

Evaluation of High Friction Surface Locations in Kansas

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*Kansas Department of Transportation
Bureau of Research*



1 Report No. KS-16-03	2 Government Accession No.	3 Recipient Catalog No.	
4 Title and Subtitle Evaluation of High Friction Surface Locations in Kansas		5 Report Date May 2016	
		6 Performing Organization Code	
7 Author(s) David A. Meggers, P.E.		7 Performing Organization Report No.	
9 Performing Organization Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		10 Work Unit No. (TRAIS)	
		11 Contract or Grant No.	
12 Sponsoring Agency Name and Address Kansas Department of Transportation Bureau of Research 2300 SW Van Buren Topeka, Kansas 66611-1195		13 Type of Report and Period Covered Final Report	
		14 Sponsoring Agency Code	
15 Supplementary Notes For more information write to address in block 9.			
<p>In 2009, the Kansas Department of Transportation entered into an agreement with the Federal Highway Administration to fulfill the requirements of the High Friction Surface Materials Enhancing Safety at Horizontal Curves on the National Highway System project.</p> <p>Four locations were chosen in Kansas, two on existing asphalt pavement and two on concrete pavement. The applications on asphalt were on highway segments and the concrete segments were medium to high volume ramps at two separate interchanges. Traffic volumes ranged from approximately 1,000 vehicles per day to 25,000 vehicles per day. In general, the surfaces are performing poorly; one of the lower trafficked surfaces, an asphalt application, failed in less than three years. The surfaces on the two applications on concrete are peeling off and skid resistance numbers are dropping.</p> <p>In late 2013 and early 2014, the surfaces were evaluated and several tests were performed to determine quality of the product with less than desirable results. Tests performed included bond testing of the High Friction Surface (HFS), rapid chloride permeability testing of the pavements with and without the HFS, and skid resistance testing. The skid resistance values were compared to skid testing that was performed immediately before placement, immediately after placement, and intermediate skid testing.</p> <p>Results of the testing were mixed; bond was generally poor and skid resistance was dropping rapidly. The results of the review have led to a rewrite of the application specification with an improvement in the surface preparation.</p>			
17 Key Words High Friction Surface, Skid Resistance, Horizontal Curves		18 Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service www.ntis.gov .	
19 Security Classification (of this report) Unclassified	20 Security Classification (of this page) Unclassified	21 No. of pages 22	22 Price

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Final Report

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Kansas Department of Transportation
Bureau of Research

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**THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS**

May 2016

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Abstract

In 2009, the Kansas Department of Transportation entered into an agreement with the Federal Highway Administration to fulfill the requirements of the High Friction Surface Materials Enhancing Safety at Horizontal Curves on the National Highway System project.

Four locations were chosen in Kansas, two on existing asphalt pavement and two on concrete pavement. The applications on asphalt were on highway segments and the concrete segments were medium to high volume ramps at two separate interchanges. Traffic volumes ranged from approximately 1,000 vehicles per day to 25,000 vehicles per day. In general, the surfaces are performing poorly; one of the lower trafficked surfaces, an asphalt application, failed in less than three years. The surfaces on the two applications on concrete are peeling off and skid resistance numbers are dropping.

In late 2013 and early 2014, the surfaces were evaluated and several tests were performed to determine quality of the product with less than desirable results. Tests performed included bond testing of the High Friction Surface (HFS), rapid chloride permeability testing of the pavements with and without the HFS, and skid resistance testing. The skid resistance values were compared to skid testing that was performed immediately before placement, immediately after placement, and intermediate skid testing.

Results of the testing were mixed; bond was generally poor and skid resistance was dropping rapidly. The results of the review have led to a rewrite of the application specification with an improvement in the surface preparation.

Acknowledgements

The author would like to acknowledge the Federal Highway Administration, the Transtec Group, and the KDOT Bureau of Traffic Safety for their assistance in funding and managing the initial installation of the High Friction Surfacing. Thank you also to the various KDOT maintenance offices that were involved in the initial placing and evaluation of the High Friction Surfacing installations and to the personnel of the KDOT Bureau of Research for performing field evaluations.

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Introduction

In July of 2009, the Kansas Department of Transportation (KDOT) entered into a Memorandum of Understanding (MOU) with the Federal Highway Administration (FHWA) to fulfill the requirements of the High Friction Surfacing (HFS) Materials in Enhancing Safety at Horizontal Curves on the National Highway System project field demonstration.

There is ample information available to verify that the use of HFS systems will increase the surface friction and enhance the safety of certain horizontal curves that have a history of accidents due to geometry rather than driver error. This has been documented by Virginia (Sprinkel, Roosevelt, Flintsch, de León Izeppi, & Mokarem, 2009), Wisconsin (Bischoff, 2008), Iowa (Adam & Gansen, 2001), and Florida (Reddy, Datta, Savolainen, & Pinapaka, 2008). The purpose of this study was to evaluate the effectiveness of the HFS in Kansas by comparing the skid values on the four applications, and to determine the cause for early failure of one of the applications and the diminished effectiveness of two others of the four applications.

The HFS materials were placed in August of 2009 on four locations as follows:

1. K-99 Wabaunsee County, Two-Lane Asphalt Pavement
2. K-5 Leavenworth County, Two-Lane Asphalt Pavement
3. Northbound I-35 – Northbound I-635 Ramp, Kansas City, Concrete Pavement
4. Eastbound K-96 – Eastbound US 54 Ramp, Wichita, Concrete Pavement

The locations were selected by KDOT and representatives of the Transtec Group. Surface friction values were collected prior to and immediately after installation and at later dates. Field evaluations of the HFS surfaces were performed in late 2013 and early 2014. Skid resistance testing was performed, pull-off tests were performed to evaluate the bond of the HFS to the existing pavement surface, cores were removed to evaluate thickness of the HFS, and Rapid Chloride Permeability (RCP) testing was performed to evaluate potential protection for the underlying pavements from intrusion of moisture which can cause early bond failure due to freeze/thaw action at the interface.

Pavement Descriptions

As previously stated, the K-99 and K-5 installations were on asphalt pavements. The K-99 pavement was a 1-inch Super Pave mix with $\frac{3}{8}$ -inch maximum sized aggregate that was placed in 2006. The average daily traffic in the application lane is approximately 1,550 vehicles. The K-5 pavement was a 1.6-inch-thick KDOT BM2A asphalt overlay with a maximum aggregate size of $\frac{1}{2}$ inch placed in 2000. The average daily traffic in the application lane is approximately 1,000 vehicles.

The I-35/I-635 and K-96/US-54 installations were both portland cement concrete pavement ramp locations. The I-35/I-635 interchange was constructed in 1990. The average daily traffic for this ramp is approximately 25,000 vehicles. The K-96/US-54 interchange was constructed in 1994. The average daily traffic for this ramp is approximately 6,400 vehicles.

Application Procedures

The material used for the Kansas applications was an ASTM C881 (2015) Type III epoxy with the appropriate adjustments to the physical properties to allow for use as a polymer overlay. The aggregate was flint from Picher, Oklahoma. This aggregate is typically used in Kansas for polymer overlay systems for bridge decks.

By specification, the asphalt and portland cement concrete surfaces were to be sand blasted sufficiently to remove contaminants and blown clean with dry oil-free air prior to application.

The resin was mixed and placed using a truck-mounted self-contained automated metering and mixing system. Once the polymer was distributed on the surface, it was leveled and dressed by hand using notched squeegees. The aggregate was dispersed on the surface within a few minutes of placing the polymer using the same truck-mounted unit.

Cracks in the asphalt surfaces were to be filled with polymer and sand previous to the application of the HFS, but joints in the concrete surfaces were taped to prevent locking of the joints.

The polymer was placed at a rate of 20 ft² per gallon; this coverage rate was determined by KDOT. In subsequent specifications, this coverage rate was increased to 27 ft² per gallon. The aggregate was placed to full coverage with the excess removed by brooming after curing.

Performance Review of HFS Sites

General Review of Application Locations

The K-99 (asphalt) application was covered with an asphalt overlay in the summer of 2012 and milled off with a full overlay action in 2013. Discussion with the Maintenance Superintendent and the Area Engineer indicated that there were significant amounts of the HFS peeling off of the existing asphalt surface. In their words, “Huge chunks of it were peeling off (especially in the northbound lane) and we decided to overlay it before the Governors motorcycle ride so none of the riders crashed while traveling through our Area.” Due to the early failure of the surface, the only data available for this location are the early skid resistance values.

The K-5 (asphalt) application was reviewed in the fall of 2013 and is still in reasonably good condition. The only areas that are showing any indication of failure are on the edges of the existing cracks in the asphalt that have reflected through the HFS, an indication that the cracks may not have been filled prior to the HFS application.

The I-35/I-635 (concrete) application was also reviewed in the fall of 2013 and was found to have significant wear. A large amount of the material has either worn off or peeled off (see Figure 1). Similar to the asphalt surface of K-5, the material is peeling along joints and reflective cracks.

The K-96/US-54 (concrete) ramp was reviewed February 19, 2014, and is in fair condition. The application is 866 feet long. The first 420 feet are in very good condition; however, the curvature is not as tight as on the remaining 440 feet where there is significant peeling of the surface similar to that of the I-35/I-635 ramp.



Figure 1: I-35/I-635 Ramp Overlay Condition

Skid Resistance Testing

Skid resistance values were obtained on the locations prior to the placement of the HFS and immediately after placement per ASTM E274 (2015) using both the ribbed and smooth tire. Skid values were obtained in late 2010 for all locations and again in late 2013 for three of the locations. No 2013 skid values are available for K-99, as the surface suffered significant bond failures between 2010 and 2011 and was removed from the program. Skid resistance values for each of the four locations can be found in Tables 1, 2, 3, and 4. Skid resistance values shown are for 40 mph, except for K-5 (Table 2) which were obtained at 30 mph due to severity of the curve.

Table 1: Skid Test Results for K-99 HFS

Lane	Tire	Initial Condition	August 2009	October 2010
North Bound	Ribbed	47.8	87.3	80.0
	Smooth	35.2	66.6	59.9
South Bound	Ribbed	50.1	88.3	77.8
	Smooth	38.2	72.6	61.6

Table 2: Skid Test Results for K-5 HFS

Lane	Tire	Initial Condition	August 2009	October 2010	November 2013
North Bound	Ribbed	35.1	87.8	68.6	58.0
	Smooth	23.4	75.5	53.8	48.9
South Bound	Ribbed	35.1	82.1	59.9	55.7
	Smooth	23.4	71.4	47.6	47.7

Table 3: Skid Test Results for I-35/I-635 HFS

Tire	Initial Condition	August 2009	October 2010	November 2013
Ribbed	40.5	69.7	56.3	48.6
Smooth	18.8	57.9	44.2	39.4

Table 4: Skid Test Results for K-96/US-54 HFS

Tire	Initial Condition	August 2009	October 2010	November 2013
Ribbed	46.4	76.1	66.1	47.9
Smooth	32.0	63.8	57.9	42.5

Skid values improved significantly upon the application of the HFS, showing an improvement of 1.5 to 3 times. The smooth tire showed greater improvement than the ribbed tire and in two cases the improvement was significant. While the initial improvement was significant, the HFS placed on the concrete surfaces rapidly lost skid resistance to the point that by 2013, values were nearly equal to the initial values. The K-5 asphalt application has maintained the skid values better than the applications on the concrete pavement, but the K-5 location also has the lowest traffic level, only 1,000 vehicles per day.

HFS Bond Testing

HFS to pavement bond was tested at the three remaining locations using ASTM C1583 (2013). Sampling was performed in the field by drilling a 2-inch diameter core to a depth of 1 inch. The top of the sample is cleaned and dried, and a 2-inch diameter pipe cap is bonded to the sample with 5-minute epoxy. The epoxy is allowed to cure and a frame is placed over the sample with an attached dynamometer to determine force at failure (Figure 2). Results of the bond tests for the three remaining applications are shown in Tables 5, 6, and 7.



Figure 2: Example of Field Pull-Off Test

Table 5: Pull-Off Test Results for K-5 HFS

Location, ft	Force, lb	Stress, psi	Break
37	284	90	50-60% Asphalt
70	808	257	100% Asphalt
115	420	134	50% Asphalt
194	612	195	50-60% Asphalt
202	Damaged	NA	100% Asphalt
225	652	208	40-50% Asphalt

Locations of K-5 were measured from the north end of the application. Location 202 (Table 5) was struck by a truck that wandered into the work zone; the break on this was approximately 1 inch deep into the asphalt, the bottom of the core. Three of the remaining five locations tested resulted in reasonably high numbers, with all five showing significant asphalt bond to the caps. The high values for the pull-off tests on this application can be explained by the fact that the evaluation was performed on November 11th, 2013. The temperature at the time of testing was approximately 45 °F. Note that four of the five tests did not have 100% failure of the asphalt even with the low temperatures. The 40 to 60% bond failure is still unacceptable.

Table 6: Pull-Off Test Results for I-35/I-635 Ramp

Location, ft	Force, lb	Stress, psi	Break
197	242	77	100% Interface
222	42	13	100% Interface
271	116	37	100% Interface
327	270	86	100% Interface
381	118	38	100% Interface
466	156	50	100% Interface

All failures on the I-35/I-635 (Table 6) ramp were complete failure of the HFS bond to the concrete substrate; no concrete was removed with the bond test sample. Locations are measured from the south end of the application.

Table 7: Pull-Off Test Results for K-96/US-54 Ramp

Location, ft	Force, lb	Stress, psi	Break
65	384	122	100% Interface
101	344	109	100% Interface
497	370	118	100% Interface
529	366	117	100% Interface
671	396	126	100% Interface
702	400	127	100% Interface

Bond testing on the K-96/US-54 (Table 7) ramp again showed complete failures of the HFS bond to the concrete substrate. Locations were measured from west to east. It appeared that the surface preparation on both of the concrete ramps was insufficient; very little surface relief was visible where the HFS had peeled or worn off.

Surface Thickness Results

The HFS thickness was measured on the cores removed for rapid chloride permeability testing. On the cores removed from the asphalt paving, the thickness was measured while the surface was attached to the core. The surface thickness on the concrete paving cores was

measured after the Rapid Chloride Permeability test was performed; at this point the HFS peeled off of the cores intact, an indication of the poor bond between the HFS and the pavement.

Thickness of the HFS varied between applications. Thickness was determined to be 0.120 inches on the K-5 (asphalt) application, 0.128 inches for the I-35/I-635 (concrete) application, and 0.151 inches for the K-96/US-54 (concrete) application. Thickness was measured on the completed surface. Thickness of the polymer film previous to application of the aggregate was not determined. At the prescribed coverage rate, this would have been a polymer film thickness of 0.08 inches. A significant portion of the system thickness was due to the imbedded aggregate.

Rapid Chloride Permeability Results

Rapid chloride permeability testing was performed according to ASTM C1202 (2012). Three cores 4 inches in diameter were removed to a depth of at least 6 inches from each of the three HFS locations remaining in service. RCP was performed on the top 2 inches of each core with the HFS intact. RCP was also performed on the second 2 inches of the cores to determine the permeability of the substrate paving material. The RCP testing indicated that the HFS surfaces did afford some level of protection to the pavements. See Figure 3 for equipment set up.

The remaining asphalt pavement (K-5) had the lowest RCP value of 33 coulombs on the top section with the HFS and a value of 167 coulombs on the second 2 inches of the core. These low values were most likely due to the nature of the asphalt paving having much lower voids and the petroleum based binder.

Both of the concrete substrate test locations had much higher RCP values for both the top 2 inches and the second 2 inches. The average RCP at the I-35/I-635 location was determined to be 856 coulombs on the top 2 inches and 1477 coulombs on the second 2 inches. The K-96/US-54 location was found to be 1,868 and 2,983 coulombs for the top 2 inches and second 2 inches, respectively. The HFS did afford some protection for the concrete pavement; the difference in apparent protection is again the difference between the materials and final internal structure of the asphalt pavement and the concrete pavement.

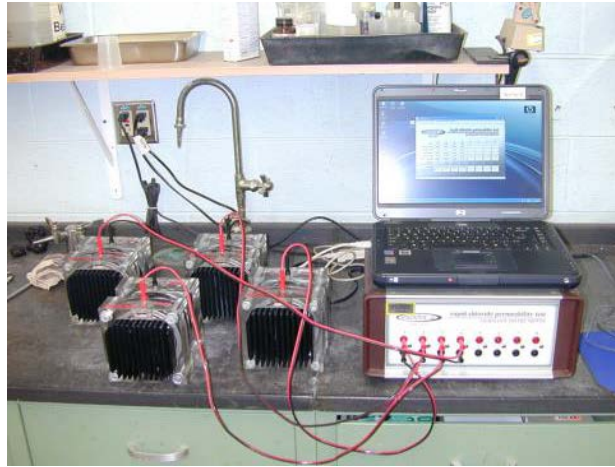


Figure 3: Rapid Chloride Permeability Equipment

Summary and Conclusions

In general, the High Friction Surface was initially very effective for increasing the skid resistance on the curves to which it was applied. However, the life of the surface at the four locations was not sufficient, with one failing in less than 3 years. This early failure was due to de-bonding of the HFS from the asphalt pavement, most likely due to insufficient surface preparation. High pressure washing or light sand blasting to only remove surface contamination simply is not the correct preparation for bonding of polymer materials; this type of surface preparation failed on the bridge deck polymer overlays and is failing on the HFS applications.

The HFS placed on K-5 (asphalt) has some de-bonding along the cracks in the asphalt surface; it appears the cracks were not filled prior to placing the HFS and the de-bonding may be due to intrusion of moisture under the surface and freeze/thaw action along the exposed edges.

The K-5 application is performing best out of the four applications, but one would expect that with an AADT of only 1,000. Both of the asphalt surfaces had been in place for at least 3 years when the HFS was placed. This would allow for the reduction of excess oil or solvents that would affect bond, and therefore points to poor preparation on the K-99 (asphalt) application. With an AADT of only 1,500 one would expect performance nearly equal to the K-5 application.

Both of the applications on concrete pavement have a significant amount of de-bonding of the HFS surface. This would be expected when one takes into consideration the low values for

the tensile pull-off test. Typically for polymer overlays on concrete bridge deck surfaces, one would expect tensile pull-off values in excess of 250 psi; none of the tests performed on the concrete surfaces were near this value. The significant early loss of surface is the major issue to be addressed. Both of these applications had significantly higher AADT values than the asphalt applications but one still needs a longer life from the surfaces to be economical.

Thickness was determined and RCP testing was performed as additional information; the thickness is difficult to evaluate as the variation in the aggregate creates a significant variation in the measurements. A more appropriate evaluation would be to determine how much material was applied to the areas receiving the HFS and evaluate the film thickness of the polymer; however, this information is not available. RCP testing indicated that the HFS does afford some protection from water penetration; this would extend the life of the application by reducing the available water for potential freeze/thaw action that would cause de-bonding of the HFS.

Using the AASHTO provisional standard for HFS treatment (AASHTO PP 79-14, 2014) as a guide, KDOT developed a specification for the materials and placing of High Friction Surfaces in Kansas.

The specification includes material properties for epoxy, polyester and methyl methacrylate materials, aggregate requirements, and construction requirements. The most significant difference between the AASHTO and the KDOT specifications is the requirement for shot blasting on asphalt pavements. KDOT implemented this specification on four HFS applications in 2014 and two applications in 2015. The KDOT Bureau of Research will be evaluating the shot blasting surface preparation on both asphalt and concrete surfaces and the amount of polymer placed as part of the effort to track the performance of the HFS applications. Long term evaluation will include intermediate skid testing, surface pull-off testing, permeability testing, and visual evaluations.

The projects have been split such that four of the locations will be using bauxite aggregate and two of the locations will receive flint aggregate. Both aggregates will be evaluated for initial friction values, longevity, and cost. The principal goal is to extend the life of HFS to 7 to 10 years on both asphalt and concrete surfaces.

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