Rejuvenators: Where do we Stand?

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- Cold Mix
- Emulsions
- Rheology
- Stabilizers

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- Customer custom formulation services
- Compositional and analytical evaluation
- Advanced rheology and thermal analysis

155,000
employees

155
years of experience

Working in
70
countries

$114,6 billion
in annual revenue

Our commitments

Responsible
We strive to strengthen the communities where we live and work.

$115 million
Total charitable contributions last year across 56 countries

Attendance at our farmer trainings for sustainable agricultural practices totaled 860,000 last year

Sustainable

- Agriculture is how we will protect the planet and our shared future.
- Climate change: Reducing supply chain emissions per ton of product 30% by 2030, and absolute operational emissions 10% by 2025
- Water resources: Achieving sustainable water management in all priority watersheds by 2030
- Land use: Eliminating deforestation in our supply chains by 2030

Agenda

- Recycling Agents: What? Why? How?
- RA Implementation: Best Practices
- RA-BMD Spec. Implementation Examples

Recycling Agents

“Rejuvenation” is an inaccurate, but popular term for Recycling Agents.

- Rejuvenators do not undo oxidative aging!!!

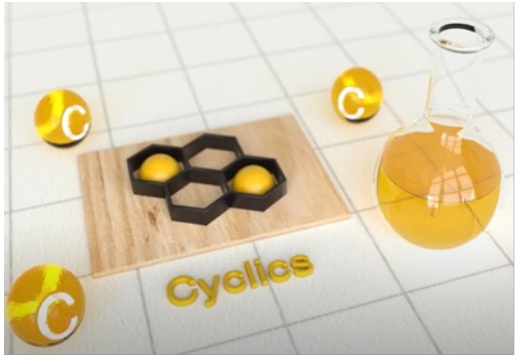
A Recycling Agent reverses the impact of aging on asphalt, reactivating the asphalt, to restore performance, and durability.

A “Rejuvenating” Recycling Agent reverses the impact of aging by:

- Restoring cracking resistance, maintain rutting performance
- Improving workability, compaction, and appearance
- Improving aging susceptibility of the pavement
- Providing predictable and reliable results

- Link to video: https://youtu.be/uwfYjy4PHDU

Rejuvenation Mechanism



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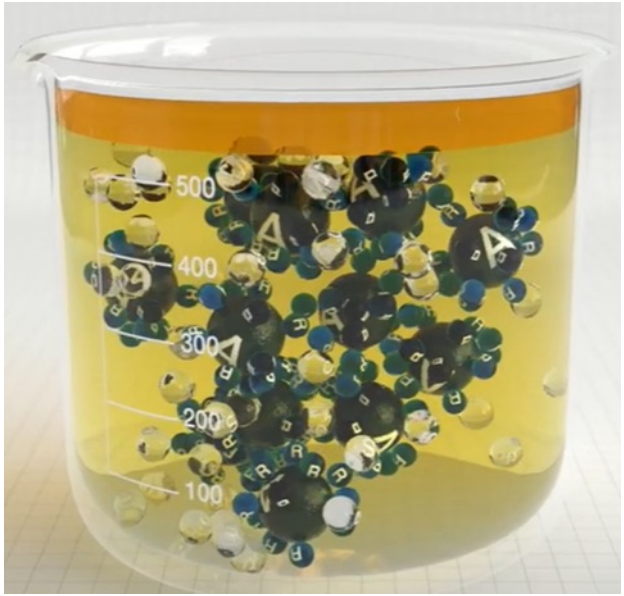
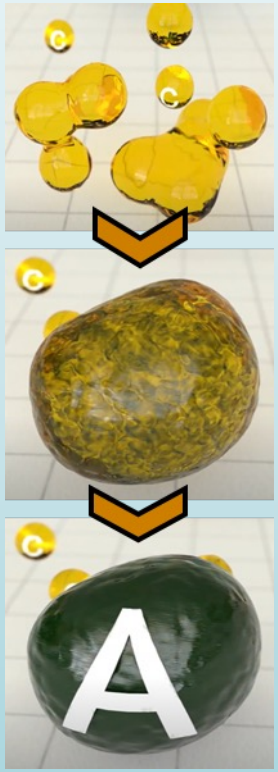
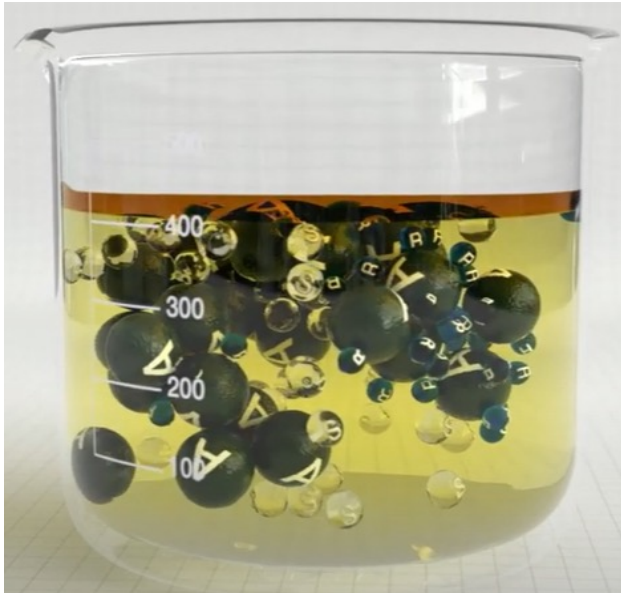
Rejuvenation Mechanism



Unaged: Balanced and disassociated polars (“Sol”)

Oxidative Aging

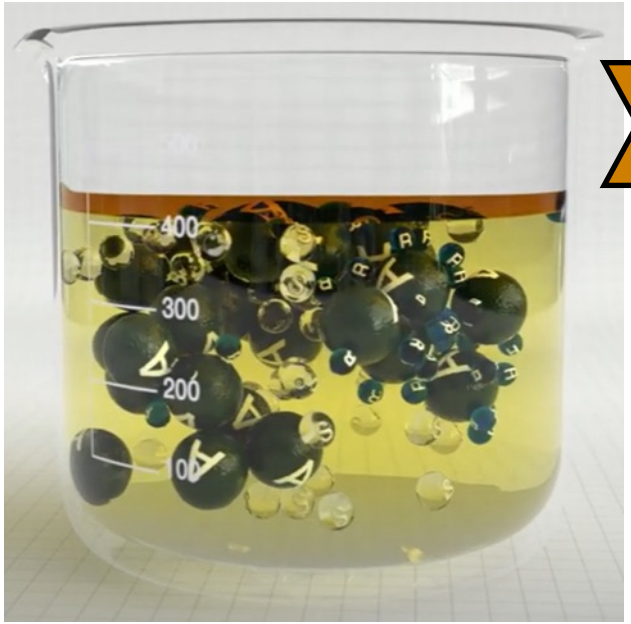


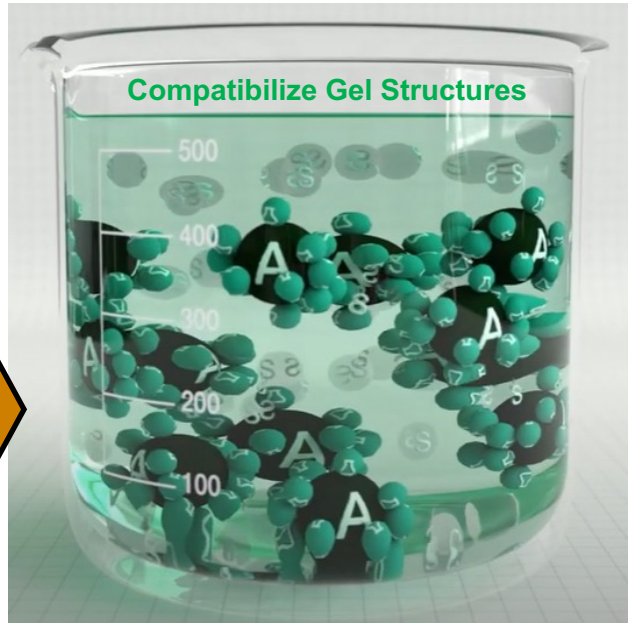


Aged: Unbalanced, polar clusters and “gelling”

- Link to video: https://youtu.be/uwfYjy4PHDU

Rejuvenation Mechanism





Aged: Unbalanced, polar clusters and “gelling”

Rejuvenated: Rebalanced and disassociated polars

Classification of RAs

- Early classifications of Recycling Agents focused on raw material type (e.g. aromatic oil vs. tall oil).
  - This was adequate when most additives were chemically unmodified.
  - However, with advent of engineered and chemically modified additives, raw material designations are less useful.
- There are several recently completed and on-going efforts to develop a system and corresponding specification to accurately describe the chemical, physical, and engineering properties of recycling agents, and classify them, regardless of their composition.
- Currently only one ASTM standard addressing Recycling Agents exists:
  - ASTM D4552: Classification of Hot Mix Recycling Agents

RA Properties via ASTM D4552-20 (By Supplier)

(Published July 2020)

This step ensures that rejuvenator meets basic requirements for safety, thermal stability, storage stability, and compatibility to be used in Hot Mix Asphalt production.

Most Bio-oils

Most Petro. oils

Test	ASTM Test Method	RA 0		RA 1		RA 5		RA 25		RA 75		RA 250		RA 500		Example Bio-based Rejuvenator
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Viscosity • 60 °C [140 °F], mm^2/s	D2170	10	49	50	175	176	900	901	4500	4501	12500	12501	37500	37501	60000	30
Flash Point, COC, °C [°F]	D92	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	>290°C
Saturates, wt. %[A]	D2007	...	30	...	30	...	30	...	30	...	30	...	30	...	30	~ 0% (Iatroscan)
Tests on Residue from RTFO 163 °C [325 °F]	D2872															
Viscosity Ratio[B]	"	...	3	...	3	...	3	...	3	...	3	...	3	...	3	1.05
Wt Change, ±, %	"	...	4	...	4	...	4	...	3	...	3	...	3	...	3	<0.5%
Specific Gravity at 25 °C [77 °F]	D70 or D1298	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.94

$$ViscosityRatio = \frac{Viscosity\ of\ Residue\ from\ RTFO\ Test\ at\ 60°C\ [140°F]}{Original\ Viscosity\ at\ 60°C\ [140°F]}$$

How do we Differentiate Rejuvenators from Softeners?

- The difference between “Rejuvenation” and “Softening” is in the ability to “compatibilize” asphaltene-association structures in asphalt.

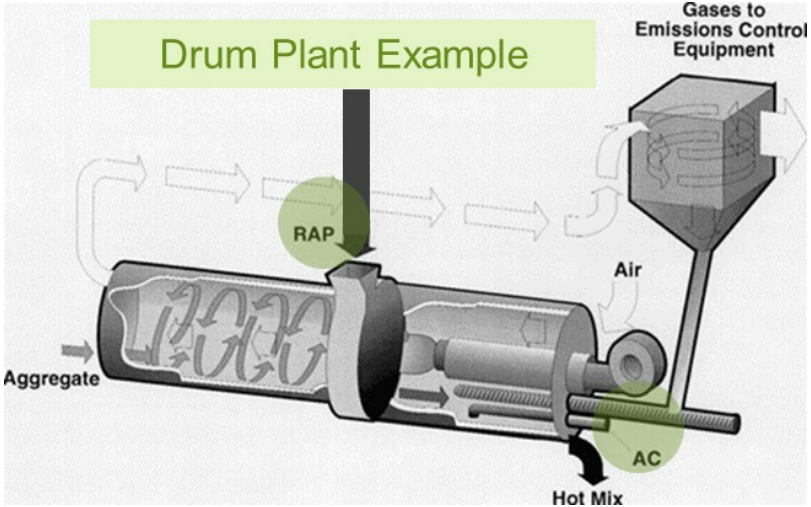
- Directly measuring asphalt compatibility is not easy. However:
  - We know that **long term-aging** decreases the compatibility of asphalt
  - We can **measure the change** in properties as a result of aging.

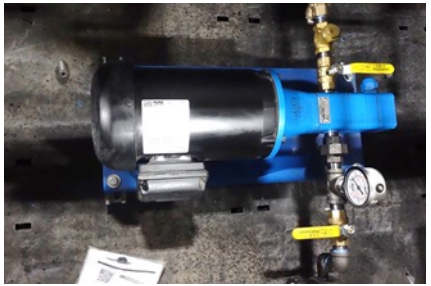
- Examples of property changes compared after long term aging:
  - Measuring the change in Analytical indices (e.g. “Colloidal Instability Index”, AFM structures)
  - Measuring change in Miscibility thermal analysis (i.e. Tg properties)
  - Measuring the change in BBR m-grade or ΔTc

Plant Implementation

Typically, **1-3% wt. of the binder or 0.05-0.15% wt. of the mix**, added via:

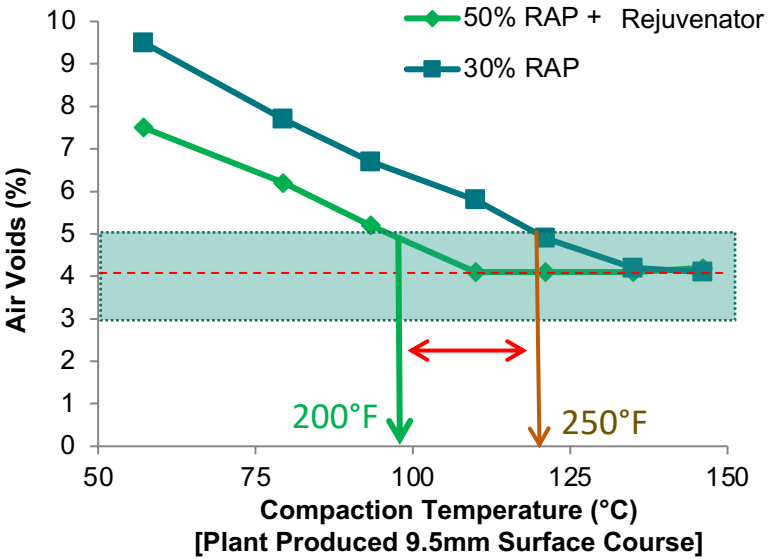
1. In-line into virgin binder using additive pump
2. Treatment of RAP (at collar or during processing)
3. Injection into pugmill or mixing drum
4. Pre-blended into virgin binder (least common)



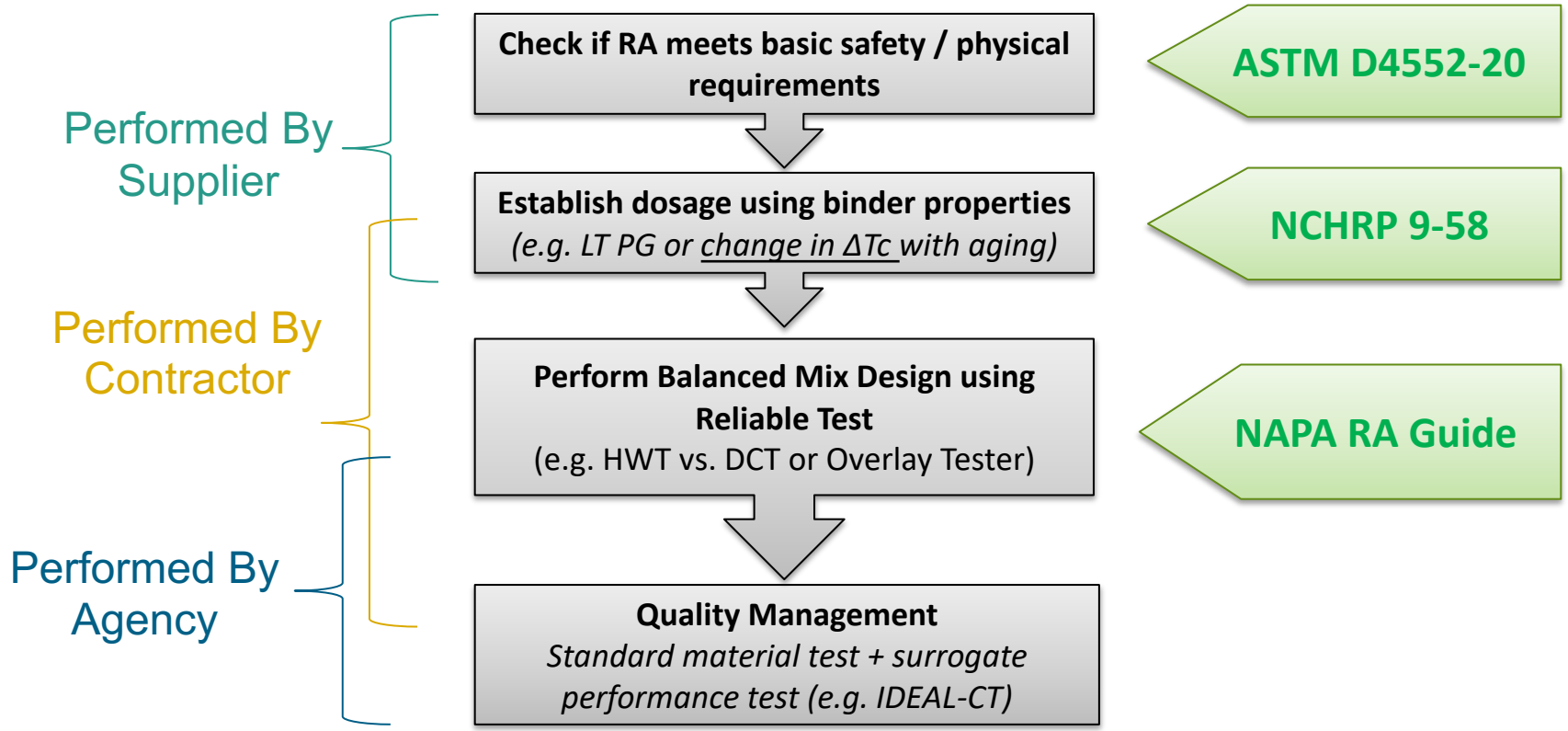


First Impressions: Improved workability

- Rejuvenation significantly improved the Compactability, even after a 20% increase in RAP content.
  - A large improvement in compaction temperatures achieved
  - No over-compaction at hot mix temperatures.



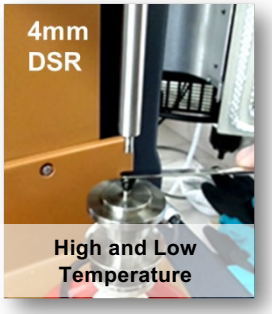
Overview: High RAP-Rejuvenated Design



Step 1: Initial RA Dosage Determination (By Supplier)

- RAP samples are extracted, graded and rheologically fingerprinted for initial dosage determination.

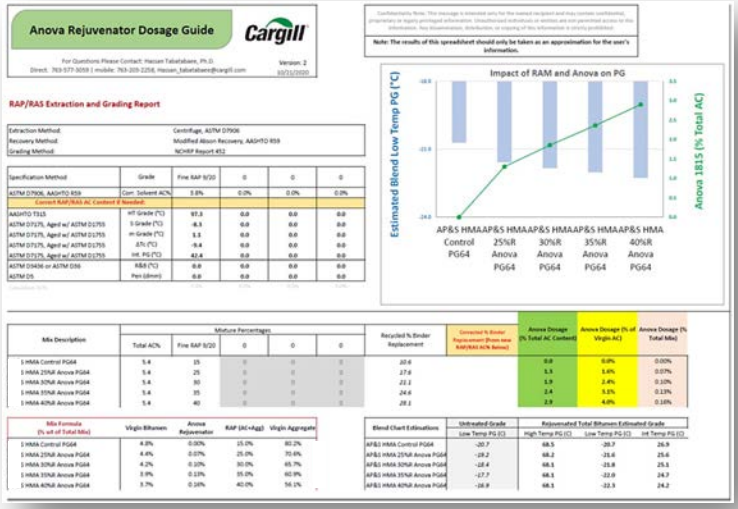
Extraction & Recovery



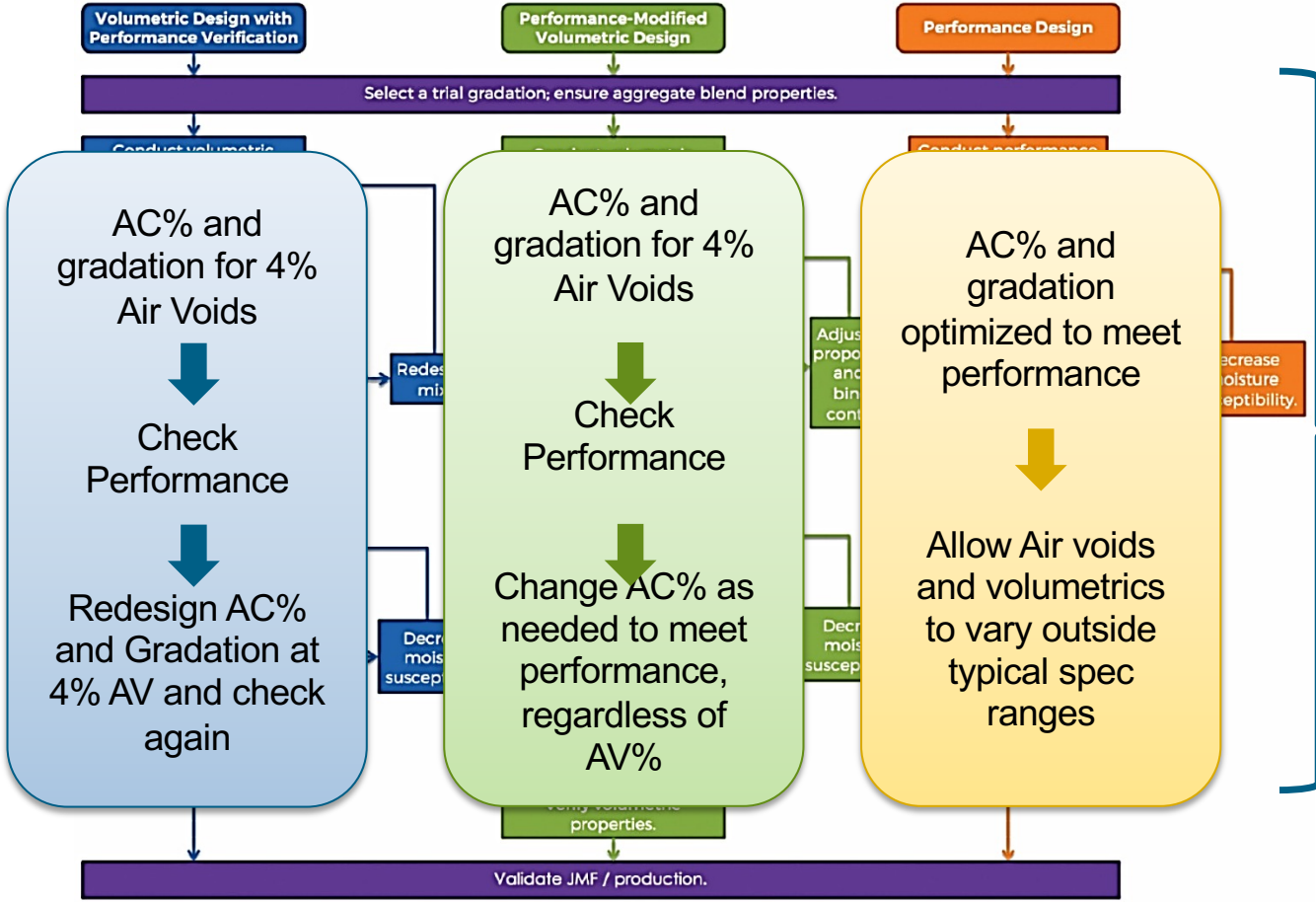
Low Temperature
Cracking Resistance

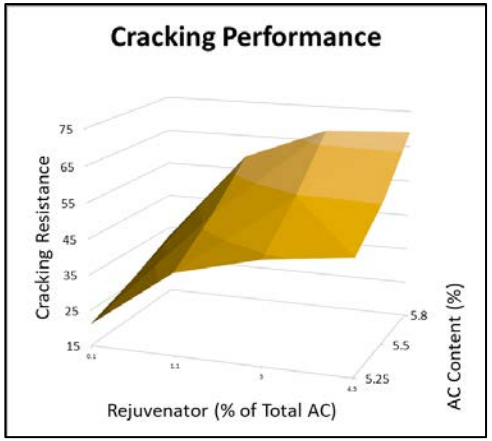
Grading and Analysis

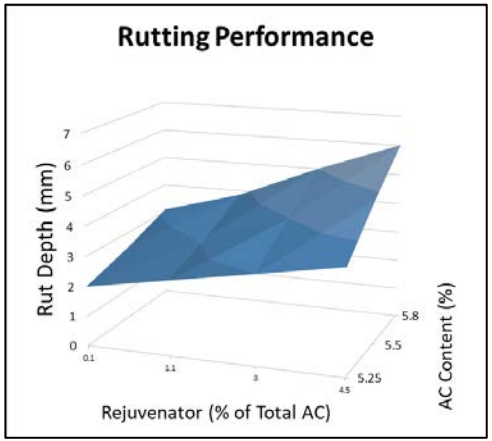
Dosage Determination Report for Target Mix Designs



Step 2: Balanced Mix Design (By Producer)







Step 3: Quality Management (All Parties)

Well-established process for Commercial Mixes

Supplier:

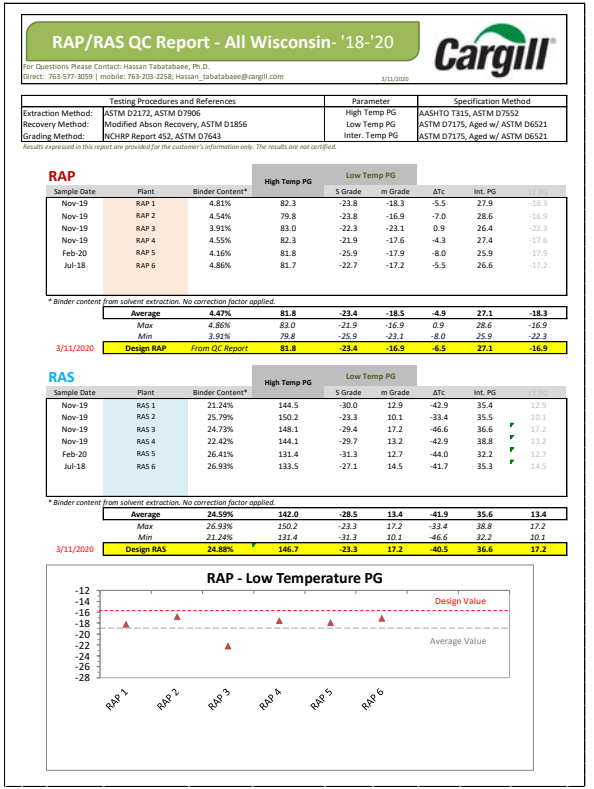
- Product delivered with verifiable Certificate of Analysis
- Support producer with periodic material sampling and verification throughout season.

Producer:

- Maintain appropriate frequency of RAP analysis (binder content and gradation control.)
- Maintain RAM processing protocols and consistency
- Mix performance verification as needed.

Owner/Agency (in development across country):

- Per agency specification
- Frequent Quality verification of mix composition/volumetrics
- Full mix design performance verification on first plant production of a specific design
- Periodic simple/surrogate mix performance verification



RAP/RAS QC Report - All Wisconsin- '18-'20

Cargill

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3/11/2020

Testing Procedures and References		Parameter	Specification Method
Extraction Method:	ASTM D2172, ASTM D7906	High Temp PG	AASHTO T315, ASTM D7552
Recovery Method:	Modified Abson Recovery, ASTM D1856	Low Temp PG	ASTM D7175, Aged w/ ASTM D6521
Grading Method:	NCHRP Report 452, ASTM D7643	Inter. Temp PG	ASTM D7175, Aged w/ ASTM D6521

Results expressed in this report are provided for the customer's information only. The results are not certified.

RAP

			High Temp PG	Low Temp PG				
Sample Date	Plant	Binder Content*		S Grade	m Grade	ΔTc	Int. PG	LT PG
Nov-19	RAP 1	4.81%	82.3	-23.8	-18.3	-5.5	27.9	-18.3
Nov-19	RAP 2	4.54%	79.8	-23.8	-16.9	-7.0	28.6	-16.9
Nov-19	RAP 3	3.91%	83.0	-22.3	-23.1	0.9	26.4	-22.3
Nov-19	RAP 4	4.55%	82.3	-21.9	-17.6	-4.3	27.4	-17.6
Feb-20	RAP 5	4.16%	81.8	-25.9	-17.9	-8.0	25.9	-17.9
Jul-18	RAP 6	4.86%	81.7	-22.7	-17.2	-5.5	26.6	-17.2

** Binder content from solvent extraction. No correction factor applied.*

	Average	4.47%	81.8	-23.4	-18.5	-4.9	27.1	-18.3
	Max	4.86%	83.0	-21.9	-16.9	0.9	28.6	-16.9
	Min	3.91%	79.8	-25.9	-23.1	-8.0	25.9	-22.3
3/11/2020	Design RAP	From QC Report	81.8	-23.4	-16.9	-6.5	27.1	-16.9

RAS

			High Temp PG	Low Temp PG				
Sample Date	Plant	Binder Content*		S Grade	m Grade	ΔTc	Int. PG	LT PG
Nov-19	RAS 1	21.24%	144.5	-30.0	12.9	-42.9	35.4	12.9
Nov-19	RAS 2	25.79%	150.2	-23.3	10.1	-33.4	35.5	10.1
Nov-19	RAS 3	24.73%	148.1	-29.4	17.2	-46.6	36.6	17.2
Nov-19	RAS 4	22.42%	144.1	-29.7	13.2	-42.9	38.8	13.2
Feb-20	RAS 5	26.41%	131.4	-31.3	12.7	-44.0	32.2	12.7
Jul-18	RAS 6	26.93%	133.5	-27.1	14.5	-41.7	35.3	14.5

** Binder content from solvent extraction. No correction factor applied.*

	Average	24.59%	142.0	-28.5	13.4	-41.9	35.6	13.4
	Max	26.93%	150.2	-23.3	17.2	-33.4	38.8	17.2
	Min	21.24%	131.4	-31.3	10.1	-46.6	32.2	10.1
3/11/2020	Design RAS	24.88%	146.7	-23.3	17.2	-40.5	36.6	17.2

Examples of Current or Considered BMD Systems

(Some details may have changed or no longer be accurate)

Agency:	New Jersey DOT	Chicago DOT	Illinois Tollway	Illinois DOT	City of Janesville	Virginia DOT	City of Columbus	ODOT (Trial)	City of Phoenix (Trial)
Cracking Test	Overlay Tester	DCT	DCT + IFIT	IFIT	DCT + IFIT	IDEAL-CT	IDEAL-CT	IDEAL-CT	IFIT
Rutting Test	APA	Hamburg	Hamburg	Hamburg	Hamburg	APA	HWT	HWT	HWT to approve RA
Binder Specification	None	Extracted pass PG XX-22, ΔT_c > 5	None	None	Extracted pass PG XX-16	None	Extracted pass climate PG + 6	Extracted pass climate PG + 6	Meet virgin grade of 70-28
QC Process	Trial Strip + performanc e test	Extracted PG	Trial Strip + Performanc e test	TBD	Performanc e test	Surrogate tests, TBD	IDEAL-CT	IDEAL-CT	Basic VMD QC
State of Implementation	Active as of 2018	Active as of 2018	Active as of 2018	Active as of 2019	Active as of 2017	Trial spec as of 2019	Implement ation in 2022	Trial in 2021	Trials in 2021

Field Evaluation Projects

NCAT: Warm Climate

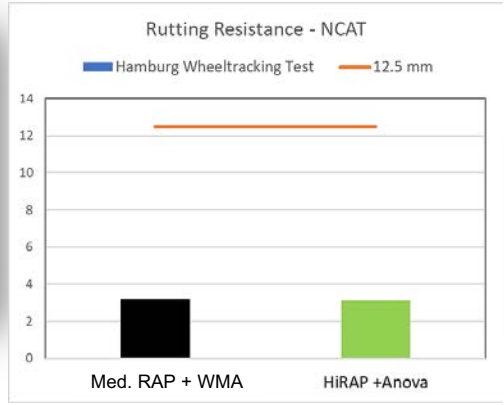
- 30% RAP (24% ABR); PG64-22 Binder + Warm Mix Additive
- 45% RAP (38% ABR); PG64-22 Binder + Rejuvenator
- Aggregates and RAP were shipped in from Virginia for the project

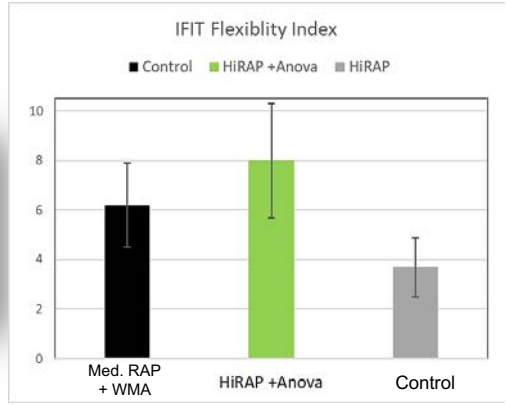
MNROAD: Cold Climate

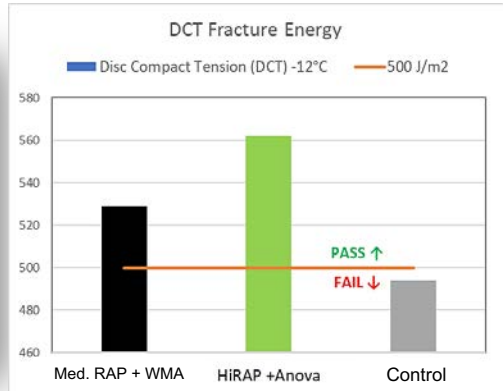
- 25% RAP (20% ABR); PG58-28 Binder
- 45% RAP (31% ABR); PG5828 Binder + Rejuvenator
- Aggregates and RAP were supplied locally in Minnesota for the project

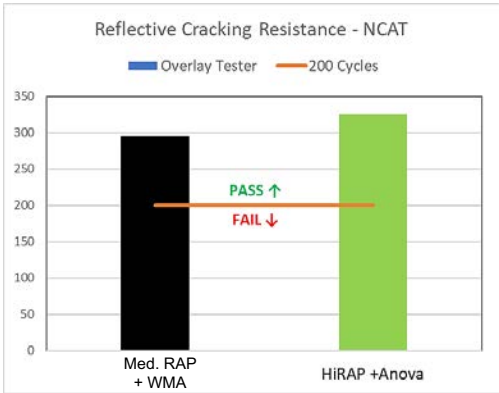
NCAT High RAP and WMA Project

- Designs were done using BMD system under consideration by VADOT at the time (IDEAL vs. APA)
- Rejuvenation of the high RAP mix achieved comparable passing performance compared to the WMA mix.
- Both the RA and WMA mix outperform the high-RAP control mix.







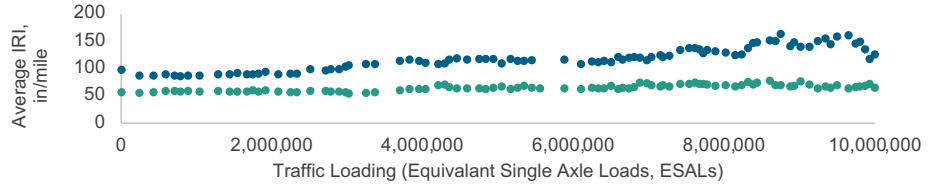


NCAT Field Performance

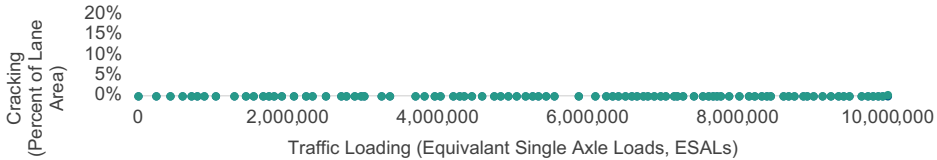
To demonstrate performance Cargill built a test section on the NCAT track using the typical 30% RAP mix with Cargill Anova® WMA, and 45% RAP with Cargill Anova® Rejuvenator.

After 10 million loadings, zero cracks appeared in the test section

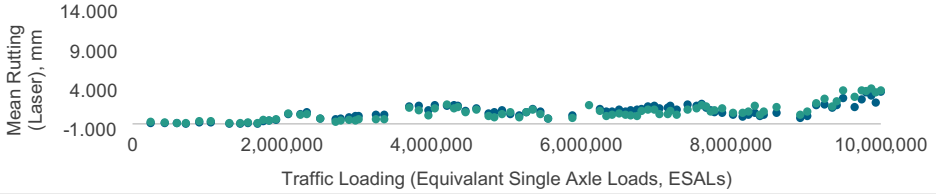
Maintaining Smooth Ride



0 Cracking



No Rutting



30% RAP + WMA 45% RAP + RA

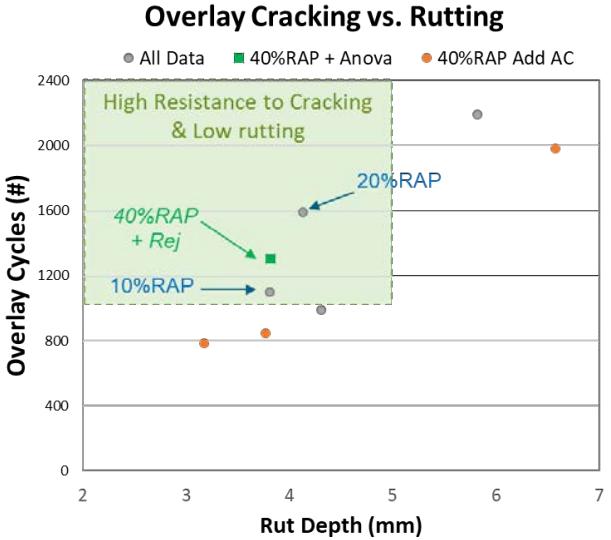
* Data provided and measured by NCAT using plant produced mix.

Balanced Mix Design for Delaware:
DelDOT Approved Mix

1. Plant samples were prepared based on Cargill dosage recommendations and HMA producer's mix design.
2. DOT directly sampled plants and carried out Laboratory performance tests.
3. Binder extraction tests were conducted on lab samples by Cargill.

- 25% RAP + 4%RAS + Rejuvenator vs. Control: 25% RAP
- 40%RAP + Rejuvenator vs. Control: 25% RAP
  - AC% optimized by VMD, standard densities
  - Performance checked with Overlay Tester, IdealCT and Hamburg

Description	Extract AC %	HT PG	LT S PG	LT m PG	ΔTc
25%RAP + 4%RAS Rej	5.58%	82.5	-22.4	-22.2	-0.2
35%RAP + 5%RAS Rej	5.91%	73. 9	-23.6	-26.6	2.9

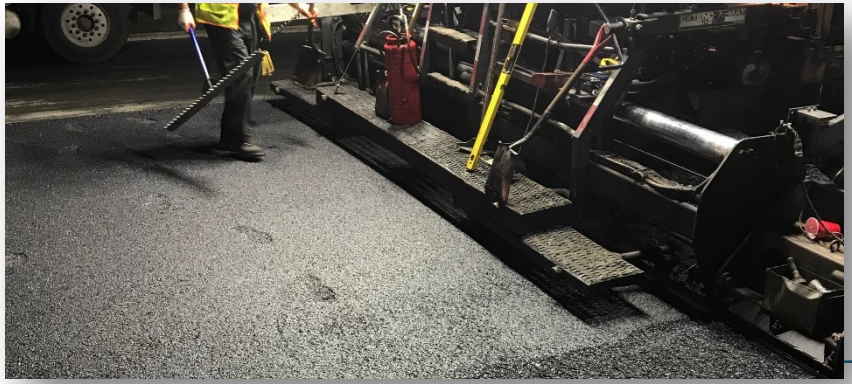


Project Highlights: New Jersey

50% RAP, 9.5 mm, Surface Course

Project Property	Value / Description
Date	June 2018
Tonnage	> 10,000 tons
Mix Type	NJDOT Surface Mix Dense Graded
Performance	Overlay Tester Cycles : 1200 > 200
	APA Rutting at 64C < 7 mm

Description	Extract AC %	HT PG	LT S PG	LT m PG	ΔTc
50%RAP Rejuvenator	5.44%	67.4	-30.1	-28.0	-2



City of Yonkers – High RAP Project, May 2021

- 12.5 mm NMAS, 40% RAP + Rejuvenator was used in surface mix in place of a typical 20% RAP mix.
- Success of project (appearance, compaction and workability, performance) has led to incorporation of allowance for similar designs in bids this season

Conclusions and Summary

- Today rejuvenation technology has been used successfully for years in millions of tons of HMA.

- Implementation of high RAP + Rejuvenators in both “non-spec” commercial mixes and spec’d Agency mixes can be highly practical and feasible today:
  - Work with rejuvenator supplier on the appropriate dosage to produce higher RAP mixes with quality consistent with normally supplied mix designs.

- The NCAT and MNROAD studies demonstrated that even for high-performance and high-service pavements a framework can be used that provides **transparency and reliability for all stakeholders**:
  - Step 1: Recycling Agent Property Certification (e.g. through ASTM D4552-20) - by supplier
  - Step 2: Initial dosage determination based on rheology, led by supplier
  - Step 3: Balanced Mix Design (BMD) process, led by producers
  - Step 4: Robust quality management practices by all parties

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