The Role of **Bio-based** Additives in Achieving **Sustainability** in Asphalt Pavements

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Cargill® Helping the world thrive

Global Leader in Asphalt Chemistries

To empower a more sustainable life and keeping people safe on the road through high-performance and advanced bio-based asphalt additives.

- Rejuvenation
- Warm Mix
- Cold Mix
- Emulsions
- Rheology
- Stabilizers

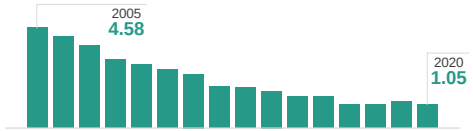
State-of-the-art Asphalt Lab

- 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

Safe
We relentlessly work to improve the safety of our people. Reduction in injuries per 200,000 hours worked over 15 years.



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

Cargill Bioindustrial manufacturing & research sites

Agenda

- Review of two sustainable technologies:
  - Rejuvenators (Recycling Agents)
  - Chemical Warm Mix Additive
- Implementation of Additives in Asphalt Design
- Review of Selected Field Studies

Sustainability: Rejuvenators

Imagine a world that increased RAP usage to 25%. This would create*:

2.4
billion kg
GHG reduction

22.4
billion
MJ energy reduction

>2.6
billion
cost reduction

80
Million
MT landfill reduction

* Industry estimation based on NAPA literature

Defining Rejuvenation:

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

Definitions:
Rejuvenators, An Engineered Solution

“Rejuvenation” is an inaccurate, but popular term.

Rejuvenators do not undo oxidative aging!

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

A good rejuvenator is an oil additive that reverses the impact of aging:

- Restores cracking resistance, maintains rutting performance
- Improves workability, compaction, and appearance
- Improves aging susceptibility of the pavement
- Provides predictable and reliable results

How are Rejuvenators and Warm Mix Additives Used?

Typically, **0.3-3% wt. of the binder or 0.015-0.15% wt. of the mix**, added via:

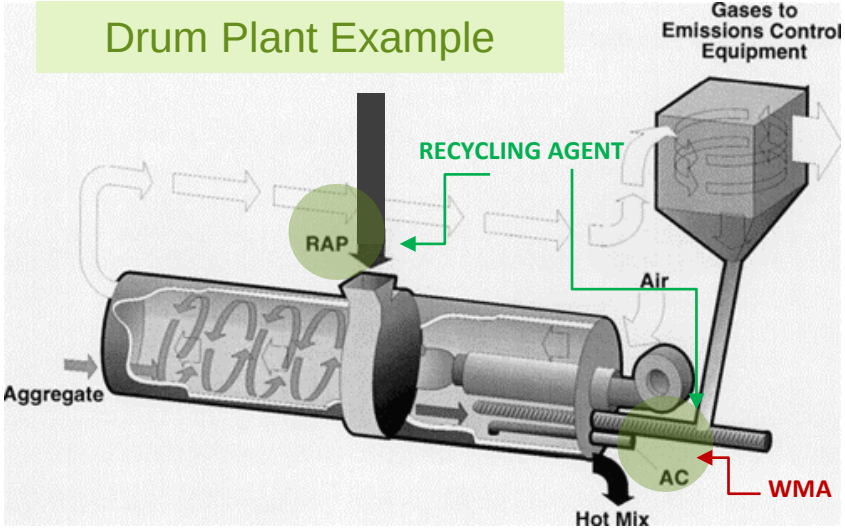
For both RA and WMA:

- In-line into virgin binder using additive pump
- Pre-blended into virgin binder (mostly for WMA)

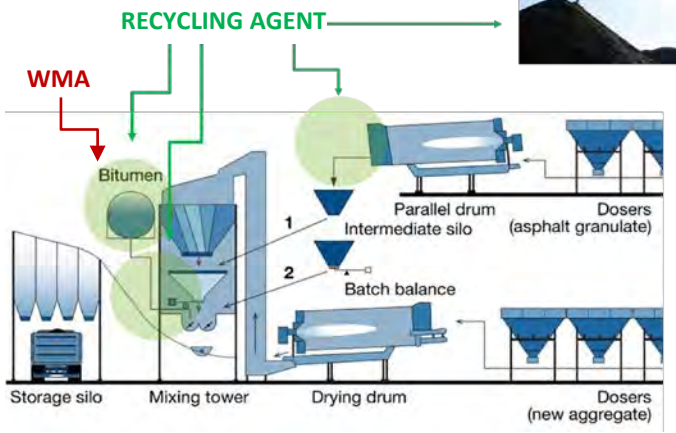
Only for RA:

- Treatment of RAP (at collar or during processing)
- Injection into pugmill or mixing drum

Drum Plant Example

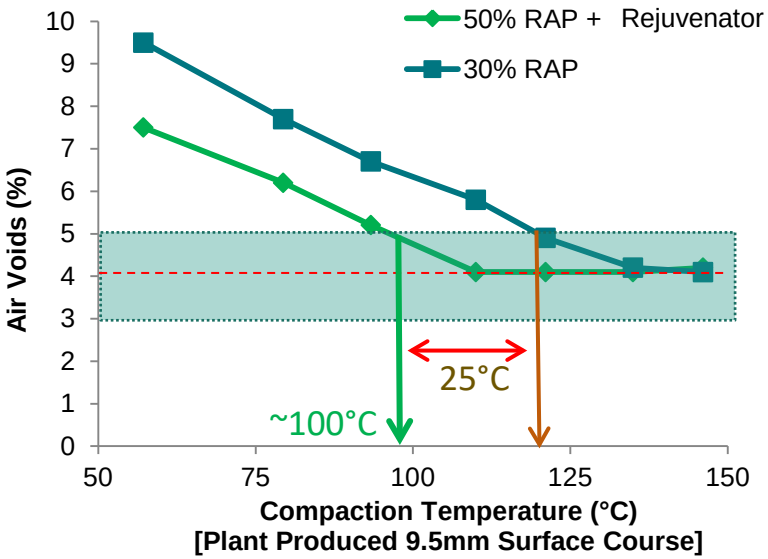


Batch Plant Example



Rejuvenators: Improved Compaction and workability

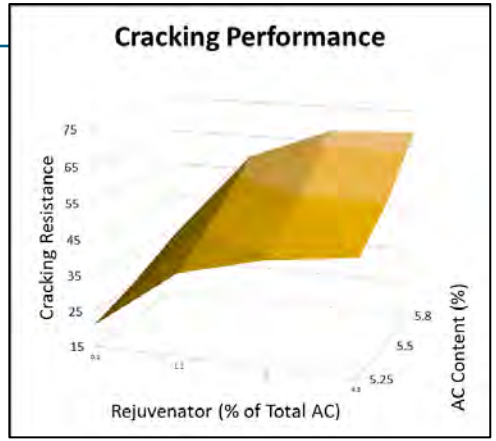
- Rejuvenation significantly improved the Compactability, even after a 20% increase in RAP content.
  - A large improvement in compaction temperatures achieved
  - No over-compaction at hot mix temperatures.

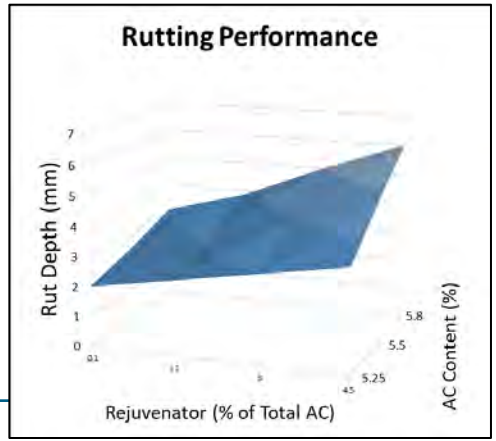


Rejuvenators Impact

- Recycling agents have been used to modify performance attributes in a mix.

Mix Parameter	Expected RA Impact
Cracking Resistance	Improve
High Temperature Stiffness	Decrease
Moisture Resistance	Typically, None





Recycling Agent Categorization - ASTM D4552-20

Assesses basic safety, thermal stability, storage stability, and compatibility property for use in asphalt plants.

Most Bio-oils Most Petro. oils

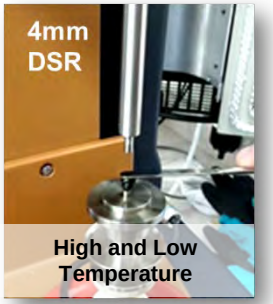
Test	ASTM Test Method	RA 0		RA 1		RA 5		RA 25		RA 75		RA 250		RA 500	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity • 60 °C [140 °F], mm^2/s	D2170	10	49	50	175	176	900	901	4500	4501	12500	12501	37500	37501	60000
Flash Point, COC, °C [°F]	D92	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...
Saturates, wt. %[A]	D2007	...	30	...	30	...	30	...	30	...	30	...	30	...	30
Tests on Residue from RTFO 163 °C [325 °F]	D2872														
Viscosity Ratio[B]	"	...	3	...	3	...	3	...	3	...	3	...	3	...	3
Wt Change, ±, %	"	...	4	...	4	...	4	...	3	...	3	...	3	...	3
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

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

Initial RA Dosage Determination

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

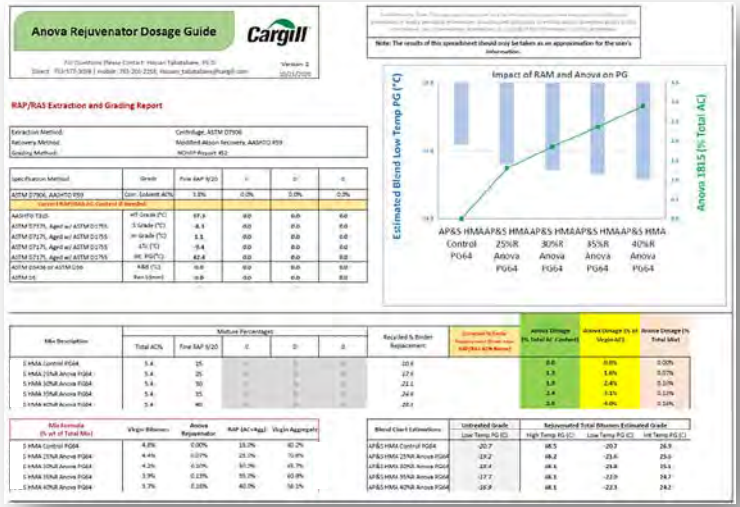
Extraction & Recovery



Low Temperature
Cracking Resistance

Grading and Analysis

Dosage Determination Report for Target Mix Designs



Field Evaluation Projects

NCAT: Warm Climate

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

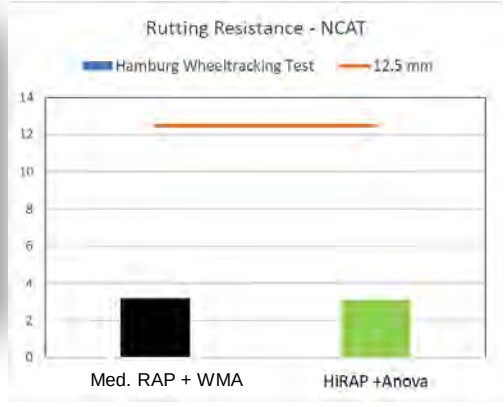
MNROAD: Cold Climate

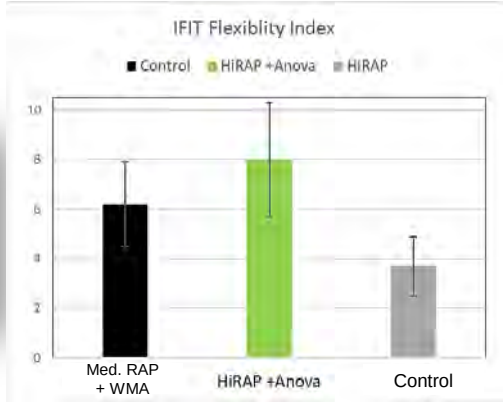
- 25% RAP (20% ABR); PG58-28 Binder
- 45% RAP (31% ABR); PG5828 Binder + Cargill Anova® Rejuvenator
- Aggregates and RAP were supplied locally in Minnesota for the project

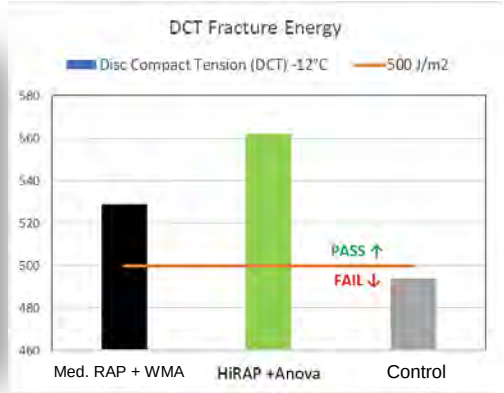
Type	Name	Description
Chemical Warm Mix	**Cargill Anova® 1501/1503**	A bio-based non-hazardous liquid warm mix additive, design for impact at low dosage without changing the bitumen grade
Recycling Agent	**Cargill Anova® 1815/1817**	An engineered bio-based oil, based chemical modification of vegetable oil for bitumen compatibility and oxidative stability

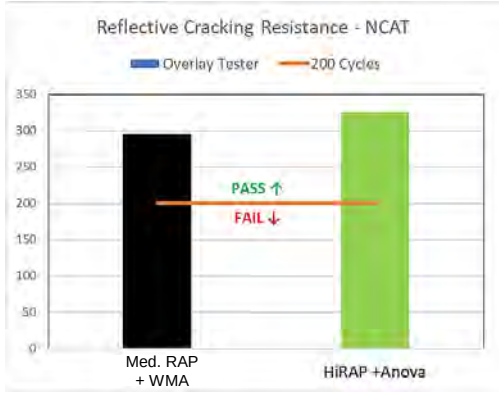
NCAT High RAP and WMA Project

- 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.

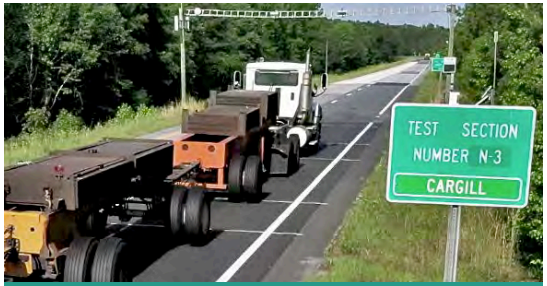








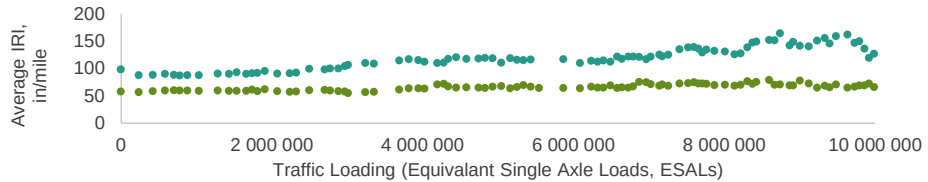
NCAT Proven performance. With Cargill Anova® Rejuvenator and Cargill Anova® Warm Mix Additive



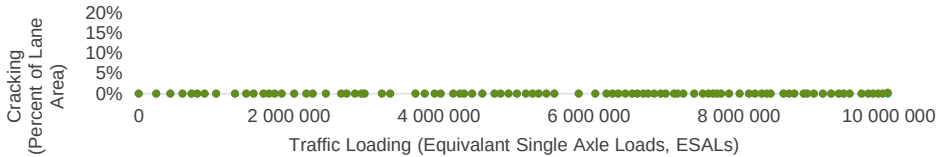
To demonstrate performance Cargill built a test section on the NCAT track using the typical 30% RAP mix with Cargill Anova® WMA, and 45% RAP with Cargill Anova® Rejuvenator.

After 17 million loadings, zero cracks appeared in the test section

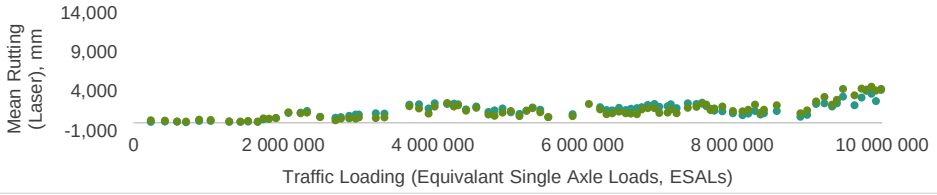
Maintaining Smooth Ride



0 Cracking



No Rutting

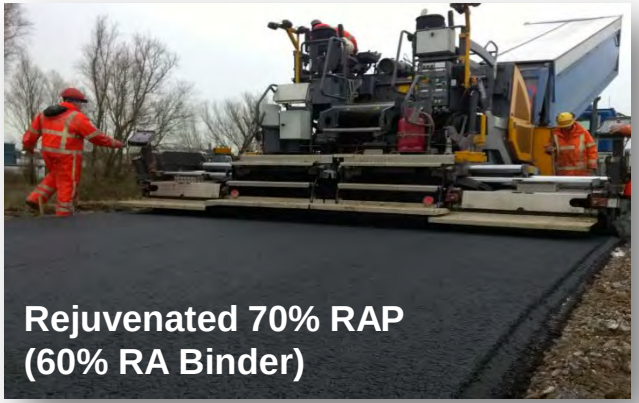


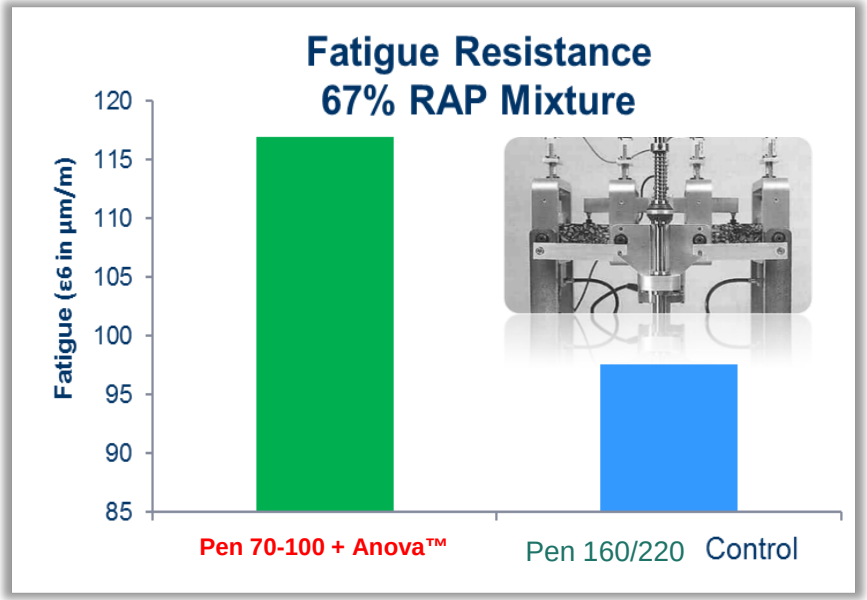
● 30% RAP + WMA ● 45% RAP + RA

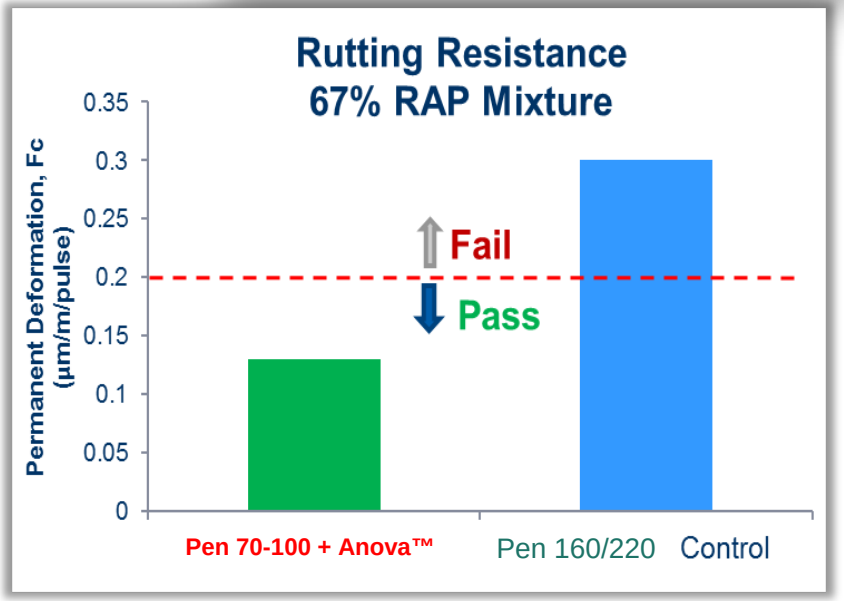
* Data provided and measured by NCAT using plant produced mix.

Example: Netherlands
70% RAP Asphalt Mix

- Beam fatigue test showed that the **rejuvenator** significantly improved the fatigue resistance.
  - The **rejuvenated mix easily** passed the rutting requirement
  - The mix using soft bitumen failed the rutting test.







Amsterdam Airport (Schiphol)
60%RAP Runway Pavement

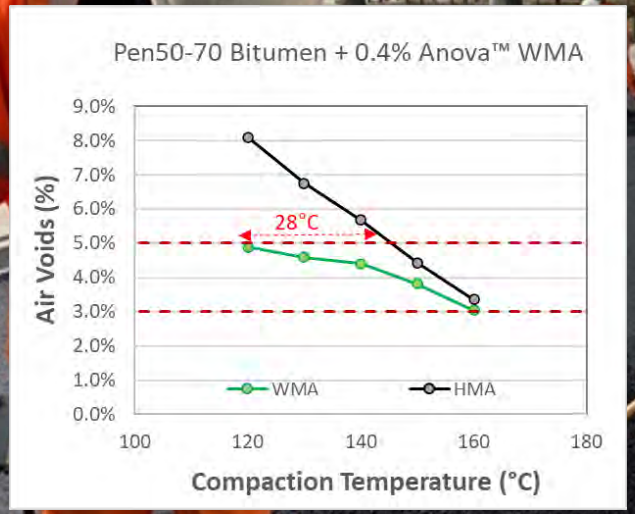
- Increased RAP from 0% to 60% using PmB and Anova™ rejuvenator.
- Design process consisted of cracking and rutting performance tests.
- Paved 225,000 m^2 using 300,000 tons.

Heijmans paving the Polderbaan with Cargill's Anova® Rejuvenator. © 2021 Heijmans

The products used needed to perform: the Polderbaan needed to be repaved with as little impact as possible on Schiphol's daily operations. © 2021 Heijmans

Overview of the paving project at the Polderbaan, with Cargill's Anova® Rejuvenator. © 2021 Heijmans

Bitumen Properties	Pen50/70 Original	Pen50/70 + 0.4%Anova
Softening Point (R&B), °C	52°C	52.5°C
Penetration at 25°C, dmm	66 dmm	66 dmm
Brookfield Viscosity at 135°C	318 cP	325 cP
Brookfield Viscosity at 150°C	149 cP	150 cP
Brookfield Viscosity at 177°C	56 cP	62 cP
Ductility, cm	> 120 cm	> 120 cm



Sustainability: Warm Mix Additive

Lower costs and a safer; work environment.

Reliably achieve density and improve workability at lower temperatures, reducing emissions and odor.

- Increased usage due to **ease of implementation** and **lack of impact on standard bitumen grade**.
- Functions by modification of the bitumen **internal friction.**
- Improve bitumen ability to coat the aggregates, often also making such additive "**adhesion promotors**"

Summary and Final Remarks

- Chemical Warm Mix additives and Rejuvenating Recycling Agents are great options to improve sustainability, economy, and performance of asphalt mix.

- Significant real-world experience exists for use and implementation of both types of technologies over the past decade.
  - Cargill is a leader in development and implementation of such sustainable additives, used in millions of tons asphalt mix every year.

- 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: Modified or Balanced Mix Design process and performance check, led by producers
  - Step 4: Robust quality management practices by all parties

Questions? Let us know!

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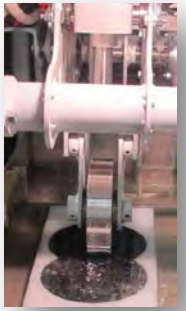
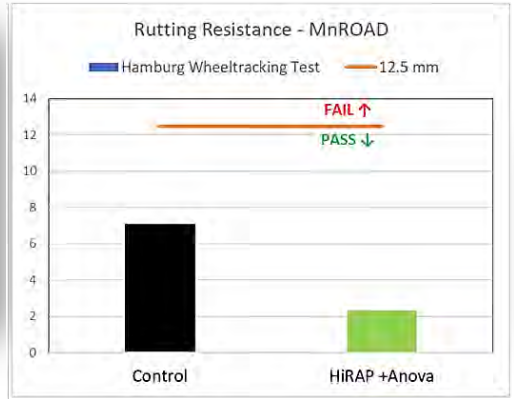
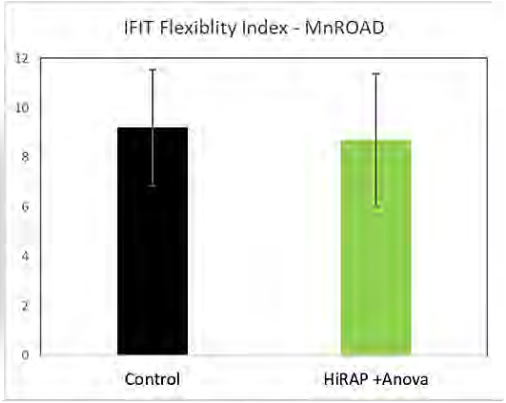
MNROAD High RAP Rejuvenated Project

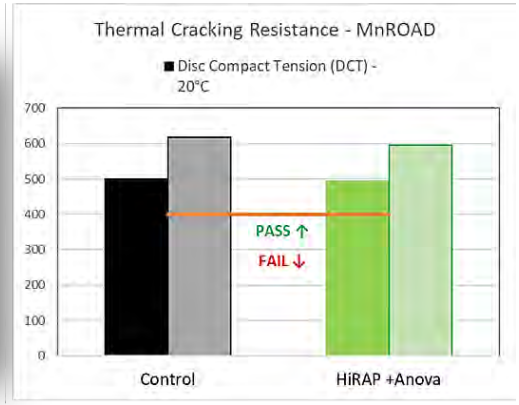
Designs were done using BMD system under consideration by MNDOT at the time (DCT vs. Hamburg)

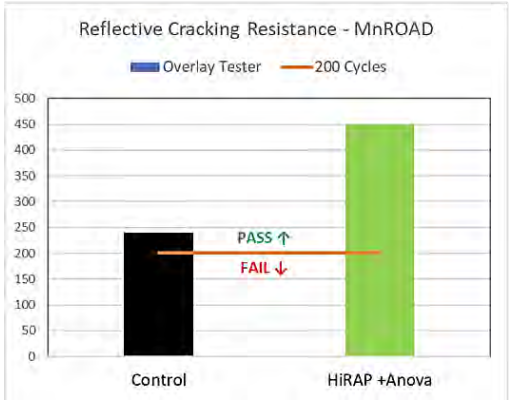
Rejuvenation of the high RAP mix achieved comparable passing performance compared to the Low RAP control mix.











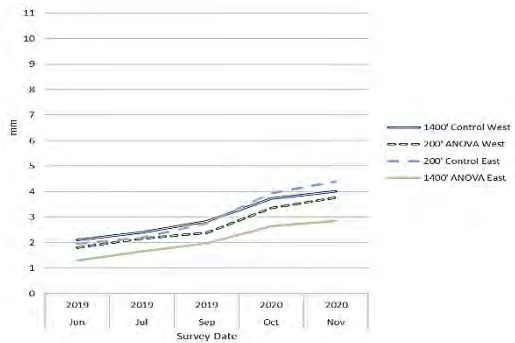
MNROAD Proven performance. With Cargill Anova® Rejuvenator.

To demonstrate performance against the typical 25% RAP mix, Cargill built a test section on the MNROAD track using 45% RAP and Cargill Anova® Rejuvenator.

After 2.5 million loadings, fully meeting performance expectations

- About 800,000 ESALs of loading per year since 2018.
- No cracking beyond expected reflective cracking from base course observed, equivalent to control.
- Sections showing good rutting performance. Cargill Anova sections have slightly lower permanent deformation.
- Smoothness has remained consistent since construction. This especially clear on the sufficiently long sections.

No Rutting



Maintaining Smooth Ride

Step 4: Quality Management (All Parties)

Well-established process for Commercial Mixes

Supplier:

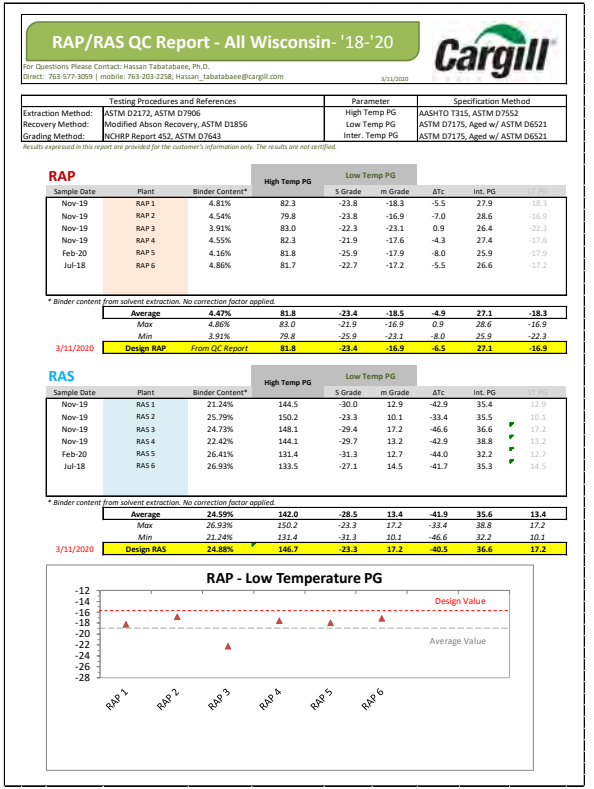
- Product delivered with verifiable Certificate of Analysis
- Support producer with periodic material sampling and verification throughout season.

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
- 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

Implementation: High RAP-Rejuvenated Design