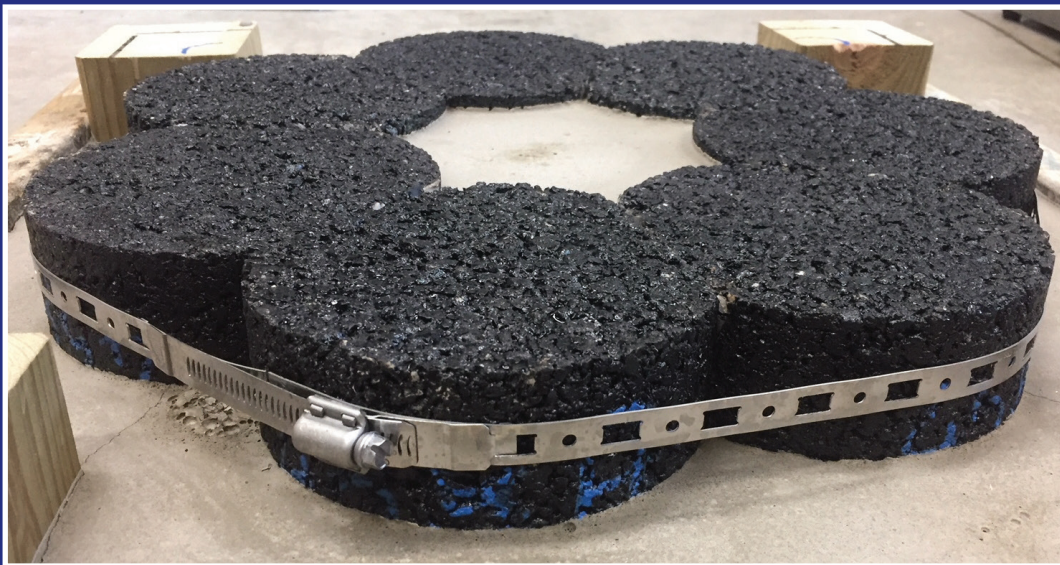


JOINT TRANSPORTATION RESEARCH PROGRAM

INDIANA DEPARTMENT OF TRANSPORTATION
AND PURDUE UNIVERSITY



Development of a Friction Performance Test for Compacted Asphalt Mixtures



Rebecca S. McDaniel, Ayesha Shah, Karol J. Kowalski

RECOMMENDED CITATION

McDaniel, R. S., Shah, A., & Kowalski, K. J. (2018). *Development of a friction performance test for compacted asphalt mixtures* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/20). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284316865>

AUTHORS

Rebecca S. McDaniel, PhD, PE

Technical Director
North Central Superpave Center
Lyles School of Civil Engineering
Purdue University
(765) 463-2317
rsmcdani@purdue.edu
Corresponding Author

Ayesha Shah, PhD, PE

Research Engineer
North Central Superpave Center
Lyles School of Civil Engineering
Purdue University

Karol J. Kowalski, PhD

Kosciuszko Foundation Visiting Professor
Warsaw University of Technology

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the contractors who provided samples and mixture data used in this study; the assistance provided by Milestone Contractors, LP; Rieth-Riley Construction Co., Inc.; and J. H. Rudolph & Co., Inc., is greatly appreciated. Thanks also to Belayneh Desta, who used AutoCAD to solve the complex geometry puzzle and develop a template for cutting cylinders to fit together in a continuous testing path. Lastly, the support and enthusiasm of the members of the Study Advisory Committee is deeply appreciated. Those members were Nathan Awwad, Matthew Beeson, Tom Duncan, Jusang Lee, and Kurt Sommer.

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure. https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at <http://docs.lib.purdue.edu/jtrp/>.

NOTICE

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 views and policies of the Indiana Department of Transportation or the Federal Highway Administration. The report does not constitute a standard, specification or regulation.

COPYRIGHT

Copyright 2018 by Purdue University. All rights reserved.
Print ISBN: 978-1-62260-511-8

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA/IN/JTRP-2018/20	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Development of Friction Performance Test for Compacted Asphalt Mixtures		5. Report Date August 2018	
		6. Performing Organization Code	
7. Author(s) Rebecca S. McDaniel, Ayesha Shah, Karol J. Kowalski		8. Performing Organization Report No. FHWA/IN/JTRP-2018/20	
9. Performing Organization Name and Address Joint Transportation Research Program (SPR) Hall for Discovery and Learning Research (DLR), Suite 204 207 S. Martin Jischke Drive West Lafayette, IN 47907		10. Work Unit No.	
		11. Contract or Grant No. SPR-4113	
12. Sponsoring Agency Name and Address Indiana Department of Transportation State Office Building 100 North Senate Avenue Indianapolis, IN 46204		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.			
16. Abstract In a previous JTRP project published in 2010, <i>Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics</i> , a laboratory procedure to polish and test the frictional properties of asphalt mixtures was developed. Subsequently, the procedure has been used in other research efforts to evaluate the frictional properties of recycled asphalt pavement (RAP) and local (possibly marginal) aggregate blends and for other testing purposes. Most notably, the procedure has been developed into Indiana Test Method (ITM) 221, "Acceptance Procedures for HMA Surface Mixture Coarse Aggregates for ESAL $\geq 10,000,000$." The method requires compaction, polishing and testing of 500 mm by 500 mm (20 in. by 20 in.) square slabs of asphalt mix. This research project was initiated based to explore the possibility of expanding use of the lab polishing/testing procedure to test gyratory specimens or field cores. It was envisioned that such a method could be used during mix design as a check on potential frictional properties and/or as a quality acceptance test. A means of fabricating a circular test ring from seven cylindrical specimens was developed and used to test five different plant produced mixtures. Comparisons of ITM 221 slabs, gyratory specimens compacted to different air void contents and field cores showed cylindrical specimens could yield similar results to the accepted slab test method.			
17. Key Words friction, asphalt, performance test		18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 35	22. Price

EXECUTIVE SUMMARY

DEVELOPMENT OF A FRICTION PERFORMANCE TEST FOR COMPACTED ASPHALT MIXTURES

Introduction

In a previous JTRP project published in 2010, *Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics*, a laboratory procedure to polish and test the frictional properties of asphalt mixtures was developed. Subsequently, the procedure has been used in other research efforts to evaluate the frictional properties of recycled asphalt pavement (RAP) and local (possibly marginal) aggregate blends and for other testing purposes. Most notably, the procedure has been developed into Indiana Test Method (ITM) 221, "Acceptance Procedures for HMA Surface Mixture Coarse Aggregates for ESAL $\geq 10,000,000$." The method requires compaction, polishing and testing of 500 mm by 500 mm (20 in. by 20 in.) square slabs of asphalt mix.

This research project was initiated to explore the possibility of expanding use of the lab polishing/testing procedure to test gyratory specimens or field cores. It was envisioned that such a method could be used during mix design as a check on potential frictional properties and/or as a quality acceptance test.

Findings

A method for fabricating test rings composed of cylindrical specimens was developed. Samples of five plant-produced mixes were tested in various forms—slabs such as those used in ITM 221, gyratory pills compacted from loose plant mix, quality control pills compacted by the contractors and field cores. The results led to the following findings.

- Proof of concept testing indicated it might be feasible to test cylindrical specimens instead of slabs of asphalt mix; this was confirmed by additional testing.
- A reliable way of fabricating test rings using cylindrical samples was developed and used successfully throughout the remainder of this research project. A minimum of four gyratory specimens or seven field cores is required.
- No differences were observed between the tops and bottoms of gyratory specimens and no aggregate breakage had occurred; therefore, it is reasonable to saw gyratory specimens in half and test both the top and bottom surfaces (not the cut surfaces); this reduces the number of gyratory pills needed for testing.
- The comparison of lab-compacted pills and test slabs from the spray paver project, compacted to similar air void levels, showed good agreement. This suggests it is reasonable to test gyratory specimens instead of slabs.

- Comparison of field cores and lab-compacted samples from three lots of a 12.5-mm SMA exhibited slightly greater differences in texture and friction than some of the other comparisons. The reasons for this are not obvious, and the differences may be normal variation. This suggests the need to further analyze variability between replicate samples of given mixtures to determine the acceptable tolerance.
- Differences in the texture depth for a given mixture do not have as great an impact on friction as differences between mixtures, such as aggregate type or gradation or binder content (if excessive). Therefore, differences between lab and field compaction do not appear to negatively impact the validity of the proposed test method.
- Comparison of four different types of samples of a 9.5-mm SMA (slab, lab-compacted, QC pills and field cores) showed similar textures for the lab-compacted pills, QC pills and slab; the cores had lower texture. Despite the difference in texture, the friction levels after polishing were comparable, reinforcing the lesser impact of texture of friction (for the same aggregates and mix).
- Testing field cores allows consideration of the effects of construction on the final product.
- Insufficient time has elapsed since the tested mixes were placed in the field for any conclusions to be drawn about the relationship between the lab and field results, though previous experience shows that ITM 221 was able to predict field friction trends. Field friction on the tested mixes should be monitored for at least two years.
- Based on research, testing experience and specification changes since ITM 221 was developed, changes to the test method were proposed and implemented.

In conclusion, the proposed test method appears to be promising. The proposed method is faster than the current method because fabricating slabs is somewhat time consuming. Less material is required since the gyratory pills are much smaller; the slab configuration requires material inside and outside the testing path that is never tested. Gyratory compaction allows greater control of the air void content than slab compaction, although air voids do not appear to have a great impact on the measured friction levels, within the range tested.

Implementation

Changes have already been made to ITM 221 as a result of discussion with this project's Study Advisory Committee; additional changes have been proposed to allow testing cylindrical samples. A new test method has been proposed for consideration by INDOT that would allow testing gyratory pills as a go/no go check on mix friction during mix design. Field cores could be tested as a quality acceptance test during construction. Shadow testing on several projects is recommended to gain more experience with the test method before widespread implementation. Additionally, lower friction mixtures need to be tested to determine specification limits.

CONTENTS

1. INTRODUCTION	1
1.1 Problem Statement	1
1.2 Objectives	1
2. LITERATURE REVIEW	1
3. RESEARCH APPROACH AND FINDINGS	2
3.1 Test Methods	2
3.2 Proof of Concept	3
3.3 Refining the Specimen Fabrication Process	4
3.4 Materials	5
3.5 Data, Analysis and Findings	6
3.6 Preliminary Field Verification	13
3.7 Recommended Changes to ITM	13
4. CONCLUSIONS AND RECOMMENDATIONS	14
4.1 Conclusions and Discussion	14
4.2 Recommendations	14
REFERENCES	15
APPENDICES	16
Appendix A. Proposed Changes to “Acceptance Procedures for HMA Surface Mixture Coarse Aggregates for ESAL \geq 10,000,000, ITM No. 221-18”	16
Appendix B. Potential New Draft Indiana Test Method for “Surface Friction of Cylindrical Asphalt Mixture Specimens”	24

LIST OF TABLES

Table	Page
Table 3.1 Early proof of concept testing: slab vs. pill comparison (19.0-mm mix)	4
Table 3.2 Later proof of concept testing: slab vs pill comparison (9.5-mm mix X661)	5
Table 3.3 Matrix of samples tested in the study	6
Table 3.4 Mix design parameters	7
Table 3.5 Mixture components	7
Table 3.6 Texture and friction data, 12.5-mm SMA (X531)	10
Table 3.7 Texture and friction data, 9.5-mm SMA (X512)	12
Table 3.8 Texture and friction data, 9.5-mm dense mixes (X458 and X503)	13

LIST OF FIGURES

Figure	Page
Figure 3.1 Circular Track Meter (a) top, (b) underside, showing laser arm	3
Figure 3.2 Dynamic friction tester (a) underside showing disk and sliders, (b) top	3
Figure 3.3 Circular track polishing machine	4
Figure 3.4 Fitting specimens to create test sample, showing need for seven cylinders with edges cut to fit together	4
Figure 3.5 Proof of concept testing: texture of slabs (grey) vs. pills (red)	5
Figure 3.6 Cores of varied heights secured in testing ring (testing surface down)	6
Figure 3.7 Completed ring ready for testing (testing surface up)	6
Figure 3.8 Gradation curves for the mixes tested in this study	7
Figure 3.9 Mean profile depth of X661 slabs and SGC pills	8
Figure 3.10 Coefficient of wet friction of X661 slabs and SGC pills	8
Figure 3.11 International friction index (F60) of X661 slabs and SGC pills	8
Figure 3.12 Wear pattern on X661 test slab (<i>left</i>) and lab-compacted SGC pills (<i>right</i>)	9
Figure 3.13 Texture measurement of 12.5-mm SMA samples (X531)	9
Figure 3.14 Friction measurement of 12.5-mm SMA samples (X531)	10
Figure 3.15 International friction index of 12.5-mm SMA samples (X531)	10
Figure 3.16 Mean profile depth of 9.5-mm SMA samples (X512)	11
Figure 3.17 Coefficient of wet friction of 9.5-mm SMA samples (X512)	11
Figure 3.18 IFI (F60) of 9.5-mm SMA samples (X512)	11
Figure 3.19 Texture readings of X458 and X503 mixes	12
Figure 3.20 Friction readings of X458 and X503 mixes	13
Figure 3.21 IFI (F60) readings of X458 and X503 mixes	13

1. INTRODUCTION

In a previous JTRP project published in 2010 (Kowalski, McDaniel, & Olek, 2010), a laboratory procedure to polish and test the frictional properties of asphalt mixtures was developed. Subsequently, the procedure has been used in other research efforts to evaluate the frictional properties of recycled asphalt pavement (RAP) and local (possibly marginal) aggregate blends and for other testing purposes (McDaniel, Kowalski, & Shah, 2012; McDaniel & Shah, 2012). Most notably, the procedure has been developed into Indiana Test Method (ITM) 221, “Acceptance Procedures for HMA Surface Mixture Coarse Aggregates for ESAL $\geq 10,000,000$ ” (INDOT, 2018).

ITM 221 describes a two-step process to evaluate an aggregate for its frictional performance in high traffic applications. In the first, laboratory step, the frictional performance of the aggregate to be evaluated is compared to that of an approved control aggregate (usually steel furnace slag). Mixtures with the same gradation are prepared with each coarse aggregate, and slabs are fabricated from each mixture. The slabs are compacted into wooden molds using a “rolling pin” assembly on a forklift. The slabs are then polished in a Circular Track Polishing Machine (CTPM) to simulate the effects of traffic. The surface texture and friction of the slabs are measured before and periodically during the polishing process using a Circular Track Meter (CTM) and Dynamic Friction Tester (DFT) respectively. The CTM and DFT measurements are used to determine the International Friction Index (IFI) for each mix.

If the proposed aggregate yields an IFI value equal to or greater than that of the approved control aggregate, the candidate aggregate can then be used in the second step of the approval process – construction and monitoring of a field test section. The field section is monitored for two years. If the proposed aggregate performs adequately in the field, it can then be approved for asphalt surface mixtures for ESALs greater than 10,000,000. The request for evaluation of an aggregate source is initiated by the aggregate producer, who bears the cost of the testing.

A comparison of the laboratory testing to the results of a field test section on SR-62 confirmed that the laboratory testing was able to successfully predict the friction trends observed in the field. The proposed polish resistant aggregate used in that field trial performed acceptably, as predicted by the lab polishing/testing, giving the INDOT Office of Materials Management (OMM) confidence in the ITM.

This research project was initiated based on interest in exploring the possibility of expanding the use of the lab polishing/testing procedure to test gyratory specimens or field cores to evaluate the frictional properties of mixtures during mix design as a go-no go check and/or during construction as a quality acceptance test. It is desirable to test the actual mixture produced rather than simply testing some of the aggregate components. It is possible to produce a mixture with poor frictional properties using a high-friction coarse aggregate, such as

by closing up the void structure with poor-quality sands or over-asphalting the mix. Conversely, it is possible to make a mixture with adequate friction using some marginal materials when blended with higher quality materials to produce a good aggregate structure and mix volumetrics. Testing the frictional properties of produced mixture could be incorporated as one aspect of a performance-based specification for asphalt surfaces. Ultimately it may be possible to streamline or replace the ITM 221 aggregate acceptance procedure with this lab-based test, eliminating the need for long-term monitoring of a field test section. Because ITM 221 is accepted practice, the tests on cylindrical specimens will be compared to slabs such as used in ITM 221.

1.1 Problem Statement

Friction is a critically important pavement characteristic to ensure safety for the traveling public. Research is needed to determine if the existing polishing and testing procedure can be refined and expanded to include testing gyratory specimens and/or field cores during mix design and construction to verify that the mix produced will have adequate frictional properties. These test results could then be used to approve mix designs and/or as a quality acceptance test during construction.

1.2 Objectives

The objectives of this research effort are to:

- Refine or expand the existing polishing and testing process to test gyratory specimens or cores,
- Evaluate the relationship between the laboratory friction testing results and the field performance,
- Develop a draft Indiana Test Method describing the testing procedure, and
- Draft a performance-based specification for asphalt surface friction for consideration by the Department.

Meeting these objectives required proof of concept as the first step. Would it be possible to polish and test cylindrical specimens in a manner similar to that used in ITM221? If so, the next step would be to refine the specimen fabrication process, then test various plant-produced mixes. If the results were favorable, the deliverables would be drafted for INDOT’s consideration. Evaluating the relationship between the lab and field will require longer term monitoring of the field friction through special testing. As a supplementary finding, revisions/updates to the existing ITM 221 were recommended.

2. LITERATURE REVIEW

Using the CTM and DFT on small sized specimens is a new concept so it was not expected that there would be any existing literature on this specific application. The literature was reviewed, however, to identify other relevant work using gyratory or “pieced together” test specimens, considering friction as a part of mix design,

examining the mix parameters influencing friction, and other topics. The most relevant of these are summarized here.

The North Carolina Wear and Polishing Machine, now known generically as the small-wheel circular track polishing machine, is standardized in ASTM E660-90, “Standard Practice for Accelerated Polishing of Aggregates or Pavement Surfaces Using a Small-Wheel, Circular Track Polishing Machine.” This device uses four rubber tires to polish 12 trapezoidal or core specimens arranged around a 36-in. diameter circle. The specimens are placed in specimen holders that are leveled to make a smooth, continuous plane. After polishing, the specimens are individually tested using a British pendulum or a North Carolina State University Variable-Speed Friction Tester. This polishing device, while not common, has been used occasionally in North Carolina and elsewhere since the 1990s or earlier.

Other researchers have attempted to assess the frictional properties of gyratory compacted test specimens. For example, Goodman, Hassan, and Abd El Halim (2006) tested the surface texture and frictional properties of gyratory-molded quality assurance test specimens from eight construction projects in Ottawa and compared those to pavement core samples of the same mixture. They used the sand patch method to assess the surface texture and the British pendulum to measure the friction. On the gyratory specimens, they tested both the top and bottom faces. No polishing was performed on the test specimens. The authors were able to establish a relationship between the initial friction measured using the British pendulum and mix properties including fineness modulus, bulk density, asphalt content and percent passing the 4.75-mm sieve. They also found that British pendulum number on the bottom faces of the gyratory sample correlated better with the field cores than the top faces did. On the other hand, the texture of the top surfaces correlated with the field better than the bottom surfaces did. They reported observing varying levels of aggregate breakdown on the top faces of some gyratory specimens.

Vaiana, Praticò, Iuele, Gallelli, and Minani, (2013) also found some correlations between macrotexture and mix properties in a laboratory study. They measured the mean profile depth (MPD) of four dense graded, three SMA and seven open graded mixtures using a laser profilometer. They then compared the MPD values to mix properties, including nominal maximum aggregate size (NMAS). In general, they found that MPD increased with increasing voids in the mineral aggregate (VMA) and air voids (AV) and decreased with increasing bulk specific gravity (G_{mb}). For dense graded and SMA mixes, however, the observed ranges of MPDs were quite narrow, between about 0.5–1.7 mm. Air voids, VMA and bulk specific gravity values were similarly narrow for the dense graded and SMA mixes. The only statistical analysis done was linear regression of MPD to VMA, AV, G_{mb} and NMAS. Fairly good correlations were found between MPD and VMA, AV and G_{mb} ($R^2 > 0.7$), but the correlation

of MPD to NMAS was only fair ($R^2 = 0.41$). It was only the inclusion of open graded mixes that allowed correlation over a wider range of surface textures (MPDs of 2.0–4.0mm); the observed differences for the dense and SMA mixes were very small.

Williams (2008) explored the relation of micro- and macrotexture of 4.75-mm Superpave mixes to design air voids (4.5% and 6%), aggregate type (limestone, sandstone and syenite), and compaction level (50, 75 and 100 gyrations). She measured microtexture of gyratory specimens with the British pendulum and macrotexture with a modified sand patch test. Statistically, aggregate type (p-value < 0.0001) and design air voids (p-value = 0.0167) were significant factors affecting the microtexture. Design air voids was not practically significant, however, as the British pendulum number only varied from 68.8 for 4.5% AV to 67.5 for 6.0% AV, a very narrow, inconsequential range. The same two factors were statistically significant for macrotexture, but again, the difference for design air voids was not deemed practically significant. The texture depth varied from 0.152 mm for mixes designed at 4.5% air to 0.142 mm for 6% air.

The findings from Vaiana et al. (2013) and Williams (2008) may suggest that air void content does not have as great an impact on friction and texture as one might think – at least when looking at dense graded and SMA mixtures.

3. RESEARCH APPROACH AND FINDINGS

This chapter describes the research approach, including the factors studied, materials and test methods. Then the test results and data analysis are presented.

3.1 Test Methods

Building on ITM 221, the friction and texture of the cylindrical specimens, either gyratory pills or cores, were determined using the circular track meter (CTM) and dynamic friction tester (DFT). The CTM uses a charge-coupled laser to measure the surface macrotexture of the test specimen with a vertical resolution of 3 μm (0.12×10^{-3} in.). The parameter of interest is the mean profile depth (MPD). Other research has shown that the MPD is highly correlated to the mean texture depth (MTD), such as measured with the sand patch test (Wambol, Antle, Henry, & Rado, 1995). The CTM is standardized in ASTM E2157-15, “Standard Test Method for Measuring Pavement Macrotexture Using the Circular Track Meter” and is shown in Figure 3.1. There is not yet a precision statement for this test standard, but the reported standard deviation of eight measurements taken on the same surface is 0.03 mm.

The dynamic friction tester (DFT) is used to measure the surface friction as a function of speed. Three rubber sliders are attached to a disk that can be rotated at speeds up to a tangential velocity of 90 km/h (55 mph). Water is sprayed on the surface and the sliders are dropped onto the test surface. The torque is measured

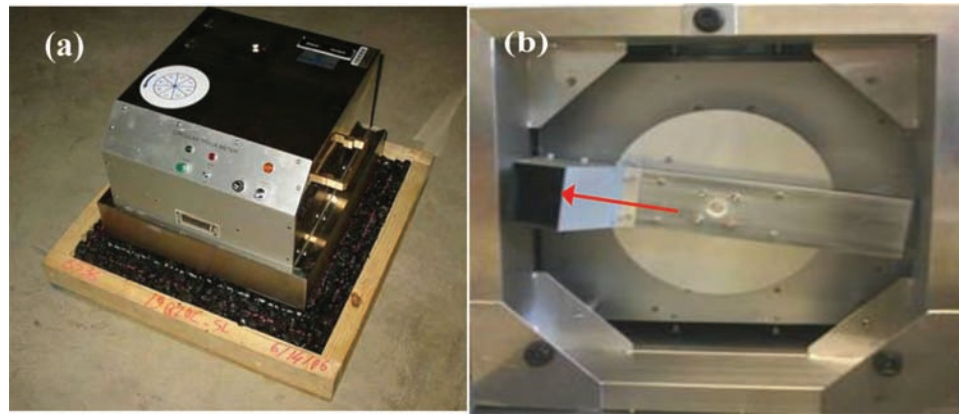


Figure 3.1 Circular Track Meter (a) top, (b) underside, showing laser arm.

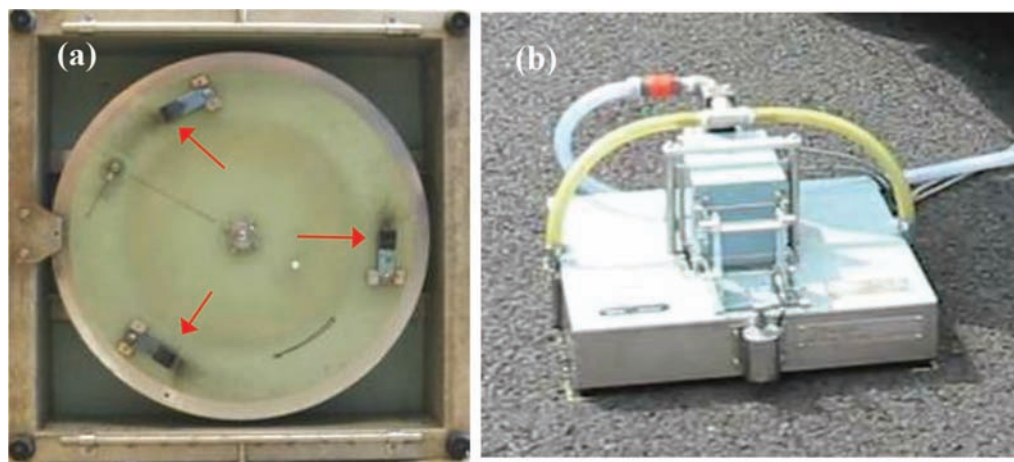


Figure 3.2 Dynamic friction tester (a) underside showing disk and sliders, (b) top.

as friction between the surface and sliders slows then stops the rotation. ASTM E1911-09, “Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester,” describes the device and its operation. The DFT is shown in Figure 3.2. As with E2157, there is no precision statement for this standard. The reported standard deviations of eight measurements taken on the same surface is 0.044 at 30 km/h and 0.038 at 60 km/h.

Using the MPD from the CTM and a DFT reading at a given speed (typically, but not always, 20 km/h, DF20) the speed constant, S_p , and the friction at 60 km/h, F60, can be calculated according to ASTM E1960-07, “Standard Practice for Calculating International Friction Index of a Pavement Surface.” Together, the S_p and F60 constitute the International Friction Index (IFI). The IFI was developed as a means to harmonize, or compare, pavement frictional properties measured using different measurement techniques (Wambold et al., 1995).

A circular track polishing machine (CTPM) is used to simulate traffic wear. The device uses three rubber tires to apply wheel passes over the same footprint as

is tested by the CTM and DFT, i.e. a circular path centered over a diameter of 284 mm (11.2 in.). The device was developed in previous research based on a device from the National Center for Asphalt Technology (Kowalski, McDaniel, & Olek, 2010). Typically 165,000 to 300,000 wheel passes are used to reach terminal friction in ITM 221 and research. The CTPM is shown in Figure 3.3.

3.2 Proof of Concept

ITM 221 uses slabs of mixtures roughly 500 mm x 500 mm x 38 mm (20 in. x 20 in. x 1.5 in.); a slab is visible in the CTPM in Figure 3.3. Fabricating these slabs with a forklift mounted “rolling pin” takes a considerable amount of mix and time. To facilitate testing core samples or gyratory pills, which would be easier and faster to obtain, would require fitting them together to produce a smooth surface suitable for polishing and testing.

In order to accommodate polishing and testing, it is necessary to shave off parts of the specimens to enable full contact across the width of the polishing tires



Figure 3.3 Circular track polishing machine.



Figure 3.4 Fitting specimens to create test sample, showing need for seven cylinders with edges cut to fit together.

and the width of the CTM and DFT paths. To illustrate this idea, Figure 3.4 shows six uncut gyratory specimens arranged on top of one of the full-sized test slabs. Since the cylinders meet only at points, there is not a wide enough path for the polishing and testing devices to follow. Early attempts at cutting the specimens met with varied success; sometimes there were gaps between the cut specimens. Eventually a fairly reliable jig/template was fabricated to guide the cuts, as will be illustrated later. AutoCAD was used to determine the precise angles at which to cut “slivers” off the sides of the cylinders to produce a continuous testing surface.

For proof of concept testing, lab-fabricated gyratory samples of a 19-mm intermediate mix were compacted to 75 mm, cut at an angle to fit together and arranged

TABLE 3.1

Early proof of concept testing: slab vs. pill comparison (19.0-mm mix).

Specimen Type	DF@20 km/h	MPD, mm	F60
Slab	0.378	1.18	0.28
Pill	0.315	1.34	0.25

together in a ring. (This mix was chosen because it was available in sufficient quantity but would not be appropriate for the main research effort because it would be covered by surface mix.) In early testing, the individual samples were held in place with wooden blocks. Seven specimens were needed to complete the path. The texture and friction of the pills was compared to slabs fabricated from the same mixture. The results of an early attempt are shown in Table 3.1. Gaps were observed between the cut gyratory pills, which led to an artificially high MPD reading; elimination of the gaps would be expected to yield values more similar to the slab. The DF and F60 are different but within the ranges observed in previous research when testing replicate slabs. Figure 3.5 shows a comparison of the texture profile for the pills (red) and the slab (grey). While there are differences, the magnitude and range of the textures are similar, suggesting this approach might be feasible if the sample fabrication could be improved.

After the sample cutting template was improved another slab vs. pill comparison was performed to prove the concept, this time using a 9.5-mm surface mix (which explains the lower MPD) collected from a concurrent research project. The results are shown in Table 3.2.

In this case, the results are more comparable and the same F60 value is determined. The DF values are within the standard deviation of replicate measurements on the same surface (~ 0.04 depending on speed) even though three different surfaces were tested. The range of MPDs was somewhat higher than the standard deviation of replicate tests on the same surface (0.03 mm) but not excessively higher and are on three different surfaces with two different types of compaction. This suggested that the approach of using cylindrical specimens was feasible, so the research progressed to the next step – refining the specimen fabrication procedure.

3.3 Refining the Specimen Fabrication Process

Aside from developing a method to cut the cylindrical specimens to fit tightly together, some means of accommodating varied heights of specimens was needed. When making lab fabricated samples, it was possible to compact them to the same height so that no height adjustment was needed. When testing cores, however, the heights could vary considerably; cutting these to height would risk damaging the core. (Cutting vertical, angled slivers off the cores so that they would fit together is also somewhat risky, but unavoidable.) In addition,

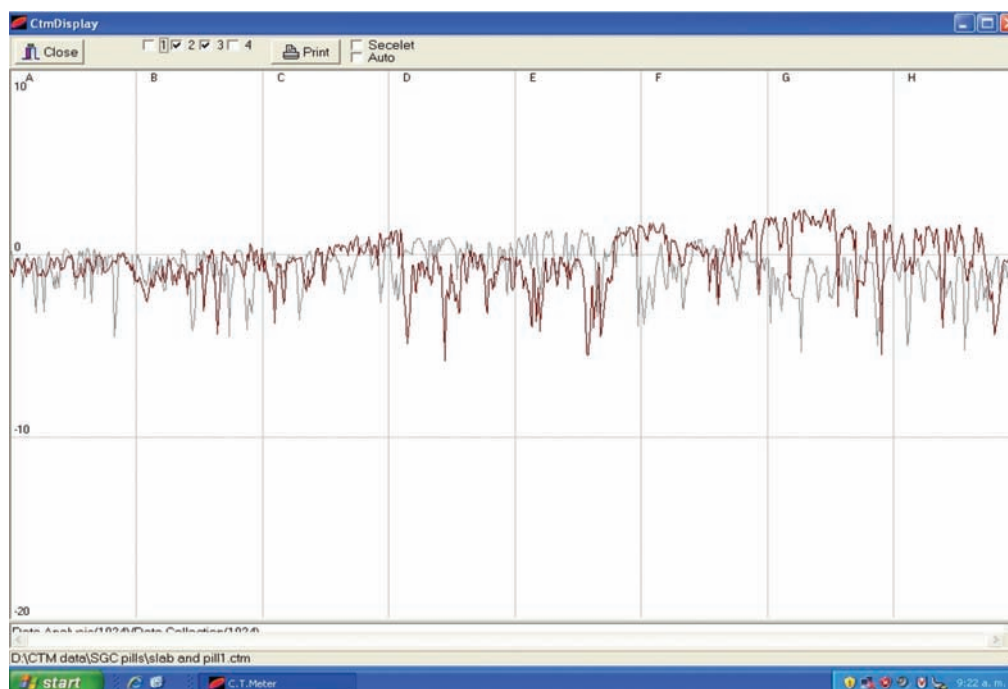


Figure 3.5 Proof of concept testing: texture of slabs (grey) vs. pills (red).

TABLE 3.2
Later proof of concept testing: slab vs pill comparison (9.5-mm mix X661).

Specimen Type	DF@40 km/h	MPD, mm	F60
Slab	0.328	0.74	0.23
Slab	0.352	0.70	0.23
Pills	0.354	0.65	0.23

attempts to cut taller gyratory (QC) pills to the same height were not very successful, resulting in an uneven test surface.

So, it was determined that cutting the specimens to height was not a viable option and an alternate approach was needed. To accommodate varied specimen heights, the test ring is fabricated by placing seven prepared (angle cut) specimens testing face down on a flat surface. After aligning them in a circle, a ring clamp is tightened around them to hold the samples in place during polishing. Once the ring clamp is tightened, the whole assembly is carefully flipped over (testing side up) and centered in a 500 x 500 x 38 mm (20 x 20 x 1.5 in.) wooden slab mold. Self-levelling grout is prepared according to manufacturer's instructions, poured into the mold and allowed to set for two days. Fifteen pounds of cement mix and 1500 ml of water were used for each mold in this study. When the self-levelling grout is poured into the mold, it is sufficiently fluid to penetrate the gaps under the thinner samples to provide underlying support. This process is used when the heights of either gyratory pills or field cores vary. Figure 3.6 shows the bottom of a test ring formed with varying height cores. Figure 3.7 shows the

testing side of a completed test ring held in place with a ring clamp and self-levelling grout.

No aggregate crushing was observed in the gyratory specimens, contrary to what Goodman et al. (2006) reported. In fact, there were no apparent differences between the tops and bottoms of the gyratory specimens. Therefore, cutting four gyratory pills to yield the necessary seven test specimens (with one spare in case of damage) seems reasonable and reduces the number of intact pills required. A minimum of seven cores is needed to test field samples since the top surface must be tested; an extra core or two are desirable in case the cores are damaged during handling.

3.4 Materials

Since testing the frictional properties of mix would most likely be performed on higher volume roadways, the main interest was in testing SMAs and dense graded Category 3 or 4 mixtures (ESALs greater than 3 or 10 million, respectively). Three contractors were asked if they would be willing to provide loose mix, unneeded QC cores and/or field cores of various higher volume mixtures. A total of six sets of mix samples were provided by the contractors. There was also some interest in testing a Category 2 (<3 million ESALs) mix with limestone because of an issue with that type of mix in the Vincennes district. OMM tried to identify a Category 2 mix for testing but eventually was unable to locate one.

Details on the six mixes were discussed with the Study Advisory Committee (SAC) to prioritize the mixes of greatest interest to the department. The SAC recommended testing three sets of materials. Later, with



Figure 3.6 Cores of varied heights secured in testing ring (testing surface down).



Figure 3.7 Completed ring ready for testing (testing surface up).

TABLE 3.3
Matrix of samples tested in the study.

Mix ID	Lab Pills	QC Pills	Field Cores	Slabs
X458	X	X		
X503	X	X		
X512	X	X	X	X
X531		X	XXX	
X661	X			XX

Note: Each X = one set of samples.

time and materials available, two additional mixes were tested; one from the six provided by the contractors and another from a concurrent tack coat study involving a spray paver. Table 3.3 summarizes the various types of samples tested as a part of this study.

The mix design details are provided in Tables 3.4 and 3.5, and Figure 3.8 shows the gradation curves.

It can be seen that each mix tested included steel slag and some recycled material. Two mixes were SMAs and the other three were dense graded. One SMA was a 12.5-mm mix; the other mixes were 9.5-mm.

Plant mixes obtained from contractors in five-gallon buckets were heated to 135°C (265°F) for approximately four hours, until the mix was soft enough to be split into smaller sizes for compacting pills and/or slabs for friction testing. Superpave gyratory pills were compacted from the loose mix to $7.5 \pm 0.5\%$ air voids and a height of 75 to 80 mm (~3" high); these are designated "lab pills." QC pills provided for four of the mixes were compacted by the contractors to the design gyration level and were expected to yield around 4% air voids. The contractors who supplied the plant mixes also supplied field cores obtained from pavements where the same mix was placed. Finally, 500 × 500 × 38 mm (20 × 20 × 1.5 in.) slab specimens were also prepared for some mixes if there was sufficient mix remaining after lab-compacted gyratory specimens were prepared. These slabs were compacted to approximately 8% AV by calculating the mass required, given the dimensions of the wooden mold and maximum theoretical specific gravity (G_{mm}) of the mix. Mix was preheated to 146°C (295°F) for two hours after which it was placed into the wooden mold and compacted with a "rolling pin" device mounted on the prongs of a forklift. Further details about this process can be found in Kowalski et al. (2010).

3.5 Data, Analysis and Findings

Initial readings (friction and texture) were measured on all test samples using the DFT and CTM. Each ring/slab was assigned and tested with a unique set of DFT rubber sliders. This is to ensure that the change in friction due to the wearing down of the test surface by polishing is not confounded with the wearing down of the rubber slider due to repeated use on other surfaces tested with the same sliders. Slabs and test rings were fabricated as described in 3.3 and 3.4.

TABLE 3.4
Mix design parameters.

Mix Parameters	X458	X503*	X512 (SMA)	X531 (SMA)	X661*
Grade	PG64-22	PG64-22	PG76-22	PG76-22	PG64-22
Pass. 19.0 mm	100.0	100.0	100.0	100.0	100.0
Pass. 12.5 mm	100.0	100.0	100.0	93.5	100.0
Pass. 9.5 mm	93.0	95.1	88.1	75.6	94.2
Pass. 4.75 mm	57.3	64.3	38.7	32.3	67.8
Pass. 2.36 mm	31.3	39.3	22.4	20.2	38.7
Pass. 1.18 mm	18.6	23.7	17.6	16.7	25.1
Pass. 0.60 mm	12.6	14.8	14.0	14.3	16.4
Pass. 0.30 mm	9.0	10.1	11.5	12.8	10.0
Pass. 0.15 mm	6.6	7.0	10.3	11.6	6.6
Pass. 0.075 mm	4.7	5.2	8.1	8.8	5.3
G _{sb}	2.581	2.638	2.822	3.016	2.850
P _{b, eff.} %	4.8	5.5	5.4	4.8	4.7
VMA	15.0	16.5	17.2	16.4	15.7
VFA	73.3	75.8	76.7	75.6	74.5

TABLE 3.5
Mixture components.

Material	X458	X503*	X512 (SMA)	X531 (SMA)	X661*
Coarse Agg	12.0% #11 limestone 33.0% #11 slag 24.0% #12 limestone	22.0% #11 limestone 22.0% #11 slag	27.0% QA11 steel slag 54.0% #11 limestone	20.0% #9 40.0% #11 steel slag 9.0% #11 crushed stone	23.0% #11 steel slag 39% #11 dolomite
Fine Agg	19.5% #24 limestone	19.0% 038 FM20 21.0% #24 QA sand	12.0% FM 21 3.0% #16 MF	6.0% #24 stone sand 6.0% QA 16 MF	18.0% #24 stone sand
RAP	10.0% fine RAP	15.0% RAP sand		15.0% SMA slag RAP	18.0% 4.75 RAP sand
RAS	—		3.0%	3.0%	—
BHF	1.5%	1.0%	1.0%	1.0%	2.0% fine return
Virgin Binder Grade and Content, %	6.2% PG 64-22	5.7% PG 76-22	6.5% PG 76-22	4.5% PG 76-22	4.7% PG 70-22
Binder Replacement, %	9.7%	15.7%	8.6%	22.4%	19.2%

*DMFs shown for these two mixes; the other three (w/o asterisk) are JMFs.

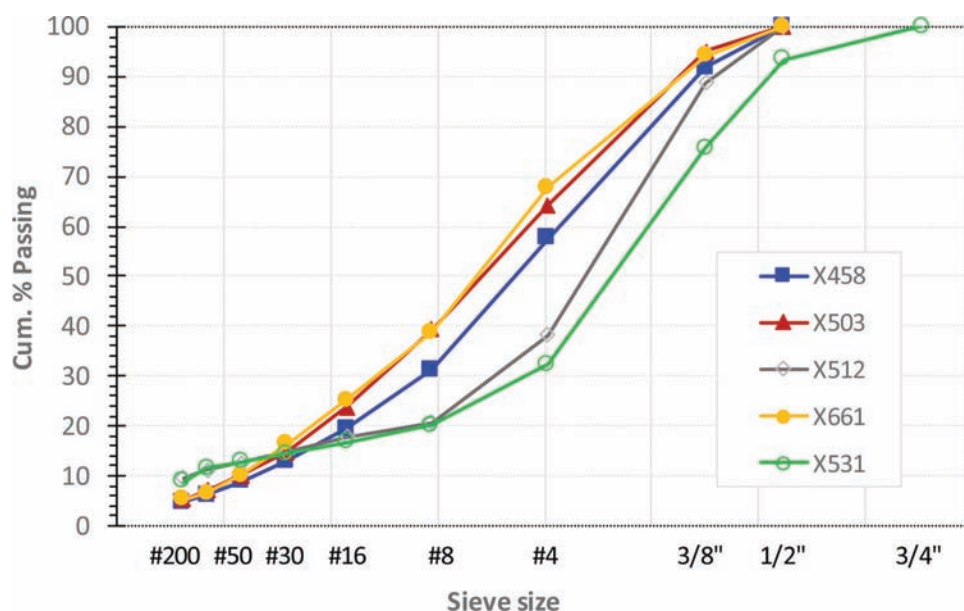


Figure 3.8 Gradation curves for the mixes tested in this study.

3.5.1 Slabs vs. Pills – 9.5-mm Surface Mix

Figures 3.9, 3.10, and 3.11 show the mean profile depth (MPD), coefficient of wet friction (DF20) and

International Friction Index (IFI, F60) for two replicate slabs and one set of lab-compacted pills, using mix from a concurrent study. (This data was summarized in 3.2, including in Table 3.2, but more detail is provided

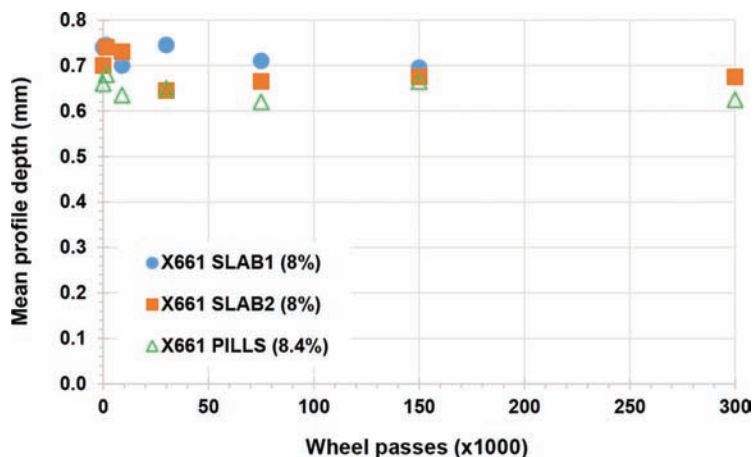


Figure 3.9 Mean profile depth of X661 slabs and SGC pills.

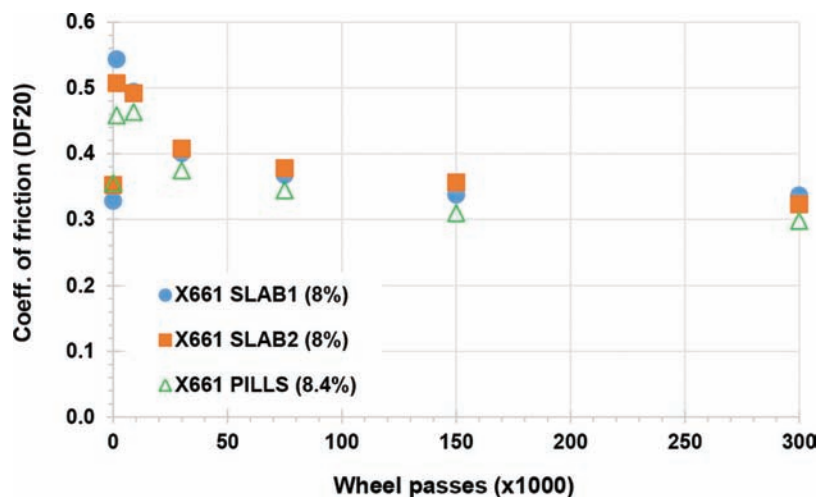


Figure 3.10 Coefficient of wet friction of X661 slabs and SGC pills.

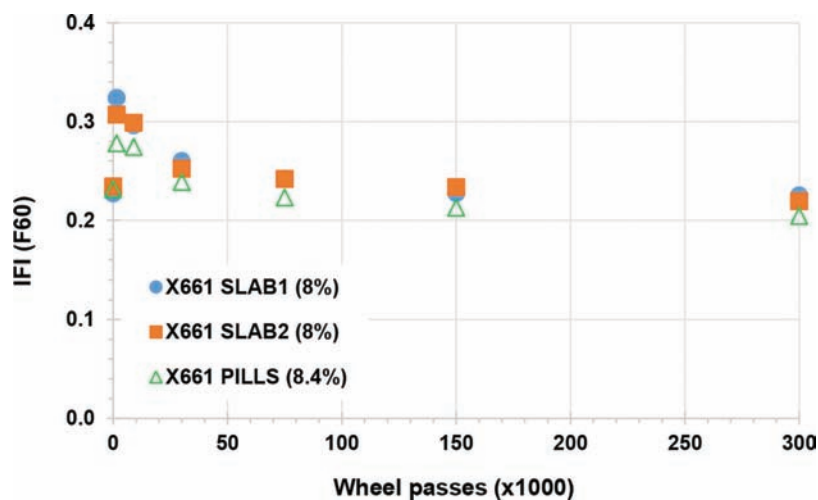


Figure 3.11 International friction index (F60) of X661 slabs and SGC pills.



Figure 3.12 Wear pattern on X661 test slab (*left*) and lab-compacted SGC pills (*right*).

here.) The average air void contents of the compacted pills and test slab were 8.4 and 8.0, respectively. Test data show good agreement between the pills and slab surfaces, with the pill test data falling slightly below the slab test data. The two replicate slabs tested also show good repeatability between the samples. In addition, the degree of wear on the test slabs was similar to that of the SGC pills, as shown in Figure 3.12. (Similar wear patterns were observed on all of the specimens tested in this study; i.e., there was no excessive wear or raveling.)

3.5.2 12.5-mm SMA Evaluation

SMA surface field cores were obtained from three lots (labelled L8, L9 and L10), which were used to make two sets of test rings. One ring consisted of samples from L9 alone, and the other set contained cores from lots 8 and 10. There were not enough cores from those two lots to test separately. QC pills compacted from the same mix were also tested. The friction and texture plots for these test surfaces are shown in Figures 3.13,

3.14, and 3.15, and the data at 300,000 wheel passes is summarized in Table 3.6.

Unlike the replicate slab samples tested earlier, slight differences in the two sets of rings prepared from field cores could be observed. Cores from lot 9 appeared to have higher friction and texture compared with cores obtained from L8+L10. The friction and texture of cores obtained from Lot 9 were similar to lab-compacted pills. While these differences are detectable, the range of DF values was comparable to the standard deviation of replicate tests on the same surface (~ 0.04). The textures of the cores from lots 8 and 10 were lower than those of the other specimens. This is likely due to the differences in compaction between the lab (gyratory) and the field (rollers). The friction level for SMAs and dense graded mixes of a given size is more a function of the aggregate quality than the macrotexture, so the DF20 and F60 values for the cores and pills are not as divergent as the MPDs. While macrotexture is certainly important, as long as there is a reasonable amount of texture, increasing the texture substantially will not increase the friction

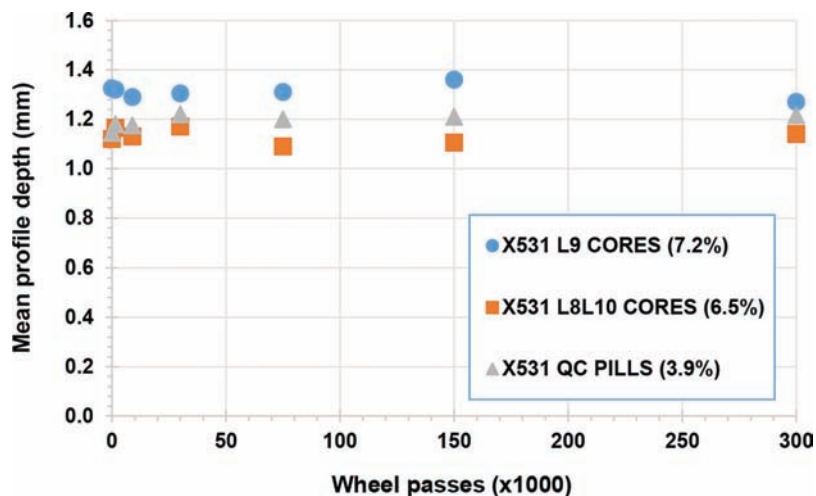


Figure 3.13 Texture measurement of 12.5-mm SMA samples (X531).

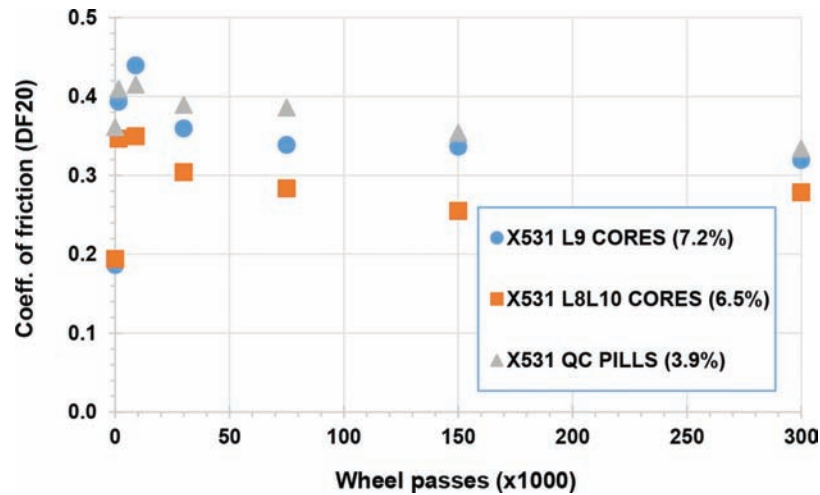


Figure 3.14 Friction measurement of 12.5-mm SMA samples (X531).

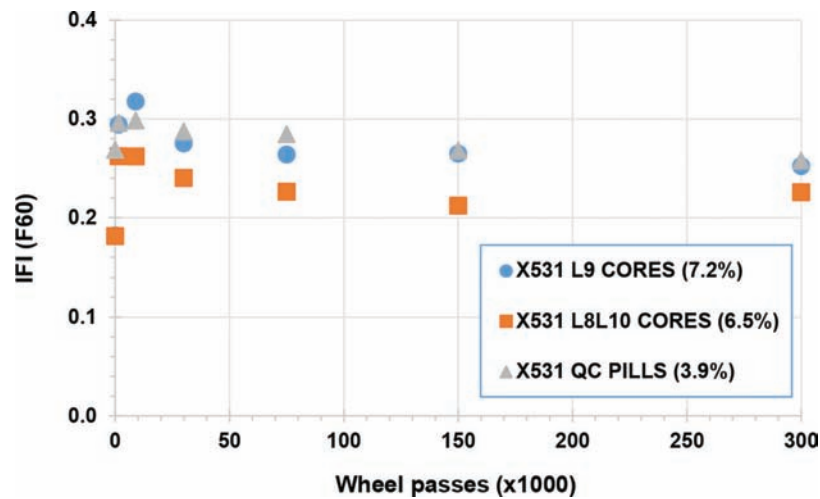


Figure 3.15 International friction index of 12.5-mm SMA samples (X531).

TABLE 3.6
Texture and friction data, 12.5-mm SMA (X531).

Specimen Type	MPD, mm	DF@20, km/h	F60
L9 Cores	1.27	0.320	0.25
L8L10 Cores	1.14	0.279	0.23
QC Pills	1.22	0.334	0.26

level proportionally. New Zealand recommends a minimum texture of 0.6 mm for their road network (Sullivan, 2005). These SMA field cores have nearly double that level.

QC data and INDOT test results for these three lots, provided by the contractor, were examined to see if there was an obvious explanation for the difference between Lot 9 and Lots 8+10. The first two sublots of Lot 8 had low air voids (2.48 and 1.96); it is not known which subplot the tested samples were from, but the average air void content of these pills was

significantly higher. Lots 8 and 10 appeared to be slightly finer than Lot 9, but the differences were not great; in fact, none of these lots had adjustment points for gradation. Lots 9 and 10 both had binder contents slightly outside (0.1 below) the acceptable tolerance and were assessed 4.0 adjustment points; Lot 8 was within tolerance. All three lots had small adjustment points (0.2–0.4) for density. So, the reason for the slight differences is not obvious. This may be normal variation when testing different surfaces.

3.5.3 9.5-mm SMA Evaluation

The next set of samples tested was a 9.5-mm NMAS SMA surface mix (X512). Four different

types of test specimens were prepared and tested; road cores, lab-compacted pills, QC pills and one slab. Figures 3.16, 3.17, and 3.18 and Table 3.7 show the CTM, DFT and IFI data for these samples.

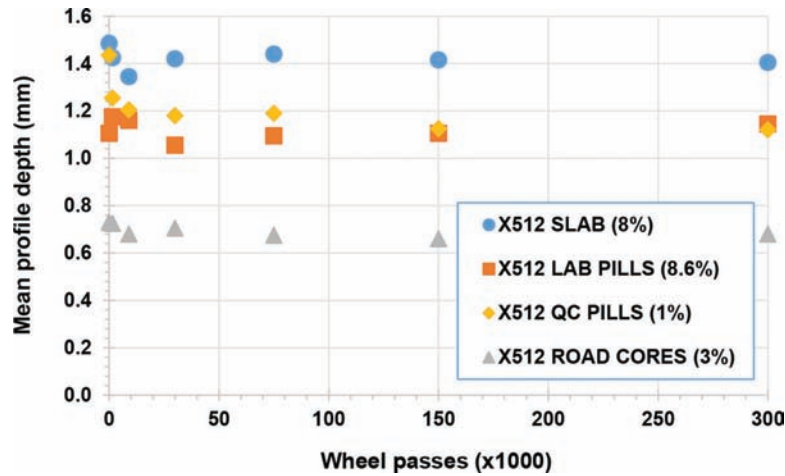


Figure 3.16 Mean profile depth of 9.5-mm SMA samples (X512).

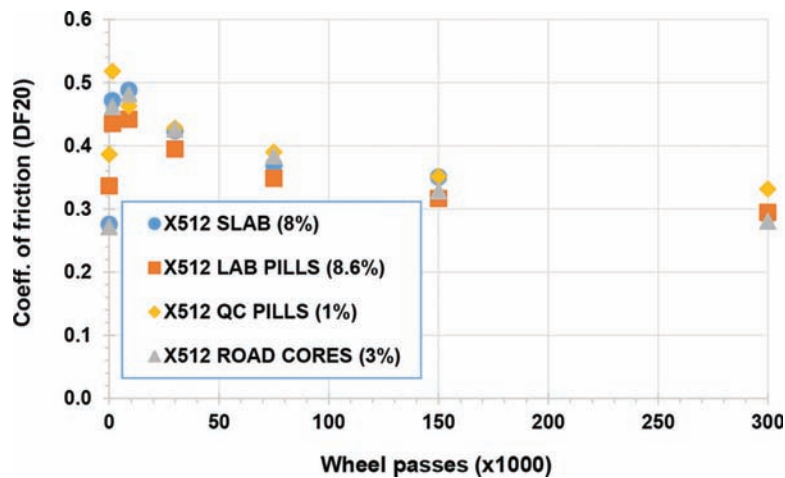


Figure 3.17 Coefficient of wet friction of 9.5-mm SMA samples (X512).

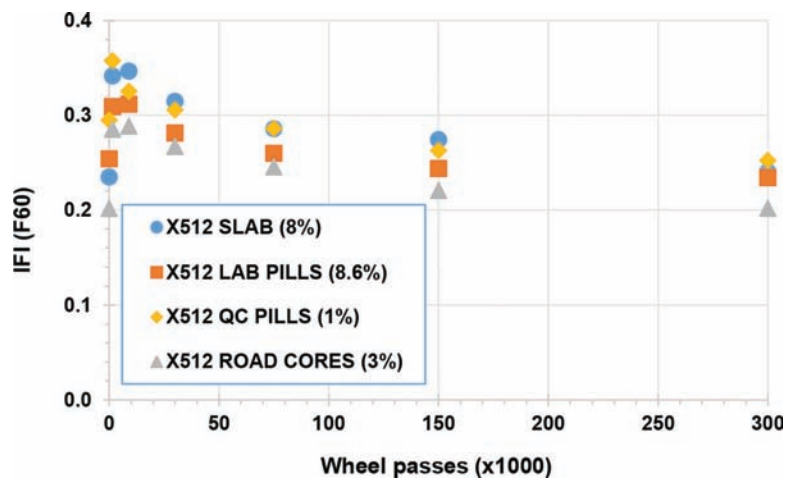


Figure 3.18 IFI (F60) of 9.5-mm SMA samples (X512).

TABLE 3.7
Texture and friction data, 9.5-mm SMA (X512).

Specimen Type	MPD, mm	DF@20, km/h	F60
X512 Slab	1.41	0.281	0.24
X512 Lab Pills	1.12	0.295	0.23
X512 QC Pills	1.12	0.332	0.25
X512 Road Cores	0.68	0.281	0.20

As with the 12.5-mm SMA in 3.5.2, the textures of lab-compacted and QC samples were similar, while road cores had the lowest texture and the test slab had the highest. Since asphalt pavements are roller-compacted to yield good ride quality and pavement smoothness, the low texture value of road cores may be attributable to this. Test slab compaction does not attain the same level of smoothness as that observed in the field due to lower compactive effort, lower placement temperature and other factors. However, the wear pattern of the polishing tires did not show any notable differences.

Towards the end of polishing cycles, the friction values of all the sample sets were similar, regardless of compaction method, except that of the QC pills was slightly higher. In spite of the large range in texture observed between the road cores and the slab, the slab, QC pills and lab pills showed similar F60 values at the end of 300k wheel passes with the road cores falling somewhat below. Again, the effect of texture is not very significant when comparing similar mixture types.

3.5.4 Dense Graded 9.5-mm Surface Mix Evaluation

The last set of samples tested were QC pills and lab-compacted pills from two projects, labelled X458 and X503. The average air void contents of the QC pills for X458 and X503 were approximately 4.9% and 4.0%, respectively, whereas those of the lab-compacted pills for X458 and X503 were approximately 9.7% and 7.2%, respectively. Figures 3.19, 3.20, and 3.21 and Table 3.8 show the texture, friction and IFI results for these test specimens.

The lab-compacted pills of the two mixes showed similar friction readings, as did the two sets of QC pills, in spite of having different aggregates and gradations. X503 contained somewhat less slag and more limestone and was finer than X458; this may be reflected in the lower DF20 and F60 values for the X503 mix. In regards to surface texture, the QC pills from X503 (which had the lowest average %AV) had the highest value, while the remaining three sets showed similar texture. At the end of 300k passes, however, all four sets showed similar F60 values regardless of variations in %AV, aggregate, gradation and compaction method.

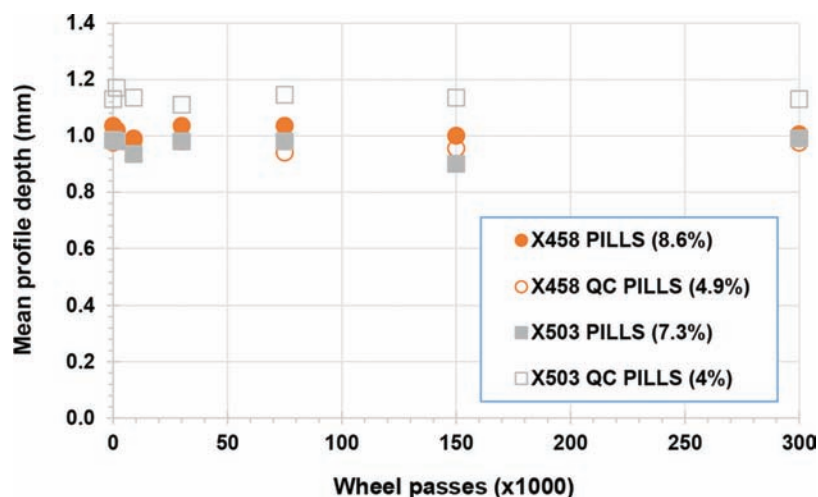


Figure 3.19 Texture readings of X458 and X503 mixes.

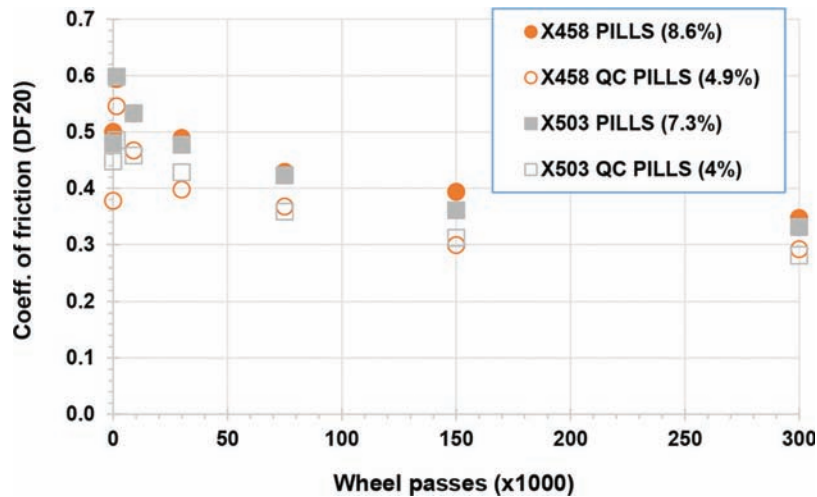


Figure 3.20 Friction readings of X458 and X503 mixes.

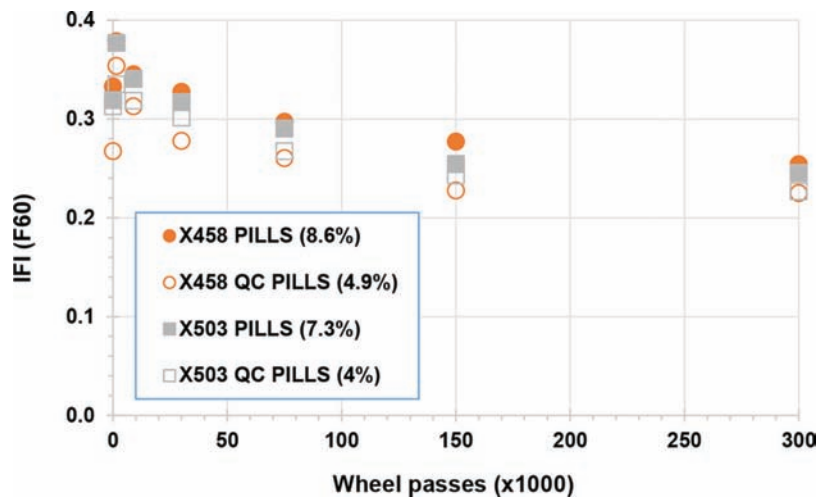


Figure 3.21 IFI (F60) readings of X458 and X503 mixes.

TABLE 3.8
Texture and friction data, 9.5-mm dense mixes (X458 and X503).

Specimen Type	MPD, mm	DF@20, km/h	F60
X458 Lab Pills	1.01	0.347	0.25
X458 QC Pills	0.98	0.292	0.22
X503 Lab Pills	0.99	0.331	0.25
X503 QC Pills	1.13	0.282	0.23

3.6 Preliminary Field Verification

The mixes tested were placed in 2017 so if field friction testing was performed on these projects, it would have been very early, before traffic had worn the binder film off the aggregate particles. (Typically friction testing is delayed by several months, often six, after construction to allow this to happen.) Friction inventory testing is not yet complete in 2018. Some of these mixes were placed on interstates, so will be tested annually as part of the inventory, but mixes off the

interstate system are not necessarily tested. Special friction testing will be requested from INDOT Research and Development (R&D) to monitor the field friction performance of the construction projects sampled and tested. This longer-term monitoring should be conducted, either by the Department (OMM or R&D) or by an extension of this project. The monitoring should continue for at least two years, as currently done under ITM 221.

3.7 Recommended Changes to ITM 221

During discussions with the SAC, it became obvious that ITM 221 needed to be updated to reflect changes in the INDOT specifications, current approved practices and greater experience with the test method and data generated. Specific recommended changes included the following.

- Category 5 mixes had been eliminated from the Standard Specifications but were still included in ITM 221.

- At the request of industry OMM allowed a candidate aggregate to be compared to another approved aggregate instead of steel slag, which the ITM required.
- Numerous test results and research showed that the friction levels could be determined reliably with fewer data points than were used in the original research and were called for in ITM 221; this would speed the testing process substantially.
- A few testing details, such as the mass of aggregate needed and load applied by the polishing device, were clarified.

The PI drafted these changes and forwarded them to OMM for consideration in April 2018. The proposed changes were implemented in May 2018. Appendix A shows the changes in ITM 221 implemented in 2018. Appendix B shows a potential new test method to verify a mix design or for quality acceptance in draft form.

4. CONCLUSIONS AND RECOMMENDATIONS

Based upon the findings of this research, the following conclusions and recommendations are offered.

4.1 Conclusions and Discussion

The different tasks and comparisons detailed in Chapter 3 lead to the following conclusions:

- Proof of concept testing indicated it is feasible to test cylindrical specimens instead of slabs of asphalt mix; this was confirmed by additional testing.
- A reliable way of fabricating test rings using cylindrical samples was developed and used successfully throughout the remainder of this research project.
- No significant testing difficulties were encountered after the specimen fabrication method was developed.
- This method requires a minimum of four gyratory specimens or seven field cores. One or two additional cores are recommended in case of damage.
- No differences were observed between the top and bottom faces of gyratory specimens and no aggregate breakage had occurred, therefore it is reasonable to saw gyratory specimens in half and test both the top and bottom surfaces (not the cut surfaces); this reduces the number of gyratory pills needed for testing. If aggregate breakage is observed, however, replacement pills should be tested, if possible.
- The comparison of lab-compacted pills and test slabs of dense graded mix X661, compacted to similar air void levels, showed good agreement in terms of texture and friction. This suggests it is reasonable to test gyratory specimens instead of slabs.
- Comparison of field cores and lab-compacted samples from three lots of a 12.5-mm SMA exhibited slightly greater differences in texture and friction than some of the other comparisons. The reasons for this are not obvious, and the differences may be normal variation. This suggests the need to further analyze variability between replicate samples of given mixtures to determine the acceptable tolerance.
- Differences in the texture depth do not have as great an impact on friction as differences between mixtures, such as aggregate type or gradation or binder content (if excessive). Therefore, differences between lab and field compaction do not appear to negatively impact the validity of the proposed test method.
- Comparison of four different types of samples of a 9.5-mm SMA (slab, lab-compacted, QC pills and field cores) showed similar textures for the lab-compacted pills, QC pills and slab; the cores had lower texture. Despite the difference in texture, the friction levels after polishing were comparable, reinforcing the lesser impact of texture of friction (for the same aggregates and mix).
- Comparison of two different 9.5-mm surface mixes was conducted between QC pills and lab-compacted loose mix at different air void contents. The QC pills at lower air voids had lower DF20 and F60 values than the lab-compacted pill at higher air voids. There was no clear pattern in the texture depth for the different types of specimens, suggesting that the CTM may not be sensitive to air voids. Notwithstanding the air void differences, the friction levels after polishing were fairly comparable. Again, an assessment of typical variability is needed.
- In most cases, the final texture and friction readings of different types of specimens of the same mixtures agreed within or close to the standard deviations of multiple readings on the same surface reported in the ASTM standards for the CTM and DFT. This lends credence to the concept of testing gyratory specimens or field cores instead of slabs since the final values compare very well.
- Testing field cores allows consideration of the effects of construction on the final product.
- Insufficient time has elapsed since the tested mixes were placed in the field for any conclusions to be drawn about the relationship between the lab and field results, though previous experience shows that ITM 221 was able to predict field friction trends. Field friction on the tested mixes should be monitored for at least two years.
- Based on research, testing experience and specification changes since ITM 221 was developed, changes to the test method were proposed and implemented.

In conclusion, the proposed test method appears to be promising. The proposed method is faster than the current method because fabricating slabs is somewhat time consuming. Less material is required since the gyratory pills are much smaller; the slab configuration requires material inside and outside the testing path that is never tested. Gyratory compaction allows greater control of the air void content than slab compaction, although air voids do not appear to have a great impact on the measured friction levels, within the range tested.

4.2 Recommendations

While the proposed testing method appears quite promising, more information is needed before INDOT considers wide-scale implementation. Nonetheless, limited shadow testing could be considered.

- The mixtures tested here were those offered by contractors (plus one that happened to be available from another study) and not well controlled. Hence, there are confounding effects of gradation, aggregate type and air voids in the data reported above. A more controlled study and additional comparisons of slabs vs QC pills, as well as comparisons of lab-compacted specimens at

different air void contents, could help to untangle the primary factors affecting the measured friction levels and relation to field performance.

- A wider range of mixtures should eventually be tested to assess the impacts of changes in mix parameters and to establish specification limits for different traffic categories.
- A testing program is needed to establish a friction flag value for mix acceptance.
- After more experience is gained with the test method, consideration should be given to how verifying a mixture's frictional properties could be incorporated into a performance based mix design procedure.

REFERENCES

- Goodman, S. N., Hassan, Y., & Abd El Halim, A. O. (2006). Preliminary estimation of asphalt pavement frictional properties from superpave gyratory specimens and mix parameters. *Transportation Research Record: Journal of the Transportation Research Board*, 1949, 173–180. <https://doi.org/10.3141/1949-16>
- INDOT. (2018). *Acceptance procedures for HMA surface mixture coarse aggregates for ESAL $\geq 10,000,000$* (ITM 221-18). Indianapolis, IN: Indiana Department of Transportation Office of Materials Management. Retrieved from www.in.gov/indot/div/mt/itm/pubs/221_testing.pdf
- Kowalski, K. J., McDaniel R. S. & Olek, J. (2010). *Identification of laboratory techniques to optimize superpave HMA surface friction characteristics* (Report No. FHWA/IN/JTRP-2010/6). West Lafayette, IN: Joint Transportation Research Program. <https://doi.org/10.5703/1288284314265>
- McDaniel, R. S., Kowalski, K. J., & Shah, A. (2012). *Evaluation of reclaimed asphalt pavement for surface mixtures* (Publication No. FHWA/IN/JTRP-2012/03). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284314665>
- McDaniel, R. S., & Shah, A. (2012). *Maximizing the use of local materials in HMA surfaces* (Report No. FHWA/IN/JTRP-2012/07). West Lafayette, IN: Joint Transportation Research Program. <https://doi.org/10.5703/1288284314667>
- Sullivan, B. W. (2005). Development of a fundamental skid resistance asphalt mix design procedure. In *International Surface Friction Conference: Roads and runways; Improving safety through assessment and design*. Wellington, New Zealand: Transit New Zealand.
- Vaiana, R., Praticò, F. G., Iuele, T., Gallelli V., & Minani, V. (2013). Effect of asphalt mix properties on surface texture: An experimental study. *Applied Mechanics and Materials*, 368–370, 1056–1060. <https://doi.org/10.4028/www.scientific.net/AMM.368-370.1056>
- Wambold, J. C., Antle, C. E., Henry, J. J., & Rado, Z. (1995). International PIARC experiment to compare and harmonize texture and skid resistance measurements. *Nordic Road and Transport Research*, 6(2), 28–31. Retrieved from <https://trid.trb.org/view/551495>
- Williams, S. G. (2008). An investigation of the design parameters affecting the microtexture and macrotexture of 4.75mm superpave mixtures. In *Proceedings of the Safer Roads International Conference*. Retrieved from <https://www.saferroadsconference.com/conference-papers-2008-2/>

APPENDICES

APPENDIX A

Proposed Changes to “Acceptance Procedures for HMA Surface Mixture Coarse Aggregates for ESAL \geq 10,000,000, ITM No. 221-18”

These changes to the existing ITM 221 are proposed to replace testing slabs of mixtures with testing test rings fabricated from gyratory specimens. These changes have not been adopted at the time of this report. For the current approved test method see <https://www.in.gov/indot/div/mt/itm/itm.htm>.

Draft Revision 10/2/18

INDIANA DEPARTMENT OF TRANSPORTATION OFFICE OF MATERIALS MANAGEMENT

ACCEPTANCE PROCEDURES FOR HMA SURFACE MIXTURE COARSE AGGREGATES FOR ESAL \geq 10,000,000 ITM No. 221-18

1.0 SCOPE.

- 1.1** This method sets forth the acceptance procedures to be used when Aggregate Producers request that coarse aggregates be evaluated for use in HMA surface mixtures with ESAL \geq 10,000,000.
- 1.2** HMA surface mixture aggregates are specified for use under certain traffic ESAL loading conditions to obtain skid-resistant HMA surface courses.
- 1.3** Coarse aggregates tested in accordance with this procedure shall be Polish Resistant Aggregates in accordance with ITM 214 or otherwise approved by the Department.
- 1.4** This method is a two part process. Part One requires a comparison of a HMA surface mixture with the proposed coarse aggregate to a HMA surface mixture with an approved steel furnace slag coarse aggregate or other coarse aggregate approved by the Department using the Circular Track Meter (CTM) in accordance with ASTM E 2157 and the Dynamic Friction Tester (DFT) in accordance with ASTM E 1911. The CTM and DFT values are used to determine the International Friction Index (IFI) in accordance with ASTM E 1960. If the results of the comparison indicate that the HMA surface mixture with the proposed coarse aggregate has an IFI value equal to or greater than the IFI value of the HMA surface mixture with steel slag then Part Two may be initiated.

Part Two requires that a test section of HMA surface mixture using the proposed coarse aggregate and a control test section of HMA surface mixture using steel slag or an approved coarse aggregate be placed on a contract. Steel slag may be blended with an approved dolomite or polish resistant aggregate for the control test section. Acceptance of the coarse aggregate is made on the basis of an evaluation of friction test data obtained after two years of exposure to traffic; however, an aggregate may be accepted after one year of exposure to traffic at the discretion of the Department.

- 1.5** The Aggregate Producer will be required to maintain a warranty bond on the HMA surface course of the test section using the proposed coarse aggregate. The bond amount shall be sufficient to replace the test section with material satisfactory to the Department. Upon opening the test section to unrestricted traffic, the warranty bond will be in effect for a total of two years. The warranty

bond is required to be properly executed by a surety company satisfactory to the Department and be payable to the State of Indiana. Appendix A shall be used for the warranty bond.

- 1.6** If within two years of exposure to traffic, the average friction number of the proposed aggregate is less than the average friction number of the approved steel slag, the Department will evaluate the test section to determine if a problem exists. If remedial work is required, the Aggregate Producer shall conduct the work at no cost to the Department. If the Aggregate Producer cannot conduct the remedial work within a timely manner, the Department has the option to execute the warranty bond and have the remedial work conducted by other forces.
- 1.7** This procedure may involve hazardous materials, operations, and equipment and may not address all of the safety problems associated with the use of the test method. The user of the ITM is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2.0 REFERENCES.

2.1 AASHTO Standards.

- T 11 Materials Finer than 75 μm (No. 200) Sieve in Mineral Aggregates by Washing
T 27 Sieve Analysis of Fine and Coarse Aggregates

2.2 ASTM Standards.

- E 274 Skid Resistance of Paved Surfaces Using a Full Scale Tire
E 524 Smooth Tread Standard Tire for Special-Purpose Pavement Skid Resistance Tests
E 1911 Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester
E 1960 Calculating International Friction Index of a Pavement Surface
E 2157 Measuring Pavement Macrot texture Properties Using the Circular Track Meter

2.3 ITM Standards.

- 207 Sampling Stockpiled Aggregates
214 Acceptance Procedures for Polish Resistant Aggregates

3.0 TERMINOLOGY. Definitions for terms and abbreviations shall be in accordance with the Department's Standard Specifications, Section 101.

4.0 SIGNIFICANCE AND USE. This ITM shall be used to evaluate coarse aggregates for use in HMA surface mixtures for ESAL $\geq 10,000,000$ applications.

5.0 APPARATUS.

5.1 Dynamic Friction Tester in accordance with ASTM E 1911

5.2 Circular Track Meter in accordance with ASTM E 2157

5.3 Circular Track Polishing Machine. This device consists of three rubber tires attached to a rotating plate that travels at approximately 47 revolutions per minute resulting in approximately 141 wheel passes per minute. Water is sprayed on the mixture **test ring** surface to remove debris generated during polishing. A total load of 217 lbm is applied through the tires to the surface.

5.4 Friction vehicle and instrumentation in accordance with ASTM E 274

5.5 Smooth Tread Standard Tire in accordance with ASTM E 524

6.0 GENERAL REQUIREMENTS.

6.1 Each Aggregate Producer requesting to have a coarse aggregate tested in accordance with this procedure shall do so in writing to the Manager, Office of Materials Management. Information concerning the type of material, and ledge numbers, if applicable, shall be included.

6.2 The steel slag or other approved control aggregate material used in the control test section shall be obtained from a Certified Aggregate Producer.

6.3 Testing shall be conducted by the North Central Superpave Center. The cost of shipping and testing of the coarse aggregate shall be the responsibility of the Aggregate Producer.

6.4 Friction testing of the test sections will be conducted by the Department at no expense to the Aggregate Producer.

6.5 Approval of the coarse aggregate for use in HMA surface mixtures for ESAL $\geq 10,000,000$ will be based on results from both Part One and Part Two of this procedure.

7.0 SAMPLING.

7.1 Sampling of the coarse aggregate and steel slag (or other approved control aggregate) shall be in accordance with ITM 207 in the presence of the Department.

7.2 Each sample shall be sufficient in quantity to yield a minimum of 60 lbm of dry material that is passing the 1/2 in. sieve.

7.3 The samples shall be washed and decanted in accordance with AASHTO T 11.

8.0 PROCEDURE (PART ONE)

8.1 Mix Design

8.1.1 Mixtures shall be produced in the laboratory using a mix design designated by the Department. The mix design shall be in accordance with 401.04 for a 9.5mm HMA mixture. PG 64-22 asphalt and a mix design for ESAL Category 4 shall be used.

8.1.2 All other aggregates in the mix design shall be the same type and source for both the mixture using the proposed aggregate and the mixture using steel slag as the coarse aggregate. The design binder content and proportion of the aggregates may vary to account for the difference in absorption and specific gravities of the various aggregates.

8.2 Mixture Test Rings

8.2.1 Laboratory produced mixtures shall be reheated to $300 \pm 9^{\circ}\text{F}$.

8.2.2 Based on the volume of the gyratory mold and the specific gravity of the mixture, the approximate weight of the mixture that would yield 7 to 8 % air voids (V_a) shall be determined.

8.2.3 A minimum of seven gyratory pills shall be compacted at the target air void content.

8.2.4 Once compacted, the gyratory pills shall be thoroughly cooled.

8.2.5 The vertical sides of the gyratory pills shall be cut at a slight angle to allow them to fit together in a test ring with a centerline diameter of 11.2 in. (i.e., to fit the footpath of the polishing machine, DFT and CTM).

8.2.6 The seven gyratory pills shall be secured in the test ring with a metal ring clamp, placed in the center of a 20 x 20 x 1.5 in. wooden mold.

8.2.7 Self-leveling cement mix and water shall be thoroughly mixed according to the manufacturer's recommendations and carefully poured into the mold around the test ring and allowed to cure for a minimum of two days before testing.

8.2.8 The mixture test ring shall be polished a total of 300,000 wheel passes with

the Circular Track Polishing Machine.

8.3 Testing and Reporting

- 8.3.1** The mixture **test ring** shall be tested for the surface texture using the CTM in accordance with ASTM E 2157 and the friction using the DFT in accordance with ASTM E 1911 initially before polishing.
- 8.3.2** Polishing shall be stopped after 1500, 9000, 30000, 75000, 165000 and 300000 passes so that the surface texture and friction of the mixture **test ring** may be measured.
- 8.3.3** The CTM and DFT values are used to determine the International Friction Index (IFI) in accordance with ASTM E 1960. If the IFI value of the mixture **test ring** using the proposed aggregate is equal to or greater than the IFI value for the mixture **test ring** using the steel slag, the Aggregate Producer may request to proceed to Part Two of this procedure.
- 8.3.4** Copies of the test information shall be sent to the Aggregate Producer and the Department and shall include the following:
- Coarse aggregate source identification
 - Type of material
 - Ledges of the aggregate, if applicable
 - Date sampled
 - Individual(s) obtaining the sample of coarse aggregate
 - The International Friction Index in accordance with ASTM E 1960

9.0 TEST SECTIONS (PART TWO).

9.1 Test Section Selection

- 9.1.1** Upon evaluation and approval of the IFI data, a contract will be selected by the Department for placement of the proposed coarse aggregate test section and a control test section using steel slag from an approved source. The contract will have traffic ESALs equal to or greater than 10,000,000 and have continuous uninterrupted traffic over the test sections.
- 9.1.2** A 1 mi test section of HMA using the proposed coarse aggregate material shall be placed adjacent to a 1 mi test control section of HMA using steel slag. A mixture blend of Polish Resistant Aggregates or dolomite coarse aggregates with steel slag may be used. Both test sections shall be placed in the same driving lane. The two test sections shall be located between any major intersections on the contract.

9.2 Friction Testing

9.2.1 Each test section will be tested by the Department in accordance with ASTM E 274. A smooth tire in accordance with ASTM E 524 and a 40 mph test speed will be used.

9.2.2 Friction testing will be performed after approximately six months, one year, eighteen months, and two years of exposure to traffic.

10.0 ACCEPTANCE CRITERIA.

10.1 If the proposed coarse aggregate HMA friction values are equal to or greater than the control section HMA friction values after two years of exposure to traffic, the proposed coarse aggregate will be approved for HMA surface mixtures for ESAL $\geq 10,000,000$.

10.2 The Department will maintain a list of Approved Aggregates including aggregates meeting the requirements outlined herein. The list will include coarse aggregates that are approved for use when air-cooled blast furnace slag, steel furnace slag, or sandstone are required in HMA surface mixtures for contracts with traffic ESALs equal to or greater than 10,000,000.

The aggregate source and ledge number(s), if applicable, will be placed on the Approved List in the ESAL $\geq 10,000,000$ category.

10.3 The aggregate will remain on the Department Approved List unless the material is not performing satisfactorily, as determined by the Department.

**AGGREGATE PRODUCER
ITM 221-12P
WARRANTY BOND**

Know all persons by these presents that we, _____ as principal and _____ as surety, are held and firmly bound unto the State of Indiana (hereinafter referred to as obligee) in the full and just sum of \$ _____, lawful money of the United States of America, for the payment of which, well and truly to be made, we bind ourselves, our heirs, administrators, executors, successors, and assigns, jointly and severally, firmly by these presents.

The condition of the above obligation is that for two (2) years after the date the test section of HMA pavement located on _____, reference point _____ to reference point _____ is
(Beginning Point) (Ending Point)
completed and opened to unrestricted traffic; such warranty is to be in accordance with the Indiana Test Method 221 which is made a part of this bond for warranted test section of HMA pavement. If the principal satisfactorily fulfills the above condition, then this obligation shall be null and void; otherwise such obligation is to remain in full force and effect.

It is agreed that no modifications, omissions, or additions in or to the terms of the ITM 221 or the contract or in or to the plans or specifications shall affect the obligation of the surety on its bond.

In witness whereof, we hereunto set our hands and seal.

Name:

Name:

Address:

Address:

By:

Signature Surety

Title

By:

Signature Principle

Title

(Print or Typed) Surety

(Print of Typed) Principal

State of Indiana, County of _____ SS:

State of Indiana, County of _____ SS:

Personally appeared before me,

Personally appeared before me,

as surety and acknowledge the executions of the
above bond

as surety and acknowledge the executions of the
above bond

this _____ day of _____, 20 _____

this _____ day of _____, 20 _____

By

Signature

Notary Public

By

Signature

Notary Public

(Print of Typed) Notary

(Print of Typed) Notary

My Commission Expires _____, 20 _____

My Commission Expires _____, 20 _____

(County of Residence)

(County of Residence)

APPENDIX B

Potential New Draft Indiana Test Method for “Surface Friction of Cylindrical Asphalt Mixture Specimens”

This draft test method is a potential method that could be implemented as part of a mixture performance specification. It is not currently under consideration as more research is needed to establish specification limits and to gain experience with designing mixtures for frictional performance.

ITM xxx-18

Draft 9/6/2018

INDIANA DEPARTMENT OF TRANSPORTATION OFFICE OF MATERIALS MANAGEMENT

SURFACE FRICTION OF CYLINDRICAL ASPHALT MIXTURE SPECIMENS ITM No. XXX-18

1.0 SCOPE.

- 1.1 This test method covers the determination of the laboratory-measured friction of gyratory specimens or field cores of asphalt mixtures.
- 1.2 HMA surface mixture aggregates are specified for use under certain traffic ESAL loading conditions to obtain skid-resistant HMA surface courses.
- 1.3 This test method shall be used to verify an asphalt surface course mixture design using gyratory specimens or as a quality acceptance test on cores of field-compacted asphalt surfaces.
- 1.4 This procedure may involve hazardous materials, operations, and equipment and may not address all of the safety problems associated with the use of the test method. The user of the ITM is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2.1 REFERENCES.

2.2 AASHTO Standards.

- T 11 Materials Finer than 75 μm (No. 200) Sieve in Mineral Aggregates by Washing
- T 27 Sieve Analysis of Fine and Coarse Aggregates

2.3 ASTM Standards.

- E 1911 Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester
- E 1960 Calculating International Friction Index of a Pavement Surface
- E 2157 Measuring Pavement Macrot texture Properties Using the Circular Track Meter

2.4 ITM Standards.

- 207 Sampling Stockpiled Aggregates
- 214 Acceptance Procedures for Polish Resistant Aggregates

3.0 TERMINOLOGY. Definitions for terms and abbreviations shall be in accordance with the Department's Standard Specifications, Section 101.

4.0 SIGNIFICANCE AND USE. This ITM shall be used to verify mix designs and/or as a quality acceptance measure for HMA surface mixtures for ESAL $\geq 10,000,000$ applications (*keep the traffic level?*).

5.0 APPARATUS.

5.1 Dynamic Friction Tester in accordance with ASTM E 1911

5.2 Circular Track Meter in accordance with ASTM E 2157

5.3 Circular Track Polishing Machine. This device consists of three rubber tires attached to a rotating plate that travels at approximately 47 revolutions per minute resulting in approximately 141 wheel passes per minute. Water is sprayed on the mixture slab surface to remove debris generated during polishing. A total load of 217 lbm is applied through the tires to the surface.

6.0 GENERAL REQUIREMENTS.

6.1 Each Mix Designer or Mixture Producer requesting (*or required?*) to have a mix design or produced mixture tested in accordance with this procedure shall do so in writing to the Manager, Office of Materials Management. Information concerning the mixture design components and volumetric properties shall be included.

6.2 The steel slag or other approved control aggregate material used in the control test ring shall be obtained from a Certified Aggregate Producer.

6.3 Testing shall be conducted by the North Central Superpave Center. The cost of shipping and testing of the gyratory specimens or cores shall be the responsibility of the Mixture Designer or Producer.

6.4 Approval of the mixture design or acceptance of a compacted surface course for ESAL $\geq 10,000,000$ will be based on results from the laboratory testing.

7.0 SAMPLING.

7.1 For mix design verification, a minimum of four gyratory specimens of the designed mixture with heights of 6 in. and air void contents of $7.5 \pm 0.5\%$ shall be provided.

7.2 For quality acceptance, a minimum of eight field cores 150-mm in diameter shall be taken at random locations within a randomly selected lot at the direction of the project engineer or delegate.

8.0 PROCEDURE

8.1 Mix Design Verification

8.1.1 Mixture specimens shall be produced in the mix design laboratory using the proposed mix design. The proposed mix design shall be compared to an approved design designated by the Department. The proposed and control mix designs shall be in accordance with 401.04 for the same size mixture, binder grade and ESAL Category.

8.2 Quality Acceptance Testing

8.2.1 Field core test results for quality acceptance testing shall be compared to the previously approved mix design's test results.

8.3 Gyratory Pill Test Ring Fabrication

8.3.1 Four gyratory pills shall be cut in half so that the uncut top and bottom surfaces can be tested.

8.3.2 The vertical sides of the cut gyratory pills shall be cut at a slight angle to allow them to fit together in a test ring with a centerline diameter of 11.2 in. (i.e., to fit the footpath of the polishing machine, DFT and CTM).

8.3.3 The prepared gyratory specimens shall be secured with the uncut faces up in the test ring with a metal ring clamp, and placed in the center of a 20 x 20 x 1.5 in. wooden mold.

8.3.4 Fifteen lbs of self-leveling cement mix and 0.4 gal. of water shall be thoroughly mixed and carefully poured into the mold around the test ring and allowed to cure for a minimum of two days before testing.

8.3.5 The mixture test ring shall be polished a total of 300,000 wheel passes with the Circular Track Polishing Machine.

8.4 Field Core Test Ring Fabrication

8.4.1 The vertical sides of seven field cores shall be cut at a slight angle to allow them to fit together in a test ring with a centerline diameter of 11.2 in. (i.e., to fit the footpath of the polishing machine, DFT and CTM).

8.4.2 The prepared cores shall be secured with the top faces down in the test ring with a metal ring clamp. The clamped ring shall be turned over carefully and placed in the center of a 20 x 20 x 1.5 in. wooden mold.

8.4.3 Self-leveling cement mix and water shall be thoroughly mixed according to the manufacturer's recommendations and carefully poured into the mold

around the test ring and allowed to cure for a minimum of two days before testing.

- 8.4.4** The mixture test ring shall be polished a total of 300,000 wheel passes with the Circular Track Polishing Machine.

8.5 Testing and Reporting

- 8.5.1** The mixture slab shall be tested for the surface texture using the CTM in accordance with ASTM E 2157 and the friction using the DFT in accordance with ASTM E 1911 initially before polishing.

- 8.5.2** Polishing shall be stopped after 1500, 9000, 30000, 75000, 165000 and 300000 passes so that the surface texture and friction of the mixture slab may be measured.

- 8.5.3** The CTM and DFT values are used to determine the International Friction Index (IFI) in accordance with ASTM E 1960. If the IFI value of the mixture slab using the proposed aggregate is equal to or greater than the IFI value for the mixture slab using the steel slag, the Aggregate Producer may request to proceed to Part Two of this procedure.

- 8.5.4** Copies of the test information shall be sent to the Mix Designer or Producer and the Department and shall include the following:

- Mixture identification
- Type of material
- Date produced or cored
- Individual(s) designing the mixture or obtaining the cores
- The International Friction Index in accordance with ASTM E 1960

9.0 ACCEPTANCE CRITERIA.

- 9.1** If the proposed mix design's friction values are equal to or greater than the control mix' friction values, the proposed mix design will be approved for HMA surface mixtures for ESAL $\geq 10,000,000$.
- 9.2** If the field cores' friction values are equal to or greater than the approved mix design's friction numbers, the mixture shall be accepted.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1 — evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: <http://docs.lib.purdue.edu/jtrp>

Further information about JTRP and its current research program is available at: <http://www.purdue.edu/jtrp>

About This Report

An open access version of this publication is available online. This can be most easily located using the Digital Object Identifier (doi) listed below. Pre-2011 publications that include color illustrations are available online in color but are printed only in grayscale.

The recommended citation for this publication is:

McDaniel, R. S., Shah, A., & Kowalski, K. J. (2018). *Development of a friction performance test for compacted asphalt mixtures* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2018/20). West Lafayette, IN: Purdue University. <https://doi.org/10.5703/1288284316865>