Texas A&M Transportation Institute

Evaluating Candidate Projects for Seal Coat Stability

Technical Report 0-7106-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

sponsored by the
Federal Highway Administration and the
Texas Department of Transportation
https://tti.tamu.edu/documents/0-7106-R1.pdf

Technical Report Documentation Page

1. Report No. FHWA/TX-25/0-7106-R1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle EVALUATING CANDIDATE PROJECTS FOR SEAL COAT STABILITY		5. Report Date Published: January 2025 6. Performing Organization Code
7. Author(s) Darlene Goehl, Tito Nyamuhokya, Carl Bierman, Mena Souliman		8. Performing Organization Report No. Report 0-7106-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-7106
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E. 11th Street Austin, Texas 78701-2483		13. Type of Report and Period Covered Technical Report: September 2021–November 2024 14. Sponsoring Agency Code

15. Supplementary Notes
Project sponsored by the Texas Department of Transportation and the Federal Highway Administration.
Project Title: Quantify Maximum Accumulated Seal Coat Layers for Stability
URL: https://tti.tamu.edu/documents/0-7106-R1.pdf

16. Abstract
With investments in seal coats exceeding $250 million annually, it is critical to apply the right treatment to the right road at the right time. Projects are typically selected based on the time since the last seal coat (an average of 7 years) with little to no testing performed to ensure that the section is a good candidate for a seal coat. The objective of this research was to determine the maximum number of seal coats that can be applied to a pavement surface before the accumulated layers of seal coats become unstable. The research team evaluated the stability of existing accumulated seal coat substrate layers through a series of laboratory and field tests and developed tests and procedures to determine when an additional seal coat may not perform well. The research team also developed guidelines to select candidate seal coat projects with multiple seal coat layers. These guidelines ensure that new seal coats are applied only to good candidate pavement sections, thus lowering risks, improving life cycle costs, and leading to better performing sections of pavement.

17. Key Words Stability, seal coat, shoving, rutting		18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia https://www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 98	22. Price

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EVALUATING CANDIDATE PROJECTS FOR SEAL COAT STABILITY

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Report 0-7106-R1
Project 0-7106
Project Title: Quantify Maximum Accumulated Seal Coat Layers for Stability

Sponsored by the
Texas Department of Transportation
and the
Federal Highway Administration

Published: January 2025

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DISCLAIMER

This research was sponsored by the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The engineer(researcher) in charge of the project was Darlene C. Goehl, P.E. #80195.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

ACKNOWLEDGMENTS

This project was sponsored by TxDOT and FHWA. The authors thank Project Manager Jade Adediwura and Project Committee members Chris Graf, Enad Mahmoud, James Robbins, John Sudela, Mona Nabakht, and Lacy Peters. Special thanks to TxDOT Maintenance Division, Brownwood District, Atlanta District, Beaumont District, and Bryan District personnel for providing case study projects and their associated pavement data history.

The research team would like to thank the material suppliers—Arcosa Aggregates, CSA Materials, Rogers Group Inc., Big Creek Construction, Zack Burkett Co., Allen Keller Company, Anderson Columbia Co. Inc., Permian Basin Materials, Texas Materials Group, Vulcan Materials, and Victory Rock Texas LLC—for providing aggregate; Knife River Corp. for donating hot mixed asphalt; and Ergon Asphalt Inc. and Wright Asphalt Products Co. for providing binder for the project.

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CHAPTER 1. INTRODUCTION

BACKGROUND

The Texas Department of Transportation (TxDOT) has numerous sections of roadway that have seal coats as the riding surface. With a significant investment in seal coats of over $250 million annually, ensuring that seal coats are used on good candidate pavement sections will lower risk to TxDOT and lead to better performing sections of pavement.

With TxDOT's strong preventive maintenance program, many roads in Texas are performing very well with multiple seal coats; however, others are not. Figure 1 shows examples of potential issues with multiple seal coats on pavement sections and Figure 2 shows a pavement core with multiple seal coats.

Figure 1. Potential Issues with Multiple Seal Coats on Pavement Sections.

Figure 2. Pavement Core with Multiple Seal Coats.

During seal coat training, TxDOT employees continue to ask, "How many seal coats are too many?" This is a very good question, and this is the first TXDOT research project to investigate this topic. What this research strives to answer is, "How many seal coats can be added before the surface becomes unstable and is therefore not a good candidate for an additional seal coat?"

TxDOT's *Maintenance Operations Manual* [1] states, "The general objectives of roadway pavement maintenance are to provide a safe roadway surface, preserve the state's capital investments in the pavement, and to maintain a riding quality satisfactory to the traveling public. Maintenance of roadway pavement includes the restoration and repair of both surface and underlying layers." To meet these objectives, proper maintenance is needed to ensure the right repair is made at the right time on the right project. This principle is reinforced by the Federal Highway Administration's (FHWA's) Everyday Counts initiative. The FHWA states, "Applying a pavement preservation treatment at the right time (when), on the right project (where), with quality materials and construction (how) is a critical investment strategy for optimizing infrastructure performance." As part of TxDOT's preventive maintenance plan, seal coats are a vital strategy for meeting these objectives.

A seal coat is a single layer of binder and aggregate. Generally, however, multiple layers of seal coat are placed, especially on roadways that were not designed to include asphalt concrete pavement as part of their structural layers. A seal coat provides a durable all-weather surfacing that:

- Seals an existing surface against the intrusion of air and water.
- Enriches an existing dry or raveled surface.
- Arrests the deterioration of a surface showing signs of distress.
- Provides a skid resistant surface.
- Provides the desired surface texture.
- Provides a uniform-appearing surface.

The main problems with seal coats are streaking, flushing, and rock loss. While this research did not explicitly address these issues, it was important to understand these problems associated with seal coats. The focus of this research was on minimizing or eliminating the main problems associated with multiple seal coat applications.

LITERATURE REVIEW SUMMARY

As part of a comprehensive literature review, the research team reviewed over 44 publications. The main purposes of a seal coat are to prevent water from entering the base and subbase of a pavement and to provide additional skid resistance. A seal coat is considered to be a very effective preventive measure for rural roads with low to medium traffic volumes. In Texas, seal coats are typically used on highways with average daily traffic (ADT) counts of less than 10,000 vehicles per day [2]. A seal coat does not provide structural strength for the pavement but instead works as a wearing surface. Therefore, the accumulation of seal coat layers can sometimes result in an unstable surface.

Limited research has been done on the stability of multiple seal coat layers. In one of the most relevant studies, *Factors Affecting Multiple Chipseal Layer Instability*, Ball et. al. [3] investigated sites with multiple seal coats and found the following:

- "The structure (aggregate packing) and binder content of seals that flush prematurely are different from seals that perform well."
- "No relationship between binder content alone and seal *instability* was found."
- "Seals with higher percentages passing the 4.75 mm (0.187" = 3/16") sieve appear to be more stable. However, no relationship between aggregate grading and chip sequence was obvious."
- "Analysis of the seal histories indicated that the start of a series of shorter than expected seal lives appeared to be associated with a *catastrophic* seal failure. Often the seal would last less than two years. Subsequent seals did not achieve the expected design life."
- "It is proposed that high bitumen content in itself is not the principal cause of flushing. Rather, the ratio of bitumen volume to the available volume in an optimum packed multilayer seal is the determinant."

In general, departments of transportation in the United States do not have tests for accumulated seals; however, many tests are available to check the stability of asphalt concrete. In some other countries, design methods include the performance of tests to check the stability of the existing seal coat before laying a new layer. For example, in the South African design method, ball penetration tests are performed on the existing pavement surface before applying a new layer of seal coat. After reviewing different design methods, tests, and stability measures for asphalt concrete, the research team selected candidate tests to measure the stability of multiple seal coats.

To determine the candidacy of a particular pavement section for an additional seal coat, the research team evaluated the procedures and tests performed in Australia, South Africa, and New Zealand as part of this research. The incorporation of international practices within current TxDOT practice would enhance the existing pavement selection method for an additional seal coat.

CHAPTER 2. LABORATORY STABILITY STUDY

In this laboratory stability study, the researchers developed a test procedure to: (1) measure the stability of an existing pavement and (2) predict the stability of an existing pavement when an additional seal coat layer is applied.

The laboratory stability study investigated the following tests:

- South African SANS 3001-BT10:2013 Ball Penetration Test for the Design of Surfacing Seals (SABPT) test method.
- Torque-based pull-off test method.
- New Zealand laboratory repeated shear strength test method.

LABORATORY SEAL COAT SURFACE PREPARATION

In the laboratory, the research team prepared 6-inch diameter hot mixed asphaltic concrete (HMA) specimens surfaced with different aggregates, binder types, surface layers, and aggregate embedment depths to assess the stability of the seal coat as layers were added. Figure 3, from left to right, shows 1, 2, and 3 seal coat layers on lab-prepared specimens. As part of the test-specimen preparation, the binder and aggregates were heated for 2 hours to the compaction temperature before they were applied to the surface of the HMA specimens. Table 1 and Table 2 list the application rates for the aggregates and binders, respectively. The material producer's *name* was changed to a *code* (pseudonym) to protect individual source data. The application rates varied depending on the embedment, aggregate grade, binder type, and substrate absorption. The application temperatures for emulsions (catatonic rapid setting polymer-modified asphalt, CRS-2P) and for asphaltic cements and aged residues (AC20-5TR, AR) were 150°F and 350°F, respectively.

Figure 3. Laboratory Seal Coat Specimens with 1, 2, and 3 Layers.

Table 1. Aggregate Application Rate on the 6-inch HMA Specimens.

Aggregate Source Code	Material Mineralogy	Grade	Caliper Measured Average Material Thickness (inches)	Aggregate Weight (lb)	Aggregate Weight (g)
M2	Synthetic	3	0.321	0.218	98.8
M2	Synthetic	4	0.274	0.188	85.1
M8E	Limestone	3	0.367	0.437	198.1
M8E	Limestone	4	0.311	0.387	175.6

Table 2. Binder Application Rate on the 6-inch HMA Specimens.

Aggregate Source Code	Material Mineralogy	Grade	Binder	Embedment (%)	Binder Weight (lb)	Binder Weight (g)
M2	Synthetic	3	AC20-5TR	25.0	0.056	25.6
M2	Synthetic	3	AC20-5TR	37.5	0.082	37.1
M2	Synthetic	3	AC20-5TR	60.0	0.128	57.9
M2	Synthetic	4	AC20-5TR	25.0	0.049	22.2
M2	Synthetic	4	AC20-5TR	37.5	0.071	32.1
M2	Synthetic	4	AC20-5TR	60.0	0.110	49.8
M2	Synthetic	3	AR	25.0	0.066	29.7
M2	Synthetic	3	AR	48.5	0.122	55.3
M2	Synthetic	3	AR	60.0	0.150	67.8
M2	Synthetic	4	AR	25.0	0.057	25.8
M2	Synthetic	4	AR	48.5	0.105	47.6
M2	Synthetic	4	AR	60.0	0.129	58.3
M2	Synthetic	3	CRS-2P	25.0	0.053	23.8
M2	Synthetic	3	CRS-2P	37.5	0.076	34.5
M2	Synthetic	3	CRS-2P	60.0	0.118	53.6
M2	Synthetic	4	CRS-2P	25.0	0.046	20.7
M2	Synthetic	4	CRS-2P	37.5	0.066	29.8
M2	Synthetic	4	CRS-2P	60.0	0.102	46.2
M8E	Limestone	3	AC20-5TR	25.0	0.064	28.9
M8E	Limestone	3	AC20-5TR	37.5	0.093	42.1
M8E	Limestone	3	AC20-5TR	60.0	0.145	65.9
M8E	Limestone	4	AC20-5TR	25.0	0.055	24.9
M8E	Limestone	4	AC20-5TR	37.5	0.080	36.1
M8E	Limestone	4	AC20-5TR	60.0	0.124	56.2

Aggregate Source Code	Material Mineralogy	Grade	Binder	Embedment (%)	Binder Weight (lb)	Binder Weight (g)
M8E	Limestone	3	AR	25.0	0.074	33.7
M8E	Limestone	3	AR	48.5	0.139	63.0
M8E	Limestone	3	AR	60.0	0.170	77.3
M8E	Limestone	4	AR	25.0	0.064	28.9
M8E	Limestone	4	AR	48.5	0.118	53.7
M8E	Limestone	4	AR	60.0	0.145	65.9
M8E	Limestone	3	CRS-2P	25.0	0.059	26.9
M8E	Limestone	3	CRS-2P	37.5	0.086	39.1
M8E	Limestone	3	CRS-2P	60.0	0.135	61.0
M8E	Limestone	4	CRS-2P	25.0	0.051	23.2
M8E	Limestone	4	CRS-2P	37.5	0.074	33.5
M8E	Limestone	4	CRS-2P	60.0	0.115	52.1

The sides of each HMA specimen were covered by a sleeve protruding to the surface to limit the asphalt flowing out of the surface and control the embedment depth. Once the binder and aggregates were applied on the surface, a 0.5-inch-thick rubber disk was placed on the surface. A 10-lb steel flat weight was used to embed the aggregates in the binder mat. The rubber disk protected the aggregates from crushing during the application. Table 3 summarizes the layer application process for a second layer applied to the surface of another seal coat.

Table 3. Seal Coat Application Procedure in the Laboratory.

Steps	Pictorial	Description
1		Heat binder and aggregate to compaction temperature according to binder type.
2		Secure the HMA specimen in a tight plastic sleeve to control the lateral movement of aggregate during compaction and binder from moving over the side. Place the HMA specimen on a scale and tare the reading.
3		Place the binder, then add aggregate at the appropriate design application rate.
4		Press the surface to embed aggregates in the binder layer. Perform compaction within 1 to 2 minutes after the aggregates are applied.
5		Verify completed specimen.

LABORATORY REPEATED SHEAR STRENGTH TEST

To simulate shearing in the laboratory, the research team performed a dynamic punching shear test on the HMA cylindrical specimens treated with seal coat surface layers. The research team used an MTS test system to induce repeated loads on the HMA specimens. Figure 4 shows the test setup and sample output. The test could also be done using a universal testing machine (UTM); unfortunately, the UTM machine was not working when testing began. The test time per sample was 6 hours. Table 4 lists the input parameters for the repeated shear test.

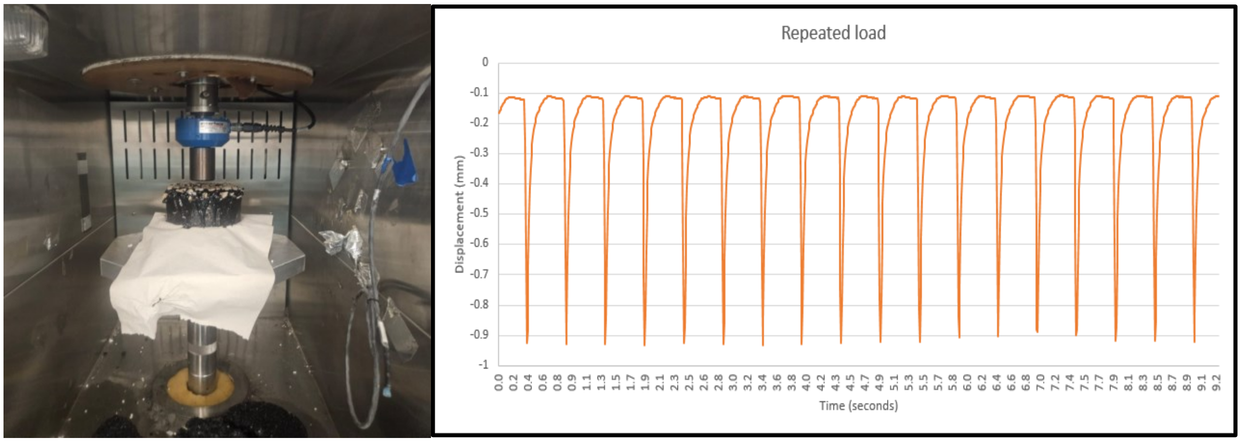

Figure 4. Setup and Sample Output for Repeated Shear Test on Seal-Coated Specimen.

Table 4. Input Parameters for the Repeated Shear Test.

Parameter	Value
Pulse type	Haversine
Pulse width	50 ms
Pulse frequency	2 s^{-1}
Pulse height	2.04 kN
Preload	0.2 kN

The research team reported the relationship between displacement and repeated load cycles. In general, the results indicated increased displacements with increased layers and a notably increased rate of change of displacement for specimens treated with three layers. The increased rate of change could be an indicator of growing instability. Figure **5**, Figure 6, and Figure 7 show the displacement vs. the load cycles with the AC20-5TR binder; 25 percent embedment; and 1, 2, and 3 seal coat layers, respectively.

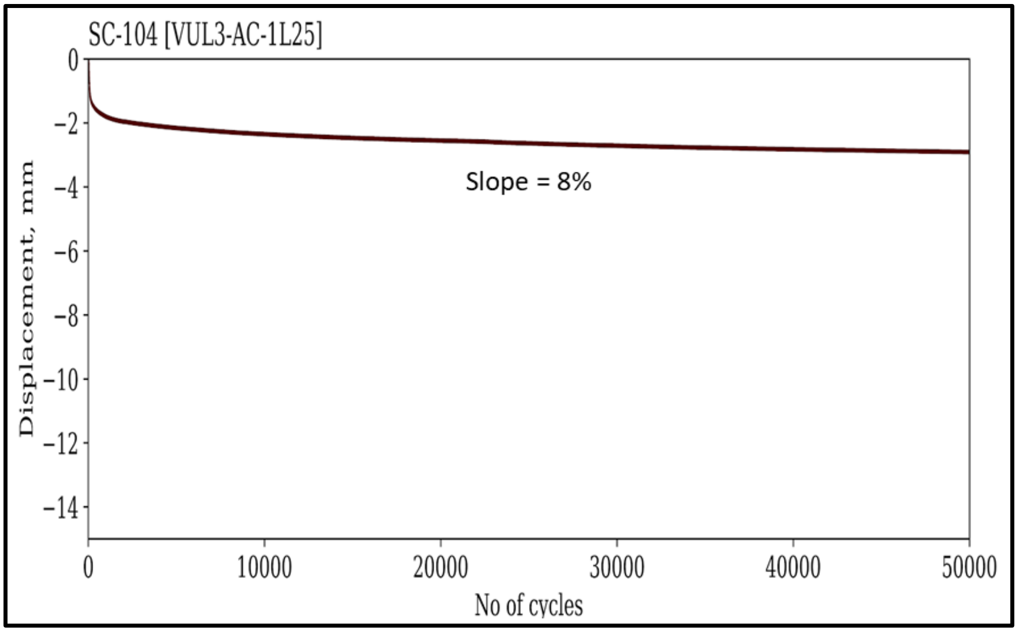

Figure 5. Displacement vs. Load Cycles with AC20-5TR Binder, 25 Percent Embedment, and 1 Seal Coat Layer.

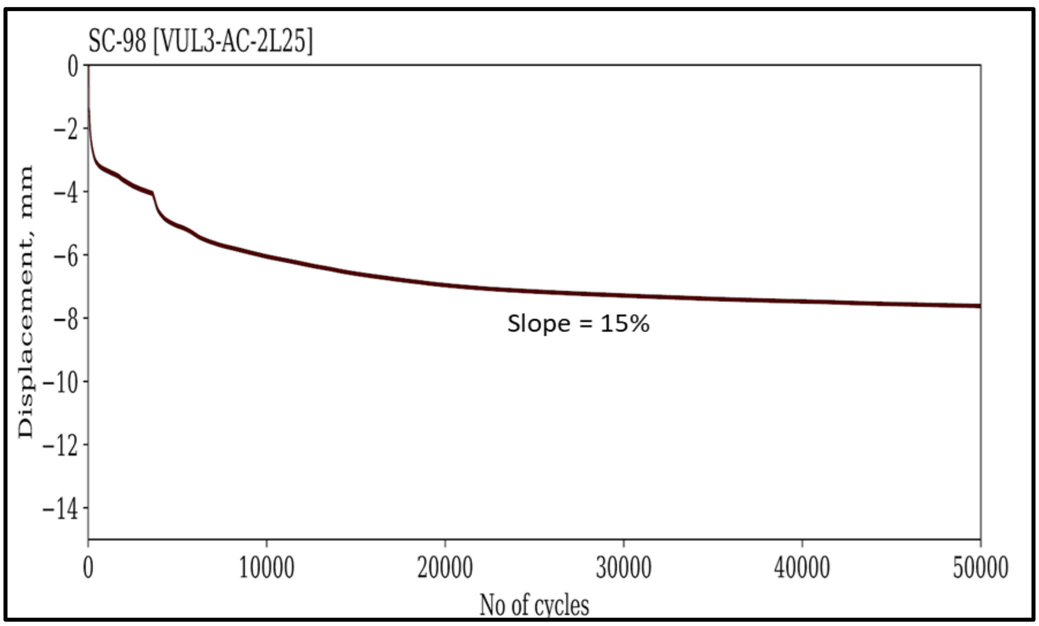

Figure 6. Displacement vs. Load Cycles with AC20-5TR Binder, 25 Percent Embedment, and 2 Seal Coat Layers.

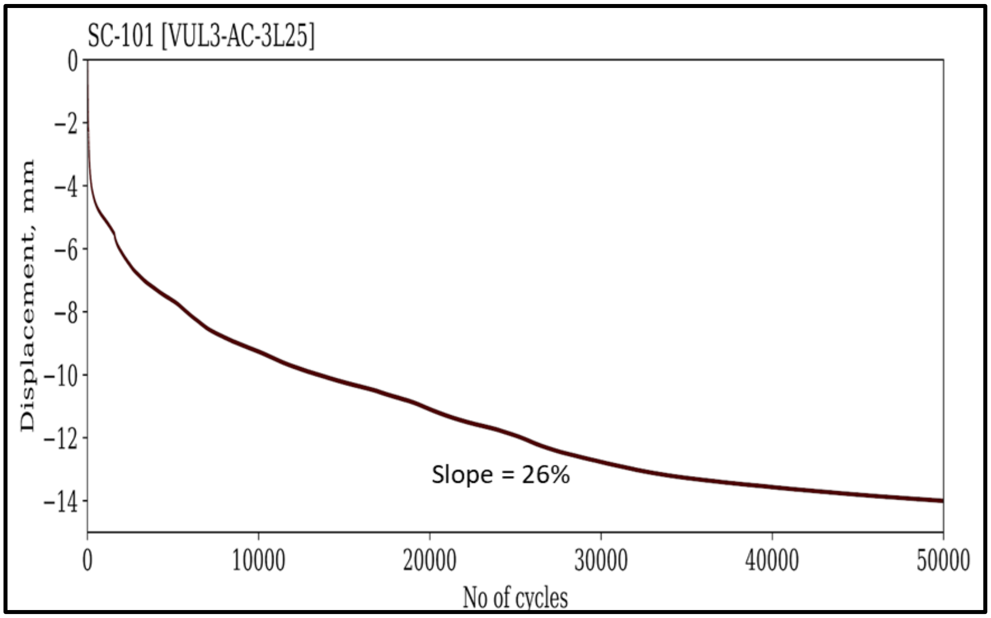

Figure 7. Displacement vs. Load Cycles with AC20-5TR Binder, 25 Percent Embedment, and 3 Seal Coat Layers.

LABORATORY TORSION TEST

One characteristic of the seal coat surface is that it resists horizontal shear due to traffic, especially when vehicles are turning and braking. Typical tests, such as the asphalt bond shear test, are challenging to apply on a seal coat. Instead, researchers determined that the most suitable test to determine the shear strength of a seal coat along the horizontal plane is a torsion test (Figure 8), which measures the amount of torque force required for the seal surface layers to fail along the horizontal plane. This test is not without issue. The test requires that a plate be glued on the surface of a specimen. The amount of glue needed is highly subjective and varies for different aggregate sizes. These different glue amounts may skew the test results. A technician must minimize erroneous results due to gluing; more errors are expected with relatively large aggregates. In this research, some results, especially for the grade 3 aggregates, may be suspect. Table 5, Table 6, and Table 7 list the raw torsion test results with the AC20-5TR, AR, and CRS-2P binders, respectively.


Figure 8. Torsion Test Example.

Table 5. Torsion Test Results with AC20-5TR Binder.

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Torque (N·m)	Torque (lb·ft)
199	M2	3	25	1	15.82	11.67
183	M2	3	25	2	34.04	25.1
185	M2	3	25	3	16.23	11.97
200	M2	3	37.50	1	31.16	22.98
184	M2	3	37.50	2	12.54	9.25
186	M2	3	37.50	3	13.28	9.79
201	M2	3	60	1	13.29	9.8
192	M2	3	60	2	12.61	9.3
187	M2	3	60	3	15.38	11.34
304	M2	4	25	1	21.48	15.84
303	M2	4	25	2	17.46	12.88
302	M2	4	25	3	17	12.54
307	M2	4	37.50	1	32.07	23.65
306	M2	4	37.50	2	27.71	20.44
308	M2	4	37.50	3	12.63	9.31
310	M2	4	60	1	13.18	9.72
309	M2	4	60	2	18.41	13.58
305	M2	4	60	3	15.8	11.65
220	M8E	3	25	1	19.87	14.65
208	M8E	3	25	2	20.35	15.01
202	M8E	3	25	3	9.47	6.98
203	M8E	3	37.50	1	11.98	8.83
209	M8E	3	37.50	2	15.42	11.37
206	M8E	3	37.50	3	12.19	8.99
204	M8E	3	60	1	14.82	10.93
210	M8E	3	60	2	11.37	8.38
207	M8E	3	60	3	14.14	10.43
255	M8E	4	25	1	33.13	24.43
254	M8E	4	25	2	12.51	9.23
253	M8E	4	25	3	9.37	6.91
259	M8E	4	37.50	1	18.27	13.47

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Torque (N·m)	Torque (lb·ft)
257	M8E	4	37.50	2	15.44	11.39
256	M8E	4	37.50	3	12.12	8.94
262	M8E	4	60	1	17.97	13.25
261	M8E	4	60	2	19.31	14.24
260	M8E	4	60	3	14.5	10.69

Table 6. Torsion Test Results with AR Binder.

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Torque (N·m)	Torque (lb·ft)
211	M2	3	25	1	24.98	18.42
214	M2	3	25	2	10.37	7.65
217	M2	3	25	3	13.68	10.09
212	M2	3	48.50	1	17.1	12.61
215	M2	3	48.50	2	21.36	15.75
218	M2	3	48.50	3	13.05	9.62
213	M2	3	60	1	11.39	8.4
216	M2	3	60	2	16.18	11.93
219	M2	3	60	3	12.39	9.14
224	M2	4	25	1	15.07	11.11
223	M2	4	25	2	7.4	5.46
222	M2	4	25	3	8.28	6.11
228	M2	4	48.50	1	16.09	11.87
227	M2	4	48.50	2	17.67	13.03
226	M2	4	48.50	3	9.83	7.25
231	M2	4	60	1	10.93	8.06
230	M2	4	60	2	14.31	10.55
229	M2	4	60	3	12.2	9
235	M8E	3	25	1	16.33	12.04
233	M8E	3	25	2	15.31	11.29
232	M8E	3	25	3	12.83	9.46
238	M8E	3	48.50	1	13.28	9.79
237	M8E	3	48.50	2	14.21	10.48

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Torque (N·m)	Torque (lb·ft)
236	M8E	3	48.50	3	11.93	8.8
241	M8E	3	60	1	16.95	12.5
240	M8E	3	60	2	16.21	11.95
239	M8E	3	60	3	14.06	10.37
245	M8E	4	25	1	8.12	5.99
244	M8E	4	25	2	15.69	11.57
243	M8E	4	25	3	9.89	7.29
248	M8E	4	48.50	1	21.25	15.67
247	M8E	4	48.50	2	18.35	13.53
246	M8E	4	48.50	3	12.77	9.42
252	M8E	4	60	1	15.82	11.67
250	M8E	4	60	2	11.42	8.42
249	M8E	4	60	3	12.23	9.02

Table 7. Torsion Test Results with CRS-2P Binder.

Sample Identifier	Aggregate Source	Grade	Embedment (%)	Number of Layers	Torque (N·m)	Torque (lb·ft)
266	M2	3	25	1	20.07	14.8
264	M2	3	25	2	11.76	8.67
263	M2	3	25	3	7.16	5.28
273	M2	3	37.50	1	15.3	11.28
268	M2	3	37.50	2	6.87	5.07
267	M2	3	37.50	3	5.33	3.93
272	M2	3	60	1	9.64	7.11
271	M2	3	60	2	6.38	4.71
270	M2	3	60	3	5.98	4.41
276	M2	4	25	1	40.85	30.13
275	M2	4	25	2	11.15	8.22
274	M2	4	25	3	7.38	5.44
280	M2	4	37.50	1	8.83	6.51
278	M2	4	37.50	2	13.11	9.67
277	M2	4	37.50	3	8.54	6.3

Sample Identifier	Aggregate Source	Grade	Embedment (%)	Number of Layers	Torque (N·m)	Torque (lb·ft)
283	M2	4	60	1	16.2	11.95
282	M2	4	60	2	6.21	4.58
281	M2	4	60	3	8.71	6.42
286	M8E	3	25	1	26.47	19.52
285	M8E	3	25	2	12.07	8.9
284	M8E	3	25	3	13.63	10.05
289	M8E	3	37.50	1	18.06	13.32
288	M8E	3	37.50	2	22.02	16.24
287	M8E	3	37.50	3	8.48	6.25
292	M8E	3	60	1	23.69	17.47
291	M8E	3	60	2	FAIL	FAIL
290	M8E	3	60	3	FAIL	FAIL
295	M8E	4	25	1	21.77	16.05
294	M8E	4	25	2	8.69	6.41
293	M8E	4	25	3	FAIL	FAIL
298	M8E	4	37.50	1	6.91	5.1
297	M8E	4	37.50	**2**	4.3	3.17
296	M8E	4	37.50	3	FAIL	FAIL
301	M8E	4	60	1	8.16	6.02
300	M8E	4	60	**2**	FAIL	FAIL
299	M8E	4	60	3	FAIL	FAIL

Figure 9, Figure 10, and Figure 11 show the percentage aggregate embedment vs. torsion resistance with the AC20-5TR, AR, and CRS-2P binders, respectively, and 1, 2, and 3 seal coat layers. The torsion resistance generally decreased as the number of layers increased. However, removing biases and erroneous data is necessary to gauge the limits for unstable layers. It is plausible to conclude that the torsion test is better for smaller-size aggregates.

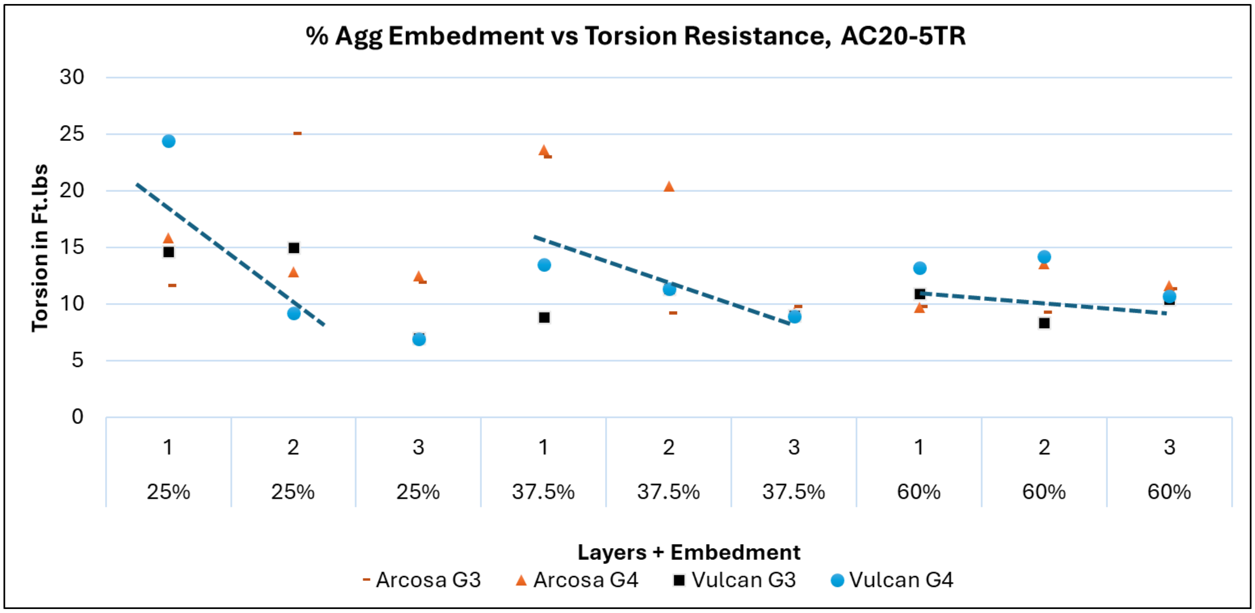

Figure 9. Percentage Aggregate Embedment vs. Torsion Resistance with AC20-5TR Binder.

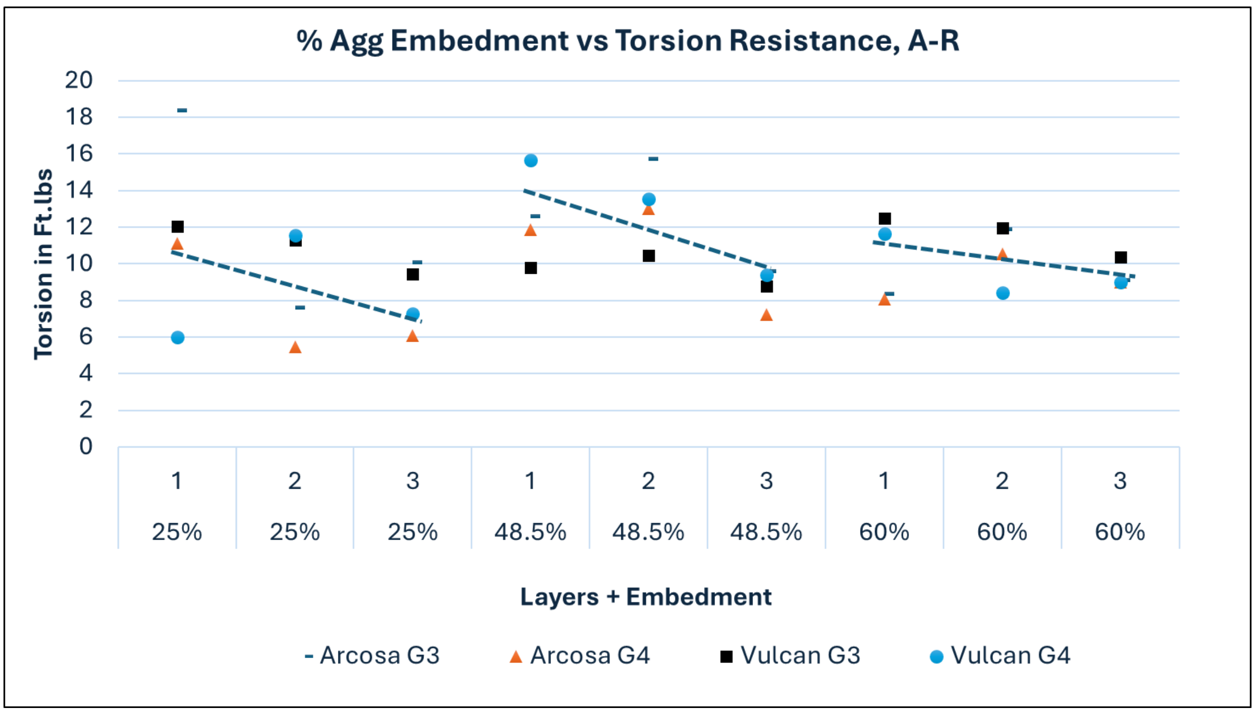

Figure 10. Percentage Aggregate Embedment vs. Torsion Resistance with AR Binder.

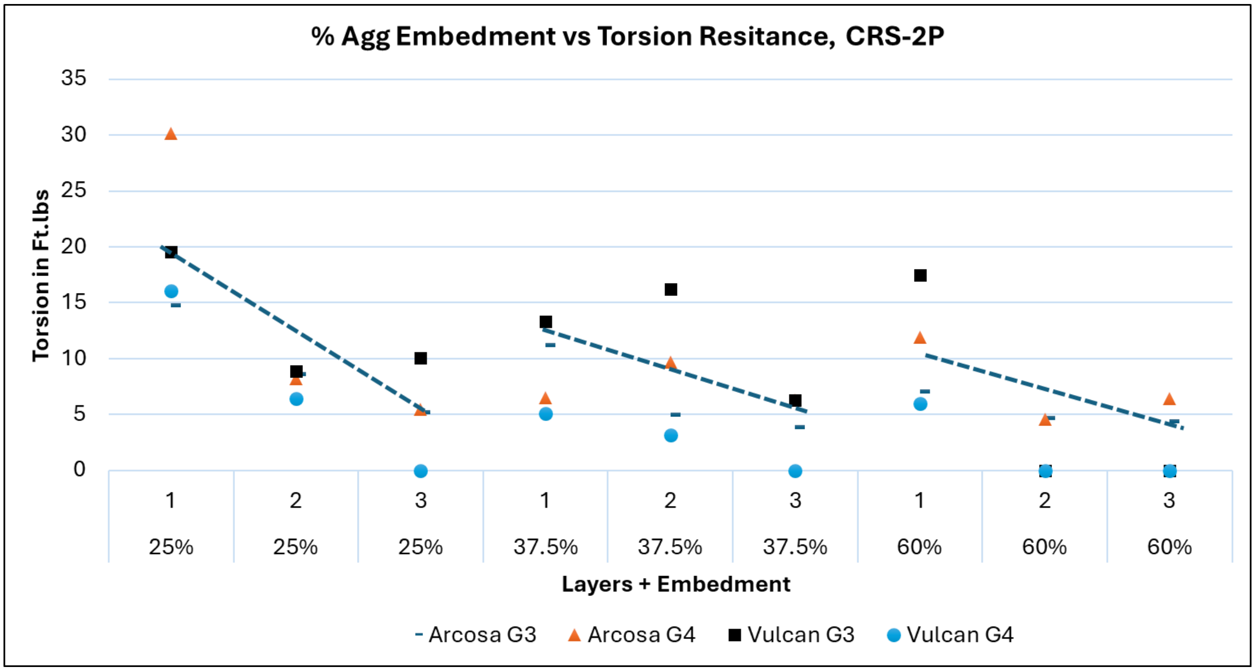

Figure 11. Percentage Aggregate Embedment vs. Torsion Resistance with CRS-2P Binder.

LABORATORY BALL PENETRATION TEST

To assess the stability of the seal coat on the lab-prepared HMA specimens, the research team performed a ball penetration test (Figure 12), among other tests. Specifically, the modified dynamic cone penetrometer (MDCP) test involves pushing a steel ball into a seal coat surface with the drop (blow) of a hammer. The research team performed two blows per test location; blow 1 was taken as a seating load and blow 2 was used as a penetration reading. Each specimen was tested in five locations; the average of these locations was used as the ball penetration value for a specimen. In total, 106 specimens were tested. Table 8, Table 9, and Table 10 detail the ball penetration test results with the AC20-5TR, AR, and CRS-2P binders, respectively. Table 11 details the averaged results by binder type and layer. Figure 13 displays these results graphically.

Figure 12. Ball Penetration Test Equipment and Sample Outcome.

Table 8. Ball Penetration Test Results with AC20-5TR Binder.

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Blow 1 Depth (mm)	Blow 2 Depth (mm)	Blow 2 Depth (inches)
53	M2	3	25	1	4.41	1.78	0.0701
47	M2	3	25	2	4.87	2.7	0.1063
9	M2	3	25	3	6.98	3.49	0.1374
49	M2	3	37.5	1	2.62	0.94	0.0370
54	M2	3	37.5	2	3.38	3.55	0.1398
2	M2	3	37.5	3	5.56	3.9	0.1535
50	M2	3	60	1	3.6	1.4	0.0551
18	M2	3	60	2	4.89	3.01	0.1185
46	M2	3	60	3	5.37	3.63	0.1429
33	M2	4	25	1	4.18	1.36	0.0535
36	M2	4	25	2	5.68	2.72	0.1071
56	M2	4	25	3	6.61	2.42	0.0953
37	M2	4	37.5	1	3.58	2.04	0.0803
34	M2	4	37.5	2	5.21	2.66	0.1047
57	M2	4	37.5	3	5.25	3.04	0.1197
38	M2	4	60	1	3.89	1.3	0.0512
35	M2	4	60	2	4.07	2.69	0.1059
58	M2	4	60	3	4.33	3.45	0.1358
104	M8E	3	25	1	5.92	1.1	0.0433
98	M8E	3	25	2	4.96	3.5	0.1378
101	M8E	3	25	3	5.74	4.29	0.1689
105	M8E	3	37.5	1	5.97	2.54	0.1000
99	M8E	3	37.5	2	4.48	5.06	0.1992
102	M8E	3	37.5	3	4.94	3.82	0.1504
106	M8E	3	60	1	3.66	1.66	0.0654
100	M8E	3	60	2	4.57	3.59	0.1413
103	M8E	3	60	3	3.72	4.26	0.1677
167	M8E	4	25	1	4.06	1.73	0.0681
122	M8E	4	25	2	6.11	2.15	0.0846
127	M8E	4	25	3	4.55	2.04	0.0803

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Blow 1 Depth (mm)	Blow 2 Depth (mm)	Blow 2 Depth (inches)
168	M8E	4	37.5	1	3.45	0.88	0.0346
123	M8E	4	37.5	2	5.35	3.1	0.1220
129	M8E	4	37.5	3	4.26	4.13	0.1626
169	M8E	4	60	1	3.99	1.46	0.0575
126	M8E	4	60	2	4.32	3.15	0.1240
131	M8E	4	60	3	3.58	2.82	0.1110

Table 9. Ball Penetration Test Results with AR Binder.

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Blow 1 Depth (mm)	Blow 2 Depth (mm)	Blow 2 Depth (inches)
66	M2	3	25	1	5.34	1.21	0.0476
62	M2	3	25	2	4.58	3.92	0.1543
59	M2	3	25	3	5.98	3.68	0.1449
67	M2	3	48.5	1	3.17	2.15	0.0846
60	M2	3	48.5	2	4.3	3.2	0.1260
63	M2	3	48.5	3	4.41	3.25	0.1280
68	M2	3	60	1	4.43	1.39	0.0547
64	M2	3	60	2	4.27	3.2	0.1260
61	M2	3	60	3	4.39	3.49	0.1374
78	M2	4	25	1	4.15	1.22	0.0480
75	M2	4	25	2	5.43	2.61	0.1028
72	M2	4	25	3	6.05	3.65	0.1437
79	M2	4	48.5	1	4.08	1.99	0.0783
76	M2	4	48.5	2	3.79	2.66	0.1047
73	M2	4	48.5	**3**	5.23	3.97	0.1563
89	M2	4	60	1	3.51	1.43	0.0563
77	M2	4	60	2	4.99	3.29	0.1295
74	M2	4	60	3	4.9	3.3	0.1299
107	M8E	3	25	1	7.38	1.33	0.0524
110	M8E	3	25	2	6.13	3.67	0.1445
90	M8E	3	25	3	7.34	3.75	0.1476

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Blow 1 Depth (mm)	Blow 2 Depth (mm)	Blow 2 Depth (inches)
108	M8E	3	48.5	1	4.79	2.02	0.0795
111	M8E	3	48.5	2	3.83	3.89	0.1531
91	M8E	3	48.5	3	4.42	4.27	0.1681
109	M8E	3	60	1	4.33	1.03	0.0406
112	M8E	3	60	2	3.9	3.25	0.1280
92	M8E	3	60	3	5.23	4.77	0.1878
180	M8E	4	25	1	4.59	1.36	0.0535
177	M8E	4	25	2	6.46	3.27	0.1287
163	M8E	4	25	3	5.87	4.55	0.1791
181	M8E	4	48.5	1	4.78	2.42	0.0953
178	M8E	4	48.5	2	5.22	2.45	0.0965
164	M8E	4	48.5	3	4.5	4.16	0.1638
182	M8E	4	60	1	3.71	2.47	0.0972
179	M8E	4	60	2	5.35	3.87	0.1524
176	M8E	4	60	3	4.8	3.75	0.1476

Table 10. Ball Penetration Test Results with CRS-2P Binder.

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Blow 1 Depth (mm)	Blow 2 Depth (mm)	Blow 2 Depth (inches)
133	M2	3	25	1	6.51	1.3	0.0512
118	M2	3	25	2	7.9	1.51	0.0594
114	M2	3	25	3	7.43	3.61	0.1421
134	M2	3	37.5	1	4.64	0.69	0.0272
119	M2	3	37.5	2	8.27	3.28	0.1291
115	M2	3	37.5	3	6.32	2.76	0.1087
135	M2	3	60	1	5.79	0.89	0.0350
120	M2	3	60	2	6.66	3.29	0.1295
116	M2	3	60	3	7.61	4.48	0.1764
143	M2	4	25	1	4.36	0.7	0.0276
140	M2	4	25	2	8.33	2.73	0.1075
136	M2	4	25	3	8.58	3.04	0.1197

Sample Identifier	Aggregate Source Code	Grade	Embedment (%)	Number of Layers	Blow 1 Depth (mm)	Blow 2 Depth (mm)	Blow 2 Depth (inches)
144	M2	4	37.5	1	5.31	1.16	0.0457
141	M2	4	37.5	2	7.3	2.7	0.1063
137	M2	4	37.5	3	8.95	3.85	0.1516
145	M2	4	60	1	5.92	1.95	0.0768
142	M2	4	60	2	6.75	3.71	0.1461
139	M2	4	60	3	7.89	3.87	0.1524
150	M8E	3	25	1	6.66	1.49	0.0587
152	M8E	3	25	2	7.11	1.56	0.0614
155	M8E	3	25	3	6.34	3.67	0.1445
158	M8E	3	37.5	1	5.84	0.96	0.0378
153	M8E	3	37.5	2	8.59	1.88	0.0740
156	M8E	3	37.5	3	7.74	2.85	0.1122
159	M8E	3	60	1	6.18	1.7	0.0669
154	M8E	3	60	2	5.79	2.99	0.1177
157	M8E	3	60	3	4.93	2.94	0.1157
173	M8E	4	25	1	6.42	2.05	0.0807
170	M8E	4	25	2	7.18	3.49	0.1374
160	M8E	4	25	3	7.59	3.12	0.1228
174	M8E	4	37.5	1	5.02	1.83	0.0720
171	M8E	4	37.5	2	6.51	3.61	0.1421
161	M8E	4	37.5	3	6.47	2.86	0.1126
175	M8E	4	60	1	5.66	2.63	0.1035
172	M8E	4	60	2	6.14	3.16	0.1244
162	M8E	4	60	3	5.75	2.75	0.1083

Table 11. Averaged Ball Penetration Test Results by Binder Type and Layer.

Binder	1 Layer		2 Layers		3 Layers	
	Penetration Depth		Penetration Depth		Penetration Depth	
	(mm)	(inches)	(mm)	(inches)	(mm)	(inches)
CRS-2P	1.4458	0.0569	2.8258	0.1113	3.3167	0.1306
AC20-5TR	1.5158	0.0597	3.1567	0.1243	3.4408	0.1355
AR	1.6683	0.0657	3.2733	0.1289	3.8825	0.1529

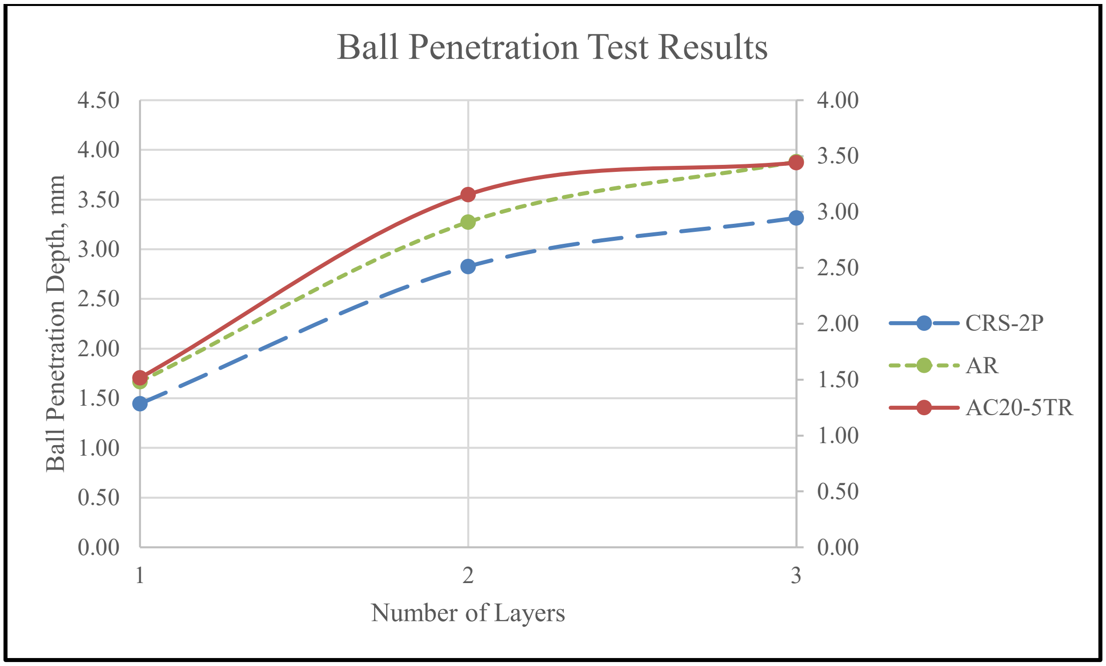

Figure 13. Averaged Ball Penetration Test Results by Binder Type and Layer.

Figure 14, Figure 15, and Figure 16 show the percentage aggregate embedment vs. ball penetration with the AC20-5TR, AR, and CRS-2P binders, respectively, and 1, 2, and 3 seal coat layers. As expected, the ball penetration depth increased as the number of layers increased.

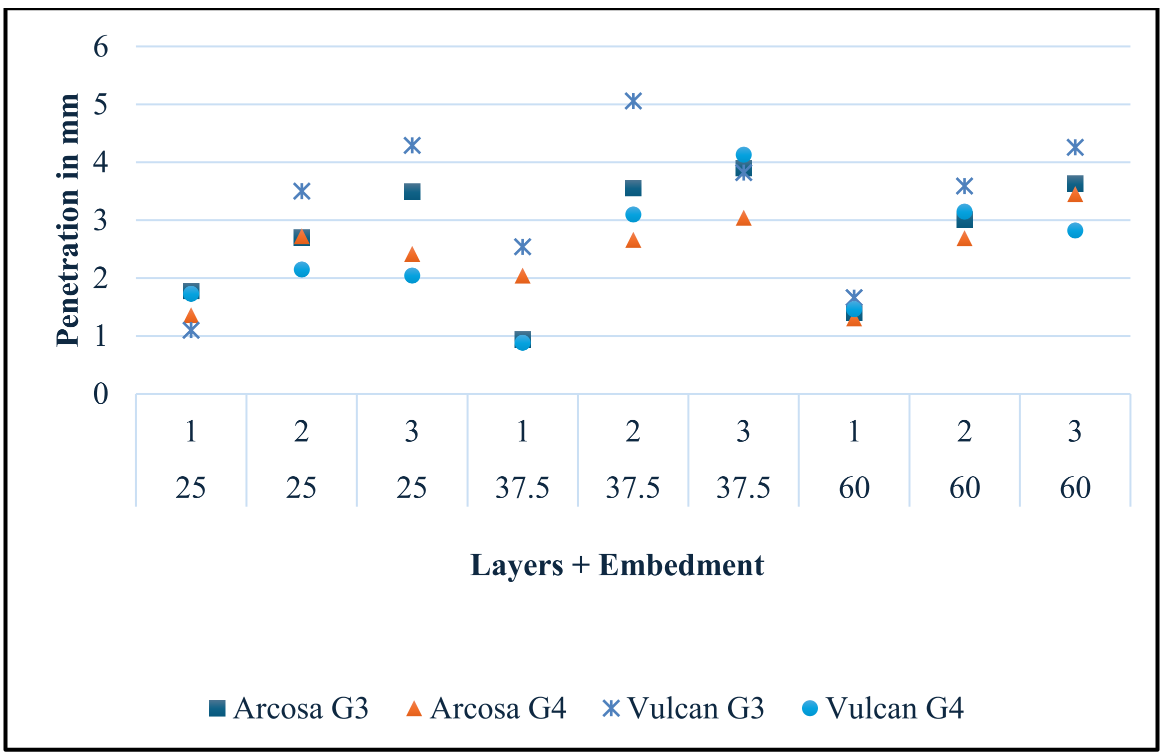

Figure 14. Percentage Aggregate Embedment vs. Ball Penetration with AC20-5TR Binder.

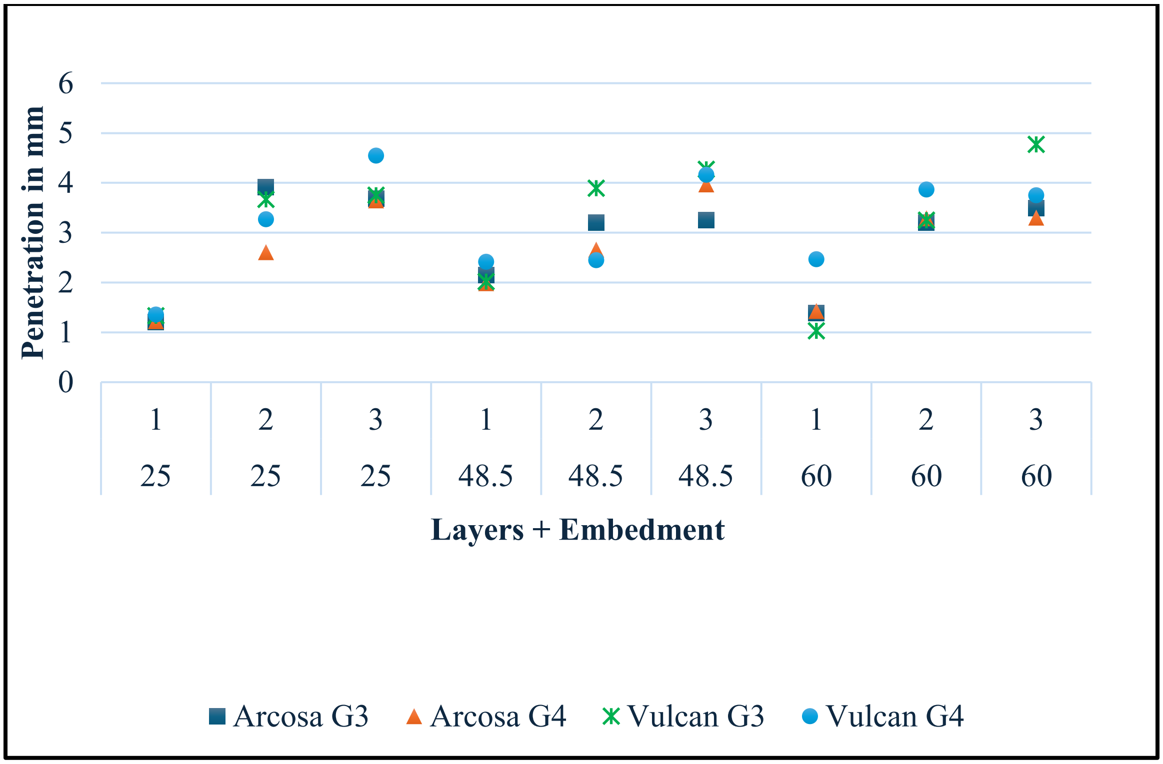

Figure 15. Percentage Aggregate Embedment vs. Ball Penetration with AR Binder.

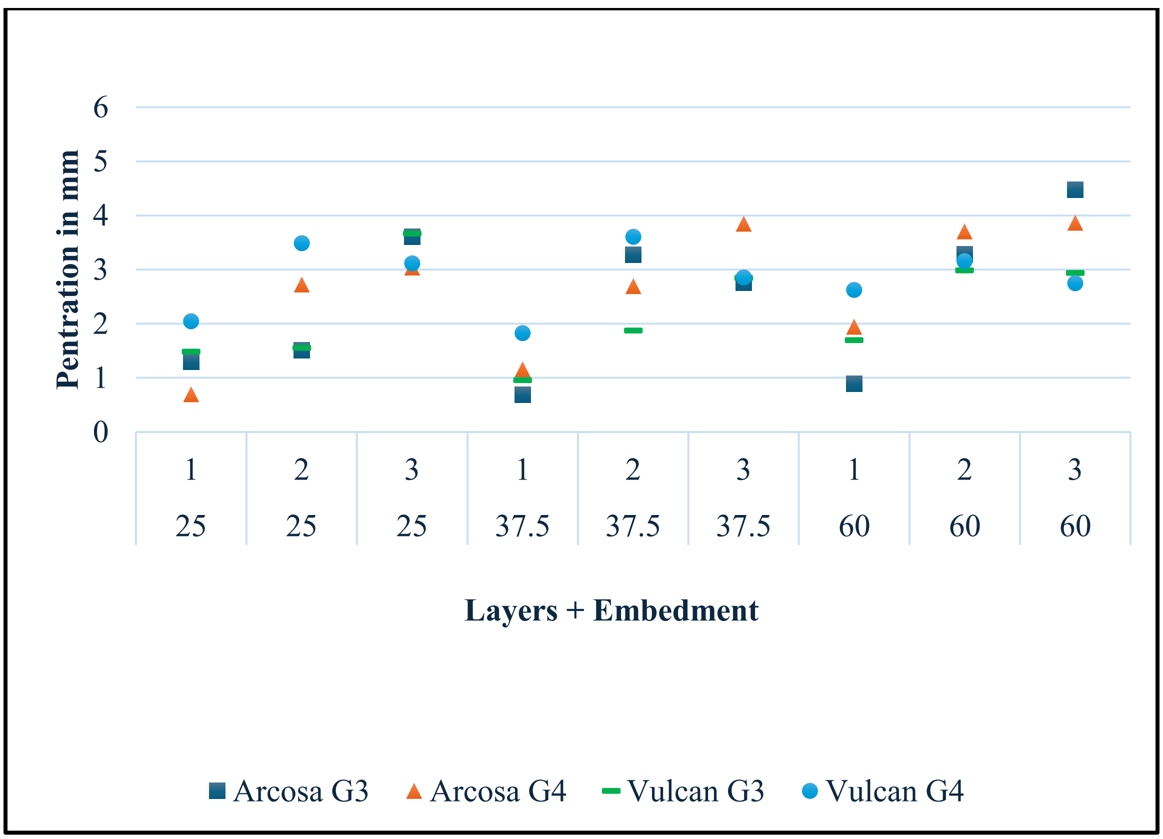

Figure 16. Percentage Aggregate Embedment vs. Ball Penetration with CRS-2P Binder.

If assuming that 0.118 to 0.157 inches (3 to 4 mm) is an upper limit envelope of stability, then three or more seal coat layers will show a more pronounced instability unless adjustments are made to the binder before layer application. The middle embedment layer designs (37.5 and 48.5 percent) were relatively stable for all numbers of layers.

Note that the specification related to the design rate for the ball penetration test (TNZ P/17:2002) requires that penetration values be adjusted as follows:

- If the penetration value is 0.039 inches (1 mm) or less, increase the average least dimension (ALD) of the aggregate by 0.039 inches (1 mm).
- If the penetration value is between 0.039 inches (1 mm) and 0.118 (3 mm) inches, make no adjustment.
- If the penetration value is between 0.118 inches (3 mm) and 0.157 inches (4 mm), decrease the ALD of the aggregate by 0.039 inches (1 mm).
- If the penetration value is greater than 0.197 inches (5 mm), conclude substrate is too soft for a chipseal (seal coat).

Also note that the ball penetration in the field is expected to be relatively lower due to long-term traffic compaction.

Figure 17, Figure 18, and Figure 19 show the effects of aggregate size (grade 3 vs. grade 4) on ball penetration with the AC20-5TR, AR, and CRS-2P binders, respectively. Initial analyses indicate that, with the AC20-5TR binder, instability was more likely to occur with grade 3 than grade 4 aggregates. The effects of aggregate size on stability (based on ball penetration) were less pronounced for the AR and CRS-2P binders.

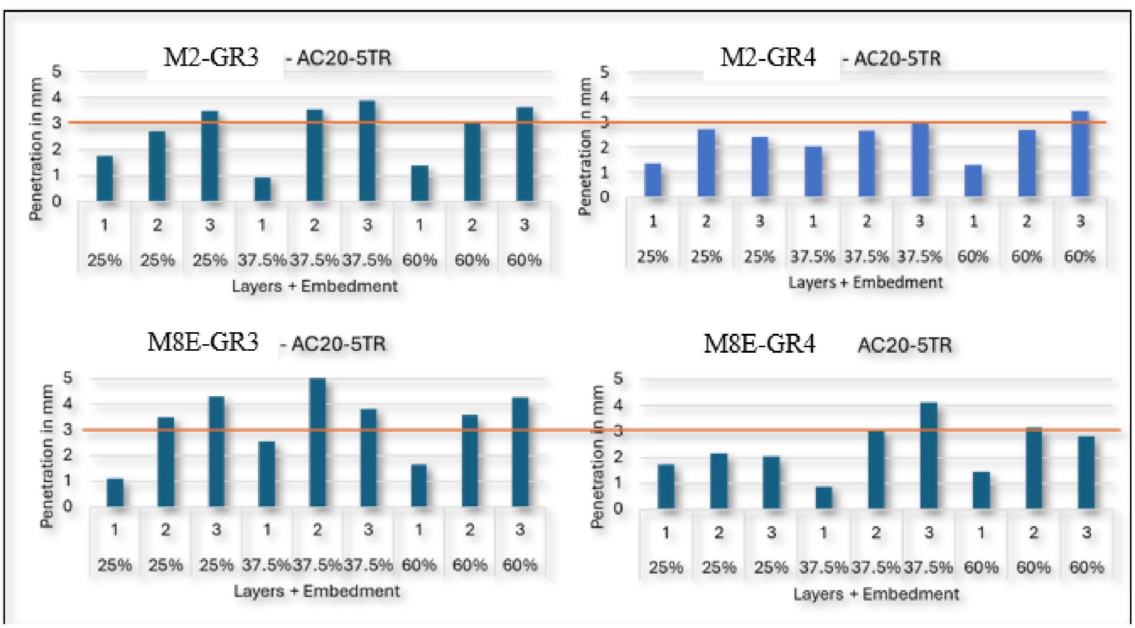

Figure 17. Effects of Aggregates Size on Ball Penetration with AC20-5TR Binder.

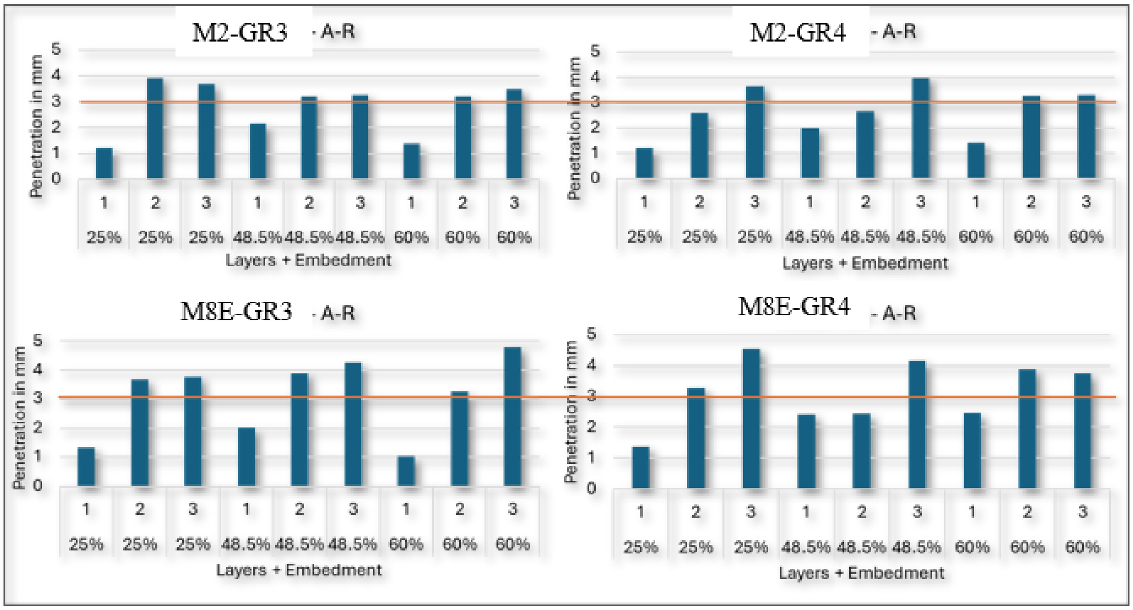

Figure 18. Effects of Aggregates Size on Ball Penetration with AR Binder.

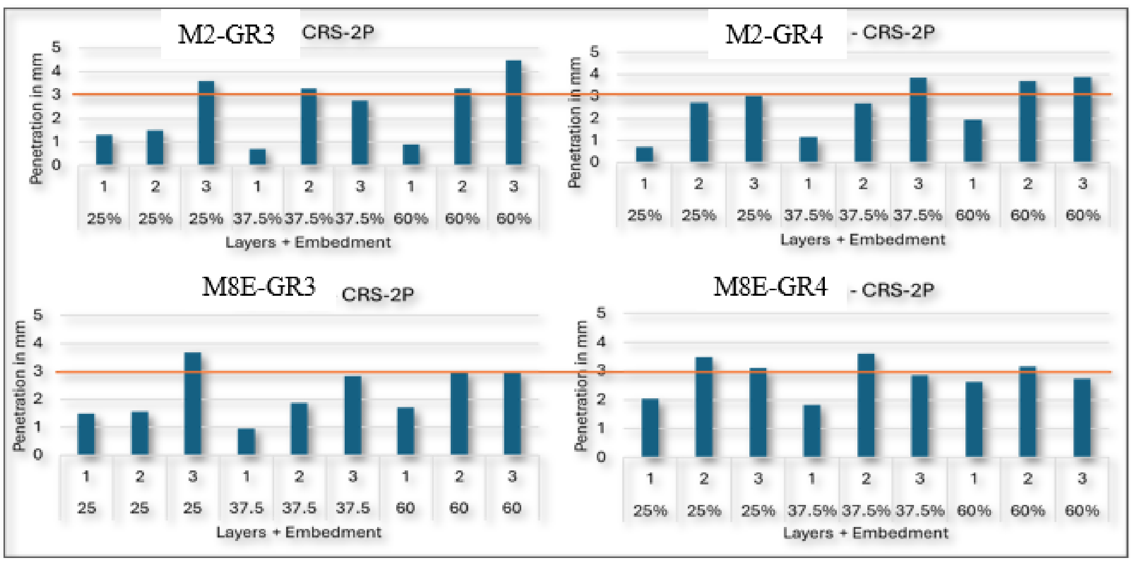

Figure 19. Effects of Aggregates Size on Ball Penetration with CRS-2P Binder.

A test procedure was developed for the ball penetration test in TxDOT's test procedure format. The proposed test is Tex-102X-S Ball Penetration Test for Seal Coat, and a copy is included in Appendix A. The climate plays a large part in the hardness of an existing surface. In the summer in Texas, pavement surface temperatures have been measured above 160°F in the sun while the pavement surface temperatures on the same roadway in the shade were near the ambient temperature. Currently New Zealand, South Africa, and Australia correlate the hardness reading based on the expected surface temperature; South Africa and Australia have produced regional maps.

To establish a temperature correction system for Texas, an HMA slab was prepared in the laboratory with 5 layers of seal coat. The ball penetration test was performed on this slab at the following temperatures:

- 50°F (10°C).
- 70°F (21.1 °C).
- 90°F (32.2 °C).
- 110°F (43.3 °C).
- 130°F (54.4 °C).

Figure 20 shows the results of this test, where E2–E1 is the measured ball penetration value.

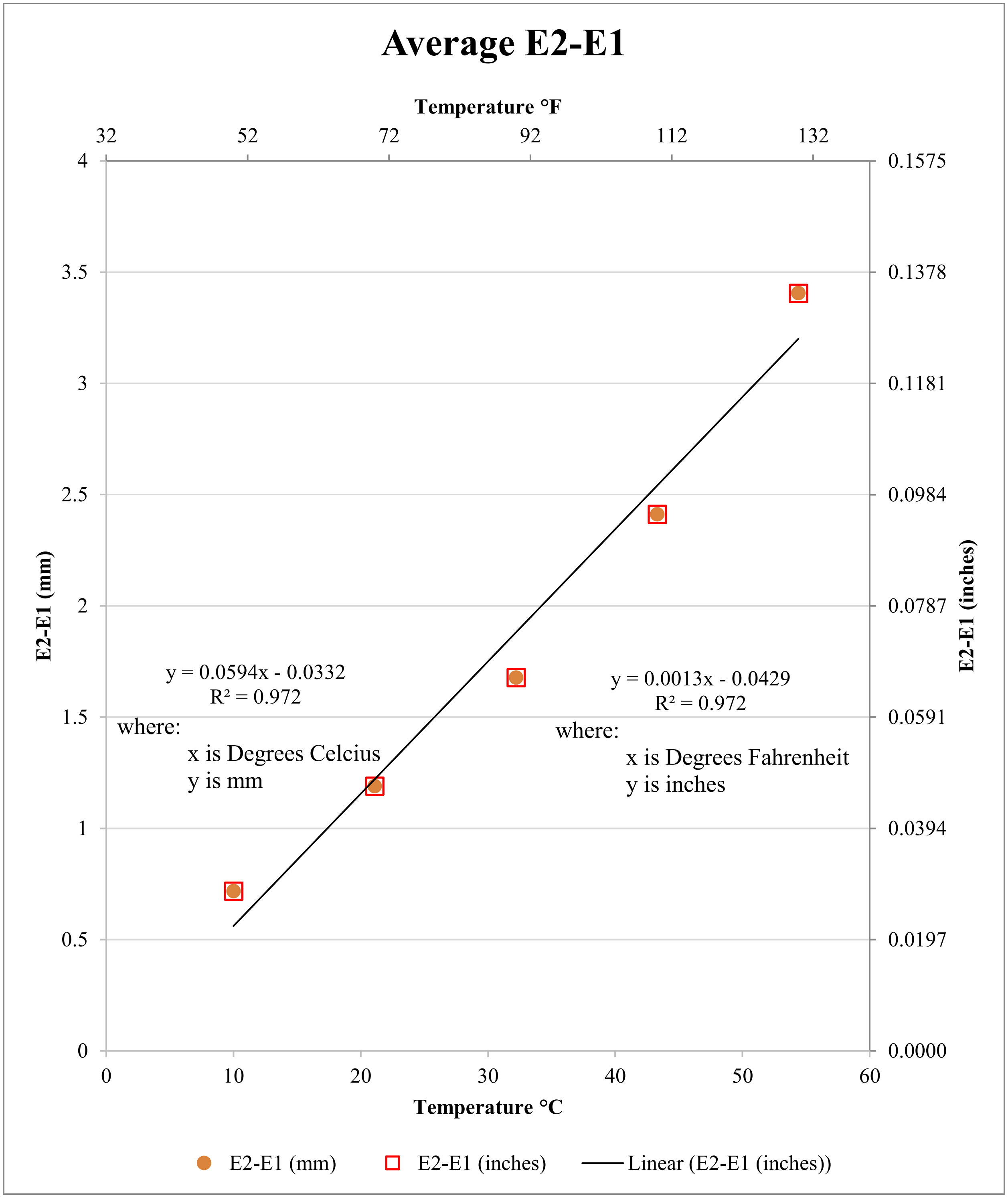

Figure 20. Temperature Range for Hardness Testing.

The relationship between the measured ball penetration value and temperature can be expressed as follows for penetration data collected in millimeters and temperature in °C (Equation 1) or for penetration data collected in inches and temperature in °F (Equation 2):

$$P = 0.0594 \times T_{(dt)} - 0.0332 \qquad \text{Equation 1}$$

$$P = 0.0013 \times T_{(dt)} - .0429 \qquad \text{Equation 2}$$

where:

P = ball penetration (mm or inches).
$T_{(dt)}$ = surface temperature (°C or °F) at design or testing.

Next, a relationship can be established between the ball penetration at the testing temperature and the ball penetration at a reference or design temperature by taking the difference between the two equation conditions (design and field test) and simplifying. When International System of Units measurements are used, the following relationship results:

$$P_d - P_t = (0.0594 \times T_d - 0.0332) - (0.0594 \times T_t - 0.0332)$$

$$P_d = P_t + 0.0594 \cdot T_d - 0.0594 \times T_t$$

$$P_d = P_t + 0.0594(T_d - T_t) \qquad \text{Equation 3}$$

where:

P_d = ball penetration at the design temperature (mm).
T_d = design temperature (°C).
P_t = ball penetration at the test temperature (mm).
T_t = test surface temperature (°C).

A similar derivation using the imperial system of units produced the following relationship:

$$P_d = P_t + 0.0013(T_d - T_t) \qquad \text{Equation 4}$$

where:

P_d = ball penetration at the design temperature (inches).
T_d = design temperature (°F).
P_t = ball penetration at the test temperature (inches).
T_t = test surface temperature (°F).

This relationship is in a form similar to the temperature correction equation used in the test methods from South Africa, New Zealand, and Australia, where K (mm/°C) represents a temperature correction constant based on the surface type. The temperature correction value from this laboratory test (K = 0.00635 mm/°C) was slightly higher than the 0.04 mm/°C value recommended for single and multiple unflushed seal coats in the New Zealand specifications. However, the laboratory prepared slab was not subject to the effects of traffic or aging, which would significantly reduce the ball penetration rate.

For design purposes, the research team recommends using the New Zealand correction of 0.04 mm/°C (0.000875 inches/°F) to account for the age hardening of an in-place seal coat. These values would replace the rate of change in Equation 3 and Equation 4, resulting in Equation 5 (International System of Units) and Equation 6 (imperial system of units) as follows:

$$P_d = P_t + 0.04(T_d - T_t) \quad \text{Equation 5}$$

$$P_d = P_t + 0.000875(T_d - T_t) \quad \text{Equation 6}$$

Figure 21 shows an example temperature correction with age hardening.

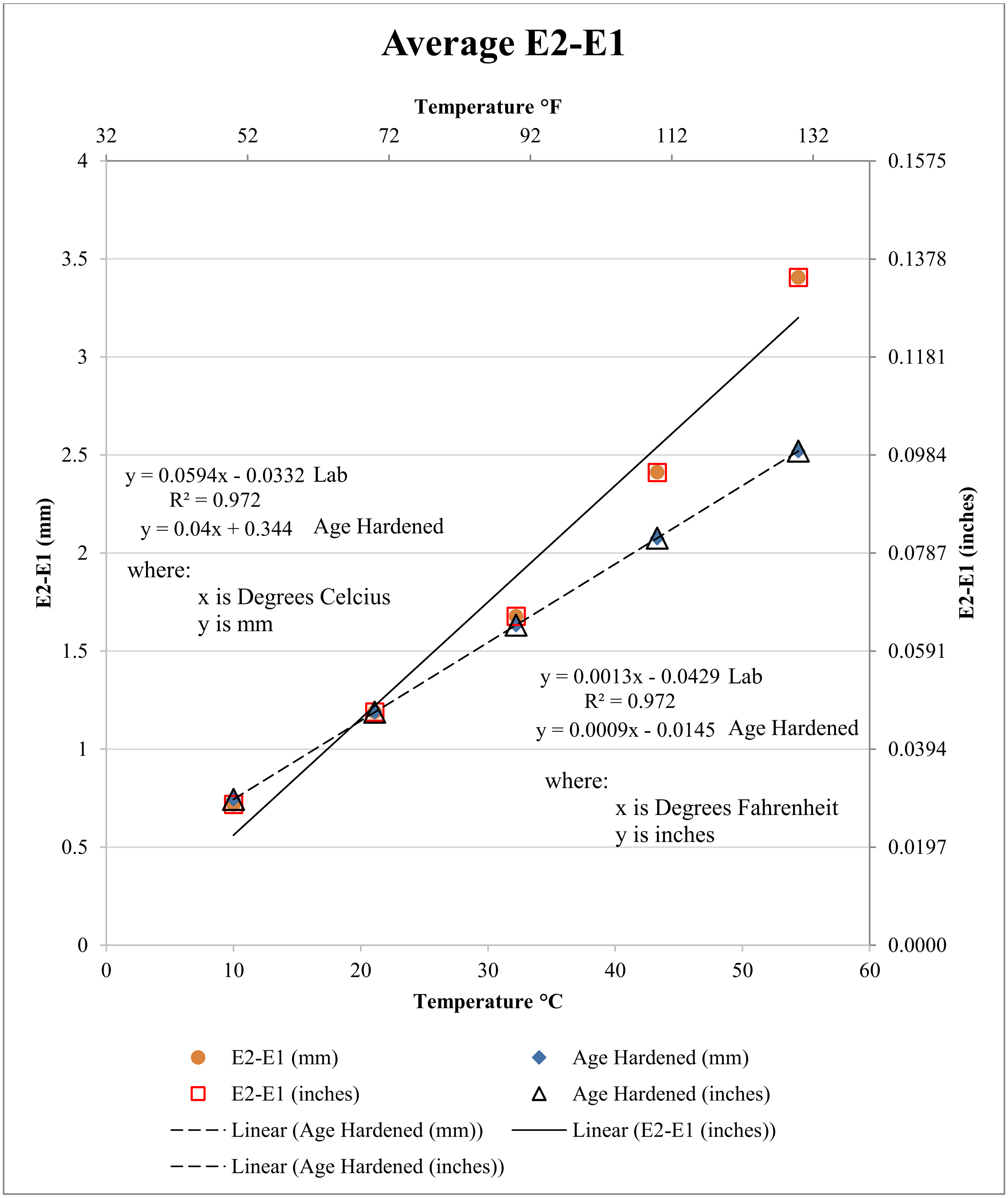

Figure 21. Example Temperature Correction with Age Hardening.

Equation 5 and Equation 6 can be used with a design temperature of 104°F (40°C) to simulate pavement conditions in shaded areas or higher design temperatures based on the expected surface temperature during construction in unshaded areas. Equation 3 and Equation 4 can be used when placing a second seal coat on a fresh seal coat. The temperature-corrected penetration value (E2–E1) should be considered for the design rate adjustment.

CHAPTER 3. FIELD STABILITY STUDY

FIELD CASE STUDY LOCATIONS

The roadway test sections selected for the field case studies were located in TxDOT's Atlanta (ATL), Brownwood (BWD), Bryan (BRY), and Beaumont (BMT) Districts. Table 12 and Figure 22 detail the test site characteristics and geographic locations.

Table 12. Field Test Site Characteristics.

Site	District	Let Year	County	Highway	Start	End
1	ATL	2022	Cass	SH 77	3.2 miles west of SH 8	0.3 miles west of FM 994
2	ATL	2023	Cass	SH 43	Railroad overpass	Marion county line
3	ATL	2023	Cass	FM 249	FM 3129	Arkansas state line
4	ATL	2023	Cass	SH 77	0.3 miles west of FM 994	FM 250
5	ATL	2023	Morris	SH 77	Cass county line	US 259
6	ATL	2023	Morris	FM 144	US 259 N	US 67
6x	ATL	2023	Titus	US 67	Morris county line	BU 271
7	BMT	2023	Chambers	FM 2936	End of maintenance	FM 562
8	BMT	2023	Chambers	SH 73	FM 1663 East	Jefferson county line
9	BMT	2023	Chambers	FM 1663	SH 61 East	1.20 miles east
10	BMT	2023	Liberty	FM 563	US 90 South	1.3 miles south
11	BMT	2022	Jasper	FM 1005	FM 252	FM 1013
12	BRY	2023	Washington	SH 36	BS 36J North	US 290
13	BRY	2023	Washington	SH 36	BS 36J South	Austin county line
14	BRY	2023	Washington	FM 390	SH 36	FM 50
15	BRY	2023	Washington	FM 1155	FM 912	FM 2726
16	BRY	2023	Washington	FM 1155	FM 2726	FM 2193
17	BRY	2023	Washington	FM 2193	SH 105	FM 1155
18	BWD	2023	Comanche	SH 36	0.4 miles south of FM 1702 East	Hamilton county line
19	BWD	2023	Comanche	US 67	Elm Street	0.5 miles west of Indian Creek
20	BWD	2023	Comanche	FM 591	FM 1476 East	FM 1702
21	BWD	2023	Comanche	FM 2561	FM 1476 East	FM 1702

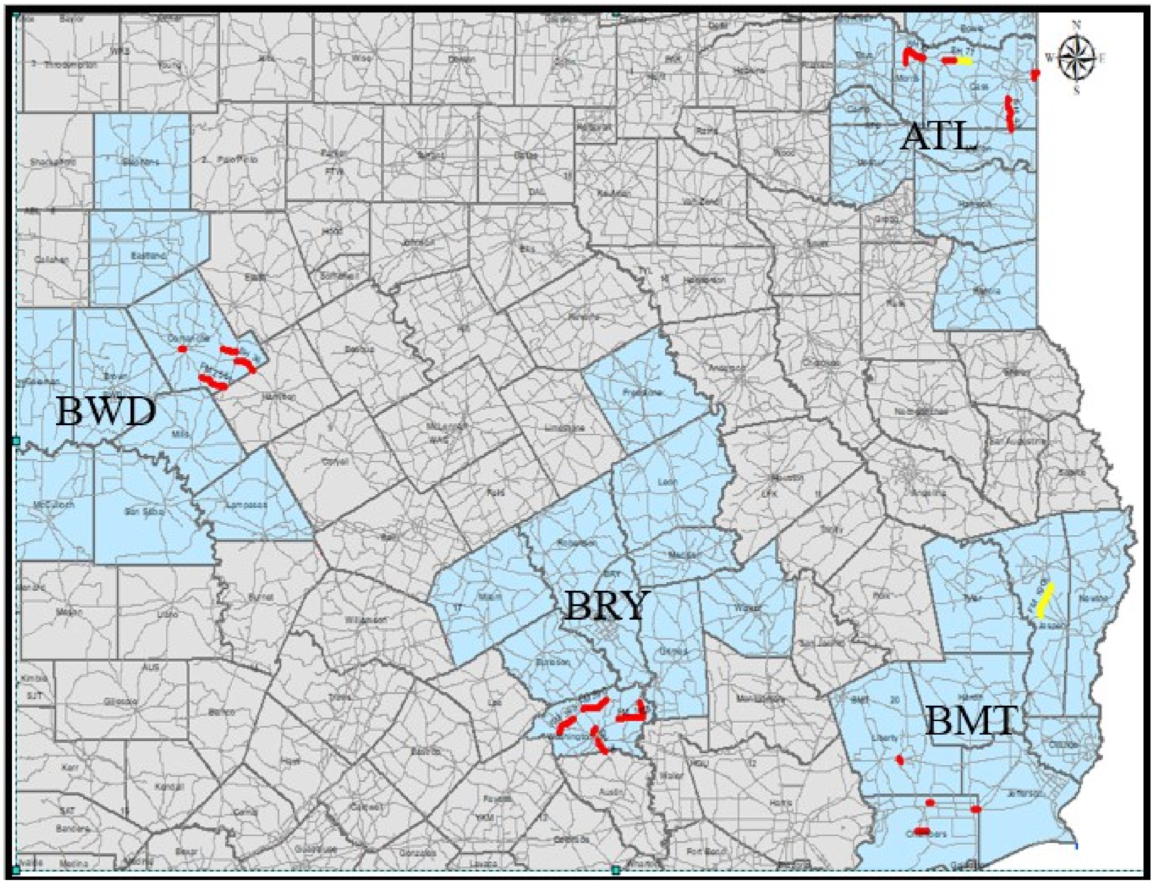

Figure 22. Field Test Site Map.

Each test section was tested before seal coat construction, just after seal coat construction, and approximately 1 year after seal coat construction. A high-definition video was taken to visually document the site conditions.

BALL PENETRATION FIELD TESTING

The fabricated MDCP (Figure 23) was field tested before the construction of new seal coats on the following two sites in Texas:

- US 67 near Comanche, Texas, in TxDOT's Brownwood District on June 20, 2023.
- US 67 near Mt. Pleasant, Texas, in TxDOT's Atlanta District on June 29, 2023.

Ball penetration measurements were taken at three locations on the old surface: in the left and right wheel paths (LWP and RWP) and between the wheel paths (BWP). The surface between the wheel paths was typically more brittle with little to no bleeding, whereas the wheel path surfaces were bleeding and flushing in most cases. Figure 24 shows the MDCP in operation on US 67 near Mt. Pleasant, Texas. Table 13 summarizes the test results. A temperature factor was developed in the laboratory to correlate the field ball penetration measurements to 104°F (40°C).

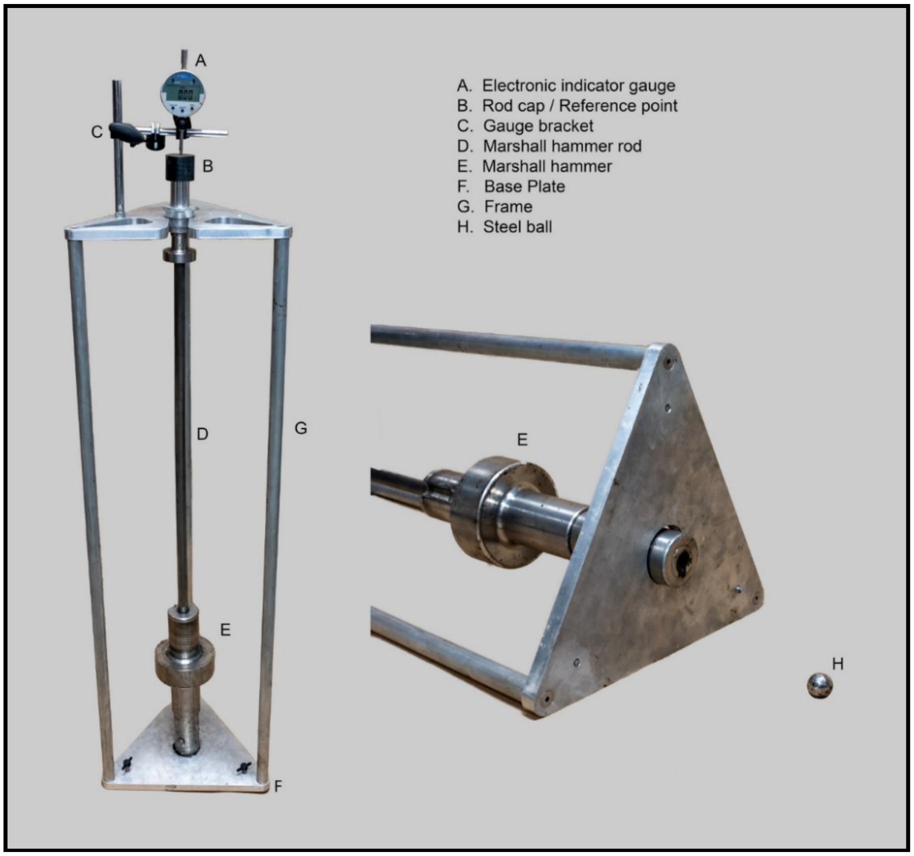

Figure 23. Fabricated MDCP.

Figure 24. MDCP Field Test on US 67 near Mt. Pleasant, Texas.

Table 13. Ball Penetration Test Results.

Road	Surfacing	Test No.	Location	Embedment		Corrected Ball Penetration (mm)	Corrected Ball Penetration (inches)
				E1	E2		
US 67-Comanche	Surface seal	1	LWP	2.2	3.44	1.25	0.049
US 67-Comanche	Surface seal	1	BWP	2.04	3.06	1.03	0.041
US 67-Comanche	Surface seal	1	RWP	2.34	3.77	1.3	0.051
US 67-Comanche	Surface seal	2	LWP	2.25	3.54	1.25	0.049
US 67-Comanche	Surface seal	2	BWP	2.83	4.06	1.17	0.046
US 67-Comanche	Surface seal	2	RWP	2.21	3.74	1.53	0.060
US 67-Comanche	HMA	3	BWP	2.04	3.04	1.01	0.040
US 67 Mt. Pleasant	Surface seal	1	LWP	2.02	3.28	1.31	0.052
US 67-Mt. Pleasant	Surface seal	1	BWP	2.19	3.68	1.5	0.059
US 67-Mt. Pleasant	Surface seal	1	RWP	2.37	3.66	1.23	0.048
US 67-Mt. Pleasant	Surface seal	2	LWP	2.39	3.72	1.26	0.050
US 67-Mt. Pleasant	Surface seal	2	BWP	2.48	3.97	1.45	0.057
US 67-Mt. Pleasant	Surface seal	2	RWP	2.3	3.6	1.17	0.046

The South African specifications note that a ball penetration test result of over 3 mm (0.118 inches) would indicate an unstable surface requiring treatment before a new seal coat can be applied. From the field results taken during July and August 2023 in Texas, no excessive penetration was observed, although some bleeding and flushing was evident. The temperature corrected ball penetration values ranged from 1.03 mm (0.04 inches) to 1.53 mm (0.06 inches), which results in an asphalt application difference of approximately 0.03 gallons per square yard, according to the South African design method.

Chipsealing in New Zealand [4] recommends increasing the ALD of the aggregate by 1 mm (0.039 inches) when the ball penetration value is less than or equal to 1 mm (0.039 inches); decreasing the ALD of the aggregate by 1 mm (0.039 inches) when the ball penetration value is between 3 and 4 mm (0.118 and 0.157 inches); and concluding the substrate is too soft for a normal chipseal and pavement repairs are required when the ball penetration value is greater than 5 mm (0.197 inches). Typical ball penetration values in New Zealand range from 2 to 3 mm (0.079 to 0.118 inches) [5]. Table 14 summarizes these New Zealand hardness adjustments.

Table 14. New Zealand Hardness Adjustments [5].

Ball Penetration Test Result	Corresponding Action
≤ 1 mm (0.039 inches)	Increase aggregate ALD by 1 mm (0.039 inches)
3–4 mm (0.118–0.157 inches)	Decrease aggregate ALD by 1 mm (0.039 inches)
> 5 mm (0.197 inches)	Opt to repair pavement instead of apply seal coat

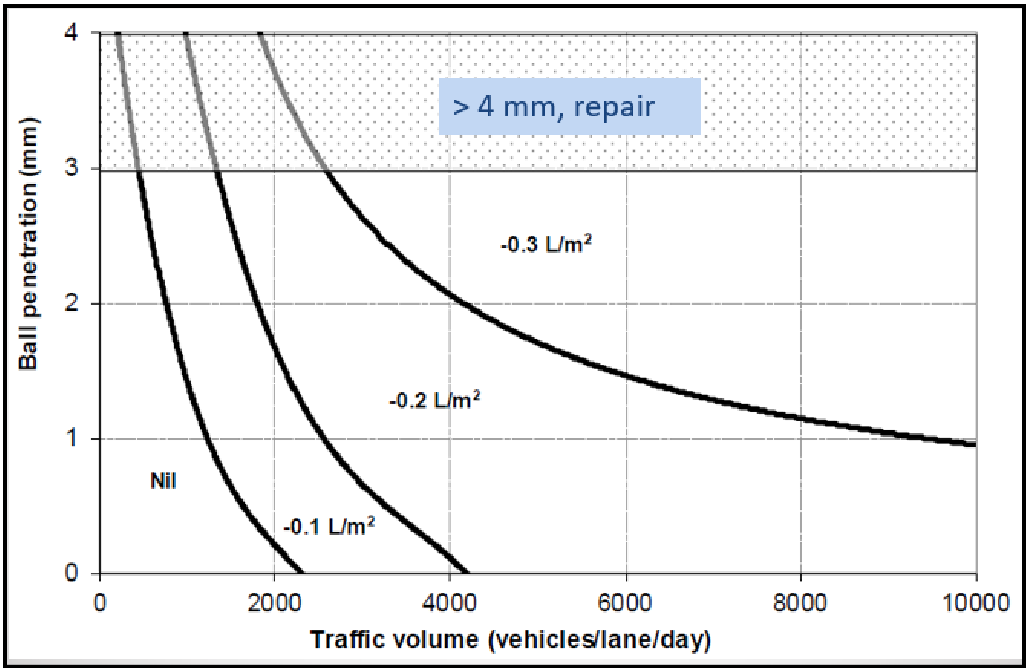

Figure 25. Australian Application Rate Adjustment [6].

Similarly, Australia's *Guide to Pavement Technology Part 4K: Selection and Design of Sprayed Seals* [7] recommends, "Where ball embedment exceeds 4 mm (0.157 inches), re-preparation of the pavement, including possibilities for improvement in quality of the pavement material, armor coating with a thin layer of good quality material, stabilization and other treatments should be considered." Figure 25 contains the Australian application rate adjustment criteria.

Figure 26 shows the average thicknesses of the aggregate and binder for grade 3, 4, and 5 aggregates and for seal coat layers 1, 2, and 3, assuming a 35 percent embedment. The shaded box represents the New Zealand and Australian limits for the ball penetration test results.

Table 15 contains typical binder layer thicknesses for different combinations of seal coats. The maximum typical combination of binders is 0.158 inches. Therefore, a pavement section with three or more layers of seal coat could exceed this limit and lead to seal coat issues.

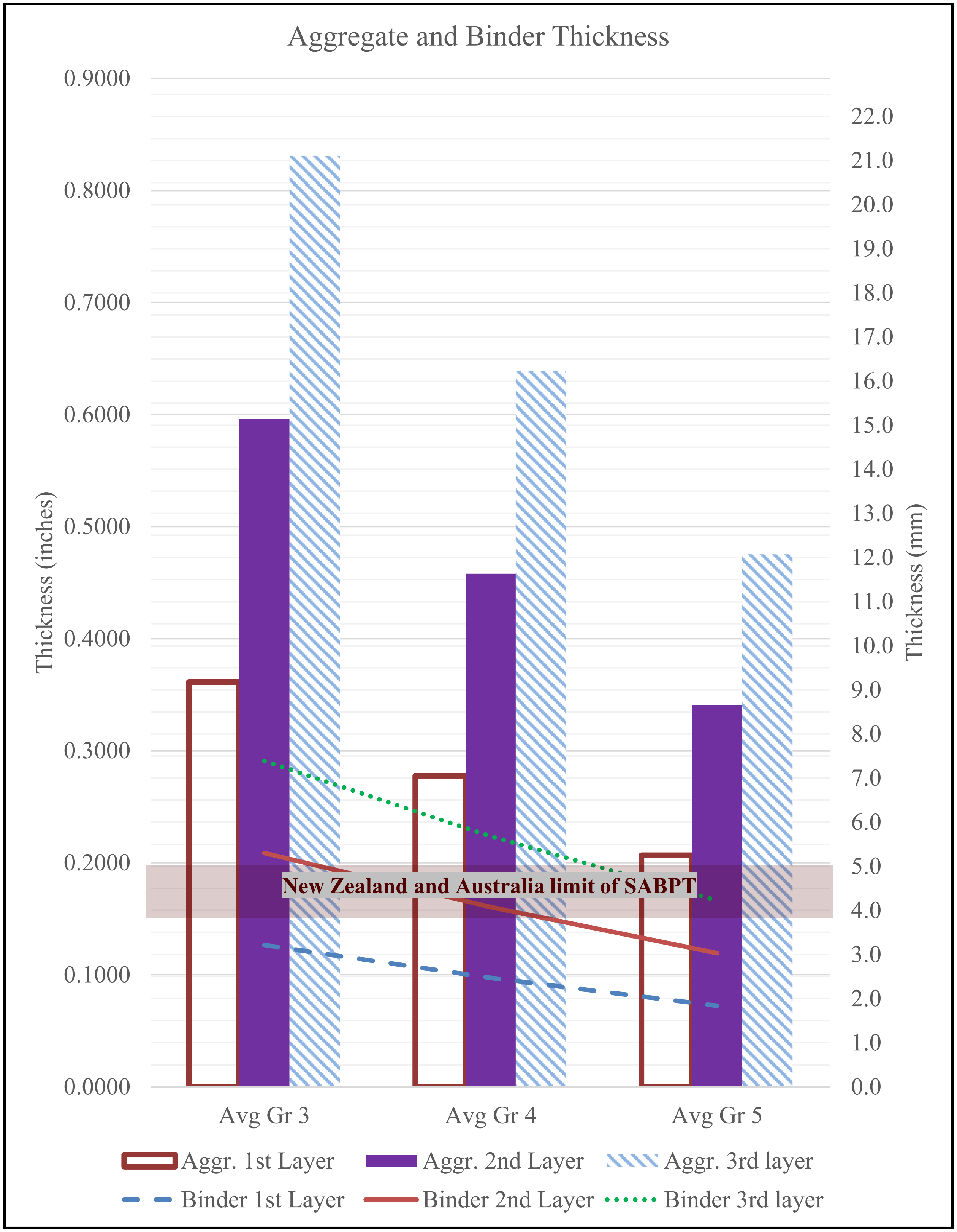

Figure 26. Average Aggregate and Binder Thicknesses for Layers 1, 2, and 3 of a Seal Coat.

Table 15. Estimated Binder Layer Thicknesses for Various Seal Coat Combinations.

Aggregate Grade (Top→Bottom)	Binder Layer Thickness (inches)	Binder Layer Thickness (mm)
Grade 3	0.126	3.212
Grade 4	0.097	2.468
Grade 5	0.072	1.837
Grade 3→grade 4	0.205	5.198
Grade 4→grade 4	0.180	4.566
Grade 4→grade 4→grade 5	0.238	6.033
Grade 4→grade 3→grade 5	0.262	6.665
Grade 3→grade 3→grade 5	0.287	7.297

FIELD SITES

The roadways selected for field evaluation are located in TxDOT's Atlanta, Brownwood, Bryan, and Beaumont Districts. Only one roadway required maintenance work just after construction due to excessive bleeding. All other roadways held up well 1 year after construction. Figure 27, Figure 28, and Figure 29 show before and after images along FM 563 in TxDOT's Beaumont District, FM 1155 in TxDOT's Bryan District, and US 67 in TxDOT's Brownwood District, respectively. These example pavement sections had no visual issues with the seal coat.

Figure 27. FM 563 in TxDOT's Beaumont District Before and After Construction.

Figure 28. FM 1155 in TxDOT's Bryan District Before and After Construction.

Figure 29. US 67 near Comanche, Texas, in TxDOT's Brownwood District Before and After Construction.

Tabular summaries of the data collected at each site and before and after construction images follow. Texture data (for TxDOT Project 0-7105) and high-definition video were collected after maintenance preparation, just after construction and approximately 1 year after construction. Note that summary data was not included for three sites: site 12 in TxDOT's Bryan District was not sealed, site 6x in TxDOT's Brownwood District was only tested for hardness, and site 18 in TxDOT's Atlanta District had incorrect limits and suspect data.

Field Site 1

Field site 1 is in TxDOT's Atlanta District, in Cass County, on SH 77 from 3.2 miles west of SH 8 to 0.3 miles west of FM 994. Table 16 lists the summary data for this site, and Figure 30 shows the before and after seal coat construction images.

Table 16. Site 1 Summary.

Description	Results
ADT (veh/day)	1,653
Trucks (%)	7.6
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.33
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	148
Construction date	2022
Texture (mils): 6/16/2022	n/a
Texture after seal coat (mils): 3/23/2023	93.4
Second texture after seal coat (mils): 5/9/2024	69.4
Observations	Preparatory work affected the seal coat. Otherwise, seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

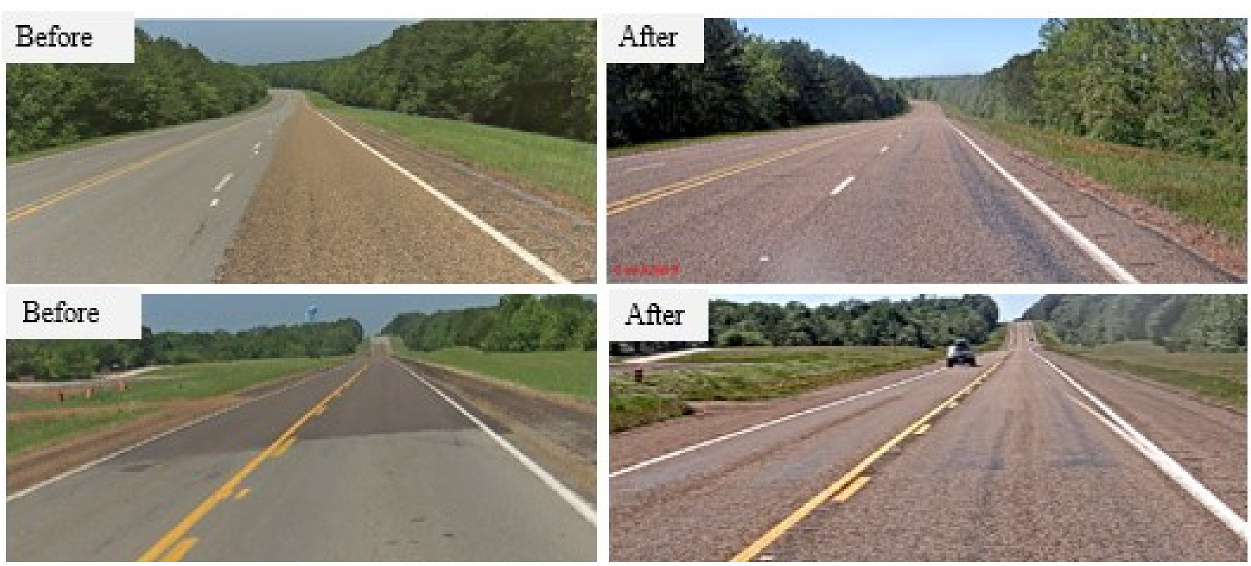

Figure 30. Site 1 Before and After Seal Coat Construction.

Field Site 2

Field site 2 is in TxDOT's Atlanta District, in Cass County, on SH 43 from the railroad overpass to the Marion county line. Table 17 lists the summary data for this site, and Figure 31 shows the before and after seal coat construction images.

Table 17. Site 2 Summary.

Description	Results
ADT (veh/day)	960
Trucks (%)	14.9
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.39
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	137
Construction date	6/19/2023
Texture (mils): 5/15/2023	32.4
Texture after seal coat (mils): 7/6/2023	103.8
Second texture after seal coat (mils): 5/13/2024	92.6
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 31. Site 2 Before and After Seal Coat Construction.

Field Site 3

Field site 3 is in TxDOT's Atlanta District, in Cass County, on FM 249 from FM 3129 to the Arkansas state line. Table 18 lists the summary data for this site, and Figure 32 shows the before and after seal coat construction images.

Table 18. Site 3 Summary.

Description	Results
ADT (veh/day)	1,197
Trucks (%)	6.9
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.36
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	142
Construction date	6/19/2023
Texture (mils): 5/15/2023	36
Texture after seal coat (mils): 7/7/2023	85.4
Second texture after seal coat (mils): 5/9/2024	56.6
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss. However, some signs of flushing were observed.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 32. Site 3 Before [9] and After Seal Coat Construction.

Field Site 4

Field site 4 is in TxDOT's Atlanta District, in Cass County, on SH 77 from 0.3 miles west of FM 994 to FM 250. Table 19 lists the summary data for this site, and Figure 33 shows the before and after seal coat construction images.

Table 19. Site 4 Summary.

Description	Results
ADT (veh/day)	1,197
Trucks (%)	6.9
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.36
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	142
Construction date	6/19/2023
Texture (mils): 5/15/2023	36
Texture after seal coat (mils): 7/7/2023	85.4
Second texture after seal coat (mils): 5/9/2024	56.6
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss. However, some signs of flushing and raveling were observed between the wheel paths.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 33. Site 4 Before and After Seal Coat Construction.

Field Site 5

Field site 5 is in TxDOT's Atlanta District, in Cass County, on SH 77 from the Cass county line to US 259. Table 20 lists the summary data for this site, and Figure 34 shows the before and after seal coat construction images.

Table 20. Site 5 Summary.

Description	Results
ADT (veh/day)	2,181
Trucks (%)	7.6
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.34
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	145
Construction date	6/24/2023
Texture (mils): 5/17/2023	46
Texture after seal coat (mils): 7/6/2023	92
Second texture after seal coat (mils): 5/13/2024	78
Observations	Preparatory work affected the seal coat. Some flushing was observed in the wheel paths.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 34. Site 5 Before and After Seal Coat Construction.

Field Site 6

Field site 6 is in TxDOT's Atlanta District, in Morris County, on FM 144 from US 259 north to US 67. Table 21 lists the summary data for this site, and Figure 35 shows the before and after seal coat construction images.

Table 21. Site 6 Summary.

Description	Results
ADT (veh/day)	954
Trucks (%)	19
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.5
Aggregate application rate (yd^2/yd^3): PB[1] grade 3	110
Construction date	6/26/2023
Texture (mils): 5/15/2023	53.6
Texture after seal coat (mils): 7/6/2023	127.9
Second texture after seal coat (mils): 5/9/2024	106.6
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 35. Site 6 Before and After Seal Coat Construction.

Field Site 6x

Field site 6x is in TxDOT's Atlanta District, in Titus County, on US 67 from the Morris county line to BU 271. Table 22 lists the summary data for this site, and Figure 36 shows the before and after seal coat construction images.

Table 22. Site 6x Summary.

Description	Results
ADT (veh/day)	7,975
Trucks (%)	12.2
Precipitation (inches/year)	49
Climate zone	East Texas
Estimated date of first frost	11/27
Binder application rate (gal/yd^2): AC20-5TR	0.34
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	145
Construction date	6/29/2023
Before Construction Texture (mils): n/a	n/a
Texture after seal coat (mils): 7/7/2023	96.6
Second texture after seal coat (mils): 4/11/2024	79.4
Observations	Flushing was observed in the wheel paths.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 36. Site 6x Before and After Seal Coat Construction.

Field Site 7

Field site 7 is in TxDOT's Beaumont District, in Chambers County, on FM 2936 from the end of maintenance to FM 562. Table 23 lists the summary data for this site, and Figure 37 shows the before and after seal coat construction images.

Table 23. Site 7 Summary.

Description	Results
ADT (veh/day)	364
Trucks (%)	10.2
Precipitation (inches/year)	56
Climate zone	Upper Coast
Estimated date of first frost	1/3
Binder application rate (gal/yd^2): AC20-5TR	0.35
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	146
Construction date	5/4/2023
Texture (mils): 3/15/2023	37.2
Texture after seal coat (mils): 5/15/2023	90.4
Second texture after seal coat (mils): 5/13/2024	61.5
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 37. Site 7 Before and After Seal Coat Construction.

Field Site 8

Field site 8 is in TxDOT's Beaumont District, in Chambers County, on SH 73 from FM 1663 to the Jefferson county line. Table 24 lists the summary data for this site, and Figure 38 shows the before and after seal coat construction images.

Table 24. Site 8 Summary.

Description	Results
ADT (veh/day)	7,586
Trucks (%)	19.4
Precipitation (inches/year)	56
Climate zone	Upper Coast
Estimated date of first frost	1/
Binder application rate (gal/yd^2): AC20-5TR	0.34
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	129
Construction date	5/8/2023
Texture (mils): K1-3/15/2023, K2-3/16/2023	28.1
Texture after seal coat (mils): 5/24/2023	46.3
Second texture after seal coat (mils): 5/9/2024	28.1
Observations	Existing flushing affected the new seal coat, which has excessive flushing in the wheel paths. Rock loss may have led to the flushing.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 38. Site 8 Before and After Seal Coat Construction.

Field Site 9

Field site 9 is in TxDOT's Beaumont District, in Chambers County, on FM 1663 from SH 61 East to 1.2 miles south. Table 25 lists the summary data for this site, and Figure 39 shows the before and after seal coat construction images.

Table 25. Site 9 Summary.

Description	Results
ADT (veh/day)	452
Trucks (%)	4.6
Precipitation (inches/year)	56
Climate zone	Upper Coast
Estimated date of first frost	1/3
Binder application rate (gal/yd^2): AC20-5TR	0.34
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	133
Construction date	5/4/2023
Texture (mils): 3/16/2023	36.3
Texture after seal coat (mils): 5/16/2023	88.1
Second texture after seal coat (mils): 5/9/2024	57.7
Observations	Existing flushing affected the new seal coat. Otherwise, the seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 39. Site 9 Before and After Seal Coat Construction.

Field Site 10

Field site 10 is in TxDOT's Beaumont District, in Liberty County, on FM 563 from US 90 South to 1.3 miles south. Table 26 lists the summary data for this site, and Figure 40 shows the before and after seal coat construction images.

Table 26. Site 10 Summary.

Description	Results
ADT (veh/day)	4,528
Trucks (%)	2.4
Precipitation (inches/year)	56
Climate zone	Upper Coast
Estimated date of first frost	1/1
Binder application rate (gal/yd^2): AC20-5TR	0.36
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	139
Construction date	5/3/2023
Texture (mils): 3/16/2023	25.1
Texture after seal coat (mils): 5/16/2023	78
Second texture after seal coat (mils): 5/9/2024	51.0
Observations	Slight flushing was observed in the wheel paths with some rock loss.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 40. Site 10 Before and After Seal Coat Construction.

Field Site 11

Field site 11 is in TxDOT's Beaumont District, in Jasper County, on FM 1005 from FM 252 to FM 1013. Table 27 lists the summary data for this site, and Figure 41 shows the before and after seal coat construction images.

Table 27. Site 11 Summary.

Description	Results
ADT (veh/day)	757
Trucks (%)	21
Precipitation (inches/year)	48
Climate zone	East Texas
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.33
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	148
Construction date	2022
Texture (mils): 6/1/2022	83.04
Texture after seal coat (mils): 3/15/2022	66.3
Second texture after seal coat (mils): n/a	n/a, overlaid
Observations	Excessive bleeding led to an overlay within 1 year of construction. Seal coat application rate was fairly low, which may indicate that the existing pavement also had excessive bleeding in the wheel paths.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 41. Site 11 Before and After Seal Coat Construction.

Field Site 13

Note that field site 12 was not sealed and was thus not included here. Field site 13 is in TxDOT's Bryan District, in Washington County, on SH 36 from BS 36J (south) to the Austin county line. Table 28 lists the summary data for this site, and Figure 42 shows the before and after seal coat construction images.

Table 28. Site 13 Summary.

Description	Results
ADT (veh/day)	6,035
Trucks (%)	20.4
Precipitation (inches/year)	42
Climate zone	South Central
Estimated date of first frost	12/12
Binder application rate (gal/yd^2): AC20-5TR	0.34
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	132
Construction date	6/6/2023
Texture (mils): 4/25/2023	34.4
Texture after seal coat (mils): 6/12/2023	52.1
Second texture after seal coat (mils): 5/9/2024	33.0
Observations	Existing flushing affected the new seal coat, which has excessive flushing in the wheel paths. Rock loss may have led to flushing.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 42. Site 13 Before and After Seal Coat Construction.

Field Site 14

Field site 14 is in TxDOT's Bryan District, in Washington County, on FM 390 from SH 36 to FM 50. Table 29 lists the summary data for this site, and Figure 43 shows the before and after seal coat construction images.

Table 29. Site 14 Summary.

Description	Results
ADT (veh/day)	754
Trucks (%)	15.5
Precipitation (inches/year)	39
Climate zone	South Central
Estimated date of first frost	12/12
Binder application rate (gal/yd^2): AC20-5TR	0.38
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	114
Construction date	5/11/2023
Texture (mils): 5/1/2023	45.4
Texture after seal coat (mils): 6/12/2023	98.4
Second texture after seal coat (mils): 5/9/2024	80.3
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 43. Site 14 Before and After Seal Coat Construction.

Field Site 15

Field site 15 is in TxDOT's Bryan District, in Washington County, on FM 1155 from FM 912 to FM 2726. Table 30 lists the summary data for this site, and Figure 44 shows the before and after seal coat construction images.

Table 30. Site 15 Summary.

Description	Results
ADT (veh/day)	297
Trucks (%)	31.6
Precipitation (inches/year)	41
Climate zone	South Central
Estimated date of first frost	12/12
Binder application rate (gal/yd^2): AC20-5TR	0.4
Aggregate application rate (yd^2/yd^3): PL[1] grade 3	117
Construction date	5/17/2023
Texture (mils): 5/1/2023	54.5
Texture after seal coat (mils): 6/12/2023	97.4
Second texture after seal coat (mils): 5/9/2024	76.2
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 44. Site 15 Before and After Seal Coat Construction.

Field Site 16

Field site 16 is in TxDOT's Bryan District, in Washington County, on FM 1155 from FM 2726 to FM 2193. Table 31 lists the summary data for this site, and Figure 45 shows the before and after seal coat construction images.

Table 31. Site 16 Summary.

Description	Results
ADT (veh/day)	414
Trucks (%)	26.1
Precipitation (inches/year)	41
Climate zone	South Central
Estimated date of first frost	12/12
Binder application rate (gal/yd^2): AC20-5TR	0.39
Aggregate application rate (yd^2/yd^3): PL[1] grade 3	97
Construction date	5/17/2023
Texture (mils): 4/25/2023	40.3
Texture after seal coat (mils): 6/12/2023	94.2
Second texture after seal coat (mils): 5/9/2024	74.4
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 45. Site 16 Before and After Seal Coat Construction.

Field Site 17

Field site 17 is in TxDOT's Bryan District, in Washington County, on FM 2193 from SH 105 to FM 1155. Table 32 lists the summary data for this site, and Figure 46 shows the before and after seal coat construction images.

Table 32. Site 17 Summary.

Description	Results
ADT (veh/day)	789
Trucks (%)	2.5
Precipitation (inches/year)	41
Climate zone	South Central
Estimated date of first frost	12/12
Binder application rate (gal/yd^2): AC20-5TR	0.36
Aggregate application rate (yd^2/yd^3): PL[1] grade 4	122
Construction date	5/17/2023
Texture (mils): 4/25/2023	36.7
Texture after seal coat (mils): 6/12/2023	61.9
Second texture after seal coat (mils): 5/9/2024	44.3
Observations	Preparatory work affected the seal coat. The seal coat application rate led to flushing in the wheel paths; however, no rock loss was observed between the wheel paths.

[1]Aggregate type, PL, includes precoated lightweight aggregate.

Figure 46. Site 17 Before [10] and After Seal Coat Construction.

Field Site 18

Field site 18 is in TxDOT's Brownwood District, in Comanche County, on SH 36 from 0.4 miles south of FM 1702 (east) to 0.5 miles north of FM 1476. Table 33 lists the summary data for this site, and Figure **47** shows the before and after seal coat construction images.

Table 33. Site 18 Summary.

Description	Results
ADT (veh/day)	1,266
Trucks (%)	35.5
Precipitation (inches/year)	31
Climate zone	North Central
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.36
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	137
Construction date	6/2/2023
Texture (mils): n/a	n/a
Texture after seal coat (mils): 7/24/2023	70.5
Second texture after seal coat (mils): 5/9/2024	36
Observations	Flushing was observed in the wheel paths. Seal coat application rate was high.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 47**. Site 18 Before and After Seal Coat Construction [11].**

Field Site 19

Field site 19 is in TxDOT's Brownwood District, in Comanche County, on US 67 from Elm Street to 0.5 miles west of Indian Creek. Table 34 lists the summary data for this site, and Figure 48 shows the before and after seal coat construction images.

Table 34. Site 19 Summary.

Description	Results
ADT (veh/day)	1,109
Trucks (%)	23.5
Precipitation (inches/year)	31
Climate zone	North Central
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.28
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	135
Construction date	6/20/2023
Texture (mils): 4/18/2023	36.9
Texture after seal coat (mils): 6/29/2023	67.8
Second texture after seal coat (mils): 5/9/2024	51.0
Observations	Existing flushing affected the seal coat. Minor rock loss was observed between the wheel paths.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 48. Site 19 Before and After Seal Coat Construction.

Field Site 20

Field site 20 is in TxDOT's Brownwood District, in Comanche County, on FM 591 from FM 1476 East to FM 1702. Table 35 lists the summary data for this site, and Figure 49 shows the before and after seal coat construction images.

Table 35. Site 20 Summary.

Description	Results
ADT (veh/day)	169
Trucks (%)	11.2
Precipitation (inches/year)	31
Climate zone	North Central
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.36
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	137
Construction date	6/2/2023
Texture (mils): 4/18/2023	61.4
Texture after seal coat (mils): 6/29/2023	85.4
Second texture after seal coat (mils): 5/9/2024	72.3
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 49. Site 20 Before and After Seal Coat Construction.

Field Site 21

Field site 21 is in TxDOT's Brownwood District, in Comanche County, on FM 2561 from FM 1476 East to FM 1702. Table 36 lists the summary data for this site, and Figure 50 shows the before and after seal coat construction images.

Table 36. Site 21 Summary.

Description	Results
ADT (veh/day)	116
Trucks (%)	8.4
Precipitation (inches/year)	31
Climate zone	North Central
Estimated date of first frost	12/1
Binder application rate (gal/yd^2): AC20-5TR	0.37
Aggregate application rate (yd^2/yd^3): PB[1] grade 4	137
Construction date	6/1/2023
Texture (mils): 4/21/2023	54.1
Texture after seal coat (mils): 6/29/2023	103.7
Second texture after seal coat (mils): 5/9/2024	70.6
Observations	Seal coat was applied at a good rate with no excessive flushing or rock loss.

[1]Aggregate type, PB, includes precoated crushed gravel, crushed slag, crushed stone, or limestone rock asphalt.

Figure 50. Site 21 Before and After Seal Coat Construction.

CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS FOR SEAL COAT PROJECT SELECTION, TESTING, AND MATERIALS

CONCLUSIONS

In this study, researchers evaluated the stability of existing accumulated seal coat layers through a series of laboratory and field tests and developed tests and procedures to determine when an additional seal coat may not perform well. Key findings from these efforts include the following:

- Laboratory testing indicated a stability change after 2 seal coat layers; however, this finding was based on unaged and untrafficked layers. Aging would likely stiffen the seal coat, and traffic would compact the layer, improving its stability.
- The repeated shear test showed potential for differentiating stable and unstable seal coat layers based on the slope of displacement vs. the load cycles.
- The ball penetration test—applied in both the laboratory and the field—produced similar results for Texas materials compared to New Zealand materials. The similarity in results provided confidence in reviewing and adopting guidance from New Zealand studies.
- The torsion test was challenging to apply to seal coats, especially when aggregates were relatively large (e.g., grade 3). However, it proved effective in differentiating unstable and stable layers for well-compacted surfaces (most likely in the field) and relatively smaller aggregates.

SEAL COAT PROJECT SELECTION

Based on these key findings, the research team developed guidelines to select candidate projects for seal coats. Most pavement management systems, including TxDOT's, have criteria that estimate when maintenance, preventive maintenance (PM), and rehabilitation are needed. The recommended criteria used for seal coat project selection is based on current TxDOT criteria and the results of this research project.

Project Selection Background

Seal coats can be performed by state forces or by contract. While seal coats are used in all types of maintenance work, the majority of seal coats are performed through PM contracts. TxDOT's *Maintenance Management Manual* [11] defines PM as "Pavement-related work performed to prevent major deterioration of the pavement. Work would normally include, but not be limited to: milling or bituminous level-ups to restore rideability, light overlays (overlays not to exceed total average depth of 2"), seal coats, crack sealing, and microsurfacing. Preparatory work such as milling, repairs, or level-ups may also be performed."

A seal coat is a durable all-weather surfacing that:

- Seals an existing bituminous surface against the intrusion of air and water.
- Enriches an existing dry or raveled surface.
- Arrests the deterioration of a surface showing signs of distress.
- Provides a skid-resistant surface.
- Provides the desired surface texture.
- Improves light-reflecting characteristics where these are required (by use of light-colored stone).
- Enables paved shoulders or other geometric features to be demarcated by providing a different texture or color.
- Provides a uniform-appearing surface [12].

The TxDOT *Seal Coat and Surface Treatment Manual* [13] states that "A seal coat or surface treatment has little or no structural strength itself but by preventing the ingress of water it enables the inherent strength of the pavement and the subgrade to be preserved. If a pavement shows evidence of traffic load associated cracking (alligator, longitudinal, transverse), a seal coat is only a temporary solution. Areas that show load-associated cracking may require base repair prior to a seal coat or overlay." It also states that "Ride quality of a pavement cannot be improved significantly by the application of a seal coat."

Table 37 summarizes the minimum criteria to maintain the roadway pavement for each level of service from TxDOT's *Maintenance Management Manual* [13]. When considering project selection for a PM seal coat, the pavement should meet the desirable level before the seal coat is placed. Ride quality is quantified by a serviceability index (SI). The SI-equivalent international roughness index (IRI) was estimated by the research team and added to the table.

Table 37. TxDOT Pavement Maintenance Level of Service [12].

Distress Type	Condition ADT Range (veh/day)	Desirable Level	Acceptable Level	Tolerable Level
Rutting	0–500	< 0.5 inches and 50% per wheel path	< 1 inch and 50% per wheel path	< 3 inches and 25% per wheel path
Rutting	501–10,000	< 0.5 inches and 50% per wheel path	< 1 inch and 50% per wheel path	< 3 inches and 25% per wheel path
Rutting	> 10,001	< 0.5 inches and 25% per wheel path	< 1 inch and 25% per wheel path	< 1 inch and 50% per wheel path
Alligator cracking	n/a	Maintain with no visible cracks	Maintain with visible cracks of < 10% per wheel path	Maintain with visible cracks of < 50% per wheel path
Ride quality	0–500	> 2.5 SI (178 IRI)	> 2.0 SI (221 IRI)	> 1.5 SI (270 IRI)
Ride quality	501–10,000	> 3.0 SI (141 IRI)	> 2.5 SI (178 IRI)	> 2.0 SI (221 IRI)
Ride quality	> 10,001	> 3.5 SI (109 IRI)	> 3.0 SI (141 IRI)	> 2.5 SI (178 IRI)
Pavement edge cracking	n/a	< 2-inch drop-off	< 3-inch drop-off	< 3-inch drop-off

Rutting and the IRI values can be found in the Pavement Management Information System data using TxDOT's Pavement Analyst (PA) software. In the PA software, rutting levels and their associated value ranges are defined as follows:

- Shallow rutting is from 0.25 to 0.49 inches.
- Deep rutting is from 0.5 to 0.99 inches.
- Severe rutting is from 1.0 to 1.99 inches.
- Failed rutting is 2.0 inches or greater [12].

Figure 51 shows an example of severe rutting, with values ranging from 1.0 to 1.99 inches.

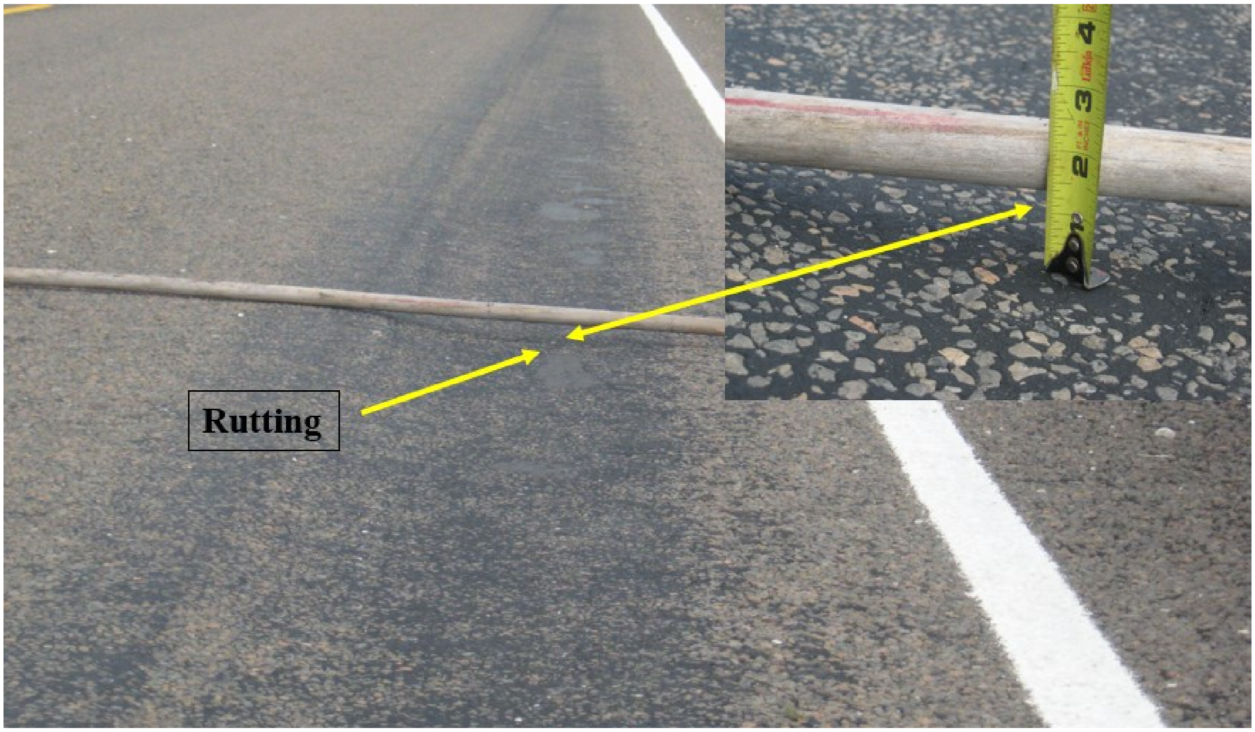

Figure 51. Example of Severe Rutting (from 1.0 to 1.99 inches).

Pavement Condition

The existing pavement condition and number of layers of seal coat should also be considered when selecting potential seal coat projects. Potential issues to consider include the following:

- Multiple seal coats overlapping along longitudinal construction joints (Figure 52).
- Surface irregularities in a seal coat, such as *shoving* and *washboards* (Figure 53).
- Bleeding or flushing in the wheel paths (Figure 54). Bleeding and flushing is the upward movement of asphalt resulting in the formation of a film of asphalt on the roadway surface [14]. Many use the terms *bleeding* and *flushing* interchangeably; however, for this report, bleeding is considered to be a more severe condition than flushing and are further defined as follows:
    - Bleeding has a pavement texture less than 0.035 inches (measured in accordance with Tex-436-A) and can be visually detected [15].
    - Flushing has a pavement texture ranging from 0.035 to 0.05 inches (measured in accordance with Tex-436-A) and can be visually detected [16].
- Unsealed cracks greater than 0.125-inch wide (Figure 55).
- Seal coat debonding from the base course (Figure 56).
- Edge cracking (Figure 57).

Figure 52. Example of Multiple Seal Coats Overlapping Along a Longitudinal Joint.

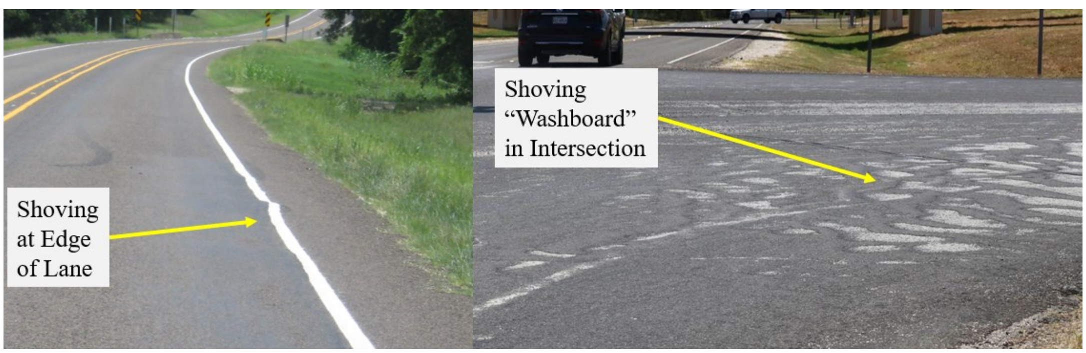

Figure 53. Examples of Shoving at an Edge Line and Intersection.

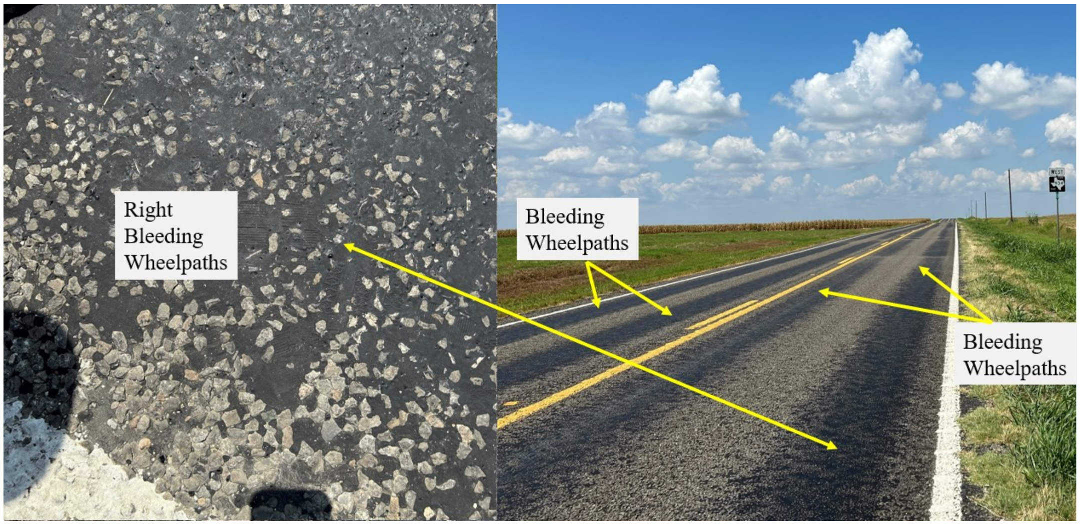

Figure 54. Example of Bleeding in the Wheel Paths.

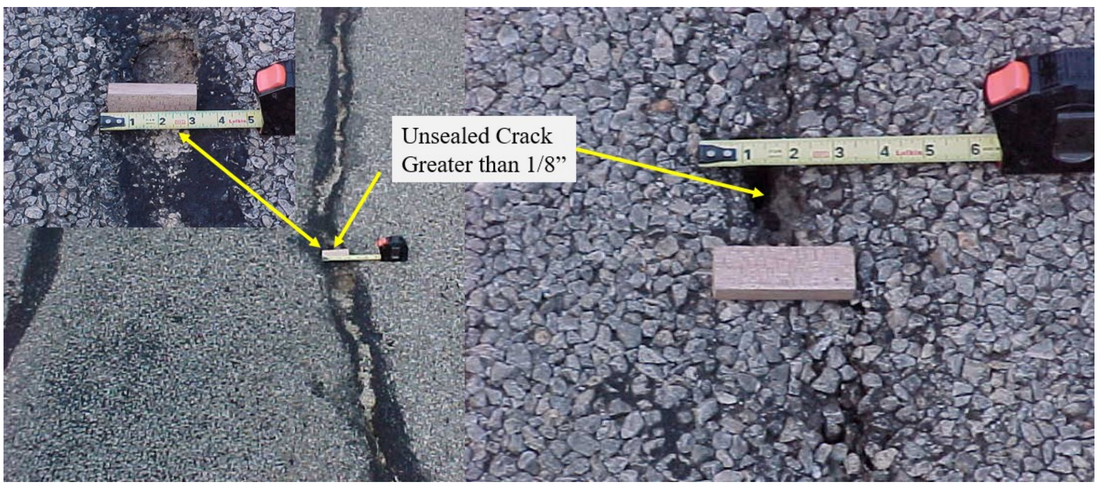

Figure 55. Example of Unsealed Cracks Greater than 0.125–inch Wide.

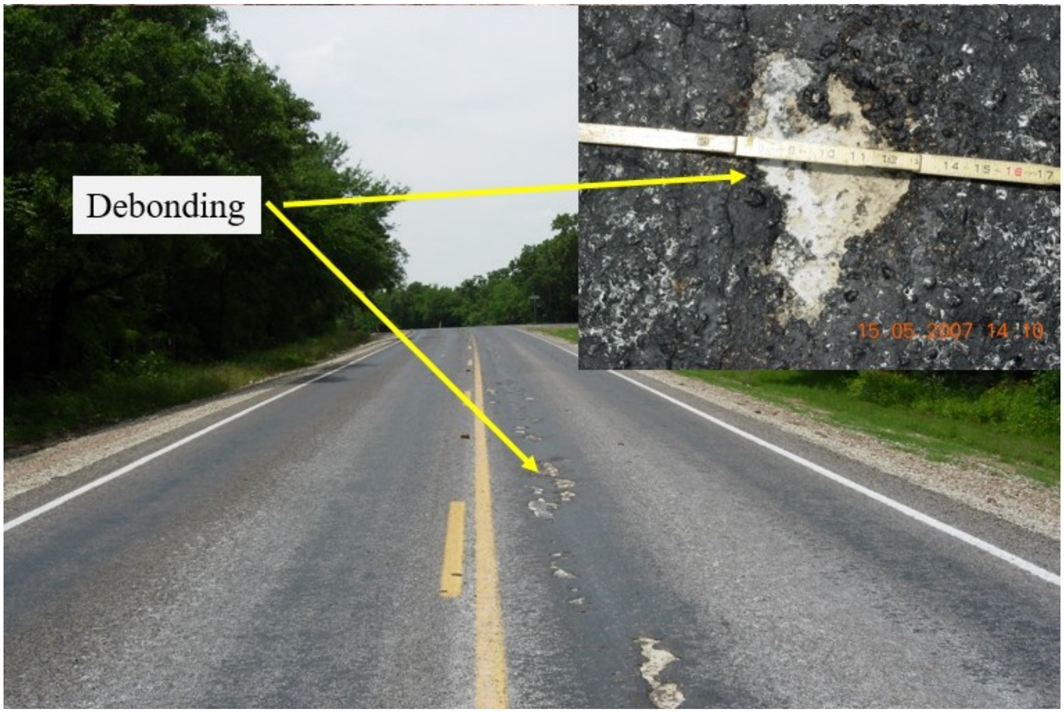

Figure 56. Example of Seal Coat Debonding from the Base Course.

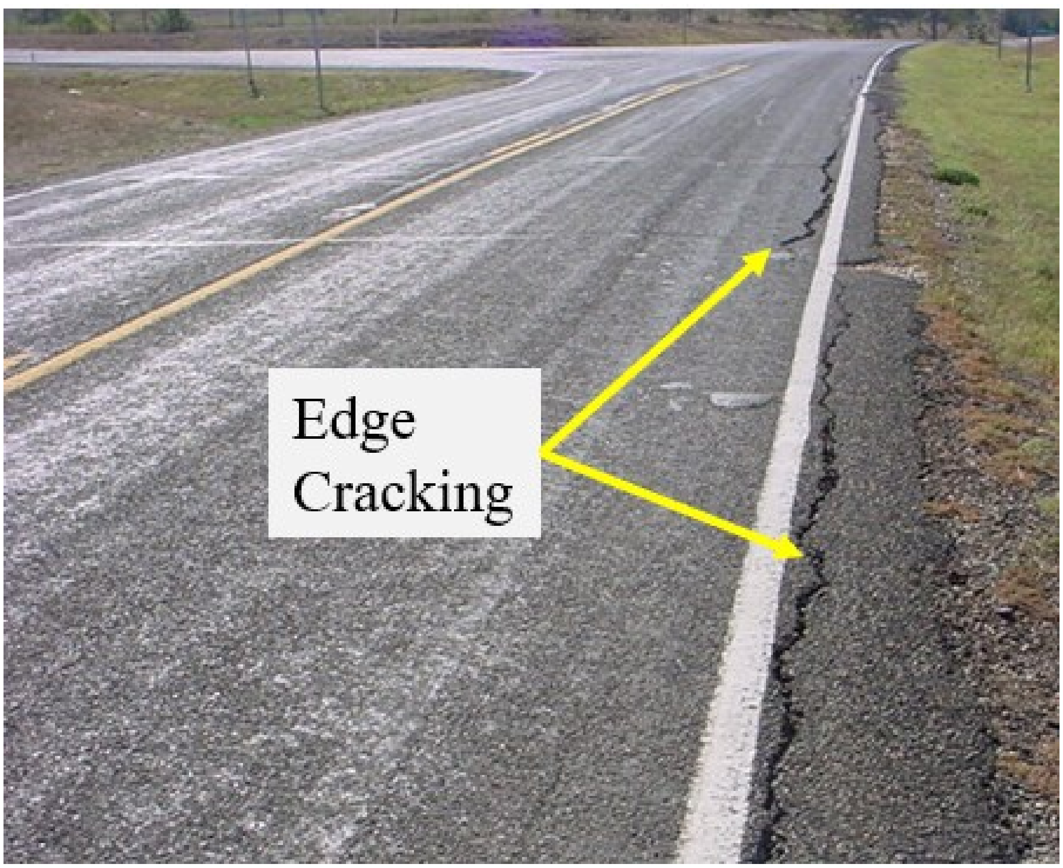

Figure 57. Example of Edge Cracking.

Project Selection Process

Based on the information presented previously, the research team developed a process to select candidate projects for seal coats. Figure 58 depicts this process as a flow chart based on an existing pavement condition evaluation. This multistep process is as follows:

1. Review the PA data for cracking, rutting, and ride quality. A good candidate should meet the desirable level of maintenance or be able to be brought up to the desirable level through minimal routine maintenance.
2. Perform a visual evaluation of the roadway to ensure that there have not been any significant changes since the PA data was collected. If the existing roadway has a seal coat surface, note any issues with the existing seal coat. Figure 52 through Figure 57 show examples of surface condition concerns.
3. Use the flow chart in Figure 58 to determine if additional maintenance or testing work needs to be performed before the PM seal coat construction. Any additional work should be performed as follows:

    a. When additional maintenance work is indicated, perform an analysis to determine the time and cost of the repairs. If the repair costs exceed the project budget or the repairs cannot be performed before the PM seal coat construction, then delay the seal coat on this section until repairs can be performed.
    b. When additional testing is indicated, perform the Tex 10XX-S Ball Penetration Test for Seal Coat (draft, see Appendix A) using the following guidelines based on penetration depth:

        i. When the penetration depth is less than 0.158 inches (4 mm), act based on the following conditions:

            1. Evaluate the penetration depth from the first blow of the drop hammer as follows:

                a. If it exceeds 0.118 inches (3 mm), consider adding this superseding value to the penetration depth.
                b. If it exceeds 0.197 inches (5 mm), conclude that the area needs to be repaired.

            2. If bleeding or flushing is the only concern:

                a. Use single-size gradation for grade 3 aggregate and transverse variable rates during construction.

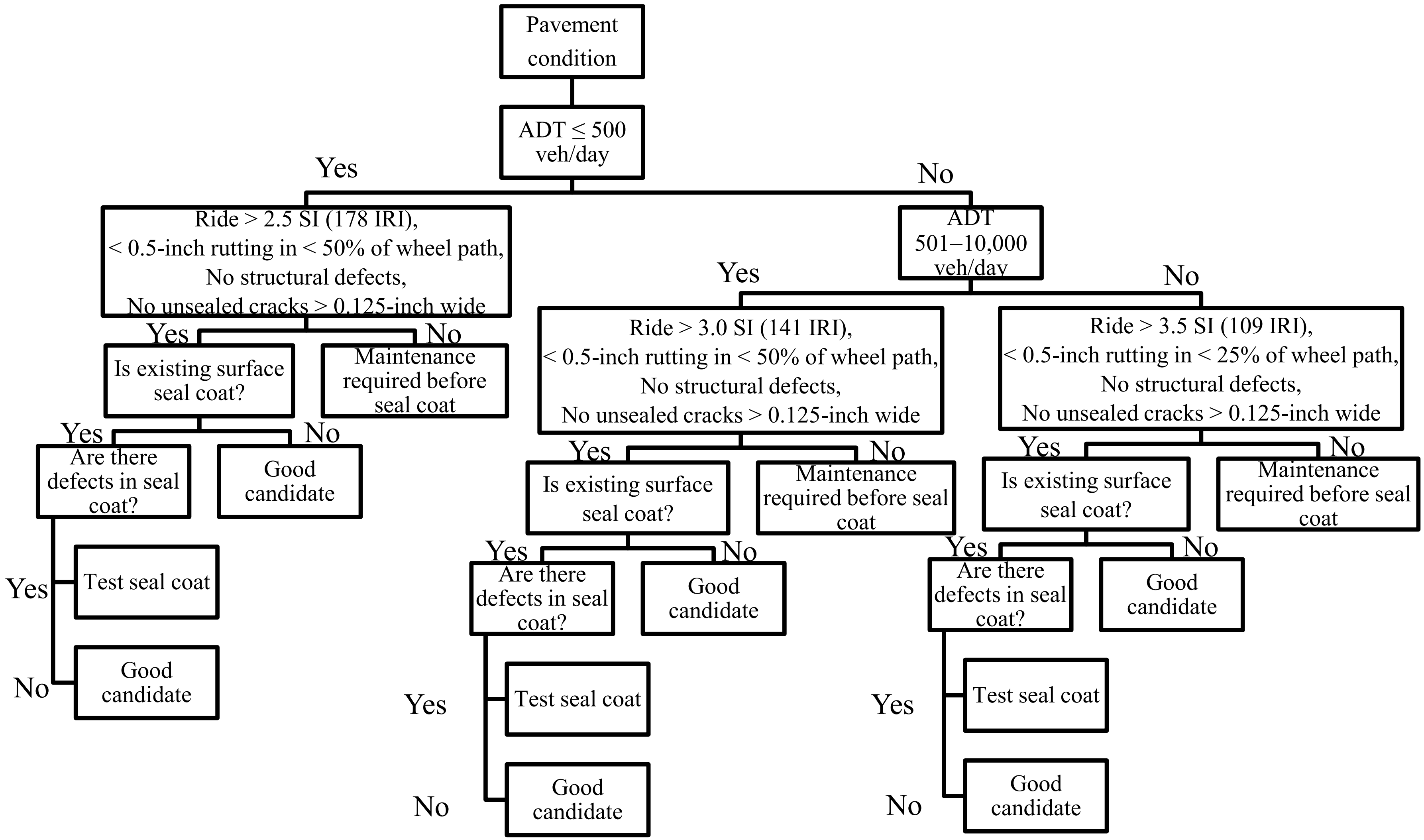

Figure 58. Seal Coat Project Selection Flow Chart Based on an Existing Pavement Condition Evaluation.

3. If repairs for other defects are required, act based on the following conditions:

    a. If the repair costs exceed the budget or the repairs cannot be performed before the PM seal coat construction, then delay the seal coat on this section until repairs can be performed.
    b. If the repairs can be performed within the budget and within the required timeframe, select this section for a PM seal coat and inform the maintenance office of the necessary repairs.

ii. When the penetration depth is between 0.158 and 0.197 inches (4 and 5 mm), act based on the following conditions:

1. Evaluate the penetration depth from the first blow of the drop hammer as follows:

    a. If it exceeds 0.118 inches (3 mm), consider adding this superseding value to the penetration depth.
    b. If it exceeds 0.197 inches (5 mm), conclude that the area needs to be repaired.

2. If bleeding or flushing is the only concern:

    a. Use single-size gradation for grade 3 aggregate and transverse variable rates during construction.
    b. Hydroblast the bleeding area.
    c. Perform other maintenance to increase stiffness.

3. If repairs for other defects are required, act based on the following conditions:

    a. If the repair costs exceed the budget or the repairs cannot be performed before the PM seal coat construction, then delay the seal coat on this section until repairs can be performed.
    b. If repairs can be performed within the budget and within the required timeframe, select this section for a PM seal coat and inform the maintenance office of the necessary repairs.

iii. When the penetration depth is greater than 0.197 inches (5 mm), act based on the following conditions:

1. Evaluate the penetration depth from the first blow of the drop hammer as follows:

    a. If it exceeds 0.118 inches (3 mm), consider adding this superseding value to the penetration depth.
    b. If it exceeds 0.197 inches (5 mm), conclude that the area needs to be repaired.

2. If bleeding or flushing is the only concern:

    a. Hydroblast the bleeding area.
    b. Perform other maintenance to increase stiffness.

3. If repairs for other defects are required, act based on the following conditions:

    a. If the repair costs exceed the budget or the repairs cannot be performed before the PM seal coat construction, then delay the seal coat on this section until repairs can be performed.
    b. If repairs can be performed within the budget and within the required timeframe, select this section for a PM seal coat and inform the maintenance office of the necessary repairs.

c. Consider coring to determine the number of existing seal coat layers.

SEAL COAT PROJECT TESTING

When a section has visual defects such as bleeding, surface irregularities, or deformation, project-level testing should be performed to determine its adequacy for supporting an additional seal coat. The following steps are recommended:

1. Take a core of the pavement to determine the number of seal coat layers.
2. Perform the Tex 10XX-S Ball Penetration Test for Seal Coat (draft, see Appendix A), and evaluate the penetration depth from the first blow of the drop hammer as follows:

    a. If it exceeds 0.118 inches (3 mm), consider adjusting the new seal coat binder application rate. Refer to the *Texas Seal Coat Design Method* [13] for adjustments.
    b. If it exceeds 0.197 inches (5 mm), conclude that the area needs to be repaired.

SEAL COAT PROJECT MATERIAL SELECTIONS

Binder

The selection of binder material is based on traffic volumes. Traffic is adjusted for the percentage of trucks in the traffic stream using the procedures developed in TxDOT Project 0-7105 and shown in Appendix A. Tiers are defined in TxDOT Form 2388. Table 40 and Table 38 present quantiles and other summary statistics for current ADT on roadways in Texas, respectively. Table 39 details the binder selection criteria.

Table 38. Quantiles for Current ADT.

Quantile (%)	Description	ADT
100.0	Maximum	319,455
99.5		192,578
97.5		101,145
90.0		28,428
75.0	Quartile	11,167
50.0	Median	3,618
25.0	Quartile	981
10.0		304
2.5		93
0.5		36
0.0	Minimum	4

Table 39. Summary Statistics for Current ADT.

Description	Value
Mean	12,612.036
Standard deviation	28,011.498
Standard error of the mean	69.298675
Upper 95% mean	12,747.86
Lower 95% mean	12,476.213
N	163,389

Aggregate

TxDOT Form 2088 is used to select the surface aggregate classification. The use of precoated material with AC or AR binders is recommended. The grade should be selected based on economics and pavement conditions.

Table 40. Binder Selection Criteria.

Condition	≤ 800 veh/day/lane or Underseal	800–1500 veh/day/lane	> 1500 veh/day/lane
No high stress areas	All approved materials	Tier II	Tier I
Horizontal curve radius ≤ 1,800 ft (3°)	All approved materials	Tier II	Tier I
Horizontal curve radius 1,800–820 ft (3–7°)	Tier II	Tier II	Tier I
Horizontal curve radius > 820 ft (7°)	Tier I	Tier I	Tier I
Superelevation > 6%	Tier I	Tier I	Tier I
Grade ≤ 2%	All approved materials	Tier II	Tier I
Grade 2–5%	Tier II	Tier II	Tier I
Steep grades > 5%	Tier I	Tier I	Tier I
Posted speed ≤ 35 mph	Tier I	Tier I	Tier I
Posted speed 35–60 mph	Tier II	Tier I	Tier I
Posted speed > 60 mph	All approved materials	Tier II	Tier I
Roundabouts	Tier II	Tier I	Tier I
Turning lanes	Tier II	Tier I	Tier I
Intersections	Tier II	Tier I	Tier I

CHAPTER 5. VALUE OF RESEARCH

The savings determined based on the value of research (VOR) assumes that the right treatment is applied to the right road at the right time, leading to improved seal coat quality with significantly less premature failures. The VOR assumes that monies currently being spent on immediate maintenance will be significantly reduced as the research is implemented.

The expected value duration is based on the expected average life (7 years) of a seal coat. The discount rate for the 7-year nominal interest rates on treasury notes and bonds (4.4 percent) is based on Office of Management and Budget Circular No. A-94. The expected value per year is based on a maintenance cost savings from the control of flushing and bleeding.

For this estimated VOR, the research team assumed that TxDOT places seal coats on 180,000,000 yd^2 of pavement per year and that 26 percent of projects have immediate maintenance needs. However, this percentage will reduce each year to only 1 percent by year 7. Researchers also assumed that 1 percent of this pavement area will need additional maintenance each year, estimated as a 1.5-inch level-up at \$15.00/yd^2. The expected savings will increase each year because the overall quality of construction is anticipated to improve each year as the research is implemented.

Table 41 details the project values and expected values inputted in the TxDOT VOR Form. Figure 59 shows the VOR over time, expressed as a net present value (NPV). Table 42 describes the VOR benefit areas.

Table 41. TxDOT VOR Form Data.

Description	Value	Years	Expected Value
Project number	0-7106	0	$27,360,000
Project name	Quantify Maximum Accumulated Seal Coat Layers for Stability	1	$23,842,286
Agency	Texas A&M Transportation Institute	2	$20,324,571
Project duration (yr)	3.0	3	$16,806,857
Expected value duration (yr)	7	4	$13,289,143
Project budget ($)	$449,211	5	$9,771,429
Expected value per year ($)	$5,081,840	6	$6,253,714
Discount rate (%)	4.4	7	$2,736,000
Economic value total savings ($)	$100,782,789		
Payback period (yr)	0.029852		
Net present value ($)	$110,257,314		
Cost benefit ratio ($1:$_)	$1:$245		

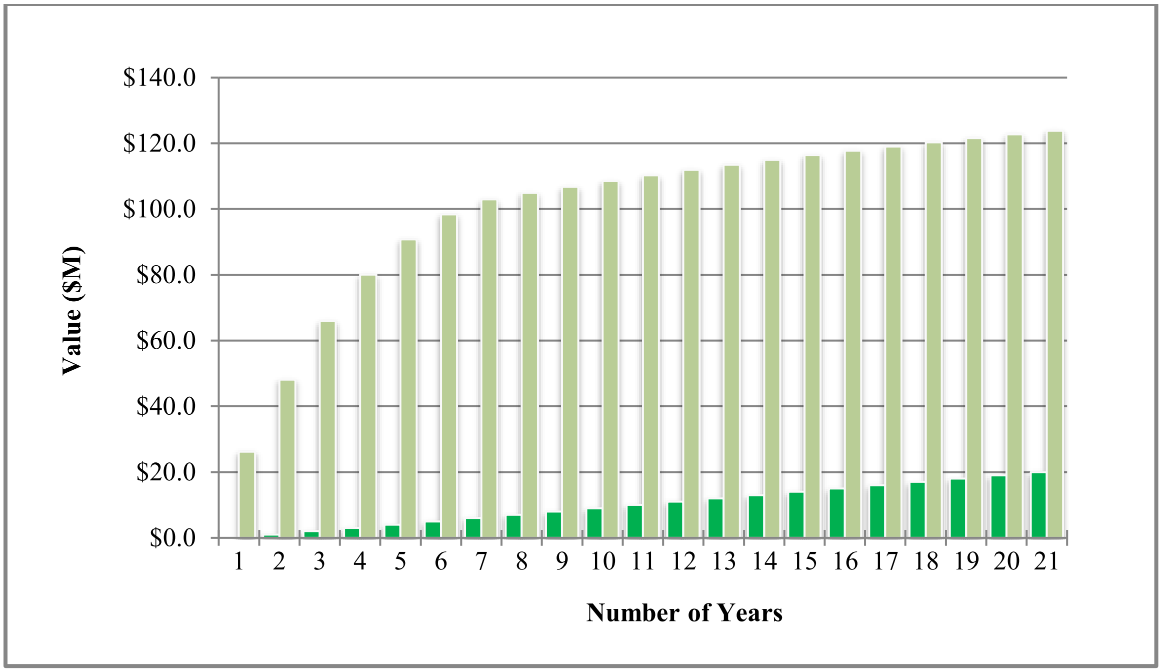

Figure 59. VOR Over Time Expressed as NPV.

Table 42. VOR Benefit Areas.

Benefit Area	Qualitative	Economic	Both	TxDOT	State	Both	Definition in Context to Project Statement
Level of knowledge	X			X			Research significantly increases the agency's understanding of seal coat project selection.
System reliability		X		X			Research promotes improved seal coat project selection, minimizing early maintenance treatments, and thereby reducing user delays and unforeseen costs to the agency.
Increased service life		X		X			Improved project selection achieves expected service life without premature failures.
Reduced user cost		X			X		Improved project selection decreases user costs/avoids lane closures and delays due to premature failure repairs.
Reduced construction, operations, and maintenance cost		X			X		Reduced premature failures saves on unexpected maintenance costs.
Materials and pavements		X			X		Research increases understanding of seal coat materials and pavement conditions affecting seal coats.
Infrastructure condition		X				X	Research improves existing structure condition by increasing service life. Quality seal coat materials and construction improve infrastructure network condition.
Safety			X			X	Improved project selection and performance provides a safe driving surface over the life of the project.

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APPENDIX. TEX-102X-S BALL PENETRATION TEST FOR SEAL COAT DRAFT TEST METHOD

Test Procedure for

BALL PENETRATION TEST FOR SEAL COAT

TxDOT Designation: TEX-102X-S

Effective Date:

1. SCOPE

1.1. Use this test method to estimate the effects of existing pavement stiffness on a new seal coat. The values obtained from this test method are used to determine whether additional repair work is needed before placing a seal coat and for the application rate design method for a seal coat.

1.2. The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. DEFINITIONS

2.1. *Ball penetration*: Resistance to penetration of a road pavement's surface when a 0.75-inch (19-mm) steel ball is subjected to blows of a 10-lb drop hammer.

2.2. *Bleeding*: Free asphalt migrating up to the surface of the layer.

2.3. *Displacement*: Movement of the layer principally upwards as a result of the ball action.

2.4. *Embedment*: Penetration of the ball into the surface of the tested layer.

3. APPARATUS

3.1. *Ball* made of corrosion resistant steel with a 0.75 ± 0.002-inch (19 ± 0.05-mm) diameter.

3.2. *Circular tripod stand* made of corrosion-resistant steel with a 5-inch (127-mm) inside diameter and a removable steel crossbar with a 0.75-inch (19-mm) diameter that can be located centrally either in slots or between lugs across the stand. A number of tripod arrangements may be used provided that the crossbar can be replaced each time in the same position relative to the ball.

3.3. *Drop hammer*, such as a Marshall compaction hammer (handheld Type 1), that complies with ASTM International's D6926 standard or equivalent, with a 10 ± 0.02-lb (4.536 ± 0.009-kg) sliding mass and an 18 ± 0.06-inch (457.2 ± 1.5-mm) freefall.

3.4. *Vernier calipers or a depth gauge* made of corrosion resistant steel, measuring to 0.004 inches (0.1 mm).

3.5. *A combining apparatus,* such as the New South Wales Roads and Maritime Service ball penetration apparatus from Australia, that incorporates the stand, drop hammer, and depth gauge may be used provided the hammer and ball comply with the requirements of 3.1 and 3.3. Figure 1 depicts an example apparatus.

3.6. *Surface thermometer* with a range of 50 to 180°F (10 to 82.2°C).

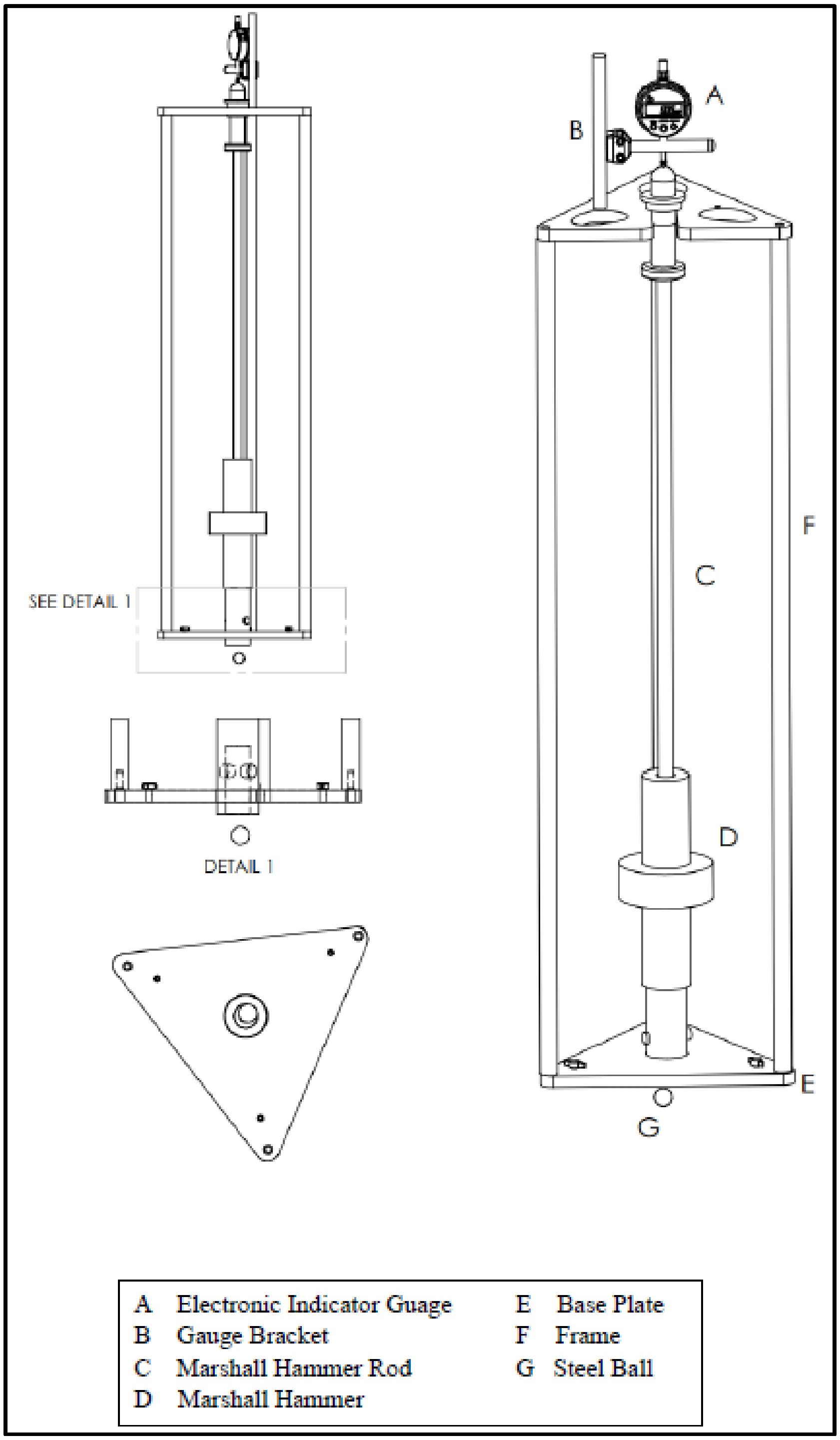

Figure 1. Example Ball Penetration Testing Device.

4. PROCEDURES

4.1. Select the test locations. Test in the wheel paths and between the wheel paths at each location. If the pavement section has areas that are shaded and unshaded, take at least one set of tests in both conditions.

4.2. Record the existing surface type and describe the surface condition in terms of bleeding, flushing, or binder condition (e.g., dry and/or brittle). Typical surface types include flexible base, stabilized base, seal coat, and asphaltic concrete. Note whether the gradient reflects flat terrain, a steep uphill grade, or a steep downhill grade.

4.3. Measure and record the surface temperature of the road surface at the test location using the thermometer from Section 3.6, and note whether the area was shaded at the time of testing.

4.4. Place the steel ball on the road surface, and position the circular tripod over it so that the ball is in the center of the circular frame.

4.5. Position the drop hammer apparatus on the steel ball, ensuring that no part of the hammer is resting on the frame.

4.6. Measure an initial displacement reading to the nearest 0.004 inch (0.1 mm) using the vernier calipers or depth gauge from the top of the crossbar to the top of the hammer and record as D1 in section X.

4.7. Apply one blow with the drop hammer to the steel ball.

4.8. Using the vernier calipers or depth gauge, measure the distance from the top of the crossbar to the top of the hammer, and record as D2 in section X.

4.9. Apply a second blow with the drop hammer to the steel ball.

4.10. Measure the distance between the top of the crossbar and top of the hammer, and record as D3 in section X.

4.11. Record any obvious and clearly discernable reactions after each blow with the drop hammer. Reactions may include embedment, crushing or aggregation, or displacement.

4.11.1. When the surfacing consists of a seal coat, record an estimate of the nominal stone size or sizes visible on the surface.

4.11.2. Repeat Sections 4.3 to 4.11 at each selected test location at least three times within each area of similar condition.

5. CALCULATIONS

5.1. Determine the embedment that has taken place when the ball has been subjected to each of the blows with the drop hammer using Equation 1 and Equation 2 as follows:

$$E1 = D2 - D1 \quad \text{Equation 1}$$

$$E2 = D3 - D1 \quad \text{Equation 2}$$

where:

E1 = ball penetration after the first drop hammer blow.

E2 = ball penetration after the second drop hammer blow.

D1 = initial distance between the front top of the crossbar and the top of the hammer.
D2 = distance between the front top of the crossbar and the top of the ball after the first drop hammer blow.
D3 = distance between the front top of the crossbar and the top of the ball after the second drop hammer blow.

5.2. Calculate the ball penetration value for each test in each area of similar condition using Equation 3 as follows:

$$BP = E2 - E1 \qquad \text{Equation 3}$$

where:
BP = ball penetration (mm or inches).

5.3. Calculate the average and standard deviation for each set of E1, E2, and BP values.
5.4. Perform a temperature correction using the following method:
5.4.1. Determine the design temperature. Use a design temperature of 104°F (40°C) to simulate pavement conditions in shaded areas, and consider using a higher value based on the expected surface temperature at the time of construction in unshaded areas.
5.4.2. Calculate the temperature-corrected BP value using either Equation 4 for the International System of Units or Equation 5 for the imperial system of units when placing on a fresh seal coat as follows:

$$P_d = BP + 0.0594(T_d - T_t) \qquad \text{Equation 4}$$

where:
BP = ball penetration (mm).
P_d = ball penetration value for design (mm).
T_d = design temperature (°C).
T_t = temperature at time of testing (°C).

Convert P_d from mm to inches for reporting.

$$P_d = BP + 0.0013(T_d - T_t) \qquad \text{Equation 5}$$

where:
BP = ball penetration (inches).
P_d = ball penetration value for design (inches).
T_d = design temperature (°F).
T_t = temperature at time of testing (°F).

5.4.3. Calculate the temperature corrected BP value using either Equation 6 for the International System of Units or Equation 7 for the imperial system of units when placing on an existing pavement as follows:

$$P_d = BP + 0.04(T_d - T_t) \quad \text{Equation 6}$$

where:

BP = ball penetration (mm).

P_d = ball penetration value for design (mm).

T_d = design temperature (°C).

T_t = temperature at time of testing (°C).

5.4.4. Convert P_d from mm to inches for reporting.

$$P_d = BP + 0.000875(T_d - T_t) \quad \text{Equation 7}$$

where:

BP = ball penetration (inches).

P_d = ball penetration value for design (inches).

T_d = design temperature (°F).

T_t = temperature at time of testing (°F).

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6. REPORTING AND DOCUMENTATION

6.1. Report all test data and pertinent information using the SiteManager TX10xx.xlsm Forms. Record the penetration depth to the nearest 0.004 inch (0.1 mm).

6.2. Include the following information in the test report for each test location:

- The test position for each set (i.e., in the wheel paths, between the wheel paths, in the shoulder or along the centerline).
- The gradient type (i.e., flat terrain, steep uphill grade, or steep downhill grade).
- The surface temperature (to the nearest 0.1°F) and shade condition.
- The reaction of the pavement surface under the ball.
- The road surface type and condition.
- The average and standard deviation values (to the nearest 0.004 inch) for each set of E1, E2, and BP values.