Responsible Use of RAP in Pavement Surface Mixtures

Ontario Asphalt PC's Third Annual Asphalt Technical Symposium (ATS)

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Main Sources for Information Presented

- **NCHRP Synthesis 495 (2016):**
  - **Use of Reclaimed Asphalt Pavement and Recycled Asphalt Shingles in Asphalt Mixtures**
- **NAPA Quality and Information Series 2008-2019**
- **NCHRP Digest Number 253:**
  - **Recommended Use** of Reclaimed Asphalt Pavement in the **Superpave Mix Design** Method Guidelines"
- **NCHRP Report 452:**
  - **Recommended Use of RAP** in the Superpave Mix Design Method: **Technician's Manual**"
- **NCHRP Report 752:**:
  - **Improved Mix Design**, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content"
- **National Standards**
  - **AASHTO M323, New Appendix**: Superpave Volumetric Design
  - **AASHTO PP53: Design Considerations** When Using **Reclaimed Asphalt Shingles (RAS)** in New Hot Mix Asphalt (HMA)"

Source: John Davis and Phil Blankenship, Asphalt Institute, August 2017


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The Case for Greater RAP Use

- The two leading reasons for using RAP (FHWA):

1. **Economic benefits:**
   - The most economical use of RAP is in asphalt mixtures that go ***into the intermediate and surface layers of flexible pavements***, where the RAP actually replaces a portion of the more expensive high grade virgin binder.

2. **. Environmental benefits:**
   - **Conserves** the non-renewable virgin binder and aggregates resources,
   - **Reduces** the energy and transportation costs of obtaining them.
   - **Reduces** the amount of construction debris going into landfills. Because RAP can be used again and again,

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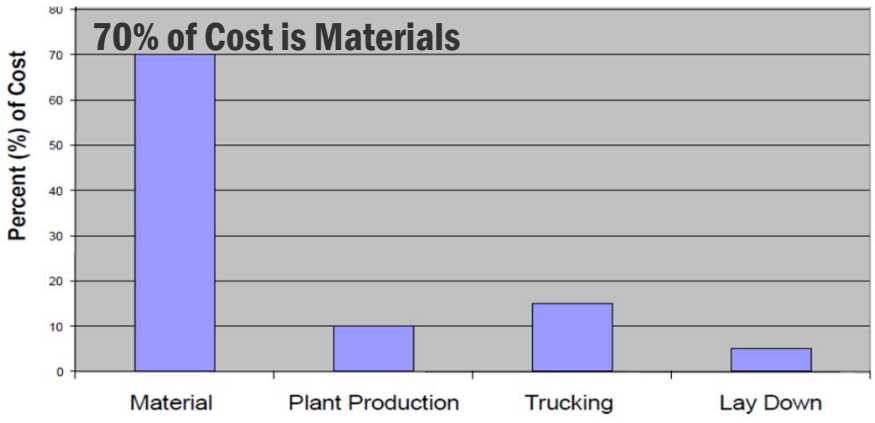
Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice

PUBLICATION NO. FHWA-HRT-11-021 APRIL 2011



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Studies on Cost Savings with RAP

15-20% less cost when using 30% RAP;
31-35% less cost when using 50 % RAP
$US3.00 –$US10.00 per HMA Ton (NCHRP 9-58, 2020)

Time Period of Study	Findings	Source
Pre-2000	Using 20% to 50% RAP may provide cost savings of 20% to 50% when materials and construction costs were considered. This is a potential savings of 1% of mixture cost for every 1% of RAP used.	Kandhal and Mallick (1997)
2004 and 2006	Savings of about 7% to 8% with 10% RAP, 15% with 20% RAP, and 20% to 22% with 30% RAP.	Vukosavlievic (2006)
2006	Using 20% RAP had the potential to save about $42 million worth of asphalt cement a year.	Ontario Hot Mix Producers Association (2007)
2007	Evaluated bid costs for three projects, but found mixed results and noted more data were needed.	Maupin et al. (2008)
2010	Reported Florida DOT estimates recycling program saved over $38 million in materials costs in 2010. About 78% of all Florida mixtures contained RAP (average about 20%).	West and Willis (2014)
2011	Estimated savings to state of $3 to $5 a ton of mix when using between 5% and 7% of RAS (Missouri).	
2012	About 5% RAS can reduce mix cost by about 13% (Texas). Combination of RAS/RAP may reduce cost by up to 20%.	
2012	Material cost savings calculated as between 15% and 20% when using 30% RAP, and between 31% and 35% with 50% RAP.	Willis et al. (2012)

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Embodied Carbon in Asphalt Bnider and Aggregates

Component	CO_2 eq/ Ton of Asphalt	
Aggregate	4	(8%)
Heating & Drying	21	
Binder	18	(36%)
Mixing	4	
Delivery	3	
Total	50	

44%

Source: Loveday 2009

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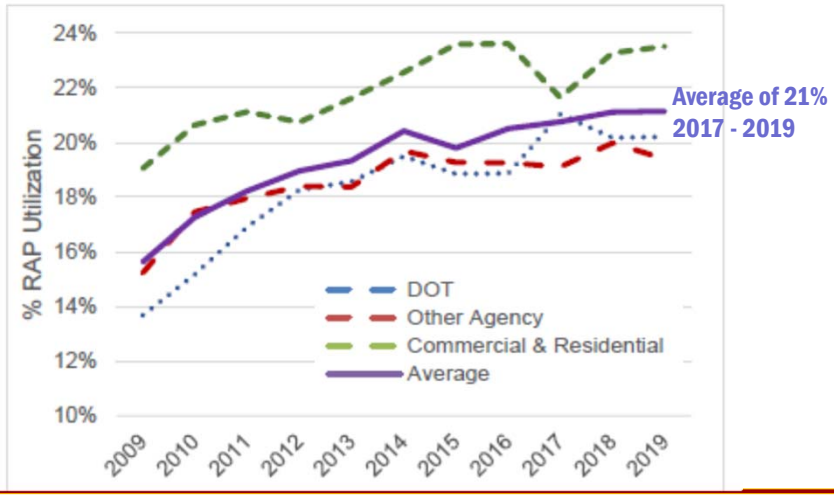
FHWA Recycling Policy

(Wright, F.G., Jr., 2002) https://www.fhwa.dot.gov/legsregs/directives/policy/recmatmemo.htm

- **The policy acknowledges that recycling may not be appropriate in all cases. The policy states:**
  - Recycled materials should **get first consideration** in materials selection.....
  - **Restrictions** that prohibit the use of recycled materials without technical basis **should be removed from specifications**.
  - Any material used in highway or bridge construction, be it virgin or recycled, **shall not adversely affect the performance**, safety or the environment of the highway system.

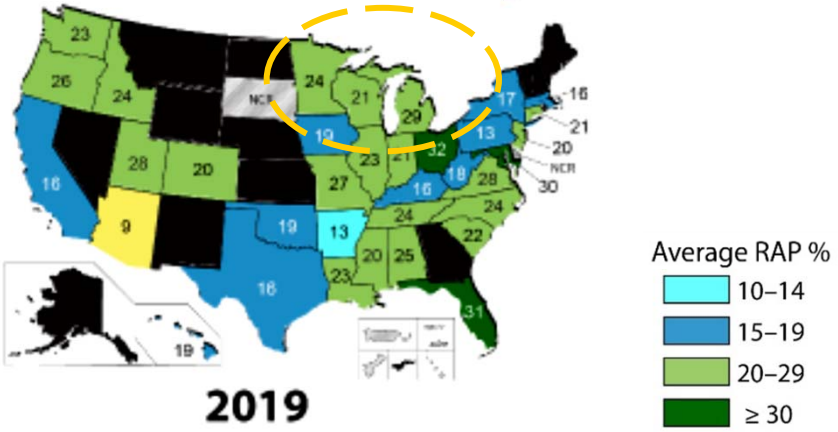
RAP Use By Sector in the USA
More than 83 million tons in 2019

Source: NAPA Informational Series 138 - 2019



So if Science and Policy are behind increasing RAP, why are we levelling at 20 %??

RAP Use in the USA – 2019 by State/Region



Source: NAPA Information Series 138

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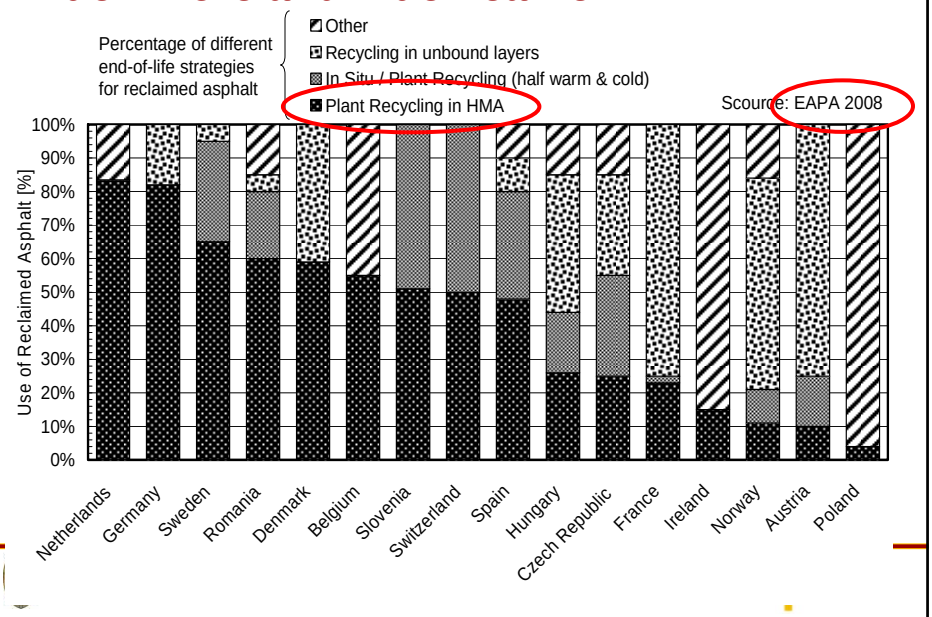
Use of reclaimed asphalt material in the EU
Much more and much earlier !



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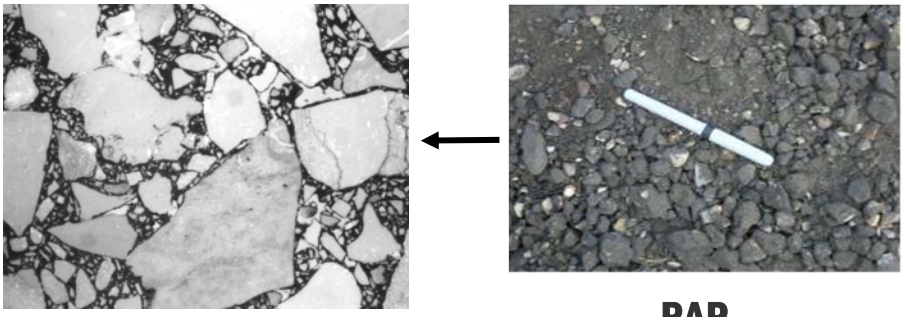
Can RAP produce high quality Surface Layer HMA?

1. Need proper RAP processing,
2. Adjustment of Mix Design, and
3. Use of Chemicals (Recycling Agents)



HMA

RAP

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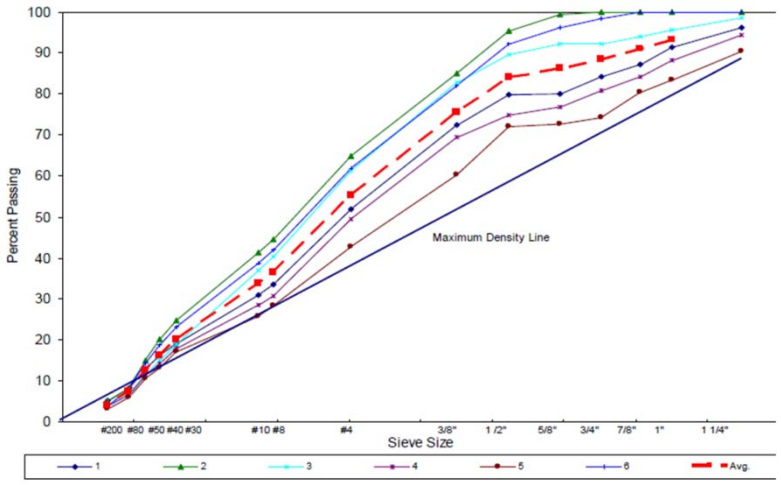
Variability of RAP Gradations



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Sources of RAP

Pavement Milling

Asphalt Pavement Removal

Plant Waste Material

Source: RMAUPG- J. D'Angelo

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Processing RAP

Screening

Crushing

Fractionating

Source: RMAUPG- J. D'Angelo

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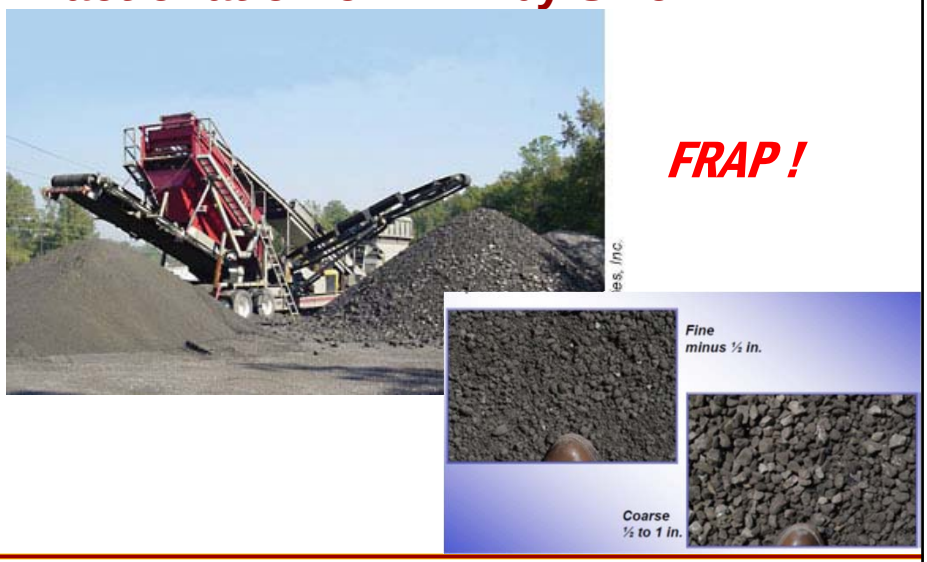
Fractionation of RAP by Size



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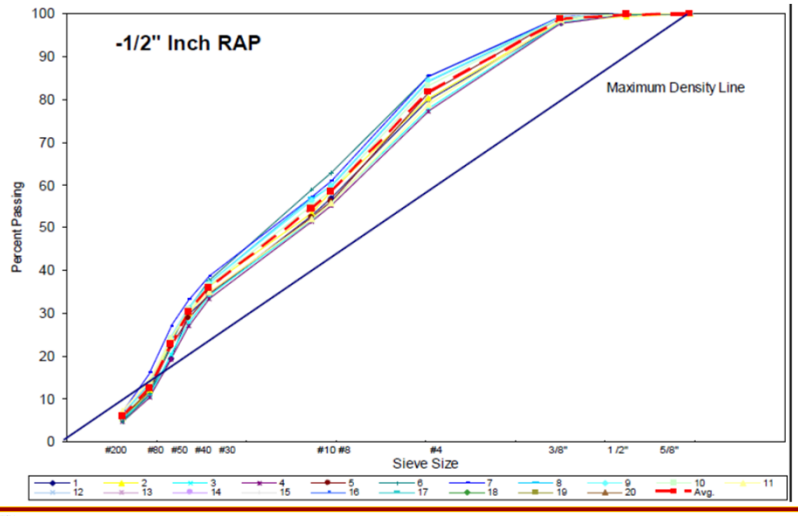
Quality Control and Processing can Make RAP consistent



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Management of the RAP Piles
Classified, Certified, Standard, Continuous

State	Specification Section (Source)	Terminology	Characteristics
Iowa	SS-0139, 2006	Classified	Documented source, defined quality of materials
Iowa	2303	Unclassified	Unknown source; visual inspection for uniformity; tested for gradation and asphalt content
		Designated RAP	Obtained from project; used on same project
		Active stockpiles	Term used but not defined
		Certified RAP	Sources known and no more than two sources in the same stockpile; stockpiles separated by aggregate quality and gradation, asphalt type, and content; no additional RAP added once tested
Ohio	401.04	Standard RAP	100% passing 2-in. screen (nonsurface mixtures) 100% passing ¾-in. screen (surface mixtures)
		Extended RAP	Fractionated or additional in-line processing of already approved stockpile; quality control plan. *In-line processing*: Double deck screen between cold feed bin and mixer with 9/16-in. screen for surface mixtures; 1.5-in. screen for base mixtures.
Florida	334-2.3.3	Continuous	RAP from one or more sources; processed, blended, or fractionated and stockpiled in a continuous manner; QC plan for monitoring gradation and asphalt content; visual inspection and review of data for suitability assessment
		Noncontinuous	Individual (single) stockpile with known gradation and asphalt content; QC plan; no additional material added once approved

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Quality of Binder and Aggregates in RAP

- Aggregates do not change with age. Since most are from approved project, quality ***can be assumed high and acceptable***.

RAP

- Binders oxidize and change physically and chemically:
  - ***Binders are stiffer and more brittle***
  - ***Chemicals are needed to*** rejuvenate/soften them.

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Challenges faced Using RAP

Source: John Davis and Phil Blankenship, Asphalt Institute, August 2017

- "How much of the binder from the RAP is actually alive, working and effective?
  - Aged binder could be very stiff and cannot blend well.
- Long term durability is at risk if the binder is not rejuvenated
- Right now, we are seeing the second and third generation of RAP use. Is this a problem?

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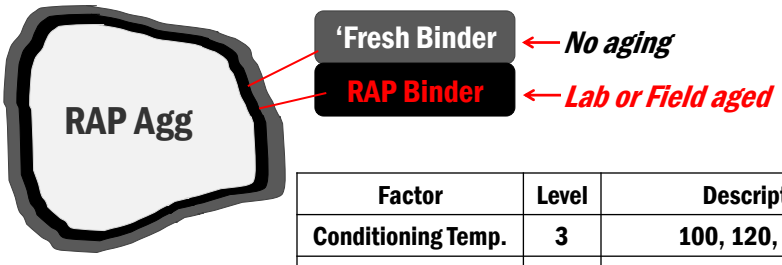
Test Methods & Experimental Design
'Direct Contact' Blending

- Simulate field blending using binder 'wafers' with known aging history and rheological properties



Factor	Level	Description
Conditioning Temp.	3	100, 120, 140 C
Conditioning Time	4	5, 30, 60, 120 min
Binder Compatibility	2	High(~16%)/Low (~9%) Asphaltene content

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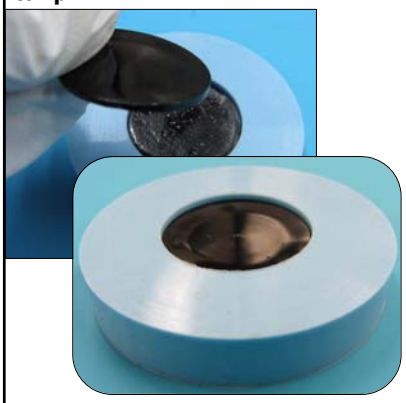
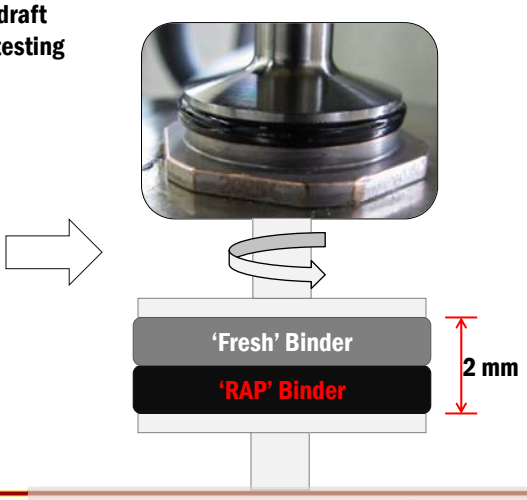
Test Methods & Experimental Design
'Direct Contact' Blending

Condition sandwiched wafers in forced draft oven, remove and immediately bring to testing temp…





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Also test conditioned 'Fresh' and 'RAP' binder alone to account for aging

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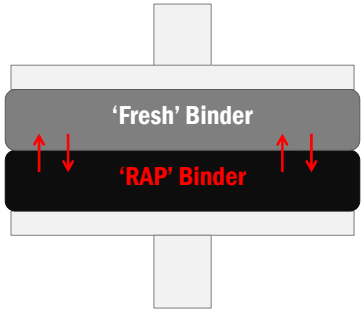
Estimating the Rate of Diffusion
Boundary conditions

- Measure the fresh binder concentration, *c*, with time, *t* , in the RAP material…



c(x, 0) = 0
c(x, ∞) = 0.5
We measure $G^*_{composite}$ in the DSR

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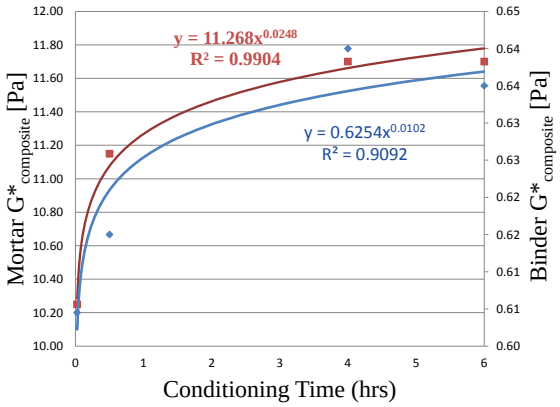
Time and Temperature Affect Blending



- Blending will occur but it is sensitive to time, temperature and binder chemistry.
- Near complete blending is possible and is likely at temperatures above 100 °C within two hours.

Mix Conditioning is very important

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Binder Selection Guidelines for RAP Mixtures (AASHTO M 323)

Recommended Virgin Asphalt Binder Performance Grade (PG)	RAP Percentage
No change in binder selection	<15
Select virgin binder one grade softer than normal (Select a PG 58-28 if a PG 64-22 would normally be used.)	15-25
Follow recommendations from blending charts	>25

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Minimum Ratio of Virgin Binder

CRITERIA FOR MNDOT MINIMUM RATIO VIRGIN ASPHALT TO TOTAL ASPHALT BINDER (ABR)

Specified Asphalt Grade	Lift	Minimum ABR for Recycled Material Asphalt Mixtures		
		RAP only	RAS only	RAP and RAS
PG XX-28 PG 52-34 PG 49-34 PG 64-22	Wear	70	70	70
	Non-Wear	70	70	65
PG 58-34 PG 64-34 PG 70-34	Wear	80	80	80
	Non-Wear			

Source: MnDOT (2013; Table 2360-8).

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Change in PG Grade with Use of RAP

VIRGIN ASPHALT GRADE FOR RAP MIXTURES

RAP Content, %	PG Grade
0–15	PG 67-22
16–30	PG 58-22
>30	PG 52-28

Source: Florida Department of Transportation Specifications (2015, Table 334-2).

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Recycling agents

- Recycling Agents Types:
  - Softer Grade Bitumen
  - Petroleum
    - Paraffinic Oil: PP-1, PP-2
    - Aromatic Oil: PR-3
  - Bio-based Oil:
    - Wood Plant Liquid or Corn Oil: BO-1, BO-2
  - Refined Used Oil:
    - Re-refined Used Motor Oil: REOB (RW)

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Outdated Classification

Designation: D4552/D4552M – 10 (Reapproved 2016)$^{\varepsilon 1}$

Standard Practice for
Classifying Hot-Mix Recycling Agents[1]

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Recycling Agents (RA) grades

D4552/D4552M – 10 (2016)$^{\varepsilon 1}$

TABLE 1 Physical Properties of Hot-Mix Recycling Agents

NOTE 1—Compliance requires the asphalt binder be extracted from the pavement to be recycled and combined with the recycling agent being tested. This combination should be in accordance with ratio of recycling agent to recovered asphalt binder used in the mix. The resulting mixture must meet all specifications for the appropriate grade within Specification D946 or Table 1, 2 or 3 of Specification D3381.

Test	ASTM Test Method	RA 1		RA 5		RA 25		RA 75		RA 250		RA 500	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity • 60 °C [140 °F], mm^2/s	D2170 or D2171	50	175	176	900	901	4500	4501	12500	12501	37500	37501	60000
Flash Point, COC, °C [°F]	D92	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...
Saturates, wt, %	D2007	...	30	...	30	...	30	...	30	...	30	...	30
Tests on Residue from RTFO or TFO oven 163 °C [325 °F]	D2872 or D1754												
Viscosity Ratio[A]	"	...	3	...	3	...	3	...	3	...	3	...	3
Wt Change, ±, %	"	...	4	...	4	...	3	...	3	...	3	...	3
Specific Gravity	D70 or D1298	Report		Report		Report		Report		Report		Report	

[A] Viscosity Ratio = Viscosity of Residue from RTFO or TFO Oven Test·60 °C [140 °F],cST / Original Viscosity·60 °C [140 °F],cSt

< 30% New Aggregates | **> 30%**

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Aggregate Properties Measured for RAP

- **Gradations** of the RAP are the most frequently evaluated recycled material aggregate property after either ignition oven or solvent extraction.
- **RAP source aggregate properties are typically considered acceptable**, usually because RAP was obtained from state projects.
- Only a limited number of agencies measure the recycled material aggregate shape, clay-sized particle content, soundness, and toughness.

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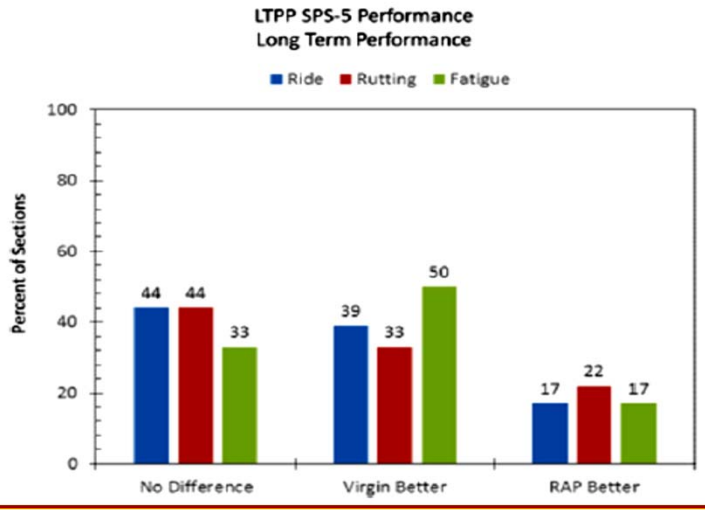
Field Performance of Pavements with RAP(LTPP Program)



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Performance of High RAP Mixtures NCAT full Scale Testing

Test Section	RAP Content*	RAP Asphalt, %	Virgin Asphalt Grade	Date of First Crack	ESALs at First Crack	Total Length of Cracking
Impact of Reducing Critical PG High Temperature (< 25% RAP)						
W4	20%	17.6	PG 67-22	No Cracking		
W3	20%	18.2	PG 76-22	4/7/2008	6,522,440	34.0
Impact of Reducing Critical PG High Temperature (>25% RAP)						
W5	45%	42.7	PG 58-28	8/22/2011	19,677,699	3.5
E5	45%	41.0	PG 67-22	5/17/2010	13,360,016	13.9
E6	45%	41.9	PG 76-22	2/15/2010	12,182,331	53.9
E7	45%	42.7	PG 76-22S	1/28/2008	5,587,906	145.5

Source: West et al. (2011).
*RAP asphalt content as a percentage of total aggregate.
**Percentage of RAP asphalt as a percentage of the total asphalt content.
S = 1.5% Sasobit in virgin asphalt.

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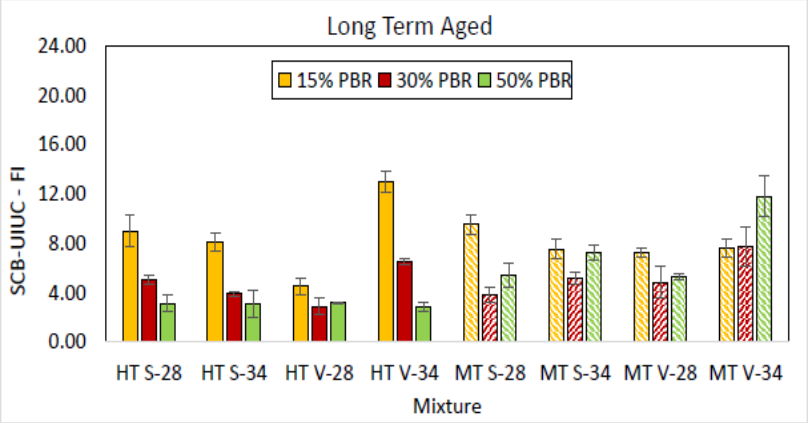
Resistance to Fatigue Cracking
Measured in Lab (Semi-Circular Bend- SCB Test)



(b) SCB-UIUC Results for Long Term Aged Mixtures

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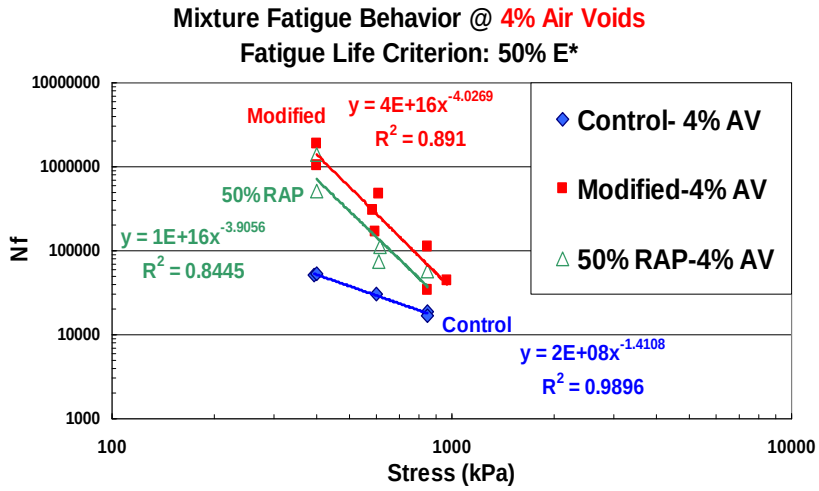
Fatigue (S-N) Curves
50% Reduction in E Criteria- Stress Controlled*



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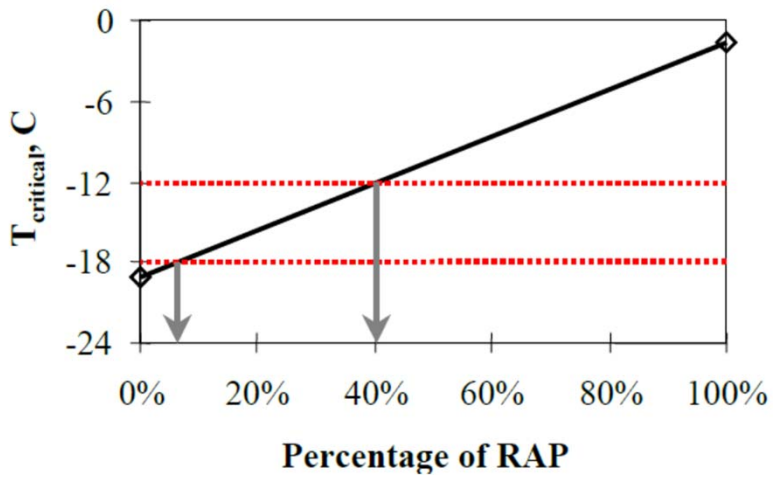
$T_{critical}$ Blending Charts- Low Temp



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NCHRP 9-58 – Most Recent Study on High RAP mixtures (Amy Epps-Martin et al. 2020)

- New formula for ***estimating dosage of recycling oil***
- New formula for ***Binder Availability Factor***

APPENDIX I

Draft AASHTO Standard Practice

Proposed Standard Practice for

Characterization of Asphalt Mixtures with High Recycled Materials Contents and Recycling Agents

AASHTO Designation: R XX-XX

1. SCOPE

1.1 This practice describes practical tools to evaluate the effectiveness of recycling agents (rejuvenators) initially and with aging for hot mix asphalt mixtures with large quantities of reclaimed asphalt pavement (RAP) and/or recycled asphalt shingles (RAS) (high recycled materials contents). This practice also describes component materials selection, proportioning guidelines for recycled materials, and selection of recycling agent dose.

$$\text{RAP BAF} = -0.014 \times \text{PGH}_{\text{RAP}} + 1.898$$

$$\text{RAP BAF} = -0.010 \times \text{PGH}_{\text{RAP}} + 1.771$$

where:

PGH_{RAP} = Continuous PGH of the RAP binder (°C).

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Concluding Remarks

- Recycling of asphalt pavement is widely used and is **considered a necessary practice**.
- How to better control RAP is very important.
  - **Processing (Fractionating) …. FRAP!**
- Performance of High RAP Mixes **can be equal to virgin mixtures if done properly**.
  - Test for Fatigue
  - Test for Moisture Damage
  - Binder issues are very important
    - True binder replacement ratio (**Binder Availability Factor**)
    - Final effective binder grade …. ePG
    - **Recycling agent selection**

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Thank you

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