Improving Pavement Friction for Safety at a Florida Signalized Intersection

Summary Report

U.S. Department of Transportation
Federal Highway Administration

ZERO IS OUR GOAL
A SAFE SYSTEM IS HOW WE GET THERE

TECHNICAL DOCUMENTATION PAGE

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16. Abstract This Summary Report documents the installation of high friction surface treatment (HFST) at an intersection in Tampa, Florida in an effort to reduce crashes and improve pedestrian safety at this location. The location was identified through a Roadway Safety Audit (RSA), which was unique for the FDOT Tampa Region in that it included continuous pavement friction measurement (CPFM) data for the first time. The installation was completed successfully and the early-age performance is excellent. Although crash data are not yet available for a statistical analysis of crash reduction, the Florida Department of Transportation (FDOT) performed an analysis of driver behavior at the intersection and found there was a reduction in crosswalk incursions since the HFST installation, significantly improving pedestrian safety.			
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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)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		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. (Revised March 2003)

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PROJECT OVERVIEW

The Hillsborough Ave. at Central Ave. intersection was selected for high friction surface treatment (HFST) to reduce crashes and improve pedestrian safety after a 2019 Road Safety Audit (RSA) by the Florida Department of Transportation (FDOT). While the FDOT Tampa Region has a long history of using RSAs to assess potential safety enhancements at intersections, this RSA was unique in that it included continuous pavement friction measurement (CPFM) data, provided through Federal Highway Administration's (FHWA's) Pavement Friction Management Program. Friction data allowed the RSA team to more closely examine pavement-related factors that may be contributing to higher-than-average crash frequency. Although HFST was recommended for application from the Central Ave. intersection through the intersections at the Interstate 275 on/off ramps east of Central Ave., the 2020 HFST installation was only applied at the Central Ave. location. This summary report documents HFST deployment at this intersection.

HFST is a proven safety countermeasure used specifically to reduce or prevent friction-related crashes. HFST significantly enhances pavement friction to reduce both wet and dry pavement skidding crashes at locations with high friction demand (FHWA 2021). While the benefits of HFST for horizontal curve and ramp applications are well-documented (Merritt 2020), intersection applications have seen comparatively limited use to date in the U.S. However, since HFST shortens stopping distance, it can reduce or prevent rear-end crashes at intersection approaches (FHWA 2020) and potentially angle crashes within an intersection, while also improving pedestrian safety at crosswalks. Florida DOT is one state highway agency taking steps towards validating the use of HFST for intersection applications.

Site Characteristics

Eastbound Hillsborough Ave. at Central Ave. has two through lanes, a pocket left-turn lane, and bicycle lane on the right which terminates at Central Ave. The intersection is signal controlled and is located less than 500 ft from another signalized intersection at the Interstate 275 ramp terminals. The existing pavement surface is a dense graded asphalt pavement at Central Ave. with a diamond ground concrete surface just east of Central Ave. extending to I-275. A bus stop is located in the right-thru lane/bicycle lane just before Central Ave. Traffic volume at the time of installation was 54,000 vehicles/day and the posted speed is 45 miles per hour (mph).

Crash History

Crash history from the 2019 RSA for years 2011-2017 indicates that of the 72 crashes at this intersection (within the limits of the 2020 HFST installation) over 86 percent are dry pavement crashes. Rear-end crashes are the predominant crash type (68 percent) occurring primarily in the eastbound thru lanes, with the majority in the left thru lane. Right angle crashes in the intersection account for approximately 17 percent of crashes and left-turn crashes account for approximately 13 percent, while sideswipe crashes account for less than 3 percent. Figure 1 and figure 2 show the wet and dry crash diagrams, respectively, for the intersection as provided in the RSA. The preponderance of rear-end crashes may indicate that the existing pavement friction (even under dry conditions) may not be adequate for friction demand from vehicles braking at the intersection approach.

A more recent analysis of crash data for this location, which included preliminary crash data for the years 2020 and 2021 indicated a mean crash rate of 13.5 crashes/year from 2015-2021.

Source: ©FDOT

Figure 1. Graphic. Dry weather crash diagram at Central Ave. intersection for 2011-2017 from the RSA.

Source: ©FDOT

Figure 2. Graphic. Wet weather crash diagram at Central Ave. intersection for 2011-2017 from the RSA.

Friction Testing

The RSA dataset included continuous pavement friction measurement (CPFM) and macrotexture data that were collected by a Sideway-force Coefficient Routine Investigation Machine (SCRIM) device in the right lane in 2016 as part of a pavement friction management program demonstration. CPFM provides a more comprehensive assessment of pavement friction through continuous reporting at a higher resolution than a single spot measurement using a locked-wheel skid tester. This allows for identifying friction changes through a location that may be contributing to crashes. The SCRIM reading (SR) provides an indication of pavement microtexture characteristics while macrotexture is measured directly and reported as mean profile depth (MPD). Both are essential for tire-pavement friction, particularly in wet weather and at higher speeds.

Friction measurements from the RSA were reported as SCRIM reading at 30 mph (SR30) and MPD in mm. SR30 can be converted to the FDOT standard FN40R value using an equation provided by de León Izeppi et al. The friction characteristics from 2016 were (Figure 3):

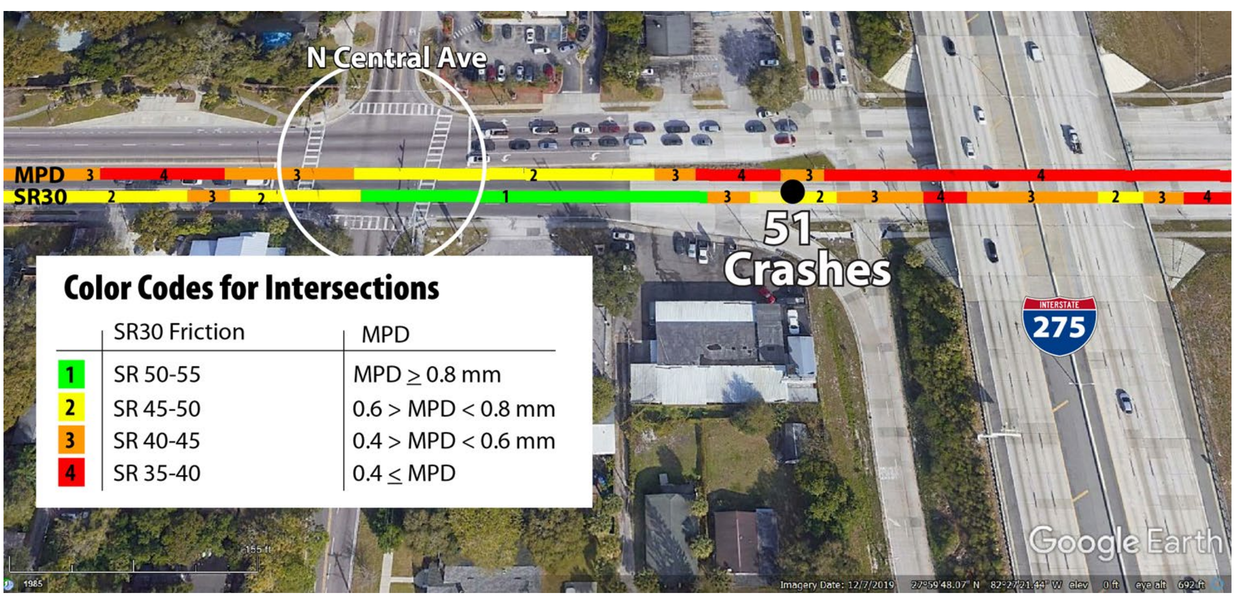
- West of Central Ave (approximate milepost 12.55): SR30 = 44.1 (FN40R = 36.9), MPD = 0.34 mm.

- East of Central Ave. (approximate milepost 12.58): SR30 = 53.9 (FN40R = 45.4), MPD = 0.70 mm.

Source: ©FDOT

Figure 3. Photograph. Surface condition, friction, and texture values at the bus stop, just prior to Central Ave.

Figure 4 shows a color-coded map of friction (bottom line), texture (top line), and total crashes (numbered circles) from the RSA for the right-thru lane for the Central Ave. intersection as well as the intersections at the I-275 interchange. Note that friction and texture vary throughout the intersection. They are lower leading up to Central Ave. when compared to the asphalt section east of Central Ave.



Source: ©FDOT

Figure 4. Graphic. Map of friction, texture, and crashes for the Central Ave. intersection from the RSA.

HFST INSTALLATION

FDOT completed the HFST installation as part of an on-call contract with an HFST installer. Installation was completed under the 2017 revision of FDOT's Section 333 "High Friction Surface Treatment" specification.

Assessment of existing pavement condition subsequent to the RSA led to a decision to repave the existing asphalt pavement prior to HFST application. Repaving consisted of a 1.5-inch mill and overlay using a dense graded FDOT friction course type FC 12.5, PG 76-22.

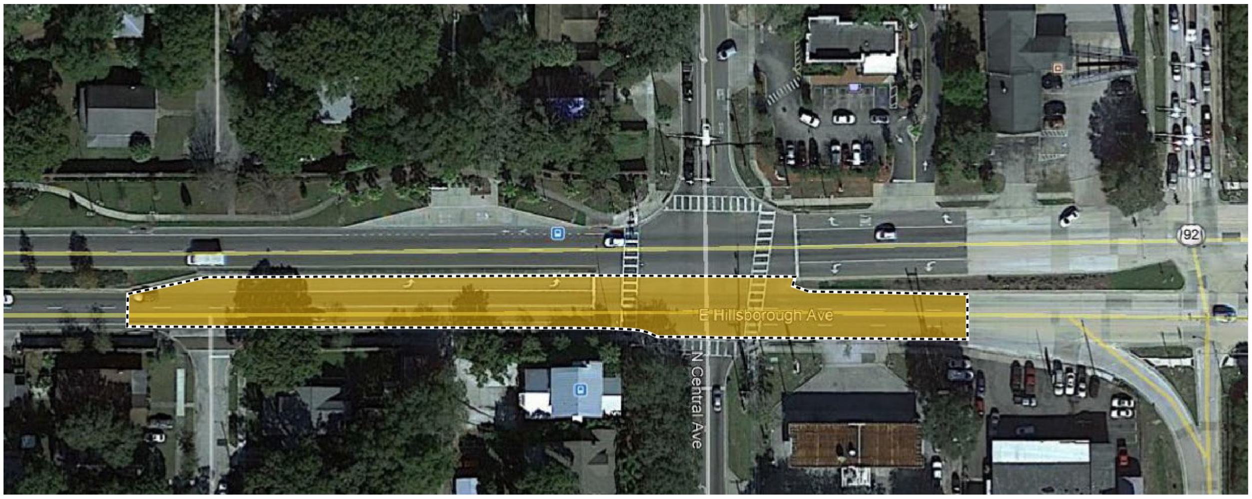
Timeline

The project contractor completed repaving in early June 2020 which required a 30-day cure period before installing HFST over the new asphalt pavement. After several weather delays, the installer completed HFST placement on July 21-22, 2020. The installer completed placement during nighttime closures of the eastbound lanes, with at least one thru lane remaining open during installation of adjacent lanes each night. FDOT permitted lane closures from 10:30 P.M. – 6:00 A.M. each night, and for the actual installation, the nightly schedule consisted of:

- Maintenance of Traffic Initiation: 10:00 P.M.
- HFST Placement: 11:00 P.M. – 1:00 A.M.
- Sweeping: 1:00 A.M. – 3:00 A.M.
- Opening to Traffic: 4:00 A.M.

Treatment Limits

The installer applied HFST to the eastbound lanes from west of Central Ave. beginning at the taper for the left-turn lane, through the intersection, terminating at the joint with the concrete pavement west of I-275. The installer applied HFST to the two through lanes, left-turn lane, bike lane, and the third lane added east of Central Ave., as shown in figure 5. The contractor installed the left turn and left-thru lanes the first night, and the right thru lane, bike lane, and third lane on the second night. The total treatment area was approximately 2,700 square yards.



Source: ©FDOT

Figure 5. Photograph. Shaded area showing HFST treatment limits.

Surface Preparation

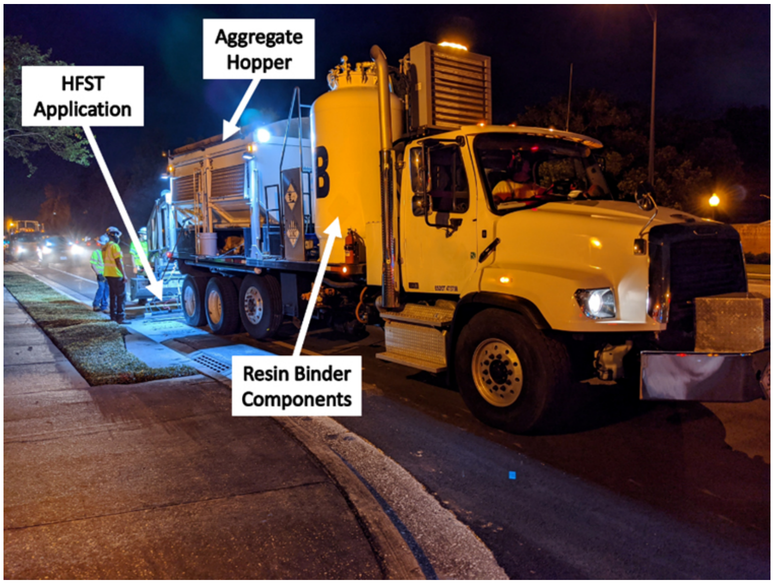
Per FDOT specification, surface preparation consisted of a vacuum sweep to remove any loose deleterious materials. The installer left the waterborne paint (not thermoplastic) pavement markings (placed after the new asphalt surface) in place and applied the HFST over them. The installer masked off the drainage inlets along the curb and manhole covers to prevent infiltration of HFST materials.

Materials

Per FDOT specification, HFST materials consisted of a polymer resin binder and calcined bauxite aggregate. The installer selected a two-part epoxy resin binder, and independent laboratory testing verified that the resin binder conformed to FDOT specification requirements. Laboratory testing of the calcined bauxite also verified conformance to FDOT specification requirements.

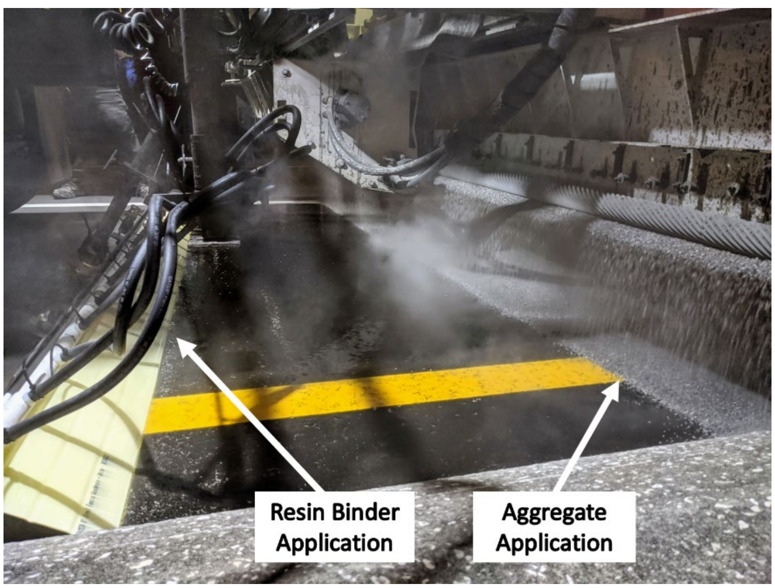
Application Method

Per FDOT specification, the HFST placement required fully-automated continuous application methods. The application vehicle conditions, meters, blends, and applies the resin binder to the specified application rate, then applies the aggregate to the resin binder immediately, as shown in figure 6 and figure 7. Automated application creates a uniform application of resin binder to the required mil thickness. Automated aggregate application helps to ensure timely placement into the resin binder such that it is properly embedded into the resin binder layer.



Source: ©FDOT

Figure 6. Photograph. Continuous fully-automated application truck.



Source: ©FDOT

Figure 7. Photograph. Application of resin binder and aggregate with continuous fully-automated installation.

Installation Observations

Project inspectors did not identify any problems with the installation. Inspectors documented observations from the various aspects of installation, which are provided in the Appendix. Some key observations from this installation documentation include:

- Inspectors noted that the aggregate from the first placement which used only virgin aggregate was noticeably less dusty than the second placement which used reclaimed aggregate blended with virgin aggregate. However, there were no issues with aggregate application or bond with the reclaimed aggregate.
- The installers used a total of 848 gallons of resin binder (424 gallons of each component), which translates to an application rate of approximately 29 SF/gal for the 2,719 SY placed. This falls within the required application rate shown in the project specifications (Section 333) to achieve the required 50-65 mil resin binder thickness.
- The installer used a total of 40,864 lbs of aggregate which translates to an application rate of approximately 15 lbs/SY. This falls within the required application rate shown in the project specifications (Section 333).
- The installer used a wet mil thickness gage to verify the appropriate resin binder thickness during placement. The resin binder application rate (above) provides a secondary check of the adequacy of the resin binder thickness.
- Sweeping to remove excess aggregate began 30-mins to 1-hr after HFST placement was complete for each pass. The installer completed follow-up sweeping within two weeks, prior to placement of permanent thermoplastic striping.

Post-Installation and Acceptance

The project inspectors noted no issues with the installed surface, and the surface was opened to traffic on schedule. Temporary striping was placed prior to opening to traffic until the permanent thermoplastic striping could be installed after a two-week cure period. The installer has since placed thermoplastic striping, in-lane markings (arrows), and raised pavement markers.

FDOT performed friction testing for acceptance approximately two weeks after installation using an ASTM E 274 locked wheel skid tester (LWST) in accordance with AASHTO T 242 using an ASTM E501 ribbed tire. The minimum acceptable friction number is FN40R = 65. Testing performed on August 5, 2020 revealed FN40R = 78 in lane 1 and FN40R = 79 in lane 2.

EARLY-AGE PERFORMANCE

Functional Performance

FDOT performed a field review of the HFST on March 11, 2021, nearly 8 months after installation to document functional performance. The field review team made the following observations based on current conditions:

- Overall the HFST was in good condition without any cracking or other deformations (figure 8).
- There was little evidence of shedding and loose aggregate particles (note that the surface has been swept several times).
- Minor delaminations were noted near the west end of the project in the outside lane (figure 9).
- A small irregular area at the southwest corner of the Central Ave. intersection is exhibiting minor HFST loss, possibly due to manual material application required at this location (figure 10).

Although the exact cause has not been determined, it is likely that the small areas of delamination near the beginning of the treatment are related to surface preparation not completely removing grease/oil deposits. The small area where HFST loss was observed at Central Ave. is likely the result of inadequate resin binder thickness at this location during manual HFST application to this area where automated application was not possible. Both areas should be monitored over time to document any additional surface loss.

Source: ©FDOT

Figure 8. Photograph. HFST condition approximately 8 months after installation.

Source: ©FDOT

Figure 9. Photograph. Small delaminations near west end of project in outside lane.

Source: ©FDOT

Figure 10. Photograph. HFST loss at an irregular area applied manually.

FDOT has not performed additional friction testing. However, per the FDOT specification, the contractor warrants the surface against friction values below the FN40R = 65 acceptance threshold. The surface is also warranted against surface defects associated with materials and workmanship issues during installation. The warrant overs the following surface defects:

- Surface cracking with severity of cracking of Class IB or greater.
- Raveling and/or delamination (loss of cover aggregate or lack of HFST on the surface).
- Soft spots/bleeding caused by uncured resin binder or bleeding due to excess binder.

Any of these distresses which exceed 10 percent of any given 100 SY of HFST application area require remediation.

Safety Performance

At the writing of this report, FDOT is still processing post-installation crash data and therefore the data are not available for an analysis of crash reduction.

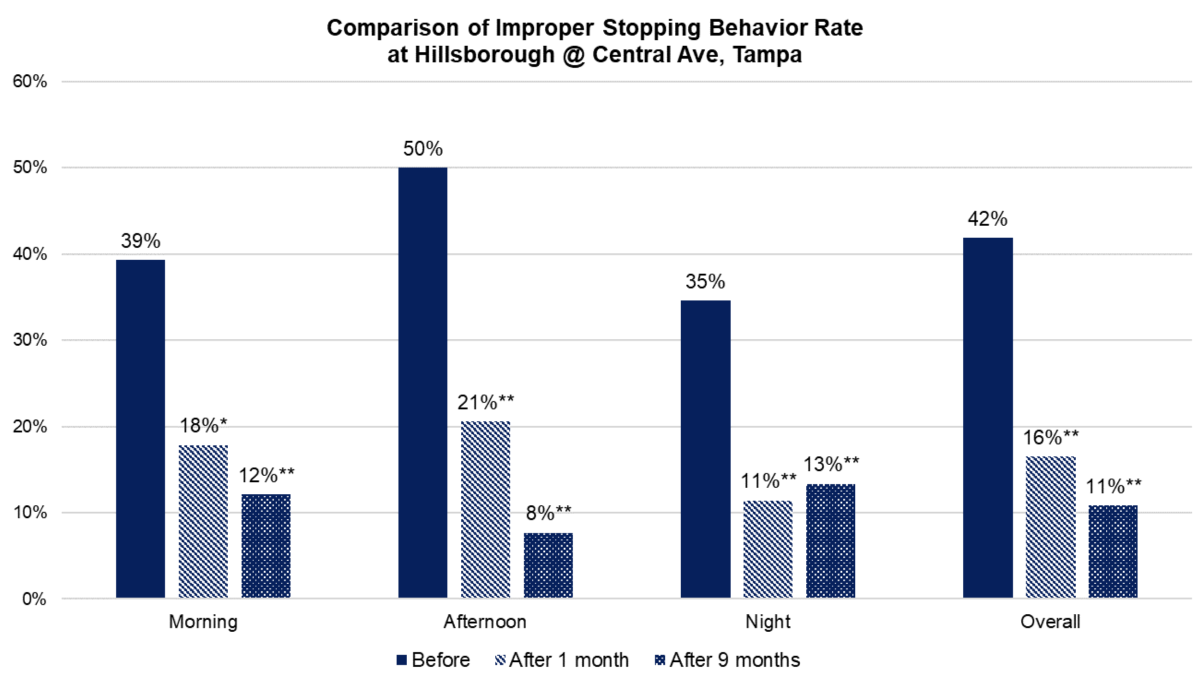
However, to document the possible effects of HFST on stopping distance/stopping behavior at the intersection, FDOT traffic cameras mounted at the intersection were used to analyze vehicle stopping behavior before and after HFST installation.

The Center for Urban Transportation Research (CUTR) at the University of South Florida performed four iterations of video analysis of the intersection to document any possible changes in stopping behavior after HFST application: approximately 1 week prior to HFST application, and at approximately 1 and 9 months after HFST application. The CUTR flagged crossing the stop bar and incursion into the crosswalk while the traffic light was red as improper stopping behavior. The CUTR normalized data based on the number of red lights within the monitoring period.

The CUTR analyzed video from the same three periods of a given day, although the day of the week varied from Thursday to Saturday:

- Morning: 8:00 A.M. to 9:00 A.M.
- Afternoon: 5:00 P.M. to 6:00 P.M.
- Night: 10:00 P.M. to 11:00 P.M.

All three iterations of the after-period analysis revealed a significant improvement in stopping behavior, with far fewer incursions into the crosswalk after HFST application, as shown in figure 11. Overall reductions in improper stopping after HFST application were reported as 26 percent after one month and 31 percent after 9 months. These results indicate that application of HFST at an intersection approach helps to reduce stopping distance and inclusions into crosswalks, improving pedestrian safety.



Source: © CUTR

Figure 11. Graphic. Improvement in stopping behavior after HFST application.

Project Summary

This project demonstrated the successful application of HFST to an intersection location exhibiting high rates of rear-end and left-turn crashes. FDOT selected the location based on an RSA which included continuous pavement friction testing that revealed the friction and macrotexture levels varied throughout the road section and were lower at the intersection approach than surrounding pavement.

Installation was performed in accordance with FDOT Section 333, with no notable problems or issues with materials or application methods. A field review of the project approximately 8 months after installation revealed only minor, isolated distresses and HFST loss.

The crash-reduction benefits of HFST at this location are not yet apparent since very preliminary results are available from only the first 8 months since installation. However, the major benefit realized from HFST at this location to-date has been a significant improvement in stopping behavior, resulting in less incursions into the crosswalk, improving pedestrian safety.

This project illustrates how a holistic approach to pavement friction management, starting with continuous pavement friction measurement, then incorporating friction data into safety assessments like RSAs, and finally by implementing friction improvements like HFST, can be a Safe System Approach that benefits all users.

REFERENCES

Merritt, D. K., Lyon, C. A., Persaud, B. N., and Torres, H. N. *Developing Crash-Modification Factors for High-Friction Surface Treatments*, Federal Highway Administration FHWA Research Report FHWA-HRT-20-061. McLean, VA. 2020.

FHWA. *High Friction Surface Treatment at Intersections*. Federal Highway Administration FHWA-SA-20-012. Washington, D.C. 2020.

FHWA. High Friction Surface Treatments (HFST) website: https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/high_friction/ (last accessed, October 2021)

APPENDIX

Table 1 lists items for documentation provided to project inspectors prior to installation along with inspector notes.

Table 1. Installation inspection documentation.

Item		Inspection Notes
Pre-installation site conditions	Pavement condition	Milled and resurfaced before HFST application
	Pre-installation repairs (if any)	N/A
	General site observations	Urban Corridor with slight down grade
Construction staging and Maintenance of Traffic (MOT)	Location of equipment and materials prior to installation	Offsite at nearby parking lots
	MOT used for intersection installation:	Standard Index 102-602 and 102-603
Surface preparation	Striping/pavement marking removal and/or masking	RPM removed, existing pavement markings were paint and remained as-is during HFST application
	Drainage inlet protection	Curb inlet protection placed within the project limits
	Surface cleaning method (e.g., sweeping, compressed air wash, etc)	Vacuum sweeper
Materials	Resin binder material types and brand names	Cornerstone Construction Material CE330 Epoxy Binder, Parts A & B
	Aggregate material types and brand name/source	Great Lakes Minerals GRIPgrain, Round Kiln (RD), RD-88 (USS 6x16 Mesh) - Chinese Bauxite - Calcined
	Re-swept aggregate used?	Yes

Item		Inspection Notes
	Subjective evaluation of aggregate cleanliness (dust, foreign material, etc):	First application relatively clean, re-swept aggregate was dustier
	FDOT laboratory test results and/or contractor-submitted test results	Contractor submitted material test results along with MSDS documentation
Installation	Scope for each night's placement (e.g., lane, length, width, approx. limits):	1-2 lanes per night, approximately 600 ft
	Timeline for installation each night:	
	MOT initiation	10 P.M.
	Begin and end time for material placement	11 P.M. – 1 A.M.
	Time of sweeping	1 A.M. – 3 A.M.
	Opening to traffic	4 A.M.
	Quantity of material placed	
	Square yards placed	Approx. 2,719 SY
	Quantity of resin binder placed (gal., from contractor)	Approximately 424 Gal of Binder A and 424 Gal of Binder B
	Quantity of aggregate placed (lb/ton, from contractor):	Approximately 40,864 lbs
	Processes used to verify proper proportioning and blending of resin binder components (e.g., printout from truck):	Information not available
	Methodology to document resin binder thickness (e.g., mill thickness gage, material usage/coverage rate):	Thickness gage
	Anomalies or other issues noted:	N/A
Aggregate Removal	Timing of aggregate removal:	Approximately thirty minutes to one hour
	Processes used for aggregate removal (e.g, vacuum sweeper, compressed air wash, etc.):	Vacuum truck (no sweeping) and leaf blower

Item		Inspection Notes
Final Inspection and Opening to Traffic	Processes used to verify that the surface is ready for opening to traffic:	Information not available
	Replacement of pavement markings (e.g., temporary or permanent tabs, striping, etc.):	Temporary paint striping, followed with more surface vacuuming after 2 weeks then thermoplastic pavement markings
Post-Installation Inspection	Documentation of anomalies in first 24-48 hours following completion of installation:	N/A
	Documentation of re-sweeping (e.g., days after installation and method used):	Information not available

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