

July 2022

# FHWA High Friction Surface Treatments

## *Frequently Asked Questions – 2022 Update*

### Non-Binding Contents:

Except for the statutes and regulations cited within, the contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to the public regarding existing requirements under the law or agency policies.

### Update Notice:

This High Friction Surface Treatment (HFST) Frequently Asked Questions (FAQ) 2022 replaces Frequently Asked Questions – High Friction Surface Treatments (HFST) – 2017 (FHWA-SA-18-004). It covers questions related to HFST safety, maintenance and operations, cost, environmental impacts, material specifications, durability, lessons learned, and installation.



U.S. Department of Transportation  
**Federal Highway Administration**

<http://safety.fhwa.dot.gov>

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

# Table of Contents

<b>GENERAL.....</b>	<b>4</b>
1. What is a High Friction Surface Treatment (HFST)?.....	4
2. What is the purpose of HFST?.....	4
3. How are potential HFST sites identified?.....	5
4. What are recommended limits for HSFT installations? .....	5
<b>SAFETY.....</b>	<b>6</b>
1. Are there any crash modification factors (CMFs) available for HFST? .....	6
2. What are the advantages of using HFST compared to using traditional safety treatments at horizontal curves?.....	7
3. What is the safety effect of these surfaces for motorcycles and bicycles? .....	8
4. Has there been an increase in truck rollovers after installation? .....	8
5. What effect does HFST have on braking distance and stopping behavior at intersections? .....	8
<b>MAINTENANCE AND OPERATIONS .....</b>	<b>9</b>
1. Does HFST promote higher operating speed? .....	9
2. What is the effect of snowplows on this pavement treatment? .....	9
3. Can HFST be applied in conjunction with rumble strips? .....	10
4. Does HFST accelerate tire wear? .....	10
5. What maintenance is required for HFST? .....	10
6. How is HFST removed and can it be recycled? .....	11
<b>COST .....</b>	<b>11</b>
1. What is the average unit cost for HFST? .....	11
2. What is the benefit-cost ratio for HFST?.....	11
3. How should the cost of HFST be evaluated? .....	12
<b>ENVIRONMENTAL .....</b>	<b>12</b>
1. What effect does HFST have on road noise? .....	12
2. What are some of the potential environmental benefits for HFST? .....	13
<b>MATERIAL SPECIFICATIONS / DURABILITY .....</b>	<b>14</b>
1. What is the life expectancy of HFST?.....	14
2. Are these materials resistant to fuels and common de-icing agents?.....	15

3. What is the difference between HFST and other pavement preservation treatments such as microsurfacing and chip seal? .....	15
4. Is it worth the investment to use HFST compared to other friction treatments? .....	15
5. Do these materials crack? If so, how do they resist crack erosion? .....	16
6. Are there any issues with thermoplastic on HFST? .....	16
7. What aggregates are appropriate for HFST and what sources are available? .....	16
8. Can reclaimed aggregate be reused and are there any special requirements for disposal? .....	17
9. What are some typical polished stone values (PSV) for HFST aggregates using ASTM E 303/AASHTO T 278 British Portable Pendulum Tester and ASTM D 3319/AASHTO T 279 British Wheel Accelerated Polishing Machine? .....	18
10. Several HFST aggregate durability studies were published in cooperation with FHWA and the National Center for Asphalt Technology (NCAT): .....	18
11. Can HFST be placed on a bridge deck? .....	18
12. Are HFST systems proprietary? .....	19
13. Is there a certification process for contractors who want to perform this type of work or training resources for agency inspectors? .....	19
14. Are there specifications for HFST? .....	19
<b>LESSONS LEARNED</b> .....	<b>20</b>
1. What are the lessons learned with HFST installation? .....	20
2. What pavement conditions caused failures that have been reported? .....	21
3. Can patches that de-bond be fixed? .....	22
4. Will the polymer have a reaction with magnesium on a bridge deck? .....	22
<b>INSTALLATION</b> .....	<b>22</b>
1. What surface preparation and installation conditions are important for successful installation? ....	22
2. Can you apply HFST over existing striping? .....	25
3. Is installation over an open-graded friction courses (OGFC) an issue? .....	25
4. What are some of the key factors that can affect the placement of HFST? .....	27
5. What is the difference between manual and fully automated HFST installation? .....	27
6. Can agency personnel install HFST? .....	28
7. What are items to look for in terms of early-age performance that may indicate materials and workmanship issues? .....	29

# GENERAL

## 1. What is a High Friction Surface Treatment (HFST)?

### *Definition*


- HFST is a cost-effective safety and pavement surface treatment consisting of a polymeric resin binder and surface-applied manufactured aggregate used to increase the long-term friction characteristics of a pavement surface.

### *Description*

- HFST is a unique low-cost safety countermeasure because it is specifically intended to dramatically increase pavement friction for the purpose of reducing crashes associated with friction demand issues. There are no other known pavement surface treatments that enhance pavement friction to the same level while sustaining this friction enhancement over time.
- HFST is installed by spreading a thin layer (< 2 mm) of polymeric resin binder (typically epoxy or polyester) over the pavement surface, then broadcasting or dropping a 1- to 3-mm abrasion and polish-resistant manufactured aggregate (calcined bauxite) onto the resin layer. The resin binder bonds the aggregate to the pavement surface, leaving a thin pavement surface treatment that can be applied during a short closure (e.g., 6-8 hours) of the roadway.
- HFST is not a structural overlay or a pavement preservation treatment and is not known to provide any extension of pavement life which can be found with microsurfacing, slurry seals, and chip seals. It simply enhances the friction of an existing pavement surface using materials and installation methods unique to the treatment.

## 2. What is the purpose of HFST?

- HFST enhances the ability of a pavement surface to provide adequate friction (i.e., *friction supply*) at locations with high *friction demand*, thereby increasing the *margin of safety*. If friction demand exceeds friction supply, vehicle skidding is likely to occur. A combination of pavement macrotexture (which allows water to evacuate from beneath vehicle tires, particularly at higher speeds) and microtexture (which provides the actual tire-pavement contact) contributes to good pavement friction. HFST provides exceptional friction supply through this combination of macrotexture and microtexture. Please refer to FHWA's HFST Site Selection and Installation Guide for additional information on friction demand, friction supply, and margin of safety concepts.  
[https://safety.fhwa.dot.gov/roadway\\_dept/pavement\\_friction/high\\_friction/docs/HFST\\_Guide\\_HPA.pdf](https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/high_friction/docs/HFST_Guide_HPA.pdf)
- Locations with high friction demand include horizontal curves, ramps, steep grades, and intersections where greater friction is needed to help keep vehicles on the road and reduces stopping distance, particularly in wet weather. In locations such as sharp horizontal curves, where vehicles apply higher side-shear force to the pavement, the pavement surface tends to



polish faster, reducing pavement friction supply and the margin of safety. Reduced friction can contribute to vehicles losing control or skidding when they are traveling at excessive speed, making abrupt turns, or braking excessively. Higher friction, maintained with polish-resistant aggregates such as calcined bauxite, helps to prevent skidding and reduce stopping distance under both wet and dry roadway conditions.


- HFST can help compensate for deficient geometric designs, such as sharp curves and/or inadequate or variable superelevation, by providing the necessary friction to maintain traction on the intended path.
- HFST has been used successfully in lieu of costly roadway realignments, which can take years to complete due to delays associated with lengthy planning phases and budget constraints, and may also necessitate lengthy traffic detours during construction. With the short construction duration, HFST can begin reducing crashes and saving lives immediately as opposed to several years later for a realignment project.

### **3. How are potential HFST sites identified?**

- The two primary approaches for HFST candidate site identification currently used in the United States are the *site-specific* safety approach and *systemic* approach.
- The *site-specific* safety approach, also known as a hot-spot approach, is a reactive approach which uses site-specific crash data to identify locations where a countermeasure is needed. Reacting to crashes is a simplified version of this approach, but more advanced approaches use historic crash data and predictive methodologies such as safety performance functions (SPFs) and Empirical Bayes (EB) to identify locations where HFST may provide benefit. These advanced approaches help identify sites over-represented with target crashes, typically run-off-road and wet weather crashes, for individual installations.
- The *systemic* approach is a more proactive approach to treat locations deemed “high risk” for friction-related crashes. Predictive methods, such as SPFs, help practitioners to identify high-risk features. Locations are identified based on the presence of several different risk factors such as roadway characteristics, traffic exposure, and pavement friction. This approach treats a broader series of sites based on the risk of target crashes at locations that may not have historically observed crashes but are at higher risk for future crashes.
- Pavement friction management programs (PFMPs) utilizing appropriate testing methodologies and devices, such as continuous pavement friction measurement (CPFM), are another proactive approach to identify potential friction issues before they manifest in the form of increased crash rates.

### **4. What are recommended limits for HFST installations?**

- While there are general recommendations for treatment limits (e.g., from point of curvature to point of tangency for curve locations), the final decision for a particular site should be as data-



driven as possible. Verification of candidate sites through friction testing and field reviews will help with the establishment of treatment limits.

- Friction testing of the candidate location, including pavement upstream and downstream from the proposed location (when possible), will help identify changes in friction leading up to, through, and away from the targeted treatment area such that treatment limits can be adjusted based on pavement friction. CPFM technologies provide a comprehensive “map” of pavement friction for identifying changes in friction at candidate locations. A margin of safety assessment can be further used to establish appropriate treatment limits based on site conditions.
- The Texas A&M Transportation Institute published the "Pavement Safety-Based Guidelines for Horizontal Curve Safety" for a margin of safety analysis of horizontal curves. This report can be found at: <https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6932-R1.pdf>
- Field reviews will provide a better understanding of driver behavior at a candidate location for the purpose of establishing treatment limits. Field reviews should include physically locating reported crashes and observing driver behavior (ideally under the same conditions when most crashes have occurred), to determine where vehicles begin to brake in advance of the curve, ramp, or intersection.
- Additional considerations for treatment limits include a determination of whether only one lane or direction need to be treated, whether adjacent paved shoulders need to be treated, and whether a treatment should be continued through multiple-curve locations rather than leaving short areas untreated between curves.
- HFST may be placed within the width of the traveled lane only or from edge of pavement to edge of pavement. The treatment may also be applied to an area that is narrower than a lane to avoid removal of striping or pavement markings. This decision should be evaluated in the design phase of the project with respect to the project budget, the behavior of vehicles, and the relevant crash data. Placement within the traveled lane only may result in lower required quantity of HFST, but may not provide enhanced friction on shoulders if traffic patterns or crash data indicate that vehicles travel partially within the shoulder area—behavior which is common on tight curves and ramps. It is generally not necessary to place HFST within 1 foot of obstructions to traffic like barriers, guardrail, or attenuators. When placing HFST on paved shoulders, it is also not usually necessary to follow a variable or degraded roadway edge exactly, but rather to establish a path that provides for a consistent width for friction enhancement.

## **SAFETY**

### **1. Are there any crash modification factors (CMFs) available for HFST?**

- CMFs are available for HFST curve and ramp applications from an FHWA study conducted as part of the Evaluation of Low-Cost Safety Improvements Pooled Fund Study. This study generated high-quality and robust CMFs and benefit-cost ratios for HFSTs with calcined bauxite aggregate

based on data-driven before- and after-crash data analysis to quantify crash reduction benefits. CMFs are provided for total, injury, run-off-road, wet road, and head-on side-swipe opposite direction crashes for curves and total, injury, run-off-road, and wet road crashes for ramps. Through a disaggregate analysis of the before-after evaluation data for curves this study also reports CMFs for HFST based on friction increase, traffic, and annual crash rates. This report can be found at: <https://www.fhwa.dot.gov/publications/research/safety/20061/index.cfm>

- Table 1 summarizes the CMFs for ramp locations from this FHWA study. While these are the only 4- and 5-star CMFs in the Crash Modification Factors Clearinghouse, others are also available: <https://www.cmfclearinghouse.org/index.cfm>

**Table 1. CMFs for HFST on Curves.**

Crashes after treatment application			
Crash Type	Observed	EB Expected	CMF (s.e.)
<b>Total</b>	329	767.84	<b>0.430 (0.028)</b>
<b>Injury</b>	106	205.02	<b>0.515 (0.037)</b>
<b>Run-off-road</b>	92	333.49	<b>0.279 (0.032)</b>
<b>Wet road</b>	82	495.54	<b>0.168 (0.020)</b>
<b>HOSSOD</b>	59	81.29	<b>0.691 (0.105)</b>

*Note:* CMF = crash modification factor; EB = empirical Bayes; HOSSOD = head-on side-swipe opposite direction; s.e. = standard error. CMFs that are statistically significant at the 5-percent level are indicated in boldface. EB expected is an estimate of the number of crashes the sites would have experienced had HFST not been installed.

## 2. What are the advantages of using HFST compared to using traditional safety treatments at horizontal curves?

- HFST should be considered when delineation treatments such as pavement markings, signage, etc. are not reducing crashes, and pavement friction is suspected to be inadequate for prevailing conditions. Generally, signs and markings are effective for prudent drivers who are trying to drive carefully, but when vehicles enter a curve too fast it is generally too late for those devices to help the driver. Whether some drivers are willfully speeding or distracted and the curve surprises them, speed is a major contributing factor for crashes in curves. Many studies have shown that a pavement with high skid resistance can give drivers a "hidden advantage" and help them still navigate the curve.
- If the pavement is polished or has lower skid resistance to begin with, safely navigating the roadway can become a problem even for prudent drivers, particularly when the pavement is wet. HFST provides a pavement that is polish-resistant and has excellent friction. Other safety enhancements may require geometric improvements, which can take a long time, be expensive, increase delay and safety risks associated with lengthy active work zone periods, and have environmental consequences. By comparison, HFST costs less and has fewer of these impacts.

### 3. What is the safety effect of these surfaces for motorcycles and bicycles?

- There are no known negative safety effects for motorcycles and bicycles. In fact, braking and cornering on a motorcycle demand more friction than similar maneuvers do for passenger vehicles, so HFST can be even more impactful in improving motorcycle safety on curves and intersection approaches.<sup>1</sup>
- In the State of Rhode Island, HFST was installed on a curve that had eight motorcycle crashes in five years. Since HFST installation in 2014 there have been no reported motorcycle crashes.<sup>1</sup>
- One recommended precaution related to motorcycles and bicycles is to ensure that all loose aggregate is thoroughly removed from the HFST and surrounding surfaces before opening to traffic as loose aggregate can have a more detrimental impact on motorcycles and bicycles. This includes subsequent re-sweeping as needed in the first few weeks after installation as the HFST naturally sheds aggregate under traffic. Agencies may consider leaving “loose gravel” warning signs in place for the first 30-60 days after installation as a precaution.
- To date, no problems with abrasiveness have been identified regarding bicycle use on HFST. This product has been used widely for many years in Europe and in many other countries that have large bicycle populations and this has not been an issue. In fact, the HFST process is used to install colored aggregate (not calcined bauxite) that serves as demarcation. This product has been requested by bicycle groups for bike lane surfaces because the texture helps reduce the problem of tires sliding when wet, which is common on some demarcation treatments.

### 4. Has there been an increase in truck rollovers after installation?

- No increase in truck rollovers has been reported from any HFST installations, and studies by FHWA in the past have shown that increases in friction help reduce truck rollover, in part by keeping trucks from running off the road where rollovers typically occur. Illinois DOT observed a reduction in truck rollovers on tight-radius ramps where HFST was installed.
- Illinois DOT also observed a substantial reduction in semi-truck roadway departure crashes on a tangent section of interstate highway with strong cross winds after HFST was applied. HFST appears to provide semi-trucks better ability to regain control.

### 5. What effect does HFST have on braking distance and stopping behavior at intersections?

- Depending on the level of friction of the existing pavement surface, HFST can increase the coefficient of friction by 200 percent or more. In theory, using the basic equation for braking distance (not accounting for site distance, grade, etc.), increasing friction by 50 percent will decrease stopping distance by one third, doubling friction will decrease stopping distance by one half, and tripling friction (e.g., 200 percent increase) will decrease stopping distance by two thirds, regardless of speed. These stopping distances will vary widely based on real-world



conditions (pavement surface condition, pavement texture, tire tread condition, driver behavior, etc.), but this is a general indication of the potential reduction in stopping distance.

- The University of South Florida's Center for Urban Transportation Research evaluated changes in driver behavior at intersections before and after HFST was applied. Using video footage from the intersections, the number of crosswalk incursions at a red light were documented as improper stopping behavior. Evaluations were performed at multiple times of the day before and after HFST was applied. For one intersection the analysis revealed a 26 percent reduction in improper stopping behavior one month after HFST application and 31 percent after nine months, indicating that the effects are sustained over time.<sup>2</sup>

## MAINTENANCE AND OPERATIONS

### 1. Does HFST promote higher operating speed?

- HNTB Corporation monitored speeds after an HFST installation for the Florida DOT and found that speeds post-installation were lower under both wet and dry conditions. The report can be found at: [https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/research/reports/bd500-v3-rpt.pdf?sfvrsn=d0ae33a5\\_2](https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/research/reports/bd500-v3-rpt.pdf?sfvrsn=d0ae33a5_2)
- While increasing superelevation does increase driver comfort, and improving driver comfort usually does increase speeds, there is no evidence that installing HFST leads to increased speed. HFST only satisfies friction needed to help the vehicle stay on the road without changing existing superelevation.
- Regardless of speed considerations, there have not been any notable increases in crashes on treated segments. All of the crash evaluations to date have shown remarkable crash reductions, which is the goal.


### 2. What is the effect of snowplows on this pavement treatment?

- Because HFST is such a thin overlay, generally less than 1/4-inch in thickness, the effect from snowplows has been minimal, even where "bare pavement" policies are followed in states such as Illinois, Vermont, and Michigan.
- Calcined bauxite aggregate wears very well under heavy snow plowing, and no deterioration from steel-tipped plows has been observed. HFST has been placed in many areas that see heavy snowplowing and winter weather, including Alaska, Pennsylvania, and South Dakota.
- South Dakota implemented HFST specifically to help reduce roadway departure crashes involving winter road conditions. Three years after installation of four initial demonstration

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<sup>1</sup> Geary, G., K. Dixon, K. Aspelin, and M. Manser. Addressing the Motorcyclist Advisory Council Recommendations: Synthesis on Roadway Geometry, Pavement Design, and Pavement Construction and Maintenance Practices. Report No. FHWA-SA-21-090. US Department of Transportation, Washington, DC., Nov. 2021.

<sup>2</sup> Merritt, D and S. Himes. Improving Pavement Friction for Safety at a Florida Signalized Intersection. Report No. FHWA-SA-22-10. Federal Highway Administration, Washington, DC., Nov. 2021.



project, South Dakota DOT reported an 80 percent crash reduction. And two years after installation at 15 additional locations, they reported a 78 percent reduction in crashes. [https://safety.fhwa.dot.gov/roadway\\_dept/pavement\\_friction/case\\_studies\\_noteworthy\\_prac/docs/SD%20HFST%20Noteworthy%20Practice.pdf](https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/case_studies_noteworthy_prac/docs/SD%20HFST%20Noteworthy%20Practice.pdf)

### **3. Can HFST be applied in conjunction with rumble strips?**

- There are no known issues with applying HFST in conjunction with rumble strips. In fact, because they serve different purposes (rumble strips alert the driver to lane departure and HFST provides additional traction for potential evasive recover maneuvers) they will complement one another as a redundancy practice under the Safe System Approach.
- If rumble strips already exist on the roadway where HFST is to be applied, avoid placing HFST over the rumble strips (i.e., mask off the rumble strips) since the resin binder will flow down into the rumble strips, potentially filling the rumble strips and reducing resin binder thickness on the surface. If rumble strips are to be installed after HFST, the HFST should be applied as usual and the rumble strips milled into the pavement through the HFST after the resin binder has fully cured (e.g., minimum 24 hours after placement). Similarly, recessed striping and recessed markers may be installed by grinding through the HFST with milling equipment.

### **4. Does HFST accelerate tire wear?**

- Excessive tire wear should not be an issue since HFST is applied only at spot locations for smaller areas. The safety benefits of HFST likely far outweigh tire wear as a concern.
- Illinois DOT reported receiving a few complaints from the public regarding perceived tire damage, but no further action was taken.

### **5. What maintenance is required for HFST?**

- A properly installed HFST should not require any routine maintenance typical of conventional pavement surfaces. However, if there is evidence of issues with the underlying pavement, such as subgrade pumping, potholes, alligator cracking, etc. conventional maintenance treatments such as crack sealing, pothole patching, and isolated repairs may be necessary to mitigate failure of the underlying pavement.
- HFST surfaces should be routinely monitored similar to conventional pavement surfaces if there is concern with dirt/debris buildup, leaf buildup, etc. The surface should be cleaned to maintain pavement macrotexture using the same methods as that for conventional pavement surfaces.
- Note that the effectiveness of HFST should not be judged based on surface appearance. An HFST surface that is showing signs of wear may still have excellent friction characteristics and would not necessitate replacement.

## 6. How is HFST removed and can it be recycled?

- HFST is typically removed with conventional milling processes. If only the HFST is to be removed and not the underlying pavement, micromilling or diamond grinding processes are recommended.
- If HFST is to be removed with the underlying pavement, it can be milled up and recycled with the underlying pavement. Because it is such a thin surface treatment, the amount of HFST should not affect the properties of the recycled material.

# COST

## 1. What is the average unit cost for HFST?

- Installed costs vary widely based on a number of factors related to agency contracting mechanisms, materials, and installation methods. Most projects are solicited as turnkey, and include mobilization, materials, labor, equipment, and traffic control. Please refer to the FHWA *HFST Site Selection and Installation Guide* for additional information on HFST cost and contact owner agencies for current bid prices.
- The cost per square yard has steadily decreased for larger projects and smaller projects which have been bundled together or with other safety-related items. Only including work pertinent to the HFST project, therefore increasing the chance of contracting directly with an established installer, can help reduce costs. In general, unless unavoidable, HFST projects should be stand-alone and not added onto paving or other related work through prime contracts, as the unit price for HFST can increase because of the additional percentages added by the general contractor.
- Many design and specification-related factors can contribute to the cost of the project. The larger the scope of the project, the lower the unit cost is likely to be. The proximity of locations to one another, time constraints on installation, and the cost of excessive material and acceptance testing will also impact project cost.

## 2. What is the benefit-cost ratio for HFST?

Published benefit-cost ratios (B/C) vary widely, based primarily on the processes used for site selection and the types of crashes (e.g., fatal and injury vs. property damage only) HFST is used to mitigate. PennDOT, the Kentucky Transportation Cabinet (KYTC), and Florida DOT all track project costs closely and regularly compute benefit-cost ratios. Based on a 2018 evaluation of 47 locations which had been in place for 3-5 years, PennDOT reported a B/C of 5.5 for all crashes and 2.4 for wet road crashes based on the KABCO scale and FHWA crash costs. KYTC has realized B/C greater than 30 for the past two years (as of 2021), and Florida DOT has reported an average 5-year B/C of 24.5 on tight curves using the KABCO method.

[https://safety.fhwa.dot.gov/roadway\\_dept/pavement\\_friction/case\\_studies\\_noteworthy\\_prac/docs/PA%20HFST%20Noteworthy%20Practice.pdf](https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/case_studies_noteworthy_prac/docs/PA%20HFST%20Noteworthy%20Practice.pdf)

### 3. How should the cost of HFST be evaluated?

Although it is a pavement surface treatment, any life-cycle cost evaluation of HFST should consider the benefit-cost from crash reduction as a safety countermeasure. While HFST is a low-cost safety countermeasure when compared to treatments such as roadway geometric improvements, it is generally not competitive based on first cost or even life-cycle cost with other low-cost safety countermeasures and pavement treatments when solely considering the cost of the treatment. However, when the safety benefit is considered (see benefit-cost ratios, above) in a life-cycle cost analysis, HFST is highly competitive.

## ENVIRONMENTAL

### 1. What effect does HFST have on road noise?


- In general, HFST will be less noisy than transversely tined concrete pavement, chip seals, and certain dense-graded asphalt pavements. While HFST does increase macrotexture depth, the relationship (for all types of pavement surfaces) between macrotexture depth and noise level is extremely weak. Therefore, it is not a valid conclusion that higher texture depth will lead to more noise.
- Some noise reductions and pavement color changes may be perceived by drivers, especially on curves, which may tend to cause a reduction in average speeds. However, additional research in this area would be needed to substantiate or refute this question.
- Overall, since most HFST installations only span from the point of curvature (beginning of the curve) to the point of tangency (end of the curve), the difference in the sound level produced by driving over the HFST will only last for a few seconds, and then the vehicle will be back on the regular pavement surface.
- Limited testing of tire-pavement noise by The Transtec Group on two HFST sections (one in Kansas and one in Montana) approximately one year after they were installed indicated that HFST applied over chip seal was slightly quieter (expressed as overall onboard sound intensity (OBSI) in A-weighted decibels (dBA)):<sup>3</sup>
  - Chip seal: ~104.4
  - HFST: ~101.95

For the HMA, HFST was slightly louder:

- HMA: ~98.75
- HFST: ~100.05

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<sup>3</sup> Merritt, D. and M. Moravec. Performance of High Friction Surfacing Demonstrations in the U.S. Proceedings of the 7<sup>th</sup> Symposium on Pavement Surface Characteristics: SURF 2012. Norfolk, VA. Sept. 2012.



*Note: 3 dBA is essentially the minimum threshold for human-perceived change in noise level.*

- The Kansas Department of Transportation further studied possibility of using HFST to reduce roadway noise through the construction and testing of an HFST test section.<sup>4</sup> This study revealed that HFST produced only a small decrease in exterior road noise ranging from 2.6 to 3.1 dBA. However, this study noted that HFST changed the tonal frequency of tire-pavement noise, such that noise was less offensive to the human ear.

## **2. What are some of the potential environmental benefits for HFST?**

- No physical reconstruction of road surface so no inadvertent changes in drainage patterns.
- No increase in impervious area footprint.
- Short construction timeframe results in less chance of environmental-related mishaps during construction.
- Minimal footprint for staging and construction.
- Installation eliminates complete road closure and lengthy detours due to HFST's capability of being applied one lane at a time, resulting in less pollution due to congestion and less traffic delay.
- Please refer to a case study highlighting a successful installation of HFST by Caltrans in an environmentally sensitive area: [https://safety.fhwa.dot.gov/roadway\\_dept/pavement\\_friction/case\\_studies\\_noteworthy\\_prac/nocal/](https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/case_studies_noteworthy_prac/nocal/)

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<sup>4</sup> Linden, E., M. Stewart, S. Embers, S. Cho, and K. Wanklyn. Use of High Friction Surface for Highway Noise Reduction. KDOT Report No. KS-18-01. Kansas Department of Transportation. Topeka, KS. May 2018.


# MATERIAL SPECIFICATIONS / DURABILITY

## 1. What is the life expectancy of HFST?

- The condition of the pavement over which the HFST is installed and the quality of the HFST installation will likely have the biggest impact on life expectancy. For a properly-installed HFST over structurally-sound pavement, life expectancy will vary with climate and roadway characteristics, such as geometry, volume and mix of traffic, and the nature of traffic movements. Accordingly, it is difficult to generalize.
  - Due to its relatively recent adoption in the United States, a limited number of HFST installations are older than 10 years, but there are a number of installations throughout the country that are still intact and performing well in reducing crashes after 8-10 years of usage without failure.
  - HFST testing on test tracks with accelerated aging/loading has shown some HFST sections continuing to last and provide friction enhancement capability with over 30 million equivalent single-axle loads (ESALs) of wear.  
<https://eng.auburn.edu/research/centers/ncat/files/technical-reports/rep18-04.pdf>  
<https://eng.auburn.edu/research/centers/ncat/files/technical-reports/rep15-04.pdf>
  - International experience indicates at least 7-12 years of service can be expected with correctly applied installations. The Road Surface Treatment Association from the United Kingdom reports an average service life of 12 years for cold applied HFST, such as those used in the United States.<sup>5</sup>
- Just like pavement performance, HFST longevity is dependent on many factors, such as initial construction quality, friction demand, and traffic volume as well as the severity of the climate and the weight and number of heavy truck axles using the facility.
- Proper installation is critical to longevity and includes ensuring uniform application of adequate resin binder mil thickness and timely application of the aggregate to achieve adequate embedment.
- Vehicular traffic with heavy chains or studded tires will increase wear within the wheel path of the HFST.
- As a treatment used specifically to improve pavement friction, remaining life should be evaluated based on friction and not just treatment condition. Although an HFST may appear visibly worn and distressed, it may still have excellent friction characteristics and therefore still

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<sup>5</sup> RSTA ADEPT. Code of Practice for High Friction Surfacing, 2<sup>nd</sup> Edition. Road Surface Treatment Association. United Kingdom. 2017.



be effective as a safety countermeasure. Even when HFST is worn in the wheelpaths, but still intact outside of the wheelpaths, it will still provide benefit for reducing lane departures.

## **2. Are these materials resistant to fuels and common de-icing agents?**

HFST installations are resistant to both fuel spills and deicing chemicals in roadway environments. Once cured, the polymer resin will remain stable even when exposed to incidental levels of solvents or diesel fuel, for example.

## **3. What is the difference between HFST and other pavement preservation treatments such as microsurfacing and chip seal?**

- HFST is a safety treatment used specifically to enhance pavement friction, primarily for spot locations with high friction demand such as severe curves and braking areas. By using calcined bauxite, which is a manufactured aggregate with exceptional abrasion and polish-resistance, high friction test results are maintained over time. Installed HFST friction test results (from locked-wheel skid testing and continuous friction measurement) are over 70 and many times in the high 80s or low 90s. The HFST resin binder material is a thermosetting, polymer-based material, providing an 8-12 year friction-enhancing treatment.
- Other treatments such as microsurfacing and chip seal/seal coat are pavement preservation treatments that may also improve skid resistance, but are generally used primarily to extend the life of the pavement. These treatments produce initial friction readings generally lower than HFST, and that friction generally declines with time due to raveling, flushing, or polishing of the aggregate. Please refer to FHWA Turner-Fairbank Highway Research Center (TFHRC) publication titled "Evaluation of Pavement Safety Performance," which included a description of various pavement treatment types. The publication is available at:  
<https://www.fhwa.dot.gov/publications/research/safety/14065/14065.pdf>.

## **4. Is it worth the investment to use HFST compared to other friction treatments?**

- The answer to this question depends on the condition of the existing pavement and the severity and type of crashes at the candidate location. For a deteriorating pavement with substandard friction characteristics and minimal pavement life remaining, more conventional pavement treatments will help extend pavement life and restore standard friction characteristics for the short term. However, if crash data indicates that a higher level of friction is needed immediately, HFST may be more appropriate, even if it will only provide a short-term solution due to the condition of the existing pavement.
- HFST can also provide an immediate low-cost remedial solution for locations where geometric issues exist (e.g., inadequate superelevation, curve radius, site distance, etc.), until the more costly geometric improvements can be made.

- In general, while many pavement preservation treatments (microsurfacing, chip seal, etc.) can improve pavement friction, they will not provide the same level of friction, sustained over time, as HFST.

#### **5. Do these materials crack? If so, how do they resist crack erosion?**

- The materials typically do not crack on their own, but any cracks (and joints) in the underlying pavement will generally reflect through.
- If there is concern with erosion (pumping of subbase fines) at reflected cracks, these cracks can be sealed using conventional crack-sealing methods, ensuring that the sealant is recessed slightly below the top surface of the HFST and not overbanded onto the HFST.

#### **6. Are there any issues with thermoplastic on HFST?**

- No. Thermoplastic bonds extremely well and will in fact last longer when applied to the textured surface of HFST. Other marking materials also bond well, but pavement marking tape should be avoided since it does not adhere well due the textured surface of the HFST.
- Masking of existing thermoplastic striping and markings prior to HFST application will save the cost of removal and replacement of the thermoplastic, especially if the existing markings are in good condition. Any masking should be removed immediately after HFST application before the resin binder begins to harden.

#### **7. What aggregates are appropriate for HFST and what sources are available?**

- Refractory-grade calcined bauxite is the only HFST aggregate permitted by most agency specifications and the current AASHTO HFST specification (note that following this specification is not required by Federal law or regulation). Calcined bauxite has a decades-long proven track record of providing exceptional polish and abrasion resistance properties necessary for HFST. While there may be other natural aggregates that can provide satisfactory friction initially, the mineralogical and physical properties of engineered calcined bauxite aggregate makes this the only material proven to maintain high levels of friction over time. While calcined bauxite aggregate is traditionally imported from overseas, there are also domestic sources available.
- Alternative aggregates can be applied in a similar manner and may perform adequately in a less demanding environment, but in critical locations they have not provided the friction durability to be classified as HFST. Other aggregates, such as flint, basalt, taconite and granite have and continue to be evaluated for performance, but at this time only calcined bauxite is recommended by FHWA for providing the expected safety performance and durability required in an HFST application.
- Please refer to Question 11 below for several HFST aggregate durability studies related to aggregate testing from the National Center for Asphalt Technology (NCAT).



## 8. Can reclaimed aggregate be reused and are there any special requirements for disposal?

- During the HFST installation process, the calcined bauxite aggregate is applied “to refusal” over the wet resin binder. This results in excess aggregate material that does not adhere to the resin and is swept up and reclaimed prior to opening the treated area to traffic.
- Use of reclaimed aggregate material should be considered very carefully. HFST aggregate is supplied to a specific gradation and, if not managed carefully, the process of reclamation may result in a material that does not meet the grading specification. Generally, reclaimed aggregate will have a finer gradation (i.e., higher proportion of smaller particles and dust) than virgin material. Smaller aggregate particles will not provide the same frictional properties, and excessive dust will inhibit embedment of actual aggregate particles into the resin binder during application.
- If reclaimed aggregate is acceptable within an agency’s specification, then the following should be considered:
  - Place only enough aggregate material to completely cover all wet resin binder without undue excess material. Note that fully-automated application processes tend to control application rate better than manual application.
  - Clean treated and adjacent surfaces (e.g., adjacent lanes and paved shoulders) thoroughly prior to HFST application and do not attempt to reclaim HFST aggregate from unpaved shoulder/gravel edges to prevent the introduction of foreign material into the reclaimed material.
  - All recovery sweeping equipment should be thoroughly cleaned and inspected prior to the sweeping operation to prevent the introduction of foreign matter into the reclaimed aggregate.
  - Upon completion of the sweeping operation, estimate the accumulation weight and obtain a representative test sample to identify the gradation of the reclaimed material.
  - Complete and record gradation tests of the reclaimed aggregate. If necessary, require that the reclaimed aggregate be washed or sieved to reduce dust and smaller aggregate content. Reclaimed aggregate should not be introduced in lower dilution ratios than one part of reclaimed aggregate to two parts of prime (virgin) aggregate. Reintroduction should only be performed using methods that will ensure complete blending of reclaimed aggregate with virgin aggregate.
- Calcined bauxite is an inert and non-toxic material. Therefore, disposal of recovered or excess aggregate material should follow standard practices for conventional aggregate materials.

## 9. What are some typical polished stone values (PSV) for HFST aggregates using ASTM E 303/AASHTO T 278 British Portable Pendulum Tester and ASTM D 3319/AASHTO T 279 British Wheel Accelerated Polishing Machine?


- Testing HFST aggregate for PSV is fairly common practice. However, keep in mind that PSV testing used in Europe based on the British method (EN 1097-8) is different than the ASTM method (ASTM D 3319/AASHTO T 279) even though the testing apparatus is the same. Also, the gradation of aggregate specified for PSV testing per ASTM is different than that commonly specified for HFST. This requires a modification of the test method that has not yet been defined within the ASTM. In order to use the PSV requirement for high-friction aggregates within a specification, a value greater than 40 will be required. This value is determined by using the primary "main scale" of the British Pendulum rather than "F-scale" which is used when measuring PSV in accordance with the British (EN 1097-8) test method. Use of these testing procedures is not required under Federal law or regulation.
- The Micro-Deval Apparatus (MDA) is another test method used to evaluate abrasion and polish resistance of HFST aggregates in accordance with ASTM D 7428. The AASHTO specification recommends a maximum of 5 percent mass loss using this test method (note that the use of these testing procedures is not required under Federal law or regulation).

## 10. Several HFST aggregate durability studies were published in cooperation with FHWA and the National Center for Asphalt Technology (NCAT):

- High Friction Surface Treatment Alternative Aggregates Study  
<https://eng.auburn.edu/research/centers/ncat/files/technical-reports/rep15-04.pdf>
- Evaluation of Laboratory Friction Performance of Aggregates for High Friction Surface Treatments <https://www.eng.auburn.edu/research/centers/ncat/files/technical-reports/rep17-01.pdf>
- Evaluation of the AIMS2 and Micro-Deval to Characterize Aggregate Friction Properties  
<https://www.eng.auburn.edu/research/centers/ncat/files/technical-reports/rep17-02.pdf>

## 11. Can HFST be placed on a bridge deck?

- HFST can be applied to bridge decks. In fact, the concept for HFST originated in the U.S. as a polymer overlay bridge preservation treatment. However, while the polymeric resin binder and installation methods used for polymer bridge deck overlays are similar to that used for HFST, polymer bridge deck overlays are used primarily to help seal and protect the bridge deck, with friction as a secondary benefit. The common practice for bridge deck overlays is to apply a double layer of resin binder and aggregate for insurance against water penetration of the deck, and to provide added durability to the surface.
- If a bridge is in a curve and identified as having a crash problem, a double layer of HFST could be substituted for a conventional bridge deck polymer overlay and accomplish both purposes—



protection and crash reduction. This has been done in many locations across the country, especially on roadways or ramps where an adjacent roadway segment is considered for HFST. Many interchanges and ramps, for example, may have non-standard geometry resulting in crash problems on both bridge and roadway segments. An HFST treatment applied to both would allow for friction enhancement and crash reduction regardless of the underlying roadway type.

## **12. Are HFST systems proprietary?**

In general, all HFST equipment and materials are commercially available, although the resin binder formulations are proprietary. There may also be proprietary components to certain application equipment. Some agencies will install HFST with their own maintenance crews, which will likely necessitate manual placement methods, and should therefore be limited to smaller applications.

## **13. Is there a certification process for contractors who want to perform this type of work or training resources for agency inspectors?**

- Currently there are no certification processes for HFST installation. A robust project specification makes worker knowledge and experience less of a factor in the quality of the end product.
- The best way to address the issue of contractor performance is to develop a robust project specification that requires previous HFST installation experience, completion of a test strip to demonstrate installation, and several quality checks. These project requirements hold the bidders accountable for meeting the specifications for a proper installation.
- Inspector training is another way to help ensure that inspectors better understand what to watch for during installation. Including a requirement for training of project inspection personnel in the project specification through a “just-in-time-training” approach is recommended to help ensure project inspectors receive the necessary training. With this approach, project specifications/special provisions include a requirement for training of project inspectors. As such, the cost of training is included in the project itself and the designated project inspectors can be trained just prior to HFST installation. At least one vendor offers an HFST installation and inspection training course that can be used for this purpose. FHWA also provides training materials and is working diligently to try to help State agencies write a better specification to cover some of these concerns.
- FHWA has produced a pocket installation guide with inspection checklist that can be downloaded from the website below and viewed on a mobile device in the field if needed.  
[https://safety.fhwa.dot.gov/roadway\\_dept/pavement\\_friction/high\\_friction/](https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/high_friction/)

## **14. Are there specifications for HFST?**

- The AASHTO Standard Specification, *High Friction Surface Treatment for Asphalt and Concrete Pavements Using Calcined Bauxite* (MP 41-19) is available for agencies to adopt in whole or in parts to their construction specifications. Use of this specification is not required by Federal law or regulation.

- Many State and local agencies now have mature specifications or special provisions for HFST that have been revised over time based on their experience. Standard specifications and special provisions used in states such as California, Delaware, Florida, Georgia, Illinois, Kentucky, Louisiana, Maryland, Pennsylvania, South Carolina, Tennessee, and Texas are often used as reference points for agencies that are developing their own standards for HFST.

## LESSONS LEARNED


### 1. What are the lessons learned with HFST installation?

- Common issues contributing to installation problems are due to one or a combination of the following practices:
  - Improper mixing of the resin binder system, either manually or by automated equipment that did not have fail safes or monitoring devices. This can result in resin binder that does not properly cure, leading to early loss of aggregates and premature wear in the wheelpath. Installations for which resin binder manufacturer instructions have not been followed can encounter problems.
  - Improper placement of the resin binder by applying it either too thin or too thick or by disturbing the resin after it has begun its gel phase.
    - If the resin material is placed too thin, it may not have sufficient depth to embed and retain the aggregate for long-term durability. Proper resin binder thickness should be indicated based on pavement macrotexture depth.
    - If the resin material is placed too thick, it may fully encapsulate the aggregate material, leading to a lower friction (glassy) resin surface and lower macrotexture to channel water away. A thick resin binder layer can also lead to higher shear stresses at the HFST-pavement interface, which can lead to delamination or substrate failure. When the material is placed on steep grades or banked roadways, it may also exhibit creep or drift towards the lower side of the roadway during curing, leading to an unevenly thick resin binder layer.
    - If the resin is disturbed after placement as it begins to build its strength in the gel phase, it may lead to a reduction in the strength properties of the final cured resin material. Sweeping excess aggregate too soon, before it has properly cured, can lead to aggregate loss and exposed pavement.
  - Application of aggregate after resin binder has begun to gel. Aggregate should be broadcast onto the resin binder immediately to ensure proper embedment. Resin binder tends to gel very fast at high temperatures, and gelled resin binder will resist aggregate penetration. This is a primary advantage of automated continuous application systems which broadcast the aggregate within seconds after placement of the binder resin.

- Improper embedment depth. Embedment depth should typically be 50 percent of the nominal aggregate size to ensure that the aggregate is held firmly in place by the resin binder while still providing adequate texture for frictional resistance and bulk water drainage. Embedment is affected by resin binder application rate which is dictated by pavement macrotexture depth.
- Application of HFST to newly-constructed pavements. HFST should not be applied to asphalt or concrete pavements that are less than 30 days old. This allows for release of oils, volatile organic compounds, etc. For concrete pavement, all curing compounds should be removed and the surface properly shot-blasted. Shotblasting removes concrete surface contaminants and increases macrotexture to facilitate bonding of the resin binder.
- Application of HFST to pavements in poor condition. Highly distressed pavements exhibiting extensive cracking, raveling, flushing, and subbase pumping will likely fail beneath the HFST under traffic and over time. Failure of the underlying pavement will result in failure of the HFST even when the resin binder and aggregate remain bonded to the failing pavement.
- Environmental requirements were ignored. The pavement surface should be dry at time of installation, and the ambient and surface temperature should be above the manufacturer's minimum recommendation. For most polymer resin binders, a minimum temperature of 50°F and rising is typical, while some recommend even higher minimum temperatures. Other polymer binders are available that can be installed at lower temperatures per the manufacturer's direction. Please see general temperature conditions under INSTALLATION.

## **2. What pavement conditions caused failures that have been reported?**

- Highly distressed pavements. Pavements exhibiting extensive durability-related cracking such as alligator, block, and map cracking. Any pattern cracking that is visible on the pavement likely makes the pavement a poor candidate for an HFST installation.
- Pavements exhibiting rutting, shoving or signs of subgrade failure are likely poor candidates for HFST.
- Poorly draining pavements. Pavements in sag curves with poor drainage and curb and gutter locations where water tends to collect. Pavements exhibiting subsurface moisture issues and the migration of subgrade fines have also led to premature failure of the underlying pavement and HFST and therefore are poor candidates for HFST. Subsurface moisture issues may not be present and obvious at all times and therefore should be checked after rain events.
- Chip seal (seal coat) in poor condition. Chip seal or seal coats exhibiting raveling or flushing in the wheel paths has led to failures. While HFST will adhere to flushed surfaces, the bond will not



be very strong due to a lack of macrotexture. In some cases, shot blasting can be used to enhance macrotexture prior to HFST installation.

- Open graded asphalt surfaces. When applied to an open graded asphalt surface, a very thick and rigid layer of resin binder is created as the resin binder fills the voids in the pavement surface. This thick layer will have different thermal properties from the underlying asphalt layers and can lead to delamination of the open graded surface from underlying layers or substrate failure of the underlying layer. A best practice is to remove existing open graded asphalt surfaces and replace them with a conventional asphalt surface before applying HFST.
- Replace pavement in poor condition prior to installing HFST to increase service life expectancy. Following recommendations, such as a 30-day cure period for new asphalt and concrete pavements prior to installing HFST, will increase the likelihood of a successful installation.

### **3. Can patches that de-bond be fixed?**

- This is not common but can be caused by an isolated spot on the pavement that was not cleaned well or had undetected solvent on the pavement. However, if small localized sections of HFST de-bond from the pavement, this can easily be repaired by milling back to a well-bonded area, cleaning the area well, and applying polymer resin and aggregate by hand to blend the patch in with the existing material.
- More common is when a small section of pavement "pops out," but the HFST is still bonded to the fragment of pavement. If this is a limited occurrence, it does not indicate a catastrophic failure of the HFST and generally means the underlying pavement had a weak area and debonded from a lower layer of pavement. The pavement should be repaired and HFST reapplied if the area is large enough to cause roadway issues. If asphalt is used to patch the pavement, HFST should not be placed for at least 30 days. And if concrete is used, any curing compound should be removed and the surface cleaned before applying the HFST, since curing compounds act as bond breakers.

### **4. Will the polymer have a reaction with magnesium on a bridge deck?**

No reactions have been found with magnesium chloride deicers. Some concrete repair materials may contain magnesium phosphate so it is important to consult the HFST resin binder manufacturer prior to the installation of any repair or patching material to confirm compatibility and installation requirements.


## **INSTALLATION**

### **1. What surface preparation and installation conditions are important for successful installation?**

#### *General*

- All manufacturer installation instructions and specifications should be followed.

- Surface preparation is key for a successful HFST installation. Shotblasting for concrete and high-pressure air wash for asphalt pavements should be done in advance of HFST application.
- Because HFST resin binders are thermosetting materials, temperature is a very important condition to consider for HFST installation. Temperature limitations for installation depend on the type of polymer resin binder being used as well as the method for applying the aggregate.
  - A general rule of thumb is to not install HFST when the pavement surface temperature is below 50°F (or expected to fall below 50°F during installation) unless the resin binder system is formulated specifically for cooler temperatures. It is important to follow resin binder manufacturer recommendations for temperature restrictions. Also keep in mind that most resin binders cure slower in cooler temperatures, which will impact installation time.
  - As temperatures rise, the resin binder system will reach initial gel faster. Automated methods for aggregate application are often capable of fully covering the resin binder before it begins to gel at these higher temperatures. As ambient temperatures reach 95°F and above, most resin binder systems will begin to thicken and gel within minutes. It is important to verify that the aggregate can be fully applied at the specified coverage rate before the resin binder begins to thicken. If the aggregate is not broadcast to the specified coverage rate while the resin binder is still in its liquid state, the application is at risk of only partial embedment of the aggregate. This can lead to early loss of aggregate in the wheel path and failure of the HFST system to provide the required friction values. Many agencies require a test section to determine that the method of aggregate application will be sufficient to install HFST at the required temperatures. It is important to follow agency specifications and the resin binder manufacturer's instructions for the HFST application.
  - Both surface and ambient temperatures are critical to a successful installation. If the aggregate can be applied to the resin binder immediately, HFST can be installed at temperatures exceeding 100°F (depending on manufacturer recommendations) as long as the resin binder has enough time to penetrate the pavement surface prior to reaching initial gel. Hence, continuous automated installation is the preferred method.
- It is generally not practical or necessary to remove small oil spots, but very large or heavily saturated oil spots may need to be removed by aggressive washing with approved detergents and rinsing with clean water. These deposits are more common at intersection locations where vehicles tend to sit on the pavement at the intersection approach. When washing techniques are used, proper drying time and/or drying techniques should be considered. In some instances, heavily contaminated pavement should be removed and replaced.
- There should be no visible moisture present on the pavement surface at the time of the resin binder application. Compressed air may be used to help dry and remove moisture from pores in the pavement surface. A surface moisture test consisting of a plastic sheet taped in place on the




pavement surface for a minimum of 2 hours, in accordance with ASTM D 4263, may be used to verify if the surface is dry enough for HFST application if there is any question. Use of this testing specification is not required by Federal law or regulation.

- Utilities, drainage structures, curbs, active joints, and any other structure within or adjacent to the treatment location should be protected against the application of the surface treatment materials. Existing pavement markings to be preserved adjacent to the application surface should be masked or care taken that the binder does not cover the markings. High-tack adhesive tape can be used to outline the perimeter of the application area, cover pavement markings, or to protect joints, etc.
- Pavement markings that are not covered or consist of material other than paint should be removed. *HFST will not fully adhere to thermoplastic road markings.* The removal method may be grinding, light milling, shotblasting, or water blasting after which the surface should be dried and swept clean prior to HFST application. Pavement marking lines should be considered clean when the pavement has exposed aggregate showing through the existing marking. Care should be taken to not damage or gouge the pavement surface when removing pavement markings. Uneven surfaces should not be repaired with the HFST system.
- Pavement cracks greater than 1/4 inch in width and depth should be sealed 30 days prior to HFST installation if rubberized asphalt or similar products are used. Several manufacturers offer crack sealing materials that are compatible with HFST resin binder and may eliminate the 30-day cure period. When sealing cracks, it is important to ensure the sealant is recessed slightly below the pavement surface and not overbanded onto the pavement. Most agencies specify that joints and cracks less than 1/4 inch be pre-treated with the mixed polymer resin just prior to HFST placement. Once the polymer in the pre-treated areas has gelled, the HFST binder and aggregate topping installation may proceed.
  - Repair all pavement defects such as spalls, potholes, raveling, and rutting prior to placing HFST. Consult the binder resin manufacturer to ensure compatibility of repair materials with the HFST system. Clean and fill all inadequately sealed joints, including shoulder areas within the treatment area. HFST may be applied over pavements exhibiting minor rutting or heaving; however, it should not be used as a repair for these conditions (e.g., to fill ruts). Proper evaluation of pavement condition during the project selection and design stage is important before considering HFST.

### *Concrete Surfaces*

- HFST should not be applied to portland cement concrete that has been in place less than 30 days. Concrete surfaces should be abrasively cleaned by shot blasting to remove oils, dirt, rubber deposits, curing compounds, paint carbonation, laitance, weak surface mortar, and other potentially detrimental contaminants that may interfere with the bonding or curing of the HFST. Shotblasting should achieve an International Concrete Repair Institute concrete surface profile





(CSP) of 5. Shotblasting should always be followed with a high-pressure compressed air wash to remove any latent dust from the shotblasting process.

- When using rapid strength concrete to shorten the 30-day waiting period prior to HFST installation, it is critical to qualify compatibility of the patching materials/rapid strength mortars with the HFST polymer resin binder as some patching materials may not provide a good bonding surface. No matter what material goes on top, installers should always refer to the manufacturer's installation instructions to determine if it qualifies as compatible with the repair material.

### *Asphalt Surfaces*


- Before placement of HFST on an asphalt surface, the entire surface should be cleaned using a high-pressure air washing or other approved washing methods to remove oils, dirt, rubber deposits, paint, laitance, and other potentially detrimental contaminants that may interfere with the bonding or curing of the HFST. Acceptable cleaning should result in a surface with no oil spots, dirt, or other debris. Asphalt deposits larger than one inch in diameter and smaller areas spaced less than six inches apart should be removed.
- For applications on new asphalt pavements, it is recommended to wait a minimum of 30 days after paving before installing HFST. Asphalt pavements that still appear to be "tacky" or look wet on the surface should be evaluated for possible extension to the waiting period prior to installing the HFST. On open-graded friction course asphalt surfaces, stone mastic asphalt, or pavement that has been treated with prior surface treatments (e.g., microsurfacing, slurry seal, etc.), contact the resin binder manufacturer for more information.
- Several agencies have experimented with pressure washing or lightly shotblasting new asphalt surfaces to shorten the 30-day waiting period. This practice is not recommended since the potential for trapping moisture or volatile oils can still be a risk and can contribute to the failure of the HFST installation.

## **2. Can you apply HFST over existing striping?**

- In general, HFST can be applied over painted lines, but thermoplastic lines should be removed prior to HFST installation. If the existing pavement markings are in good condition, it is recommended that the markings be retained by masking them off prior to HFST placement. Refer to resin binder manufacturer recommendations before applying over any surface treatment like paint lines.

## **3. Is installation over an open-graded friction courses (OGFC) an issue?**

- While there have been many successful applications of HFST on OGFC, it is not recommended practice. OGFCs are relatively thin and the bond with underlying asphalt layers can be a highly variable. This has led to a few problematic installations since it is often difficult to detect



underlying pavement issues. Recommended practice is to remove OGFC within the limits to be treated with HFST and place conventional asphalt pavement prior to HFST.


- Successful installations over OGFC have used a double layer treatment to seal the voids with the first layer and use the top course to maintain the proper binder depth, which is necessary for the aggregate embedment into the HFST riding surface. However, the following precautions should be considered for placing a double layer HFST:
  - Since a double layer is less flexible than a single layer, a sound pavement is most important. A double layer creates a thick layer of resin binder which is much less flexible than a single layer system and the underlying pavement (asphalt in particular). This thicker layer can increase shear forces at the bond interface due to differing thermal properties, leading to delamination (of the HFST or OGFC) or substrate failure.
  - Resin binder demand, or the application rate required to achieve proper aggregate embedment will likely be different for the second layer than the first, depending on the texture of the existing pavement surface.
  - A double-layer HFST is also less permeable than a single layer system, which increases vapor pressure between the HFST and underlying pavement, increasing the potential for stripping of underlying bituminous pavement surfaces.
- Additionally, if placing HFST over OGFC, the shoulder on the high side of the superelevation may need to be sealed to keep water from running through the OGFC and under the HFST, which can cause failure. It may also be necessary to extend the HFST further when the curve is on a grade in order to seal the OGFC to prevent water from running down the grade and under the HFST as well. Be aware that this adds to the quantity of HFST required.

#### 4. What are some of the key factors that can affect the placement of HFST?

- Current methods of installing HFST vary based on recent advancements and the automation of mixing and placement equipment. Although some agencies still allow hand mixing and placement for HFST, the opportunities for human error with these methods are significant and warrant stringent quality control procedures within a specification to ensure consistent and proper application. The selection of different methodologies depends on the size of the installation, site-specific conditions like storage and ready access, and the availability of acceptable detour routes or traffic restrictions.
- Because the HFST system will have a greater coefficient of thermal expansion than the pavement substrate, applying an even and consistent wet mil thickness for the resin binder is critical to the longevity of the system. Variable thickness within the HFST installation can increase the potential for cracking and spalling, especially when installed on pavements that show signs of degradation.
- Consistent mil thickness of the HFST is also important for maintaining even contact with vehicle tires. Any high spots that are created because of un-even installation practices can create "point loading" under traffic over the HFST system. These high spots can potentially transfer very high dynamic impact to the underlying pavement potentially leading to early age spalling and delamination of the HFST.
- Prompt application of aggregate onto the resin binder is important to ensure proper embedment of the aggregate within the resin binder. At higher temperatures, resin binder systems tend to reach initial gel within minutes. When the binder gels, the viscosity increases which can inhibit aggregate penetration and proper embedment. This can result in premature loss of surface aggregates.

#### 5. What is the difference between manual and fully automated HFST installation?

- There are two main methods for installing HFST: manual and fully automated. The preferred application method depends on the size of the project, the number of installations within the contract, and specific project needs. For example, manual installation may be used for small spot-treatments or irregular areas where a fully automated process is not practical, while a fully automated process might be used for larger contracts consisting of numerous sites. Most agencies contract out their HFST installations to avoid purchasing HFST-specific equipment. Regardless of the method used for installation, robust specifications and good inspection practices are essential for a proper installation, but particularly for manual installation where there are more opportunities for human error.
  - **Manual** – Manual HFST application is ideal for small spot locations of 200 SY or less where it may be difficult or not economical to bring in automated installation equipment. For a completely manual application, the resin binder components and any additives are manually proportioned and mixed on site in a large mixing vessel. The



mixed resin binder is poured onto the prepared surface and spread to the proper mil thickness using notched squeegees. Next, the aggregate is broadcast on top of the resin binder. There is no preferred method to broadcast the aggregate, but the binder should be completely covered (i.e., until refusal). While the manual application method is ideal for keeping costs low on small projects, this method has a few drawbacks. Given the opportunity for human error and inconsistency in all aspects of application (proportioning, mixing, and placing resin binder and application of aggregate), quality and uniformity of manually applied treatments are a concern. Manual application is a much slower process and working under live traffic conditions increases safety risks by prolonging workers' exposure to traffic. In addition, the prolonged presence of a work zone can potentially cause secondary crashes. While there are several mechanically-assisted methods for resin binder proportioning and mixing and aggregate application which may help reduce human error, these devices generally do not improve resin binder application and may only marginally decrease application time.

- **Fully Automated** – A fully automated HFST application typically involves a truck that is customized to condition, meter, and mechanically blend the resin binder components in accordance with manufacturer guidelines based on the current ambient or surface temperature. These machines are capable of applying a consistent and uniform wet mil thickness of the resin binder to the proper application rate, followed immediately by a uniform layer of aggregate, without any manual squeegeeing or spreading. The truck contains the binder and aggregate in large bulk containers on its chassis. The application can be customized to the intended lane width of the treatment. The fully automated method minimizes lane closures due to quick installation time and reduces the number of workers on the roadway. The installation speed and the uniformity of application of binder and aggregate reduces the risk of premature failure and improves the likelihood of a higher quality application. This method may reduce overall cost on large projects or projects bundled from numerous small installations.

## 6. Can agency personnel install HFST?

Yes, but agency personnel should receive proper training before attempting an installation, and a trial project or test strip is highly recommended if the installation crew does not have prior experience. Due to the cost of investment in automated application equipment, agency personnel will typically use manual installation methods. As such, this should be limited to small or isolated applications only.

## 7. What are items to look for in terms of early-age performance that may indicate materials and workmanship issues?

- Uncured resin binder. This will normally appear as a discolored area where the HFST is soft and is typically caused by improper or incomplete blending of the resin binder components. These areas will not retain aggregate under traffic wear and should be removed and patched.
- Aggregate loss. HFST will normally shed aggregate over the first 24-72 hours after opening to traffic. This aggregate will accumulate along the edge of the lane or out in the shoulder or adjacent lane and should be removed through re-sweeping. If significant aggregate loss continues, the cause should be further investigated.
- Delamination. This generally manifests as “sheets” of HFST peeling away from the underlying pavement and may be caused by improper surface preparation. Sounding techniques can be used to identify the extent of delamination. These areas should be patched.
- Aggregate polishing. Polishing will cause the surface to have a smooth or glassy appearance under traffic wear. Calcined bauxite aggregate should not polish and therefore any polishing should be investigated further.
- Discoloration. This will appear as a visible difference in color of localized areas, and may be an indicator of moisture trapped beneath the HFST. It does not necessarily indicate a problem with the HFST but should be monitored over time.
- Surface wear loss of HFST. This is a condition when the HFST wears off, exposing the underlying pavement. It generally begins with loss of aggregate, which exposes the resin binder which is quickly worn off by traffic. It is an indicator that the HFST resin binder was placed too thin, aggregate was applied after gelling occurred, or the resin binder was not strong enough to retain the aggregate, and will call for the reapplication of HFST.
- Friction loss. Friction loss is identified through routine measurement of HFST friction. A sustained decrease in friction indicates a problem with the aggregates (e.g., polishing) or the HFST system.
- Failure of underlying pavement. This generally manifests as potholes in the HFST surface where both the HFST and underlying pavement break away under traffic and is more common with asphalt pavement. It generally indicates a cohesive failure within a weak asphalt layer or stripping of the asphalt due to moisture. Isolated areas can be patched but if deterioration progresses, removal and replacement should be undertaken.

### For additional information, please contact:

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