Noteworthy Practice: HFST Institutionalized at PennDOT

Pennsylvania Advances High Friction Surface Treatment (HFST)

In Pennsylvania, over 50% of the fatal and serious injury crashes involve a lane departure, and intersection crashes account for 21% of the annual fatalities and 30% of serious injuries[1]. Slippery and wet roads often contribute to many of the fatal and serious injury crashes in Pennsylvania. To reduce wet-pavement crashes at curves and intersections throughout the Commonwealth, the Pennsylvania Department of Transportation (PennDOT) has been installing high friction surface treatments (HFSTs) at strategic locations. A HFST is a safety countermeasure intended to restore and maintain pavement friction in wet and dry conditions to reduce crashes. This treatment is especially effective where there is a history of wet-pavement crashes.

How Do HFSTs Work?

Where drivers brake excessively (e.g., going around curves, on steep downgrades, or approaching intersections), the road surface can become polished, reducing the available pavement friction. Reduced pavement friction may contribute to vehicles losing control, skidding, or hydroplaning when they speed, turn abruptly, or brake excessively. With HFSTs, a thin layer of calcined bauxite aggregate provides increased friction to the pavement surface and makes the pavement more resistant to wear and polishing. HFSTs help vehicles maintain their lane as they traverse around curves and allows drivers to stop within reasonable distances at intersections, resulting in safer roads for the traveling public. Figure 1 illustrates the physical difference between a normal pavement surface and a surface treated with a HFST.

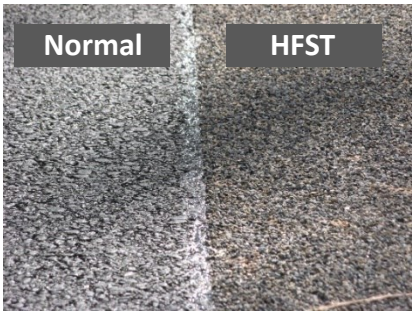

Figure 1: Boundary between Normal and HFST Pavement Surfaces. Source: PennDOT

PennDOT's Approach to Implementation

In 2007, PennDOT installed its first HFST at a high-crash location along State Route 611 in Northampton County (District 5) (see Figure 2). The treatment was applied at a sharp horizontal curve on a rural two-lane road with 9-ft travel lanes and no shoulders. The roadside on one side was a steep cliff, and on the other side was a steep drop-off. In the 10 years prior to installation of the HFST, 20 wet-pavement-related crashes occurred at the site. Over the years, PennDOT had tried other treatments (e.g., chevrons, advanced warning signs, centerline rumble strips) without much success in reducing the frequency of wet-pavement crashes[2].

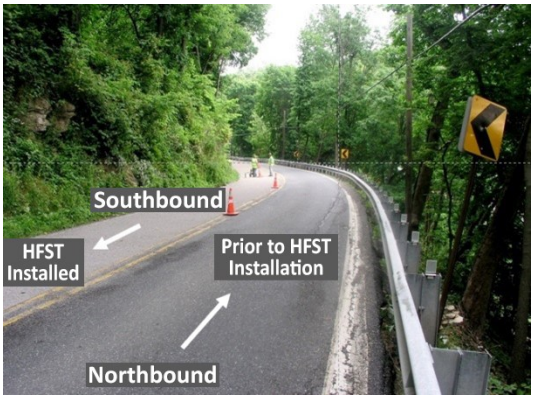

Figure 2: HFST Pilot Project. Source: PennDOT

[1] Pennsylvania Department of Transportatation. *Pennsylvania Strategic Highway Safety Plan*, 2017.
[2] State Transportation Innovation Council. 2015 Fact Sheet - High Friction Surface Treatment, 2015.

U.S. Department of Transportation
Federal Highway Administration

Following a series of skid tests and an analysis of the crash data over the next few years, the pilot project proved successful. In the first five years following installation of the HFST at the pilot project location, zero wet-pavement-related crashes occurred. While PennDOT evaluated the performance of the HFST pilot project, numerous wet-pavement crashes continued to occur at other locations throughout the state.

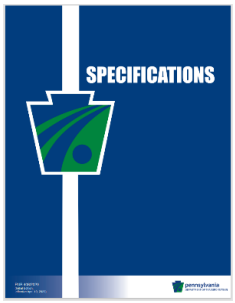

Figure 3: Current Construction Specifications for PennDOT Projects

Based on the success of the pilot project, PennDOT added HFST to its approved materials listing and developed specifications for installation of the treatment (now in the fourth version of specifications)[3] (see Figure 3). Then, in 2012, PennDOT District 5 applied the treatment to 13 additional sites experiencing a high frequency of wet-pavement crashes. In addition, HFSTs were included as one of the potential countermeasures for consideration within the *Pennsylvania Roadway Departure Safety Implementation Plan* [4]*,* prepared in conjunction with the Federal Highway Administration (FHWA) Roadway Departure Team. In the *Pennsylvania Roadway Departure Safety Implementation Plan,* the initiative called for the systemic deployment of relatively low-cost, cost-effective countermeasures at many targeted locations with a frequency of roadway departure crashes. HFSTs were to be considered as a means of reducing wet-pavement crashes when deployed along rural and urban tangent and curved sections of highway and intersection approaches. Figure 4 illustrates three types of locations where PennDOT has installed HFSTs.


Curves on Rural Two-Lane Roads


Curves on Rural Multilane Roads


Intersection Approaches

Figure 4: Types of Locations Where PennDOT Has Installed HFSTs. Source: PennDOT

The primary steps and schedule for implementation of HFST through the roadway departure plan involved:

1. The Safety Management Office working with Design, Maintenance, and District Offices to develop guidelines for use of the micro-textures and epoxies to be applied on the sections of highway with high incidences of wet-pavement crashes,
2. Conducting skid testing at the potential locations to determine if low frictional characteristics may be contributing to the wet-pavement crashes, and
3. Determining the appropriateness of applying a HFST to the location.

Other factors that could potentially influence the decision to install HFST at a location included:

- Evidence of excessive braking at intersection approaches with running stop signs, running red light, and rear-end crashes.
- Inability to move fixed objects to increase the clear zone.
- Inability to make geometric changes to a curve with known crash history.

From 2012 to 2018, HFSTs were installed at approximately 44 new locations annually to reduce wet-pavement crashes. By 2018, HFSTs were installed at 305 locations throughout the Commonwealth, covering approximately 53.5 miles of roadway. In 2021, PennDOT estimates HFSTs have been installed at close to 500 to 600 locations. The treatment has been installed at curves and intersections on urban and rural two-lane and multilane roadways, including high-speed freeways. To streamline the project delivery process, PennDOT often bundled the safety contracts that were bid out districtwide or countywide. This helped the treatment to be implemented more quickly throughout the district/county, and PennDOT realized a substantial cost savings. For example, when

[3] Pennslyvania Department of Transportation. *Specifications*. Publication 408, 2020.
[4] *Pennsylvania Roadway Departure Safety Implementation Plan*, 2012. https://www.penndot.gov/TravelInPA/Safety/Documents/PA%20Roadway%20Departure%20Safety%20Implementation%20Plan%20(RDIP).pdf

installed on an individual project basis, PennDOT found the cost of a HFST was approximately $36/square yard (SY); but when PennDOT HFST projects were bundled, the cost of a HFST was reduced to approximately $16/SY.

Safety Effectiveness and Economic Benefits

Since the initial assessment of their pilot project, PennDOT has tracked the safety performance at many treatment sites and conducted several studies to estimate the safety effectiveness and economic benefits due to HFST applications in Pennsylvania:

- In 2016, based on an evaluation of 15 locations and an analysis of three years of before-after crash data and cost data, PennDOT estimated the benefit-cost ratio of HFSTs to be 20.5 to 1[5].
- Even though data were not sufficient to apply an advanced statistical assessment, in 2017, based on an extensive before-after study of 106 locations, PennDOT estimated that HFSTs reduced the number of roadway departure crashes by 74% at curves, and most importantly fatalities were reduced by 100%. The study results also showed the greatest reduction in crash frequency and severity and greatest return on investment occurred for intersections on horizontal curves in rural areas[6].
- In 2018, based on an evaluation of 47 locations with up to five years of before-after crash data, PennDOT estimated that HFSTs resulted in a benefit-cost ratio of 5.50 for all crashes and 2.40 for wet-road crashes[7].

PennDOT has also found HFSTs have year-round benefits, especially in the fall and winter. In the fall, when leaves fall onto the treated surface, the leaves are practically ground away against the surface reducing the chance for vehicles to skid on wet leaves (see Figure 5). In the winter, HFSTs hold up well during snow plowing (i.e., PennDOT has not seen degradation of the material or decreased longevity due to plowing operations); and the treatment is effective at reducing crashes during icy, slushy, and snow-covered conditions.

Figure 5: Benefits Experienced during the Fall. Source: PennDOT

Table 1 presents findings from a multistate study, published in 2020, based on curve treatment data for 95 sites in Pennsylvania, 36 sites in Kentucky, and 26 sites in West Virginia. As shown in Table 1, the researchers developed crash modification factors (CMFs) using the Empirical Bayes before-after method and estimated a benefit-cost ratio associated with the safety effectiveness of HFSTs reducing crashes at curve locations[8].

Table 1. Recommended Crash Modification Factors (CMFs) and Benefit-Cost Ratio for Installation of HFST at Curves[8]

Crash Type	CMF (95-percent Confidence Interval)	Benefit-Cost Ratio (Sensitivity Range)
Total crashes	0.430 (0.375-0.485)	6.000 (3.360-8.450)
Injury crashes	0.515 (0.442-0.588)	—
Run-off-road crashes	0.279 (0.216-0.342)	—
Wet-road crashes	0.168 (0.485-0.897)	—
Head-on plus opposite-direction sideswipe crashes	0.691 (0.485-0.897)	—

Note: A dash denotes *not applicable*.

[5] Federal Highway Administration. *Northeast Roadway Departure Safety Peer Exchange, 2016.* https://rosap.ntl.bts.gov/view/dot/49575

[6] Musey, K., M. Kares, S. Park, and G. Kennedy. Safety Impact of High-Friction Surface Treatment Installations In Pennsylvania, Transportation Research Circular, Number E-C220, First International Roadside Safety Conference, San Francisco, CA, Transportaion. Research Board, 2017. http://onlinepubs.trb.org/onlinepubs/circulars/ec220.pdf

[7] Pennsylvania Department of Transportation. Highway Friction Surface Treatments in Pennsylvania, Keeping You on the Road. https://www.tesc.psu.edu/assets/docs/high-friction-surface-treatments.pdf

[8] Merritt, D.K., C.A. Lyon, and B.N. Persaud. *Developing Crash-Modification Factors for High-Friction Surface Treatments.* Report No. FHWA-HRT-20-061. Federal Highway Administration, 2020.

Demonstrated Skid Resistance Qualities of HFST Sites

During the first few years as PennDOT was beginning to institutionalize the use of HFSTs, skid testing (see Figure 6) was conducted to monitor the frictional performance of the treatment sites. Through this monitoring program, PennDOT found the HFST sites had average skid numbers over 70 when measured multiple years after installation of the treatment; whereas traditional pavement overlay initial skid numbers normally ranged from 50 to 55 and declined into the 40s after a few years[9].

Figure 6: Skid Testing Equipment. Source: PennDOT

HFST Installation Basics and Specifications

As PennDOT has been installing HFSTs at locations for many years, the Department has developed specifications for the installation of HFSTs in Pennsylvania. Basically, HFSTs are applied to an existing asphalt or concrete pavement surface. The pavement must be structurally sound. PennDOT requires a 30-day waiting period before a HFST can be applied to a new asphalt pavement and a 28-day waiting period before applying the treatment to a new concrete pavement[3].

At the beginning of the installation process, all pavement surfaces are prepared prior to installation of the HFST. All existing pavement markings and utilities (i.e., manholes/inlets) are covered and protected. The pavement surface is cleaned of all debris; washed with a mild detergent solution to remove oils, greases, and other deleterious material; rinsed with water; and dried using a hot compressed air lance. If cracks are present, loose material is removed; and cracks one-fourth inch or greater are filled with a resin binder. After the binder in the pre-treated cracks has gelled, the resin binder is applied to the pavement surface. Next, a thin layer of high-quality polish-resistant calcined bauxite aggregate is placed on top of the resin binder. After the binder treatment has cured and before opening the road to traffic, the travel lanes and shoulders are cleaned using a vacuum sweeper to reclaim surplus aggregate. The treatment is usually installed one lane at a time and takes about two to four hours to install per lane. Between 15- to 30-days after placing the HFST, the site is again cleaned using a vacuum sweeper to reclaim loose aggregate.

PennDOT permits installation of HFST using three main application methods (see Figure 7): manual, semi-automated, and fully-automated. Permissible application methods vary by size of the project and volume of the road (see Tables 2 and 3).

Manual Application

Semi-Automated Application

Fully-Automated Application

Figure 7: Three Primary Application Methods. Source: PennDOT

[9] Federal Highway Administration. Pennsylvania SR611-Northampton County. Case Study – High Friction Surface Treatment. FHWA-SA-16-056. Federal Highway Administration, 2016.

Table 2. Permissible Application Methods for Roads Under 25,000 ADT[3]

Site Size (Square Yards)	Main Application Method
Less than 300	Hand Mixing and Manual Application, Semi-Automated Application, or Fully-automated Application
300 or above	Semi-Automated Application, or Fully-Automated Application

Table 3. Permissible Application Methods for Roads of 25,000 ADT and Above[3]

Site Size (Square Yards)	Main Application Method
Less than 300	Hand Mixing and Manual Application, Semi-Automated Application, or Fully-Automated Application
300 to 1,500	Semi-Automated Application or Fully-Automated Application
Larger than 1,500	Fully-Automated Application

Figure 8: Equipment Associated with Fully-Automated Application. Source: PennDOT

The primary benefits of using the fully-automated application method versus the hand mixing and manual application method include[10]:

- Improved speed and quality resulting in reduced installation time.
- Consistent with proven specification.
- Reduced exposure of workers to live traffic.
- Full lane width (i.e., 12 ft) continuous operation in one pass.
- Less material component waste.
- Even application of binder and aggregate.

The primary disadvantage of the semi-automated application method is the amount of dust that can be generated when spreading the aggregate.

Figure 9: Boundary between HFST and Pavement Surface. Source: PennDOT

Bauxite vs Alternative, Non-Bauxite Aggregates[11]

Figure 10: Aggregate Used in HFST. Source: PennDOT

The aggregate specified in PennDOT's HFST specification is based on industry standards and requires a certain amount (87%) of the aggregate to be aluminum oxide (bauxite). Aluminum oxide is very abrasive and durable. Most bauxite is imported from overseas and can be relatively expensive.

Aggregates used in HFSTs are a hot topic, and many questions associated with these aggregates arise. For example, would lesser percentages of bauxite work satisfactorily? Are there other non-bauxite aggregates that perform just as well but are less expensive? After experimenting and evaluating the potential use of alternative aggregates (non-bauxite), PennDOT realized that the cost of the aggregate is relatively small compared to the cost of the epoxy; so using a less expensive aggregate will not save much money over the long term. In addition, if the durability of a less expensive aggregate is also less, the less expensive aggregate could cost more on a life-cycle basis. Therefore, PennDOT's specifications require the use of clean, dry, high-friction bauxite aggregate[3].

[10] Atkinson, J., J. Clark, and S. Ercisli. *High Friction Surace Treatment Curve Selection and Installation Guide.* Report No. FHWA-SA-16-034, Federal Highway Administration, Washington, DC, 2016.
[11] Pennsylvania Department of Transportation. *Technology Insider*. July 2017.

Benefits of HFSTs[12]

The benefits of using HFSTs include:

- Reduces injury crashes on curves and intersections that exhibit a high propensity for wet-pavement-related crashes.
- Installs quickly with minimal impact on traffic (e.g., usually installed one lane at a time and takes about two to four hours to install per lane).
- Provides a durable, long-lasting, moderate-cost surface option over the pavement's life cycle.
- Improves skid resistance.
- Decreases braking distance, hydroplaning, splash, and spray.

Figure 11: Typical HFST Application on Rural Two-Lane Road. Source: PennDOT

Lessons Learned

Based on their experience with HFSTs, PennDOT shared some lessons learned:

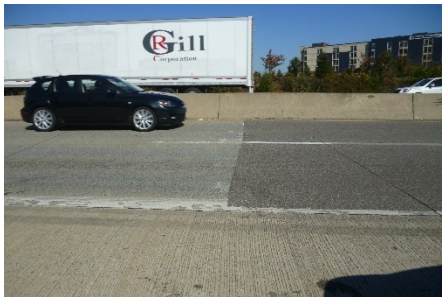

Figure 12: Typical HFST Application on Urban Freeway. Source: PennDOT

- HFST is a proven safety countermeasure and is suitable for all weather applications at strategic locations and can be deployed systemically.
- There are crashes that only HFSTs can mitigate. This treatment is working and is suitable for States that want to save lives at targeted locations.
- HFST should be installed on pavement in good structural condition. If the pavement is cracked, raveled, or rutted, the HFST will not last long.
- HFST should not be installed in cold weather. The treatment will not stick.
- If the wet road crashes are due to drainage issues where there is ponding water, HFST is not the solution. The drainage issue should be addressed first.
- In the fall when leaves, walnuts, apples, and other debris fall on the road and create slick surfaces, the HFST countered these issues by helping to grind down the debris and maintain the skid resistance of the pavement surface.
- Installing HFST through a bundled project contract is the most economical process to install HSFT across the state [e.g., cost of HFST when installed on individual project basis ($36/SY) compared to cost when HFST projects are bundled ($16/SY)].
- Communicate with the county maintenance staff to make them aware of the locations where HFSTs are installed so treatments are not removed shortly after installation (e.g., one or two years) during resurfacing projects.
- Construction inspectors should coordinate installation dates of HFSTs with maintenance staff responsible for skid testing so skid testing can be conducted in a timely manner following installation of the treatments.

For Additional Information

For additional information about HFSTs contact Joseph Cheung, FHWA Office of Safety, at **joseph.cheung@dot.gov**.

For additional information about the Pennsylvania Department of Transportation's use and institutionalization of HFSTs, contact Jason Hershock, Pennsylvania Department of Transportation, at **jhershock@pa.gov**.

PennDOT created a website, a video, and other materials promoting the use of HFSTs. For more information, visit https://www.penndot.gov/about-us/StateTransportationInnovationCouncil/Innovations/Pages/High-Friction-Surface-Treatment.aspx

Publication Number FHWA-SA-21-127

[12] Casadei, D. *PennDOT District 10 Demos Benefits of High Friction Surface Treatment*. PennDOT Way, 2018. https://www.penndot.gov/PennDOTWay/pages/Article.aspx?post=174