Steel Furnace Slag in Hot Mix Asphalt

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Rebecca S. McDaniel, PE, PhD
Technical Director
Long History of Use in Indiana

- Local aggregates predominantly carbonates
  - Gravels can be 60% carbonates
  - Prone to polishing
- Air-Cooled Blast Furnace Slag use pre-dates 1946
- Steel Furnace Slag use pre-dates 1988
- Preferred aggregate for high volume surfaces for friction
Steel Slag Research at NCSC

- Long Term Performance of a Porous Friction Course
- Identification of Laboratory Technique to Optimize Superpave HMA Surface Friction Characteristics
- Evaluation of Recycled Asphalt Pavement for Surface Mixtures
- Maximizing the Use of Local Materials in HMA Surfaces
Long Term Field Evaluation of Porous Friction Course

- I74 Eastbound East of Indianapolis
- Constructed August 2003

- Comparison of Stone Matrix Asphalt (SMA), Porous Friction Course (PFC) and conventional HMA (Superpave)
Why Porous Asphalt Surfaces?

- Control noise generation and propagation at the source, tire-pavement interface
- More cost effective than noise walls
- Impact more people over a larger area
- Offer other benefits, particularly safety
  - Improved friction
  - Reduced splash and spray
Long Term Performance Questions

- How long will benefits persist?
  - Does the PFC clog and lose effectiveness?
  - High permeability is supposed to help prevent that, but ....
  - Will traffic wear off film and increase IFI on PFC and SMA?
- Will PFC lose macrotexture and friction?
- Can the aggregate withstand traffic?
• 9.5mm mixtures used Steel Slag and PG76-22 binder
• PFC designed at 18-22% air voids
• Polymer modified binder and fiber
Changes in Noise vs. Traffic

- **PFC at 100 km/h**
- **SMA at 100 km/h**
- **DGA at 100 km/h**

SPL, dB(A)

<table>
<thead>
<tr>
<th>Date</th>
<th>SPL (dB(A))</th>
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<tr>
<td>6/2005</td>
<td>74</td>
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<td>82</td>
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<td>6/2008</td>
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no. of axle passes, $10^6$

- **6/2005**
- **5/2006**
- **6/2006**
- **7/2007**
- **7/2007**
- **10/2007**
- **8/2008**
Changes in Texture

![Graph showing changes in texture with number of axle passes and MPD values.]

- **MPD, mm**
  - SMA: 9/2003

- **No. of axle passes, 10^6**
  - 0, 10, 20, 30, 40, 50, 60

- **Dates**
Changes in Friction (F60)

- For SMA:
  - 9/2003
  - 5/2006
  - 11/2006

- For PFC:
  - 10/2006
  - 8/2007
  - 10/2007

- For DGA:
  - 8/2005
  - 10/2007
  - 8/2008

- Axes:
  - F60 (Y-axis)
  - No. of axle passes, 10^6 (X-axis)
Conclusions

- Porous Friction Courses can perform well over the long term (5+ years)
- Steel Slag aggregate withstood effects of traffic
- Void structure was maintained
  - Proper material selection and mix design
  - Proper maintenance
  - Proper application (high speed)
Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics

- Assess/optimize micro- and macrotexture
- Develop/modify lab device and tests to polish HMA
- Evaluate influence of mix composition on friction
- Develop model for friction prediction
- Funded by Indiana and Iowa DOTs
Designing for Pavement Friction

- Most states specify allowable surface aggregates by type based on historical usage and aggregate tests.
  - Useful, but do not consider macrotexture.
  - Need mixture test and specifications.
- Polish resistant aggregates are not readily available and must be hauled in -- $$$.
- Coarser mix texture may reduce the need for high microtexture aggregates.
Background

- Pavement friction is function of microtexture and macrotexture.
  - Microtexture – provided by aggregate surface
  - Macrotexture – determined by overall properties of the pavement surface (NMAS and gradation of aggregates, binder content, etc.)

- Friction at the tire-pavement interface is caused by:
  - Adhesion – between tire and surface (microtexture)
  - Hysteresis - deformation of tire around surface irregularities (macrotexture)
Lab Test for Optimizing Friction

- Test friction and texture
- Simulate/accelerate polishing
- Test asphalt *mixtures*, not aggregates only
- Ideal to be able to test in lab and field
- Led to identification of Dynamic Friction Tester and Circular Track Meter
- Needed a polisher to match
- Idea from NCAT, refined by NCSC
Dynamic Friction Tester (DFT)

DFT – dynamic friction at 20 km/h (DF20)
Circular Track Meter (CTM)

CTM – Mean Profile Depth, mm
International Friction Index

IFI (F60, S_p)

\[ F_{60} = 0.081 + 0.732D F_{20} e^{Sp} \]

\[ S_p = 14.2 + 89.7MPD \]
Circular Track Polishing Machine
IFI (F60)
Experimental Design

- 3 Gradations – Fine, Coarse, S-shaped
- 2 Aggregate Sizes – 9.5 mm and 19 mm
- 2 Friction Aggregates – steel slag and quartzite
- 3 “Soft” Aggregates – hard and soft limestones, and dolomite
- 4 Friction Agg Contents – 10, 20, 40, 70%
Key Findings

- Steel slag more polish resistant than quartzite.
- Mixes with soft limestone polished more than hard limestone or dolomite.
- Increasing friction aggregate content improved polishing resistance.
- Friction aggregate content should be at least 20%.
- Larger NMAS mixes have higher friction.
- Fineness modulus correlates with macrotexture.
Key Findings

- S-Shaped gradation generally resulted in higher macrotexture.
- Frictional properties can be improved by using polish resistant aggregate blends or by increasing macrotexture (FM).
- A model for describing the change in friction parameters under traffic/ polishing was developed.
- The lab procedures are very promising tools.
  - Included in new Indiana test method.
Evaluation of Recycled Asphalt Pavement for Surface Mixtures

- RAP not used to full extent in surfaces
  - Unknown aggregates
- Determine threshold level of RAP that has minimal effect or method to test aggregates in the RAP
Experimental Design

- Mix Type – HMA and SMA
- Lab Fabricated “Worst Case” RAP
- RAP Content – 0, 15, 25, 40%
- Friction Aggregate – Steel Slag and ACBF Slag

- Field testing of 8 existing surfaces (15-25% RAP)
Use of the Model

- DGA
- SMA
Findings and Implementation

- Adding small quantities of poor quality RAP had little effect on friction.
- When blended with high quality friction aggregates, performance was still acceptable at 25% RAP.
- Field friction testing suggests 15% RAP is acceptable and higher RAP contents are possible for medium volume roadways.
- Allowable RAP content raised to 25% by binder replacement for Category 3 and 4 roadways.
Maximizing the Use of Local Materials in HMA Surfaces

Objective – explore opportunities to allow the use of more local materials in HMA in place of “imported” fine and coarse aggregates
Experimental Design

- Local coarse aggregate content – up to 40% blended with the same 3 high quality aggs
- Local fine aggregate content – up to 20% (with steel slag, ACBF slag and sandstone CA)
- HMA and SMA mixes
Findings

- Adding polish susceptible agg caused decrease in surface friction in HMA and SMA.
- But friction was still acceptable at up to around 20% local agg.
- Fine aggregate data was somewhat erratic.
- Appears fine agg up to 20% was small negative effect on friction.
- Other considerations besides friction.
These Studies

• Confirm that steel furnace slag is a premium aggregate.
• Steel slag stands up to traffic without
  • Loss of friction or
  • Degradation.
• Blending in steel slag allows use of marginal materials.
• Very sustainable practice.
Questions???

Rebecca McDaniel
rsmcdani@purdue.edu
765/463-2317 x 226
https://engineering.purdue.edu/NCSC