High Friction Surface Treatments at High-Crash Horizontal Curves

Arizona Pavements/Materials Conference
Phoenix, AZ
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Senior Highway Engineer
Federal Highway Administration
Office of Infrastructure
About Every Day Counts

- Launched in 2010
- Encourages the rapid deployment of existing, proven technologies to:
  - Shorten project delivery
  - Enhance highway safety
  - Protect the environment

- Initiatives range from modern project delivery techniques such as cloud-based data sharing to GPS guided paving machinery
A Continuous Cycle of Innovation

Every Day Counts Two Year Cycle
Completed Summit Schedule

**Fall 2012 Summits**

**Accelerating Project Delivery**
- Programmatic Agreements
- Locally Administered Projects

**Reducing Construction Time**
- 3D Engineered Models for Construction
- Accelerated Bridge Construction
- Intelligent Compaction

**Innovative Contracting**
- Design Build
- CMGC
- Alternative Technical Concepts

**Spring 2013 Virtual Summits**

**Accelerating Project Delivery**
- Geospatial Data Collaboration

**Improving Performance**
- High Friction Surface Treatments
- Intersection and Interchange Geometrics
- Implementing Quality Environmental Documentation
- National Traffic Incident Management Responder Training (SHRP 2)
High Friction Surface Treatments (HFST)

- **Key message:** HFST reduce crashes, injuries, and fatalities.
- **Benefits include:**
  - customizable to specific state and local safety needs
  - high return on investment
  - minimal impact to traffic during construction
  - negligible environmental impact
Overview

- What are High Friction Surface Treatments?
- Why HFST for Horizontal Curves?
- SEAHC Demonstration Projects.
Overview

• What are High Friction Surface Treatments?
• Why HFST for Horizontal Curves?
• SEAHC Demonstration Projects.
What is a High Friction Surface Treatment?

- High Friction Surface Treatments (HFST) are pavement surfacing systems with exceptional skid-resistant properties that are not typically acquired by conventional materials.
- Generally proprietary resin-based products and processes.
- Guidelines from the British Board of Agrément (BBA) “...defined as having a minimum skid resistance value (SRV) of 65 measured using the portable Skid-Resistance Tester as defined in TRL Report 176: Appendix E.”
• Aggregates
  – Generally calcined bauxite or flint, but slags, granite, and other materials with high PSV have also been used
  – Generally 3-4 mm maximum size
HFST Materials

- Binder system (proprietary blends)
  - Bitumen-extended epoxy resins
  - Epoxy-resin
  - Polyester-resin
  - Polyurethane-resin
  - Acrylic-resin
HFST Installation

• Manually
  – Manual mixing of epoxy material
  – Manual application of epoxy with squeegee
  – Hand broadcast and distribution of aggregate
  – Production rates: 165-420+ m$^2$/hr (200-500+ SY/hr.)
HFST Installation

- Automated (machine-aided)
  - Machine mixing and application of epoxy (limited hand/squeegee work)
  - Machine broadcast/application of aggregate
  - Production rates up to 1920 m²/hr (2,300 SY/hr.)
Overview

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Why HFST for Horizontal Curves

- Horizontal Curve Crash Picture
- Strategies for reducing crashes
- Pavement Friction Demand and location selections for HFST
Fatal Horizontal Curve Crashes

- 28% Straight
- 72% Curve

U.S. Department of Transportation
Federal Highway Administration
Average crash rates for horizontal curves is about 3 times that of tangent segments.

Source: Glennon, et al, 1985 study for FHWA
Roadway Departure Risk Strategy

- Keep Vehicles on Roadway
- Reduce Likelihood of Crashes
- Minimize Severity
Where Can HFST Benefit Safety?

1. Horizontal curves
2. Approach to intersections

When the pavement has:

- Low friction
- Marginal friction effected by weather
- Friction values not compatible with approach speeds and geometrics (friction demand)
Skid related crashes are determined by many factors:

- Friction Demand
- Road Geometry
- Vehicle Speeds
- Weather Conditions
- Traffic Characteristics
- Driver Actions

Source NCHRP 108
Basis for AASHTO Curve Design
Model Is Driver Comfort

Although the curve design policy stems from the laws of mechanics, the values used in design depend on practical limits and factors determined empirically over the range of variables involved.
AASHTO Horizontal Curve Design Model

\[ e + f = \frac{V^2}{15} R \]

- \( e \) = superelevation
- \( f \) = side friction factor
- \( V \) = design speed (mph)
- \( R \) = radius of curve (ft)

**US Customary**

\[
R = \frac{\sqrt{\frac{V^2}{e+f}}}{15}
\]

**Metric**

\[
R = \frac{\sqrt{\frac{V^2}{e+f}}}{15}
\]
Improving Friction to Keep Vehicles on the Roadway

AASHTO Design assumes vehicles:
- Do not exceed the design speed
- Traverse the curve following a constant radius.

Likelihood of skidding increases when these assumptions are violated.

Several studies have shown that under real world conditions both of these assumptions are violated.

NCHRP 500 Volume 7
What about Friction Demand?

When the:

- superelevation,
- radius
- approach speed is known

Solve for friction demand:

\[ F_s = \frac{V^2 - e}{15R} \]
Skidding trucks may lead to overturn
Friction demand varies per tire
Trucks on downgrade curves generate greater lateral friction demand
Margin of safety for ‘f’ is lower for trucks
Trucks with high centers of gravity may overturn before losing control due to skidding

Source: NCHRP 505
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Overview

- Overview of SEAHC Program
- Results from SEAHC Study
- NCAT Aggregate Durability Study
- Summary of Observations
Overview

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Goals of SEAHC:

- Demonstrate the effectiveness of High Friction Surface Treatments (HFST) in enhancing/restoring friction to reduce lane departure crashes at horizontal curves (and ramps).
- Measure the properties of HFST and monitor changes and performance over first year
- Monitor crashes before and after HFST application

Utilize currently available HFST products

3+ year study for each site

Generally 1-5 sites per State
• 24 Installations in 10 States
  – Installation, Testing, Monitoring: 19
  – Testing Only: 5
• 5 Different HFST vendors
• 5 Pavement types
  – PCCP
  – Conventional dense-graded HMA / SMA
  – Chip Seal
  – Open Grade Friction Course
FHWA Surface Enhancements At Horizontal Curves (SEAHC) Program
Data Collection

- Crash Data:
  - Historical: min. 3 years prior to installation
  - Post-Installation: 3 years following installation
- Friction
- Texture
- Tire-Pavement Noise (*OBSI, select sites only*)
Friction

Dynamic Friction Tester (DFT)

GripTester

Highway Friction Tester

DOT-provided Locked Wheel Skid Trailer (ribbed and/or smooth tire)
Texture

Circular Track Meter (CTM) – MPD

RoboTex – MPD

ASTM E965 (“Sand Patch”) – MTD
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• Summary of Observations
MICHIGAN

- Aggregate: Calcined Bauxite and Crushed Flint

- Projects:
  - NB I-75 to NB Baldwin Rd. ramp, Auburn Hills (PCC)
  - NB I-75 to Rochester Rd. ramp, Auburn Hills (HMA)
  - WB I-69 to SB I-75 ramp, Flint (PCC)
  - WB I-96 to NB US 131 ramp, Grand Rapids (PCC)
Michigan – PRELIMINARY Results

20 kph Friction Value (DFT)

<table>
<thead>
<tr>
<th>Site</th>
<th>SB Baldwin</th>
<th>Rochester</th>
<th>I-69/I-75</th>
<th>I-96/US 131</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bauxite</td>
<td>□ Pre-HFS</td>
<td>□ Post-HFS □ 1-Year</td>
<td>□ Pre-HFS</td>
<td>□ Post-HFS</td>
</tr>
</tbody>
</table>
Michigan – 1-Year Performance
Preliminary Crash Reduction Results

- **Michigan**
  - **Site 1**
    - 3 yr before: 26 crashes (8 wet)
    - 1 yr after: 4 crashes (1 wet)
  - **Site 2**
    - 3 yr before: 55 crashes (15 wet)
    - 1 yr after: 16 crashes (2 wet, 3 snow/ice)
  - **Site 3**
    - 3 yr before: 22 crashes (7 wet)
    - 1 yr after: 2 crashes (1 icy)
  - **Site 4**
    - 3 yr before: 25 crashes (12 wet)
    - 1 yr after: 3 crashes (1 wet, 1 icy, 1 alcohol)

Overall, 60% crash reduction in first year!
I-380 Cedar Rapids, IOWA

RSA Crash Data Analysis (2001-2008):

• 139 total crashes, 1 fatal, 4 major injury

Large Truck involvement (21 crashes):
1 fatality, 8 total injuries, $862,000 property damage

• 11 impacted bridge rail, 5 jackknife
• Wet pavement conditions in 20 of 21
• 8 listed speed as major cause

HFST was recommended
I-380 Cedar Rapids

- I-380 Cedar River crossing
- Connects Iowa City to Waterloo
- 85,000 AADT
- 7800 AADT Trucks
- Bridge constructed in 1979
Potential Solution

- FHWA Surface Enhancement at Horizontal Curves (SEAHC) Demo
  - Would provide additional funding
  - Monitor crashes before and after HFST application
  - Friction testing before and after HFST
  - Contribute to the national evaluation

www.highfrictionroads.com
Construction Components

• Night Work
  – Deck Patching
  – Pavement marking removal
  – Joint covering
  – Shot-blasting
  – Mechanical Application
Shot-Blasting

- 1 foot per pass
Mechanical Application
Sweeping
• DOT Friction Testing

<table>
<thead>
<tr>
<th>Lane</th>
<th>Prior Section</th>
<th>HFST Section</th>
<th>Post Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1(Outside Lane)</td>
<td>29.9</td>
<td>73.0</td>
<td>33.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>71.7</td>
<td></td>
</tr>
<tr>
<td>Lane 2 (Middle Lane)</td>
<td>26.3</td>
<td>70.9</td>
<td>30.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>70.9</td>
<td></td>
</tr>
<tr>
<td>Lane 3(Inside Lane)</td>
<td>38.6</td>
<td>79.8</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>79.1</td>
<td></td>
</tr>
</tbody>
</table>
Highway Friction Tester

6875H HFT Friction Test Results for I-380 HFST Project

Notes:
- Test Date: 6/2/12
- All tests shown conducted at 50 mph
- HFST had not been applied to any NB lanes
- Only middle and outside SB lanes had been treated
- SB middle lane data is for ~1,850 ft that had been treated
- SB inside lane had been shotblast
- Test data were collected over the proposed (and actual) HFST treatment sections provided by FHWA

![Bar Chart](chart.png)
• Total Cost: $493,725.60

• Friction Treatment: $22.00 per yd$^2$
## Crash Reduction

### Before HFST

**May 1, 2008 - April 30, 2012**

<table>
<thead>
<tr>
<th>Category</th>
<th>5-yr Total</th>
<th>Annual Avg (5 yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crashes</td>
<td>54</td>
<td>10.8</td>
</tr>
<tr>
<td>Injuries</td>
<td>28</td>
<td>5.6</td>
</tr>
<tr>
<td>Tractor/Semi-trailer</td>
<td>8</td>
<td>1.6</td>
</tr>
<tr>
<td>Property Damage</td>
<td>$981,616</td>
<td>$196,323</td>
</tr>
<tr>
<td>Lost Control/Speed Too Fast/Evasive</td>
<td>29</td>
<td>5.8</td>
</tr>
<tr>
<td>Road Surface Contributing</td>
<td>9</td>
<td>1.8</td>
</tr>
<tr>
<td>Wet Roadway</td>
<td>17</td>
<td>3.4</td>
</tr>
<tr>
<td>Snow/Ice/Slush</td>
<td>17</td>
<td>3.4</td>
</tr>
</tbody>
</table>

### After HFST

**June 13, 2012 - June 12 2013**

<table>
<thead>
<tr>
<th>Category</th>
<th>Annual (1 yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crashes</td>
<td>4</td>
</tr>
<tr>
<td>Injuries</td>
<td>1</td>
</tr>
<tr>
<td>Property Damage</td>
<td>$9,500</td>
</tr>
<tr>
<td>Lost Control/Speed Too Fast/Evasive</td>
<td>0</td>
</tr>
<tr>
<td>Road Surface Contributing</td>
<td>0</td>
</tr>
<tr>
<td>Wet Roadway</td>
<td>2</td>
</tr>
<tr>
<td>Snow/Ice/Slush</td>
<td>0</td>
</tr>
</tbody>
</table>

* 2013 data is preliminary
Benefits

- Fewer Crashes
- Fewer Traffic Impacts
- Much Quieter Ride
What’s Next for Iowa?

• **EDC2 Implementation Plan**
  – Data Analysis (Fall/Winter 2013)
    • Curve Identification
    • Crash, Friction, and Pavement Assessment
  – Identify Candidate Locations (Spring 2014)
  – Develop Projects (Summer/Fall 2014)
  – HFST Installation (by Fall 2015)
Wisconsin – Marquette Interchange

Construction Completed: November 2008

Application Type: Rehabilitation

Treatment Date: October 2011

Purpose: High Incident Rate

2009: 61 crashes
2010: 95 crashes
2011: 76 crashes
Case Study #1 - The Issue
Case Study #1 – Marquette Interchange

Pre-Application Incident Statistics

West to North Ramp Crashes

Number of Crashes

U.S. Department of Transportation
Federal Highway Administration
Marquette Interchange

Post-Application Incident Statistics

West to North Ramp Crashes

Number of Crashes

97% REDUCTION
Marquette Interchange

Post-Application Incident Statistics

West to North Ramp Crashes

97% REDUCTION
I-43 at North Avenue

Construction Completed: September 2008
Application Type: Resurface
Treatment Date: November 2012

Purpose: High-Density Incident Rate (0.5 mile)

2005: 12 crashes
2006: 11 crashes
2007: 21 crashes
2008: 50 crashes
2009: 53 crashes
I-43 at North Avenue
I-43 at North Avenue

I-43 NB & SB Crashes

Jan-05  Mar-05  Jul-05  Sep-05  Nov-05  Jan-06  Mar-06  May-06  Jul-06  Sep-06  Nov-06  Jan-07  Mar-07  May-07  Jul-07  Sep-07  Nov-07  Jan-08  Mar-08  May-08  Jul-08  Sep-08  Nov-08  Jan-09  Mar-09  May-09  Jul-09  Sep-09  Nov-09

U.S. Department of Transportation
Federal Highway Administration
Construction Completed: October 2012
Application Type: Resurface
Treatment Date: November 2012

Purpose:

Incident Prevention
- friction scans indicated low coefficient

Incident Study:
Ongoing
Additional Projects: I-94E at STH 67
Additional Projects: I-94W at CTH F
Overview

• Overview of SEAHC Program
• Results from SEAHC Study
• **NCAT Aggregate Durability Study**
• Summary of Observations
NCAT Aggregate Durability Study

• Purpose: Test the durability of various aggregate types under the same conditions
  – Installed on similar sections NCAT Test Track on a curve
  – Installed by same HFST supplier using the same resin, crew, and equipment
  – Exposed to the same traffic and climatic conditions
NCAT Aggregate Durability Study

• Purpose: Test the durability of various aggregate types under the same conditions
  – Installed on similar sections NCAT Test Track on a curve
  – Installed by same HFS supplier using the same resin, crew, and equipment
  – Exposed to the same traffic and climatic conditions

• 5+ Million ESAL applications (April 2011 - July 2013)
Laboratory Testing of smaller samples of each

Aggregates Tested:
- Granite, Bauxite, Flint (100’ each)
- Basalt, Silica, Steel Slag, Emery, Taconite (15’ each)

Phase II (ongoing)
- Bauxite, Steel Slag, OK Chat, Taconite
NCAT Aggregate Durability Study
NCAT Aggregate Durability Study

HFS Installation Location

- N1 through N11 and S8 through S12 are structural sections
- All other sections have deep perpetual foundations
- Research cycle of construction shown by color
NCAT Aggregate Durability Study
NCAT Aggregate Durability Study

100'

Flint

Bauxite

Granite
NCAT Aggregate Durability Study

- Taconite
- Emery
- Steel Slag
- Silica
- Basalt
- Flint
- Bauxite
- Granite

100'

15'
Night View
NCAT Aggregate Durability Study

- Laboratory Testing
- Three Wheel Polishing Device
  - Friction and Texture tested at 70k and 140k cycles
  - 2 replicates for each aggregate type
NCAT – PRELIMINARY Test Track Results

Mean Profile Depth (CTM)

Site

Granite  Bauxite  Flint  Basalt  Silica  Slag  Emery  Taconite

Post-Install  Post-Traffic
NCAT – PRELIMINARY Test Track Results

20 kph Friction Value (DFT)

<table>
<thead>
<tr>
<th>Site</th>
<th>Post-Install</th>
<th>Post-Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>0.6</td>
<td>0.55</td>
</tr>
<tr>
<td>Bauxite</td>
<td>1.0</td>
<td>0.95</td>
</tr>
<tr>
<td>Flint</td>
<td>0.8</td>
<td>0.75</td>
</tr>
<tr>
<td>Basalt</td>
<td>0.8</td>
<td>0.75</td>
</tr>
<tr>
<td>Silica</td>
<td>0.7</td>
<td>0.65</td>
</tr>
<tr>
<td>Slag</td>
<td>0.7</td>
<td>0.65</td>
</tr>
<tr>
<td>Emery</td>
<td>0.8</td>
<td>0.75</td>
</tr>
<tr>
<td>Taconite</td>
<td>0.9</td>
<td>0.85</td>
</tr>
</tbody>
</table>
NCAT – PRELIMINARY Test Track Results

HFS - lab DFT Summary

DFT Fn (40 km/hr)

granite  bauxite  flint  basalt  silica  slag  emery  taconite

70K  140K
• Wind is another potential weather delay
• Ensure adequate lighting for night work
• Need bigger shot blasters (width)
• Strong vacuums are needed to collect extra aggregate from lane and shoulder debris
• Review the weight of the machine and loaded materials
• HFST is working well by both crash and friction performance metrics
SEAHC - General Observations

• Underlying pavement must be in good condition – no alligator/block/map cracking
  – Cracks will reflect through regardless of the pavement type
  – HFS still adheres well in the presence of cracking
HFST products used to date have adhered well to all pavement types – HMA, Chip Seal, SMA, and PCC

Surface preparation is very important

- Shotblasting is generally required for concrete pavement
- Removal of latent oils/grease and debris for all pavement types
• HFST naturally “sheds” aggregate for the first few weeks/months after installation
  – May result in “artificial” texture depth and friction readings immediately after installation
  – Shoulders must be monitored and cleared of loose aggregate
SEAHC - General Observations

- HFST appears to perform well under snowplow wear, but poorly under studded tires / chains
  - Double-layer HFS may be necessary for these locations
• Calcined Bauxite is the “premium” aggregate for HFST, but other aggregates have also performed satisfactorily under non-aggressive conditions
  – NCAT Durability Study showed other potentially promising aggregates, but requires further testing and evaluation
  – Selection of aggregate type should be governed by traffic and environmental conditions
SEAHC - Summary

• HFST has been demonstrated to be an effective surface treatment material for reducing crashes at curves.
• HFST vendors are continually seeking to improve materials, application equipment, and installation practices
• HFST vendors have been extremely supportive and are the key element to the successful projects to date
• FHWA continues to support HFS as a solution for enhancing safety on pavement surfaces
FHWA continues to support HFS as a solution for enhancing safety on pavement surfaces.

HFST has been selected by FHWA as an Every Day Counts 2 (EDC2) initiative and as a result will be highly promoted in the next two years.