Permeable Friction Course (PFC) Mixtures are Different!

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1st Annual Flexible Pavement Research Symposium

Amy Epps Martin, Allex E. Alvarez

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OUTLINE

1. Introduction
2. Current Research
3. Experimental Design and Results
4. Summary and Recommendations - Future Work

1. Introduction

Dense-graded mixtures Vs Porous friction course mixtures (PFC or OGFC) as surface courses

Kringos et al., 2007

PFC Advantages

- Reduce splash and spray
- Improve skid resistance in wet conditions
- Decrease noise
- Produce cleaner runoff

2. Current Research

Improve TxDOT PFC mix design procedure and recommend construction practices based on:

- ✓ Volumetrics
- ✓ Durability
- ✓ Drainability
- ✓ Densification Effects

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3. Experimental Design and Test Results

Selected Mixtures

Mixture	Asphalt Type	OAC (%)	Aggregate	Other Materials
I-35	PG 76-22	6.1	Sandstone, Limestone	Lime (1%), Fibers (0.3%)
US-59Y		5.8	Limestone	
IH-30		6.6	Sandstone	
US-83		6.4	Limestone	
IH-20		6.5	Limestone	
US-59		5.9	Granite, Limestone	
US-281	Asphalt Rubber	8.1	Sandstone, Limestone	None
US-290		8.3	Sandstone	
US-288		8.0	Granite, Limestone	

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3.1 Volumetrics

a. Total AV Content

$$Total\ AV\ Content = \left(1 - \frac{G_{mb}}{G_{mm}}\right) * 100\ (\%)$$

G_{mm}: theoretical max. specific gravity of the mixture

G_{mb}: bulk specific gravity of the compacted PFC mixture

Current practice:

- Total AV content (or corresponding density)
- Vacuum method or dimensional analysis for G_{mb}
- Measured G_{mm}

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Theoretical Max. Specific Gravity, G_{mm}

Method 1-measured G_{mm}

$$Measured\ G_{mm} = \frac{W_{mix}}{W_{pyc,w} - W_{pyc+mix,w} + W_{mix}}$$

mixture at the design asphalt range (6 to 10%)

or

mixture at low binder content (3.5 to 4.5%)

Method 2-calculated G_{mm}

$$G_{se} = \frac{100 - P_b}{\frac{100}{G_{mm}} - \frac{P_b}{G_b}} \qquad Calculated\ \ G_{mm} = \frac{100}{\frac{100 - P_b}{G_{se}} + \frac{P_b}{G_b}}$$

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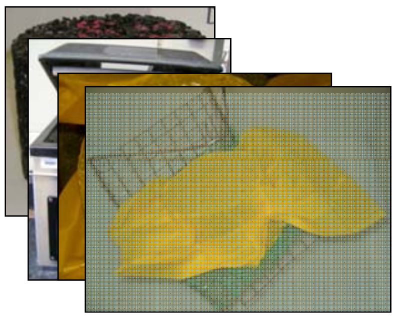
Bulk Specific Gravity, G_{mb}

Method 1-vacuum

$$G_{mb}\ Vacuum = \frac{W}{W_b + W - W_{bs,w} - \frac{W_b}{CF}}$$



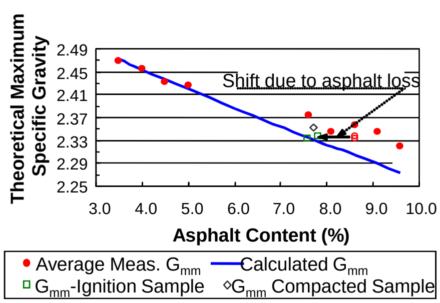
Method 2-dimensional

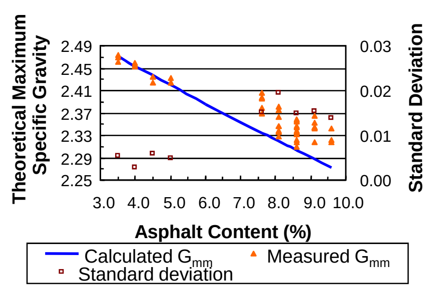
$$G_{mb}\ Dim = \frac{\frac{W}{V_t}}{\rho_w}$$

$V_t = \pi * r^2 * h$

Results and Discussion

G_{mm} Comparison and Variability, AR Mixtures





Calculated G_{mm}: less variability and less asphalt-loss error

G_{mb} *Dim:*

Simpler, faster, less expensive, cleaner, required equipment is readily available, and data can be directly used to analyze X-ray CT images

b. Connected AV Content

Water-Accessible AV Content

Method 1-vacuum method

$$WA\,AV = \frac{W_b + W - W_{bs,w} - \left(\frac{W_b}{CF}\right) - (W - W_{SV})}{W_b + W - W_{bs,w} - \left(\frac{W_b}{CF}\right)} * 100\ (\%)$$

Method 2-dimensional analysis

$$WAAV_{dimensional} = \frac{V_{td} - \frac{(W - W_s)}{\rho_w}}{V_{td}} \times 100\ (\%)$$

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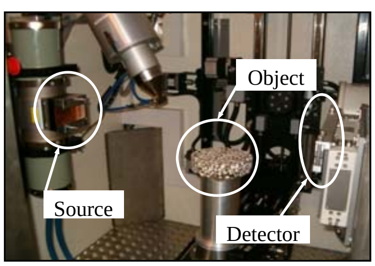
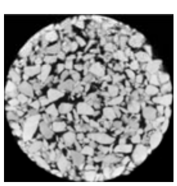
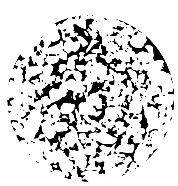
Interconnected AV Content - X-ray Computed Tomography and Image Analysis

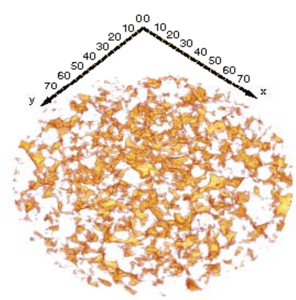




Grayscale image



B&W image



3D render

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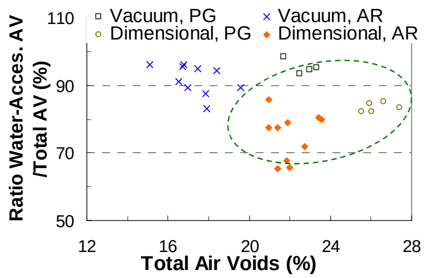
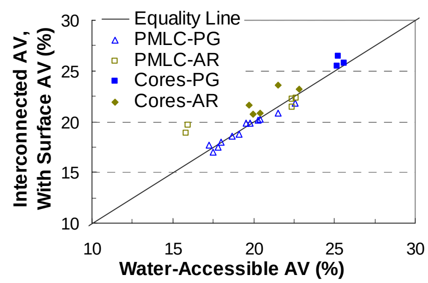
Comparison of Water-Accessible AV and Total AV Content



Most AV in PFC are water accessible



Good agreement for interconnected AV and water-accessible AV

Dimensional analysis with vacuum

Summary and Recommendations-Volumetrics

- Use dimensional analysis for determining both G_{mb} and water-accessible AV content
- Use calculated G_{mm}

- The methods used for determining G_{mm} and G_{mb} affect:

✓ OAC, mixture aggregate gradation, and fibers content

➡ Include mixture-durability test for PFC mix design

Future work:

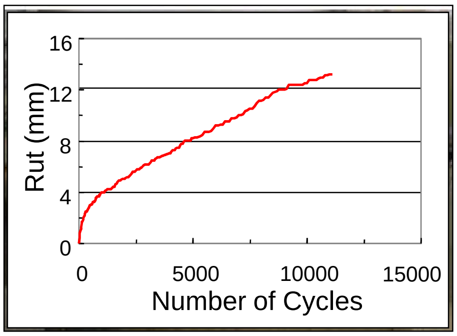
- Explore the use of *connected AV content* for mix design and evaluation

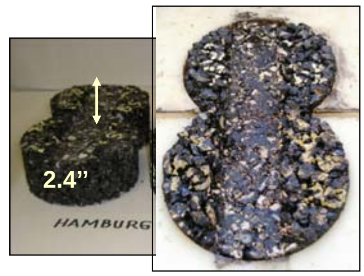
3.2 Durability

Current practice:

- No durability test applied

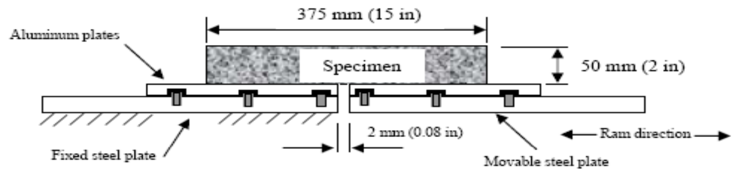
Hamburg Wheel-Tracking Test (Hamburg)



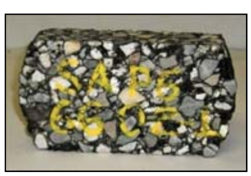


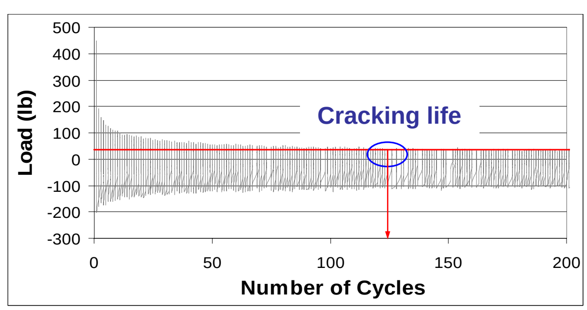
Wet Conditioning

TTI Overlay Test (Overlay)



Zhou et al., 2003





No Conditioning (dry)

Cantabro Loss Test (Cantabro)

$$\text{Cantabro Loss (\%)} = \frac{W_o - W_f}{W_o} * 100$$

No Conditioning (dry)

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Results and Discussion

Comparison of Mixture Evaluation Tests

Test	Specimen Preparation	Air Voids Variability (COV)	Availability of Equipment (in Texas)	Testing Time (hours)	Results Variability (COV)
Hamburg	Saw trimming	0.030	Medium	5	0.02 to 0.57
Overlay	Saw cutting, drying, final AV checking, and gluing	0.030	Low	2	0.22 to 1.17
Cantabro	Not required	0.016	High	0.3	0.07 to 0.36

Additional Cantabro Testing: wet (24 hrs @ 60°C + drying), cold (3°C), & aged (3 & 6 months @ 60°C)

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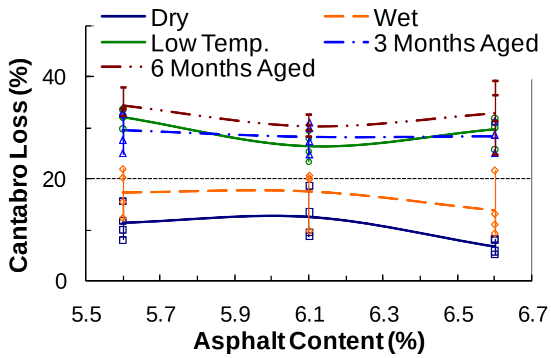
Cantabro Results - Effect of Conditioning



PG 76-22 mixtures

Summary and Recommendations-Durability

- Cantabro Loss test recommended
- Cantabro test results suggest:
  - ✓ Mixture resistance to disintegration is affected more by aggregate than binder properties
  - ✓ The test can be used as a *screening tool* for PFC mix design, but it may not provide enough sensitivity for selecting the OAC
  - ✓ Cantabro Loss values showed a direct relationship with water-accessible AV content

Future work:

- Evaluate relationships between field and lab. responses
- Use analytical performance models to improve PFC mix design

3.3 Drainability

Current practice - design (SGC specimens):

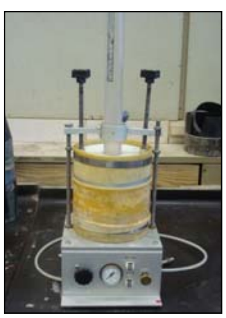
- Ensure total AV content (min. 18%)
- Measure lab permeability (min. 100 m/day)

Current practice - field

- Measure field drainability: water flow value (max. 20 secs)

Laboratory and Field Measurement of Drainability

Lab drainability



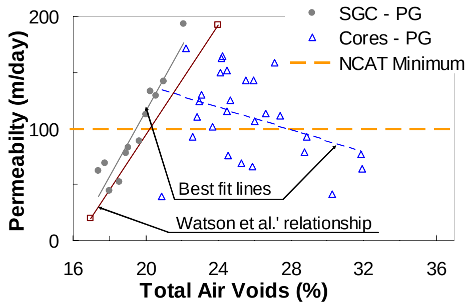
Coefficient of permeability (*k*)

Field drainability

Water flow value (outflow time)

Results and Discussion

Evaluation of Current Practice

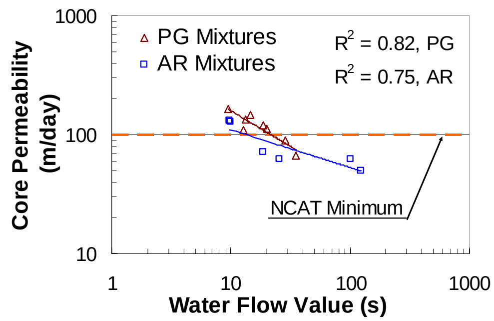


Lack of correlation can be related to differences in:
(i) Total AV content,
(ii) Specimen thickness, and
(iii) Internal structure of the mixture

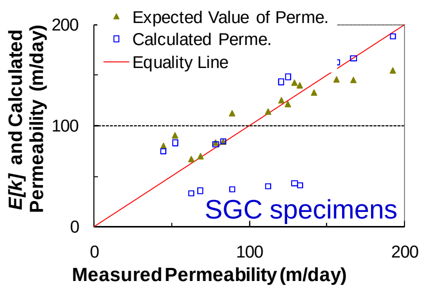
Alternatives Evaluated

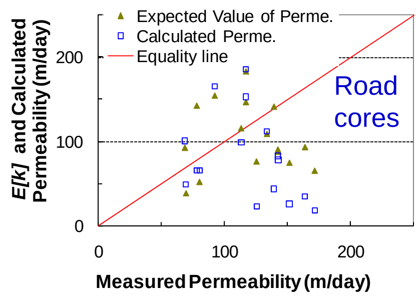
(i) Relationship of water-accessible AV content and lab-measured permeability,
(ii) Relationship of lab and field drainability, and
(iii) Analytical prediction of permeability (Expected value of permeability using modified Kozeny-Carman Eq.)

(ii) Relationship of lab and field drainability



(iii) Expected Value of Permeability (*E*[*k*]) and Calculated Permeability (Modified Kozeny-Carman Equation)





Parameters for *E*[*k*]:

- Average and variance of both aggregate-particle size (gradation) and total AV content (X-ray CT)
- Covariance of aggregate-particle size and total AV content
- Empirical calibration coefficient
- Aggregate, asphalt and fluid (water) parameters

Summary and Recommendations-Drainability

- Current practices led to poor drainability evaluation of field-compacted mixtures
- *Water-accessible AV content* may be used as a surrogate of the *total AV content* to indirectly assess permeability
- Use the Expected value (*E*[*k*]) as an estimator of permeability. Alternatively, the WFV can be used to asses field drainability

Future Work

- Further assess permeability of field-compacted mixtures using laboratory-compacted mixtures

3.4 Densification Effects

Current Construction Control

✓ Asphalt content, gradation

✓ Visual inspection: density, material variability, segregation

✓ Minimum smoothness

- No field density requirements for PFC

Objective

Assess effects of densification on PFC based on:

Internal structure (air voids [AV] characteristics)

Macroscopic response (durability and functionality)

FOR TWO COMPACTION LEVELS

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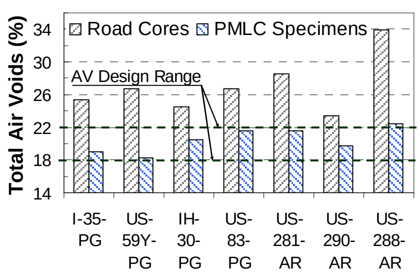
Results and Discussion

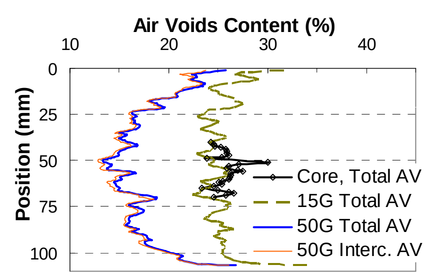
Comparison of Total AV Content



Field Vs Lab (SGC) air voids content

Field AV content reproduced at 15 gyrations of the SGC

Ongoing Research!



Distribution of AV content US-59Y mixture

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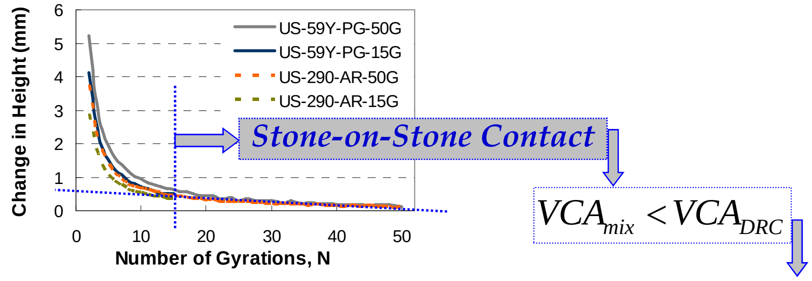
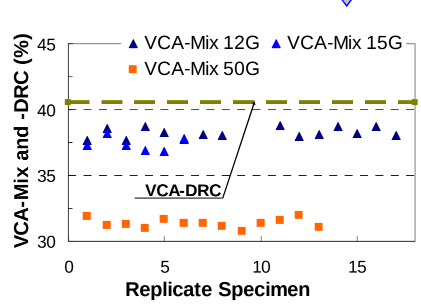
Compaction Curve and Stone-on-Stone Contact



Ongoing Research!



US-59Y-PG mixture

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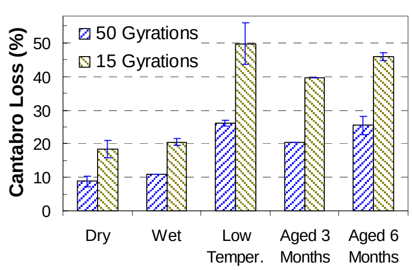
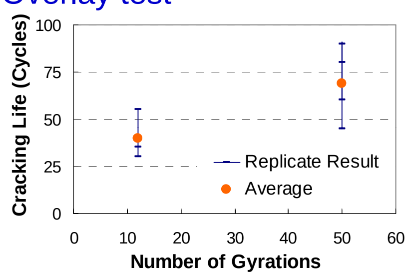
Effect of Densification on Durability

Cantabro test



Overlay test



Hamburg-Wheel Tracking test

Mixture	SGC Gyrations	Total AV Content	Cycles to Failure @ 12.5 mm	Rut Depth @ 20000 Cycles (mm)
US-59Y-PG	12	22	-	11.41
	12	22.3	-	8.96
	50	17.6	-	4.82
	50	16.2	-	5.43

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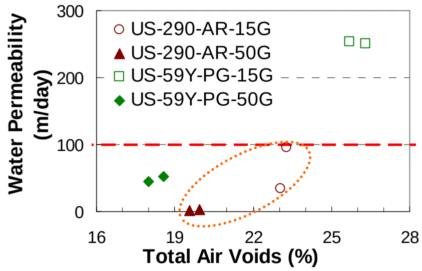
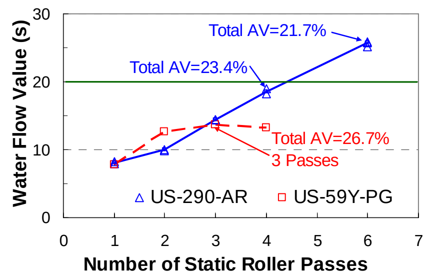
Effect of Densification on Drainability



Laboratory permeability



Field drainability (WFV)

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Summary and Recommendations-Densification

- High levels of densification (after reaching stone-on-stone contact) are required for mixture durability
- These findings suggest the necessity of:

  ✓Checking stone-on-stone contact during mix design
  ✓Including a construction density control

Short-term action:

  ✓ Increase efforts to establish required roller patterns

Future Work

- Develop techniques (e.g., nondestructive methods) to evaluate the field density and enforce a density specification
- Improve the current SGC compaction protocol
- Evaluate long-term mixture performance to obtain final recommendations for field density control

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