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High Friction Surface Treatments

Prepared by CTC & Associates LLC

The Federal Highway Administration's Every Day Counts initiative promotes innovations and technologies that enhance road safety. Among the innovations supported through this effort is the implementation of high friction surface treatment (HFST), a spot pavement surfacing treatment applied in locations with high friction demand, such as curves and other crash-prone areas. This technology is expected to significantly enhance skid resistance and reduce crashes.

MnDOT and local transportation agencies in Minnesota are evaluating the use of HFST as a safety strategy on roadways. To gather information for this evaluation, selected state departments of transportation were surveyed about their practices and experience with HFST applications, including materials specifications, locations that benefit most from HFST, the pavement treatment's durability and the resulting impact on safety. This Transportation Research Synthesis presents the findings of that survey along with the results of a limited literature search. Publications provided by survey respondents that are not publicly available are included in a separate TRS supplement, TRS 1802S, available at http://mndot.gov/research/TRS/2018/TRS1802S.pdf.

Technical Advisory Panel

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Grant County, Minnesota

Mitch Bartelt, Technical Liaison
MnDOT Research Services & Library

Christine Kline, Principal Investigator
CTC & Associates LLC

Matt Mullins, Principal Investigator
CTC & Associates LLC

Mark Linsenmayer, Principal Investigator
CTC & Associates LLC

Dan Warzala, Project Coordinator
MnDOT Research Services & Library

Mark Vizecky, Panelist
MnDOT State Aid

High Friction Surface Treatments

Introduction

MnDOT and local transportation agencies in Minnesota are considering the use of a high friction surface treatment (HFST) as a safety strategy. HFST is used as a spot pavement surfacing treatment in locations with high friction demand (for example, crash-prone areas such as curves). Using a polish-resistant aggregate that is bonded to the pavement surface using an epoxy or polymer resin binder, HFST is expected to significantly enhance skid resistance and reduce crashes.

To inform its evaluation of HFST for possible use, MnDOT sought information from state departments of transportation (DOTs) with a climate similar to Minnesota and expected to have experience with HFST applications. This Transportation Research Synthesis presents findings from the survey, including information about the number and location of installations, the materials used in surface treatments, the durability of HFST and its impact on safety. Results of a limited literature search supplement survey findings.

Summary of Findings

Survey of Practice

An online survey was distributed to 21 states; 15 states responded to the survey. Below are highlights of survey results in seven topic areas:

- HFST program background.
- Aggregates and binders.
- Friction requirements.
- Effectiveness.
- Safety performance.
- Durability.
- Specifications.

Findings from the limited literature search appear in **Related Resources** sections throughout this report and in the **Specifications** section. Publications provided by respondents that are not publicly available are included in a separate TRS supplement, TRS 1802S, available at http://mndot.gov/research/TRS/2018/TRS1802S.pdf. Citations for these documents include the following direction: *See Appendix in the TRS Supplement*.

HFST Program Background

Number of Installations

The number of HFST installations varied significantly among state DOTs responding to the survey. Five states (Illinois, Iowa, Michigan, Ohio and Wisconsin) have 15 or fewer installations; four states (Alaska, Indiana, South Dakota and Texas) have 20 to 35 completed or soon-to-be-completed installations; and four states (California, Georgia, Kentucky and Pennsylvania) have 100 or more installations. Only one state (North Dakota) reported no completed or soon-to-be-completed installations. The Tennessee DOT respondent did not provide a number, reporting only that the state has numerous installations.

Plans for additional HFST installations are equally varied. Most states plan to install a small number of HFST sites. Four states (California, Georgia, Indiana and Pennsylvania) have plans for 100 to 250 additional installations.

Location of Installations

Respondents described where in traffic lanes or curves their HFST installations are located. Responses were varied, with some respondents describing the location in terms of the point of curvature and point of tangent of a curve, while others reported on how much of the traffic lane is covered with the treatment. Some agencies will apply HFST to some portion of the shoulder; others apply the treatment from edge line to edge line.

Site Characteristics

Respondents reported on the characteristics that make a site eligible for HFST. Most respondents reported on some type of evaluation of crash data, including California's use of a specific set of queries in the agency's crash database to identify locations for possible treatment. Other data-gathering practices include programs in Georgia and Indiana to collect ball-bank data on curves. (The ball-bank indicator method is one of several methods that can be used to determine curve advisory speeds.) Other respondents conduct benefit—cost analyses and review friction data.

Factors Influencing Use

Most respondents cited safety-related issues when asked to describe the factors influencing their agencies' decision to use HFST. Respondents most often cited the use of HFST to address roadway departure (RwD) crashes and wet pavement crashes. Other respondents noted the cost-effectiveness of HFST as opposed to making geometric changes to improve safety.

Aggregates and Binders

Aggregates Used in HFST

All respondents use calcined (heat-treated) bauxite as the aggregate in their HFST installations. While Indiana DOT's HFST program now exclusively uses calcined bauxite aggregate, a research project initiated in 2017 is testing blast furnace slag (also referred to as "steel slag") as a possible alternate material. A research proposal has been submitted to Indiana DOT for a follow-on project for roadway skid testing and test installations using blast furnace slag to allow for direct comparison to calcined bauxite. Pennsylvania DOT has also investigated other aggregate sources, but all tests have failed. Wisconsin DOT has defined a separate category for applications using alternate aggregates—enhanced friction surface treatment (EFST). An EFST is composed of aggregate in an asphaltic binder on hot-mix asphalt (HMA) or concrete pavements.

Binders Used in HFST

Binders used in HFST are typically epoxy or polymer resin. Respondents use both types of binder:

- Epoxy-based binder: Alaska, California, Illinois, Ohio and Tennessee.
- Polymer resin binder: Indiana, Iowa, Kentucky and South Dakota.
- Polymer resin or methyl methacrylate resin binder: Michigan and Pennsylvania.
- Unspecified resin binder: Georgia, Texas and Wisconsin.

Comparison of Materials Used in Chip Seals, Microsurfacing and HFST

Respondents using chip seals and microsurfacing were asked how the binders and aggregates used for chip seals and microsurfacing differ from the materials used for HFST. Several respondents described how the purpose of the treatments differs, noting that chip seals and microsurfacing are used for pavement preservation and HFST is used to increase friction. Other respondents described the differences in materials, noting that asphalt emulsions are used as a binder in chips seals and microsurfacing; the aggregate used for these treatments is crushed stone or fine and coarse aggregates.

Friction Requirements

Respondents described their agencies' friction requirements (also referred to as "skid resistance") for two types of pavements—HMA and HFST—using two types of measurement values:

- Friction numbers (FNs). FNs are used in the U.S. to quantify friction using methods described in ASTM standards that require the use of ribbed or smooth testing tires.
- Dynamic friction tester (DFT). The DFT measurement method is described as providing more information about friction because it allows measuring friction as a function of speed.

Few respondents offered friction requirements for HMA, with values ranging from 30 FN to 50 FN and 0.30 DFT. More respondents offered values for HFST, with 65 FN most common (ranging up to 75 FN); DFT values ranged from 0.75 DFT to 0.90 DFT.

Effectiveness

For those respondents able to address the effectiveness of their HFST installations, six indicated that HFST has proved to be very effective or is performing well or very well (California, Georgia, Ohio, Pennsylvania, Tennessee and Wisconsin). The Kentucky respondent noted that performance varies by site. Only one state—Alaska—reported signs of early wear on HFST sites. It is too early to draw conclusions in five states—Illinois, Indiana, Iowa, Michigan and Texas.

Safety Performance

In addition to addressing the effectiveness of their HFST installations, seven of the 10 respondents reporting the availability of before-and-after crash data described specific safety-related results:

- One site in the San Francisco Bay Area that recorded 52 crashes per year recorded less than three per year after HFST installation. At the same site, wet pavement crashes dropped from 47 to less than one per year (California).
- An approximate reduction of 70 percent in targeted crashes over all HFST sites (Kentucky).
- Overall reduction for all crashes of 33.78 percent for 10 HFST sites; a 61.31 percent reduction in wet crashes (Michigan).
- After four years, a 100 percent reduction in fatalities and 90 percent decrease in fatalities and injuries for wet pavement crashes at 18 of the agency's original HFST locations (Pennsylvania).
- After three years, an 86 percent reduction in winter road condition RwD crashes at four horizontal curves installed with HFST (South Dakota).
- Significant reduction in all crash types at three installation sites in the years after installation (see the table on page 28) (Tennessee).
- The Marquette Interchange recorded 219 crashes in the almost three years *before* HFST installation, and nine crashes in the almost three years *after* HFST application—a 95 percent reduction in crashes for the location (Wisconsin).

Durability

HFST as Compared to Standard Roadway Surfaces

Some respondents reported positively on the durability of HFST as compared to a standard roadway surface, reporting that HFST pavements will "hold up" for five to seven years (Kentucky), eight years (Pennsylvania) and at least 6.5 years (Wisconsin). Other respondents reported on factors that appear to affect the durability of HFST, with several focusing on preparing the pavement for installation and the condition of the pavement surface accepting the HFST. The Alaska respondent reported that HFST installations have not proved to be durable, showing wear after one winter. In Iowa and Texas, it's too early to know about durability.

Durability of Aggregate Surfaces

Respondents were asked to describe the durability of aggregate surfaces for two types of pavement treatments: HMA and HFST. Some respondents described the durability of aggregate surfaces in terms of an expected service life (in years), though more than half of respondents did not provide any data. Generally, when data is available, respondents expect a longer service life from aggregate surfaces in HMA than HFST. Consistent with other respondent feedback presented in this report, several respondents highlighted the significance of the underlying pavement or subsurface as a contributing factor in the life of HFST.

Impacts of Snowplowing on HFST Installations

All but two respondents with enough experience to determine the impacts of snowplowing on HFST installations reported that the surface treatment has performed acceptably or held up "very well." Two agencies identified limited impact, and five agencies do not have enough experience with snowplowing or lack data to determine its impact.

Specifications

This section of the report includes specifications, special provisions and contract notes associated with respondents' use of HFST. Additional specifications, guidance and other HFST program details appear in **Related Resources** sections throughout this report.

Next Steps

Going forward, MnDOT might consider:

- Consulting with states using HFST that also employ an aggressive snowplowing strategy similar to Minnesota's to learn more about:
  - Snowfighting practices.
  - Types of plows used, including underbody plows.
  - Detailed findings of the impacts to HFST associated with winter maintenance practices.

  These states might include Alaska, Michigan and Wisconsin.
- Reviewing in detail the agency specifications that address the materials and installation practices used by respondents.
- Contacting selected states to learn more about agency practices and experiences, including:
  - Selecting and preparing binders for installation.
  - Preparing pavements to receive HFST.
  - Any other issues associated with the binder materials used in HFST installations.

Detailed Findings

Background

Through its Every Day Counts initiative, the Federal Highway Administration (FHWA) has encouraged transportation agencies and the paving industry to try spot application of a high friction surface treatment (HFST) in locations with high friction demand (for example, crash-prone areas such as curves). This pavement surfacing system is described in a February 2018 FHWA online resource of frequently asked questions about HFST:

Definition

- A High Friction Surface Treatment is a cost-effective safety countermeasure in which a polish-resistant aggregate such as calcined (i.e., heat treated) bauxite aggregate is bonded to the pavement surface using a polymer resin binder, significantly enhancing skid resistance and reducing crashes.

Description

- HFST places a layer of highly durable, anti-abrasion and polish-resistant aggregate over a thermosetting polymer resin binder. The mineralogical and physical properties of these aggregates make the overlay exceptionally resistant to wear and polishing by traffic. The polymer resin binder locks the aggregate firmly in place, creating an extremely durable surface capable of withstanding even the most extreme roadway demands, from cornering and heavy braking to snowplowing. HFST restores, and, in most cases, significantly enhances, pavement surface friction where traffic has worn down existing pavement surface aggregates. HFST can also help compensate for inadequate geometric designs, such as sharp curves and substandard superelevations.

(See **Related Resources** on page 13 for the citation for this February 2018 FHWA online resource.)

MnDOT and local transportation agencies in Minnesota are considering use of HFST. To inform its evaluation of HFST for possible use, MnDOT sought information from other state departments of transportation (DOTs) that have experience with this pavement surfacing system to learn more about the number and location of installations, the materials used in surface treatments, the durability of HFST and its impact on safety.

Survey of Practice

An online survey was distributed to 21 states with a climate similar to Minnesota and expected to have experience with HFST applications. Fifteen states responded to the survey:

- Alaska.
- California.
- Georgia.
- Illinois.
- Indiana.
- Iowa.
- Kentucky.
- Michigan.
- North Dakota.
- Ohio.
- Pennsylvania.
- South Dakota.
- Tennessee.
- Texas.
- Wisconsin.

The full text of the survey questions is provided on page 37 in this report. Contact information for survey respondents and others who provided supplemental information begins on page 38 in this report.

The following summarizes survey results in seven topic areas:

- HFST program background.
- Aggregates and binders.
- Friction requirements.
- Effectiveness.
- Safety performance.
- Durability.
- Specifications.

Findings from a limited literature search that supplement survey results appear in **Related Resources** sections throughout this report and in the **Specifications** section. Publications provided by survey respondents that are not publicly available are included in a separate TRS supplement, TRS 1802S, which is available at http://mndot.gov/research/TRS/2018/TRS1802S.pdf. Citations for these documents include the following direction: *See Appendix in the TRS Supplement*.

HFST Program Background

General information about respondents' HFST programs is provided below in four topic areas:

- Number of installations.
- Location of installations.
- Site characteristics.
- Factors influencing use.

Publications relating to respondents' HFST programs are in a **Related Resources** section that begins on page 15.

Number of Installations

The number of HFST installations varied significantly among state DOTs responding to the survey. Five states (Illinois, Iowa, Michigan, Ohio and Wisconsin) have 15 or fewer installations; four states (Alaska, Indiana, South Dakota and Texas) have 20 to 35 completed or soon-to-be-completed installations; and four states (California, Georgia, Kentucky and Pennsylvania) have 100 or more installations. Only one state (North Dakota) reported no completed or soon-to-be-completed installations. The Tennessee DOT respondent did not provide a number, reporting only that the state has numerous installations.

Plans for additional HFST installations are equally varied. Most states plan to install a small number of HFST sites. Four states (California, Georgia, Indiana and Pennsylvania) have plans for 100 to 250 additional installations. The table below summarizes survey responses.

Number of HFST Installations

State	Number of Installations	Additional Installations Planned
Alaska	31	Not provided
California	≈114 (including local roads)	≈135 (including state and local roads)
Georgia	Approximately 479	Approximately 250
Illinois	10 (some involve multiple locations)	2 or 3 projects per year

Number of HFST Installations		
State	**Number of Installations**	**Additional Installations Planned**
Indiana	22 (planned for spring 2018)	100+
Iowa	11	3
Kentucky	100+	Annual network screening; none planned for installation at this time.
Michigan	4	8
North Dakota	0	1
Ohio	14 (from 2008 to 2016)	3
Pennsylvania	198	110
South Dakota	22	20
Tennessee	Numerous	Unspecified; annual regionwide contracts are based on traffic data.
Texas	35	31
Wisconsin	3	15 to 20

Location of Installations

Respondents described where in traffic lanes or curves their HFST installations are located. Responses were varied, with some respondents describing the location in terms of the point of curvature (PC) and point of tangent (PT) of a curve, while others reported on how much of the traffic lane is covered with the treatment. Some agencies will apply HFST to some portion of the shoulder; others apply the treatment from edge line to edge line. Below are highlights of respondents' descriptions:

Alaska. Locations depend on geometry, with some locations limited to application from centerline to fog line; other locations include the shoulder. Determinations are made on a case-by-case basis depending on shoulder width, presence of rumble strips and pavement condition.

California. HFST placement is determined by the traffic safety engineer in each district. The agency stresses that "more doesn't mean better," and the HFST should only be placed "where the friction demand is needed to reduce the crash concentrations that you are seeing in your investigation."

Illinois. HFST locations include full-lane widths of interstate highway ramps and selected curves on U.S. and state highways.

Indiana. HFST installations on curves begin 140 feet upstream of the curve PC and end at the end-of-curve PT for each travel direction. HFST is to be placed no closer than 6 inches from the centerline and edge line pavement markings. See **Related Resources** on page 16 for a detail drawing of the application area.

Iowa. HFST installations on curves cover the roadway surface from edge of roadway to edge of roadway.

Kentucky. HFST is applied approximately 50 to 100 feet prior to the PC and typically covers both lanes and approximately 1 inch onto the shoulder. Sites may vary based on conditions or crash distribution.

North Dakota. HFST will be installed from PC to PT.

Ohio. HFST is applied across the entire lane width.

Pennsylvania. HFST is installed from the start of the horizontal curve and ends at the end of the horizontal curve. The entire lane is applied with HFST. Most of the time HFST can be applied between painted lines if necessary.

South Dakota. The agency applies HFST from the PC to the PT of a curve.

Tennessee. Placement of HFST installations is based on the May 2016 FHWA publication that provides guidance for identifying candidate curves for HFST (see page 15 for the citation for this publication).

Texas. HFST is typically applied on two-lane, two-way highways. Installations cover from edge line to edge line and PC to PT.

Wisconsin. HFST is generally only applied to the travel lanes. In some cases, the agency has applied HFST to 2 to 3 inches of shoulders where vehicles drift outside lanes on curves.

Site Characteristics

Respondents provided varying degrees of detail when asked to describe the characteristics that make a site eligible for HFST. Below are summaries of each state's site evaluation practices:

Alaska. The following issues, data or characteristics are considered when selecting sites for application of HFST:

- Previous safety recommendations.
- Single vehicle run-off-road crashes (particularly motorcycle crashes).
- Curves with crash history.
- The first signal on a high-speed roadway transitioning to or from a different road classification (i.e., freeway ending into arterial, or major collector into arterial with a long distance between signals).
- Steep grade into signal (targeting rear-end crashes).
- Limited, cost-effective engineering countermeasures.

California. A specific set of queries is used in the agency's crash database to identify locations to investigate for possible treatment. The agency's central office generates an annual wet pavement high collision concentration list (Wet Table C) that is distributed to the agency's 12 districts to conduct a safety investigation. The agency requires that all locations appearing on this list be investigated with a recommended action (including no action). A safety index (benefit—cost analysis) is calculated to determine if the project is cost-effective and qualifies for Highway Safety Improvement Program (HSIP) funding. Most locations selected for HFST have been on horizontal curves on freeways, expressway and conventional highways, loop-on ramps, and areas approaching high-speed signalized intersections.

Georgia. Site assessment begins by "riding" a curve in both directions at the posted speed limit and noting the reading on the ball-bank indicator (the ball-bank indicator method is one of several methods that can be used to determine curve advisory speed). Indicator readings registering 12 or more on the ball-bank indicator will receive HFST.

Illinois. Locations with a high number of run-off-road crashes in curves are considered for application of HFST, particularly if the crash data shows a correlation between crashes and a wet or snow-covered roadway surface. HFST is also used where friction data shows friction numbers (FNs) below what is "preferable." (The respondent did not specify the "preferable" FNs.)

Indiana. Selection of HFST project locations is based on a recent program to collect ball-bank data on curves. This program, conducted by district traffic offices, prioritizes locations for inclusion in the agency's curve warning sign program based on the ball-bank data collected. District traffic offices were asked to also consider geographic information system (GIS) crash location data for run-off-road, head-on and sideswipe crashes to prepare a prioritized list of rural highway curves appropriate for treatment. In the future, the agency may expand the HFST program to include freeway ramps and urban curves that exhibit a history of lane departure. The agency will also consider intersection approaches with a history of rear-end and red-light-running crashes to receive HFST.

Iowa. A combination of characteristics is used to identify locations for HFST:

- Iowa Safety Improvement Candidate List (see https://iowadot.gov/crashanalysis/top200.aspx).
- Safety performance function (SPF) models for curve type 1, jurisdictions 1 and 6 (see **Related Resources** on page 15 for a September 2013 FHWA guide for developing jurisdiction-specific SPFs).
- Iowa DOT's Pavement Friction Evaluation Program.
- Lane departure crashes, including multivehicle crossed centerline and single vehicle run-off-road crashes.

Results from these analyses are then ranked by schemes that involve allocating weights from the normalized factors that equal one.

Kentucky. The following methodology is used to select appropriate locations for HFST:

- Utilize Highway Safety Manual (HSM) methodologies to evaluate the roadway network for wet pavement condition crashes.
- Provide analysis to indicate overrepresentation of targeted crashes.
- Evaluate existing and previous installations for maintenance needs.
- Implement projects annually where reinstallation is desired or where new installations provide the best opportunity to reduce overall fatalities and serious injuries.

Michigan. Low friction values and crash data are used to select HFST sites. The agency also uses wet surface friction test results of less than 30 to evaluate locations for treatment.

North Dakota. In addition to crash history, the agency examines site characteristics such as sharp horizontal curves, steep grade and poor stopping conditions.

Ohio. The agency considers frequency of crashes that occur under wet pavement conditions and the potential for crashes based on geometrics. To illustrate the latter factor, HFST would be installed on an approach to an intersection associated with a steep grade.

Pennsylvania. The following data and conditions are used to select HFST locations:

- Roadway departure (RwD) and wet road crash data.
- Skid testing (most locations failing a skid test are eligible for HFST).
- Excessive braking while approaching intersections leading to running stop signs or red signals and rear-end crashes.
- Unable to move fixed objects to increase clear zone.
- Other RwD crashes not related to wet roads (such as road geometry).

South Dakota. A benefit—cost analysis is conducted for locations with road departure crashes under winter road conditions.

Tennessee. Traffic accident data and friction data are used to select HFST sites.

Texas. The respondent cited wet-weather fatal (K), incapacitating injury (A) and nonincapacitating injury (B) (or KAB) crashes on curves or at intersections as providing the impetus for the application of HFST.

Wisconsin. The agency reviews the types of crashes present at a location, paying particular attention to wet-weather run-off-road crashes. Pavement condition and friction value (if available) are also considered. Candidates for application are those locations with a low friction value and a crash trend with pavement "good enough" to support HFST.

Factors Influencing Use

Most respondents cited safety-related issues when asked to describe the factors influencing their agencies' decision to use HFST. Respondents most often cited the use of HFST to address RwD crashes and wet pavement crashes. Other respondents noted the cost-effectiveness of HFST as opposed to making geometric changes to improve safety. The table below summarizes survey responses.

Factors Influencing Respondents' Use of HFST

Factor	State	Description
Accident or friction data	Ohio	Friction demand issues. (The respondent indicated that HFST is only used in select locations and not in *any* area with a need for increased friction.)
	Tennessee	Traffic accident and friction data.
Administrative issues	Alaska	Fast design/bid/award process for HFST.
Effectiveness	California	The agency identified limitations with other countermeasures, such as placing open-graded asphalt concrete (OGAC), drainage improvements, or grinding or grooving the pavement (the respondent noted that OGAC was particularly problematic). HFST provided the agency with another option to address locations with high-collision rates under wet pavement conditions. As the respondent noted, "HFST has shown to be the best countermeasure that we have seen in dramatically reducing crashes."
	North Dakota	HFST's reputation as "an effective product."

Factors Influencing Respondents' Use of HFST		
Factor	**State**	**Description**
Every Day Counts initiative	Alaska, Texas	Both agencies highlighted FHWA's Every Day Counts initiative encouraging the use of HFST.
Meeting federal guidelines	Georgia	Federal guidelines on curve sign requirements were used to identify curves to receive HFST.
Other states' experiences	California	Webinars conducted during 2009 and 2010 "showed great collision reduction results other states agencies were experiencing."
	Iowa	Feedback from peer exchange and neighboring states.
	Tennessee	Success of the HFST program in other locations.
	Texas	Proven benefits in other states.
Research	Iowa	Research to determine the benefits of use within the state.
Safety: General	Alaska	High Risk Rural Roads penalty. (The Fixing America's Surface Transportation Act (FAST Act) High Risk Rural Roads (HRRR) rule requires states to obligate a certain amount of funds on HRRRs if the fatality rate on its rural roads increases; see **Related Resources** on page 13 for more information about HRRR.)
	Michigan	Safety and the agency's Toward Zero Deaths initiative.
Safety: Alternative to geometric changes	Kentucky	The need to implement a countermeasure to combat the increased friction demand for locations that are difficult to reconstruct.
	Wisconsin	HFST typically costs less than making geometric changes.
Safety: Curve countermeasure	Iowa	HFST is used as a potential curve countermeasure.
	Georgia	Georgia DOT, which is among the states with an RwD Focus State Implementation Plan (finalized in 2013), is using HFST as a low-cost countermeasure for curves.
	Pennsylvania	HFST is used to reduce fatal and serious injury crashes due to hit-fixed-object crashes on rural highway horizontal curves, and intersections where vehicles have limited ability to stop before entering the intersecting roadway (such as a sag vertical curve (a curve that connects descending grades) that hides an intersecting roadway and stop sign).
Safety: RwD crashes	Illinois	HFST is a proven safety strategy to reduce RwD crashes.
	Indiana	Lane departure events have resulted in a consistently high percentage of fatal and severe injury crashes in Indiana. A range of safety strategies have been deployed as countermeasures to lane departure (safety edge, cable barrier, rumble stripes on centerlines and edge lines, and upgrades to curve warning signs and chevrons). HFST has been selected as the agency's next

Factors Influencing Respondents' Use of HFST		
Factor	**State**	**Description**
		systemic countermeasure program.
	Pennsylvania	HFST is used to reduce fatal and serious injury crashes due to RwD.
	South Dakota	Overrepresentation of RwD crashes on curves with winter road conditions.
	Wisconsin	Few alternatives exist for high-volume, high-speed facilities for reducing RwD crashes.
Safety: Wet pavement crashes	California	HFST is used to reduce the number of crashes on roadways, especially under wet pavement conditions.
	Pennsylvania	HFST is used to reduce fatal and serious injury crashes due to wet road crash cluster locations where drainage or realignment cannot be easily addressed.
	Wisconsin	The agency's first pilot project "was very successful in reducing wet-weather run-off-road crashes."

Related Resources

Cited below are national publications that provide an overview of HFST and state-related publications that offer details of respondents' use of HFST.

National Resources

Frequently Asked Questions—High Friction Surface Treatments (HFST)—2017, Federal Highway Administration, February 2018.
https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/faqs_links_other/hfst_faqs/
This FAQ addresses a wide range of topics related to HFST, including:

- Safety.
- Maintenance and operations.
- Cost.
- Environmental impacts.
- Material specifications/durability.
- Lessons learned.
- Installation.

The printable version of this online resource was not available at the time of publication.

High Risk Rural Roads (HRRR), Office of Safety, Federal Highway Administration, December 2017.
https://safety.fhwa.dot.gov/hsip/hrrr/
From the program overview: High Risk Rural Roads are defined in 23 USC 148(a)(1) as "any roadway functionally classified as a rural major or minor collector or a rural local road with significant safety risks, as defined by a State in accordance with an updated State strategic highway safety plan."

While the Moving Ahead for Progress in the 21st Century Act (MAP-21) eliminated the $90 million set-aside for the HRRR program, it also established a Special Rule for high risk rural road safety under 23 USC 148(g). This rule was continued with the Fixing America's Surface Transportation Act (FAST Act) and requires a State to obligate a certain amount of funds on HRRRs if the fatality rate on its rural roads increases. FHWA issued MAP-21 High Risk Rural Road Guidance and a set of Questions and Answers in December, 2012.

First International Roadside Safety Conference: Safer Roads, Saving Lives, Saving Money, Transportation Research Circular Number E-C220, June 2017.
http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf
This publication includes several conference papers related to HFST, including:

- Safety Impact of High-Friction Surface Treatment Installations in Pennsylvania (see page 6 of the circular, page 24 of the PDF).
- High-Friction Surfacing Treatment: How a 45-Year-Old Process Has Been Reengineered into the Leading National Safety System Used by Highway Agencies to Reduce Fatalities and Serious Injuries (see page 21 of the circular, page 39 of the PDF).
- Improving Pavement Friction to Advance Roadway Safety on Horizontal Curves: Advancements in Roadway Safety Features (see page 27 of the circular, page 45 of the PDF).

A companion set of conference slides is available at http://onlinepubs.trb.org/onlinepubs/conferences/2017/roadsidesafety/6a-bergner.pdf. HFST-related slides begin with slide 34 and continue through the remaining slides in the file.

NTPEP Committee Work Plan for Evaluation of High Friction and Thin Overlays for Bridges and Pavements, National Transportation Product Evaluation Program, October 2016.
http://www.ntpep.org/Documents/Technical_Committee/HFTO/Documents/HFTO%20Work%20Plan%20Clean%2010-13-16.pdf
From the scope:

1.1 This standard practice covers the requirements and testing criteria for the National Transportation Product Evaluation Program (NTPEP) evaluation of high friction and thin overlays for bridges and pavements (HFTO). The National Transportation Product Evaluation Program (NTPEP) serves the member departments of the American Association of State Highway and Transportation Officials (AASHTO).

1.2 The results of this program may be used to provide AASHTO Member States a list of tested HFTO resins and primers, by type and manufacturer, which have been evaluated in accordance with AASHTO, AASHTO-AGC-ARTBA Task Force 34 and ACI materials specifications and guidelines. Member departments are encouraged to apply this information to improve their specifications or establish approved or prequalified products lists as they deem appropriate for their individual programs.

1.3 This program consists of a battery of laboratory evaluations and 36 month field evaluation. Field test sites will be selected on asphalt pavement, concrete pavement, and concrete bridge deck. These evaluations are intended to assess the product adhesion properties and any improved skid resistance of the applied products.

Standard Practice for High-Friction Surface Treatment for Asphalt and Concrete Pavements, PP 79-16, American Association of State Highway and Transportation Officials, June 2016.
https://www.techstreet.com/standards/aashto-pp-79-14-r2016?product_id=1884965
From the document scope: This practice describes furnishing and applying a high-friction surface treatment (HFST) for asphalt and concrete pavements. The HFST is composed of a minimum of a single layer using a binder resin system and surface-applied aggregate. Binder resin systems include polymeric and methyl methacrylate resins.

"Step 1: Identify Candidate Curves for HFST," High Friction Surface Treatment Curve Selection and Installation Guide, Federal Highway Administration, May 2016.
Step 1 available at
https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/faqs_links_other/hfst_guide/ch1.cfm
Complete guide available at
https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/faqs_links_other/hfst_guide/
This guide provides a step-by-step process for identifying potential curves for HFST implementation. Step 1 of the process describes the criteria used for choosing suitable HFST sites, including high crash frequency, low pavement friction and pavement quality.

Focus State Roadway Departure Safety Plans and High Friction Surface Treatments Peer Exchange, Federal Highway Administration, August 2014.
https://rspcb.safety.fhwa.dot.gov/p2p_reports/peer_report_AL_Aug2014.pdf
From the introduction: On August 5 and 6, 2014, the FHWA Office of Safety and FHWA Resource Center convened representatives from seven States: Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, and Missouri. The purpose of this event was to facilitate the exchange of information between States regarding approaches to roadway departure (RwD) safety, including implementation of RwD Focus State Implementation Plans and High Friction Surface Treatments (HFST). The event consisted of a combination of presentations and facilitated discussions on rumble strips and stripes, curve delineation, HFST, and RwD Safety Implementation Plans. Refer to Appendix A for the content and agenda of the virtual peer exchange.

Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs, Raghavan Srinivasan and Karin Bauer, Office of Safety, Federal Highway Administration, September 2013.
https://safety.fhwa.dot.gov/rsdp/downloads/spf_development_guide_final.pdf
From the abstract: This guidebook is intended to provide guidance on developing safety performance functions (SPFs) from the Highway Safety Manual (HSM) (AASHTO, 2010). The guidebook discusses the process to develop jurisdiction specific SPFs. It is intended to be of use to practitioners at state and local agencies and to researchers.

Procedures for Setting Advisory Speeds on Curves, R. Milstead, X. Qin, B. Katz, J. Bonneson, M. Pratt, J. Miles, and P. Carlson, Federal Highway Administration, June 2011.
https://safety.fhwa.dot.gov/speedmgt/ref_mats/fhwasa1122/fhwasa1122.pdf
See page 23 of the report (page 30 of the PDF) for information about the ball-bank indicator method, one of several methods used to determine the curve advisory speed. Georgia and Indiana DOTs use this method to identify locations for HFST.

State Resources

Alaska

"High Friction Surface Treatment in the Last Frontier," Anna Bosin, Ron Martindale and Jeanne Bowie, Alaska Department of Transportation and Public Facilities, *Western Association of State Highway and Transportation Officials 2017 Annual Meeting*, 2017.
See Appendix A in the TRS Supplement.
This presentation provides an overview of HFST installations in Alaska. Included in the presentation are planning and crash analysis details, design and construction considerations, and post-construction analysis.

Georgia

Sharp Curve Treatment Process, Georgia Department of Transportation, undated.
See Appendix B in the TRS Supplement.
Details about Georgia DOT's process for determining curves that will receive HFST are provided in this two-page fact sheet.

Indiana

High Friction Surface Treatment Plans, Indiana Department of Transportation, 2018.
ftp://ftp.ragleinc.com/Indiana/..Archived%20Projects/Call%20730%20T-40130-A%20High%20Friction%20Surface%20Treatment/Plans/FT%20Plans%201400003%20for%20Contract%20Services.pdf
Page 3 of these plans provides application details for HFST installations on curves.

Iowa

Research in Progress: High Friction Surface Treatment for High Crash Locations, Iowa Department of Transportation, project start date: July 2014, expected completion date: September 2019.
http://www.intrans.iastate.edu/research/projects/detail/?projectID=2024370363
From the project description: The primary focus of [Phase I] is utilization of disparate data sets to develop site selection criteria, and ultimately identify candidate sites, for HFST application to improve traffic safety. … The Phase 2 effort focuses on evaluation of HFST as a mitigation strategy, which directly relates to the [Midwest Transportation Center] theme of data-driven performance measures for safety. The results of this project may establish a framework for determining which horizontal curves may be the best candidates for HFST, given the many other possible mitigation strategies available.

High Friction Surface Treatments: Not Just for Rural Curves, Federal Highway Administration, undated.
https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/case_studies_noteworthy_prac/iowa/hfst_ia_cs.pdf
Iowa DOT installed its initial HFST application in Cedar Rapids on a bridge over the Cedar River. The treatment was applied at a location where several ramps in close proximity fed traffic onto Interstate 380. This case study provides details about the project, including factors influencing HFST selection and results of the HFST implementation.

Data Shows High-Friction Pavement Treatment Improves Safety on I-380 Cedar Rapids, Transportation Matters for Iowa, Iowa Department of Transportation, February 7, 2014.
http://www.transportationmatters.iowadot.gov/2014/02/data-shows-high-friction-pavement-treatment-improves-safety-on-i-380-cedar-rapids.html
This brief summary of the I-380 HFST application in Cedar Rapids includes before and after installation data for a number of incidents, including crashes and road conditions.

Michigan

Wet Weather Crash Reduction Program, Michigan Department of Transportation, July 17, 2017.
See Appendix C in the TRS Supplement.
This document describes Michigan DOT's Wet Weather Crash Reduction Program, which has been collecting pavement friction data at three-year intervals from regions throughout the state. The document describes the program's structure, data analysis procedures and crash mitigation techniques. Two graphs illustrate the

number of test locations with an FN less than 30 and the number of wet-weather crashes per Michigan DOT region.

Pennsylvania

Map of Innovations, State Transportation Innovation Council, Pennsylvania Department of Transportation, undated.
http://www.dot7.state.pa.us/stic/index.html
This website features innovative projects in Pennsylvania's transportation system. An interactive map features products and techniques, including HFST locations, that have been implemented throughout the state.

Texas

Solutions for Saving Lives on Texas Roads, Texas Traffic Safety Task Force Report, Texas Department of Transportation, June 2016.
http://ftp.dot.state.tx.us/pub/txdot-info/trf/trafficsafety/saving-lives.pdf
In 2016, the Texas Traffic Safety Task Force developed a five-year plan to reduce fatalities and crashes in the state. The plan provides recommendations in two categories: highway safety engineering (including HFST installations on curves) and driver behavior education and enforcement. As part of the highway safety engineering recommendations, the task force recommends installing HFST on up to 1,000 curves with a wet-weather crash ratio higher than the statewide ratio (see page 16 of the report, page 20 of the PDF).

Wisconsin

High Friction Surface Treatments, Wisconsin Department of Transportation, undated.
http://wisconsindot.gov/Pages/safety/safety-eng/high-friction.aspx
This web page summarizes Wisconsin DOT's use of HFST as a strategy for improving traffic safety.

Aggregates and Binders

Respondents described the aggregates and binders used in their HFST installations and compared them with the materials used in other types of pavement treatments. Reponses are summarized below in three topic areas:

- Aggregates used in HFST.
- Binders used in HFST.
- Comparison of materials used in chip seals, microsurfacing and HFST.

Publications relating to the materials used for HFST and other pavement treatments appear in a **Related Resources** section that begins on page 20.

Aggregates Used in HFST

The aggregate used in HFST applications is often calcined (heat-treated) bauxite, a polish-resistant aggregate. A February 2018 FHWA online resource provides more information about this material:

- Several indigenous aggregates can initially improve the friction of a pavement surface. However, it is important to maintain a distinction between improved initial friction and the long-lasting friction benefit from a true HFST. This benefit comes from the use of calcined bauxite aggregate which is highly abrasion- and polish-resistant.
- Bauxite is a natural resource, mined in many countries, principally for its use in the production of aluminum. Calcined bauxite used for HFST is categorized as "non-metallurgical refractory grade" which

comes from high-quality bauxite that is calcined, or heat-treated, at 2900 to 3000°F, to produce a dense, high-purity, stable aggregate. Refractory grade calcined bauxite has a high-alumina (≥ 82 percent Al_20_3), low-alkali content (≥0.4 percent) and a bulk density of ≥ 3.0 with very low residual moisture levels.

- After the calcination process, the aggregate is subsequently crushed and sieved to a specific gradation to meet the specification requirements for HFST.
- Calcined bauxite has a resistance to polishing and wear that is superior to other aggregates.

(See **Related Resources** on page 13 for the citation for this February 2018 FHWA online resource.)

All respondents use calcined bauxite as the aggregate in their HFST installations. While Indiana DOT's HFST program now exclusively uses calcined bauxite aggregate, a research project initiated in 2017 is testing blast furnace slag (also referred to as "steel slag") as a possible alternate material (see **Related Resources** on page 20 for information about this research in progress). A research proposal has been submitted to Indiana DOT for a follow-on project for roadway skid testing and test installations using blast furnace slag to allow for direct comparison to calcined bauxite. As the respondent noted, "Indiana has several steel mills that produce both blast and arc furnace slag that potentially could provide similar friction values at a lower unit cost."

Pennsylvania DOT has also investigated other aggregate sources, but all tests have failed. Wisconsin DOT has defined a separate category for applications using alternate aggregates—enhanced friction surface treatment (EFST). An EFST is composed of aggregate in an asphaltic binder on hot-mix asphalt (HMA) or concrete pavements.

<u>Binders Used in HFST</u>

Binders used in HFST are typically epoxy or polymer resin. Respondents use both types of binder. The table below summarizes survey responses. (More details about the physical requirements of the binders used in respondents' HFST installations are provided in publications cited in **Related Resources** beginning on page 20 and in the **Specifications** section of this report on page 34.)

Binders Used in Respondents' HFST Installations

Binder Type	State	Description
Epoxy	Alaska, California, Illinois, Ohio, Tennessee	N/A
Polymer resin	Indiana, Iowa, Kentucky, South Dakota	*Indiana*. Two-part thermosetting polymer resin binder. *Iowa*. Two-part thermosetting polymer resin compound. *Kentucky*. Two-part polymer resin binder that holds the aggregate firmly in position.
Polymer resin or methyl methacrylate resin	Michigan, Pennsylvania	*Pennsylvania*. Binder suppliers can be found in Bulletin 15 (Publication 35), Qualified Products List for Construction (see **Related Resources** on page 21).
Unspecified resin	Georgia, Texas, Wisconsin	*Georgia*. Two-part modified exothermic resin binder containing a binder capable of retaining a skid-resistant calcined bauxite aggregate topping under vehicular traffic conditions. The binder must consist of a thermosetting compound that holds aggregate

Binders Used in Respondents' HFST Installations		
Binder Type	**State**	**Description**
		firmly in position. *Texas*. Binder resin system is typically composed of an epoxy or polymer resin. *Wisconsin*. Two-part thermosetting resin binder that is compatible with the pavement type, holds the aggregate firmly in place in a broad range of climates including below-freezing temperatures, and meets the requirements specified in the agency's specifications. A primer must be supplied if recommended by the resin binder manufacturer.

Comparison of Materials Used in Chip Seals, Microsurfacing and HFST

HFST is one of several pavement surfacing techniques transportation agencies use when managing pavements. Chip seals and microsurfacing are other examples of pavement surfacing treatments.

Chip seals are a "thin film of heated asphalt liquid sprayed on the road surface, followed by the placement of small aggregate ('chips'). The chips are then compacted to orient the chips for maximum adherence to the asphalt, and excess stone is swept from the surface. This protects the pavement from the effects of sun and water, increases skid resistance, fills small cracks and other surface defects" (see https://www.dot.state.mn.us/information/roads/chip-seal.html).

Microsurfacing is an advanced form of slurry seal developed to fill in wheel ruts in HMA. It uses the same basic ingredients as traditional slurry but combines these ingredients with advanced polymer additives.

Respondents using chip seals and microsurfacing were asked how the binders and aggregates used for chip seals and microsurfacing differ from the materials used for HFST. (All but the Alaska respondent reported using chip seals and microsurfacing.) Their responses are summarized below:

Differences in Purpose

- Chip seals and microsurfacing are used for pavement preservation, contrasted with HFST, which is used only to address safety in reducing crashes at spot locations (California).
- Material friction requirements and site selection for implementation differ. Chip seals and microsurfacing are typically performed for preventative maintenance (Kentucky).
- Chip seals and microsurfacing are used to seal a roadway, contrasted with HFST, which is used to add friction and can have road-sealing benefits (Pennsylvania).
- Chip seals and microsurfacing are used as a wearing course, not just to increase friction (South Dakota).
- Unlike HFST, chip seals and microsurfacing are used for pavement preservation (Tennessee).

Differences in Materials

- The binders used for chip seals and microsurfacing are asphalt emulsions. Regular fine and coarse aggregates are used, not the calcined bauxite used for HFST (Indiana).

- Microsurfacing binder is a blend of quick-set polymer, modified asphalt emulsion and latex-based polymer; the aggregate material for microsurfacing is crushed stone. This is contrasted with HFST binder, which is a two-part thermosetting polymeric resin; the aggregate material for HFST is calcined bauxite (Iowa).

Differences in Safety Performance

- Chip seals and microsurfacing may have fairly good FNs when placed and may produce some safety benefits, but these pavement surfaces polish over time and the FNs drop to the 30s in a short time. Contrast this with the calcined bauxite used in HFST, which resists polishing and retains a consistently high FN in the 60s (California).

Related Resources

State Resources

Illinois

Qualified Product List of High Friction Surface Treatment, Bureau of Materials and Physical Research, Illinois Department of Transportation, April 29, 2016.
See Appendix D in the TRS Supplement.
This document lists preapproved HFST materials (epoxy resin binder and calcined bauxite aggregation) and application vendors.

Submittal: High Friction Surface Treatment, Bureau of Materials and Physical Research, Illinois Department of Transportation, April 29, 2016.
See Appendix E in the TRS Supplement.
These guidelines describe the submittal requirements for manufacturers of HFST materials (epoxy resin binder and calcined bauxite aggregation) and application vendors.

Chapter Fifty-Two: Pavement Preservation, Bureau of Design and Environment Manual, Illinois Department of Transportation, September 2010.
https://idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Split/Design-And-Environment/BDE-Manual/Chapter%2052%20Pavement%20Preservation.pdf
Pavement preservation strategies, including specifications for surface treatments, are provided in this chapter.

Indiana

Research in Progress: SPR-4164: Blast Furnace Slag Usage and Guidance for Indiana, Indiana Department of Transportation, start date: May 2017, expected completion date: not specified.
https://engineering.purdue.edu/JTRP/projects (scroll down to find the project number)
From the website: The objective of the proposed research is to understand the extent of blast furnace slag (BFS) usage for completed INDOT projects, factors that control BFS leaching, review and recommend remediation strategies, and identify applications where future usage restrictions or sitting criteria are needed, if any. Completion of this project will equip INDOT staff with information to make decisions about future BFS usage.

Standard Specifications, Indiana Department of Transportation, 2018.
http://www.in.gov/dot/div/contracts/standards/book/sep17/2018Master.pdf
Section 404, Seal Coat (page 295 of the report, page 377 of the PDF), and Section 411, Warranted Micro-Surfacing (page 321 of the report, page 403 of the PDF), include information about the aggregates and binder used for chip seals and microsurfacing, respectively.

Friction Surface Treatment Selection: Aggregate Properties, Surface Characteristics, Alternative Treatments and Safety Effects, Shuo Li, Rui Xiong, Demei Yu, Guangyuan Zhao, Peiliang Cong and Yi Jiang, Indiana Department of Transportation, July 2017.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3173&context=jtrp
From the abstract: This study aimed to evaluate the long term performance of the selected surface friction treatments, including high friction surface treatment (HFST) using calcined bauxite and steel slag, and conventional friction surfacing, in particular pavement preservation treatments such as chip seal, microsurfacing, ultrathin bonded wearing course (UBWC), and diamond grinding. This study also attempted to determine the correlation between vehicle crash and pavement surface friction, which makes it possible to quantitatively establish the so-called crash modification factors (CMFs) that are extremely useful in selecting a cost-effective solution to reduce wet pavement vehicle crashes.

Special Provision 617-T-213 High Friction Surface Treatment, Indiana Department of Transportation, May 19, 2016.
http://www.in.gov/dot/div/contracts/standards/rsp/sep17/600/617-T-213%20170101.pdf
Section 617.02 of this special provision provides the material property requirements of calcined bauxite aggregate and polymeric resin binder used in HFST installations on asphalt or concrete pavement.

Pennsylvania

Bulletin 15: Qualified Products List for Construction, Pennsylvania Department of Transportation, March 1, 2018.
http://www.dot.state.pa.us/public/pdf/BOCM_MTD_LAB/PUBLICATIONS/PUB_35/Current_Edition/Bulletin15.pdf
Bulletin 15 describes prequalified materials that may be used in Pennsylvania DOT construction projects. Section 659 (page 96 of the report) lists qualified binder and aggregate products for HFST installations.

eCAMMS, Materials Lab, Pennsylvania Department of Transportation, undated.
https://www.ecamms.pa.gov/Public/Pages/Bulletins/BulletinSearch.aspx?BulletinTypeKey=2
Pennsylvania DOT's eCAMMS website allows contractors to search for approved construction materials and binder products using various criteria, including product trade names.

Texas

Standard Specifications for Construction and Maintenance of Highways, Streets and Bridges, Texas Department of Transportation, November 2014.
ftp://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf
Included in this document are the agency's specifications for microsurfacing (page 368 of the report, page 378 of the PDF).

Wisconsin

Section 5—Seal Coat, Special Provision, Wisconsin Department of Transportation, 2018.
See Appendix F in the TRS Supplement.
From the description: This section describes applying asphaltic material, aggregate cover, and fog seal on a previously completed asphalt surface.

Asphaltic Binder Enhanced Friction Surface Treatment, Project Special Provisions and Support, Quality Management Program, Wisconsin Department of Transportation, undated.
http://wisconsindot.gov/Documents/doing-bus/eng-consultants/cnslt-rsrces/tools/qmp/asphtefst.pdf
From the description: This special provision describes providing an enhanced friction surface treatment (EFST) composed of aggregate in an asphaltic binder on HMA or concrete pavements.

Friction Requirements

Respondents described their agencies' friction requirements (also referred to as skid resistance) for two types of pavements—HMA and HFST—using two types of values:

- Friction numbers (FNs).
- Dynamic friction tester (DFT).

A November 2008 National Cooperative Highway Research Program (NCHRP) report addressing the texturing of concrete pavements describes both friction measurement methods, beginning with a description of the test method used to generate FNs and the indices used to quantify friction (see page A-10 of the report, page 18 of the PDF):

> The most common method for measuring highway friction in the U.S. is the ASTM E 274 locked-wheel testing equipment, with some variations in test speed and tire properties. This method simulates braking without using anti-lock brakes (Henry, 2000). … Indices used in the U.S. for quantifying friction include FN at 40 mi/hr (64 km/hr) (ASTM E 274) using ribbed (ASTM E 501) or smooth (ASTM E 524) testing tires. These indices are designated as FN40R and FN40S by AASHTO specifications (SN40R and SN40S by ASTM specifications). When the speed number is in metric units (km/hr), the number is placed in brackets (e.g., FN(64)R) (Henry, 2000).

The same NCHRP report describes DFT, a test method that was gaining acceptance at the time of publication (see page A-10 of the report; page 18 of the PDF):

> The Dynamic Friction Tester (ASTM E1911) is gaining acceptance and provides more information because it allows measuring friction as a function of speed over the range from 0 to 56 mi/hr (0 to 90 km/hr) (Flintsch et al., 2002). The DFT measured at 12.5 mi/hr (20 km/hr) correlates well with BPN [British Pendulum Number], as shown in figure A-8 (Henry, 2000). Friction measurement using a ribbed test tire does not adequately assess road macro-texture, because their grooves allow for removal of water at the pavement–tire interface, eliminating the need for good road macro-texture (Henry, 2000).

(See **Related Resources** on page 25 for a citation for this November 2008 NCHRP publication.)

The table below summarizes the friction requirements reported by respondents for HMA and HFST pavements using FN and DFT values. Few respondents offered friction requirements for HMA, with values ranging from 30 FN to 50 FN and 0.30 DFT. More respondents offered values for HFST, with 65 FN most common (ranging up to 75 FN); DFT values ranged from 0.75 DFT to 0.90 DFT.

Respondents' Friction Requirements			
State	**Skid Resistance Required of HMA (FN or DFT)**	**Skid Resistance Required of HFST (FN or DFT)**	**Description**
Alaska	Not provided	0.75 DFT	*HFST skid resistance*. The agency consistently records close to 1.0 DFT post-construction.
California	0.30 DFT (minimum)	0.75 DFT (minimum)	N/A
Georgia	Not provided	0.90 DFT (after 5 days) 0.80 DFT (after 90 days)	N/A
Illinois	Not specified[1]	0.90 DFT (minimum) 72 FN (minimum)	*HFST skid resistance*. Testing thus far has demonstrated that the installed products are meeting the requirements of the agency's special provision. Results are not final and have not been released.
Indiana	50 FN (new surfaces)	0.90 DFT (minimum) 72 FN (minimum)	*HFST skid resistance.* Requires 0.90 DFT for calcined bauxite, 0.65 DFT for steel slag.
Iowa	Not provided	65 FN	*HFST skid resistance.* FN data is gathered within 90 days of construction in accordance with ASTM E274.
Kentucky	Not provided	75 FN (minimum)	*HFST skid resistance.* Aggregate must meet specified polish resistance (the required certification form is available at https://transportation.ky.gov/Organizational-Resources/Forms/TC%2064-763.pdf).
Michigan	Wet surface friction of at least 30 FN	Wet surface friction of at least 30 FN	See the agency's Wet Weather Crash Reduction Program in Appendix C in the TRS Supplement.
North Dakota	Not provided	Not provided	N/A
Ohio	Not required[2]	Not required[3]	N/A
Pennsylvania	Above 30 FN is acceptable	70 FN or greater (pay 100%) 65 to 69 FN (pay 90%) Less than 65 FN (not acceptable)	*HFST skid resistance.* See Publication 408: Specifications (page 484 of the PDF) in the **Specifications** section of this report for further details.
South Dakota	Not required	65 FN	N/A
Tennessee	Not published	70 FN (minimum)	*HFST skid resistance.* The agency uses the FN40R index in accordance with ASTM E274.
Texas	Not required	65 FN	*HFST skid resistance.* The agency uses the FN40R index in accordance with ASTM E274.

Respondents' Friction Requirements			
State	**Skid Resistance Required of HMA (FN or DFT)**	**Skid Resistance Required of HFST (FN or DFT)**	**Description**
Wisconsin	Not required	Not required	*HFST skid resistance*. Current friction values are used to supplement crash data to identify eligible sites. The agency is updating its specifications.

1 Illinois DOT has higher friction mix designs that optimize friction based on the type, angularity, size and polishing resistance of the aggregate. Pavements are evaluated with a friction tester using treaded and smooth tires to establish friction values. Those values are used to monitor pavement performance.

2 While not a requirement, Ohio DOT generally expects new HMA surfaces to have ASTM E501 (ribbed tire) FNs at 40 mph in the mid-40s or higher; ASTM E524 (smooth tire) FNs at 40 mph are expected to be in the high 20s to low 30s or higher.

3 Ohio DOT does not require skid testing of new HFST surfaces. Such testing is at the discretion of the Ohio DOT project engineer and is encouraged if there is evidence of poor quality application or materials (loss of bauxite chips, evidence of epoxy without chips, or lack of uniformity in appearance). In these cases, the agency expects a value of 75 FN or greater using the ASTM E501 testing protocol (ribbed testing tires) at 40 mph. The respondent noted that "[w]e have never seen a problem with new HFSTs constructed in a quality manner. Testing these surfaces really eats up your test tires."

Friction Testing Practices

Two respondents provided information about their agencies' friction testing practices:

HMA Friction Testing

- *Indiana DOT* conducts pavement friction skid trailer testing every year on interstate highways and rotates testing every three years on state and U.S. routes. An FN of 20 or less prompts the agency to immediately begin planning an "intervention project." Under the agency's asset management system, locations with FNs between 20 and 25 will prompt the inclusion of resurfacing projects with a priority ranking in a future year's work plan.
- *Pennsylvania DOT* conducts skid trailer testing during roadway maintenance. Action points for skid trailer tests include:
    - FNs of 20 or below require action to resurface the pavement and placement of "slippery when wet signs" until the location is resurfaced.
    - FNs of 21 to 30 warn of areas that require additional skid tests and prompt crews to resurface the areas as soon as possible. "Slippery when wet signs" signs are also installed.
    - FNs of above 30 are acceptable.

  Skid tests for most HMA or warm mix asphalt result in FNs in the high 40s to low 50s.

HFST Friction Testing

- *Indiana DOT* obtained its recommended values for HFST specifications through lab testing using a three-wheel polishing and test strip for traffic polishing. The respondent expects this practice to be modified after installation and testing of the agency's first HFST projects.

Related Resources

National Resources

Texturing of Concrete Pavements, Final Report Appendixes A-F, National Cooperative Highway Research Program, November 2008.
http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_634appendixes.pdf
This report includes a discussion of methods and equipment for measuring friction (see page A-10 of the report, page 18 of the PDF).

ASTM E274/E274M-15, Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire, ASTM International, 2015.
https://www.astm.org/Standards/E274.htm
From the abstract: This test method establishes the standard procedure for measuring the skid resistance of paved surfaces by the use of a specified full-scale automotive tire. This test method utilizes a measurement representing the steady-state friction force on a locked test wheel as it is dragged over a wetted pavement surface under constant load and at a constant speed while its major plane is parallel to its direction of motion and perpendicular to the pavement. The values measured represent the frictional properties obtained with the equipment and procedures stated herein.

ASTM E501-08(2015), Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests, ASTM International, 2015.
https://www.astm.org/Standards/E501.htm
From the abstract: This specification covers the general requirements for the standard rib tire for pavement skid-resistance testing. The tire covered by this specification is for use in evaluation of tire-pavement friction. The fabric shall be polyester body or carcass plies and fiber glass belt plies. Different tests shall be conducted in order to determine the following properties of tread compound: tensile sheet cure, modulus, specific gravity, tensile strength, elongation, and tire tread durometer.

ASTM E524-08(2015), Standard Specification for Standard Smooth Tire for Pavement Skid-Resistance Tests, ASTM International, 2015.
https://www.astm.org/Standards/E524.htm
From the abstract: This specification covers the general requirements for the standard smooth tire for pavement testing. The tire covered by this specification is intended for evaluation of tire-pavement friction. The tires shall conform to the physical and mechanical test requirements. The following test methods shall be performed: tensile sheet cures; modulus; tensile sheet durometer; restored energy (rebound and resilience); specific gravity; tensile strength; elongation; and tire tread durometer.

Effectiveness

For those respondents able to address the effectiveness of their HFST installations, six indicated that HFST has proved to be very effective or is performing well or very well (California, Georgia, Ohio, Pennsylvania, Tennessee and Wisconsin). The Kentucky respondent noted that performance varies by site. Only one state (Alaska) reported signs of early wear on HFST sites. It is too early to draw conclusions in five states (Illinois, Indiana, Iowa, Michigan and Texas). The following table summarizes responses.

Respondents' Assessment of the Effectiveness of HFST		
Assessment of Effectiveness	**State**	**Description**
Very effective	California, Georgia, Ohio, Pennsylvania	*California*. The respondent noted that HFST has proved to be "very effective in reducing crashes," citing a location on State Route 17 referred to as "Laurel Curve" in the San Francisco Bay Area. This area experienced 52 crashes per year, with 47 of those crashes in wet pavement conditions. In the three years after placement of HFST, crashes dropped to less than three per year; wet pavement crashes dropped to less than one per year. *Georgia*. While the respondent believes the treatment has been "very effective," the agency does not have data to support that conclusion at this time. *Ohio*. The respondent noted that "HFST has been very effective in the areas it has been installed. As you know, it drastically raises the skid numbers, so we usually never see a problem after [installation]." *Pennsylvania*. HFST installations have been "very effective," with 110 HFST project locations planned for various highways in Pennsylvania.
Performing well or very well	Tennessee, Wisconsin	*Tennessee*. Most HFST locations have performed "very well." *Wisconsin*. HFST "is performing well for maintaining the friction number (FN40R by ASTM E274, ribbed tire) for at least six years."
Varied performance	Kentucky	Some HFST sites perform better than others.
Wear visible after one year	Alaska	The respondent noted that wear after one year was "substantial visually, [and] dynamic friction test values show significant wear in locations that are high speed, high AADT [annual average daily traffic]." The agency has also noticed "spot wear" on lower-volume roads.
Too early for a determination	Illinois, Indiana, Iowa, Michigan, Texas	*Illinois*. The agency is still evaluating HFST and is waiting for the availability of five years of post-installation crash data to evaluate effectiveness. *Indiana*. With no HFST installations completed at the time of publication, the agency has no data on effectiveness. *Iowa*. The agency is "still studying its performance." *Michigan*. Before-and-after studies are not available given the recency of HFST installations. *Texas*. Installations are too recent (2015) to assess effectiveness.

Safety Performance

In addition to addressing the effectiveness of their HFST installations, seven of the 10 respondents reporting the availability of before-and-after crash data described specific safety-related results:

California. The respondent noted that other HFST locations have proved to be as effective as the project described in the table above in terms of the reduction of crashes for each location. A formal before-and-after study of HFST sites may be conducted now that the agency has access to at least three years of after-installation crash data for many locations.

Kentucky. Naive analysis (a method based on simple arithmetic and elementary randomization) shows an approximate 70 percent reduction in targeted crashes over all sites.

Michigan. A December 2013 Michigan DOT report describes five HFST locations installed as part of a 2010 FHWA pilot and five other locations installed in 2007 and 2008 as contractor demonstrations. An overall reduction for all crashes of 33.78 percent was reported for all 10 HFST sites; wet crashes were reduced by 61.31 percent. An analysis calculated the overall and wet crash reductions and increases for state trunklines within the county where each HFST installation is located. Overall crashes in the corresponding counties had an average crash reduction of 8.54 percent and a wet crash reduction of 10.08 percent. The authors note that "[a]lthough not statistically significant due to the number of test locations and the before/after crash data, the high friction surface did provide a reduction of overall and wet crashes."

Pennsylvania. Below is an excerpt from the 2017 AASHTO Safety Leadership Award Nomination for Pennsylvania DOT that describes the HFST program's success as a safety countermeasure (see **Related Resources** on page 29 for this citation):

> PennDOT began installation of High Friction Surface Treatments (HFST) in June of 2007. In 2012 & 2013 PennDOT installed HFST at another 18 locations. These pilot efforts were so successful in reducing crashes that it has led to a total of 181 total HFST locations in Pennsylvania to date with another 118 planned. Locations for the application of [an] HFST have been mostly curves with crash cluster histories of wet road crashes, single vehicle run-off-road crashes (SVROR) and hit fixed object (HFO) crashes. Eighteen of the original locations have been evaluated over a four[-year] period and have shown dramatic improvements. The four years prior to the HFST installation these 18 locations had a total of 190 wet pavement crashes, which included 3 fatalities and 122 injuries of various severity. The four years after shows the total wet road crashes dropped to 15 which resulted in zero fatalities and only 13 injuries of various severity. This is a 100% reduction in fatalities and almost a 90% decrease in fatalities & injuries. When looking at the SVROR crashes at these same locations there were 197 SVROR crashes in the four years before with 6 fatalities and 95 injuries of various severity. The four years after installation show the total SVROR crashes dropped to 23. Fatalities dropped to zero and all other injuries to 20. The SVROR crashes across the entire state shows the statewide 5-year average of 49,660 in 2006-2011 when only one HFST location was in place. For 2012-2016 there are now an average of 46,661 SVROR crashes over 5 years with 181 HFST locations in place. HFST has become one of the best safety countermeasures for wet roads crashes and SVROR crashes in Pennsylvania.

South Dakota. The agency has three years of crash history for four horizontal curves with HFST. An 86 percent reduction in winter road condition RwD crashes was recorded at these locations after installation of HFST. When applying a Winter Severity Index, which takes into account the number of "winter weather" days, the adjusted crash reduction is 77 percent.

Tennessee. The respondent provided a November 2017 conference presentation (see Appendix H in the TRS Supplement) that described the agency's use of HFST as a safety treatment. The table below summarizes the accident reduction described in that presentation.

Accident Reduction on Curves (Tennessee Department of Transportation)					
Location/Time Period	Total Crashes	# Fatal Crashes	# Serious Injury Crashes	# Lane Departure Crashes	# Wet-Weather Crashes
Davidson County (I-440)					
Three years before installation	31	1	0	31	31
Seven years after installation	1	0	0	1	1
Cocke County (LR 01326)					
Unspecified years before installation	10	0	1	7	4
Unspecified years after installation	4	0	0	3	1
Cheatham County (SR 249)					
Three years before installation	6	0	0	1	1
Three years after installation	0	0	0	0	0

Wisconsin. The agency installed HFST on the Marquette Interchange West to North ramp in September 2011. In the two years and 10 months *before* application of HFST, there were 219 crashes at that location. In the two years and 11 months *after* HFST application, there were nine crashes—a 95 percent reduction in crashes for the location (see Appendix I in the TRS Supplement).

While the Alaska respondent noted that the data needed to complete a formal before-and-after safety analysis is not available, the respondent did describe a single "drag skid test" conducted by law enforcement personnel during a black ice weather condition. In this test, stopping distance was reduced by 34 feet on the HFST section versus the nontreated section.

Two states—Iowa and Texas—do not have enough after-installation crash data to determine effectiveness. Three states—Georgia, Illinois and Indiana—are not using before-and-after crash data to assess HFST installation sites, though the Illinois and Indiana respondents reported interest in doing so. The Illinois respondent elaborated on this interest:

> Illinois DOT is still evaluating HFST and is waiting for a preferred five years of post-installation data to conduct its analysis. Preliminary post-installation data shows a reduction in severe injury and roadway departure crashes at most locations, though a few have had a slight increase. However, data is still incomplete. The agency's earliest HFST project was completed in July 2014 at the I-74/I-57 interchange. Some post-project data (a minimum of three to five years) will become available for project locations over the next 24 months.

Related Resources

National Resources

Evaluation of Pavement Safety Performance, David K. Merritt, Craig A. Lyon and Bhagwant N. Persaud, Federal Highway Administration, February 2015.
https://www.fhwa.dot.gov/publications/research/safety/14065/14065.pdf
From the abstract: The intent of this study was to isolate the effects of various low-cost pavement treatments on roadway safety. This was a retrospective study of pavement safety performance, looking back at crash data before and after treatments were installed. Both flexible and rigid pavement treatments were analyzed, with the majority typically used for pavement preservation or minor rehabilitation purposes. Although State highway agencies recognize that most of these treatments generally improve pavement friction, they are not typically installed explicitly for safety improvement, with one exception, high-friction surfacing, which is typically applied as a spot safety treatment.

State Resources

Michigan

High Friction Surfaces, Michigan Department of Transportation, December 1, 2013.
See Appendix G in the TRS Supplement.
This report describes the installations of 10 pilot HFST projects in Michigan from 2007 through 2010. Information includes materials used, site eligibility criteria and before-and-after crash data.

Pennsylvania

2017 AASHTO Safety Leadership Award Nomination for Pennsylvania DOT, Pennsylvania Department of Transportation, undated.
https://safety.transportation.org/wp-content/uploads/sites/17/2017/03/Pennsylvania-2017-AASHTO-Safety-Leadership-Award-Nomination.docx
This nomination for an AASHTO safety leadership award includes a description of the safety impacts of Pennsylvania DOT's HFST installations.

"Safety Impact of High Friction Surface Treatment Installations in Pennsylvania," Kimberley Musey, Seri Park and Monica Kares, *TRB 96th Annual Meeting Compendium of Papers*, Paper #17-02448, 2017.
http://docs.trb.org/prp/17-02448.pdf
From the abstract: Each year, thousands of drivers in the United States are involved in motor vehicle crashes. In order to address this issue, transportation professionals have continued to investigate countermeasures to improve roadway safety including high friction surface treatments (HFSTs). This treatment maximizes the existing infrastructure, and provides exceptional skid resistance in spot locations where friction demand is critical, such as intersection approaches or horizontal curves.

Since the early 2000s, there has been an increase in state HFST installation projects. This research seeks to evaluate the performance of HFST installation projects in the state of Pennsylvania from both a safety and economic perspective. Using project construction and crash data provided by the Pennsylvania Department of Transportation (PennDOT), it reviews how effective the installations were in reducing both crash rates and crash severity through a before-after and benefit-cost study of over 70 sites. The results of these two investigations show that Pennsylvania received the greatest reduction in crash number and severity as well as the greatest return on investment for intersections on horizontal curves that are located in an urban environment.

Tennessee

"Use of High Friction Surface Treatments," Danny Lane, Tennessee Department of Transportation, 2017 Infrastructure Maintenance Symposium, November 2017.
See Appendix H in the TRS Supplement.
Tennessee DOT's use of HFST as a safety treatment is summarized in this presentation. Highlights include installations at various locations around the state, product evaluations and the application process.

Wisconsin

Marquette Interchange West to North Ramp Crashes Before & After High Friction Surface Treatment (HFST), Wisconsin Department of Transportation, August 30, 2017.
See Appendix I in the TRS Supplement.
Before-and-after crash data plotted in this graph shows a 95 percent reduction in wet-weather crashes on this interstate ramp.

Durability

Respondents assessed the durability of their HFST installations in three topic areas:

- HFST as compared to standard roadway surfaces.
- Durability of aggregate surfaces.
- Impacts of snowplowing on HFST.

HFST as Compared to Standard Roadway Surfaces

Five respondents reported positively on the durability of HFST as compared to standard roadway surfaces:

- While some HFST sites installed in 2010 are still providing adequate coverage and friction performance, durability depends on the condition of the underlying pavement. Pavement that is less than five years old will typically hold up for five to seven years after installation (Kentucky).
- HFST applications have lasted at least eight years, which is similar to a normal resurfacing cycle (Pennsylvania).
- Four curve sites were installed with HFST more than three years ago. These surfaces are "holding up very well to traffic and snowplows" (South Dakota).
- HFST has performed "very well" for concrete and asphalt pavements. For concrete above grade, the agency places two lifts, and those installations have performed "extremely well" (Tennessee).
- An HFST site that is 6.5 years old is still performing well and maintaining "good FN40R," with an average 70 FN measured in 2017 (Wisconsin).

Other respondents reported on factors that appear to affect the durability of HFST, with several focusing on preparing the pavement for installation and the condition of the pavement surface accepting the HFST:

- HFST locations hold up "very well" as long as the preparatory work and installation are conducted according to agency specification, which requires that HFST be placed by machine automation. A premature failure in the Fresno district was determined to be caused by failure to ensure a clean pavement surface before installing the HFST. As a result, patches of the calcined bauxite and epoxy started "popping out" (California).

- While durability is still being evaluated, the agency has noted some failures that are attributed to poor installation practices (Georgia).
- Overall, installations have proved to be durable. One site has presented issues, most likely due to flawed installation practices (Illinois).
- HFST is not a good treatment choice if the existing surface is not relatively new and in good condition. If existing surface conditions are taken into consideration and effective installation practices are used, the agency has seen good performance. Some surfaces have lasted 10 years or more in high-stress locations (Ohio).

The Alaska respondent reported that HFST installations have not proved to be durable, showing wear after one winter. For other states, it's too early to know about durability:

- Iowa DOT is currently studying the durability of its HFST sites.
- In Texas, the first HFST installation was completed in 2015. The agency estimates a five-year service life.

Durability of Aggregate Surfaces

Respondents were asked to describe the durability of aggregate surfaces for two types of pavement treatments:

- HMA.
- HFST.

Some respondents described the durability of aggregate surfaces in terms of an expected service life (in years). (More than half of respondents did not provide any data.) Generally, when data is available, respondents expect a longer service life from aggregate surfaces in HMA than HFST. Consistent with other respondent feedback presented in this report, several respondents highlighted the significance of the underlying pavement or subsurface as a contributing factor in the life of HFST. The table below summarizes survey responses.

Expected Service Life of Aggregate Surfaces (in Years)

State	Expected Service Life of Aggregate Surfaces in HMA	Expected Service Life of Aggregate Surfaces in HFST	Description
Alaska	Not provided	3	*HFST service life.* The agency hopes for a three-year service life but is skeptical of achieving it.
California	20	10 (minimum)	*HFST service life*. HFST "is only as good the pavement underneath it. So goes your pavement, so goes HFST."
Georgia	7 to 10	Not provided	*HFST service life*. The agency expects the surface to last as long as the subsurface; still under evaluation.
Illinois	Not provided	10	*HFST service life*. The agency requires use of calcined bauxite to optimize the durability of the surface aggregate.
Indiana	No requirement	No requirement	*HMA service life*. No current requirement for durability. For warranty pavement projects, the

Expected Service Life of Aggregate Surfaces (in Years)			
State	**Expected Service Life of Aggregate Surfaces in HMA**	**Expected Service Life of Aggregate Surfaces in HFST**	**Description**
			agency may specify a requirement of three to five years, with a 35 FN. *HFST service life.* No current requirement for durability. The agency plans to conduct testing approximately 90 days after construction. A durability requirement is likely after proposed staged testing on the initial HFST projects has been completed.
Iowa	20	10	N/A
Kentucky	Not provided	Not provided	N/A
Michigan	Not provided	Not provided	N/A
Ohio	Not provided	Not provided	N/A
Pennsylvania	Not provided	Not provided	See Publication 408 in the **Specifications** section of this report for construction specifications.
South Dakota	Varies	12 to 15	*HMA service life*. The agency uses a mix of quartzite and limestone, which varies widely with regard to durability. *HFST service life*. Durability is dependent on the surface of the underlying pavement.
Tennessee	8 (interstates) 12 (state routes)	Up to 10	*HFST service life*. The agency expects these pavements to last at least as long as asphalt pavements and up to 10 years for concrete double lift pavements.
Texas	10	5	*HMA service life*. The agency specifies durable particles but not service life in its HMA specifications. *HFST service life*. The agency does not specify durability or service life in its pavement specifications.
Wisconsin	Not provided	Not provided	N/A

Impacts of Snowplowing on HFST Installations

All but two respondents with enough experience to determine the impacts of snowplowing on HFST installations reported that the surface treatment has performed acceptably or held up "very well." Two agencies identified limited impact, and five agencies do not have enough experience with snowplowing or lack data to determine its impact. The following table summarizes responses.

Impacts of Snowplowing on HFST Installations		
Assessment of Performance	**State**	**Description**
Holding up very well	California, Illinois, Pennsylvania, South Dakota, Tennessee	*California*. Most HFST locations are not in areas receiving snow; however, in locations where HFST is placed and snowplowing occurs, it has held up "very well," with some wear due to snow chains. The agency avoids installing HFST in locations where snow chains are frequently used or required, especially across the Sierra Nevada mountain pass on I-80 and the Siskiyou mountain pass on I-5. *Pennsylvania*. Several locations are in high-traffic volume areas and the HTST "has not been scraped away for several years." *Tennessee*. The respondent noted that "HFST has held up very well, for as much as we plow."
Acceptable performance	Illinois, Ohio, Wisconsin	*Illinois*. The respondent reported a few remarks from plow drivers that blades are "wearing out," but the agency has no data that supports this claim. *Ohio*. If good existing conditions were present and quality installation practices observed when the HFST was installed, the agency has "not seen poor performance with respect to snow and ice removal operations." *Wisconsin*. The agency has "not noticed any deterioration from plowing."
Limited impact	Alaska, Kentucky	*Alaska*. Plowing hasn't made as much of an impact as studded tires. To date, wear has been seen within the tire tracks. *Kentucky*. The agency has noted minor damage but has not identified any major damage as the direct result of plowing. The respondent advises other agencies to avoid the use of rubber-tipped blades to plow HFST, noting that HFST "will eat the rubber off the plows."
Impact unknown or no data	Georgia, Indiana, Iowa, Michigan, Texas	*Georgia*. The agency doesn't plow enough snow to make a good determination. *Indiana*. No data available. *Iowa*. The agency does not yet know how well HFST will stand up to snowplowing (it was installed less than one year ago). *Texas*. No data available.

Specifications

This section includes specifications, special provisions and contract notes associated with respondents' use of HFST. Additional specifications, guidance and other HFST program details appear in **Related Resources** sections throughout this report.

Alaska

Work Plan for High Friction Surface Treatment Material Monitoring Project, Anna Bosin, Alaska Department of Transportation and Public Facilities, December 2015.
See Appendix J in the TRS Supplement.
This work plan provides the scope of Alaska's first HFST highway application. Included are pre- and post-construction monitoring and evaluation materials.

HSIP: CR High Friction Surface Treatment, Project No. 0001501/Z570920000, Central Region, Alaska Department of Transportation and Public Facilities, November 10, 2015.
See Appendix K in the TRS Supplement.
These specifications provide various contract materials for HFST installations at numerous sites in Alaska's Central Region.

Proposed Highway Project HSIP: CR High Friction Surface Treatment, Project No. 0001501/Z570920000, Central Region, Alaska Department of Transportation and Public Facilities, November 2015.
See Appendix L in the TRS Supplement.
This document provides plan details and drawings for HFST installations at numerous sites in Alaska's Central Region.

California

Section 37-7 High Friction Surface Treatment, Contract Specifications, Caltrans, July 2017.
Appendix M in the TRS Supplement.
From the summary: Section 37-7 includes specifications for applying high friction surface treatment (HFST).

Georgia

Section 419—High Friction Surface Treatment, Special Provision, Georgia Department of Transportation, July 17, 2017.
See Appendix N in the TRS Supplement.
From the special provision: This work includes furnishing and installing a textured, high friction surface treatment (HFST) system in accordance with this Section and in conformity with the lines and details shown on the plans.

Illinois

Special Provision for High Friction Surface Treatment, Illinois Department of Transportation, March 10, 2017.
See Appendix O in the TRS Supplement.
From the description: This work shall consist of constructing an experimental High Friction Surface Treatment (HFST) on a hot-mix asphalt (HMA) or portland cement concrete (PCC) pavement surface to restore or enhance the skid resistance. The HFST shall be composed of calcined bauxite aggregate bound with an epoxy resin.

Indiana

"INDOT High Friction Surface Treatment Special Provision," Joe Bruno, Indiana Department of Transportation, March 2016.
https://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=3947&context=roadschool
This presentation provides a concise summary of the special provision related to HFST.

Iowa

Special Provisions for High Friction Surface Treatment, Iowa Department of Transportation, June 20, 2017.
https://iowadot.gov/specifications/provisions/2015/SP-150282b.pdf
This special provision describes Iowa DOT's standard specifications for HFST installations.

Kentucky

Special Note for Polymer Concrete Overlay Systems, Kentucky Transportation Cabinet, April 6, 2017.
See Appendix P in the TRS Supplement.
This document provides the materials and construction specifications for HFST installations.

Standard Specifications for Road and Bridge Construction, Kentucky Transportation Cabinet, June 2012.
https://transportation.ky.gov/Construction/Standard%20amd%20Supplemental%20Specifications/Complete%20KYTC%20Standard%20Specifications-2012.pdf
This document includes materials and construction specifications for pavement projects in Kentucky.

Michigan

Special Provision for High Friction Surface Treatment, Michigan Department of Transportation, July 2016.
https://mdotcf.state.mi.us/public/dessssp/spss_source/12SP-800A-03.pdf
This special provision describes the materials and construction specifications for HFST installations in Michigan.

Ohio

690 Special Misc: High-Friction Epoxy Aggregate Surface Treatment, Ohio Department of Transportation, December 16, 2013.
See Appendix Q in the TRS Supplement.
These general notes provide the materials and construction specifications for HFST installations in Ohio.

Pennsylvania

Publication 408: Specifications, Pennsylvania Department of Transportation, October 2016.
http://www.dot.state.pa.us/public/PubsForms/Publications/Pub_408/408_2016/408_2016_3/408_2016_3.pdf
This publication includes the construction specifications for Pennsylvania DOT projects.

- Section 659, High Friction Surface Treatment (HFST) (page 480 of the PDF) describes the materials and construction specifications for HFST installations in Pennsylvania.
- Section 659.2 (page 480 of the PDF) provides binder and aggregate specifications.
- Table 6 in Section 659.3.h (page 484 of the PDF) provides the skid numbers required at HFST sites.

Publication 242: Pavement Policy Manual, Change No. 2, Pennsylvania Department of Transportation, May 2015.
https://www.dot.state.pa.us/public/PubsForms/Publications/PUB%20242.pdf
This manual addresses all issues related to pavement design, including maintenance criteria. Chapter 5 briefly addresses HFST installations (page 82 of the PDF).

South Dakota

Special Provision For High Friction Surface Treatment: Project PH 00SW(43), PCN 05H9, Fall River, Lawrence, Meade, and Pennington Counties, South Dakota Department of Transportation, January 3, 2017.
http://apps.sd.gov/HC65C2C/EBS/lettings/specprov/05H9_SpecProv.pdf
This document describes the requirements for HFST installations in several South Dakota counties. The special provision for HFST (pages 18 through 28 of the PDF) includes details about the polymeric resin binder and skid resistance requirements.

Tennessee

Special Provision Regarding High Friction Surface Treatments (HFST), Tennessee Department of Transportation, January 1, 2015.
https://www.tn.gov/content/dam/tn/tdot/construction/special-provisions/Const-406HFST.pdf
These specifications address HFST requirements for use on asphalt and concrete pavements.

Texas

Special Specification 3037: High Friction Surface Treatment, Texas Department of Transportation, November 2017.
ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/specs/2014/spec/ss3037.pdf
This document describes Texas DOT's standard specifications for HFST installations.

Wisconsin

Resin Binder High Friction Surface Treatment, Item SPV.0180.XX, Wisconsin Department of Transportation, undated.
http://wisconsindot.gov/Documents/doing-bus/eng-consultants/cnslt-rsrces/tools/qmp/resinhfst.pdf
This special provision describes Wisconsin DOT's specifications for HFST materials and installation.

High Friction Surface Treatments: Survey Questions

The following survey was provided to 21 states with a climate similar to Minnesota and expected to have experience with HFST applications.

High Friction Surface Treatment Program

1. How many high friction surface treatment (HFST) installations are in your state?
2. How many additional HFST installations are planned for your state?
3. What issues influenced your state's decision to implement HFST?
4. What characteristics make a site eligible for HFST?

Materials and Applications

5. Does your agency use standard specifications for HFST installations?
6. Does your agency use calcined bauxite in HFST installations?
7. Does your agency use alternatives to calcined bauxite for HFST aggregates?
8. What binder(s) does your state use in HFST installations?
9. Does your agency use chip seals or microsurfacing?
10. Where in traffic lanes or on curves are HFST installations located?

Effectiveness and Safety Performance

11. How effective has HFST been in your state?
12. Is crash data from before and after installation of HFST available?

Durability and Friction Requirements

13. How durable has HFST been in your state compared to standard roadway surfaces?
14. How well has HFST stood up to snowplowing in your state?
15. What skid numbers or data are required of hot-mix asphalt in your state?
16. What skid numbers or data are required of HFST in your state?
17. How durable do you expect aggregate surfaces to be in hot-mix asphalt in your state?
18. How durable you expect aggregate surfaces to be in HFST in your state?

Wrap-Up

Please provide links to online documents related to HFST in your state or email these documents to matt.mullins@ctcandassociates.com.

High Friction Surface Treatments: Contact Information

Below is the contact information for the individuals responding to the survey or providing supplemental information for this report.

Alaska
Anna Bosin
Alaska Department of Transportation and Public Facilities
907-269-6208, Anna.Bosin@alaska.gov

California
Robert Peterson
California Department of Transportation
916-653-4333, Robert.Peterson@dot.ca.gov

Georgia
Michael Turpeau Jr.
Georgia Department of Transportation
404-631-2831, MTurpeau@dot.ga.gov

Illinois
Jon McCormick
Illinois Department of Transportation
217-785-5678, Jon.M.McCormick@illinois.gov

Indiana
Michael Holowaty
Indiana Department of Transportation
317-232-5337, MHolowaty@indot.in.gov

Joseph Bruno
Indiana Department of Transportation
317-234-7945, JBruno@indot.in.gov

Shuo Li
Indiana Department of Transportation
765-463-1521, ext. 247, SLI@indot.in.gov

Iowa
Jan Laaser-Webb
Iowa Department of Transportation
515-239-1349, Jan.Laaser-Webb@iowadot.us

Jon Frederiksen
Iowa Department of Transportation
515-239-1077, Jon.Frederiksen2@iowadot.us

Kentucky
Tracy Lovell
Kentucky Transportation Cabinet
502-782-5534, Tracy.Lovell@ky.gov

Michigan
Steve Shaughnessy
Michigan Department of Transportation
517-373-8950, ShaughnessyS@michigan.gov

North Dakota
Shawn Kuntz
North Dakota Department of Transportation
701-328-2673, SKuntz@nd.gov

Ohio
Michael McNeill
Ohio Department of Transportation
614-387-1265, Michael.McNeill@dot.ohio.gov

Pennsylvania
Jason Hershock
Pennsylvania Department of Transportation
717-705-1437, JHershock@pa.gov

South Dakota
Andy Vandel
South Dakota Department of Transportation
605-773-4421, Andy.Vandel@state.sd.us

Tennessee
Danny Lane
Tennessee Department of Transportation
615-350-4175, Danny.Lane@tn.gov

Texas
George Villarreal
Texas Department of Transportation
512-416-3135, George.Villarreal@txdot.gov

Wisconsin

Myungook (MK) Kang
Wisconsin Department of Transportation
608-246-7957, Myungook.Kang@dot.wi.gov

Brian Porter
Wisconsin Department of Transportation
608-267-0452, Brian.Porter@dot.wi.gov

Supplement to This Report

Many state DOT representatives who completed the online survey also provided publications related to high friction surface treatment practices in their state. Some of these publications are included in **Related Resources** sections throughout this report and in the **Specifications** section. Any publications that are not publicly available are included in TRS 1802S, a separate supplement to this report that is available at http://mndot.gov/research/TRS/2018/TRS1802S.pdf.

Below is a list of the publications included in the supplement:

Appendix A	Alaska: High Friction Surface Treatment in the Last Frontier
Appendix B	Georgia: Sharp Curve Treatment Process
Appendix C	Michigan: Wet Weather Crash Reduction Program
Appendix D	Illinois: Qualified Product List of High Friction Surface Treatment
Appendix E	Illinois: Submittal: High Friction Surface Treatment
Appendix F	Wisconsin: Section 5—Seal Coat
Appendix G	Michigan: High Friction Surfaces
Appendix H	Tennessee: Use of High Friction Surface Treatments
Appendix I	Wisconsin: Marquette Interchange West to North Ramp Crashes Before & After High Friction Surface Treatment (HFST)
Appendix J	Alaska: Work Plan for High Friction Surface Treatment Material Monitoring Project
Appendix K	Alaska: HSIP: CR High Friction Surface Treatment
Appendix L	Alaska: Proposed Highway Project HSIP: CR High Friction Surface Treatment
Appendix M	California: Section 37-7 High Friction Surface Treatment
Appendix N	Georgia: Section 419—High Friction Surface Treatment
Appendix O	Illinois: Special Provision for High Friction Surface Treatment
Appendix P	Kentucky: Special Note for Polymer Concrete Overlay Systems
Appendix Q	Ohio: 690 Special Misc: High-Friction Epoxy Aggregate Surface Treatment