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EVALUATION OF LABORATORY FRICTION PERFORMANCE OF AGGREGATES FOR HIGH FRICTION SURFACE TREATMENTS

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Fairmount Minerals, Chardon, OH
Washington Rock, Graham, WA
US Silica, Mauricetown, NJ
Earthworks Solutions, Gillette, WY

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LIST OF ABBREVIATIONS

AASHTO .... American Association of State Highway and Transportation Officials
ASTM .... American Society for Testing and Materials
CTM .... circular texture meter
DFT .... dynamic friction tester
DFT(40) .... dynamic friction measured at 40 km/h
DOT............................ Department of Transportation
FHWA .... Federal Highway Administration
Fn............................... friction number
HFST .... high friction surface treatment
K .... thousand
km/h .... kilometers per hour
lb................................ pounds
MDOT .... Michigan Department of Transportation
MTD........................... mean texture depth
NCAT.......................... National Center for Asphalt Technology
psi .... pounds per square inch
rpm .... revolutions per minute
SN40R .... skid number at 40 mph with ribbed tire
TWPD......................... three wheel polishing device

INTRODUCTION/BACKGROUND

Pavement friction is one component of the Federal Highway Administration's (FHWA) Roadway Departure Safety Program and one of the tools is high friction surface treatments (HFST). An HFST is an important application for critical safety locations like bridge decks, horizontal curves, and high speed deceleration ramps. HFST use began in the early 1950's in the USA as a thin polymer-bonded bridge deck treatment. The industry that installed this product for many years used a variety of aggregates that they felt performed well. The use of calcined bauxite as the HFST aggregate was first published in 1976. At this point, the FHWA and American Association of State Highway and Transportation Officials (AASHTO) view HFST as a specialized subset of thin-bonded polymer overlays for locations with critical friction demand. The question that continues to be examined is the use of other regionally available and less expensive friction aggregates that can provide satisfactory performance as a thin-bonded polymer overlay.

While this concept was being successfully used in other countries for crash reduction and similar products were being used in the USA on bridges, the FHWA Office of Pavement Technology initiated the Surface Enhancements at Horizontal Curves program to demonstrate the application of HFST in roadway curves. When the demonstration program began, AASHTO had not written the guide specification for HFST and companies that bid the demonstration projects often bid their thin polymer-bonded bridge deck treatment systems, which did not always include calcined bauxite.

FHWA, AASHTO, and the American Traffic Safety Services Association (ATSSA) have developed an HFST guide specification (PP 79-14 Standard Practice for High Friction Surface Treatment for Asphalt and Concrete Pavements). Currently, the guide specification only recognizes calcined bauxite aggregate (*1, 2*). Therefore, the AASHTO definition for HFST requires calcined bauxite.

The Michigan Department of Transportation (MDOT) has special provision 12SP-800A-03 for HFST, and it specifies the use of calcined bauxite (*3*). The Department's special provision 12SP-712B-01 for thin epoxy polymer bridge deck overlay specifies aggregate properties and includes a list of six approved suppliers (*4*).

Comparative field friction testing of alternative aggregates for thin polymer-bonded bridge deck treatment systems is not practical. The ideal test site requires a single location and the length of each test section must accommodate consistent locked wheel skid trailer testing and uniform traffic abrasion. There are very few sites that would meet these comparative testing criteria. If multiple sites are needed, it is difficult to find sites with similar traffic, climate, and winter maintenance.

The National Center for Asphalt Technology (NCAT) Three Wheel Polishing Device (TWPD), as shown in Figure 1, offers a practical and technically sound controlled evaluation of alternative friction aggregates. The lab evaluation is not a true field traffic examination of performance, but the method permits a direct comparison of alternative aggregates by applying uniformly controlled conditioning and testing.

Figure 1 NCAT Three Wheel Polishing Device

Figure 2 depicts a generic pavement friction performance curve for an asphalt pavement. The early portion of friction performance exhibits a dramatic increase in friction as the asphalt binder film wears off the pavement surface followed by a steep friction loss due to initial aggregate polishing. After the initial aggregate polishing, the surface friction performance stabilizes as defined by long-term friction loss trend, commonly called terminal friction. When a thin epoxy polymer surface is placed on an existing pavement or bridge deck, there is no asphalt film on the new surface, so the surface begins with its peak friction value. This study focused on the long-term friction loss trend (terminal friction) of each aggregate.

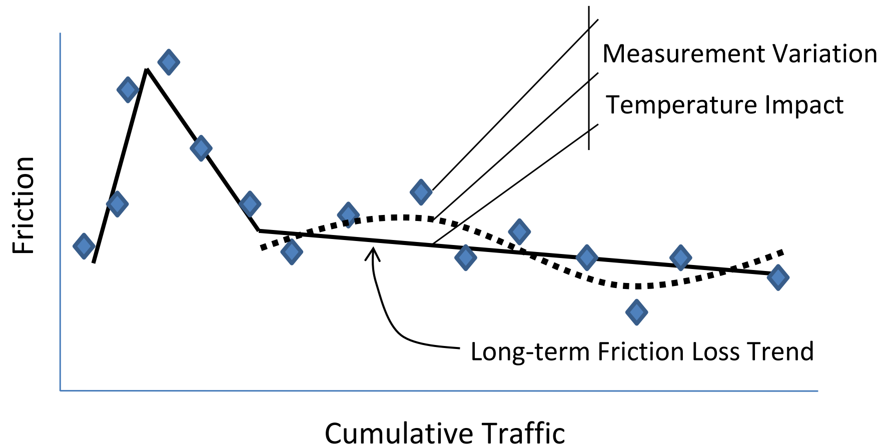

Figure 2 Generic Asphalt Surface Friction Performance Curve

SCOPE OF STUDY

For the purposes of this study, the terms bauxite and HFST are used generically and do not fully agree with the recently adopted AASHTO standard practice (PP 79-14) discussed in the Introduction. While the term bauxite refers to a natural aggregate with relatively soft properties, in this report, calcined bauxite will be simply referred to as bauxite. In this report, the term HFST will be used to describe the placement of a thin polymer-bonded friction aggregate surface treatment to improve the friction properties of the pavement surface. As such, the term HFST does not meet all the criteria of PP 79-14.

This study was a direct comparison of eleven aggregates applied as HFST using an NCAT laboratory evaluation process. The use of the TWPD for surface friction comparisons in the laboratory is an analysis process that is still developing. Since there are no specified standards or thresholds for friction values, this test procedure allows engineers and researchers to make relative comparisons of friction performance between surfaces. It will be the responsibility of governing agencies to determine what an acceptable threshold should be.

The scope of the laboratory study was to provide MDOT with friction performance data for determining which aggregate sources met the agency's criteria for HFST. The objective was to evaluate the friction performance of eleven aggregates using identical conditioning (polishing) with the NCAT TWPD. The description and source of the aggregates are given in Table 1. Testing each aggregate for specification compliance was not a part of the study. Each aggregate sample, as received, was expected to meet thin epoxy polymer bridge deck overlay criteria.

Table 1 Study Aggregate Types and Sources

Aggregate Name/ Aggregate Type	Location	Supplier	Supplier's Office Location
Basalt	Eau Claire, WI	Red Flint Group	Eau Claire, WI
Copper Slag	Eau Claire, WI	Red Flint Group	Eau Claire, WI
Flint 65-8	Picher, OK	Flint Rock Products	Commerce, OK
RK Bauxite 6x14C calcined bauxite	Newell, WV	FX Minerals	Newell, WV
47 - 4x20 calcined kaolin	Roswell, GA	C-E Minerals	Andersonville, GA
60 - 4x20 calcined kaolin	Roswell, GA	C-E Minerals	Andersonville, GA
70 - 4x20 calcined kaolin	Roswell, GA	C-E Minerals	Andersonville, GA
Best Sand 612 quartz	Chardon, OH	Fairmount Minerals	Chardon, OH
Armor Stone quartz	King Creek Pit Orting, WA	Washington Rock	Graham, WA
EP5-Mod quartz	Frederick, MD	US Silica	Mauricetown, NJ
Traction Control Feldspar mineral	Gillette, WY	Earthworks Solutions	Gillette, WY

TEST PROCEDURE

Sample Preparation

The 11 HFST aggregates were placed on 20x20 inch asphalt test slabs. Two replicate slabs were made for each aggregate. The asphalt surfaces of the 22 slabs were cleaned using a light sand-blast spray to remove the surface asphalt film. To ensure a good bond between the aggregate and epoxy, each aggregate sample was washed to remove dust and oven dried. The epoxy bonding agent, E-BOND 526, was applied to the surface of each slab at an approximate rate of 0.04 gal/sq ft and spread uniformly with a notched-tooth trowel. The aggregate was broadcasted by hand onto the uncured epoxy surface. After the epoxy cured for 24 hours, the surface was swept to remove loose aggregate, aggressively rubbed with a wooden board to dislodge loosely bound aggregate, and swept again.

Test Protocol

The laboratory protocol for the NCAT TWPD is a developing procedure. The NCAT TWPD was initially developed at NCAT in a 2004-2006 study (*5*). A second study completed in 2010 refined the test parameters and found a reasonable correlation between laboratory results and field tests (*6*). The TWPD is designed to uniformly condition (polish) a 284 mm diameter path on the surface of a test slab.

The conditioned path is tested by ASTM test methods E 2157 (Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter) and E 1911 (Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester), commonly called the circular texture meter (CTM) and dynamic friction tester (DFT), respectively. The CTM and DFT are used for measuring the surface texture and friction of pavement surfaces. Both test methods can be used in the laboratory or in the field. The CTM measures the pavement surface macrotexture profile and provides a mean profile depth (MPD) in millimeters to quantify the macrotexture. The DFT measures pavement surface friction properties as a function of speed (20, 40, and 60 km/h for this study) and provides a dimensionless value called the friction number (Fn). There is no consistent trend that higher DFT speed measures higher friction, so the speed that produces the most repeatable measure, 40 km/h, was used for the entire study. In this report, the DFT friction values are commonly expressed as DFT(40), meaning the Fn at 40 km/h. For both test procedures, increasing values indicate higher surface friction characteristics.

For the evaluation of HFST aggregates in this laboratory study, the following test protocol was used.

- The two replicate slabs of each HFST aggregate were divided for conditioning on separate TWPD units.
- A new set of three TWPD tires was installed for each slab tested. The TWPD was operated at 60 rpm, 50 psi tire pressure, and 91 lb gross carriage weight. Previous studies using the TWPD showed that 80,000 to 100,000 (80K to 100K) conditioning cycles were needed to reach a terminal surface friction condition. This study extended the polishing to 140K cycles to help distinguish performance between the higher quality aggregates.
- Each CTM test included three replicate measurements on the dry slab surface. A template was placed over the slab to ensure the measurements were taken at the same location.
- Each DFT test included three replicate measurements. A template was placed over the slab to ensure the measurements were taken at the same location. DFT rubber slider pads were replaced after every six measurements. Although the ASTM standard allows the rubber sliders to be used for twelve measurements, the aggressive wear on HFST surfaces requires more frequent replacement.
- The sequence of DFT testing and NCAT TWPD conditioning was as follows:

1. One pair of slabs was prepared for testing and conditioning.
2. Initial CTM and DFT measurements were taken on each slab.
3. TWPD conditioning for 70K cycles was performed on each slab.
4. The slabs were dried overnight.
5. CTM and DFT measurements were taken on each slab.
6. An additional 70K cycles of conditioning was performed for each slab matching the same TWPD and slab.
7. The slabs were dried overnight.
8. Final CTM and DFT measurements were taken.
9. The test protocol sequence was repeated for each set of slabs.

Test Results

The DFT measurements are listed in Table 2 and CTM measurements are listed in Table 3.

Test Quality Control

Laboratory testing consisted of 99 sets of DFT measurements (three cycle periods, three measurement speeds, and eleven materials). Testing quality control examined the difference between the DFT measurements of the replicate slabs to determine if the two slabs for each HFST aggregate generated similar results. For example, the average DFT(40) results from 70K cycles of TWPD for slab 1 were compared to the same results for slab 2. Differences between the slab measurements were combined into a histogram to show the distribution of slab test differences, shown in Figure 3. Overall, the average difference was a DFT delta of 0.034. Two standard deviations from the mean was 0.08 and only three delta values were greater than two standard deviations. Those values are highlighted in Table 2. Those test values represent initial DFT tests on unconditioned surfaces and are not critical to the analysis.

The results of this quality control analysis were similar to an earlier HFST study presented in NCAT report 15-04. That study observed that 65% of the ranges were below 0.040 and 98% were below 0.120.

CTM measurements are very repeatable. No quality control evaluation was performed on the data.

Table 2 Summary of DFT Results

# Cycles	km/h	Basalt Slab 1 - Avg	Basalt Slab 2 - Avg	Flint Rock - Flint Slab 1 - Avg	Flint Rock - Flint Slab 2 - Avg	RK Bauxite Slab 1 - Avg	RK Bauxite Slab 2 - Avg	Copper Slag Slab 1 - Avg	Copper Slag Slab 2 - Avg
0 cycles	20	0.60	0.54	0.78	0.82	0.90	0.94	0.72	0.72
	40	0.62	0.55	0.81	0.88	0.95	0.97	0.75	0.77
	60	0.68	0.58	0.87	0.95	0.94	1.05	0.80	0.83
70,000 cycles	20	0.50	0.52	0.55	0.56	0.78	0.81	0.54	0.49
	40	0.53	0.51	0.57	0.59	0.77	0.79	0.58	0.53
	60	0.51	0.55	0.57	0.61	0.74	0.79	0.64	0.57
140,000 cycles	20	0.48	0.52	0.55	0.55	0.79	0.81	0.50	0.50
	40	0.52	0.52	0.57	0.56	0.79	0.80	0.53	0.53
	60	0.51	0.54	0.56	0.59	0.77	0.82	0.56	0.54

# Cycles	km/h	47-4x20 Slab 1 - Avg	47-4x20 Slab 2 - Avg	60-4x20 Slab 1 - Avg	60-4x20 Slab 2 - Avg	70-4x20 Slab 1 - Avg	70-4x20 Slab 2 - Avg	Armor Stone Slab 1 - Avg	Armor Stone Slab 2 - Avg
0 cycles	20	0.82	0.80	0.81	0.77	0.84	0.79	0.87	0.82
	40	0.86	0.82	0.84	0.80	0.86	0.79	0.85	0.81
	60	0.92	0.86	0.87	0.80	0.89	0.84	0.85	0.81
70,000 cycles	20	0.62	0.61	0.60	0.59	0.58	0.55	0.59	0.66
	40	0.64	0.63	0.64	0.63	0.60	0.58	0.61	0.67
	60	0.66	0.66	0.66	0.61	0.65	0.59	0.63	0.70
140,000 cycles	20	0.57	0.54	0.58	0.54	0.57	0.54	0.51	0.57
	40	0.60	0.58	0.60	0.57	0.59	0.57	0.52	0.57
	60	0.64	0.61	0.65	0.58	0.63	0.56	0.53	0.60

# Cycles	km/h	Best Sand Slab 1 - Avg	Best Sand Slab 2 - Avg	EP5 MOD Slab 1 - Avg	EP5 MOD Slab 2 - Avg	Traction Control Slab 1 - Avg	Traction Control Slab 2 - Avg
0 cycles	20	0.69	0.64	0.60	0.62	0.77	0.78
	40	0.70	0.67	0.62	0.66	0.80	0.81
	60	0.72	0.73	0.66	0.69	0.80	0.82
70,000 cycles	20	0.45	0.44	0.41	0.43	0.51	0.54
	40	0.48	0.49	0.43	0.45	0.55	0.57
	60	0.51	0.50	0.45	0.49	0.57	0.62
140,000 cycles	20	0.41	0.43	0.41	0.39	0.47	0.51
	40	0.45	0.46	0.43	0.41	0.47	0.54
	60	0.48	0.49	0.47	0.44	0.50	0.53

Table 3 Summary of CTM Results

	Basalt	Flint Rock-Flint	RK Bauxite	Copper Slag	47-4x20	60-4x20
0 cycles	2.09	2.38	1.97	2.14	2.88	1.81
70K cycles	1.82	1.64	1.35	1.57	1.79	1.62
140K cycles	1.67	1.65	1.39	1.44	1.76	1.55

	70-4x20	Armor Stone	Best Sand	EP5 MOD	Traction Control
0 cycles	2.30	1.83	2.22	1.65	1.62
70K cycles	1.33	1.53	1.33	1.45	1.54
140K cycles	1.29	1.40	1.35	1.50	1.49

all values are MTD (mm)

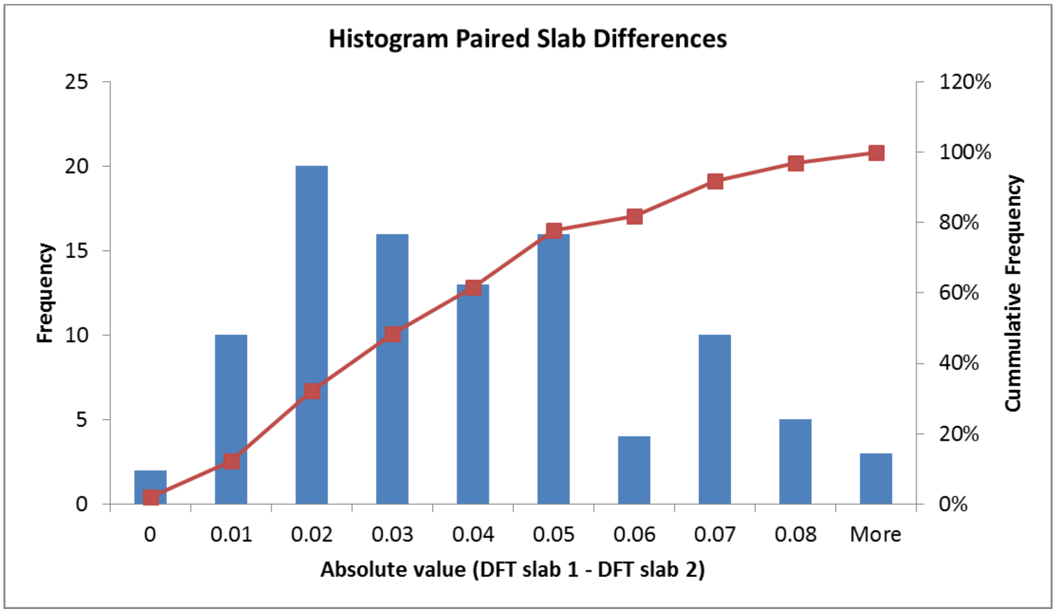

Figure 3 Slab Replicate DFT Comparison

Data Analysis

The analysis focused on the terminal (70K and 140K cycles) friction characteristics of the high friction surfaces, including the change in values between the 70K and 140K measurement increment. The comparison of the change in test measurements between 70K cycles and 140K cycles is particularly important to determine if the aggregate reached a terminal friction condition. Figure 4 displays the DFT friction results for all aggregates tested. Figure 5 displays the CTM macrotexture results for all aggregates tested. The CTM surface texture data shows all surfaces with MTD macrotexture in the range of 1.2 to 1.8 mm, which is common for HFST after conditioning. In comparison, typical conventional dense-grade asphalt mixtures have terminal macro-texture below 0.60 mm and porous mixtures are below 1.2. Figure 6 displays the 140K terminal DFT friction and CTM surface texture terminal values for the eleven aggregates. Similar to previous studies, there is no correlation between measured friction and surface macrotexture for HFST surfaces.

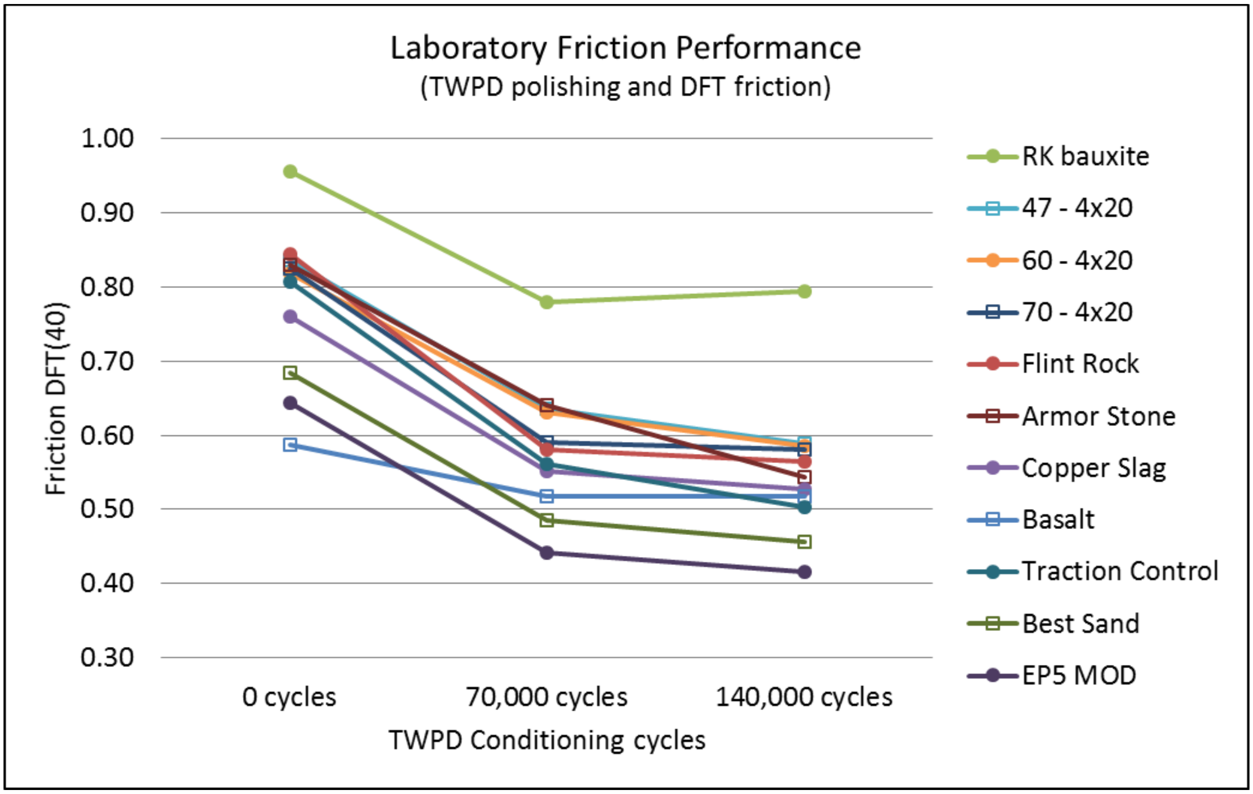

Figure 4 Comparison of Laboratory Friction Performance

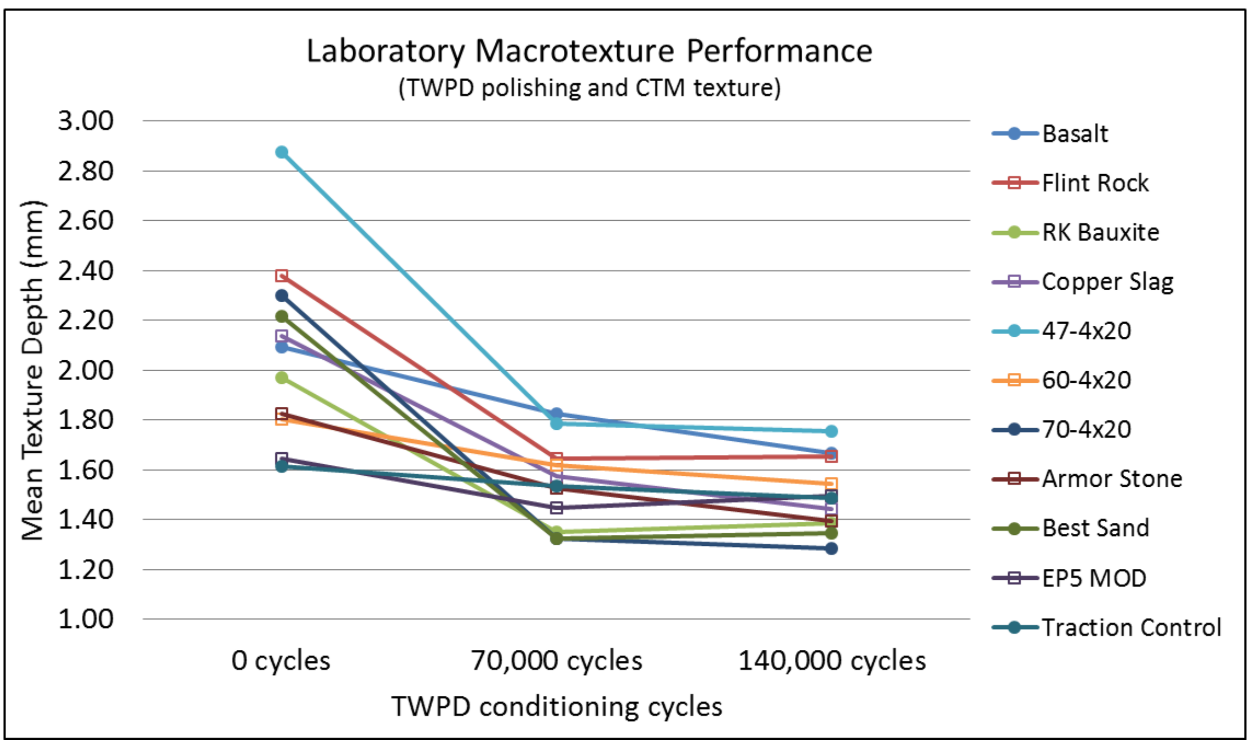

Figure 5 Comparison of Laboratory Surface Texture Performance

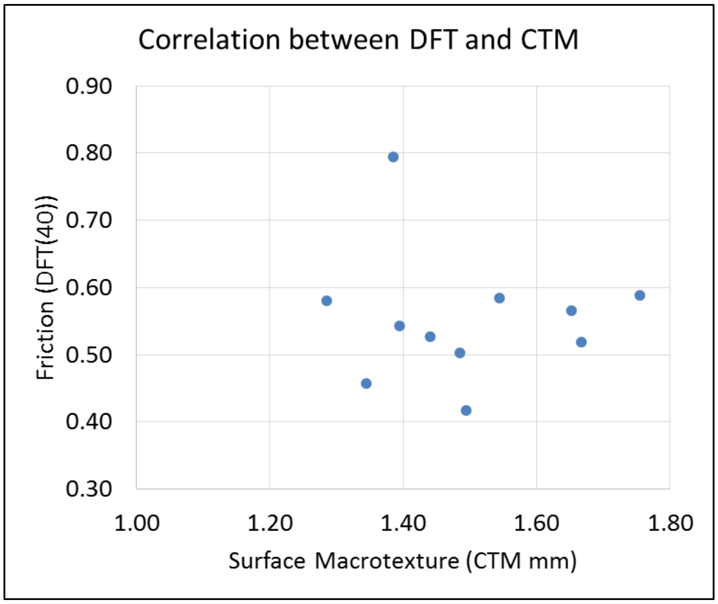

Figure 6 Correlation of Friction and Surface Macrotexture

The legend in Figure 4 places the aggregates in order from highest friction after 140K polishing cycles to lowest friction based on DFT(40) values. From the summary of the friction testing, the following observations are made.

- Calcined bauxite maintains higher friction than all other aggregates in the study.
- All three products from Roswell, GA and Flint Rock displayed similar high performance compared to other aggregates (except bauxite).
- Armor Stone continued to polish between 70K cycles and 140K cycles. Based on 140K cycle ranking, it falls into a middle category, but at 70K cycles it was performing in a higher category.
- Copper slag and Traction Control showed similar middle category friction performance.
- Basalt displayed consistent friction, losing minimal friction performance from 0 cycles to 140K cycles. The aggregate has less angularity prior to polishing as noted by the low DFT(40) at 0 cycles, but has very good polish resistance as shown by the minimal friction loss after polishing.
- Best Sand and EP5 MOD demonstrated the lowest friction performance.

Based on a previous FHWA study on HFST friction, laboratory terminal friction values are higher than field terminal friction values, as shown in Figure 7 (*7*). Using the FHWA study's correlation, the expected terminal field friction would be approximately 40 (SN40R) for the Roswell products and Flint Rock.

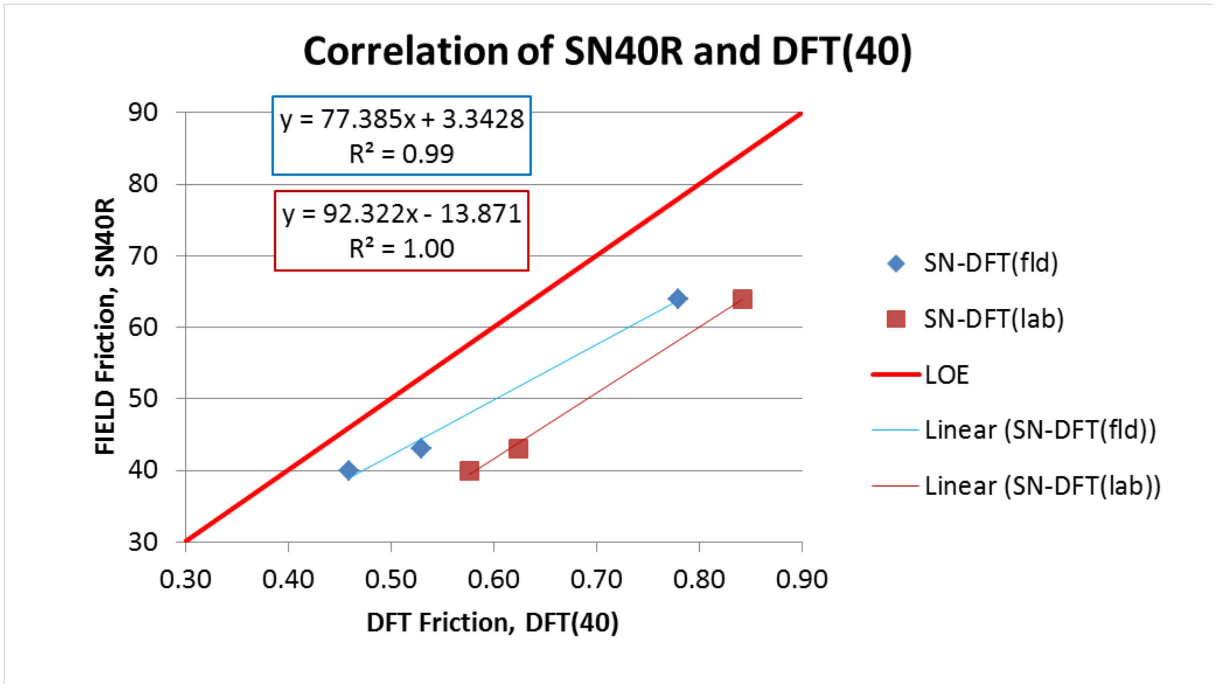

Figure 7 Correlation of Laboratory and Field Terminal Friction Values (*7*)

CONCLUSIONS AND RECOMMENDATIONS

This study compared the laboratory performance of 11 different friction aggregates preselected by the agency. The study focused on laboratory test measurements that resemble a terminal friction condition after polishing with the NCAT Three Wheel Polishing Device. The friction, measured by the Dynamic Friction Tester, has a wide range from 0.40 to 0.80, indicating that there was a substantial difference in friction performance between aggregates. The macrotexture range, measured as mean texture depth, was common for HFST after conditioning. There was no correlation between measured friction and surface macrotexture for HFST surfaces.

It is the responsibility of the governing agency to determine an acceptable threshold for HFST performance. The success (reduction in crashes) of locally placed sections with regionally available friction aggregate may be an appropriate approach for setting acceptable material thresholds.

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