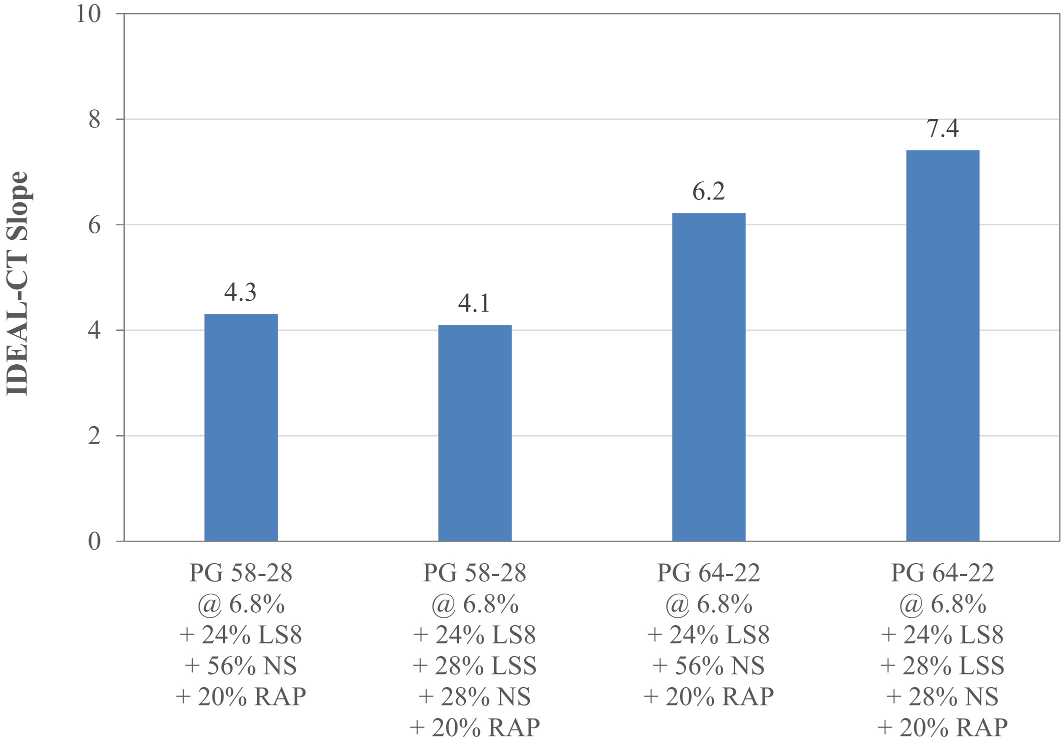

Figure D.44. Effect of Fine Aggregate Type on S.

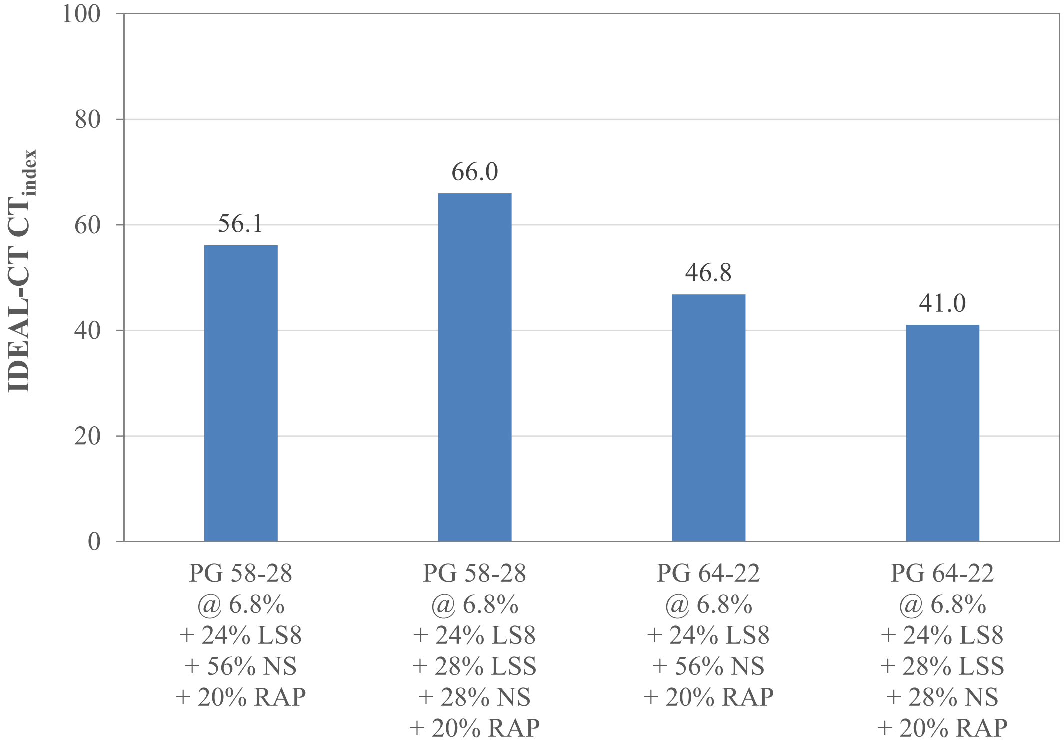

Figure D.45. Effect of Fine Aggregate Type on CT$_{index}$.

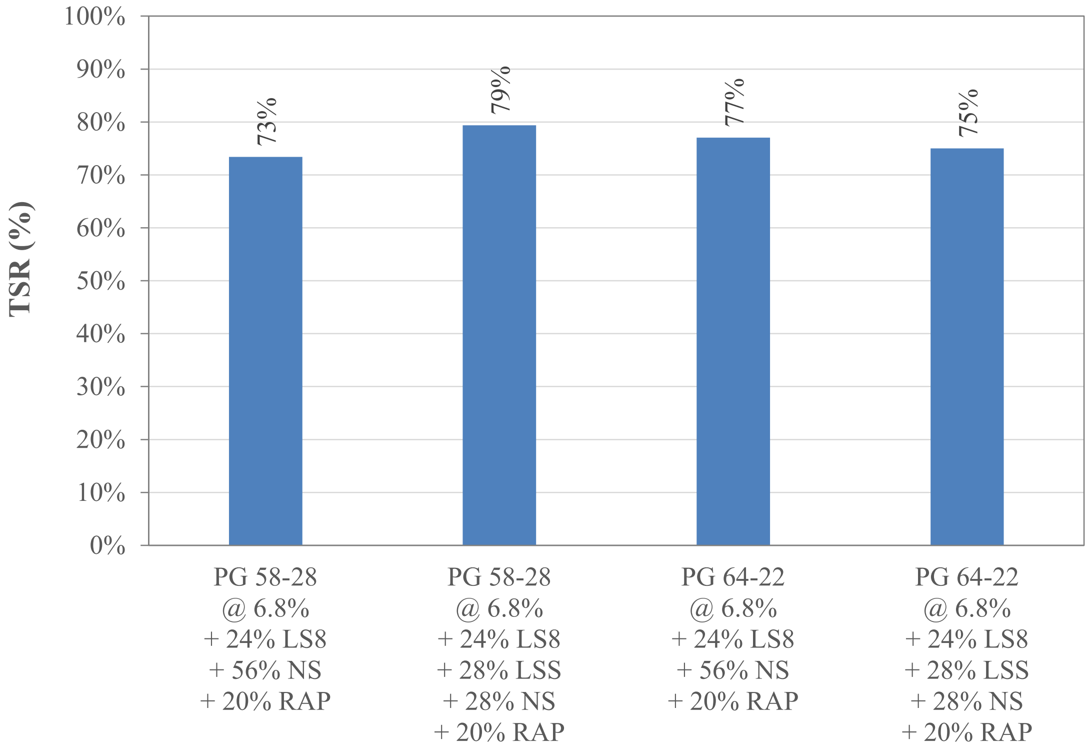

Figure D.46. Effect of Fine Aggregate Type on TSR.

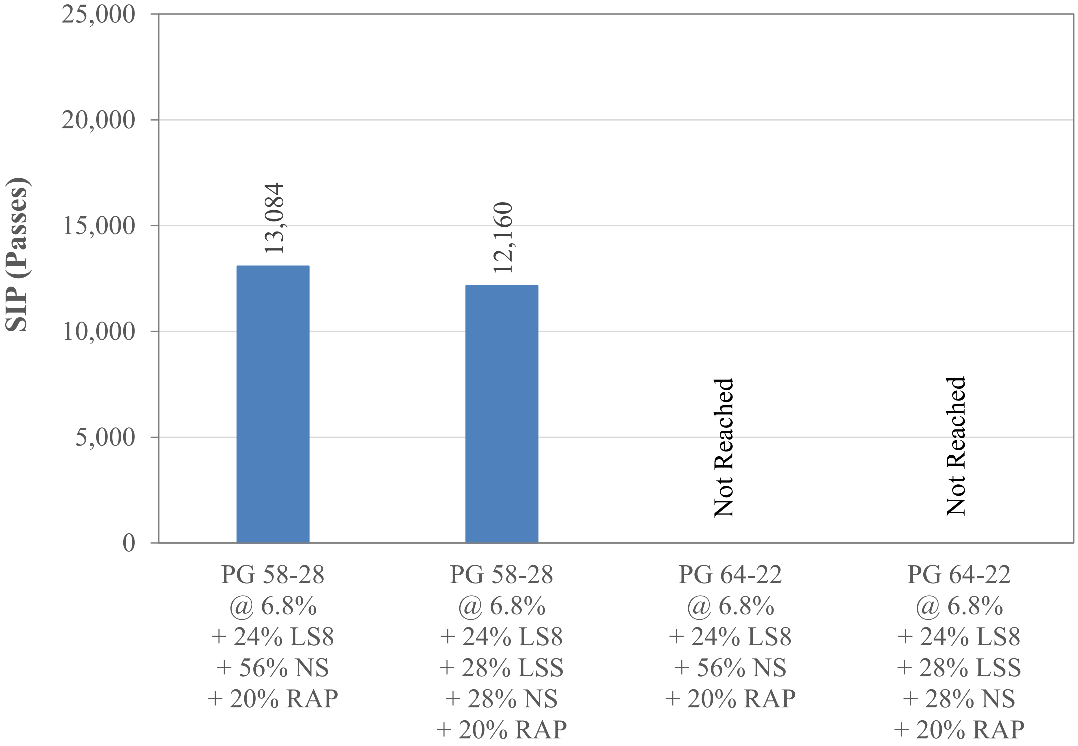

Figure D.47. Effect of Fine Aggregate Type on SIP.

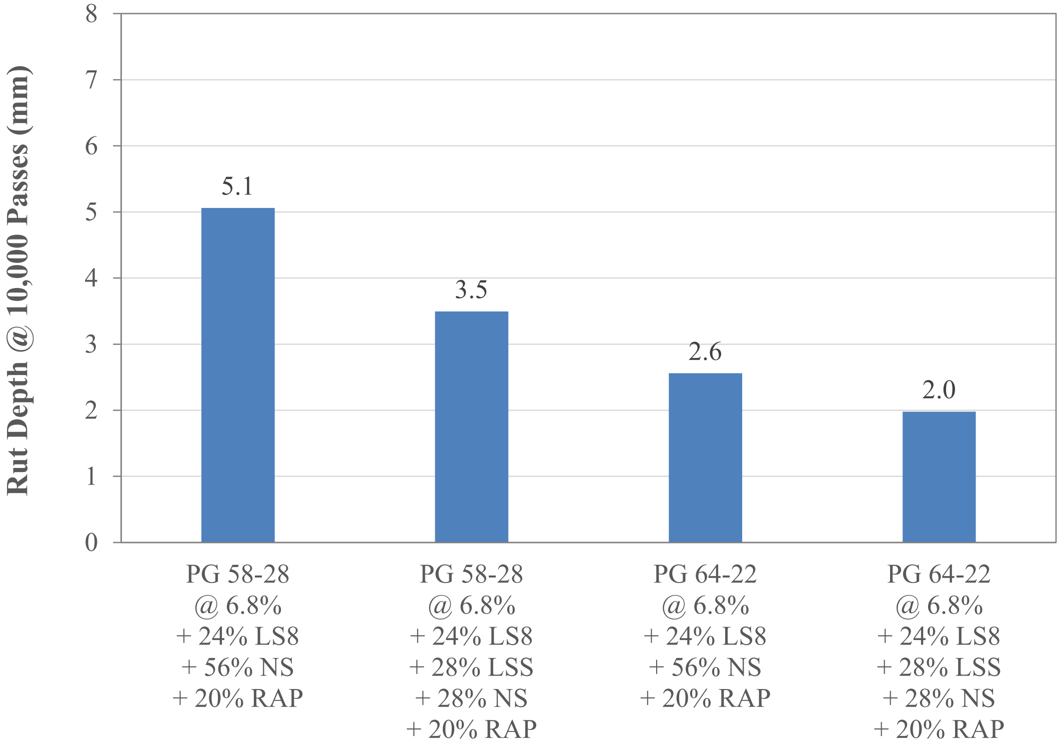

Figure D.48. Effect of Fine Aggregate Type on Rut Depth after 10,000 Passes.

D.7 Effect of Aggregate Source

Nine asphalt mixtures were used to evaluate the effect of the aggregate source on the performance of 404LVT mixes:

- 24% LS8 + 56% NS + 20% RAP @ 6.8% PG 58-28 (Fayette County)
- 23% GR8 + 57% NS + 20% RAP @ 6.6% PG 58-28 (Fayette County)
- 24% LS8 + 26% LSS + 30% NS + 20% RAP @ 6.8% PG 58-28 (Darke County)
- 28% GR8 + 20% LSS + 32% NS + 20% RAP @ 6.6% PG 58-28 (Miami County)
- 25% LS8 + 27% LSS + 28% NS + 20% RAP @ 6.8% PG 58-28 (Madison County)
- 22% GR8 + 29% LSS + 29% NS + 20% RAP @ 6.6% PG 58-28 (Athens County)
- 27% SLAG8 + 20% SLAGS + 33% NS + 20% RAP @ 6.8% PG 58-28 (Cuyahoga County)
- 26% LS8 + 20% LSS + 34% NS + 20% RAP @ 6.8% PG 58-28 (Richland County)
- 25% GR8 + 20% LSS + 35% NS + 20% RAP @ 6.6% PG 58-28 (Richland County)

The indirect tensile strength (ITS), fracture energy (G_f), displacement corresponding to 75% of the peak load in the post-peak portion of the load versus displacement curve (L), post-peak slope (S), and CT_{index} obtained using the IDEAL-CT test for the different asphalt mixtures are presented in Figures D.49 to D.53, respectively. As can be noticed from Figure D.53, the majority of the asphalt mixtures had a CT_{index} value greater than 60, with several mixtures exceeding a value of 90. This suggests that the asphalt binder contents specified in the 2015 404LVT specifications are relatively close to the optimum for fatigue cracking. A relatively low CT_{index} value of 52 was obtained for an asphalt mixture prepared using slag coarse aggregates. Therefore, a slightly higher asphalt binder content might be needed for such mixtures.

The tensile strength ratio (TSR) values obtained using the modified Lottman (AASHTO T 283) test for the different asphalt mixtures are presented in Figure D.54. As can be seen in this figure, all mixtures met the minimum TSR requirement of 70%. This suggests that moisture-induced damage is not a major concern for 404LVT mixes.

The average number of passes needed to reach the stripping inflection point (SIP) and the average rut depth after 10,000 passes obtained using the HWTD for the different asphalt mixtures are presented in Figures D.55 and D.56, respectively. As can be noticed from these figures, the average number of passes needed to reach the SIP was less than 10,000 passes and the average rut depth at 10,000 passes was higher than 12.5 mm or the test ended prior to 10,000 passes for approximately half of the mixes. This suggests that rutting is a concern for 404LVT mixes. Hence, to ensure that permanent deformation (or rutting) will not be an issue for roads where this mix is placed, it is recommended to include a maximum truck traffic requirement in the 404LVT specifications.

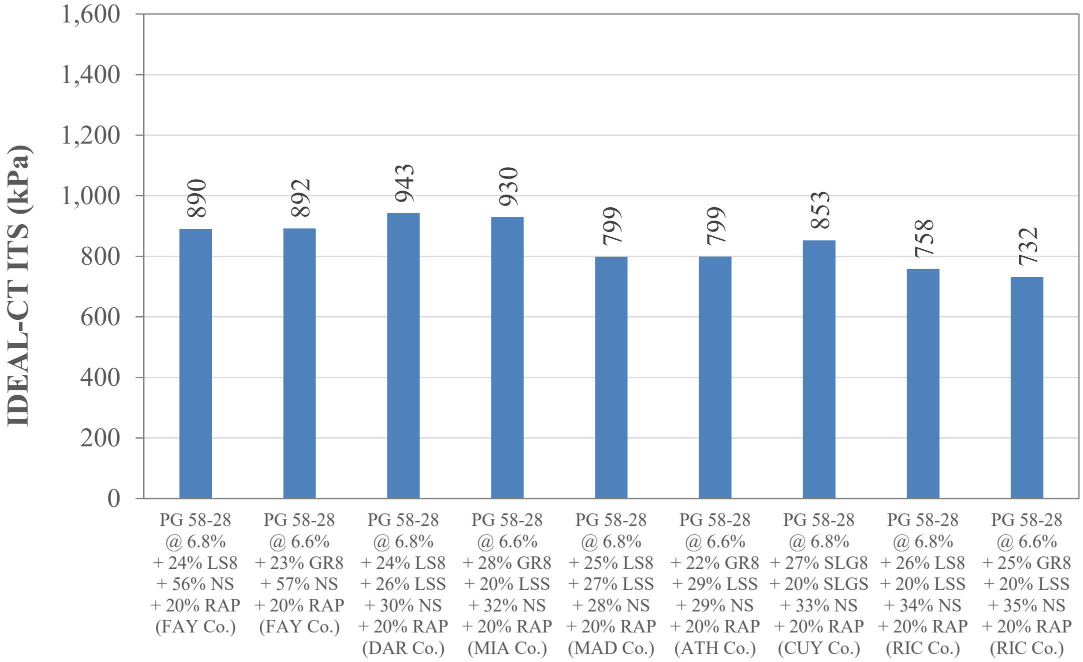

Figure D.49. Effect of Aggregate Source on ITS.

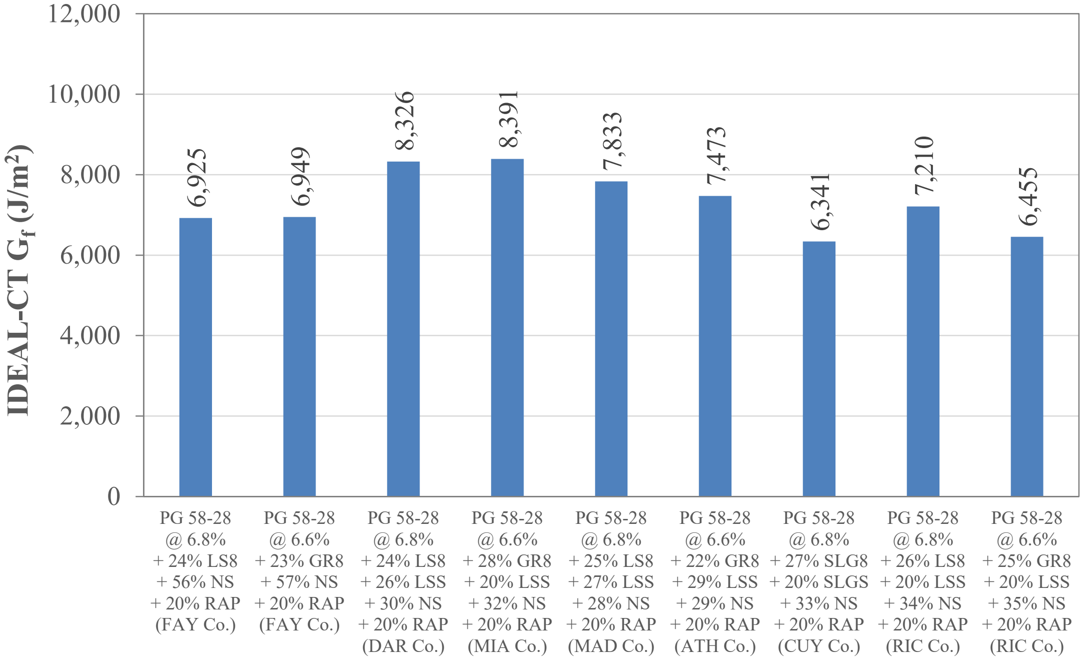

Figure D.50. Effect of Aggregate Source on G_f.

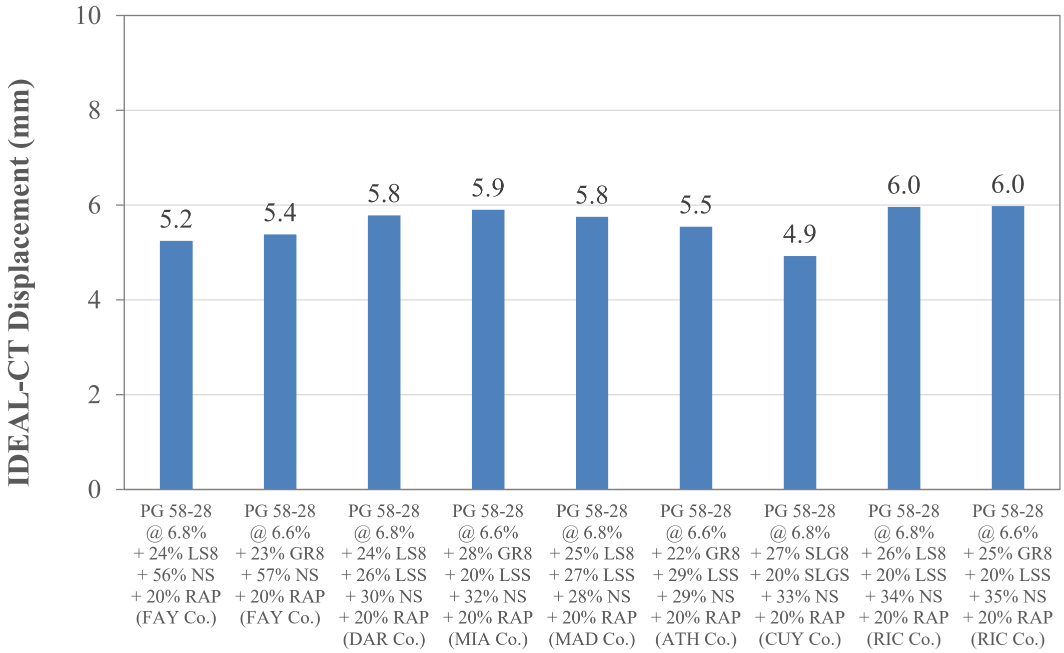

Figure D.51. Effect of Aggregate Source on L.

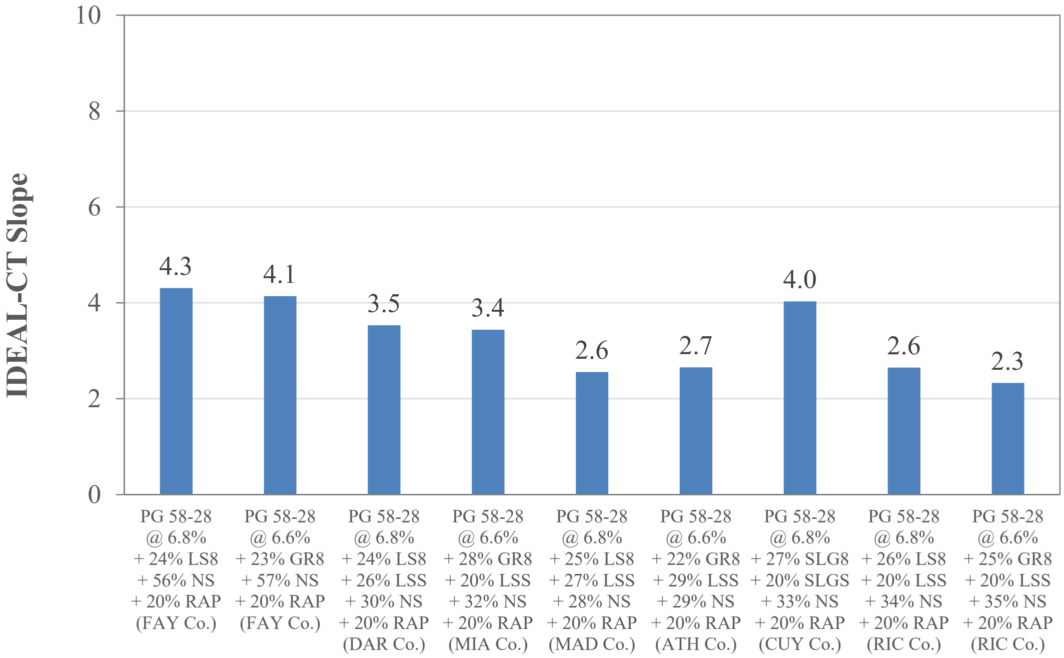

Figure D.52. Effect of Aggregate Source on S.

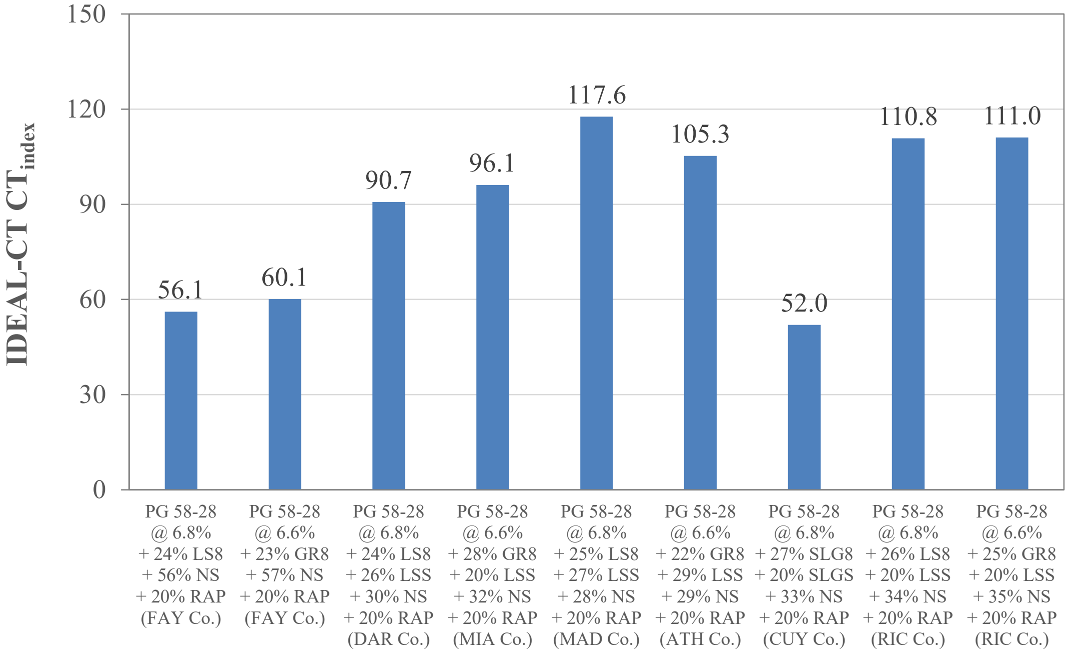

Figure D.53. Effect of Aggregate Source on CT$_{index}$.

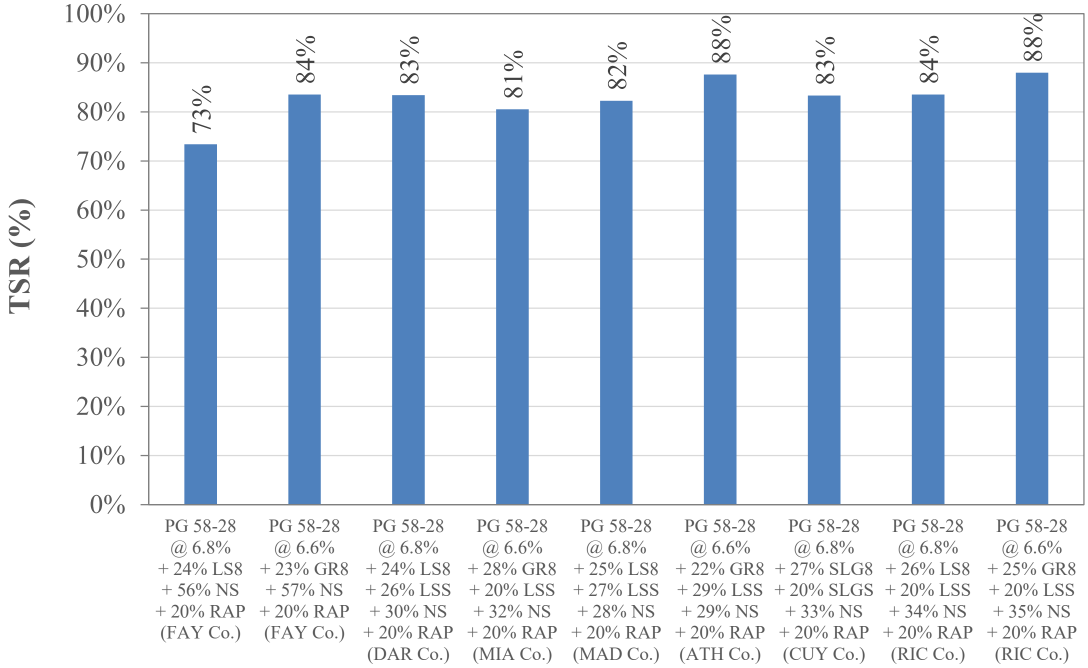

Figure D.54. Effect of Aggregate Source on TSR.

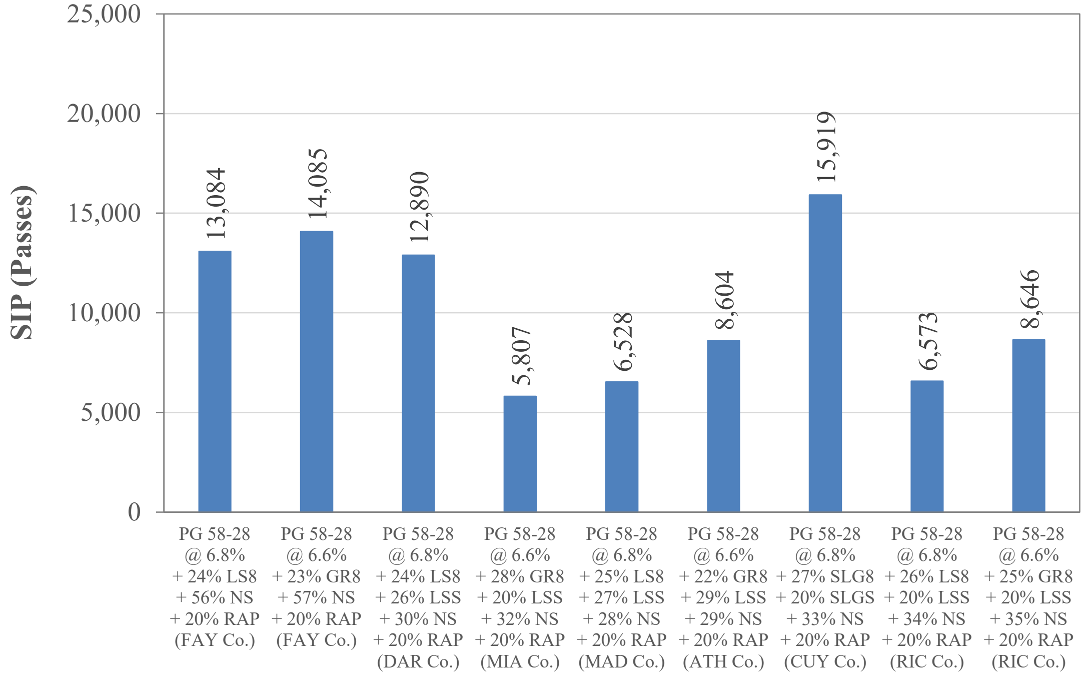

Figure D.55. Effect of Aggregate Source on SIP.

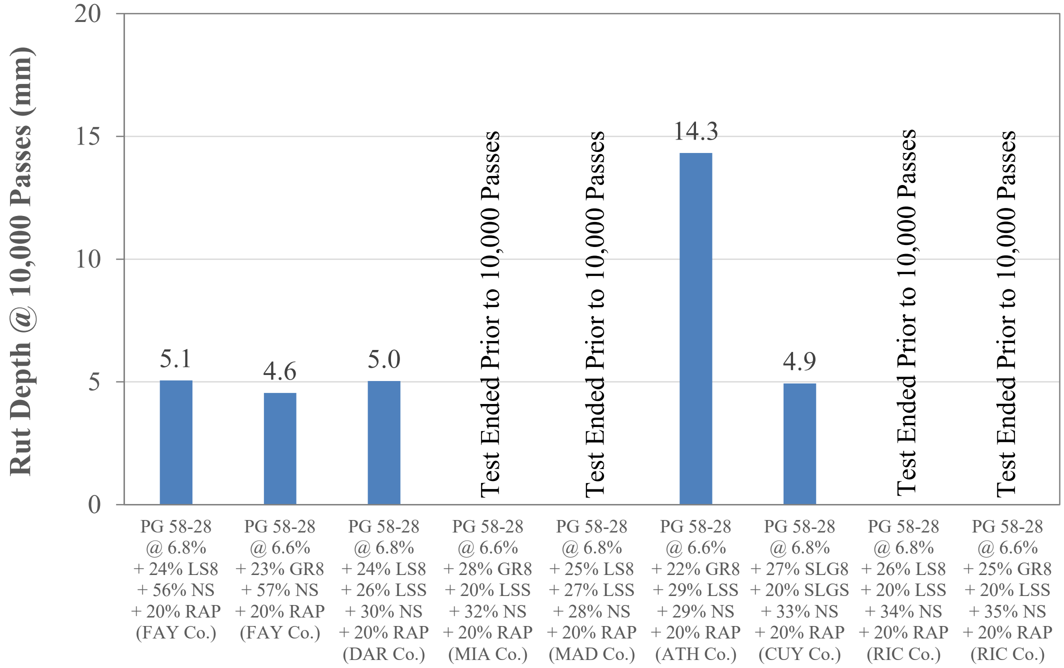

Figure D.56. Effect of Aggregate Source on Rut Depth after 10,000 Passes.

D.8 ACCD Test Results

The ACCD test results obtained for a relatively large number of 404LVT mixes are presented in Figure D.57. Asphalt mixes prepared using PG 58-28 are shown in blue, while mixes prepared using PG 64-22 are shown in red. This figure shows that the most significant factor affecting ACCD cracking temperature is the asphalt binder type. Mixes prepared using PG 58-28 show significantly lower ACCD cracking temperatures than those prepared using PG 64-22. The other factors seem to have little influence on the ACCD cracking temperature.

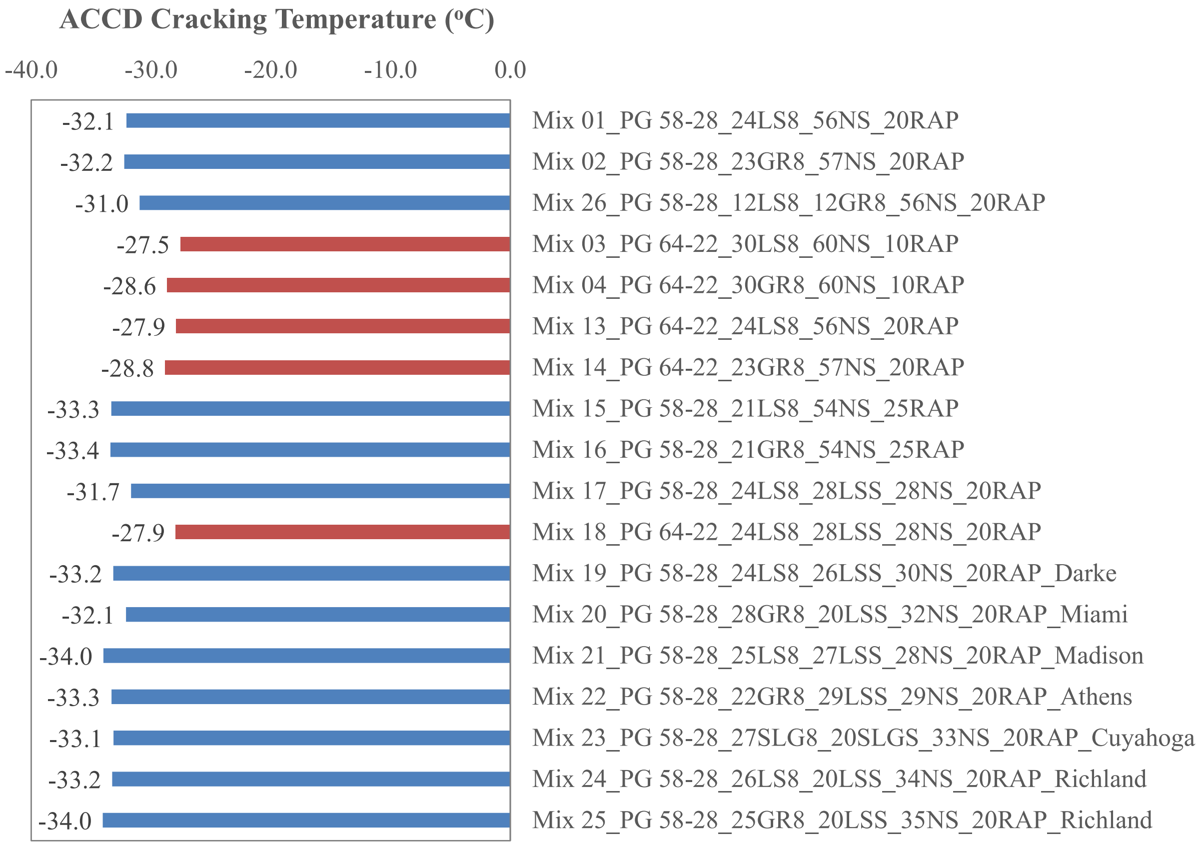

Figure D.57. ACCD Cracking Temperatures for Different 404LVT Mixes.

Appendix E
Field Evaluation of Pavements Constructed using 404LVT Mixes

E.1 Introduction

As discussed in the main report in Section 3, the research team evaluated the condition of different pavement sections constructed using 404LVT mixes in Fayette County, Darke County, and Miami County, where this type of mixture is widely used. Pavement sections constructed from 2015 to 2017 were primarily targeted by the research team. However, Darke County did not start using 404LVT mixes on a wide scale until 2017; therefore, sections constructed from 2017 to 2018 were included in the pavement condition evaluation for Darke County. Information about the mix designs of the 404LVT mixes used in the construction of the different pavement sections was collected from the three counties as part of this effort. In addition, traffic information for the different pavement sections was obtained from ODOT Transportation Information Mapping System (TIMS) and supplemented with truck traffic information obtained from the three counties. Photographs and videos for the different pavement sections were collected to document the condition of the pavements in the three counties.

The pavement condition evaluation was conducted according to the ODOT Pavement Condition Rating (PCR) Manual for local roads surfaced with asphalt using the rating form presented in Figure E.1. As can be noticed from this figure, pavement distresses typically encountered on local asphalt roads are rated in terms of severity (Low, Medium, or High) and extent (Occasional, Frequent, or Extensive). It is noted that the primary objective of the pavement condition evaluations conducted in this study was not to obtain a PCR rating for the various pavement sections, but rather to identify the main distresses encountered for 404LVT mixes and the corresponding severity and extent levels four to seven years after construction.

This appendix presents a summary of the field condition evaluations conducted in Fayette County, Darke County, and Miami County for pavement sections constructed using 404LVT mixes. The 404LVT mix designs that were used for the construction of the different pavement sections as well as the prevailing traffic levels are also discussed in this appendix.

Section:__________________

Log Mile: _______ to _______

Sta:____________ to_______

KEY

ASPHALT SURFACE LOCAL

RATING FORM

Date: ________________________

Rated by: ____________________

# of Utility Cuts ________________

DISTRESS	Distress Weight	SEVERITY*			EXTENT**			STR ***
		L	M	H	O	F	E	
RAVELING	10	Slight Loss of Sand	Open Texture	Rough or Pitted	<20%	20-50%	>50%	
BLEEDING	5	not rated	Bitumen & Agg. Visible	Black Surface	<10%	10-30%	>30%	
PATCHING	5	<1 ft^2	<1 yd^2	>1 yd^2	<10/mile	10-20/mile	>20/mile	
SURFACE DISINTEGRATION / DEBONDING /POTHOLES	5	depth <1" area <1 yd^2	<1", >1 yd^2 >1",<1 yd^2	>1" and >1 yd^2	<5/mile	5-10/mile	>10/mile	
RUTTING	10	1/8" - 3/8"	3/8" - 3/4"	>3/4"	<20%	20-50%	>50%	✓
MAP CRACKING	5	5' x 5' to 9' x 9'	1' x ‘1 to 5' x 5'	< 1' x 1' or alligator	<20%	20-50%	>50%	
BASE FAILURE	10	Barely Noticeable Pitch & Roll	Noticeable Pitch & Roll, Jarring Bump	Severe Distortion, Poor Ride	<2/mi	2-5/mi	>5/mi	✓
SETTLEMENTS	5	Noticeable effect on ride	Some Discomfort	Poor Ride	<2/mi	2-4/mi	>4/mi	
TRANSVERSE CRACKS	10	<1/4", no spalling	1/4 - 1", >.5 spalled	>1", >.5 spalled	CS>100'	100'<CS<50'	CS<50'	✓
WHEEL TRACK CRACKING	15	Single/multiple cracks <1/4"	Multiple cracks >1/4"	Alligator >1/4" Spalling	<20%	20-50%	>50%	✓
LONGITUDINAL CRACKING	5	<1/4", no spalling	1/4 - 1", >.5 spalled	>1", >.5 spalled	<50' per 100	50 -150' per 100'	>150' per 100	✓
EDGE CRACKING	5	Tight, <1/4"	>1/4", some Spalling	>1/4",moderate Spalling	<20%	20-50%	>50%	✓
PRESSURE DAMAGE/ UPHEAVAL	5	bump <½", Barely Noticeable	½" -1", Fair Ride	>1", Poor Ride	<5/mile	5-10/mile	>10/mile	
CRACK SEALING DEFIC.	5	Not considered			<50%	>50%	No Sealant	

*L = LOW
M = MEDIUM
H = HIGH

**O = OCCASIONAL
F = FREQUENT
E = EXTENSIVE

***STR = DISTRESS INCLUDED IN STRUCTURAL DEDUCT CALCULATIONS.

Figure E.1. ODOT PCR Form for Asphalt Pavements on Local Roads.

E.2 Fayette County Pavement Evaluations

The pavement condition evaluation in Fayette County was conducted on June 7, 2022. Table E.1 provides a list of the pavement sections that were included in the evaluation along with the traffic level at these sites. Table E.2 presents a summary of the condition evaluations for the various pavement sections in Fayette County. Photos taken at a selected pavement section in Fayette County are presented in Figures E.1 and E.2.

As can be noticed from Table E.2, raveling, transverse cracking, longitudinal cracking, and edge cracking were observed at most sites in Fayette County, while wheel track cracking was observed at some sites. It can also be noticed from this table, that rutting was not observed at any of the sites in Fayette County. The pavement condition evaluations in Table E.2 also demonstrate that the majority of the distresses encountered at Fayette County had low severity, with the exception of raveling on two sections, transverse cracking on two sections, and longitudinal cracking on one section. It is noted that the 404LVT asphalt mix used in 2015 in Fayette County was produced using an earlier specification that called for a lower asphalt binder content. This might explain the moderate severity of raveling observed for the two pavement sections on Old US 35 that were constructed in 2015. As for transverse cracking (also known as low-temperature thermal cracking), this type of distress is mainly related to the asphalt binder type used in the asphalt mixture. The mix design information obtained from Fayette County revealed that a PG 64-22 asphalt binder was used in the production of the 440LVT asphalt mixes that were produced in Fayette County in 2015. The use of an asphalt binder with a higher low-temperature performance grade such as PG 64-22 (as compared to PG 58-28) might have contributed to the moderate severity transverse cracking observed for the two pavement sections on Old US 35. Subsequent traffic counts obtained at both sections also revealed a relatively high number of trucks at both sections, exceeding 100 trucks per day, as compared to the other pavement sections, which had a lower number of trucks per day. This might have contributed to the moderate severity of longitudinal cracking observed for one of the two pavement sections on Old US 35.

Table E.1. List of Pavement Sections and Corresponding Traffic Level in Fayette County.

Section ID	Route	Begin	End	Traffic (vehicle per day)
2015-01	Creek Rd.	Miami Trace Rd.	Rock Bridge Rd.	332
2015-02	Harrison Rd.	Danvile Rd.	White Oak Rd.	Unavailable
2015-03	Old US 35	Palmer Rd.	Jupiter St.	2,237 - 3,215
2015-04	Old US 35	SR 753	Kennedy Ave.	1,656 - 2,214
2016-01	Bloomingburg-New Holland Rd.	Waterloo Rd.	Pickaway Co. Line	258
2016-02	Harrison Rd.	White Oak Rd.	SR 62	Unavailable
2016-03	Miami Trace Rd.	Palmer Rd.	SR 3 & US 22	361 – 570
2016-04	Snowhill Rd.	Greenfield-Sabina Rd.	US 62	714
2016-05	White Rd.	Ross Co. Line	US 22	Unavailable
2017-01	Old US 35	Palmer Rd.	SR 729	1,523 – 1,701
2017-02	Washington New Martinsburg Rd.	SR 41	Highland Co. Line	593 – 1,157
2017-03	Worthington Rd	Miami Trace Rd.	Greenfield Sabins Rd.	245

Table E.2. Summary of Pavement Condition Evaluations in Fayette County.

Section ID	Raveling	Rutting	Transverse Cracking	Wheel Track Cracking	Longitudinal Cracking	Edge Cracking
2015-01	LE		LO			
2015-02	LE		LE		LO	
2015-03	LE		ME		LO	LE
2015-04	ME		ME		MF	LE
2016-01	ME		LE	LO	LF	
2016-02	LE		LE	LO	LF	LF
2016-03	LE		LE	LO		LF
2016-04	LE		LE	LO	LF	
2016-05	LE		LE		LE	LO
2017-01	LE		LE		LO	LO
2017-02	LE		LE		LO	LO
2017-03	LE		LE		LF	LO

Figure E.1. Photo Taken at Miami Trace Rd. (Last Paved in 2016).

Figure E.2. Photo Taken at Miami Trace Rd. (Last Paved in 2016).

E.3 Darke County Pavement Evaluations

The pavement condition evaluation in Darke County was conducted on June 9, 2022, and June 10, 2022. Table E.3 provides a list of the pavement sections that were included in the condition evaluation along with the traffic level at these sites. Table E.4 presents a summary of the condition evaluations for the various pavement sections in Darke County. Photos taken at a selected pavement section in Darke County are presented in Figures E.3 and E.4.

As can be noticed from Table E.4, transverse cracking and longitudinal cracking were observed at most sites in Darke County, while raveling, wheel track cracking, and edge cracking were observed at a small number of sites. It can also be noticed from this table, that rutting was not observed at any of the sites in Darke County. The pavement condition evaluations in Table E.4 also demonstrate that nearly all distresses encountered at Darke County had low severity, with the exception of longitudinal cracking on one section. As can be noticed from this table, moderate severity longitudinal cracking as well as low severity transverse cracking, wheel track cracking, and edge cracking were observed at Meeker Road. The county reported that this section is located in a floodplain, which might explain the higher severity of distresses encountered at this site.

By comparing the performance of the pavement sections in Darke County to Fayette County (Appendix E.2) and Miami County (Appendix E.4), it can be observed that very few sections in Darke County showed any signs of raveling, while low-severity raveling was observed for the majority of the pavement sections in Fayette County and Miami County. This can be attributed to the coarse aggregate type used in the 404LVT mixes in these counties. Limestone coarse aggregates were used in the 404LVT mixes in Darke County, while gravel or gravel/limestone blends were used as coarse aggregates in Fayette County and Miami County. In Ohio, raveling is more commonly observed for asphalt mixtures containing gravel than limestone coarse aggregates. Another factor that might have contributed to the reduced raveling in Darke County is the slightly higher total asphalt binder content used for 404LVT mixes in this county. Since limestone coarse aggregates were used in the 404LVT asphalt mixes in Darke Count, a total asphalt binder content of 6.8% was used in these mixes. In Fayette County and Miami County, the 404LVT mixes had a total asphalt binder content of 6.6% when gravel coarse aggregates were used and 6.7% when gravel/limestone coarse aggregate blends were used, as per FPO 2015 404LVT specifications.

Table E.3. List of Pavement Sections and Corresponding Traffic Level in Darke County.

Section ID	Route	Begin	End	Traffic (vehicle per day)
2017-01	Requarth Rd.	Greenville	Arc-Beamsville	527 – 1,193
2017-02	Meeker Rd.	SR 49	Greenville Corp	1,368
2017-03	Hogpath	SR 571	Co. Line	1,381
2017-04	Hollansburg-Sampson	N. Madison-Coletown	SR 503	294 – 660
2017-05	N. Madison-Coletown	Hollansburg-Sampson	SR 502	552
2017-06	Pitsburg-Laura	Pitsburg	Co. Line	841
2017-07	Frazers	Grubbs-Rex	SR 503	Unavailable
2018-01	Mcfeeley-Petry	SR 49	SR 118	101 – 195
2018-02	Greenville-St. Marys D	Burns	SR 185	577
2018-03	Chase	Old 242	SR 121	Unavailable
2018-04	Beamsville-Union City	SR 571	SR 49	893 – 980
2018-05	Ohio-Indiana	Pickett	UC Corp	Unavailable
2018-06	Palestine-Union City	SR 502	SR 571	163
2018-07	Rush	Richmond-Palsitine	N. Madison Corp	Unavailable
2018-08	Coletown-Lightsville	SR 571	SR 47	293

Table E.4. Summary of Pavement Condition Evaluations in Darke County.

Section ID	Raveling	Rutting	Transverse Cracking	Wheel Track Cracking	Longitudinal Cracking	Edge Cracking
2017-01			LO		LO	
2017-02			LO	LO	MO	LO
2017-03				LO		
2017-04			LE		LO	
2017-05			LE		LF	
2017-06	LE		LO		LO	
2017-07			LE		LO	
2018-01			LE		LF	
2018-02			LF	LO	LO	
2018-03	Seg.		LO		LO	
2018-04					LO	
2018-05			LO		LO	
2018-06			LO		LO	
2018-07			LE		LO	
2018-08			LF		LO	

Figure E.3. Photo Taken at Pitsburg-Laura Rd. (Last Paved in 2017).

Figure E.4. Photo Taken at Pitsburg-Laura Rd. (Last Paved in 2017).

E.4 Miami County Pavement Evaluations

The pavement condition evaluation in Miami County was conducted on June 23, 2022, and June 24, 2022. Table E.5 provides a list of the pavement sections that were included in the condition evaluation along with the traffic level at these sites. Table E.6 presents a summary of the condition evaluations for the various pavement sections in Miami County. Photos taken at selected a pavement section in Miami County are presented in Figures E.5 and E.6.

As can be noticed from Table E.6, raveling, transverse cracking, and longitudinal cracking were observed at most sites in Miami County, while edge cracking was observed at one site. It can also be noticed from this table that no wheel track cracking or rutting was observed at any of the sites in Miami County. The pavement condition evaluations in Table E.6 also demonstrate that the majority of the distresses encountered at Miami County had low severity, with the exception of raveling on one section, transverse cracking on two sections, and edge cracking on one section. The moderate severity raveling observed on Peterson Road was only encountered in the eastbound direction, which implies that it might have resulted from asphalt mix segregation and not deficiencies in mix design. Miami County reported using PG 64-22 for 404LVT mixes until 2015 before switching to PG 58-28 in 2016. The use of an asphalt binder with a higher low-temperature performance grade such as PG 64-22 might have contributed to the moderate severity of transverse cracking on Studebaker Road and Union Shelby Road. Similar to Fayette County, an earlier 404LVT specification that called for a lower asphalt binder content was used for the mix design of 404LVT mixes in Miami County until 2015. This might have contributed to the higher severity of edge cracking observed on Nashville Road. Traffic information obtained from ODOT TIMS indicated a traffic count of 1,426 to 2,062 vehicles per day for Nashville Road. No truck counts were available for this section, but a relatively high number of trucks was observed at this site during the condition evaluation.

Table E.5. List of Pavement Sections and Corresponding Traffic Level in Miami County.

Section ID	Route	Begin	End	Traffic (vehicle per day)
2015-01	Nashville Road	State Route 571	State Route 55	1,426 – 2,062
2015-02	Scarff Road	New Carlisle Corp.	Dayton-Brandt Road	357
2015-03	Studebaker Road	State Route 201	Dayton-Brandt Road	204
2015-04	Swailes Road	Peters Road	County Road 25A	1,900
2015-05	Union Shelby Road	Loy Road	USR 36	Unavailable
2016-01	Alcony-Conover Road	Walnut Grove Road	State Route 41	815
2016-02	Alcony-Conover Road	Casstown-Clark Rd.	State Route 55	815
2016-03	Burr Oak-New Hope Road	Loy Road	Miami-Shelby Road	122
2016-04	Kessler-Cowlesville	Nasville Road	Rosewood Creek	Unavailable
2016-05	Lostcreek-Shelby Road	Snyder Road	Miami-Shelby Road	284
2016-06	Loy Road	Stringtown Road	Fairview-Snodgrass Road	414
2016-07	Miami-Shelby Road East	Hetzler Road	Troy-Sidney Road	423
2016-08	Peterson Road	State Route 589	Bollinger Road	400
2016-09	Sugar Grove-Circle Hill	State Route 721	Rangeline Road	Unavailable
2017-01	Casstown-Clark	Casstown Corp.	Hufford Road	523
2017-02	Jay Road	N. Mont. Co. Line Road	Frederick-Garland	914
2017-03	Klinger	Range Line Road	State Route 48	Unavailable
2017-04	Loy Road	Free Road	Troy-Sidney Road	612
2017-05	Old Staunton Road	State Route 202	State Route 55	1,995
2017-06	Springcreek-Stringtown	Piqua-Troy	Peterson Road	585
2017-07	Troy-Frederick	Ginhamsburg-Fred	Peters Road	551
2017-08	Troy-Urbana	Alcony-Conover	Champaign Co. Line	433

Table E.6. Summary of Pavement Condition Evaluations in Miami County.

Section ID	Raveling	Rutting	Transverse Cracking	Wheel Track Cracking	Longitudinal Cracking	Edge Cracking
2015-01	LE		LE		LF	HO
2015-02	LE		LF		LO	
2015-03	LE		ME		LO	
2015-04			LE		LO	
2015-05	LE		ME		LO	
2016-01	LE		LE		LO	
2016-02			LE		LO	
2016-03			LO		LO	
2016-04			LO			
2016-05	LE		LO		LO	
2016-06	LE		LO		LO	
2016-07	LE		LO		LO	
2016-08	MO		LE		LO	
2016-09	LO		LO		LF	
2017-01	LE		LO		LO	
2017-02			LE		LE	
2017-03			LE		LO	
2017-04	LE		LO			
2017-05	LE		LO		LO	
2017-06			LE		LO	
2017-07			LO		LO	
2017-08			LE		LO	

Figure E.5. Photo Taken at Studenbaker Rd. (Last Paved in 2015).

Figure E.5. Photo Taken at Studenbaker Rd. (Last Paved in 2015).

Appendix F

Cost Comparison of 404LVT and Item 441 Type 1 Surface Mixes

F.1 Introduction

Table F.1 presents a comparison between the estimated costs of 404LVT and Item 441 Type 1 surface mixes produced using limestone coarse aggregates at a reclaimed asphalt pavement (RAP) content of 20%. A total asphalt binder of 6.8% was used in estimating the cost of the 404LVT asphalt mixes, and a total asphalt binder of 6.0% was used in estimating the cost of the Item 441 Type 1 surface mixes. PG 58-28 asphalt binder was used for the 404LVT mixes (as recommended in this study) at a price of $650 per ton, while PG 64-22 asphalt binder was used for the Item 441 Type 1 surface mixes at a price of $600 per ton. For both mix types, $30 per ton was used for No. 8 limestone aggregates and $15 per ton was used for natural sand. The construction cost was assumed to be the same for both mix types and was estimated to be $35 per ton.

As can be noticed from Table F.1, the total unit price for one ton of asphalt mixture is slightly higher for 404LVT mixes ($88.03 per ton) than for Item 441 Type 1 surface mixes ($83.93 per ton), which is mainly due to the higher asphalt binder content used in 404LVT mixes as well as the slightly higher price for the PG 58-28 (which is not as commonly used as PG 64-22).

The estimated costs for paving one mile of road with asphalt overlays produced using 404LVT and Item 441 Type 1 surface mixes are presented in Table F.2. A total paving width of 24 feet was used in the analysis, with an overlay thickness of 1 inch for 404LVT and 1.5 inches for Item 441 Type 1 surface mixes. As can be noticed from this table, it is significantly less expensive to place an asphalt overlay using 404LVT mixes (~$67,500 per mile) than using Item 441 Type 1 surface mixes (~$96,500 per mile) due to the lower overlay thickness used for 404LVT. Therefore, assuming that both mix types will last between 12 and 15 years, it will be more cost-effective to use 404LVT than Item 441 Type 1 surface mixes. It is emphasized that 404LVT mixes are only suitable for low-volume traffic roads where heavy, slow-moving trucks are not commonly encountered.

Table F.1 Comparison of Estimated Costs of 404LVT and Item 441 Type 1 Surface Mixes.

	404LVT	Item 441 Type 1 Surface
Mix Composition	25% No. 8 Limestone + 55% Natural Sand + 20% RAP	50% No. 8 Limestone + 30% Natural Sand + 20% RAP
Binder Type and Content	PG 58-28 @ 6.8% Total Binder Content (5.9% Virgin Binder Content)	PG 64-22 @ 6.0% Total Binder Content (5.1% Virgin Binder Content)
Material Cost	$38.35/ton	$30.60/ton
Construction Cost	$35.00/ton	$35.00/ton
Total Cost	$88.03/ton	$83.93/ton

Table F.1 Estimated Costs for Paving One Mile of Road

using 404LVT and Item 441 Type 1 Surface Mixes

	404LVT	Item 441 Type 1 Surface
Pavement Length	1 mile = 5,280 ft	1 mile = 5,280 ft
Pavement Width	2 lanes @ 12 ft = 24 ft	2 lanes @ 12 ft = 24 ft
Layer Thickness	1 inch = 1/12 ft	1.5 inch = 1.5/12 ft
Mix Volume	10,560 ft^3	15,840 ft^3
Mix Weight	765.6 tons	1,148.4 tons
Mix Cost	$67,395.00	$96,385.21