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FINAL REPORT ~ FHWA-OK-15-10

DEVELOPMENT OF ALTERNATIVE HIGH FRICTION SURFACES FOR OKLAHOMA

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December 2015

Oklahoma Department
of Transportation

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Submitted to:

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16 . ABSTRACT

Oklahoma DOT wanted to identify maximum surface friction performance of asphalt surface mixtures using regionally available aggregates as alternatives to a standard high friction surface treatment using resin binder and imported calcined bauxite aggregate. The laboratory study was divided into two phases. Phase I compared aggregate/mixture combinations that were expected to have the best potential to provide high pavement surface friction characteristics. Phase II studied the types of tack coats to determine the best tack application for the selected friction surface. The OK DOT staff identified regionally available sources with good friction performance characteristics, including mine chat, rhyolite, sandstone, and granite. The mixture type selected for the study was open graded friction course (OGFC). A testing and conditioning protocol developed at NCAT was used for measuring the friction performance of pavement surfaces. Based on the Phase I friction results, the sandstone OGFC section was selected for further study on the NCAT Pavement Test Track. Variables in the Phase II tasks were one type of tack coat and two application rates. Preparing laboratory slabs involved compacting the underlying slab, conditioning the surface of the slab, applying the tack coat, and placing the OGFC layer on top. Cores were taken from the slabs for bond strength shear testing. Cores from the slabs with the higher tack coat application rate had higher interface bond strength.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

Development of Alternative High Friction Surfaces for Oklahoma

Dr. Michael Heitzman, Assistant Director, National Center for Asphalt Technology
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Background

Oklahoma DOT wanted to identify maximum surface friction performance of asphalt surface mixtures using regionally available aggregates as alternatives to a standard high friction surface treatment using resin binder and imported calcined bauxite aggregate. Safety is commonly measured as a rate of crashes, especially wet-weather crashes. Pavement surface friction is measured by skid resistance (aggregate micro-texture) and surface texture (mixture macro-texture). Aggregates commonly used in Oklahoma for pavement surface friction are granite in the western portion of the State, sandstone in the eastern part, and mining chat in the northeastern part. Asphalt pavement surface mixtures are routinely dense-graded, gap-graded (commonly called stone matrix asphalt (SMA)), or open-graded (commonly called porous friction course (PFC) or open graded friction course (OGFC)). Other special asphalt surfaces are micro-surfacing and ultra-thin bonded wearing course (UTBWC).

The current high friction surface treatment (HFST) applied to critical crash locations uses surface application of epoxy or polymer resin binder embedded with No 8 to No 16 calcined bauxite aggregate. The HFST is bonded to the existing pavement surface as a 5 mm thick treatment. This surface has shown to provide high micro-texture and high macro-texture when properly applied. A study at NCAT has found that regionally available friction aggregates will not achieve the same level of friction performance when used in place of bauxite as a HFST.

NCAT has developed a laboratory procedure to compare the friction performance of pavement surfaces. The procedure includes the use of ASTM standard test methods for pavement surface friction using the Dynamic Friction Tester (DFT) and for surface texture using the Circular Texture Meter (CTM). The procedure uses the NCAT Three Wheel Polishing Device (TWPD) to abrade the surface. A friction performance curve is developed over a series of DFT/CTM measurements during 100,000 polishing cycles in the TWPD. Full friction performance curves provide more information about the rate of friction loss over time. Tests which provide a single "terminal" friction value are less informative. Figure 1 demonstrates this difference. Depending on the anticipated target service life, Surface-Z may have acceptable friction performance which is not expressed in the ranking of the surfaces based solely on terminal friction value.

The Figure 2 and Table 1 conceptually compare surfaces with numerous combinations of aggregate and mixture type. As micro-texture increases and macro-texture increases, safety of the pavement surface also increases. Micro-texture is the key component in pavement-tire interaction and is a function of the aggregate's polish resistance. Macro-texture is a critical component for high water film (hydroplaning) conditions and is a function of the surface texture. Both high micro-texture and high macro-texture are important for safety-critical locations.

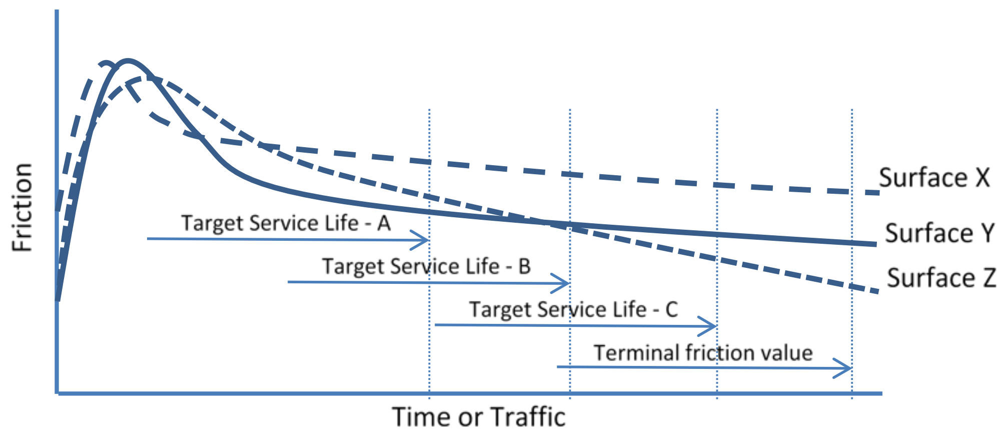


Figure 1 General friction performance curves

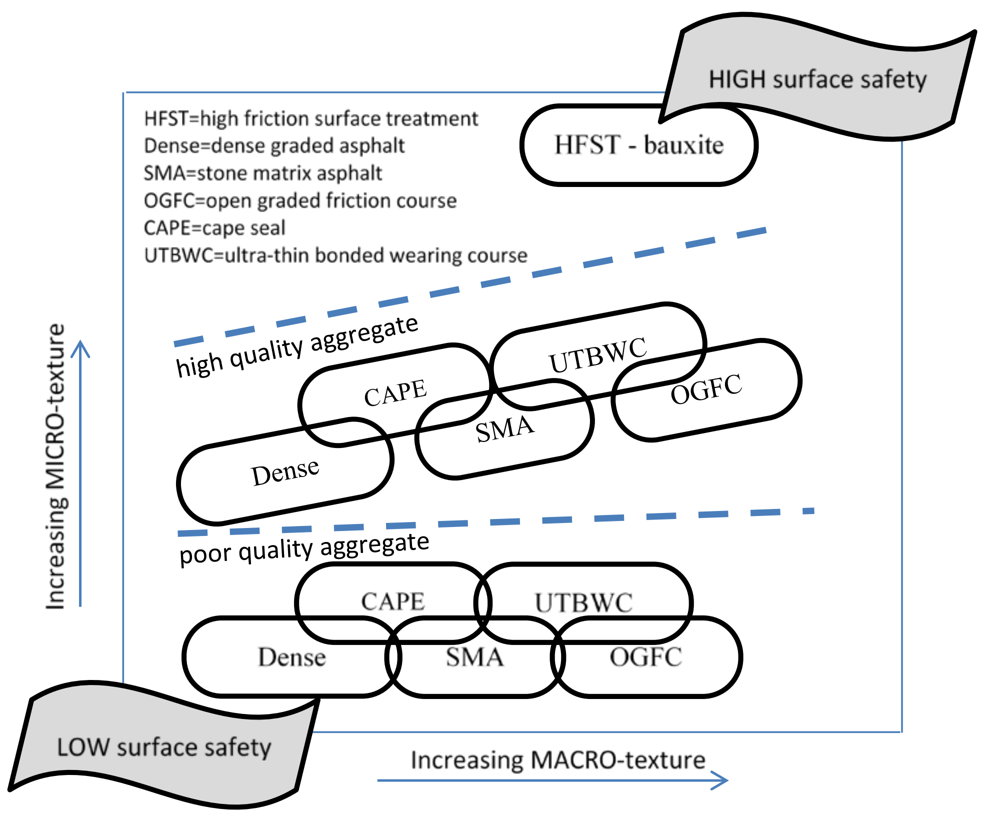


Figure 2 General surface friction ranking

Table 1 General comparison of surface types

Mix type	Material cost	Mix design	Production control	paving	Macro texture	Micro texture	Bond to existing	Perform life	Safety scale
Chip seal	Binder $$	Simple	Standard	Simple No grade control	high	high	???	3-4 yrs	Mod
Cape seal	Binder $$	Complex	Standard	Simple No grade control	Moderate	high	Okay	5-7	Mod
Dense-fine	Low	Standard	Standard	Standard Grade control	V low	high	Okay	10 yrs	Low
SMA	Binder $	Complex	Tight QC	Standard Grade control	Moderate	High	Okay	10 yrs	Mod
UTBWC	Binder $	Simple	Standard	Special equipment	Moderate	High	Better	10 yrs	Mod
OGFC	Binder $$ No chat	Complex	Tight QC	Standard Grade control	Moderate	High	Okay	7-8 yrs drainage	Mod
HFST	Epoxy $$$	Simple	Special equipment	Special equipment	high	high	high	5-7 yrs	High

NCAT has worked with Oklahoma aggregates in other friction research studies. NCAT had friction measurements on HFST with bauxite and Oklahoma chert for lab prepared, conditioned, and tested slabs and full-scale NCAT Test Track sections. Another portion of the NCAT HFST study examined the influence of aggregate particle size on HFST performance. The NCAT 2006 Test Track included Oklahoma sponsored Section N9 with a SMA surface incorporating Oklahoma granite aggregate. Friction results from the granite SMA, limestone/granite PFC, and flint HFST are shown in Figure 3. The flint HFST performed better during the first three-quarters of traffic loading.

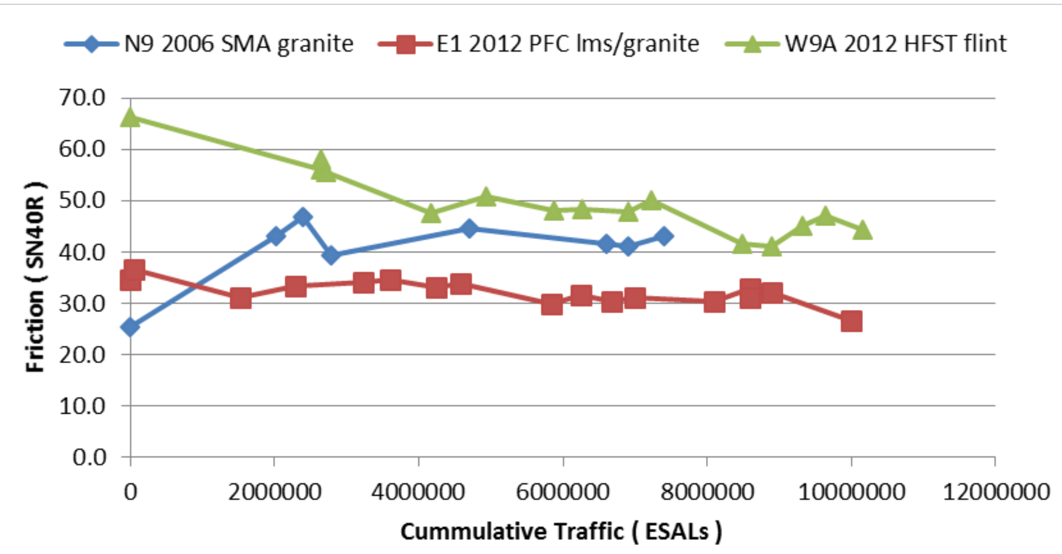


Figure 3 Comparison of Oklahoma friction performance on the NCAT Test Track

Scope

This study examined the friction performance of asphalt mixtures using regionally available aggregates in Oklahoma and appropriate asphalt binders as alternatives to standard HFST using resin binder and calcined bauxite aggregate. The study determined which more conventional asphalt mixture placed as a 0.75-inch thin surface lift could maintain acceptable high friction characteristics. The study provided an objective measure of friction performance for asphalt mixtures that OK DOT reviewed and selected one for further study on the NCAT Test Track.

The key components of this study were aggregate type and size, binder type, and mixture type. Since there is no standard value for pavement friction, the study used results from Oklahoma sections on the NCAT Test Track as a point of reference to compare the measurements from the study. OK DOT mixtures on the NCAT Test Track provide a baseline understanding of "conventional" friction from OK surface mixtures, predominantly granite and limestone. Oklahoma granite-limestone OGFC and granite SMA measured SN40R friction of 35 and 40, respectively, while the bauxite HFST measured over 60.

Work Plan

The laboratory study was divided into two phases. Phase I compared aggregate/mixture combinations that were expected to have the best potential to provide high pavement surface friction characteristics. Phase I tasks provided comparable data on the friction performance achievable from conventional mixtures and other asphalt surfaces using regionally available aggregates. Phase II studied the types of tack coats to determine the best tack application for the selected friction surfaces. The results of the study were intended to guide decisions for further field testing at the NCAT Test Track for the 2015-2018 research cycle.

The originally proposed work plan examined various combinations of aggregate type and mixture type for a total of ten surfaces to study. The final work plan reduced the study to four surfaces. This still allowed for a basic study of multiple aggregate sources and mixtures types. One proposed combination was three aggregate sources in one surface mixture type and one of the aggregate sources in a second mixture type.

Phase I – Measure Friction Performance

Select Aggregates and Mixtures

Meetings were held with OK DOT staff to select aggregate sources and mixture types for the laboratory friction study. Candidate aggregate sources were selected based on historic perspective on the friction performance of conventional surface mixtures. The OK DOT staff identified regionally available sources with good friction performance characteristics, including mine chat, rhyolite, sandstone, and granite.

The selection of the mixture type focused on surfaces with the potential to perform well on high traffic, medium to high speed routes that could be placed with conventional asphalt equipment. Mixture types that could experience aggregate loss (like conventional chip seals) were not considered. The OK DOT staff concluded that placement with a common asphalt paver was a priority, but other equipment such as a spray paver, slurry truck, and chip-seal operation would be considered. The mixture types considered for the study were OGFC and ultra-thin wearing course. After further discussions, although spray-pavers were routinely used in OK for ultra-thin wearing courses, the decision was made to focus on OGFC surface mixture.

The final selection of materials and mixture types for Phase I was four aggregate sources all placed as an OGFC. The four aggregates are listed in Table 2.

Table 2 Aggregates included in the study

Aggregate Type	Study Name	Source
Mine chat	Flint OK	Flint Rock, Pitcher, OK
Rhyolite	Hanson OK	Hanson Aggregate, Murray Co, OK
Sandstone	Sawyer OK	Martin Marietta, Sawyer, OK
Granite	Snyder OK	Martin Marietta, Snyder, OK

Prepare Mixtures and Slabs for Friction Testing

OK DOT worked with the aggregate suppliers to deliver the quantity of each aggregate to build the OGFC mixtures. Each aggregate source was screened into multiple size fractions. NCAT laboratory staff rebuilt the gradations to a defined OGFC gradation that matched an OK DOT OGFC test section E1 placed on the NCAT Test Track in 2012. Rebuilding each OGFC to a common gradation minimized any differences related to surface macro-texture so that friction measurements would reflect differences in aggregate micro-texture. NCAT prepared four asphalt mixtures and compacted each mixture into three replicate 20-inch square slabs for friction testing. Two slabs were tested and the third slab was held as a back-up.

Condition and Test the Surfaces

NCAT used a testing and conditioning protocol developed at NCAT for measuring the friction performance of pavement surfaces. The protocol uses the DFT to measure surface friction and the CTM to measure surface macro-texture. Conditioning (polishing) is accomplished with the TWPD. The scope of the study warranted DFT and CTM testing at multiple intervals of polishing to develop full friction performance curves. While some studies focus on terminal friction values, the friction performance curves provided a better understanding of how long good friction values are maintained. The testing intervals were 0, 5k, 40k, 80k and 140k cycles.

Figure 4 shows the results of the Phase I friction comparison. The performance curves, with one exception, followed normal trends. Pre-conditioning results are low due to the asphalt binder film covering the aggregate. After the first 5,000 cycles of TWPD conditioning, the asphalt film is worn away and the peak friction is achieved. Additional conditioning cycles polish the aggregate surface and the friction measurements reflect the degree to which the aggregate surface micro-texture is degraded. The friction performance results clearly show the Sawyer sandstone performed better than the other three aggregates. The Hanson rhyolite slab 2 data was well outside normal friction performance and was not used in the aggregate comparison. No additional effort was made to determine the cause of the unusual Hanson slab 2 results.

Figure 5 shows the results of the CTM measurements. The measured macro-texture was very typical for OGFC mixture surfaces. No additional examination of the CTM data was required.

Based on the Phase I friction analysis, the decision was made to place a sandstone OGFC section on the NCAT Pavement Test Track for further study.

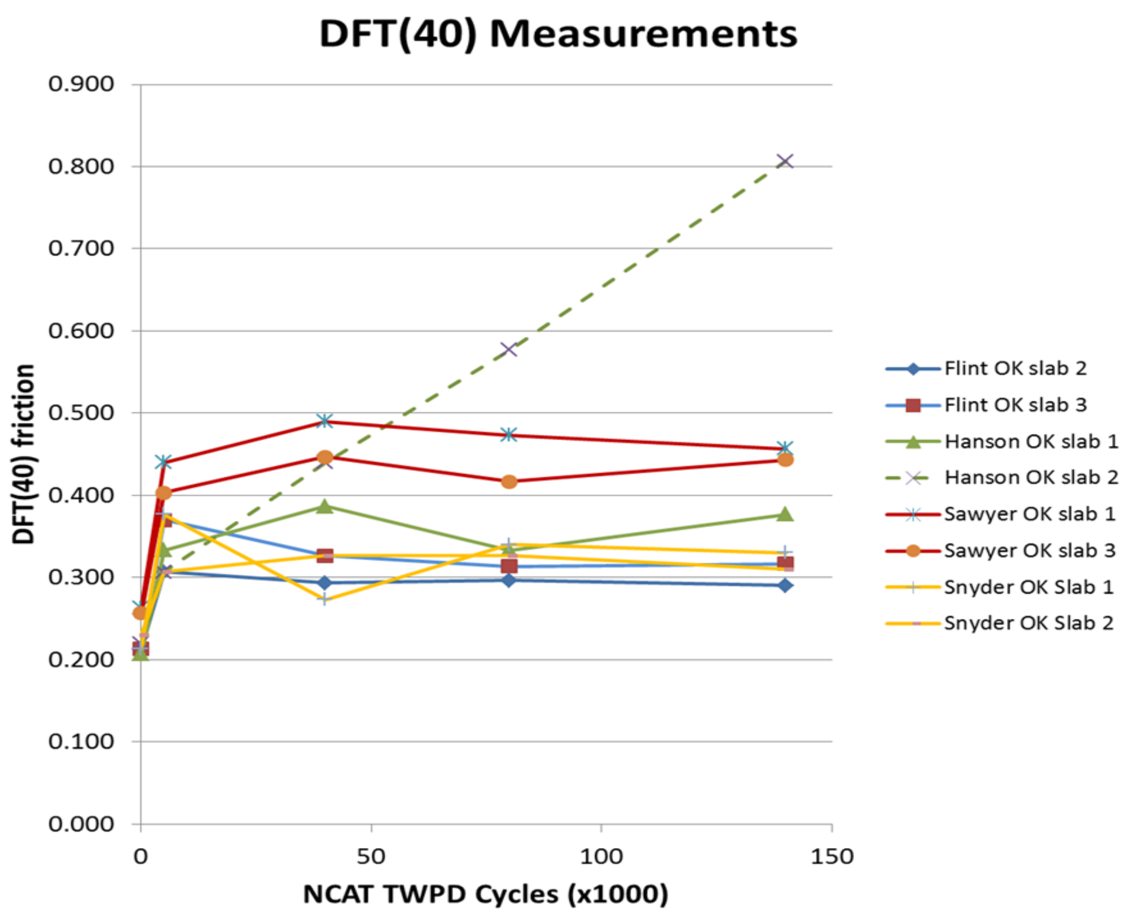


Figure 4 Phase I friction performance results

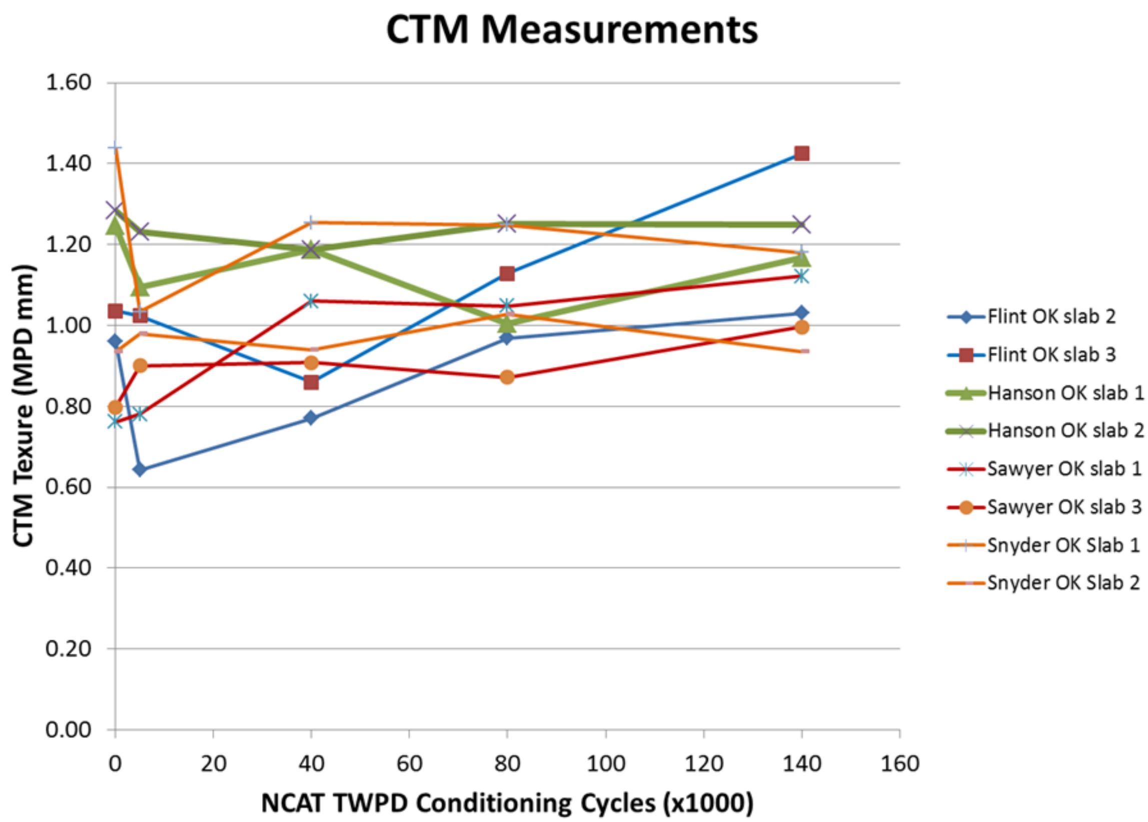


Figure 5 Phase I surface texture performance results

<u>Phase II – Measure Tack Coat Performance</u>

The objective of Phase II was to determine the type and optimum application rate for the tack coat to bond the OGFC to an existing pavement. The proposed work plan called for evaluating two type of tack material at two application rates. Due to a number of delays in assembling the two-layer slabs, the variables in the Phase II tasks were reduced to one type of tack coat (Ultrafuse) and two application rates (0.08 and 0.15 gal/sq yd residual). Two 20-in by 20-in slabs were prepared for each tack coat application rate.

Prepare slabs for testing.

This laboratory tack coat performance study involves preparing a 2-in thick dense graded mixture as the underlying surface, placing the tack coat on the prepared slab, and then placing the OGFC on top. The surface of the underlying dense-graded mix is a key factor in the tack coat performance evaluation. If the surface is left untreated, the bond testing would resemble placing both layers without any traffic to wear the asphalt film. Another option is milling the surface of the dense-graded mix prior to placing the tack coat. A third option would use some abrasive process to remove the asphalt film and reduce the surface macrotexture. All three options could relate to real field construction conditions. The study team discussed the options with the DOT and the decision was made to abrade the surface.

Several methods of wearing the lab mix surface were considered. Solvent washing the surface to remove the asphalt binder film was rejected because it could leave a residue that may influence the tack coat material. Three methods were considered to have the best chance to succeed: wire brush, sandblasting, and grinding stone. The grinding stone was determined to be the most effective method. This abrasion method used a drill-mounted concrete grinding disc that could be placed flat on the asphalt surface. The grinding process removed the surface asphalt film and flattened the surface of some of the exposed aggregate. Figure 6 shows one slab with the surface conditioned by grinding (right slab) along with a slab prior to conditioning (left slab).

Figure 6 Test slab surface conditioning

The next step in preparing the composite slabs for testing was placement of the tack coat. Due to the timing of the OGFC mix availability; this step in the process was able to have the tack coat distributor spray the tack coat directly on the slabs. This was done during the distributor's spray calibration process for placement of the tack on the Test Track section. The actual measured application rates were 0.05 and 0.10 gal/sq yd residual based on pads recovered during distributor calibration. Each slab surface had one uncoated strip caused by non-uniformity of the distributor. An example is shown in Figure 7. These locations were documented before the OGFC was placed so the locations of cores taken from the slab would avoid the untacked area.

After the sandstone aggregate source was selected for further study, the OK DOT prepared a mix design for the OGFC to be placed on the Test Track. The design used standard stockpiles at the Martin Marrietta Hugo quarry which included a coarse stockpile (Pile 5) not used in the Phase I friction study. Once the mix design was complete, the DOT had additional aggregate shipped to NCAT to prepare the OGFC mixture. The mix design used to prepare the OGFC for the laboratory slabs is given in Table 3.

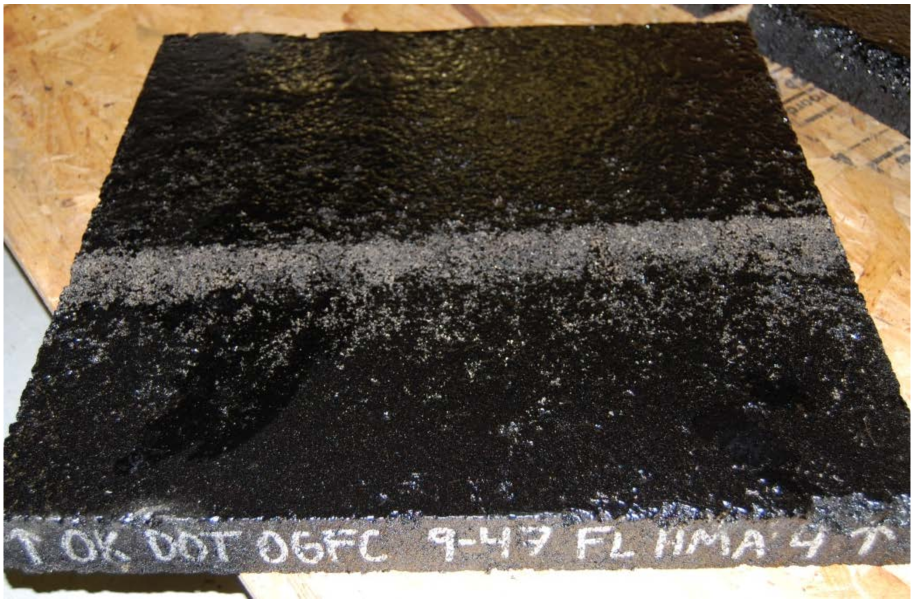


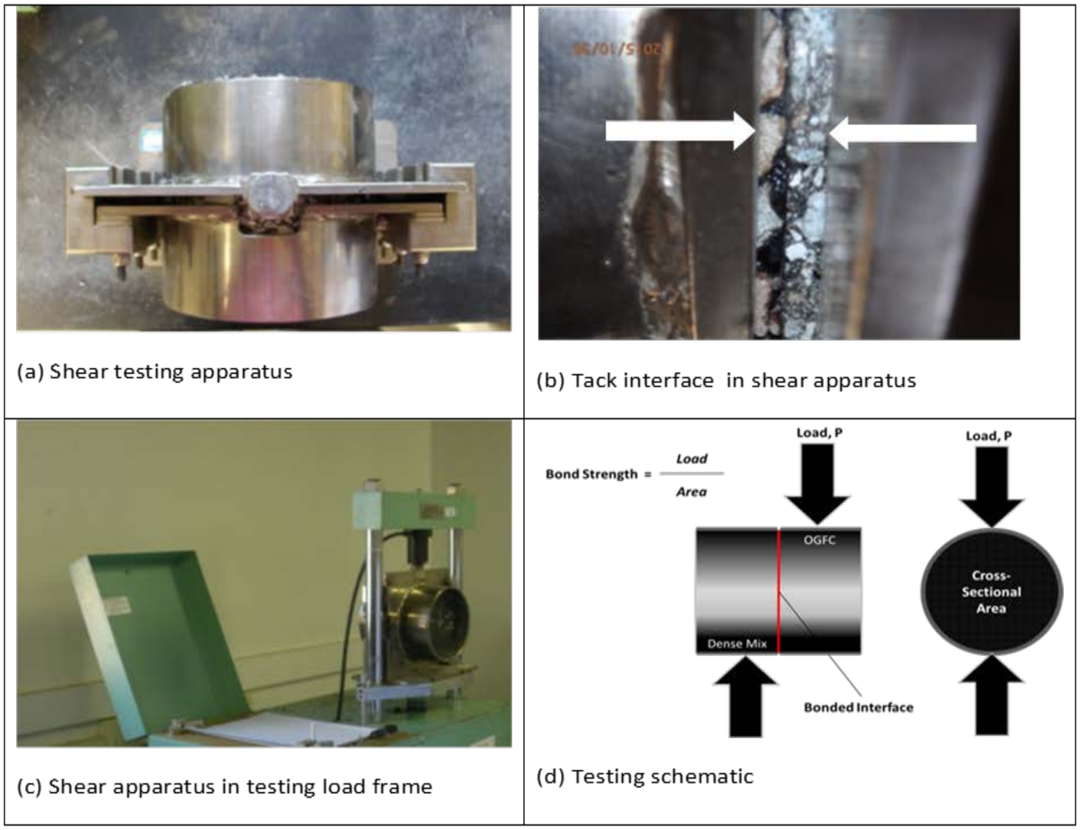
Figure 7 Example of untacked strip along test slabs

Table 3 OGFC mix design for the tack coat study

Mixture Identification	Asphalt Binder (PG)	Aggregate Source	Stockpile and Percent Used	Combined Gradation Sieve	Combined Gradation % Passing
OGFSC	76 -28 OK	Martin Marietta @ Sawyer	Grade 4, 75%	¾	100
Matl Code asco024	7.0%	Martin Marietta @ Sawyer	Pile 5, 25%	½	95
OSc00931 500100		Cellulose fiber	0.3%	3/8	60
				No 4	5
				No 8	4
				No 200	3.3

The OGFC mix was prepared and placed on top of the tacked slabs to achieve a 2-in thick OGFC surface. The thickness was required for the shear test cores. The mix was placed at 315°F on top of the tacked slabs that were at room temperature (70°F). The slab kneading compactor seated the OGFC on the prepared slabs. The target density was 80% of the maximum specific gravity of the mix, G_{mm}.

Cores were taken from the slabs for shear bond strength testing. Shear testing was conducted using a guillotine-like shear apparatus, as seen in Figure 8-a. Each specimen was loaded into the shear apparatus with the tack interface visible between the two sides of the shear apparatus, as shown in Figure 8-b. The gap between shear sleeves is 0.25 inches. The shear apparatus and specimen were then placed into a compression loading frame for testing (Figure 8-c). Per OKDOT test procedure, a loading rate of 0.1-in per minute was used. No confining pressure was applied, as shown schematically in Figure 8-d.



(a) Shear testing apparatus

(b) Tack interface in shear apparatus

(c) Shear apparatus in testing load frame

(d) Testing schematic

Figure 8 Shear bond strength testing

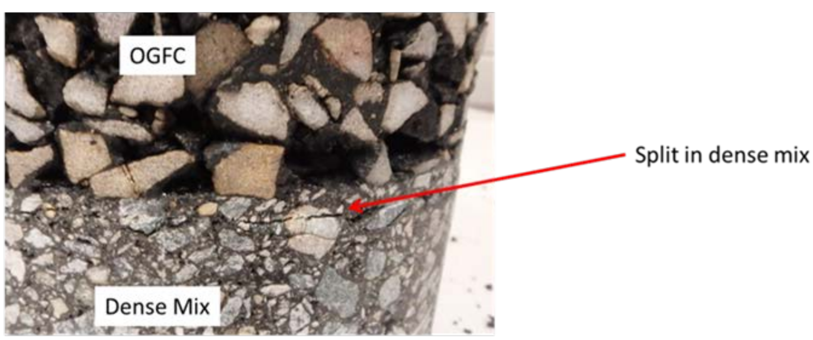
The testing results are presented in Table 4. The number of cores taken from each slab was dependent on avoiding the location of the non-uniform tack application path from the distributor (shown previously in Figure 7). The location of the break greatly affected the results. Some specimens sheared in the dense mix instead of the bonded interface (Figure 9) giving higher strength values. This added strength should be considered in the analysis. In general, cores from the slabs with the higher application rate had higher interface bond strength. Previous NCAT research found similar low bond strength values when testing OGFC mixes.

A forensic examination of the cores was performed to attempt to identify the variation in shear strength results. Test results on multiple cores from the same slab were generally consistent, but two slabs with comparable mix and tack coat rate varied significantly. It was determined that the uniformity of the asphalt binder appeared to play a key role. The asphalt binder was obtained from a 3-gallon bucket sample drawn from the in-line sampling fixture at the mix production plant. The binder was a highly modified PG 76 -28. The characteristics of the binder varied in the OGFC layer. It is very probable that the some polymer separation and settling occurred in the binder as it cooled in the bucket. The level of polymer modification in the binder taken to prepare the OGFC is reflected in the shear test results. Slabs 1 and 3 had a low binder modification.

Table 4 Shear test results

Tack Application Rate, gal/yd^2	Slab	Strength, psi	Break Location
0.05	1	27.1	Interface
0.05	1	13.7	Interface
0.05	1	12.6	Interface
0.05	2	36.3	Interface
0.05	2	35.2	Interface
0.05	2	65.5	Dense Mix
0.05	2	56.8	Dense Mix
0.10	3	13.7	Interface
0.10	3	19.0	Dense Mix
0.10	3	15.7	Interface
0.10	4	46.0	Interface
0.10	4	54.7	Dense Mix
0.10	4	42.8	Interface
0.10	4	101.4	Dense Mix

(a) Sheared at interface



(b) Sheared in dense mix

Figure 9 Specimens showing failure locations of shear test

A forensic examination of the cores was performed to attempt to identify the variation in shear strength results. Test results on multiple cores from the same slab were generally consistent, but two slabs with comparable mix and tack coat rate varied significantly. It was determined that the uniformity of the asphalt binder appeared to play a key role. The asphalt binder was obtained from a 3-gallon bucket sample drawn from the in-line sampling fixture at the mix production plant. The binder was a highly modified PG 76 -28. The characteristics of the binder varied in the OGFC layer. It is very probable that the some polymer separation and settling occurred in the binder as it cooled in the bucket. The level of polymer modification in the binder taken to prepare the OGFC is reflected in the shear test results. Slabs 1 and 3 had a low binder modification.

Summary

Oklahoma DOT is exploring the maximum surface friction performance of asphalt surface mixtures using regionally available aggregates. Four Oklahoma sources were selected and used in a common OK DOT OGFC mixture with identical gradations. The surfaces were polished and tested for friction using NCAT accelerated laboratory testing protocol. The sandstone source was selected for further testing on the NCAT Pavement Test Track and for laboratory bond strength testing.

The bond strength phase of the lab study applied the same tack coat material at two spread rates on to four laboratory prepared dense-graded asphalt mixture slabs. The slab surface was conditioned with a grinding disc to remove the asphalt film before the tack coat was applied. The sandstone OGFC was then placed on the tacked surface. Cores were cut from the prepared slabs for shear loading along the bond interface. The shear test results were higher for the layers tacked at the higher application rate.

This study provided preliminary information for further full-scale testing on the NCAT Test Track. On August 14, 2015 the micro-milled surface of section N9 was tacked with the same binder at the same application rates (0.05 and 0.10 gal/sq yd residual). The left longitudinal joint was tacked with an overlap of at least 2-inches to maximize longitudinal joint performance. Approximately one foot width on the right edge was not tacked to accommodate the left longitudinal joint overlap. The sandstone OGFC was placed 0.75-in thick on the tacked surface. Additional bond strength and friction testing will be performed over the two-year truck loading period.