Enabling more sustainable pavements using recycled plastic and Reactive Elastomeric Terpolymers (RET)

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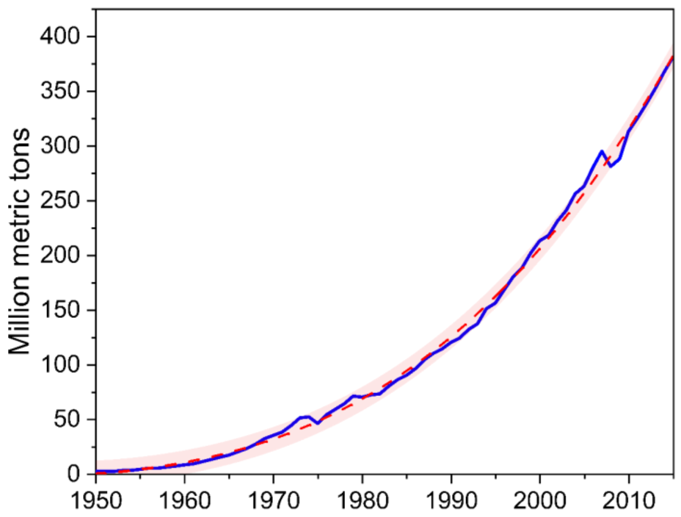
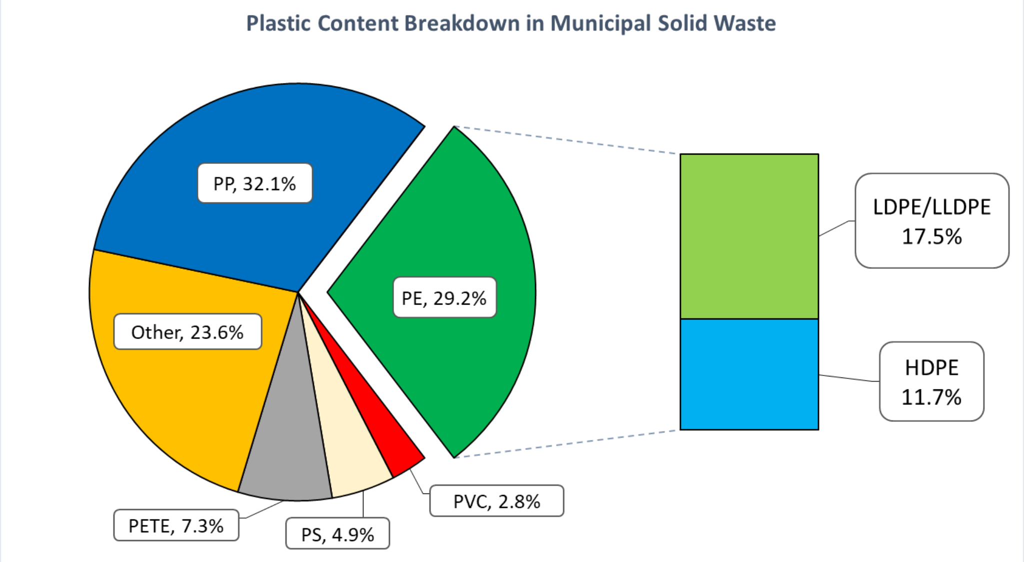
DOES RECYCLED PLASTIC MAKE ECONOMIC AND ECOLOGICAL SENSE FOR PAVING?

- **Recycled plastics have a broad range of polymer chemistries**
  - Critical these materials meet defined selection criteria
  - Compatibility with asphalt varies
  - Not all types of recycled plastic are suitable as asphalt modifiers
- **Recycled plastic must improve the road performance**
  - Not a virgin vs recycled material dynamic – most polymers in packaging applications are plastomeric
  - Elastomeric polymers (SBS, RET) bridge performance gaps for unmodified asphalts
  - Must meet performance specifications – i.e., engineering standards
  - Must follow existing construction best-practices – i.e., “drop-in”
  - Must not have a negative impact on asphalt re-recyclability
- **Multiple ways to participate in via mechanical recycling**
  - Target hard to recycle plastics like PE-rich film – largest potential impact
  - Multiple ways to introduce material – wet vs dry dynamic

Annual Global Plastics Production





Advancing Sustainable Materials Management: Facts and Figures Report, EPA (2017)

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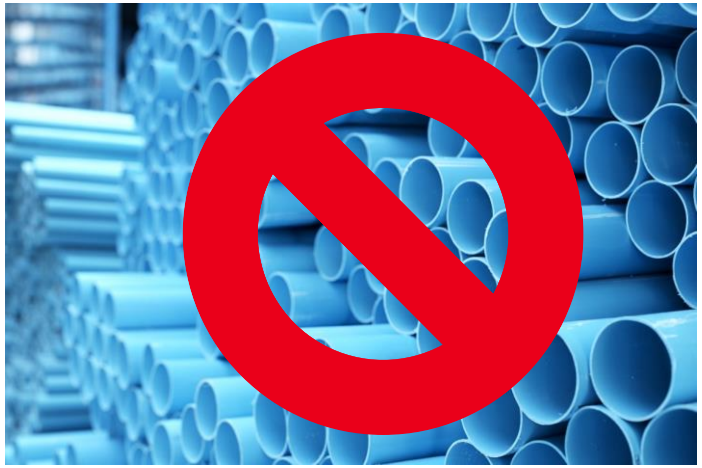
MAJOR CLASSES OF PLASTICS

Not every plastic as appropriate as an asphalt modifier!



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How do we address knowledge gaps captured by AI and NAPA?

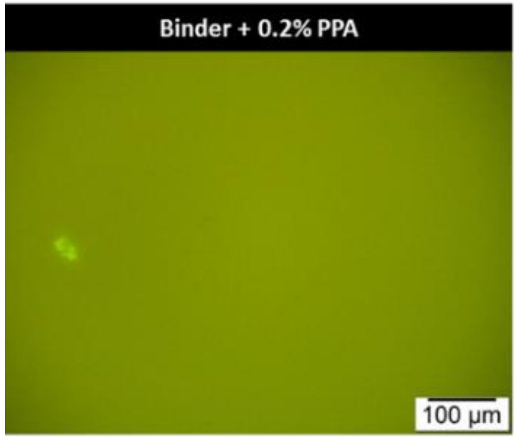
- **Understand the material being used**
  - Choose clean, sorted PE-rich sources (i.e., multilayer food packaging >70% PE)
- **Address incompatibility of recycled plastic and asphalt binder**
  - Wet process - appropriate balancing of compatibilizer vs recycled plastic enhances storage stability
  - Dry process – use of a compatibilizer allows for full incorporation of PE-rich sources and reduces the need for other additives
- **Validate performance - rutting and fatigue/cracking resistance**
  - Binder - meet AASHTO M320 including Plus Specifications
  - Mix - meet Balanced Mix Design criteria including index-based cracking tests
- **Prove compatibility between recycled plastics and other additives used in asphalt binders including RAP**
  - Successful incorporation up to 30% RAP (at this point) without rejuvenators
- **Demonstrate field performance to highlight no changes to current construction practice is required**
  - Numerous field projects dating to early 2019 – no early signs of distress observed
  - Reduced nuisance odors during construction – lower sulfur emissions
- *Generate long-term pavement performance data vs traditional materials*

VISUALIZING RECYCLED PLASTIC INCOMPATIBILITY

PE-only modified asphalt shows phase separation

RET significantly reduces PE domain sizes demonstrating compatibilization

Low Magnification Epifluorescence Microscopy



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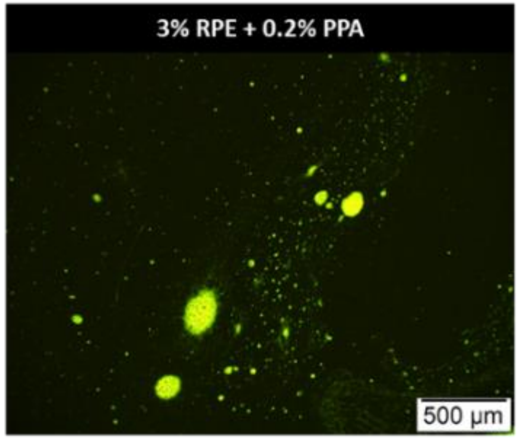

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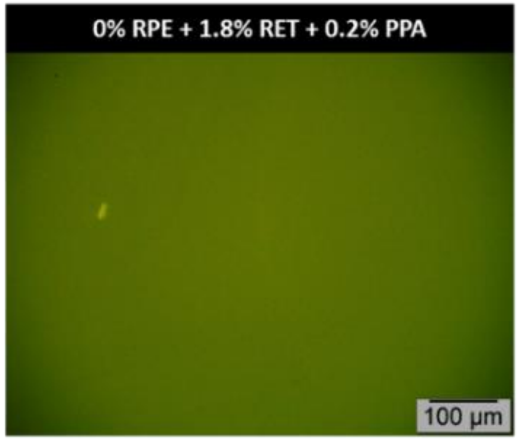

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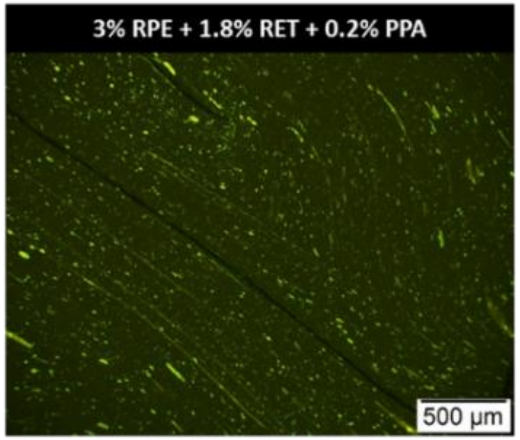

Domains smaller than RPE control

MULTIPLE DEMONSTRATION PROJECTS WITH MORE PLANNED

Location	Binder Specification	Type	Size	Waste Plastic Diverted	Additional comments
Freeport, TX	TXDOT PG70-22	Wet	~ 2,600 ft^2	1,700 lbs ~129k single-use grocery bag eq.	Two roads at Dow Texas Operations Martin Asphalt, American Materials, and Vernor
Midland County, MI	MDOT PG64-28	Wet	136,390 ft^2	10,400 lbs ~787k single-use grocery bag eq.	Four county roads, two parking lots at Dow Headquarters Winpak, Central Asphalt and K-Tech Specialty Coatings
Saginaw Valley State University, University Center, MI	MDOT PG64-28	Wet	60,000 ft^2	1600 lbs ~121k single-use grocery bag eq.	Large event parking lot Winpak, Central Asphalt and K-Tech Specialty Coatings
Orange, TX	TXDOT PG76-22	Wet	3,480 yd^2	1,830 lbs ~138k single-use grocery bag eq.	Two roads at Dow Sabine River Operations; Martin Asphalt and Gulf Coast
Holland, MI	MDOT PG64-28	Wet	151,039.17 yd^2	12,500 lbs ~946k single-use grocery bag eq.	Meijer grocery chain parking lot and gas station PADNOS, K-Tech Specialty Coatings, and Reith-Riley
University of Missouri, Columbia, MO	MODOT PG64-28	Dry	Three 0.5-mile test sections	24,000 lbs ~1,816k single-use grocery bag eq.	Three field test sections using different PCR levels University of Missouri and MODOT.
National Center for Asphalt Technology, Auburn, AL	PG76-22	Wet	200 ft test section	1000 lbs ~76k single-use grocery bag eq.	Additive Group study – part 1 FHWA, ALDOT, FDOT, MDOT, TDOT, TXDOT funded
Solterra, Buckeye, AZ	AZ DOT PG64-28	Dry		~2000 lbs ~152k single-use grocery bag eq.	Loading zone at HMA plant Ecologic Materials, Western Emulsions, Solterra Materials, and Sunland
MnROAD, Minnesota	MNDOT PG58H-28	Wet	400 ft test section	~500 lbs ~38k single-use grocery bag eq.	Additive Group study - part 2 FHWA, ALDOT, FDOT, MDOT, TDOT, TXDOT, DOW funded
Stockyard Rd, Pueblo CO	CODOT PG64-28	Dry	~0.25-mile test section	4000 lbs ~304k single-use grocery bag eq.	Test section to ensure mix, equipment and supply chain readiness Ecologic Materials, County of Pueblo, Owens Corning, Beltramo and Sons
Siloam Rd, Pueblo CO	CODOT PG64-28	Dry	3.5 lane-miles	27,000 lbs ~2,045k single-use grocery bag eq.	Two-lane county road with medium/heavy agricultural traffic Ecologic Materials, County of Pueblo, Owens Corning, Beltramo and Sons

Total **>94k lbs or ~7.2MM single-use grocery bag eq.**

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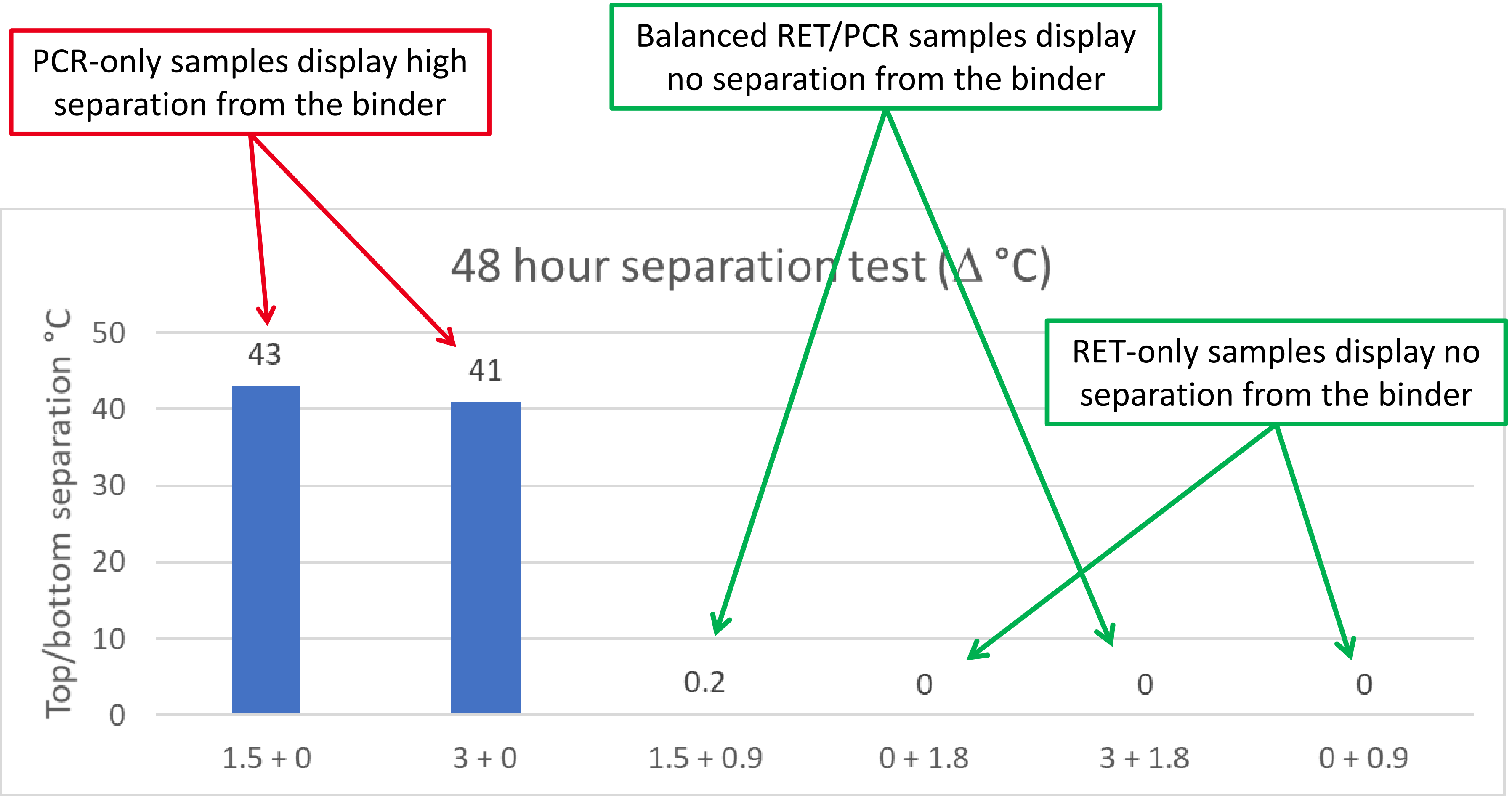
CASE 1 – RET + PCR BLENDS PASS SEPARATION TEST

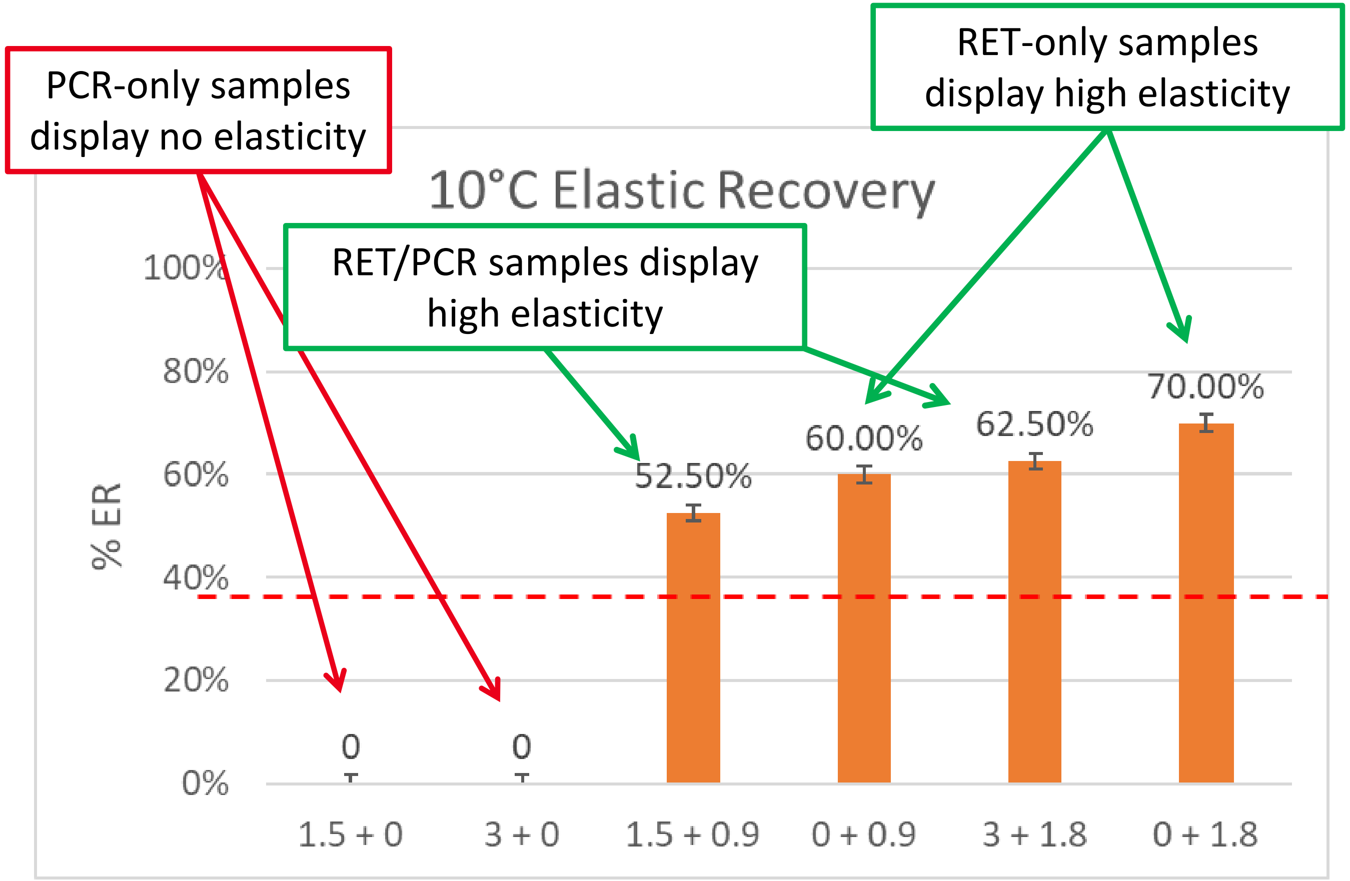
- ASTM D5976 – 48-hour separation test
- High values indicate polymer incompatibility, i.e. separation from the binder

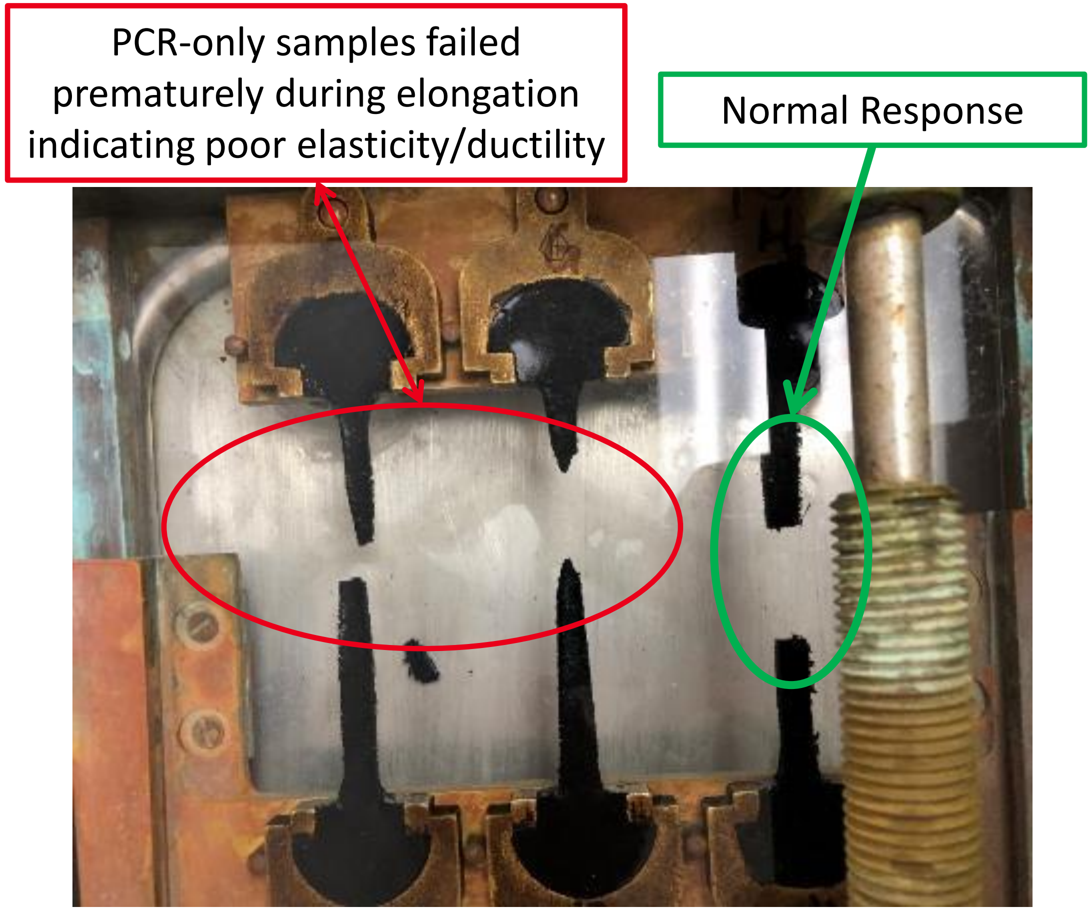


*Numbers in x-axis denote weight %; first PCR/second RET

CASE 1 - RET + PCR BLENDS EXHIBIT HIGH ELASTICITY

- Texas 539-C 10°C elastic recovery
- All RET/PCR blends exceed minimum PG 70-22 specification (30+%) and some blends meet PG82-22 (60+%)





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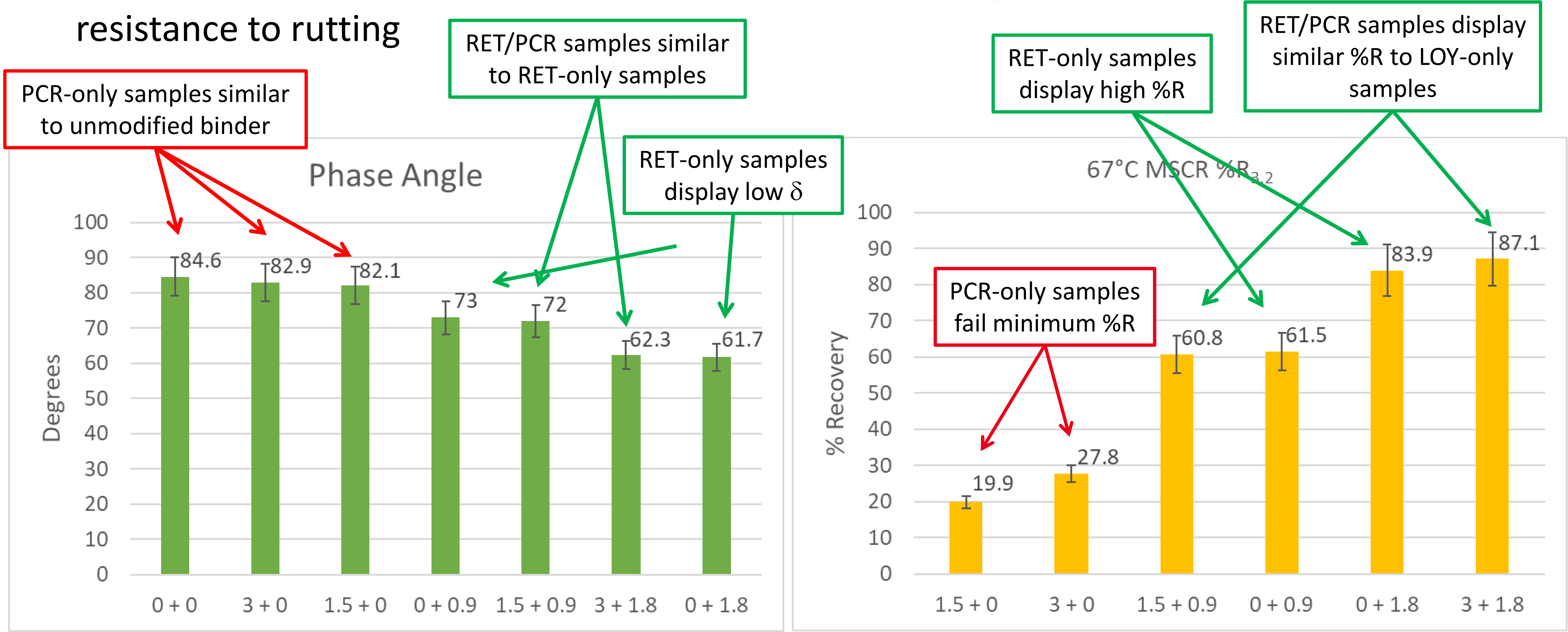
CASE 1 - RET + PCR BLENDS BLENDS SHOW INCREASED RUTTING RESISTANCE

Reduced Phase Angle indicates more elastic behavior; High % Recovery indicates increased resistance to rutting



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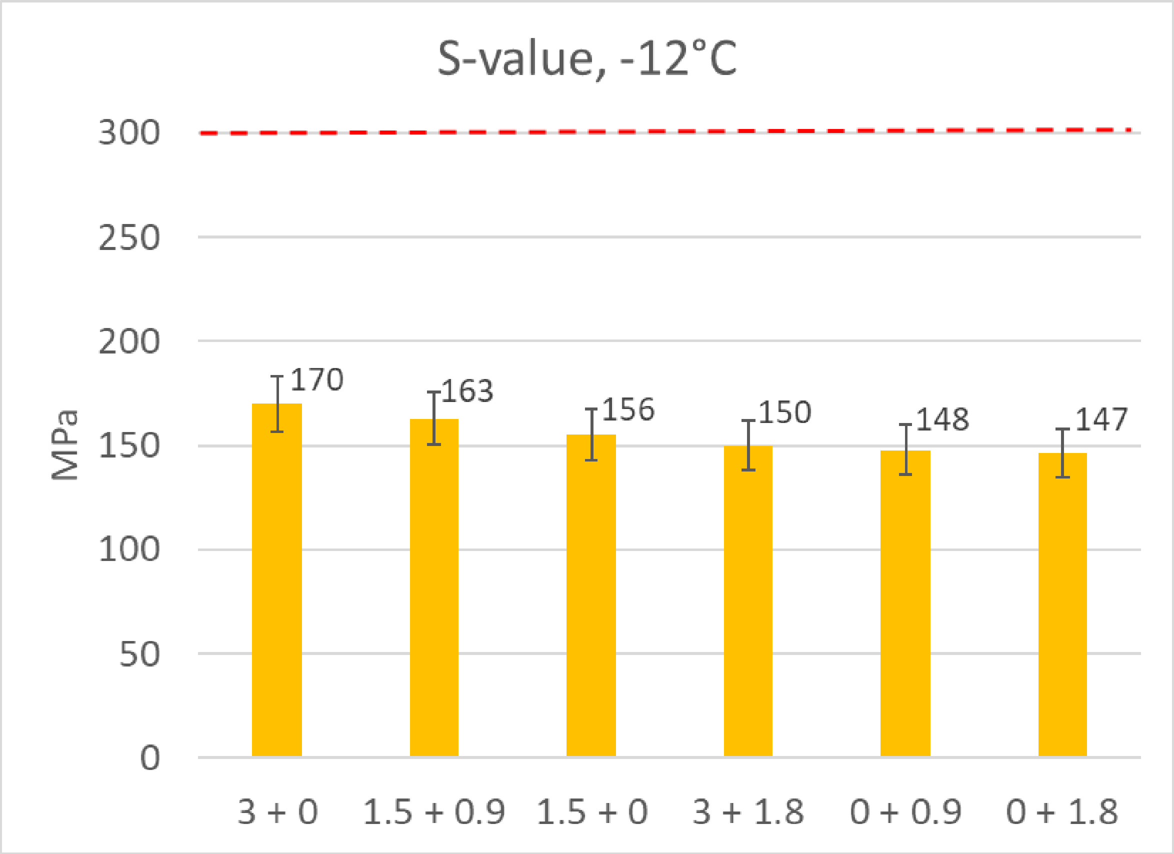
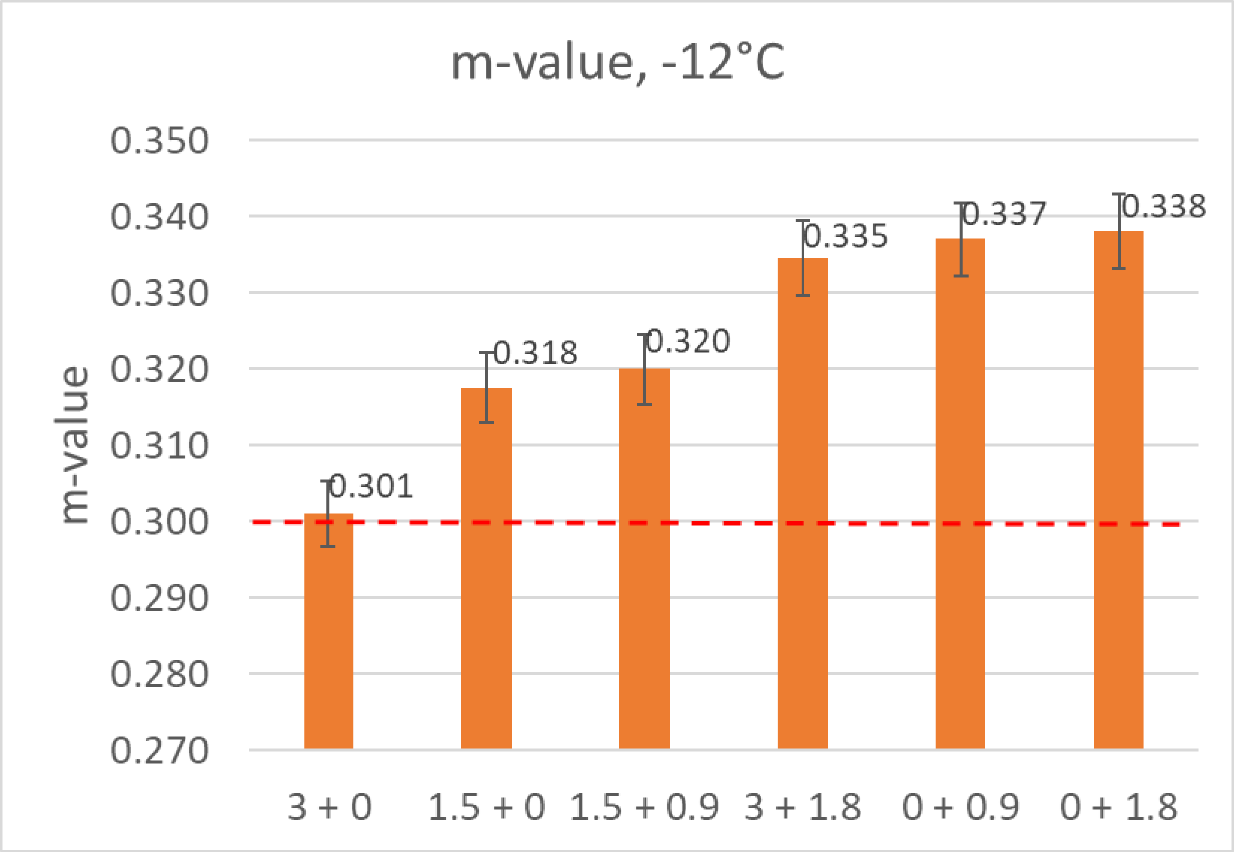
CASE 1 - RET + PCR BLENDS MEET LOW TEMPERATURE PERFORMANCE

Values below 300 MPa indicate resistance to thermal cracking



Values above 0.300 indicate resistance to thermal cracking



*Numbers in x-axis denote weight %; first PCR/second RET

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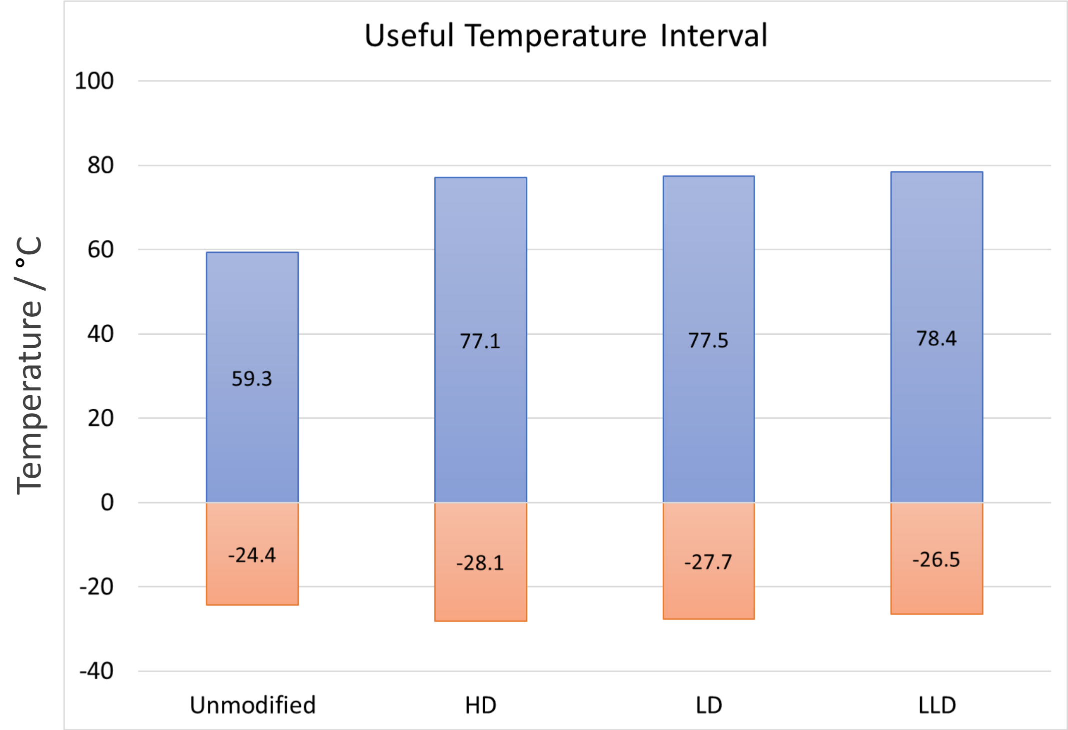
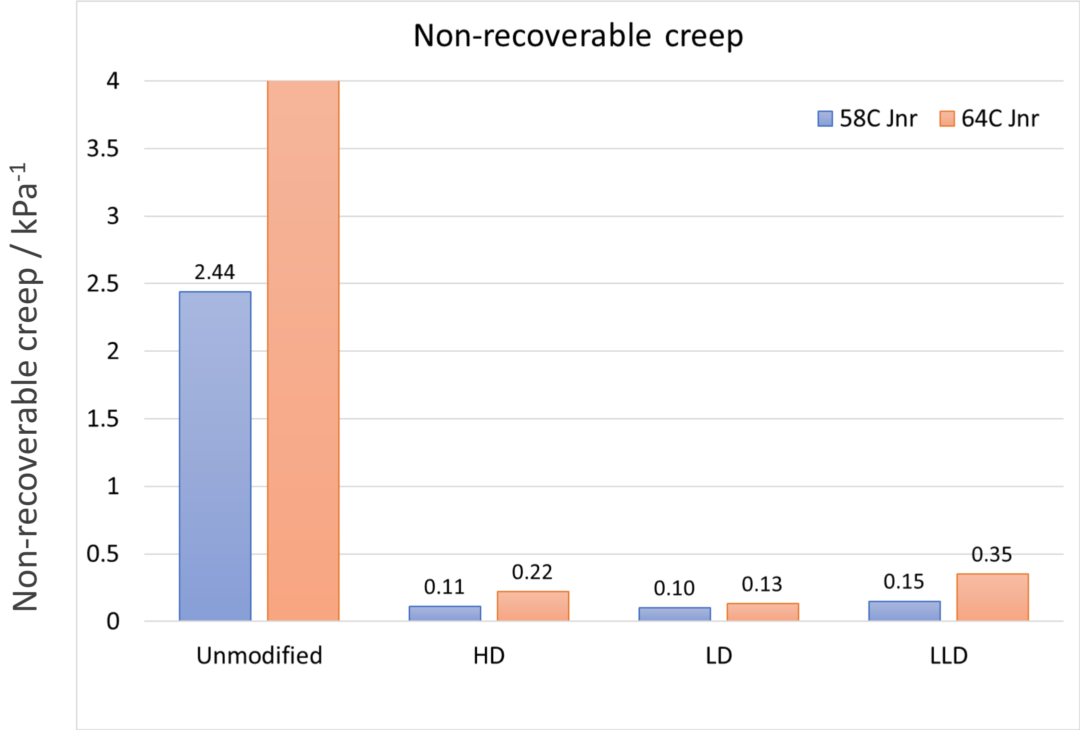
CASE 1 - MINIMAL EFFECT ACROSS ALL PE-RICH PCR DENSITIES

- No effect of density observed for high temperature performance
- All polymer modified formulations demonstrated improvement of low temperature properties



- No observable effect of density for non-recoverable creep studies



Wet process - 1.5 wt% PCR + 1.5 wt % RET

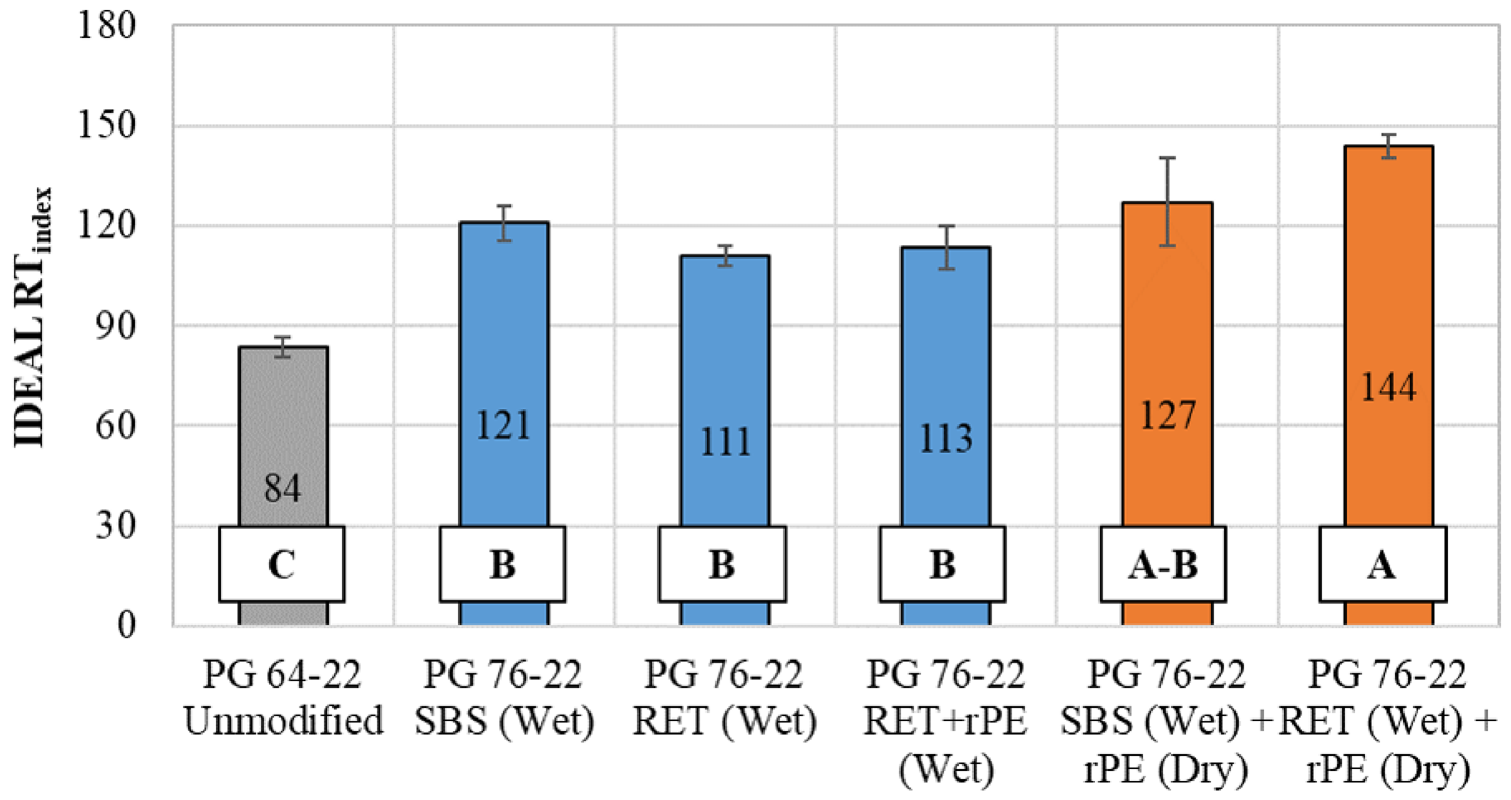
CASE 2 – NCAT ADDITIVE GROUP STUDY

- "WET" hybrid formulation:
  - 1.0% Avangard Natura PCR LLDPE
  - 1.6% ELVALOY™ RET
  - 0.32% PPA as co-reactant
- Experimental design
  - Unmodified control binder – Ergon PG67-22
  - PMA control binder – Ergon PG76-22 SBS
  - SBS and RET+PCR had comparable MSCR Jnr and %R
  - No cigar tube separation observed with R&B, upper PG, and MSCR measurements
- Mix Design
  - 12.5 mm NMAS, 20% RAP
  - BMD with HWTT and IDEAL-CT
    - ✓ < 12.5 mm rutting at 20k passes
    - ✓ > 50 CT_{index}

Measurement	PG 67-22 Unmodified	PG 76-22 SBS Modified	LLDPE and ELVALOY™ RET Modified
PG Grade	67-22	76-22	76-22
True Grade	68.7-23.4	78.1-23.4	81.8-24.0
Low-temp. Grade (stiffness)	-25.7	-25.5	-25.3
Low-temp. Grade (m-value)	-23.4	-23.4	-24.0
PAV Delta Tc	-2.4	-2.1	-1.4
% Recovery, 3.2 kPa	1.43	69.19	68.77
J_{nr} 3.2 kPa (kPa^{-1})	2.02	0.20	0.16
Viscosity, 135°C (Pa s)	0.51	1.45	2.23

CASE 2 – NCAT ADDITIVE GROUP STUDY

- Improved rutting resistance due to polymer modification and adding dry rPE
- Hybrid-process PMA (more PCR) > wet-process PMA > unmodified



IDEAL-RT

Note: SBS dosage ~2x RET dosage

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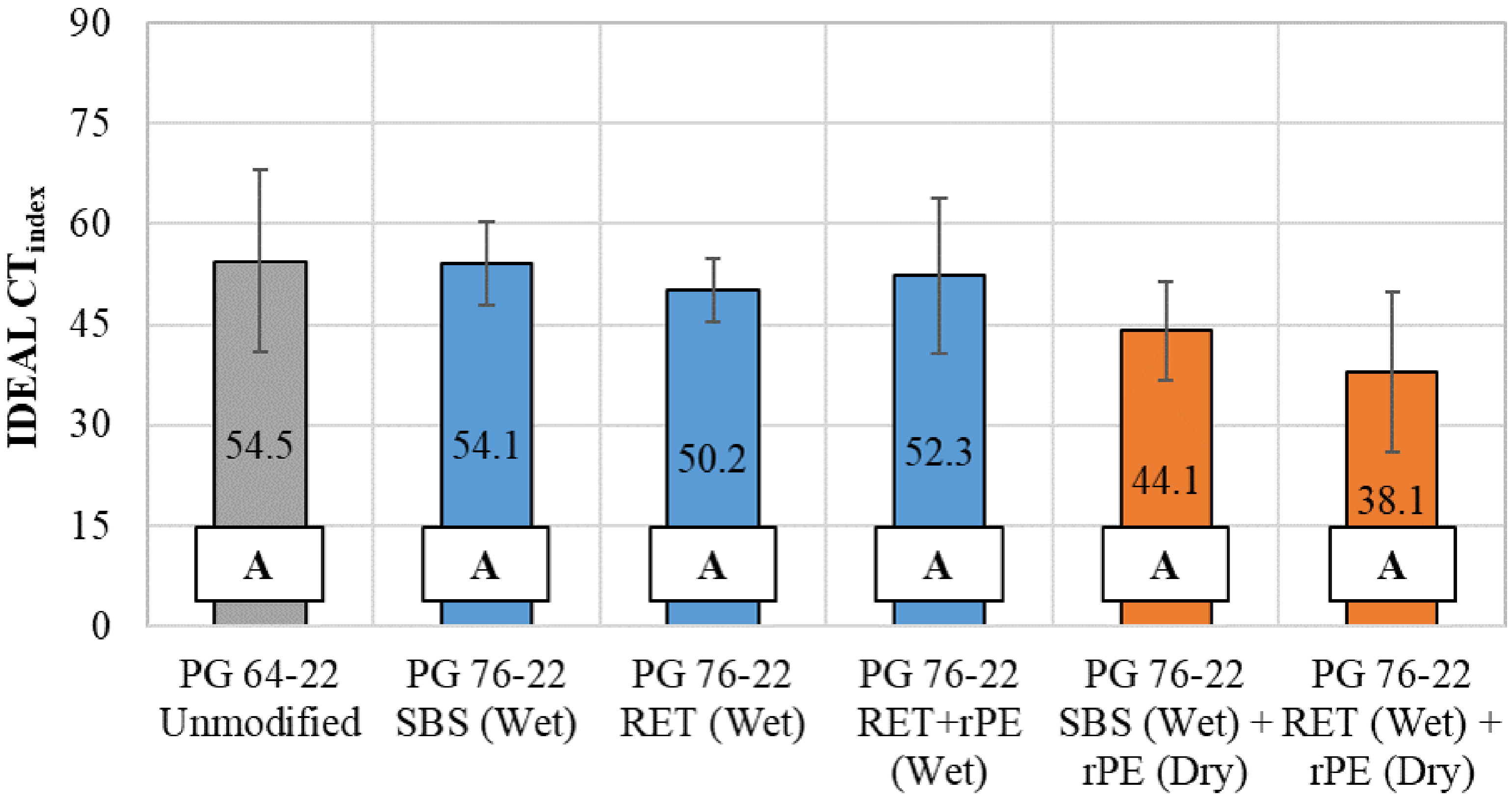
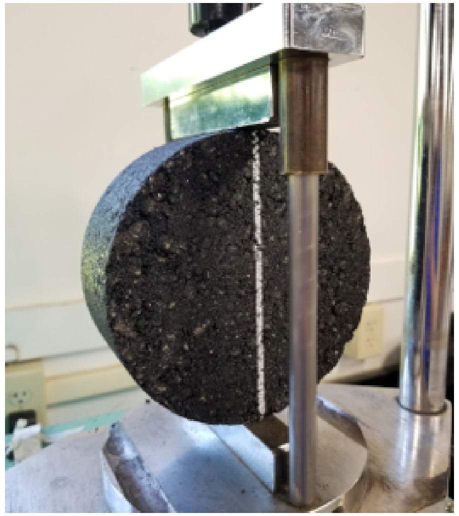
CASE 2 – NCAT ADDITIVE GROUP STUDY

- No statistical discrimination between unmodified and PMA mixtures
- No impact on intermediate-temperature cracking resistance from polymer modification and adding dry rPE



IDEAL-CT

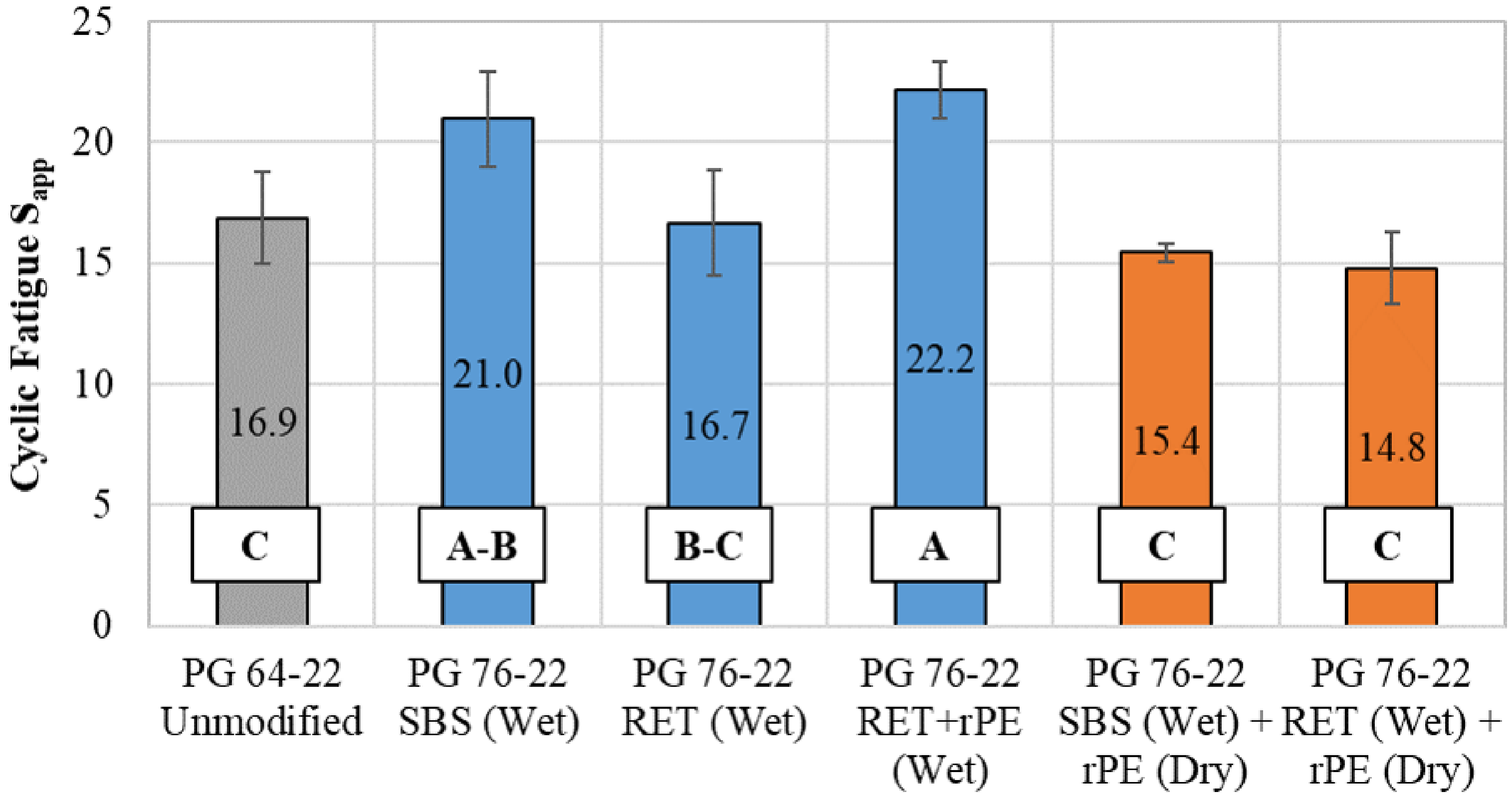


Note: SBS dosage ~2x RET dosage

Yin et al. Performance Characterization and Fatigue Damage Prediction of Asphalt Mixtures Containing Polymer Modified Binders and Recycled Plastics, 2022 AAPT Annual Meeting

CASE 2 – NCAT ADDITIVE GROUP STUDY

- Improved fatigue resistance from polymer modification
- Wet-process RET + rPE > SBS > RET > unmodified ≈ hybrid-process PMA
- Reduction in cyclic fatigue resistance with dry process



Cyclic Fatigue

Note: SBS dosage ~2x RET dosage

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Yin et al. Performance Characterization and Fatigue Damage Prediction of Asphalt Mixtures Containing Polymer Modified Binders and Recycled Plastics, 2022 AAPT Annual Meeting

CASE 2 – NCAT ADDITIVE GROUP STUDY

Construction August 2021

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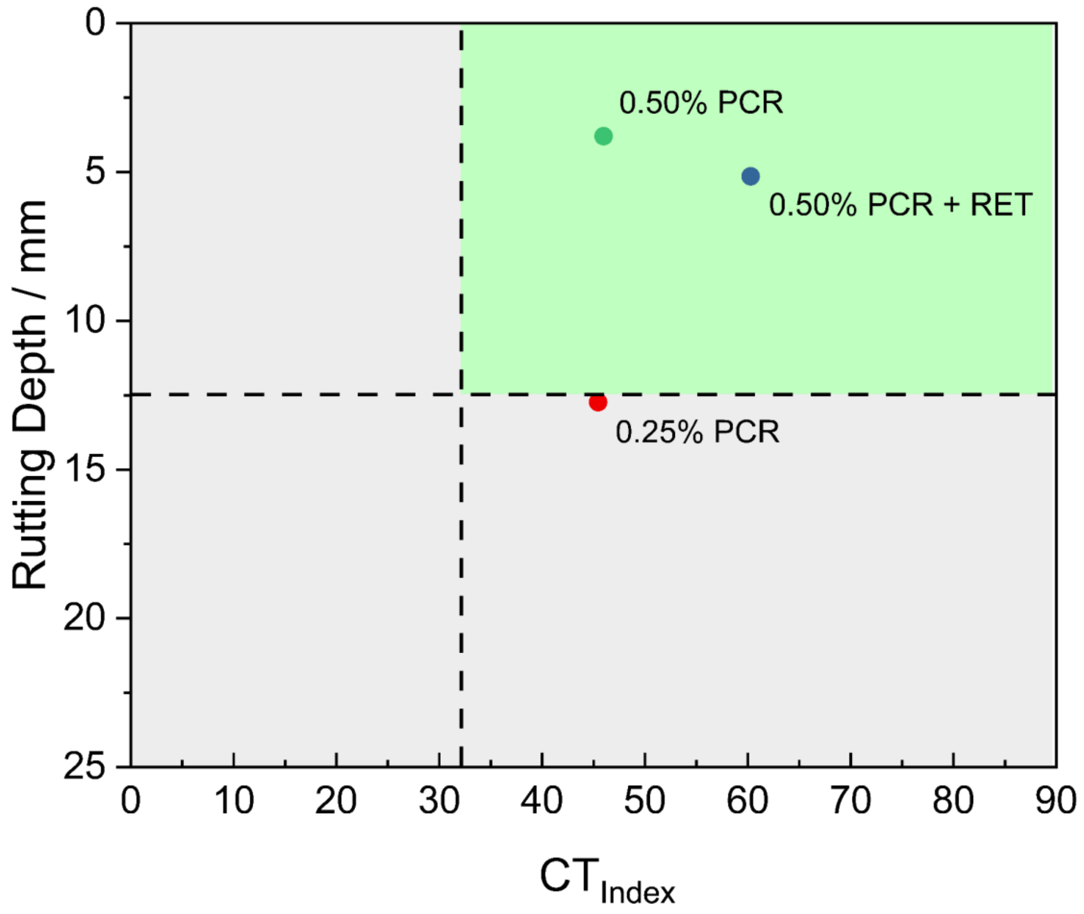
CASE 3 – UNIVERSITY OF MISSOURI STUDY

- Balanced Mix Design targets:
  - CT_{INDEX} >= 32
  - HWTT RUT DEPTH @ 20,000 PASSES <= 12.5 mm
- Five iterations to reach to a final balanced mix design
- Contains 30% RAP + 30% SLAG
- All CT values were above threshold
- Best performer involved hybrid process
  - Wet PG64-28 RET (1.0%)
  - 0.5 wt % dry PCR vs mix
  - 3% Evoflex CA-4 rejuvenator vs binder
    - ✓ RET compatibilization enabled remova



CASE 3 – UNIVERSITY OF MISSOURI STUDY

Construction August 2021

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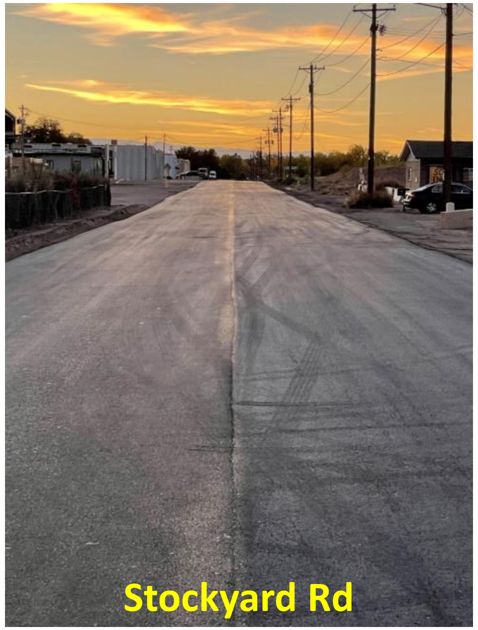
CASE 4 – STOCKYARD, AND SILOAM ROADS PUEBLO CO

Construction November 2022

- Dry process
- Binder target: CDOT PG64-28
- Stockyard road
  - 400 mix ton test section (4,000 lbs rPE*)
- Siloam road
  - 1.75-mile section plus 0.25-mile control (27,000 lbs rPE)
- No significant mix or placement issues encountered
- Testing in-progress
- ~2.4 M grocery bags equivalent diverted from landfill



*rPE= recycled Polyethylene

HIGHLIGHTS

- RET enables RPE incorporation – mitigating separation when properly formulated
- There is no compromise on performance properties when RPE is appropriately dosed with RET-PMA including
  - Binder specifications
  - Balanced Mix Design
- The total amount of polymer (RET + RPE) positively impacts
  - Increases upper PG grade
  - Reduces Jnr including meeting V and E grades
- Field projects have shown these materials are “drop-ins” to existing best practice production and construction

THANK YOU