High Friction Surface Treatment Guidelines

Project Selection, Materials, and Construction

FDOT

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.

PERFORMANCE

Benefit-Cost Comparison

In Florida, HFSTs on tight curves have reduced the rate of total crashes by 32% and wet-weather crashes by 75% on average. Other agencies have reported crash reductions ranging from 24% to 70% to even 93%.

Historically, the average bid unit cost of HFST in Florida is $34/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 county are sitting around $20/sy.

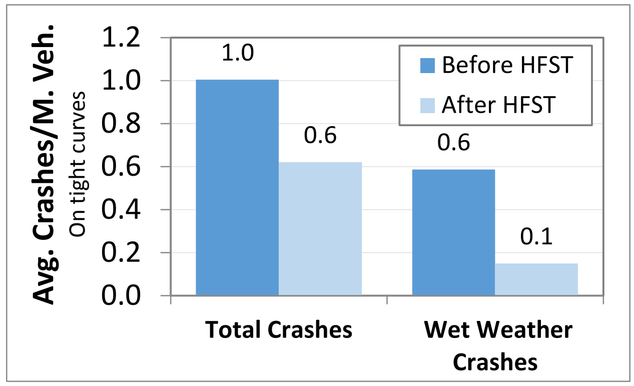

FIGURE 2 – Crash rates before and after HFST on tight curves.

HFSTs on tight curves have reduced the rate of wet weather crashes by 75%

Compared to conventional pavement maintenance treatments, this 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. The alternative to HFST is actually 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. 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.

CANDIDATE PROJECTS

What to Look for and Avoid

HFST is, first and foremost, a safety treatment. Ideal candidate locations 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 mixed. Other scenarios include approaches to rail crossings, school crossings, and tolling areas.

> *Most effective on rural and urban horizontal curves and tight radius loop ramps.*

TABLE 1 gives general guidance on where and where *not* to apply HFST.

HFST can be used as a preventative maintenance treatment for concrete bridge-decks. If the safety-benefit is not critical, a slightly lower-quality aggregate could be used to save money. HFST is not cost-effective for preventative maintenance on asphalt pavements.

The treatment may be placed over dense-graded asphalt pavement and rigid pavement. Due to several premature failures throughout the state, FDOT does not recommend placement directly on open-graded friction course (OGFC). OGFC has high voids, requiring excessive amounts of binder to offset draindown. Moisture also tends to get trapped under the HFST, causing stripping and substrate failure. Existing OGFC needs to be milled and inlaid with dense-graded asphalt before applying HFST.

HFST should only be used on structurally sound pavements requiring minimal surface repair. The top layer should be milled and inlaid in the following conditions:

- 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.)
- Widespread rutting is 0.25 inches or greater. (Constructability issues with uneven resin binder thickness.)
- Raveling. (Inadequate pavement strength.)
- Bleeding surface mix. (Poor HFST bond.)

On concrete, slab replacement is required for:

- Any single slab with moderate or severe distress (transverse cracking, longitudinal cracking, patching, spalling, and corner cracking).
- Any single shattered slab in more than 3 pieces.

> *May be placed over dense-graded asphalt pavement and rigid pavement.*
>
> *OGFC needs to be milled and inlaid with dense-graded asphalt before applying HFST.*

The district should perform any spot repairs, seal joints, and fill larger cracks with resin binder prior to placing HFST. If the surface layer is old and weak, then high shear forces after HFST is constructed can actually accelerate layer failure. Applications over pavements needing extensive rehabilitation or structural improvement will not be effective.

FIGURE 3 – HFST on Tight Curve before a Signalized Intersection.

TABLE 1 – General Guidance on Candidate Pavements.

Where to Use HFST	Where NOT to Use HFST
Roadway applications	
• Locations 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 take turns too fast and super elevations are inadequate. • On tight-radius freeway loop ramps. • At a downhill signal approaches. • On roadways that may need geometric corrections, but the agency does not have the funding. • On concrete pavements and bridge decks, to help with preservation.	• 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. • Inside signalized intersections. • After a tight curve or more than 1,000 ft before a curve. (No benefit here) • Preventative maintenance on asphalt pavement.
Pavement condition	
• Dense-graded asphalt or concrete. • Pavement condition rating of "Good" and higher. • Polished surface. • Highly oxidized. • Few low-severity cracks. Very few cracks greater than 0.25 inch Wide. • Minor rutting ≤ 0.25 inch. • No structural damage.	• Open-graded asphalt (OGFC) • Asphalt pavements with 6+ percent of cracking in or outside the wheel paths. • Widespread rutting > 0.25 inch deep. • Raveling surface. • Bleeding pavement. • 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.

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 the following sections.

High-Friction Aggregate

The most common aggregate used for HFST is calcined bauxite. This aggregate is first in class in terms of skid resistance. Other aggregates like flint, basalt, and granite may only be used for preventative maintenance applications that are not safety-critical.

Calcined bauxite is first-in-class in terms of skid resistance

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 were used, the HFST would require more resin binder without any added safety benefits.

FIGURE 4 – Calcined bauxite, crushed and graded.

Calcined bauxite is mandated in Section 333.The critical aggregate properties here are 1) a low aggregate abrasion value (20% max) and 2) a high aluminum oxide (Al_2O_3) content (86% minimum).

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 is an imported product in the United States. Raw bauxite is primarily mined to produce aluminum. The leading bauxite producers are Australia, China, Brazil, India, Guinea, and Jamaica. When raw bauxite is heated to high temperatures (1,000 to 1,500°C), it undergoes calcination, increasing in physical hardness. Calcined bauxite is shipped to the states and then crushed to size, washed, dried, and bagged before shipping to regional business like the HFST installer. At present, virtually all the calcined bauxite we use comes from China. Suppliers from different countries are expected to enter the market.

FIGURE 5 – Bauxite sources.

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. What you need is a strong polymer resin binder.

Polymer resin binders are multi-component systems that react chemically and harden when mixed. One component contains a resin (includes filler material to help with flow-ability), and other components contain curing agents. The critical characteristics of the resin binder for HFST applications are summarized below.

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

There are many flavors of resin binders though the following are most common:

- **Epoxy-Resin** - Good durability and bond strength. Longer curing time of 2-3 hours. 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

The success of HFST is dependent on proper surface preparation and mixing/application techniques. These steps should not be treated lightly since failure in any one would jeopardize the project.

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Test Strip

FDOT requires that projects larger than 200 sy incorporate, at minimum, a 20-ft long mechanical application test strip before full-scale application. Most often this is 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 following:

- **Surface preparation** - Adequate sweeping and air-washing to produce a clean, dry, dust-free surface. On concrete, correct shot blasting techniques (and subsequent cleaning) to produce the specified texture (FIGURE 8).
- **Resin binder proportioning** – Equipment settings to achieve the correct binder proportioning. Generally, the gel-time test is not sensitive to misproportioning except at extremes. This test is not a substitute for proper maintenance and calibration of the equipment. Still, this simple test does have a place to ensure against major problems. A 2-oz sample in a small paper cup will typically gel within 10 to 25 minutes (temperature dependent).
- **Resin binder application rate** – Equipment settings to achieve correct resin binder thickness. In production, the application rate will be measured by material weights and flow rates in the equipment. Beforehand, this rate should be verified with a wet film thickness gauge. (FIGURE 1) In a couple locations, use this simple device to check the film thickness prior to spreading aggregate.

FIGURE 6 – Wet film thickness gauge.

- **Cure time** – The initial cure 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. HFST wants to expand and contract much more than asphalt or concrete 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 follow-up with a high-pressure air wash. Experience has shown that sweepers alone can leave a lot of 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. (FIGURE 7)

FIGURE 7 – Proper air wash technique.

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 again be cleaned with a sweeper and a high-pressure air wash.

Don't rush shot blasting. 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.

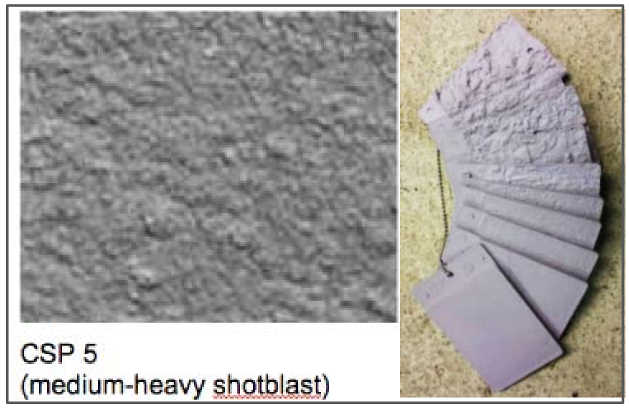

FIGURE 8 – Concrete Surface Profiles.

Don't rush shot blasting.

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 any joints and cracks greater than 1/4-inch wide with resin binder.

Applications over new asphalt pavement should be installed a minimum of 30 days after asphalt placement. In that time, any 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. 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 9 – Continuous automated HFST applicator vehicles.

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 10 – Electric mixer with "Jiffy Mixer" attachment.

FIGURE 11 – 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. Too much, and the surface texture is decreased and there is greater material waste.

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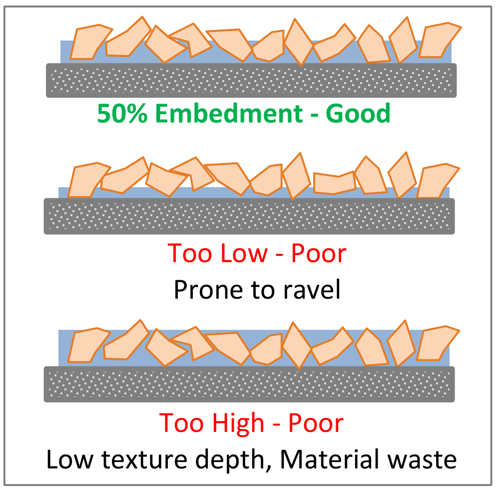

FIGURE 12 – Aggregate embedment.

The typical binder yield rate is between 25-32 sf/gal, which depends on the texture of the surface. Before-hand, walk the project and identify if there are any changes in the surface. Adjust the resin-binder rate whenever the surface texture changes significantly.

Aggregate is spread immediately following the resin binder. For automated systems, this should be in less than 30 seconds, and for manual methods 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 fist 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 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 Warrantee

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 warrantee from surface defects.

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

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. Most common on concrete surfaces. (FIGURE 15)

The force that actually 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 13 – Aggregate loss over uneven texture.

FIGURE 14 – Aggregate loss over concrete.

FIGURE 15 – Delamination.

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 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 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 16 – Widespread localized failures due to poor binder mixing.

FIGURE 17 – Soft splotchy areas shortly after construction.

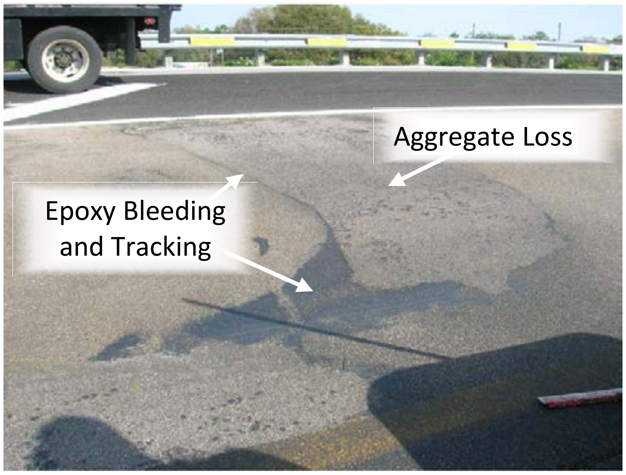

FIGURE 18 – Result of incorrect proportioning: aggregate loss, epoxy bleeding and tracking.

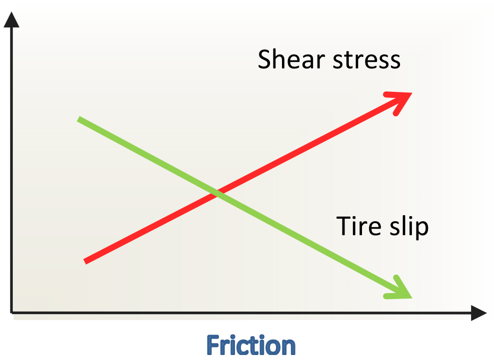

FIGURE 19 – Substrate top-down tearing theory.

FIGURE 20 – Substrate top-down tearing at a signalized approach (transverse cracking).

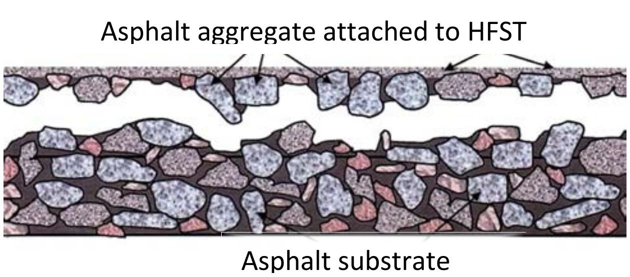

FIGURE 21 – Shallow tearing.

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 22 – Reflective cracking.

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