

High Friction Surface Treatment Guidelines

Site Selection, Materials, and Construction



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OVERVIEW

High friction surface treatment (HFST) is a safety-first pavement treatment intended to restore and maintain pavement friction to reduce crashes. It is a thin layer of high-quality polish-resistant aggregate bonded to the pavement surface with polymer resin binder, specified in FDOT Section 333.



FIGURE 1 – High friction surface treatment.

This document highlights the benefits of HFST, and provides guidance on selecting sites, HFST materials, construction methods, and repair and rehabilitation techniques. It also reviews several types of HFST failures that might be encountered.

PERFORMANCE

Benefit-Cost Comparison

In Florida, HFSTs on tight curves have reduced the rate of total crashes by 44% and wet-weather crashes by 84% on average. Other agencies have reported crash reductions ranging from 24% to 70% to even 93% (1).

Historically, the average bid unit cost of HFST in Florida is \$37/sy and has been as low as \$26/sy. The

comprehensive HFST costs, which include all related construction costs, range from \$36 to \$113/sy with an average of \$59/sy. For reference, bid unit prices around the country are sitting around \$20/sy (1).

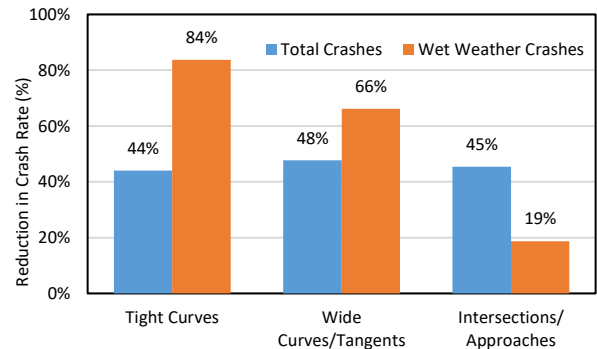


FIGURE 2 – Reductions in crash rates after HFST application (various roadway segment types).

HFSTs on tight curves have reduced the rate of wet weather crashes by 84%.

Compared to conventional pavement maintenance treatments, HFST seems quite expensive. What must be considered is that HFST is NOT a pavement maintenance treatment, and the costs being saved are the prevention of crashes and fatalities. One alternative to HFST is roadway geometric corrections, which are considerably more expensive and time consuming.

Looking at the costs saved by reducing total crashes and fatalities, the average 5-yr benefit-cost ratio for HFST on tight curves is 24.5 (1). So, for a typical 1,500-sy application, costing roughly \$92,000, the agency could estimate savings of \$2.2M over a 5-yr period. The actual service life of HFST can be as long as 10 years.



SITE SELECTION

What to Look for and Avoid

HFST is, first and foremost, a safety treatment. Ideal candidate sites would have a crash history indicating a pavement friction deficiency (i.e. numerous run-off-the-road and wet-weather crashes). When compensating for deficiencies in roadway geometry (insufficient super elevation, small radius, etc.), HFST can be a temporary or even permanent solution. Crash reduction has proven most effective on rural and urban horizontal curves and tight-radius loop ramps. HFST has also been applied at high-volume intersections and downhill approaches, though the measured safety benefit in these scenarios is still being studied. Other scenarios include approaches to rail crossings, school crossings, and tolling areas.

Most effective on rural and urban horizontal curves and loop ramps.

When identifying candidate sites, agencies must consider the following safety-based criteria:

- High crash frequency.
- Friction demand and roadway geometry
- Low pavement friction.
- Failure of prior low-cost treatments.

Agencies must also consider:

- Pavement condition and maintenance activities.
- Begin and end locations within a curve.

Each of these topics is discussed in the following subsections, and a summary of guidance on where and where *not* to apply HFST is given in TABLE 1. A checklist of important items to review for candidate sites is also provided.

Parts of this section are derived from two documents: “High Friction Surface Treatment Curve Selection and Installation Guide,” by Atkinson et al. in 2016, funded by the Federal Highway Administration (FHWA) (2); and “Recommendations Report for High Friction Surface Treatments: Candidate Sites, Materials, and Construction” by Wilson et al. in 2020, funded by FHWA (3).

Site Selection Checklist

Obtain a safety study report which includes most features in the following checklist. Some additional information collection may be warranted.

☒ **Request crash history.**

- Past 3 to 5 years.
- Total and wet-weather crash rates.
- Crash severities.
- Crash diagrams.

☒ **Record roadway and traffic features.**

- Curve radius.
- Superelevation.
- Approach and curve advisory speeds (speed differential).
- Average annual daily traffic.
- Intersections near or within the curve.
- Points of curvature and tangent.
- Location where vehicles start to break (observe brake lights)

☒ **Conduct a friction test.**

- Locked-wheel skid trailer at safe speed for site conditions.

☒ **Consider low-cost countermeasures.**

- Does site already have low-cost countermeasures and what condition are they in?
- Should another countermeasure be tried before HFST?

☒ **Assess pavement condition.**

- Pavement type
- Visual distress evaluation.
- Plan for asphalt resurfacing or concrete repairs as needed.
- Review scheduled pavement maintenance and construction activities.

☒ **Determine HFST begin and end Locations.**

- Where braking starts
- Points of curvature and tangent
- Not adjacent to open-graded pavement
- Crash locations

TABLE 1 – General Guidance on Candidate Pavements.

Where to Use HFST	Where <u>NOT</u> to Use HFST
Roadway applications	
- Sites with a high crash rate related to a friction deficiency. (i.e. Run-off-the-road crashes, and wet-weather crashes.) - On rural horizontal curves where drivers tend to drive too fast for the road conditions. - On tight-radius freeway loop ramps. - At downhill signal approaches. - On roadways that may need geometric corrections, but the agency lacks the funding. - On concrete bridge decks where preservation and safety are both a concern.	- If less-expensive traffic control devices (chevrons, curve-warning signs) are expected to adequately reduce crashes. - Tangent sections where crashes are related to driver errors. - On high-speed mainline (>45 mph). - After the PT of a curve or more than 1,000 ft before a curve. (No benefit here.) - For preventative maintenance on asphalt pavement. - Rigid pavement at turn lanes and intersections subjected to frequent heavy truck turning movements.
Pavement condition	
- Dense-graded asphalt or concrete. - Pavement condition rating of “Good” and higher. - Polished or oxidized surface. - Few low-severity cracks. Very few cracks greater than 0.25 inch wide. - Minor rutting $\leq$ 0.25 inch. - No structural damage.	- Open-graded asphalt (OGFC) - Asphalt pavements with 6+ percent of cracking in or outside the wheel paths. - Rutting > 0.25 inch deep. - Asphalt bleeding. - Areas where layer debonding or subsurface stripping is suspected. (Verify with coring and other pavement forensics.) - Concrete single slab with moderate or severe distress, patching, or shattered in more than 3 pieces.

High Crash Frequency

The first criterion is a history of high crash frequency. This is calculated as the total crashes per year over several years, or average over several years. A more robust method, described in the Highway Safety Manual, is to perform a crash analysis comparing the observed crashes to predicted crashes from carefully calibrated safety performance functions.

FDOT further considers the crash type by calculating the ratio of wet-weather crashes to total crashes. Sites with a wet/total crash ratio greater than 0.25 (wet weather crashes make up 1 in 4 crashes) will warrant a safety improvement, but not necessarily HFST. Also review crash diagrams from the past three to five years. Sites with high percentage of run-off-the-road crashes (as opposed to rear-end, side impact, etc.) will be better addressed by HFST.

Another consideration is crash severity. A property damage-only crash has a much smaller impact socially and economically than an injury or fatality crash. So, sites with more severe crash types may be prioritized.

Crash data, contained in the Safety Report, can be requested from the State/District Traffic Safety Office.

Friction Demand and Roadway Geometry

Friction demand is the level of friction needed for a vehicle to safely decelerate and maneuver through a curve. Friction demand increases for higher vehicle speeds, smaller curve radii, and lower roadway superelevation. Sites with increased friction demand also correspond with higher crash rates. For example, Pratt et al from the Texas A&M Transportation Institute (TTI), found an exponential relationship between small curve radius and high

crash modification factor (CMF) (high crash rate), shown in FIGURE 3. Where friction demand is greatest, HFST can provide additional friction and safety to the motorist.

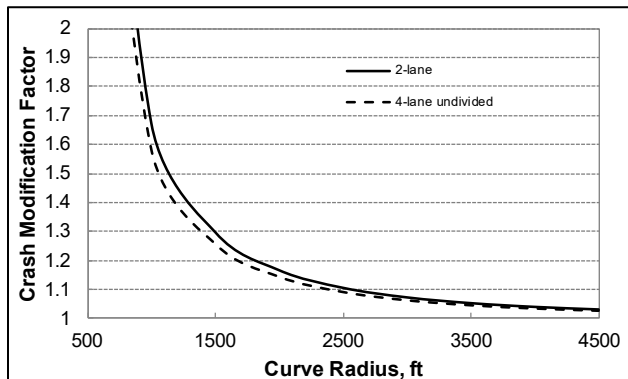


FIGURE 3 – Crash Modification Factor as a Function of Curve Radii. (4)

When selecting and prioritizing candidate sites, the calculated friction demand can be a useful tool. The basic side friction equation is shown below in Equation 1. (5)

$$\text{Friction Demand } \mu = \frac{\text{Speed(mph)}^2}{15 \cdot \text{Radius(ft)}} - 0.01e \quad \text{Equ. 1}$$



FIGURE 4 – HFST on Tight Curve before a Signalized Intersection.

Also consider the speed differential between the tangent approach speed and the curve advisory speed. The greater the differential, the more likely that a driver will fail to decelerate properly and will navigate the curve too quickly. Herrstedt and Greibe, from Denmark, recommended risk categories based on speed differential (FIGURE 5). Sites at greatest risk, falling in the D and E regions, may be good candidates for HFST.

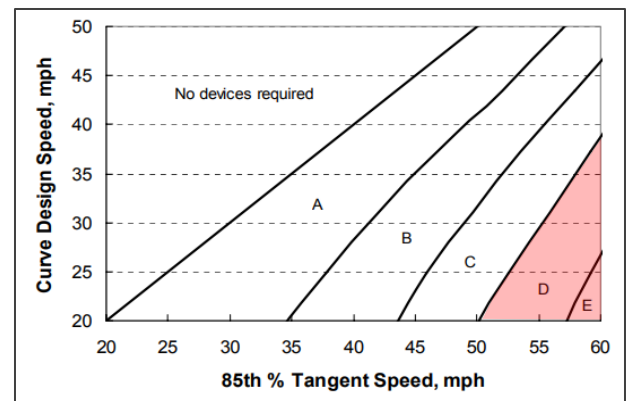


FIGURE 5 – Curve Risk Categories. (6)

Low Pavement Friction

Lower pavement friction results in higher rates of wet-weather crashes. In the study by Pratt et. al., the authors found that, on average, wet-weather run-off-road crashes doubled (CMF of 2) as the friction number (FN50S) dropped from 40 to 20. And crashes halved (CMF of 0.5) as friction number increased from 40 to 80 (FIGURE 6).

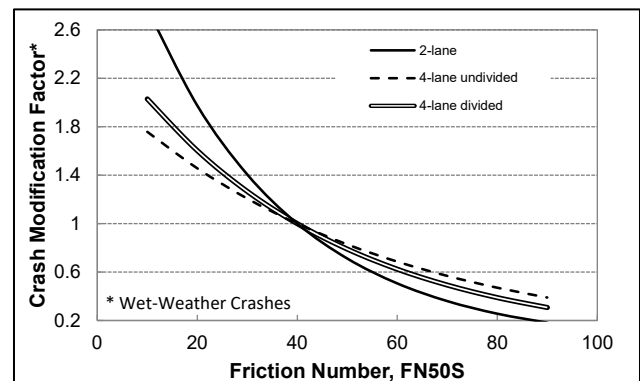


FIGURE 6 – Friction Number Crash Modification Factors for Wet-Weather Crashes. (4)

Since friction number is not routinely collected on horizontal curves, freeway ramps, or intersection approaches, request friction number testing on sites before making final recommendations.

There are several pavement treatment options that can enhance friction. Among these treatments, HFST is well-suited when the existing friction numbers are typical for the area but still insufficient to meet the friction demand, or when the agency is concerned that the surface material will not adequately maintain good friction performance over time.

Failure of Prior Low-Cost Treatments

Outside of geometric redesign, HFST is a comparatively expensive treatment for crash reduction. Agencies often employ different low-cost treatments first, such as:

- Horizontal alignment signs (see MUTCD).
- Center line and edge line pavement markings.
- On-pavement or vertical roadside delineators.
- Advanced curve warning pavement markings.
- Audible milled-in rumble strips.
- Guardrail.

Signs, markings, and rumble strips require the driver to first observe and then react to avoid an accident. A guardrail does not prevent accidents but mitigates the crash severity. HFST, on the other hand, is a passive countermeasure that is always acting to help the driver stay on the road as they navigate a curve. If the other countermeasures fail to reduce crashes to an acceptable level, HFST may be the next most cost-effective option.

Pavement Condition and Maintenance Activities

HFST should only be placed on structurally sound pavements requiring minimal surface repair. If the pavement surface is in marginal or poor condition, the agency should repair or replace the layer. HFST applications on weak and aged pavement could potentially accelerate pavement failure. The pavement condition and repair methods for asphalt and concrete pavement are as follows.

HFST should only be placed on structurally sound pavements.

Asphalt Pavement

Surface defects that are unacceptable on asphalt pavement are:

- Cracking in or outside the wheel path covers 6 percent or more of the surface. (Cracking readily reflects through the HFST and may indicate structural deficiency.)

- Rutting of 0.25 inches or greater. (Constructability issues with uneven resin binder thickness.)
- Bleeding. (Poor HFST bond.)

In these cases, mill out the deteriorated layer and in-lay with new asphalt.

Due to several past premature failures, HFST is not recommended to be placed on open-graded friction course (OGFC). OGFC has high voids, requiring excessive amounts of binder to offset draindown. Moisture also gets trapped under the HFST, causing stripping and substrate failure. Existing OGFC needs to be milled and inlaid with dense-graded asphalt before applying HFST.

Concrete Pavement

Surface defects that are unacceptable on concrete pavement are:

- Any single slab with moderate or severe distress.
- Transverse cracking.
- Longitudinal cracking.
- Spalling.
- Corner cracking.
- Shattered slab in more than three pieces.

Any of these distressed slabs need to be repaired or replaced.

Maintenance Activities

Thin polymer overlays are a common preventative maintenance treatment for concrete bridge-decks. The materials and application of this treatment and HFST are very similar, except that HFST must have high friction calcined bauxite aggregate. If safety on the bridge deck is a concern, the agency may consider applying HFST in lieu of the bridge deck treatment.

When selecting candidate sites, also consider the timing of other pavement maintenance activities. Communicate with the maintenance office to review the schedule of their resurfacing operations at and around the site. Delay HFST installation if the road is scheduled for a mill and inlay or work to expedite the maintenance operation.

Begin/End Locations of HFST

After a site has been selected, determine the begin and end locations of the HFST.

- Observe when drivers start braking (i.e. brake lights) before a location for the beginning location.
- Treatments on loop ramps should not be applied adjacent to OGFC in the mainline. This would cause drainage issues with moisture getting trapped under the HFST. Typically, the loop ramp treatment would end when the gore area terminates.
- At intersections, apply HFST within the approach and not within the intersection itself. End the treatment at the stop bar.
- Review crash diagrams and ensure that the HFST covers locations where most crashes initiated.
- Do not go beyond the point of tangent (PT) or more than 1,000 feet before the point of curvature (PC). There is no benefit here.
- Additional guidance was suggested by Brimley and Carlson with TTI (7). The recommended starting point for HFST is based on the curve speed differential. (See Table 5.)

HFST MATERIALS

Quality Counts

HFST is composed of hard, polish and abrasion-resistance aggregate bonded to the pavement using a polymer resin binder. These components are detailed in this section.

High-Friction Aggregate

Calcined bauxite is the only accepted aggregate for HFST. Other aggregates like flint, basalt, and granite may only be used for preventative maintenance applications that are not safety-critical.

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The aggregate gradation is a very fine gravel. The maximum size is 3 to 4 mm and the minimum size is

about 1 mm (95% passing No. 6 sieve and 5% passing No. 16). If a larger gradation is used, the HFST would require more resin binder without any added safety benefits.



FIGURE 7 – Calcined bauxite, crushed and graded.

Calcined bauxite is mandated in Developmental Specification 333. The critical aggregate properties are a low aggregate abrasion value (20% max) and a high aluminum oxide (Al_2O_3) content (86% minimum). Al_2O_3 content is measured in a laboratory with an X-ray fluorescence spectrometer. The use of a portable XFR device might be used for quality control in the field.

In storage and transportation, the aggregates **MUST** be stay clean and dry. Any moisture in the aggregate could result in a poor bond and eventual aggregate loss.

Where does calcined bauxite come from?

Calcined bauxite has historically been an imported product to the United States. The leading bauxite producers are Australia, China, Brazil, India, Guinea, and Jamaica. Recently though, there is some domestic mining of bauxite. Raw bauxite is primarily mined to produce aluminum, but when raw bauxite is heated to high temperatures (1,000 to 1,500°C), it undergoes calcination, increasing in physical hardness. Calcined bauxite is crushed to size, washed, dried, and bagged before shipping to regional business like the HFST installer.

Polymer Resin Binder

The role of binder is to hold the high friction aggregate in place. Because traditional bituminous binders are relatively soft (especially in the summer),

they are not suitable under the extreme shear forces inherent to curves and approaches. A polymer resin binder with high bond strength and other key mechanical properties is vital for the longevity of the HFST installation.

Polymer resin binders are multi-component systems that react chemically and harden when

mixed and throughout curing. The resin binder system includes a base resin, a curing agent, and often additives to improve performance and constructability. The critical characteristics of the resin binder for HFST applications are summarized in TABLE 2.

TABLE 2 – Key Characteristics of Polymer Resin Binder.

Characteristic	Importance
Viscosity	Spreadable without being too runny
Gel Time	Adequate time to mix and apply
Cure Rate	Need to open to traffic quickly
Strength	Must not crush or get torn apart under traffic
Hardness	Must not shove under traffic
Elongation	Needs flexibility to resist cracking
Low Water Absorption	Resistant to moisture-related damage
Adhesive Strength	Hold to the ground and to the aggregate

Resin binders that are allowed by FDOT are:

- **Epoxy-Resin** – Good durability and bond strength. Longer curing times of 2 to 3 hours and dependent on temperature. Cannot be applied at temperatures below 60°F. May be susceptible to UV aging. Historically, the most common system used for HFST in Florida.
- **Polyester-Resin** – Good durability and bond strength. Short to long curing times depending on additive use. May be applied at lower temperatures. Resistant to UV aging. Has a good track record, but less common in Florida.
- **Polyurethane-Resin** – Good durability and bond strength. Variable curing time. May be applied at lower temperatures. Resistant to UV aging.

The specific properties for a given resin binder can vary from one formulation to another. In time, new products are likely to emerge with superior properties for constructability and long-term performance. Also, note that some products produce caustic fumes that, if improperly handled, may cause irritation during application.

The HFST installer will likely prefer a certain product and their installation equipment will be

calibrated accordingly. Their equipment may be adaptable to different resin-binder types.

Material Certifications

The proposed aggregate and resin binder materials need to be certified by the producers. The certifications are good for 12 months and whenever a new source or batch is used.

CONSTRUCTION

Tips for Success

If installed properly, HFST could last for at least 7 to 10 years with superior friction performance. The success of HFST is dependent on proper surface preparation and mixing/application techniques. Overlooking any of these considerations could jeopardize the life of the product.

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Test Strip

FDOT requires that projects larger than 200 sy incorporate a minimum 20-ft long application test

strip before continuing construction. Most often can be placed the same day as full construction. The contractor will have a chance to identify and fix problems, and of equal importance, the FDOT inspector will become more familiar with the process and potential issues. If the contractor is prequalified and the inspector has overseen several successful projects, the engineer may waive the test strip.

Both parties should identify the followings:

- **Surface preparation** – Identify adequate sweeping and air-washing methods to produce a clean, dry, dust-free surface. On concrete, this includes correct shot blasting techniques (and subsequent cleaning) to produce the specified texture (FIGURE 9).
- **Resin binder proportioning** – Identify equipment settings to achieve the correct binder proportioning. Generally, the gel-time test is not sensitive enough to misproportioning to substitute for proper maintenance and calibration of the equipment. Still, this simple test helps ensure against major mixing problems. A 2-oz sample in a small paper cup will typically gel within 10 to 25 minutes (temperature dependent).
- **Resin binder application rate** – Identify equipment settings to achieve the correct resin binder thickness. Underapplication of binder will reduce HFST service life. In production, the application rate will be measured by material weights and flow rates in the equipment. A wet film thickness gauge (FIGURE 1) may be helpful to verify the flow rate before spreading the aggregate; however, the proper use of the gauge is very subjective on uneven pavement surfaces.

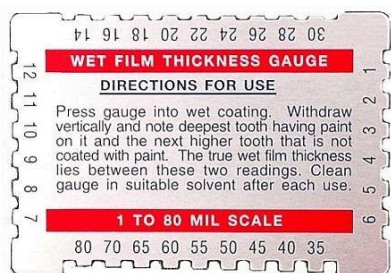


FIGURE 8 – Wet film thickness gauge.

- **Curing time** – Determine the initial curing time when traffic is permitted. Time will vary by product, ambient temperature, and surface temperature.

Surface Preparation

Without adequate surface preparation, the HFST is liable to de-bonded and delaminate, especially on concrete. This issue is often caused by changes in temperature where the HFST wants to expand and contract more than substrate and will pop-off under thermal stress if the bond is insufficient.

On asphalt pavements, first clean with a mechanical sweeper or vacuum sweeper, then it is recommended to follow-up with a high-pressure air wash. Experience has shown that sweepers alone can leave dust on the road. Vacuum sweepers are not always properly maintained and, in some cases, can even make the dust situation *worse*. Follow these procedures for air washing:

- Use dry compressed air
- Use a minimum of 180 cfm
- Compressor oil traps must be functioning (or compressor may start misting oil!)
- Maintain air lance perpendicular and within 12 inches of the surface.

On concrete pavement, the surface first needs to be shot blasted to remove curing compounds, loosely bonded mortar, surface carbonation, etc. Sand blasting will be inadequate. The shot blasted surface should also be cleaned with a sweeper and a high-pressure air wash.

Do not rush shot blasting. The rate that the shot-blasting equipment moves will affect the final surface profile of the pavement. A fast brush-off blasting will not be adequate. The final surface must have a minimum texture of Concrete Surface Profile (CSP) 5 as specified by the International Concrete Repair Institute (ICRI) (FIGURE 8). The texture should not go beyond CSP 7. Reference CSP chips can be purchased online directly from the ICRI website.

Longitudinal diamond grooving is recommended for concrete turn lanes before applying HFST. The concrete surface should be grooved longitudinally to

a depth of 3/16 inch - 5/16 inch and at parallel spacing of 5/8 inch - 3/4 inch.

Do not rush shot blasting.

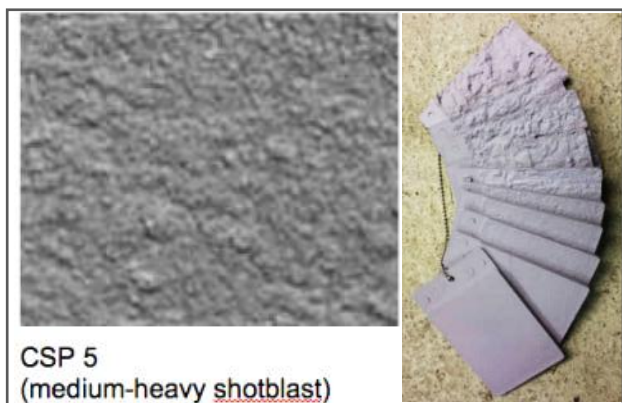


FIGURE 9 – Concrete Surface Profiles. (8)

Contaminated, oily, or heavily polished asphalt surfaces may also be shot blasted. Exposing and abrading the aggregate will give the binder something to grip. Ensure that the shot blasting process is not overly aggressive as to damage and fracture the pavement surface.

Cover utilities, drains, and curbs to protect them from the HFST treatment. Tape and plastic sheeting work well. Pavement markings should be covered or removed if within the intended treatment area. Fix any outstanding pavement distresses. Pre-treat cracks and joints greater than 1/4-inch wide with the resin binder. Do not treat bridge expansion joints.

Applications over new asphalt pavement should be installed a minimum of 30 days after asphalt placement. In that time, asphalt binder coating the surface will wear away under traffic. In addition, the surface texture will be more compact, reducing the amount of resin binder required for the HFST. Applications on new concrete pavement should also be delayed 30 days so the concrete can fully cure.

Equipment

FDOT mandates the use of a continuous automated applicator vehicle for all projects. (FIGURE 9) This automated method minimizes or eliminates problems often observed with manual application methods: inadequate binder mixing, improper and uneven binder thickness, delayed aggregate placement, and inadequate aggregate coverage. In addition, the automated process is

considerably faster (2,000+ sy/hr), permitting a quicker return to traffic. Semi-automated methods are not allowed nor mechanical methods that do not guarantee uniform distribution of both binder and aggregate. Manual application is only allowed for areas less than 200 sy or where the automated equipment cannot reach.

The automated applicator must mechanically meter, mix, monitor and apply the resin binder and apply the aggregate in one uniform and continuous pass. The metering pumps may be heated to lower the viscosity. The system must be capable of applying at least a 12-ft width at the recommended rates.

At present, there are several HFST application companies that own automated equipment. These companies develop and operate their equipment in-house. New equipment suppliers and contractors are expected to enter the market as the popularity of HFST continues to grow.



FIGURE 10 – Continuous automated HFST applicator vehicles. (9)

Equipment for the manual method includes:

- Containers for mixing.
- Electric mixer.
- “Jiffy Mixer” attachments to minimize air entrainment. Use two attachments to mix each component alone in original containers and then another for mixing components together.
- V-notched neoprene squeegees (3/16”).
- Spiked shoes.
- Blower for spreading aggregate (optional).



FIGURE 11 – Electric mixer with “Jiffy Mixer” attachment.



FIGURE 12 – V-notched squeegee.

Mixing

The resin binder must be proportioned correctly and mixed thoroughly. This is a particular problem when applying HFST manually. Spend at least 3 minutes mixing (longer than you may expect), and thoroughly work the sides and bottom of the

container. Inadequate mixing can also occur with automated systems if not properly maintained and monitored.

Poor mixing will be very apparent as soft spots of uncured binder in the final HFST. These spots can be small (<1 sf) or substantial (several sy). Uncured HFST must be removed and replaced at the contractor’s expense.

Application

Applications on dense-graded HMA and rigid pavement require one layer of HFST.

The resin binder should be applied to achieve a film thickness of 50-65 mils. The goal is to achieve 50% embedment depth of the aggregate. With too little binder, the aggregate is prone to ravel, and with too much binder, the surface texture is decreased and there is greater material waste. By far the most common problem, however, is too little binder.

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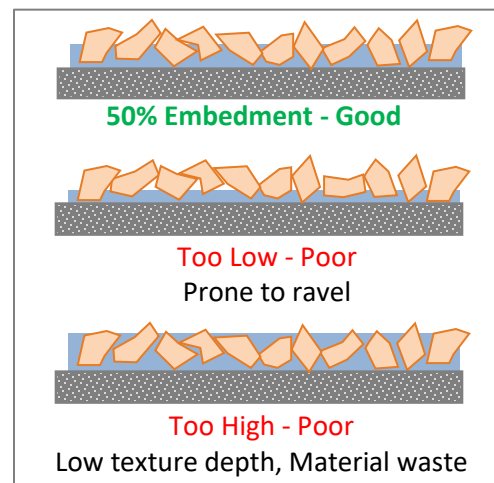


FIGURE 13 – Aggregate embedment.

The typical binder yield rate is between 25-32 sf/gal, depending on the texture of the surface. Beforehand, walk the project and identify if the surface texture varies, then adjust the resin-binder rate accordingly. When installing in hot weather, be aware that the binder will be less viscous and may partially drain into the surface voids before setting, in which case slightly more binder is required.

Aggregate is spread immediately following the resin binder. For automated systems, this should be

in less than 30 seconds, and for manual methods it should be done within 5 minutes. The aggregate should completely cover the binder, leaving no “wet” spots. The typical rate is between 12 to 15 lbs/sq-yd.

Adjust the resin binder rate whenever the surface texture changes significantly.

Dust-free recovered aggregate may be reused only once and must be blended with new aggregate at a rate of 2:1 (two parts new aggregate to one part recovered aggregate). This will ensure the HFST color and texture remain uniform and that contaminated aggregate is not applied. The contractor should clearly label storage containers of recovered aggregate, and include the project and date when it was first applied.

Curing and Sweeping

The HFST must be allowed to cure according to manufacturer recommendations. The time will vary depending on the type of resin binder and the temperature. Protect the treatment from all traffic until fully cured.

After curing, excess aggregate must be removed by sweeping. If the contractor wants to reuse the aggregate, they must use a vacuum sweeper. Ensure that the system is clean and dry and will not contaminate the aggregate.

As required by the Engineer, restriping should be done after aggregate removal. This striping may be temporary or permanent, according to the contract.

HFST will continue to shed loose aggregate for several days and weeks. This is normal. The contractor must do additional follow-up sweeping within 2 weeks.

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Acceptance and Warranty

Within 90 days after construction, the Department will measure the friction with a locked-wheel skid trailer. The surface must have an FN40R of 65 or greater. All HFST applications require a minimum 1-year warranty from surface defects.

REPAIR AND REHABILITATION

HFST installations may need to be repaired to correct existing flaws, or rehabilitated entirely by removal and reinstallation. This section describes what to do in these scenarios. Detailed descriptions of failures and underlying mechanisms are given in the next section.

The repair or rehabilitation approach depends on the situation. The repair area shall at least cover 150% of the distressed area.

- **Uncured binder after construction:** Scrape treatment off with a loader, shot blast and clean all contaminated surfaces, then reapply HFST.
- **Aggregate loss from thin binder:** Aggressively brush the surface to dislodge and remove loose aggregate, then reapply HFST. Note that this will result in a non-uniform treatment thickness around repaired areas.
- **Remove cured HFST (sound pavement):** Diamond grind (or possibly micro-mill) the HFST with minimal intrusion into the existing pavement. Reapply HFST as needed.
- **Remove cured HFST (poor pavement):** Mill away HFST to the required depth of pavement to get past deteriorated layer. Place new pavement layer and reapply HFST as needed.

FAILURE MECHANISMS

When Problems Develop

In general, HFST has a service life of 5 to 10 years. To stay on the upper end of that range, we need to avoid premature failures. This section describes some potential problems and likely causes.

Aggregate Loss

This common failure type happens when the aggregate is lost from the resin-binder (FIGURE 13 and FIGURE 14). It is often associated with poor construction techniques.

Possible causes:

- Resin-binder layer was too thin.
- Application rate was too low.
- Surface texture was non-uniform.
- Draindown on HMA with higher surface voids. More severe with low-viscosity resin-binder and during warmer conditions.
- Aggregate was not clean or dry.

Delamination

Delamination occurs when the bond between the HFST and existing surface fails, noted by the complete HFST system coming off with little or no substrate attached. This distress is mostly observed on concrete surfaces (FIGURE 15).

The force that causes delamination is usually thermal stress. HFST has a much higher coefficient of thermal expansion than concrete and asphalt. When the bond is insufficient, this thermal cycling will break the bond and traffic break and remove the loose material.

Possible causes:

- Concrete shot blasting not adequate.
- Surface contamination during construction.
- Poor sweeping and air-wash practices.
- Moisture during construction. May not be visible on surface but is inside surface voids.



FIGURE 14 – Aggregate loss over uneven texture.



FIGURE 15 – Aggregate loss over concrete.



FIGURE 16 – Delamination of a bridge deck overlay.

Uncured binder failure

Dramatic failure mode where the resin binder does not properly cure. Results in aggregate loss, binder flushing/tracking, and in some cases localized substrate failure (FIGURE 16 through FIGURE 18).

Possible causes:

- Incorrect resin binder proportioning.
- Poor resin-binder mixing (most likely).

Substrate Failure

Some project failures, at face value, appear to be a delamination or cracking problem, but in reality, are failures of the substrate. These fall under two modes: 1) top-down tearing, and 2) shallow-horizontal tearing.

Possible causes:

- HFST application on a weak substrate.
- Extreme stopping and slow-turning traffic.
- Thermally-induced stress.
- Excessively thick and stiff HFST layer.

Top-Down Tearing

Manifest as a cracking distress. When HFST is applied to the surface, the shear force transferred into the pavement from breaking and turning vehicles increases. This can accelerate deterioration of weak substrates (FIGURE 19 and FIGURE 20).

Shallow Horizontal Tearing

This may first look like delamination failure, except that the loose HFST is still bonded to a failed part of the substrate. The failure is generally shallow (~20 mm) and is caused by thermal incompatibility and/or stripping (FIGURE 21).

While thermal incompatibility on concrete manifests itself as delamination, on weaker asphalt substrates, it may tear apart the substrate. This has been noted as surface cracking in roughly circular patterns. If the area is removed, the failure in the substrate is the shape of an inverted cone.

This problem is more severe when the HFST layer is thicker and, therefore, less flexible.



FIGURE 17 – Widespread localized failures due to poor binder mixing.



FIGURE 18 – Soft splotchy areas shortly after construction.

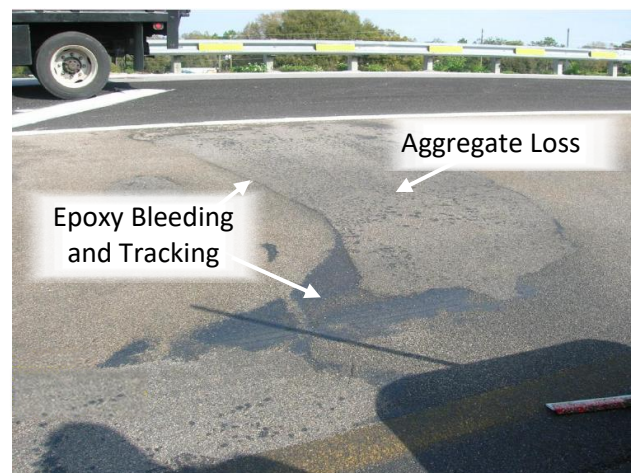


FIGURE 19 – Result of incorrect proportioning: aggregate loss, epoxy bleeding and tracking.

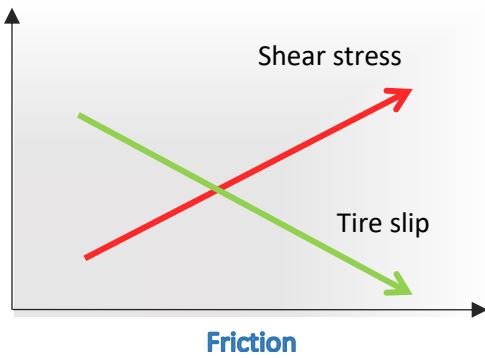


FIGURE 20 – Substrate top-down tearing theory.



FIGURE 21 – Substrate top-down tearing at a signalized approach (transverse cracking).

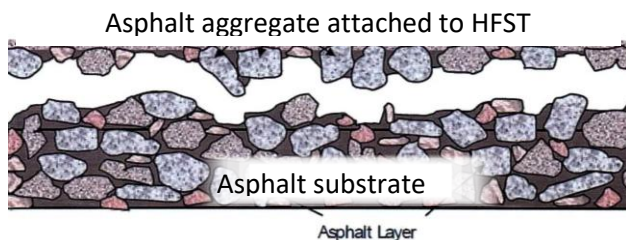


FIGURE 22 – Shallow tearing.

Reflective Cracking

HFST has some flexibility and should resist brittle cracking under traffic. However, existing cracks will still propagate through the HFST under traffic and thermal cycling. Other than restoring the surface before HFST application, this distress is unavoidable (FIGURE 22).



FIGURE 23 – Reflective cracking.

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[For more information contact:](#)

Guangming Wang, P.E.
FDOT-State Materials Office
5007 NE 39th Ave., Gainesville, FL 32609
Email: Guangming.Wang@dot.state.fl.us
Phone: 352-955-6326