National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

Recycled Binder Availability – Impact on Asphalt Mixture Performance

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Background

- Using RAP/RAS in asphalt mixtures
  - Cost savings and environmental benefits
  - Cracking performance challenges
- Binder quality: RAP/RAS binder is highly aged and thus of lower quality
- Binder quantity: not all RAP/RAS binder can be activated to contribute to aggregate coating/binding and mixture flexibility
- BMD will address these issues, but its implementation takes time
  - Thus, need short-term solutions in the meantime
- Cracking mitigation strategies
  - Softer binder, higher ΔT_c binder, recycling agent
  - Increase V_{be} (increase VMA, regress air voids, recycled binder availability)

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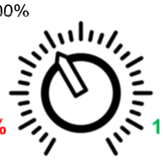
Recycled Binder Availability (RBA)

- "The amount of recycled asphalt binder from RAP/RAS that activates and contributes to the total effective binder content in an asphalt mixture" – Epps Martin et al. (2021)
  - Assume only a portion of the RAP/RAS binder is "active"
  - Adjust mix design to address the "inactive" RAP/RAS binder
- Expressed as a percentage ranging from 0 *to* 100%
  - **0%**: 'black rock' with no binder activation
  - **100%**: full binder activation
- An intrinsic property of the RAP/RAS mixture
  - RAP/RAS properties
  - Mix design variables
  - Mixture production conditions

0%  **100%**

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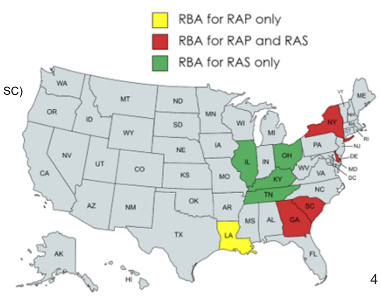
RBA Implementation Status

- 9 states
  - 1 for $RAP_{(LA)}$
  - 4 for $RAS_{(IL,\ KY,\ OH,\ TN)}$
  - 4 for RAP & $RAS_{(DE,\ GA,\ NY,\ SC)}$
- RBA value
  - 60 to 90%
  - RAP ≤ RAS



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Incorporate RBA into Mix Design

- Approach 1: discount binder content or G_{sb} of RAP/RAS
  - Lower VMA calculation
    - If pass min. VMA requirements, mix is 'good to go'
    - Otherwise, redesign mix with more virgin binder
  - Example: 9.5mm NMAS mix with 35% RAP, 5.7% total AC (3.8% virgin)

Binder Content of RAP	RAP AC	Total AC	P_s	VMA
5.4% (no discount)	1.9%	5.7%	94.3%	15.7%

- **Eliminate mixes with marginal VMA**

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Incorporate RBA into Mix Design

- Approach 2: add more virgin binder to compensate for the "inactive" RAP/RAS binder
  - Amount of virgin binder added = RAP/RAS% × RAP/RAS P_b × (1-RBA)
  - Example

RAP%	RAP P_b	RBA	Additional Virgin Binder
20%	5.0%	80%	**0.2%**

- **Improve cracking resistance due to increased virgin binder content**
- Aka "Corrected Optimum Asphalt Content (COAC)" approach

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Key Questions

1. Will RBA improve overall mixture performance (rutting, cracking, and moisture resistance)?
2. Will RBA make pavements last longer?
3. Will RBA be cost-effective from life-cycle cost perspective?

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NCAT Studies

1. Will RBA improve overall mixture performance (rutting, cracking, and moisture resistance)?

FDOT — Yin et al. (2023)

GDOT (Georgia Department of Transportation) — Vivanco et al. (2021)

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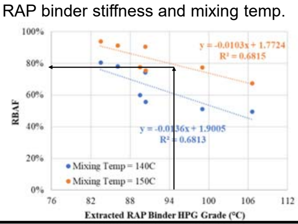
FDOT Study (2021-2023)

- Performance evaluation and cost-benefit analysis of RAP mixes with and without RBA
- RBA selection
  - NCHRP 9-58: RBA as a function of RAP binder stiffness and mixing temp. (Epps Martin et al., 2019)
    - Softer RAP = higher RBA
    - Higher RBA at 150°C vs. 140°C
  - Florida conditions
    - Average RAP HPG: 95°C
    - RAP mixes produced ~ 150-160°C
  - **80% RBA**
    - 80% 'active', 20% 'inactive'



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Experimental Plan

- 4 RAP mix designs

RAP Content	Agg/RAP Type	Virgin Binder	Volumetric Optimum Binder Content (V-OBC)	RBA-adjusted Binder Content (A-OBC)	A-OBC vs. V-OBC
20%	GA GRN	PG 76-22 PMA	5.40%	5.62%	0.22%
40%	GA GRN	PG 52-28	5.40%	5.85%	0.45%
20%	FL LMS	PG 76-22 PMA	6.20%	6.43%	0.23%
40%	FL LMS	PG 52-28	6.20%	6.66%	0.46%

- Performance testing
  - Cracking/durability: IDEAL-CT, OT, and Cantabro
  - Rutting: HWTT, APA, and IDEAL-RT
  - Binder rheology: PG (ΔT_c), MSCR, LAS, and DSR FS (G-R)

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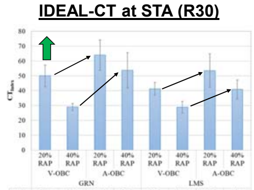
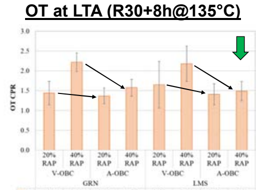
Cracking Test Results

- Improved cracking resistance at A-OBC vs. V-OBC
- Improvement more pronounced for 40% RAP than 20% RAP mixes

IDEAL-CT at STA (R30)



OT at LTA (R30+8h@135°C)



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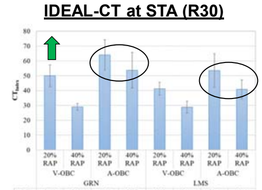
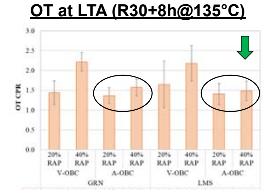
Cracking Test Results

- Similar cracking resistance at A-OBC
  - 20% RAP with PG 76-22 PMA
  - 40% RAP with PG 52-28

IDEAL-CT at STA (R30)



OT at LTA (R30+8h@135°C)



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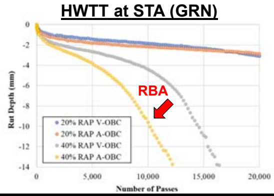
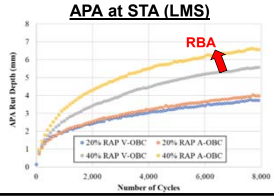
Rutting Test Results

- A-OBC vs. V-OBC
  - No significant impact on 20% RAP mixes with **PG 76-22 PMA**
  - Reduced rutting resistance for 40% RAP mixes with **PG 52-28**
- Rutting resistance: 20% RAP mixes >> 40% RAP mixes, due to PMA

HWTT at STA (GRN)



APA at STA (LMS)



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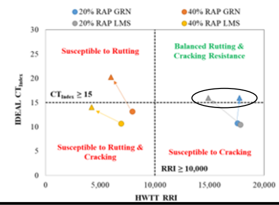
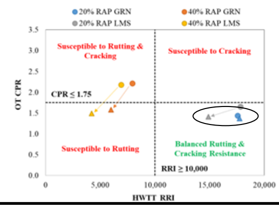
BMD Performance after RBA Adjustments

- 20% RAP mixes with PG 76-22 PMA become 'balanced'





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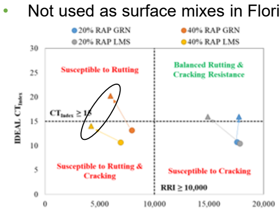
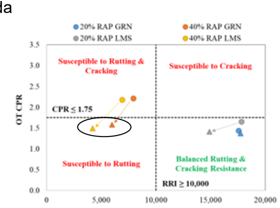
BMD Performance after RBA Adjustments

- 20% RAP mixes with PG 76-22 PMA become 'balanced'
- 40% RAP mixes with PG 52-28 remain 'unbalanced' due to inadequate rutting resistance despite improved cracking resistance
  - Not used as surface mixes in Florida





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Cost-benefit Analysis

- 2-lane rural road with 5-foot paved shoulders
- Milled and resurfaced with 1.5-inch FC-12.5 mix (20% RAP, PG 76-22) over 1.5-inch SP-12.5 mix (30% RAP, PG 58-28)
- Scenario 1: not consider RBA
  - Expected pavement life: 15 years
  - Project cost: $737,437 per mile
- Scenario 2: consider 80% RBA
  - **Add 0.25% to 0.35% more virgin binder**
  - **Increase mix cost by $1.7 to $2.0/ton**
  - Increase project cost by $5,144 per mile
  - *How long does the pavement need to last to breakeven the increased cost?*
    - **+ 2 months!**

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NCAT Studies

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- Will RBA improve overall mixture performance (rutting, cracking, and moisture resistance)?

Yin et al. (2023)

Vivanco et al. (2021)

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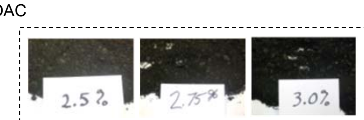
GDOT Study

- Performance comparison of virgin vs. RAP mixes at OOAC vs. COAC
- COAC method & implementation history
  - 2012 to 2018: 75/25 COAC
  - 2019 to present: 60/40 COAC

Preheated RAP

RAP Aggregate



RAP Aggregate + Virgin Binder

(Hines, 2012)

COAC determined based on the amount of virgin binder required to provide a similar appearance as preheated RAP, averaged at 60%

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GDOT Study

- 4 RAP mix designs

+ 0.60% to 0.75%

+ 0.35% to 0.45%

Mix Type	RAP Content	Virgin Binder	OOAC	COAC (75/25)	COAC (60/40)
9.5mm SP	30%	PG 64/67-22	5.30%	5.65%	5.87%
12.5mm SP	30%	PG 64/67-22	5.00%	5.37%	5.59%
19mm SP	30%	PG 64/67-22	4.30%	4.73%	5.00%
25mm SP	35%	PG 64/67-22	4.11%	4.57%	4.85%

- 4 companion virgin designs
- HWTT and IDEAL-CT

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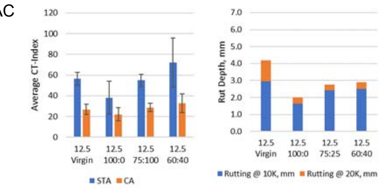
GDOT Study

- Example: 12.5mm SP mix designs
  - Increased CT_{index} at COAC
  - Minimal HWTT rutting
  - No sign of stripping



- Findings
  - COAC significantly improved the cracking resistance of RAP mixes while maintaining good rutting resistance
  - RAP mixes at 60/40 COAC outperformed virgin mixes

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NCHRP 09-65

- Capture durability of high RBR asphalt mixtures
  - Framework for evaluating mixture durability
  - Cracking, raveling, and moisture damage mitigation strategies
- Strategies to improve surface cracking resistance
  - Different virgin binder source (Higher ΔT_c)
  - Softer binder
  - PMA
  - Recycling agent
  - Decreased RBA (85% RAP, 75% RAS)
  - Hybrid combos

- Most effective strategies
- Did not create raveling and moisture damage issues

(Epps Martin et al., 2023)

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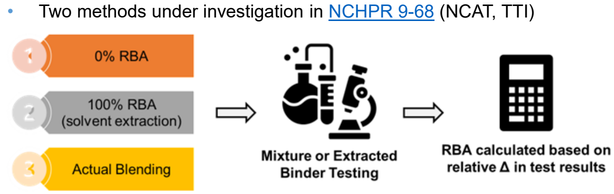
Remaining Questions

- How to measure RBA?
  - Different methods available in the literature
  - All have pros and cons but do not provide the same results
  - Need a standardized method
- Two methods under investigation in NCHPR 9-68 (NCAT, TTI)



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Virgin Aggregate vs. RAP

- Before mixing

- After mixing

Glass Beads

(Mohajeri, 2015)

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Remaining Questions (continued)

- How do mix design and production variables affect RBA?
  - RAP/RAS source
  - Virgin binder grade/type/quality
  - Additives (WMA, rejuvenator)
  - Production temperature
  - Silo storage

- How much can RBA extend pavement service life?
  - Sufficient to justify the increased material cost?
  - Need long-term field performance data (upcoming NRRA study)
- How to incorporate RBA into mix production practice?
  - Adjust volumetric targets (V_a, VMA, etc.) due to additional virgin binder
  - Revisit acceptance quality characteristics (AQCs)

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Summary & Takeaways

- Advance high RAP/RAS asphalt mixtures for **economics, sustainability, and performance**
- RBA is effective in improving cracking resistance
- When used alone, RBA is not likely to cause rutting issues
  - Nevertheless, recommend verifying rutting resistance, especially when using RBA together with a softer binder or rejuvenator
- RBA offers a pathway to achieve **balanced performance**, but requires relaxing volumetric requirements for mix design
  - BMD allows more innovation (not just about adding asphalt binder)
- Stay tuned for more RBA research findings

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National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

End-of-Cycle Conference for the 2021 NCAT Pavement Test Track and the MnROAD Pavement Research Partnership

May 7-9, 2024
Auburn, AL

Save Contact

Thank You

Questions?

References available upon request

National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

References

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