# Steel Furnace Slag in Hot Mix Asphalt

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# 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

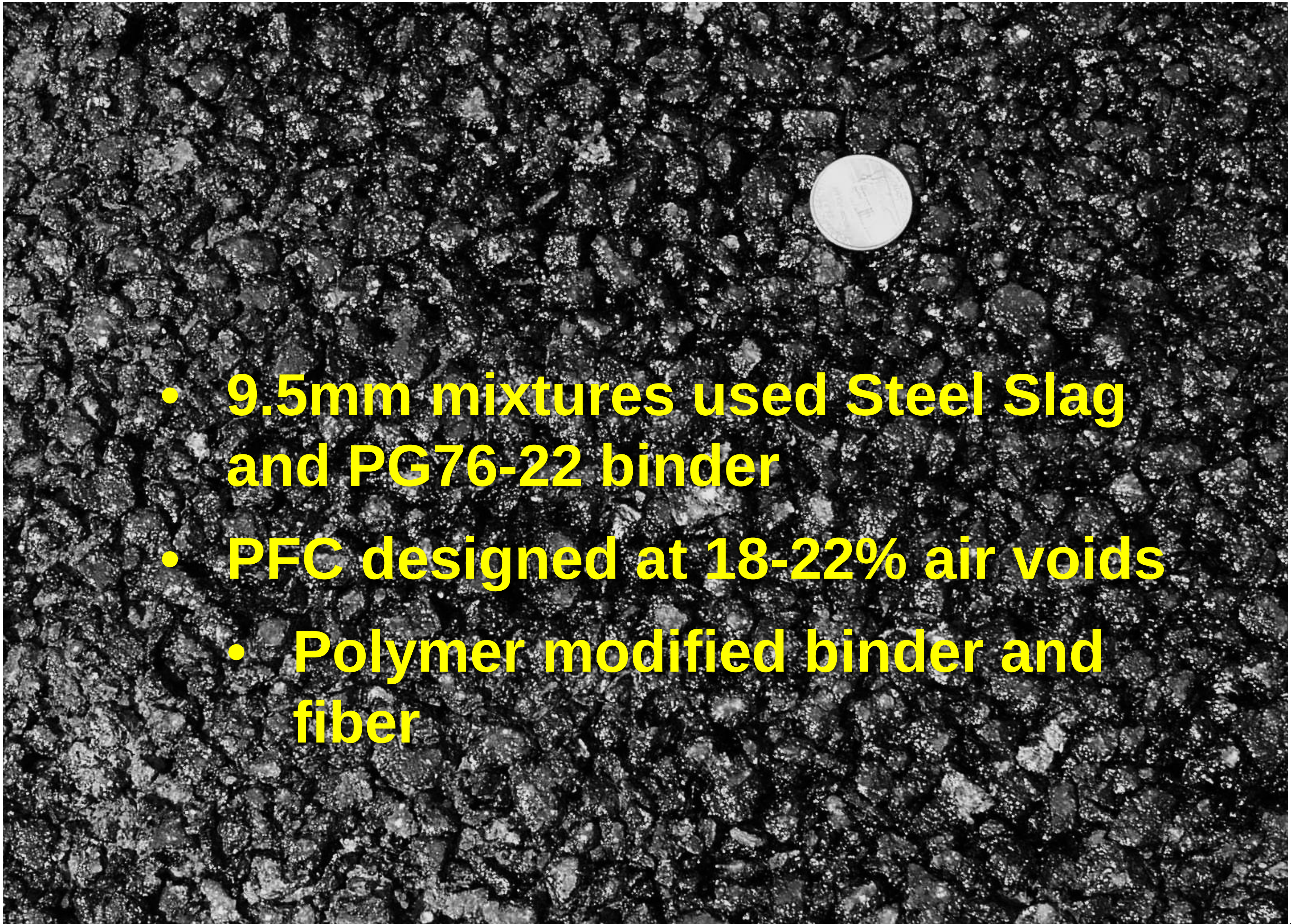
- Comparison of Stone Matrix Asphalt (SMA), Porous Friction Course (PFC) and conventional HMA (Superpave)

# 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

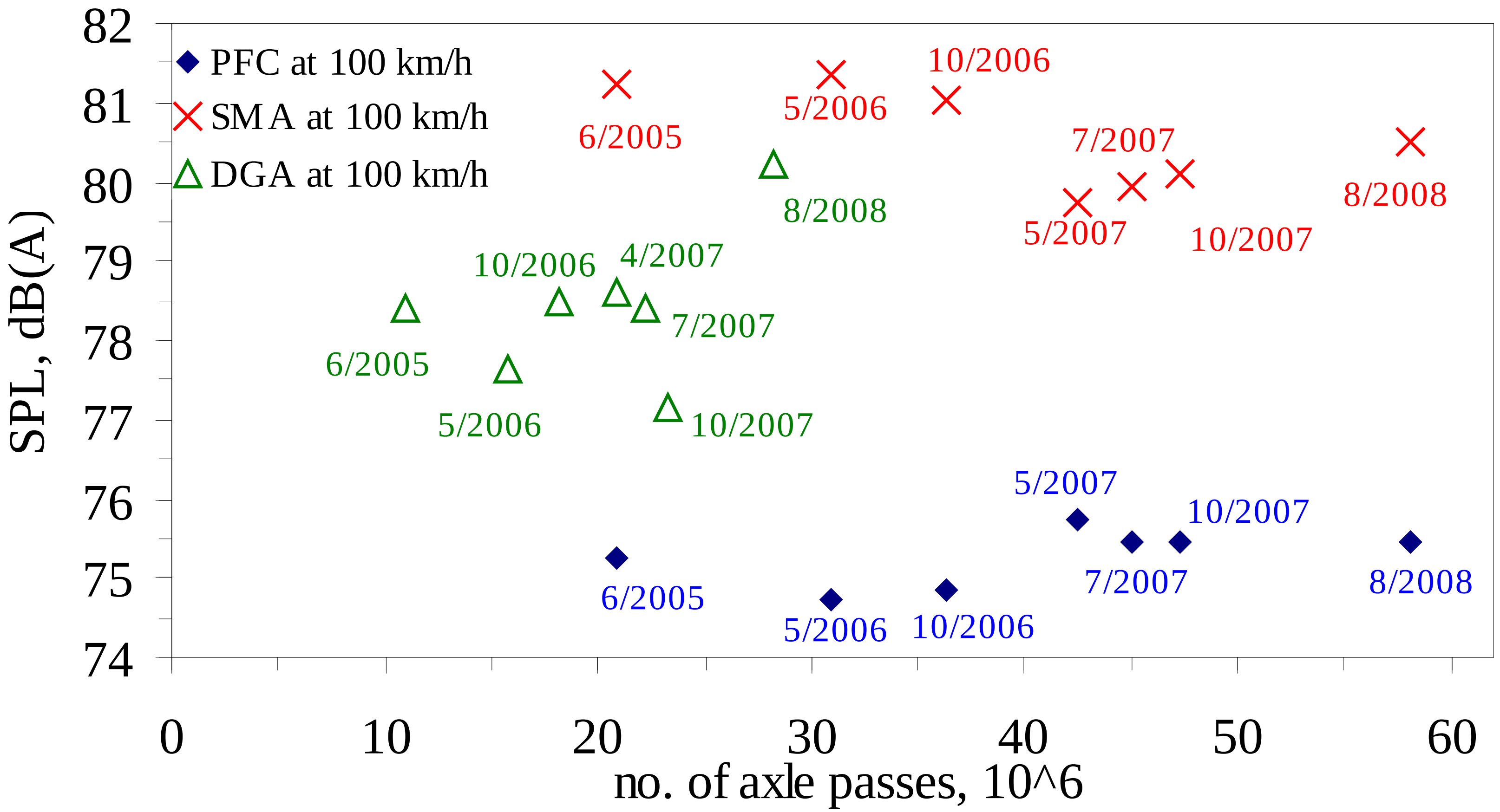
# Long Term Performance Questions

- 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?

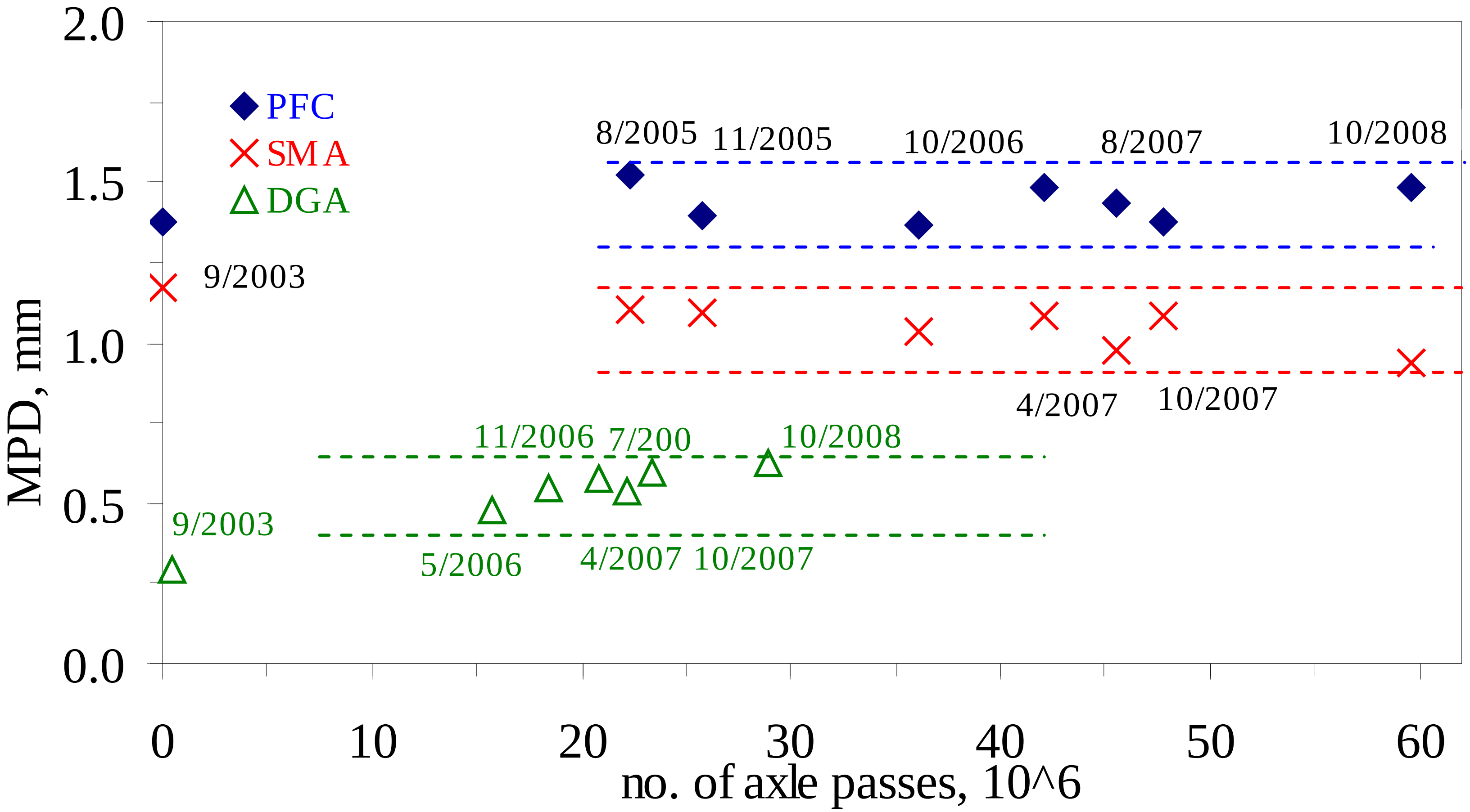


- 9.5mm mixtures used Steel Slag and PG76-22 binder
- PFC designed at 18-22% air voids
    - Polymer modified binder and fiber

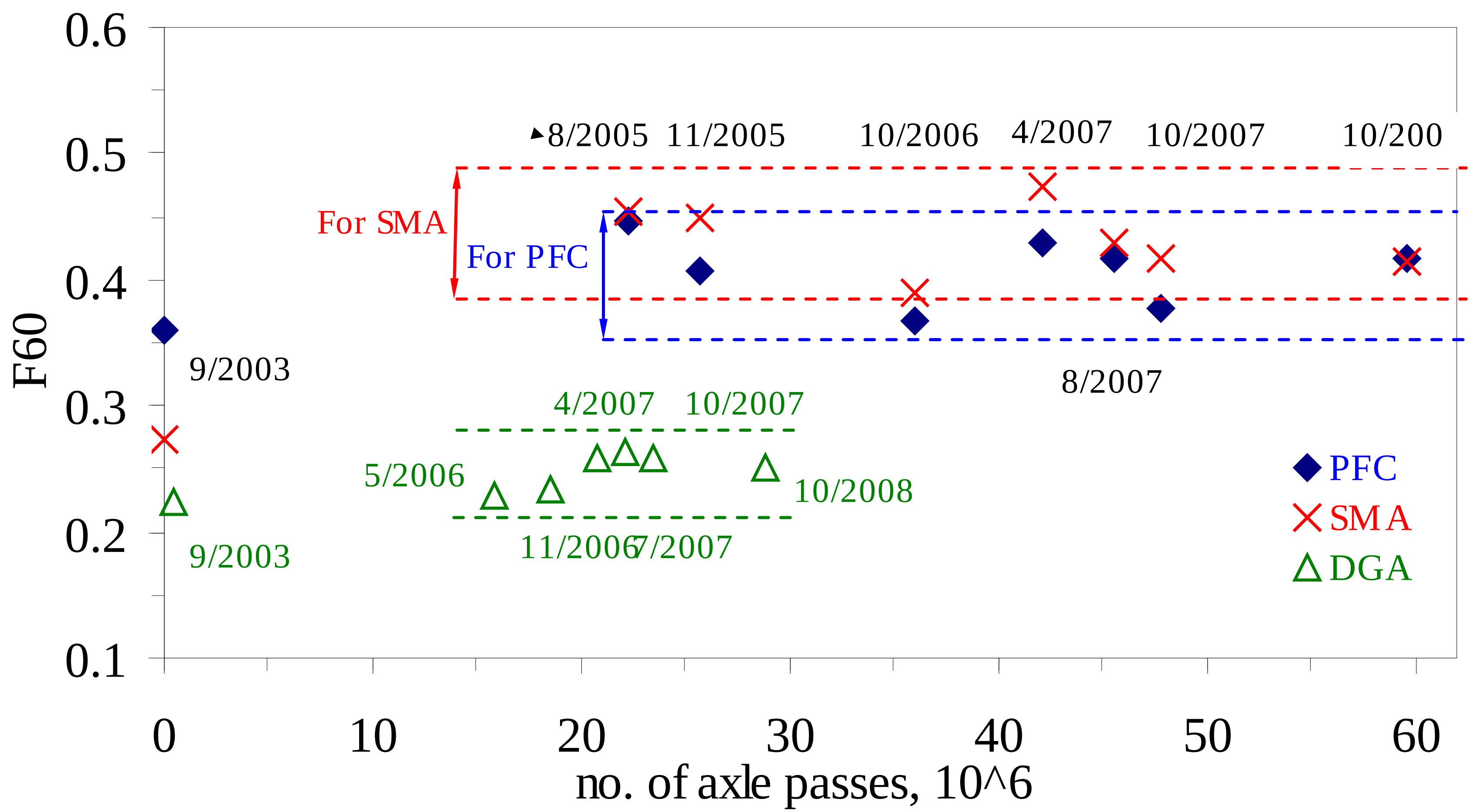
# Changes in Noise vs. Traffic



# Changes in Texture



# Changes in Friction (F60)



# 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.

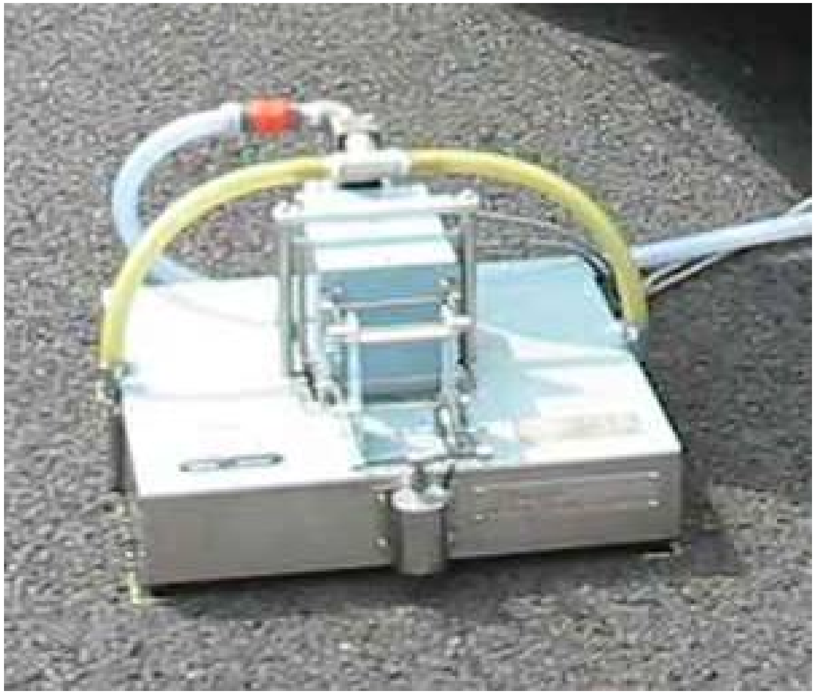
# Background

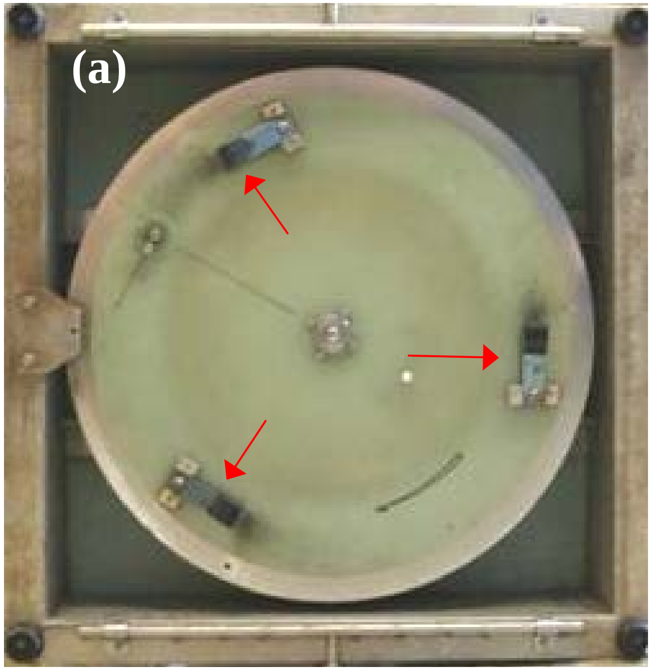
- Pavement friction is function of microtexture and macrotexture.
  - Microtexture – provided by aggregate surface
  - Macrotexture – determined by overall properties of the pavement surface (NMAS and gradation of aggregates, binder content, etc.)
- Friction at the tire-pavement interface is caused by: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

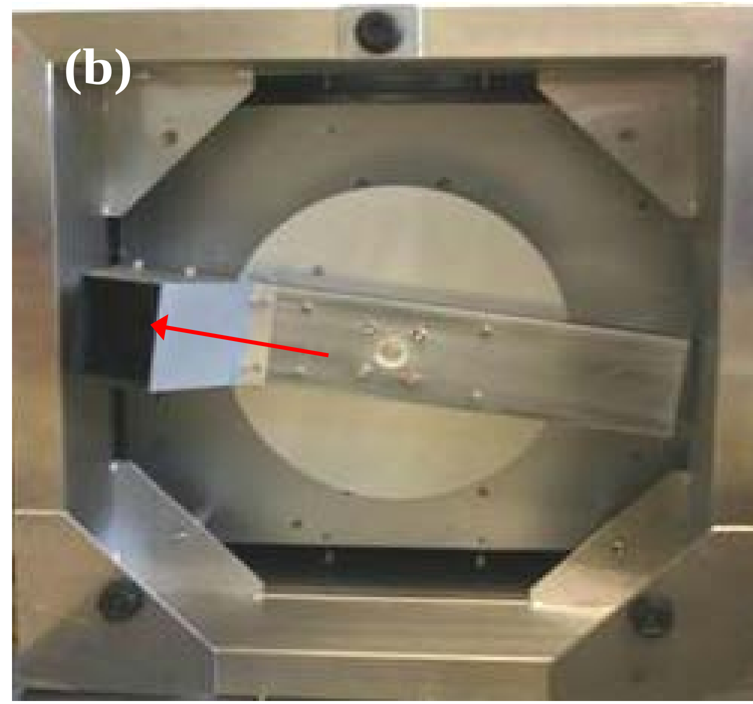
# Dynamic Friction Tester (DFT)






DFT – dynamic friction at 20 km/h (DF20)

# Circular Track Meter (CTM)

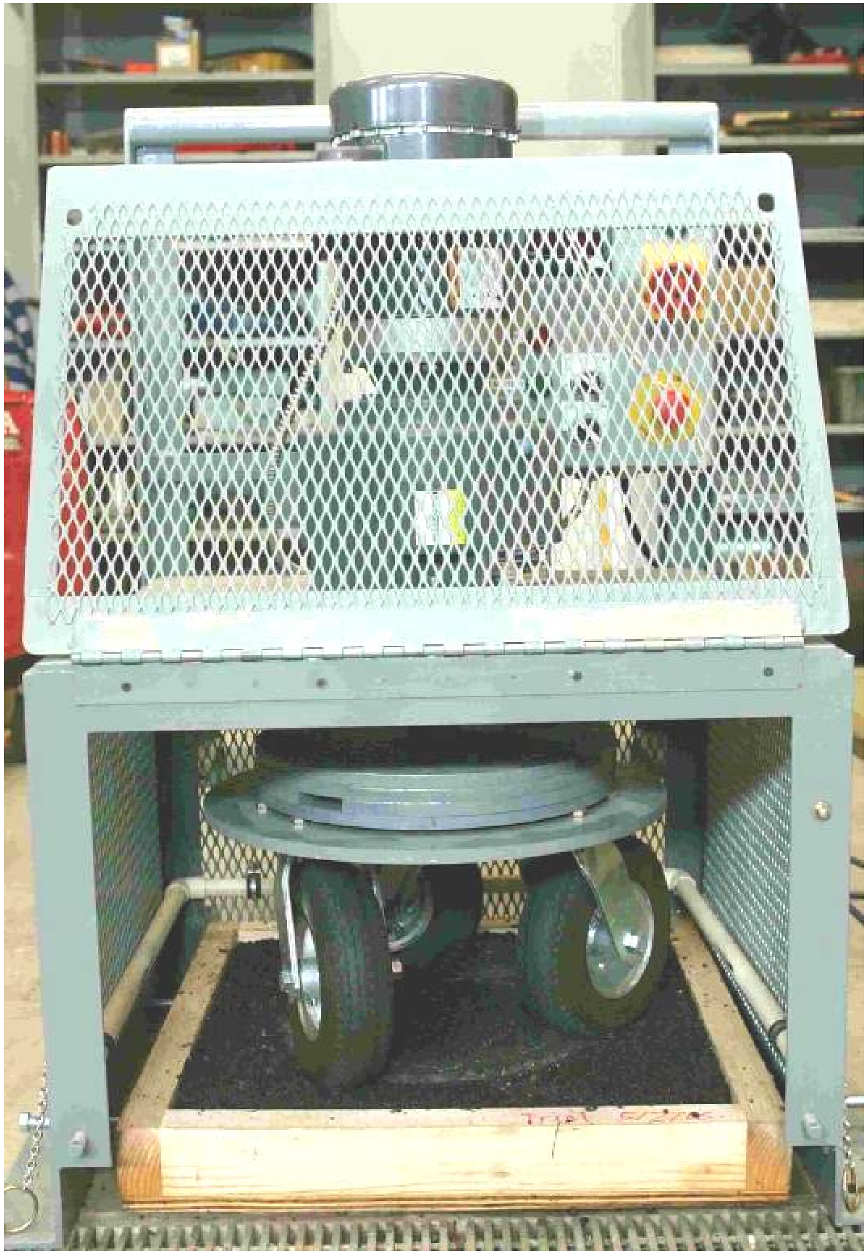

CTM – Mean Profile Depth, mm

# International Friction Index

IFI (*F60*, $S_p$)

$$\begin{cases} F60 = 0.081 + 0.732 DF_{20} e^{\frac{-40}{Sp}} \\ S_p = 14.2 + 89.7 MPD \end{cases}$$

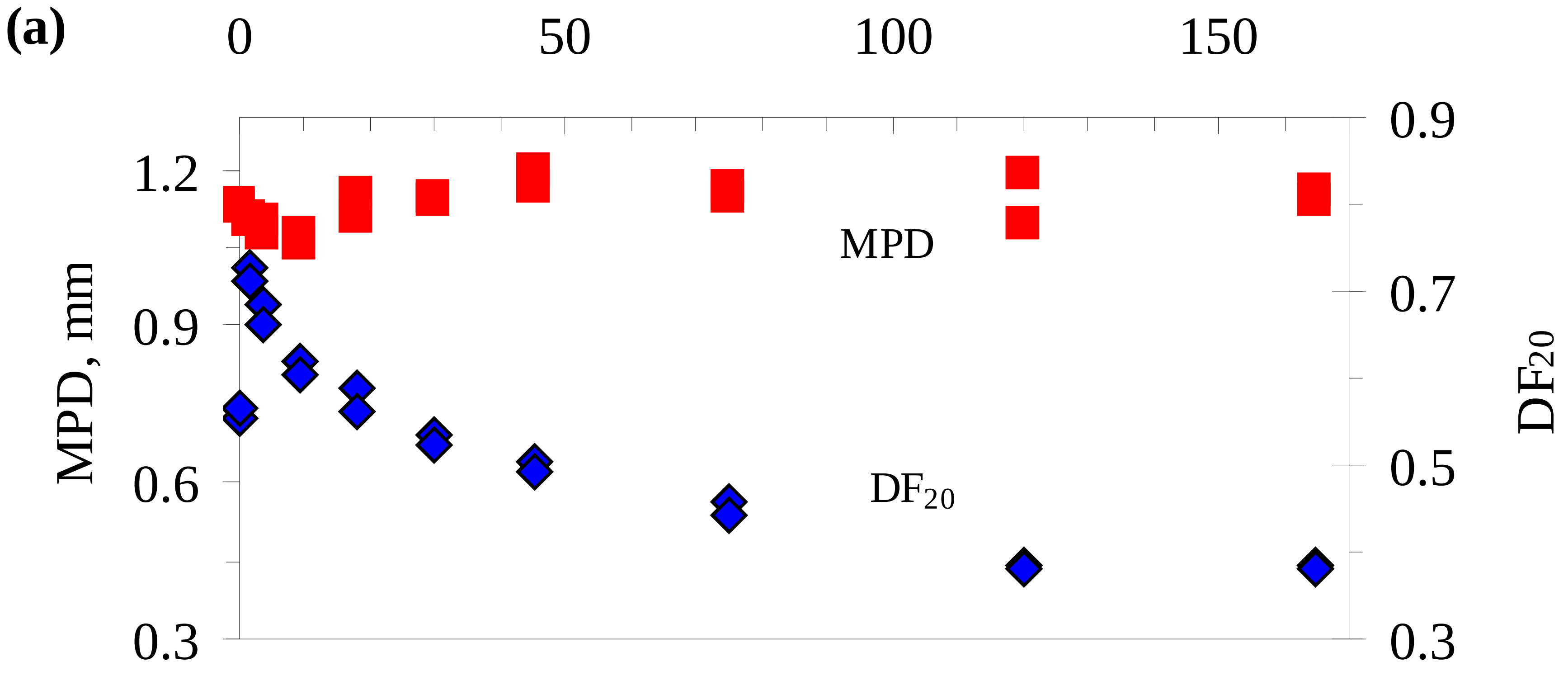

(a)



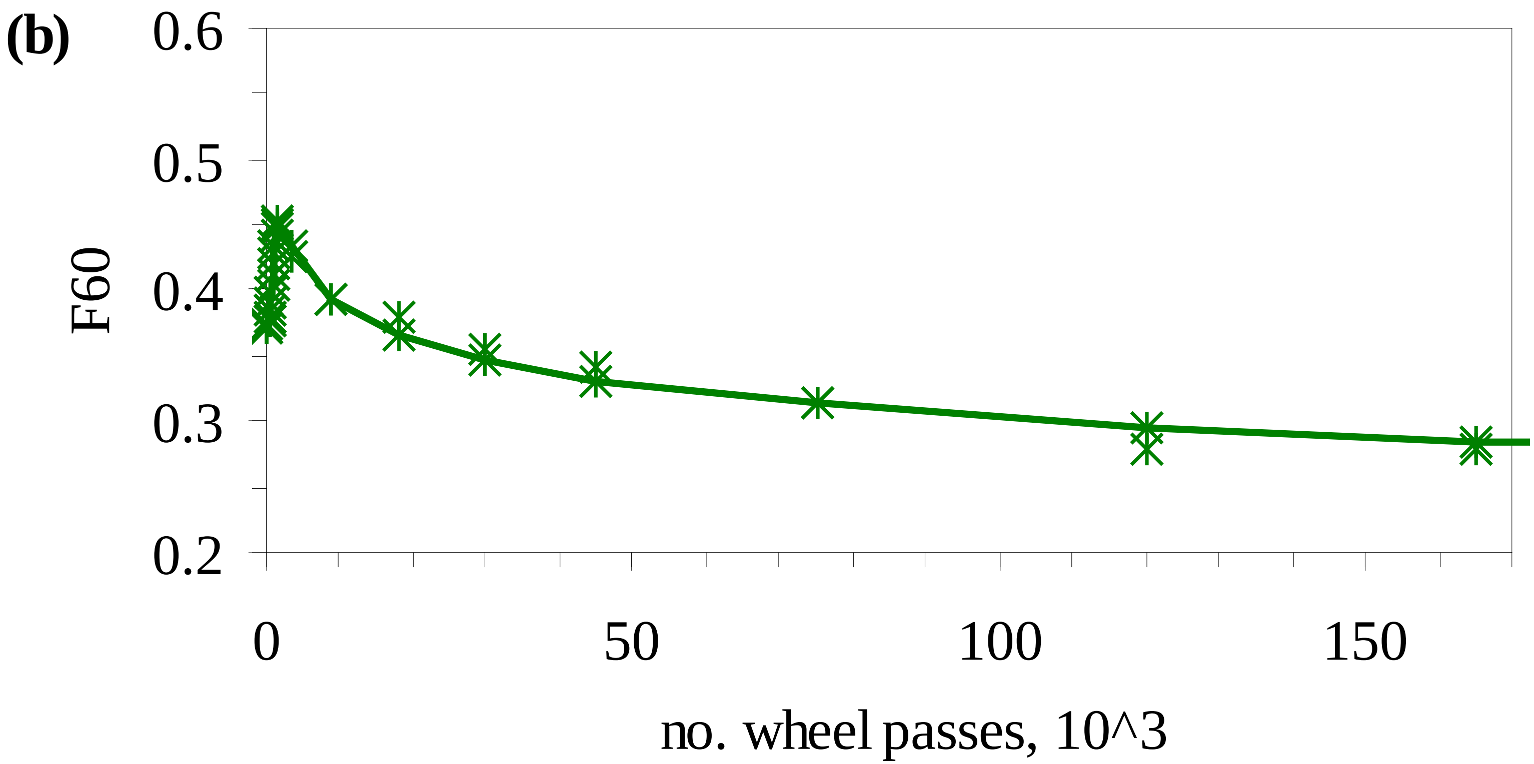
# Circular Track Polishing Machine


(a)
(b)
(c)
(d)

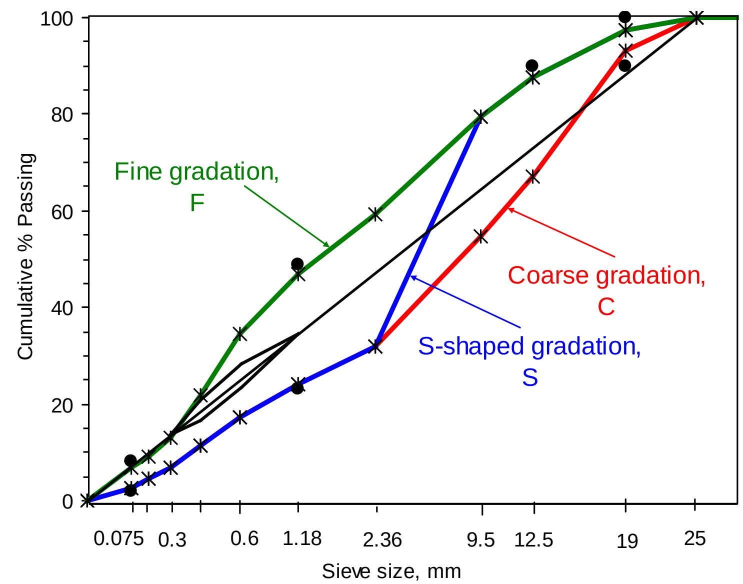
# Texture and Friction (DF20)



# 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

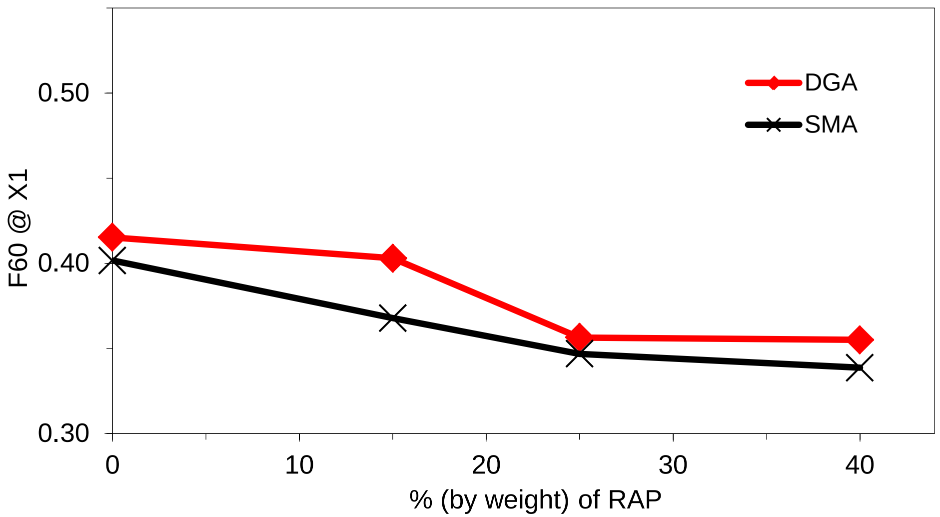
- Determine threshold level of RAP that has minimal effect or method to test aggregates in the RAP

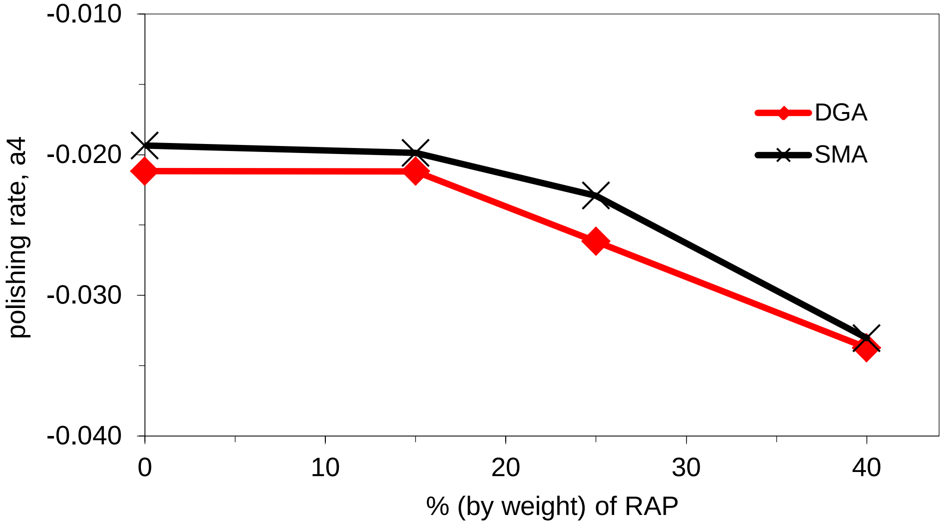
# Experimental Design

- 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



# Findings and Implementation

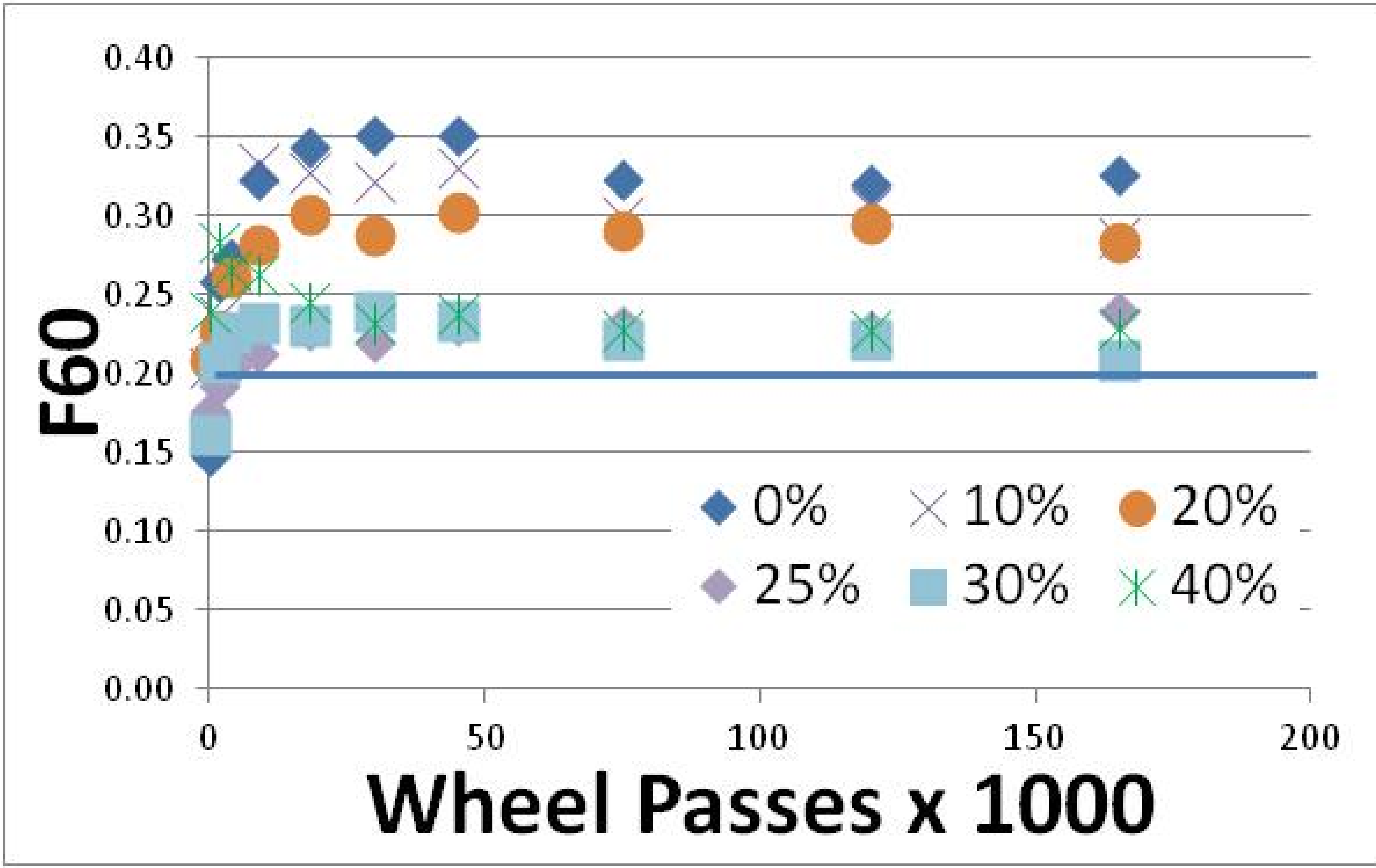
- Adding small quantities of poor quality RAP had little effect on friction.
- When blended with high quality friction aggregates, performance was still acceptable at 25% RAP.
- Field friction testing suggests 15% RAP is acceptable and higher RAP contents are possible for medium volume roadways.
- Allowable 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



F60
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
Wheel Passes x 1000
0%
10%
20%
25%
30%
40%

# 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???*

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