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An Innovation Partnership with States

Frequently Asked Questions – High Friction Surface Treatments (HFST) – 2017

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

Definition

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

Description

- HFST places a layer of highly durable, anti-abrasion and polish-resistant aggregate over a thermosetting polymer resin binder. The mineralogical and physical properties of these aggregates make the overlay exceptionally resistant to wear and polishing by traffic. The polymer resin binder locks the aggregate firmly in place, creating an extremely durable surface capable of withstanding even the most extreme roadway demands, from cornering and heavy braking to snowplowing. HFST restores, and, in most cases, significantly enhances, pavement surface friction where traffic has worn down existing pavement surface aggregates. HFST can also help compensate for inadequate geometric designs, such as sharp curves and substandard superelevations.
- Aggregates used for HFST, by definition, have a high polished stone value (PSV). Please see question #11 under the **Material Specifications/Durability** section for more details on PSV. Laboratory PSVs have been correlated with successful HFST performance in field installations. Although several aggregates have been evaluated, only calcined bauxite aggregate has consistently met the threshold for performance necessary to be used for HFST.

2. What is the purpose of HFST?

- HFST can enhance the ability of a road surface to provide adequate pavement friction for vehicles in critical braking or cornering maneuvers. Maintaining the appropriate amount of pavement friction is critical for safe driving. Compared to tangent sections of road, horizontal curves and intersections have a much greater friction demand for keeping vehicles on the road and ensuring safe 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 the available pavement friction. Reduced friction can contribute to vehicles losing control or skidding when they are traveling at excessive speed, make abrupt turns, or brake excessively. Higher friction, maintained with polish-resistant aggregates, helps to keep vehicles on track.

3. Where is HFST likely to be beneficial?

- HFST technology has benefited State transportation agencies, counties, cities, Tribes, and Federal agencies across the country. The greatest benefit from HFST is often gained where friction demand exceeds the available friction of a roadway surface. These areas are often interchange ramps, rural curves, steep grades, and intersections. HFST has also been successful when used in lieu of costly roadway realignments, which can take years to complete due to delays associated with lengthy planning phases and budget constraints.
- While HFST has been proven successful in preventing crashes under dry roadway conditions, installing HFST where clusters of wet weather crashes have occurred may demonstrate the greatest benefit.
- Some agencies have made a determination to install HFST systemically as a preventive safety countermeasure based on specific roadway characteristics and friction at various locations. HFST can increase roadway friction significantly in locations with these common characteristics, thus increasing roadway safety.

4. Are there guidelines for HFST installations limits?

- Typically, HFST should be installed at a point where vehicles start to brake. At horizontal curves, brake lights are a good indication of where treatment should start. Most States will end the treatment at the point of tangency (PT).
- The Texas A&M Transportation Institute published a paper titled, "Evaluating the Need for Surface Treatments to Reduce Crash Frequency on Horizontal Curves" that provides recommendations on how to select start and end points for HFST installation. This paper can be found at: *https://static.tti.tamu.edu/tti.tamu.edu/documents/0-6714-1.pdf*

5. What is the state of HFST installations around the nation?

- The FHWA Office of Safety web portal provides a map for the current status of HFST implementation at: *https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/high_friction/*

SAFETY

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

- There are few CMFs available related to HFST at this time, but data collection efforts are ongoing.
- The FHWA Turner-Fairbank Highway Research Center (TFHRC), as part of the Evaluations of Low Cost Safety Improvements Pooled Fund Study, published the report "Evaluation of Pavement Safety Performance," which included some preliminary CMFs. The report indicated the results for the before-after study for treatment sites with adjustment using Highway Safety Manual

CMFs correction factor yield a CMF for total crashes of).653 for ramps and 0.385 for curves, and a CMF for wet-road crashes of 0.139 and 9.481 for ramps and curves. Additional data collection efforts are also underway, including studies of additional control sites to develop more robust CMFs and benefit-cost ratios. The evaluation report is available at: *https://www.fhwa.dot.gov/publications/research/safety/14065/14065.pdf*

- The Pennsylvania, Kentucky, and South Carolina DOTs report a before/after total crash reduction of 100 percent, 90 percent, and 57 percent, respectively, for their signature trial projects, for which the after periods were from three to five years. Kentucky went on to install and monitor 60 additional HFST applications during the 2010-2012 period; these sites are showing total crash reductions of 78 percent for the group, with wet-weather crash reductions of 85 percent. Additional analysis was performed in early 2015 and these sites are showing total crash reductions of 80 percent, with wet-weather crash reductions of 87 percent and dry-weather crash reductions of 58 percent.

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

- HFST should be considered when delineation treatments 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. While everything has a practical limit, in general, studies have shown that doubling the friction reduces the crashes by half.
- 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. Therefore, placing HFST provides a pavement that is polish-resistant and has excellent friction. Otherwise, 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 many fewer impacts.
- HFST provides one of the best long-term life-cycle costs available due to its durability and positive impact on safety. HFST has the potential to provide (and in many instances is already providing) a higher crash reduction rate than would be generally expected with lower cost safety treatments such as chevrons and rumble strip applications on horizontal curves. As mentioned previously, several States are experiencing large crash reductions of 50-100 percent after application of an HFST at specific sites. In addition, National Cooperative Highway Research Program (NCHRP) Report 617 indicates a crash reduction of 20 percent for all intersection crashes. Please refer to the FHWA Office of Safety – Roadway Departure, Pavement Friction webpage for case studies on crash reduction benefits: *https://safety.fhwa.dot.gov/roadway_dept/pavement_friction/case_studies_noteworthy_prac/*

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. The United Kingdom uses HFST as a safety countermeasure to specifically address motorcycle crashes at these locations. In addition, a colored version of HFST has been used for the treatment of many miles of bike lanes in the USA.

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

- No increase in 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.

5. Has accelerated tire wear from HFST been studied?

- Because HFST is applied only at spot locations for smaller areas, excessive tire wear should not be an issue. Getting people home safely far outweighs tire wear as a concern.

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 actually lower. The report can be found at: *http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_SF/BD500/BD500_v3_rpt.pdf*
- 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.
- Regardless of speed considerations, there have not been notable increase in crashes on treated segments. All of the crash evaluations to date have shown remarkable crash reductions, which is the bottom line.

2. What is the effect of snow plows on this pavement treatment?

- Because HFST is such a thin overlay, generally less than 1/4-inch in thickness, the effect from snow plows has been minimal, even where “bare pavement” policies are followed in locations 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.

3. 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. Always refer to resin binder manufacturer recommendations before applying over any surface treatment like paint lines.

COST

1. What is the average unit cost for HFST?

- Installed costs vary according to the quantity of material to be installed and the site location for the project. Most projects are solicited as "turnkey," meaning they including materials, labor, equipment, and traffic control. Project costs range from $21/yd^2 to $26/yd^2 as of 2017. However, the cost per square yard has been steadily decreasing for larger projects and where smaller projects have been bundled with other safety-related items. In addition, only including work pertinent to the HFST project, and 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.
- A 2017 project for Georgia DOT with multiple locations in 16 counties that totaled 1,200,000 yd^2 cost on average $21.00/yd^2. Multiple projects in California, New York, Pennsylvania, South Carolina, and New Jersey were priced in the same range. Some of these projects included the total project cost in the unit prices, including mobilization, traffic control, striping, remedial crack sealing, and, in some cases, patching.
- Many scenarios within an HFST contract can contribute to the cost of the project. The larger the scope of the project, the lower the cost per yd^2 will be. The same is true with the proximity of locations to be treated within a project. The closer locations are within a project, the more work the contractor can perform within each production day. Other items for consideration are the cost of excessive material testing and testing of friction values on a new HFST installation. Time constraints on project duration are often necessary to keep traffic flowing during construction, but most actual HFST production happens during short windows. The larger the window allowed for each production day the lower the cost will be. Keep in mind the cost of the polymer resin binder, equipment, and labor are the significant project bid drivers, not the cost of the aggregate.

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

- A recent before-and-after study for a series of curve installations by the South Carolina DOT indicates cost-benefit ratios of about 24 to 1. A recent study by Villanova University that assessed 122 rural two-lane roadway locations in Pennsylvania where HFST was installed between 2007 and 2015 shows a benefit-cost ratio range from 48 to as high as 105.

ENVIRONMENTAL IMPACTS

1. What effect does HFST have on road noise?

- In general, roads treated with HFST will be less noisy than transversely tined concrete pavement, chip seals, and certain dense-graded asphalt pavements. While HFST does increase the mean texture depth (MTD) and mean profile depth (MPD), the relationship (for all types of pavement surfaces) between MPD and noise level is extremely weak, and it is even worse for MTD. 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. Additional research in this area is 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.
- Tire-pavement noise was measured by The Transtec Group on two HFST sections (one in Kansas and one in Montana) approximately 1 year after they were installed. The Kansas installation was on a dense-graded asphalt pavement and the Montana installation was over a chip seal. These were very limited tests, and further study of this issue should be performed to generate more reliable correlations; however, the findings indicate that HFST applied over the chip seal was slightly quieter (expressed as overall onboard sound intensity (OBSI) in A-weighted decibels (dBA)):
    - Chip seal: ~104.4
    - HFST: ~101.95

  For the HMA, HFST was slightly louder:
    - HMA: ~98.75
    - HFST: ~100.05

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

2. Bike groups have expressed concerns about the abrasiveness of HFST. How is this being addressed across the country?

- To date no problems 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 being used to install colored aggregate that serves as delineation. This product has been requested by bicycle groups for bike lane surfaces because the texture provides a superior smoothness and should help reduce the problem of tires sliding when wet, which is common on some demarcation treatments.

3. What are some of the major environmental benefits for HFST?

- No physical reconstruction of road surface so no change in drainage patterns.
- No increase in impervious area footprint.
- Short construction timeframe results in less chance of environmental-related mishaps during construction.
- Installation eliminates complete road closure 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/*

MATERIAL SPECIFICATIONS / DURABILITY

1. What is the life expectancy of HFST?

- Life expectancy will vary with climate and roadway characteristics, such as geometry, volume and mix of traffic types, 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 8 years, but there are a number of installations throughout the country that are still intact and performing well in reducing crashes after 5-8 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 25 million equivalent single-axle loads (ESALs) of wear.
    - International experience indicates at least 7-12 years of service can be expected with correctly applied installations. A recent report by 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.
- Vendors have reported 5-8 years of service life for traffic volumes around 15,000 vehicles per day, and up to 5 years with traffic volumes closer to 50,000 vehicles per day.
- Just like pavement performance, HFST wear 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.
- Vehicular traffic with heavy chains and/or studded tires will increase wear within the wheel path of the HFST.

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 made for spot locations with high friction demand (shear forces) such as severe curves and braking areas. By using calcined bauxite, which is much smaller (1-3 mm nominal size) and possesses very anti-abrasion and polish-resistant material, as an aggregate, high friction numbers can be maintained over time. Installed HFST friction numbers (from locked-wheel skid testing) are over 70 and many times in the high 80s or low 90s. The HFST resin binder material is a thermosetting, polymer-based material and is an 8 to 12 year friction-enhancing treatment.
- Other treatments such as microsurfacing and chip seals are pavement preservation treatments that may also improve skid resistance, but are generally used 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 always worth the investment to use HFST compared to other friction treatments?

- The answer to this question likely depends on: (1) the condition of the existing pavement, since HFST only lasts as long as the pavement it is placed on, and (2) the severity and type of crash the location is experiencing. For a deteriorating pavement with substandard friction characteristics and minimal pavement life, the problem can be dealt with using more conventional pavement treatments to restore standard friction characteristics, at least for the short term. However, HFST may still be a good idea if the location has challenging geometric features and high incidences of speeding, since this tends to escalate pavement polishing and the problem may return even with new pavement installation.
- Many pavement preservation treatments (microsurfacing, chip seal, etc.) can improve available friction, especially on a polished pavement, and FHWA is currently working to establish and quantify the beneficial impacts of improved and enhanced friction as a result of the installation of selected pavement preservation treatments.
- It may not always be necessary to apply the treatment that provides the highest, most sustained friction at a particular site. Consideration should be given to the nature and severity of existing traction problems, life expectancy of the installation, and the friction demand produced by the traffic at the location.

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.

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

- Several indigenous aggregates can initially improve the friction of a pavement surface. However, it is important to maintain a distinction between improved initial friction and the long-lasting friction benefit from a true HFST. This benefit comes from the use of calcined bauxite aggregate which is highly abrasion- and polish-resistant.
- Bauxite is a natural resource, mined in many countries, principally for its use in the production of aluminum. Calcined bauxite used for HFST is categorized as 'non-metallurgical refractory grade' which comes from high-quality bauxite that is calcined, or heat treated, at 2900-3000°F, to produce a dense, high-purity, stable aggregate. Refractory grade calcined bauxite has a high-

alumina (≥ 82 percent Al_2O_3), low-alkali content (≤0.4 percent) and a bulk density of ≥ 3.0 with very low residual moisture levels.

- After the calcination process, the aggregate is subsequently crushed and sieved to a specific gradation to meet the specification requirements for HFST.
- Calcined bauxite has a resistance to polishing and wear that is superior to other aggregates.
- Generally, vendors that sell HFST systems procure the aggregate from mineral companies that specialize in the mining, calcining, crushing, and grading process for specialized aggregates. A U.S. Geological Survey report states that a world bauxite shortage is not foreseen for the next century. *https://minerals.usgs.gov/minerals/*
- Other aggregates such as flint, basalt, taconite, and granite have been evaluated but have not performed as well as calcined bauxite in terms of sustained frictional resistance.
- Alternative aggregates can be placed in a similar manner and may perform adequately in a less demanding environment, but in critical locations they have not provided the duration of friction service 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 to provide the expected safety performance and durability required in an HFST application.
- Please refer to #13 below for several HFST aggregate durability studies related to aggregate testing from the National Center for Asphalt Technology (NCAT).
- Other aggregates other than Calcined Bauxite can be considered as acceptable provided these aggregates met the testing requirement as outlined in Section 7, Method of Testing, the AASHTO Standard Practice for High Friction Surface Treatment for Asphalt and Concrete Pavements AASHTO Designation: PP 79-14 (2016).

8. Can the leftover/reclaimed aggregate be reused?

- During the HFST installation process, the calcined bauxite aggregate is typically installed to refusal over the wet resin—i.e., excess bauxite material is placed that does not adhere to the resin and is swept up and reclaimed prior to opening the treatment area to traffic.
- Recovery of excess aggregate at a project site and subsequent use of the reclaimed material should be considered very carefully. HFST aggregate is supplied to a specific grading specification and, if not managed carefully, the process of reclamation may introduce uncontrolled particles, leaving a material that does not have an equal distribution of particle sizes as originally supplied.
- If reclamation is considered acceptable within an agency's specification, then the following should be considered:
    - Place only enough excess bauxite material to completely cover all wet resin without undue excess placement.
    - Clean roadway areas and adjacent areas thoroughly prior to placement and never attempt to reclaim bauxite off roadway shoulder/gravel edges to prevent the introduction of foreign material into the reclaimed material.
    - All recovery sweeping equipment must 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.
- Under no circumstances should reclaimed aggregate be introduced in lower dilution ratios than 1 to 2 bags of prime (new) aggregate.
- Reintroduction should only be performed using aggregate hoppers that feed aggregate to the final discharge point by screw conveyors. Application equipment with conveyor belt discharge should not be used to blend reclaimed aggregate with prime product.

9. If a large amount of calcined bauxite comes from international sources, does the Buy America provision apply when using Federal funds for HFST?

- No, Buy America applies only to steel products.

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

- Testing the HFST aggregate for PSV is fairly common practice. Keep in mind that PSV testing gained popularity in in Europe and the British method for testing PSV (EN 1097-8) is different than the ASTM method even though the testing apparatus is the same. Also, the gradation of aggregate specified for testing PSV 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 >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.

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

- High Friction Surface Treatment Alterative 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*

12. Can HFST be placed on a bridge deck?

- HFST can be applied to bridge decks. The common method for applying epoxy overlays to bridge decks for bridge preservation 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 installation. For installations focused on bridge preservation, the aggregate friction and polish resistance is generally not as important as aggregate hardness, so the aggregates used may not all meet the PSV qualification for HFST.

- If this same bridge was in a curve and was also identified as having a crash problem, a double layer of HFST could be substituted for a bridge deck 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 to both would allow for friction enhancement and crash reduction regardless of the underlying roadway type.

13. There has been some discussion of placing HFST in a double layer. Why is this done?

- Double-layer HFST is generally used to provide a more durable, longer-lasting surface in aggressive environments (i.e., where vehicles are equipped with studded tires or snow chains, or where snowplows are common) or on roadways with very high traffic volumes.
- In addition to the double layer installation on bridge decks (noted above), Double-layer HFST applications have also been successfully installed on open-graded friction course (OGFC) asphalt pavements. Using a double-layer treatment on OGFC seals the voids in the pavement surface with the first layer and maintains the proper binder depth of the top course with the second layer, which is necessary for the aggregate embedment in the final HFST riding surface.
- A double layer should not affect noise any more than a single layer, as the surface texture generally remains the same.
- Care must be taken when considering more than one layer of HFST. Since a double layer is less flexible than a single layer, a sound pavement is most important. Any pavement with signs of pattern cracking should likely be replaced prior to HFST installation. Discuss pavement condition assessment with an expert prior to scoping for an HFST application.

14. Are HFST systems proprietary? Are there any good examples of generic specification?

- All HFST products are non-proprietary. In general, all the equipment and materials are commercially available. Some agencies will install HFST with their own maintenance crews.
- Many State and local agencies now have a specification or special provision for HFST. Standards and specifications used in States such as Florida, South Carolina, Maryland, California, Illinois, Arkansas, Georgia, Pennsylvania, and Texas are often used as guidance for agencies that are developing their own standards for HFST.

15. Is there a certification process for contractors who want to perform this type of work?

- Not at this time. It would be beneficial to have a certification process since, during installation, we have experienced some good contractors but also a few who were not quite as knowledgeable. The best way to address the issue of contractor performance is to develop a good specification that requires several quality checks and holds the bidders accountable for meeting the specifications for a proper installation. FHWA is working diligently to try to help State agencies write a better specification to cover some of these concerns. However, certification does not always ensure good installation because it is possible that workers who are not trained or familiar with the process could end up doing the work. A good specification makes worker knowledge and experience less of a factor in the quality of the end product.

16. Are there specifications for HFST?

- The AASHTO Standard Practice for High Friction Surface Treatment for Asphalt and Concrete Pavements AASHTO Designation: PP 79-14 (2016) is available for agencies to adopt in whole or in parts to their construction specifications.

LESSONS LEARNED

1. Can patches that de-bond be fixed?

- This is not extremely 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, it 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 “pops out,” but the HFST is perfectly attached to a fragment of pavement. If this is a limited occurrence, this does not indicate a catastrophic failure of the HFST. Generally, this means the underlying pavement had a weak spot and lost its bond with 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, then any curing compound must be removed and the surface cleaned before applying the HFST, since curing compounds act as bond breakers.

2. 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 and caution is advised. Always consult the HFST resin binder manufacturer prior to the installation of any repair or patching material to confirm compatibility and installation requirements.

3. What negative issues have occurred with HFST installation?

- Common contributing issues for installation problems appear to be due to a combination of the following improper 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 early loss of aggregates and premature wear in the wheelpath. Installations for which the written instructions of the HFST binders have not been followed are always subject to potential problems.
  - Improper placement of the resin binder by installing either too thin or too thick a layer of resin material or by disturbing the resin after it has begun its gel phase.
    - If the resin material is placed more thinly than indicated by the specification, it may not have sufficient depth to embed and retain the aggregate for long-term durability.
    - If the resin material is placed more thickly than indicated by the specification, it may fully encapsulate the aggregate material, leading to a lower friction (glassy) resin surface and lower macrotexture to channel water away. If the material is too

thick on steep or banked roadways, it may also exhibit creep or drift towards the lower side of the roadway.

- 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.

- 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 embedment. 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.
- Application of HFST to immature pavements. The HFST should not be applied to asphalt that is less than 30 days old or concrete pavements less than 28 days old. For concrete pavement, all curing compounds must be removed and the surface properly shot-blasted. Proper shot-blasting will remove all concrete surface paste, dirt, dust, debris and other surface contaminants.
- Application of HFST to pavements in poor condition. Existing pavement may have experienced significant cracking prior to HFST placement, so that over time the asphalt or concrete beneath the HFST failed. In these instances, the resin binder and aggregate have remained completely bonded, but the underlying pavement failed, so it was a poor candidate for HFST.
- Environmental requirements were ignored. The pavement surface must be dry at time of installation, and the ambient temperature must be above the manufacturer's minimum recommendation. For most polymers, a minimum temperature of 50 degrees 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 manufacturers direction. Please see general temperature requirement under INSTALLATION.

4. What pavement conditions caused failures that have been reported?

- In North Carolina and in Colorado, two different problems combined to cause the underlying asphalt pavement to be delaminated: poorly draining pavement that trapped water underneath the HFST and cracking of the underlying asphalt pavement that reflected through the HFST. However, the HFST remained intact on the asphalt material.
- Any pattern cracking that is visible on the pavement such as map cracking and/or alligator cracking likely makes the pavement a poor candidate for an HFST installation. Replace un-sound pavement prior to installing HFST to increase service life expectancy. Follow guidelines such as a 28-day hydration period for new concrete pavement and 30 days waiting period for new asphalt pavements prior to installing HFST.

INSTALLATION

1. What surface preparation and installation conditions are required?

General

- Surface preparation is the key for all successful HFST installations. Shot-blasting for concrete and high-pressure air washing for asphalt pavements are required prerequisites for HFST application.
- Temperature is a very important condition to consider for HFST installation. Temperatures will be determined by the type of polymer resin binder being used as well as the method for broadcasting the aggregate.
    - A good rule of thumb would be not to install HFST when the surface temperature of the pavement is below 50°F unless the resin binder system is formulated specifically for cooler temperatures.
    - As temperatures rise, the resin binder system will reach initial gel faster. Automated methods of broadcasting are often capable of fully covering the resin binder before it begins to gel at these higher temperatures. As ambient temperatures begin to reach 95°F and above, most resin binder systems will begin to thicken and gel within minutes. It is important to determine that the aggregate can be fully broadcast 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 broadcasting aggregate will be sufficient to install HFST at the required temperatures. Always follow the guidelines of the State specifications and the manufacturer's written instructions for the HFST binder.
- Both surface and ambient temperatures are critical to a successful installation. If the aggregate can be broadcasted immediately, it can be installed at temperatures >100°F as long as the resin binder has enough time to penetrate the pavement surface prior to reaching initial gel. Hence, mechanical installation is always the preferred method.
- It is generally not practical 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. Proper drying time and/or techniques may be required. In some instances, heavily contaminated pavement should be removed and replaced.
- For pavement surfaces, there should be no visible moisture present on the surface at the time of the binder application. Compressed air may be used to dry the surface. A plastic sheet left taped in place for a minimum of 2 hours, according to ASTM D 4263, may be used to identify significant moisture in the pavement during periods after rain, for example.
- Utilities, drainage structures, curbs, 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 that are adjacent to the application surfaces to be preserved should be covered 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. Any existing moving joints should be protected, or re-cut with the correct saw-cutting practices after the installation cures.
- Pavement markings that are not covered or consist of material other than paint should be removed. The removal method may be grinding, water blasting, or other treatments; the surface should then be dried and swept clean prior to the polymer binder application. Pavement marking lines should be considered clean when the pavement has exposed aggregate showing through the existing marking. Care must be taken to not remove and/or gouge the pavement profile when removing pavement markings. Un-even surfaces should not be repaired with the HFST system. **NOTE:** HFST will not fully adhere to thermoplastic road markings.
- 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. When sealing cracks, it is important to ensure the sealant is recessed slightly below the pavement surface and not overbanded onto the pavement. Pre-treat joints and cracks with the mixed polymer resin. 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, pot holes, raveling, and rutting prior to placing HFST. Contact the binder resin manufacturer to review which materials will permit proper adhesion of the HFST system. Clean and fill all inadequately sealed joints, including shoulder areas. HFST may be applied over pavements exhibiting minor rutting or heaving; however, the product is not intended as a repair for these conditions and will not level pavements. Proper evaluation of pavement condition is important before considering HFST.

Concrete Surfaces

- The polymer resin overlay should not be placed on Portland cement concrete that has been in place less than 28 days. Patching and cleaning operations should be inspected and approved prior to placing each layer of the overlay. After initial cleaning, any contamination of the deck or intermediate courses should be removed.
- Concrete surfaces should be abrasively cleaned by shot blasting to remove oils, dirt, rubber, curing compounds, paint carbonation, laitance, weak surface mortar, and other potentially detrimental contaminants that may interfere with the bonding or curing of the overlay.
- 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 polymer resin. 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.

Asphalt Surfaces

- Before placement of HFST on an asphalt surface, the entire surface should be cleaned by high-pressure air washing or approved washing methods to remove oils, dirt, rubber, paint, laitance, and other potentially detrimental contaminants that may interfere with the bonding or curing of the overlay. Acceptable cleaning is recognized as a surface with no oil spots, dirt, or 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, contact the resin binder manufacturer for guidance.
- Several agencies have experiment with pressure washing or lightly shotblasting new asphalt surfaces to shorten the 30 day waiting period. This practice is still 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. Is installation over an open-graded friction courses an issue?

- Many HFST applications have been successfully installed on OGFC. However, OGFCs are relatively thin and vary in strength based on the aggregate used and the condition of the pavement. This has led to a few problematic installations since it is often difficult to detect existing pavement issues. Successful installations over OGFC have used a double layer treatment in order 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.
- 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.

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

- Current methods of installing HFST can 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 level of experience with these methodologies can vary dramatically and should warrant stringent quality control procedures within a specification to ensure consistent and proper coverage rates. 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 linear 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 vehicles’ tires. Any high spots that are created because of un-even installation practices can create “point loading” once traffic travels over the HFST system. These high spots can potentially transfer very high dynamic impact to the underlying pavement and could potentially manifest as early age spalling and delamination of the HFST.
- Prompt broadcasting of high-friction aggregates is important to ensure full embedment of the aggregate within the resin binder. As temperatures rise during summer months, resin binder

systems tend to reach initial gel within minutes. When the binder gels, the viscosity begins to thicken which can inhibit the aggregates in reaching embedment properly. This could manifest in early loss of surface aggregates.

- 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 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 (and is much more costly) 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.
- HFST may be placed in conjunction with rumble strips for additional safety enhancement. If HFST is installed on a roadway with existing rumble strips, it is generally not placed over them but rather on a near-parallel offset a few inches from the rumble strip alignment. If the rumble strips are being added to the project, they may be placed first with the HFST installed in an offset alignment later, or they may be ground in after HFST placement by grinding through the HFST. Similarly, recessed striping, recessed markers, or other recesses may be achieved by grinding through the HFST with milling (cutting) style machinery. Diamond grinding or abrasive grinding machinery will not work as well for this application due to the hardness of the HFST aggregate.

4. What is the difference between manual, machine-aided manual, and fully automated HFST installation?

- HFST can be installed using any of three main application methods: manual, machine-aided, 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 while a fully automated process might be used for larger systemic contracts consisting of numerous sites. Most transportation agencies contract out their HFST installations to avoid purchasing HFST-specific equipment.
    - **Manual** – Manual HFST application is ideal for small spot locations of 200 sq. yd. 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 mixed on site in buckets. The mixed resin binder is poured onto the prepared surface and spread to the proper mil thickness using squeegees. Next, the aggregate is broadcast on top of the binder. There is no preferred method to broadcast the aggregate, but the binder must be completely covered. While the manual application method is ideal for keeping costs low on small spot-treatments, this method has a few drawbacks. Working under live traffic conditions increases safety risks by prolonging workers' exposure to traffic. Further, given the opportunity for human error and inconsistency, quality and uniformity in manually applied treatments are a concern. In addition, the prolonged presence of a work zone can potentially cause secondary crashes.

- **Machine-Aided Manual** – As its name implies, machine-aided manual application of HFST involves a combination of manual labor and machine-aided application. The exact combination largely depends on the type of application truck. Trucks are equipped with any combination of a mixing machine, binder spreader, and aggregate spreader. The contractor will typically use equipment that mixes the binder components at the correctratio. Some binder materials are mixed with catalysts and accelerators at varied rates based on temperature to speed up cure rates in cooler weather. The machine often pumps the binder out a spigot located directly behind the truck as the truck slowly drives down the lane. Workers use squeegees to evenly spread the binder behind the truck. This installation method allows the roadway surface to be covered more quickly than manual application, but is still subject to human error and inconsistency in resin application. On larger projects, the reduced labor hours can offset the cost of additional equipment, resulting in a lower installation unit cost.
- **Fully Automated** – A fully automated HFST application typically involves a truck that is customized to mechanically mix the binder components in accordance with the current ambient or surface temperature. It is also capable of applying a consistent wet mil thickness of the binder and controlled rate of aggregate to the pavement surface 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 ensures a higher quality application and reduces overall project costs on large systemic installations.

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