Development of High Friction Surface Treatment (HFST) Prescreening Protocols and an Alternative Friction Application

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(Somewhere from my house)
High Friction Surface Treatment (HFST)

- Typically consists of calcined bauxite (polish resistant) bonded to pavement with polymer resin
- HFST installed as a thin overlay (< ½ inch)
- Applied as a single “surface”
- Used to improve frictional characteristics of pavement surfaces
Creating Pavement Friction Through Texture

Texture Wavelength Influence on Pavement Surface Characteristics

<table>
<thead>
<tr>
<th>Texture Categorization</th>
<th>Texture Wavelength ((\lambda))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microtexture</td>
<td>(\lambda &lt; 0.5) mm</td>
</tr>
<tr>
<td>Macrotexture</td>
<td>(0.5) mm (&lt; \lambda &lt; 50) mm</td>
</tr>
<tr>
<td>Megatexture</td>
<td>(50) mm (&lt; \lambda &lt; 500) mm</td>
</tr>
<tr>
<td>Roughness/Smoothness</td>
<td>(0.5) m (&lt; \lambda &lt; 50) m</td>
</tr>
</tbody>
</table>

Source: Flintsch, et.al.
Source: [http://www.mto.gov.on.ca/](http://www.mto.gov.on.ca/)
Recommended Locations of HFST

- Horizontal curves*
- Intersections
- On and Off Ramps*
  - Elevation changes (loops ramps)
- Steep grades
- Line of Sight problem locations
- High speed connectors/merge locations
- High crash clusters, roadway departures or poor roadway friction conditions
HFST Safety Benefits
CA Highway 17 at Laurel Curve

Collisions at Santa Cruz Route 17, Post Miles 9.4 to 9.6 in the Southbound direction, from 1/1/09 to 12/31/2014

- Installed HFST July 2012.
- 2012 - 2014 collision data from CHP.
- AADT for Route 17 is 60,000.

<table>
<thead>
<tr>
<th>Year</th>
<th>WET</th>
<th>DRY</th>
<th>Total Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>34</td>
<td>7</td>
<td>41</td>
</tr>
<tr>
<td>2010</td>
<td>62</td>
<td>19</td>
<td>81</td>
</tr>
<tr>
<td>2011</td>
<td>44</td>
<td>2</td>
<td>46</td>
</tr>
<tr>
<td>1/1/12 to 6/30/12</td>
<td>21</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>7/1/12 to 12/31/12</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2013</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2014</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Total Crashes: 183

HFST Installed: 3 Crashes
PennDOT Study (Musey et al., 2017 TRB)

- 74 sites across the state
- HFST reduced accident related injuries significantly, including NO FATALITIES
**State Agency HFST Studies**

- Kentucky

The Kentucky Transportation Cabinet installed HFSTs at selected locations with a history of wet roadway departure crashes.

HFSTs were one of the eight countermasures identified when the Kentucky Transportation Cabinet implemented a statewide Roadway Departure Safety Plan to address problem curve sites. They identified a list of the 30 worst curves: 15 for wet crash and 15 for total crash. Additionally, 10 of the worst ramps were also selected. One such location is Oldham County, KY 22. Through a 4-year before-and-after (August 2007 to August 2011) study period, lane-departure crashes were reduced from 47 crashes in the 2 years before to only 5 crashes in the 2 years after.

- Washington State

HFST at the intersection of Forest Drive and Cole Creek Parkway in Bellevue, Washington results in 78 percent fewer accidents per year. Associated accident costs dropped by 83 percent.

The City of Bellevue in Washington State installed the HFST "Tyre-grip" on the westbound approach of Forest Drive at its intersection with Cole Creek Parkway in Bellevue in October 2004 (resurfaced again in May 2007 due to a surface water issue). This is a downgrade intersection approach often affected by icy weather conditions. Approximately 35,000 vehicles use the westbound approach weekly. Bellevue tried several countermasures, including installing a large flashing warning sign at the bottom of the grade, additional road markers, new street lights, and raised pavement buttons, but did not achieve the desired result. After applying HFST, accidents at this intersection dropped 78% and costs associated with accidents declined by 83%.
### HFST Roadway Applications Do’s and Don’ts (FDOT, 2016)

<table>
<thead>
<tr>
<th>Pavement condition</th>
<th>Where to Use</th>
<th>Where Not to Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense-graded asphalt or concrete.</td>
<td></td>
<td>Open-graded asphalt (OGFC)</td>
</tr>
<tr>
<td>Pavement condition rating of “Good” and higher.</td>
<td></td>
<td>Asphalt pavements with 6+ percent of cracking in or outside the wheel paths.</td>
</tr>
<tr>
<td>Polished surface.</td>
<td></td>
<td>Widespread rutting &gt; 0.25 inch deep.</td>
</tr>
<tr>
<td>Highly oxidized.</td>
<td></td>
<td>Raveling surface.</td>
</tr>
<tr>
<td>Few low-severity cracks. Very few cracks greater than 0.25 inch Wide.</td>
<td></td>
<td>Bleeding pavement.</td>
</tr>
<tr>
<td>Minor rutting ≤ 0.25 inch.</td>
<td></td>
<td>Areas where layer debonding or subsurface stripping is suspected. (Verify with coring and other pavement forensics.)</td>
</tr>
<tr>
<td>No structural damage.</td>
<td></td>
<td>Concrete single slab with moderate or severe distress, patching, or shattered in more than 3 pieces.</td>
</tr>
</tbody>
</table>
What is a "Good" Pavement for HFST?

- A prerequisite for HFST application is a "good" pavement
- Pavement screening extremely important in success of HFST
  - How do you define "good"?
    - No cracking
    - No rutting
    - Fairly "new"
    - Can a "new" or "visually good" asphalt pavement actually be "old" or prone to durability issues?
What is a “Good” Pavement for HFST?

- Asphalt mixture factors that accelerate aging, cracking, and raveling in asphalt pavements
  - Low asphalt contents
  - High dust content
  - Excessive production temperatures
  - Recycled asphalt
    - Recycled Asphalt Pavement (RAP)
    - Recycled Asphalt Shingles (RAS)
Both county roads received HFST application in 2017

- **CR511:**
  - 8 to 13 inches of HMA over gravel base;
  - Recent HMA overlays from 2012 to 2015;
  - Visual distress survey showed pavement in “relatively good” condition (some deterioration near shoulder areas due to poor drainage)

- **CR700:**
  - 8 to 9 inches of HMA over gravel base;
  - Recent HMA overlays from 2013 to 2015;
  - Visual distress survey showed pavement in “relatively good” condition
Late Winter/early Spring 2018, pavement distress began showing up
HFST Distresses and Possible Causes

- Substrate Failure – Top-down & Shallow Horizontal Cracking
  - Due to weak substrate
  - Areas of extreme stopping & slow turning
  - Thermally induced stress
  - Excessively thick & stiff HFST layer (epoxy)
HFST Distresses and Possible Causes

- Substrate Failure – Top-down & Shallow Horizontal Cracking
  - Typically ¼” to ½” deep
  - Epoxy and asphalt mixtures are thermally incompatible
    - Epoxy has an expansion/contraction rate 3 to 4 times greater than asphalt mixtures
    - Worst situation – cool/cold temperatures with a quick, large temperature decrease
The current guidance of “good condition” for asphalt pavements is not adequate for such an investment.

- Immediate need for a method to characterize existing asphalt pavements prior to HFST application.
- In addition, if the pavement is shown to not be a candidate, is there a similar “system” compatible with the existing pavement?
Proposed Testing Protocols for HFST Prescreening
Test methods selected:

- ASTM C1583 – testing pull-off strength of existing substrate tested at 25°C
  - 6 inch field cores work well
- Asphalt binder characterization from upper ½” to ¾” of existing asphalt pavement for “durability”
  - Glover-Rowe Parameter
  - ΔTc (Difference in critical low temperature cracking)
Rowe (AAPT, 2011) proposed the DSR master curve analysis to calculate the “Glover-Rowe” parameter

- As G-R parameter increases, the binder is more prone to fatigue cracking
- Correlates very well to ductility of asphalt binder
  - $G^* = \text{shear modulus (stiffness of asphalt binder)}$
  - $\delta = \text{phase angle (relaxation of asphalt binder)}$

$$\frac{|G^*|(\cos \delta)^2}{\sin \delta}$$
Asphalt Binders Age

- As asphalt binders age, the relaxation properties (m-value) are negatively affected at a greater rate than the stiffness (\(S\)).
- The difference between the low temperature cracking grade of m-value and S is defined as the \(\Delta T_c\):
  \[ \Delta T_c = T_c, S - T_c, m-value \]
- Anderson et al. (2011) showed that the \(\Delta T_c\) correlated to non-load associated cracking on airfields (i.e. – cracking due to lose of ductility from aging).
  - The more negative value, the more aged the asphalt binder.
Substrate testing of 5 different pavement sections (8 different performing areas)

- Results indicate that pull-off testing alone may not be able to predict suitability of substrate for epoxy resin-based HFST
- For CR511 and CR700, there was noticeable lower strength compared to other sections
Recovered the asphalt binder for ½” to ¾” of surface

- “Good” HFST performance was identified with Glover-Rowe < 100 kPa
- $\Delta T_c$ indicated values “warmer” than 0°C
  - Some projects not able to be tested due to limited material
Even though a pavement is visually in “good condition”, asphalt may still be prone to raveling/durability issues of “aged” asphalt

- Binder testing to address quality of asphalt binder in existing pavement surface
- Mix testing to address quality of mix strength properties in existing pavement surface
Potential Alternative to HFST – NJDOT High Friction Chip Seal (HFCS)
What if we tried high friction aggregate with a highly modified asphalt binder?

- Asphalt-based binding system more thermally compatible than epoxy resin
- High PG to maintain stiffness in hot temperatures
- Low PG properties to aid in thermal contraction movements
Route 68 High Friction Chip Seal (HFCS) Case Study

- Looked at using a chip seal process using hard, angular stone
- Evaluated different aggregate sources
  - Diabase (NJ) – Lane 1
  - Calcine Bauxite – Lane 2
  - Flint Rock (OK) - Shoulder
- Compared aggregate “polishing” resistance
  - Utilized micro-deval & Aggregate Imaging to assess polishing resistance (Masad et al., 2011)
Asphalt binder met the requirements for FAA P404, *Fuel Resistant (FR) Asphalt Mixture*
- PG88-22 with Evotherm applied hot 0.3 to 0.38 gal/yd²
- Aggregate “chips” spread at 14 to 18 lb/yd²
- Rubber wheel rollers to seat aggregate & loose aggregate swept
NJ Route 68 High Friction Chip Seal (HFCS)

Diabase Aggregate

Calcine Bauxite
Looked at pull-off strength of HFCS applied to Rt. 68 surface
  - Could aggregate get pulled out of HFCS binder?
Results were consistent for aggregate (Average ≈ 118 psi) and failures occurred between binder and pavement surface
  - Pull-off strength statistically greater than adjacent asphalt rubber chip seal

<table>
<thead>
<tr>
<th></th>
<th>Pull-off Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DGA - No HFCS</td>
<td>264.0</td>
</tr>
<tr>
<td>HFCS - All Aggregates</td>
<td>118.0</td>
</tr>
<tr>
<td>HFCS - Calcined Bauxite</td>
<td>116.6</td>
</tr>
<tr>
<td>HFCS - Diabase</td>
<td>119.4</td>
</tr>
<tr>
<td>HFCS - Flint Rock</td>
<td>116.6</td>
</tr>
<tr>
<td>AR Chip Seal</td>
<td>78.3</td>
</tr>
</tbody>
</table>
Skid Resistance, SN₄₀ (ASTM E₂₇₄)

- Skid Testing was conducted in accordance to ASTM E₂₇₄
  - Initial results looked good (SN₄₀ Ave > 60)
  - After 2 years, values dropped around 10 to 20%
    - Skid friction influenced by bleeding of adjacent asphalt rubber chip seal major issue
Conclusions

- HFST surfaces can provide significant improvement in surface friction to reduce lane departure accidents
  - However, lack of quantifiable prescreening criteria may result in premature HFST failures
- Proposed prescreening would utilize recovered field cores to evaluate pull-off strength and relative asphalt binder aging prior to HFST placement
  - More information required to “fine tune” and validate proposed criteria
- High Friction Chip Seal (HFCS) possible alternative for existing pavements with marginal substrate conditions
  - Thermally compatible and provides high level of friction
  - Similar systems being evaluated at NCAT test track
Thank you for your time!

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