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Evaluating Storage Stability and Performance Characteristics of Recycled Composite Plastic Modified Asphalt Binders

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Publication

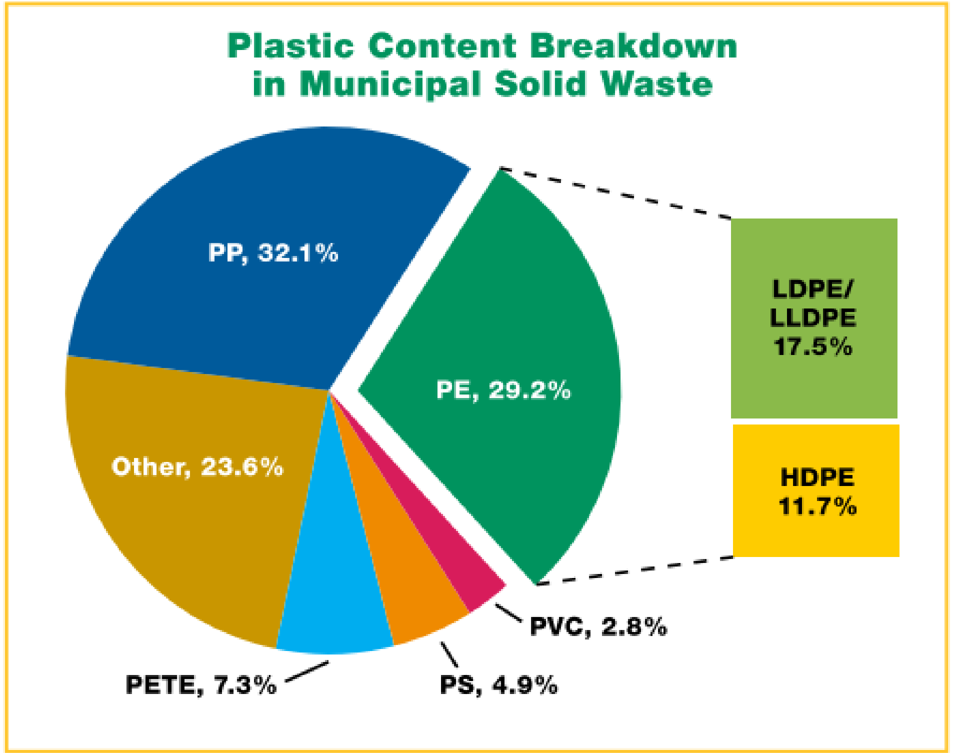
- “Evaluating Storage Stability and Performance Characteristics of Recycled Composite Plastic Modified Asphalt Binders”- **Accepted for presentation at TRB 2026 and recommended for TRR review.**
- “Evaluating the Rheological and Aging Characteristics of Plastic Modified Asphalt Binders Incorporating Reactive Elastomeric Terpolymer”- **Accepted for presentation at TRB 2026 and recommended for TRR review.**

Outline of this Presentation

- Background
- Problem statement/Objective
- Composite plastic modified asphalt binder
- Experimental methodology
- Phase separation and performance analysis
- Conclusions
- Next steps..

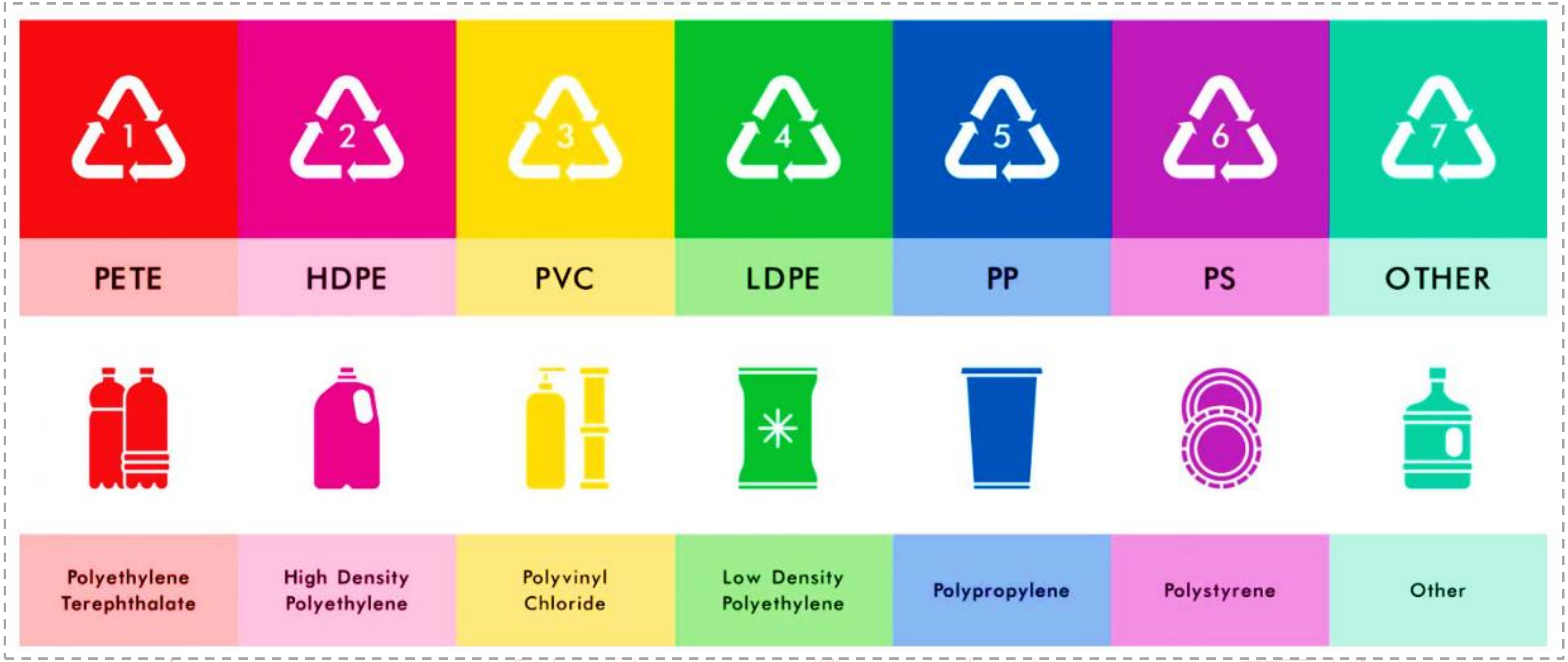
Background: Recycled Plastics

- Waste plastic accumulating to > 20 million tons per year with only 9% recycling rate
- About ***30%*** of recycled plastic comprises of ***PE and 33% PP***
- ***15%*** of ***Polystyrene, PVC and Polyethylene Terephthalate***



Source: Recycled plastics in asphalt PART A: State of knowledge, DuBois, C., 2020. Wet Processed Plastics in Asphalt. Transportation Research Board,. Washington, D.C, Presented on January 13, 2020

Different Types of Plastic



Source: Plastics Codes 1 to 7 – What Do They Mean? https://forte.bunzl.com.au/recycle-codes/

Plastic Recycling Chain

Waste plastic
20 MT - (100%)

Landfills:
14 MT - (~70%)

Plastic Manufacturer

STEP 1

Household/ Industrial waste

STEP 2 (30%)

Trash bags reaching plastic recycling plants.

STEP 3 (10-30%)

- Sorting the plastics based on size, type, color etc

Sorting levels vary from plant to plant

STEP 4

- Shredding / processing/ grinding

Recycled plastics to asphalt pavements

Recycled plastic/ Processed plastic
2 MT - (~10%)

Sources:

https://www.forconstructionpros.com/asphalt/news/21137929
https://www.plasticsrecycling.com/
https://www.plasticpollutioncoalition.org/blog/2022/5/16

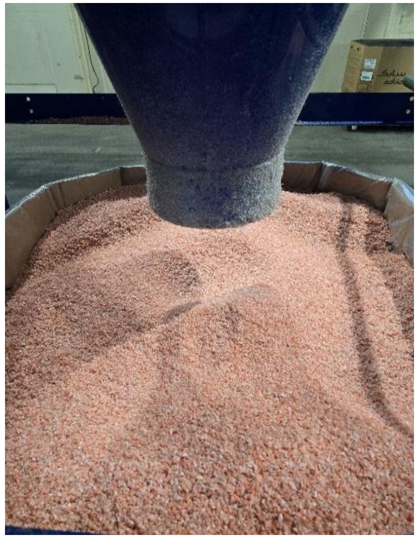
Problem Statement/Objective

- **Problem statement:**
  - Pavements in regions with seasonal temperature extremes are subject to intense frost heaving in winter and softening in summer, deteriorating under the excessive strain from these cyclical weather events.
  - Furthermore, the use of plastic has escalated during the past five decades.

- **Overall Objective:**

Formulate a sustainable mixture design including recycled plastics that enhances performance to withstand distress while mitigating environmental pollution.

Incorporating Composite Plastics into Asphalt Binder



Methods of Incorporating Plastics

Wet Mixing Method:

- Blending shredded waste plastics into the asphalt binder before mixing it with aggregates.

Dry Mixing Method:

- Recycled plastic is shredded into small granules and mixed with aggregates and asphalt in a heated drum.

Source: Revelli et al. 2024)

Challenges in Incorporating Plastics

➢ Wet Method

- Phase separation
- Initial higher cost/ Sophisticated equipment

➢ Dry Method

- Improper coating of aggregate
- Microplastics in the air
- Potential leaching to soil

Phase Separation Issue

Plastic due to non-compatibility and density difference phase separates from asphalt and migrates to asphalt surface during hot storage conditions

Associated problems:

- Variability in field construction
- Reduce the performance of polymer-modified binders
- Premature Failure / Increased maintenance costs

Phase Separation Issue (Cont.)

Impact on performance: To effectively enhance the rheology of modified asphalt binders, a polymer must become a continuum in the asphalt matrix.

Solution:

- By enhancing the compatibility between the asphalt binder and plastics using cross-linking agents to create a stable network.

Poor workability with phase separated plastic modified asphalt binder

Selected Composite Plastic Samples

LDPE+HDPE+PP (LHP)
Composite plastic

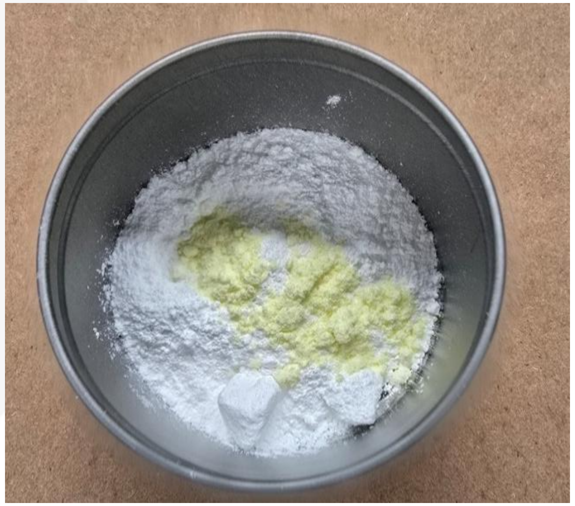
HDPE+PP (HP)
Composite plastic

0.6mm passing for blending

Stabilizers to Solve Phase Separation

- Using stabilizers to create cross linking between plastic and asphalt binder

Reactive Elastomeric Terpolymer (RET)



Maleic Anhydride (PE-g-MA) and sulfur

Experimental Methodology

Control binder
PG 58-28

Plastics @ 1%,2% and 3% by binder wt.
- HDPE+PP
- LDPE+HDPE+PP

DSC analysis
(melting point, 2 replicates)

Stabilizers
- Elvaloy RET 4170 @ 1:1
- Maleic anhydride @ 1% by binder wt.

Storage stability assessment

Separation Index(SI)

Morphology Analysis

Identification of storage stable plastic modified binder

Rheological properties and performance characterization

T. F. Sweep (High and Intermediate PG Grading)

MSCR (Rutting performance)

LAS (Intermediate cracking resistance)

BBR (Low PG Grading)

Blending of Plastics

Wet blending method with Maleic Anhydride *(Nizamuddin et al. 2023)*

- Type of plastics: HDPE+PP & LDPE+HDPE+PP
- Plastic dosage & size: 1, 2 and 3%, 0.6 mm passing
- Stabilizers dosages: 1% Maleic Anhydride by wt of binder
- RPM and temperature : 4500 rpm, 180 °C
- Mixing method and duration : High shear mixing for 120 minutes

Blending of plastics with binders

Blending of Plastics (Cont.)

Wet blending method with RET *(Paul et al. 2022)*

- Plastic dosage & size: 1 % and 2%, 0.6 mm passing
- Stabilizers dosages: 1:1 ratio by wt of plastic and 20% PPA by wt of RET
- Mixing method and temperature : 4000 rpm (180 °C) at high shear and 500 rpm (165°C) at low shear
- Mixing duration: High shear mixing for 30 minutes and low shear mixer for 120 minutes

Blending of plastics and RET with binders

Phase Separation Assessment

Separation Index of Plastic Modified Binder

Cigar Tube Separation Test (ASTM D7173-14)

Aluminum tubes
Diameter: 25 mm
Length:125 mm

Kept vertical for 48 hours at 165℃ and at -10℃ in freezer for another 5hours

$$\frac{G^*/\sin\delta_{top}}{G^*/\sin\delta_{bottom}}$$

Complex modulus Separation Index (SI)

Desirable value = 1

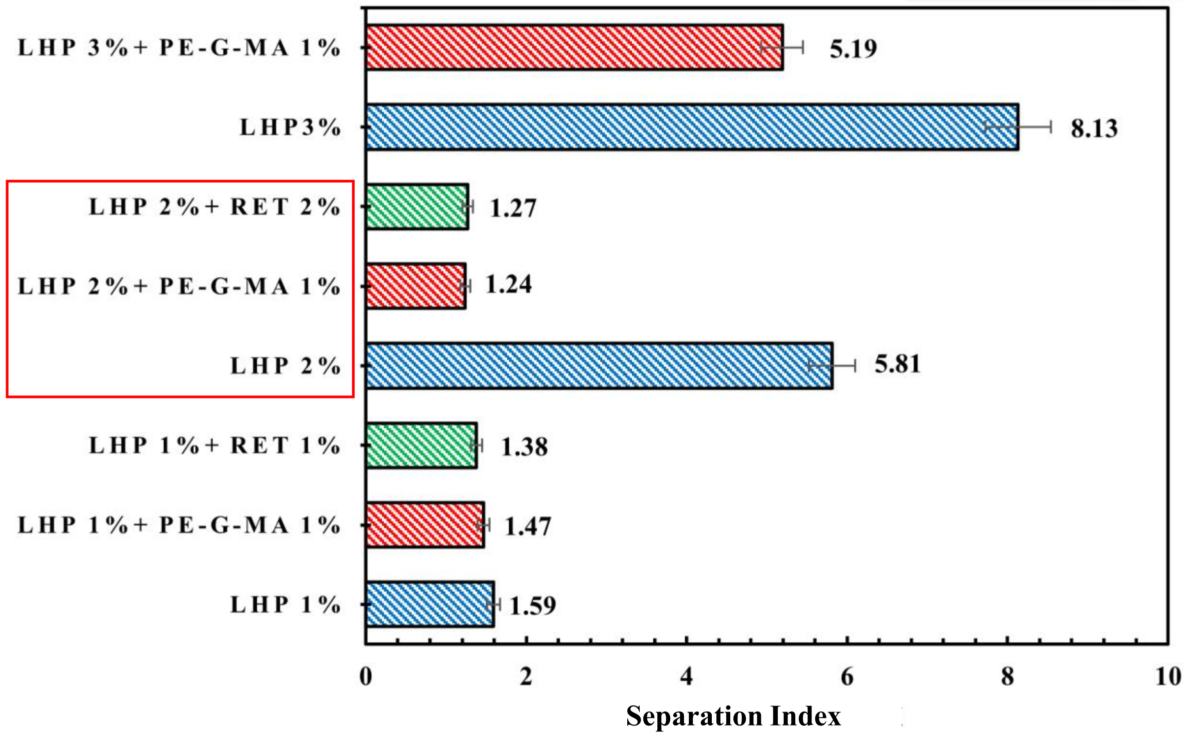
Desirable range = 0.8 – 1.2

Separation Index of Plastic Modified Binder (Cont.)

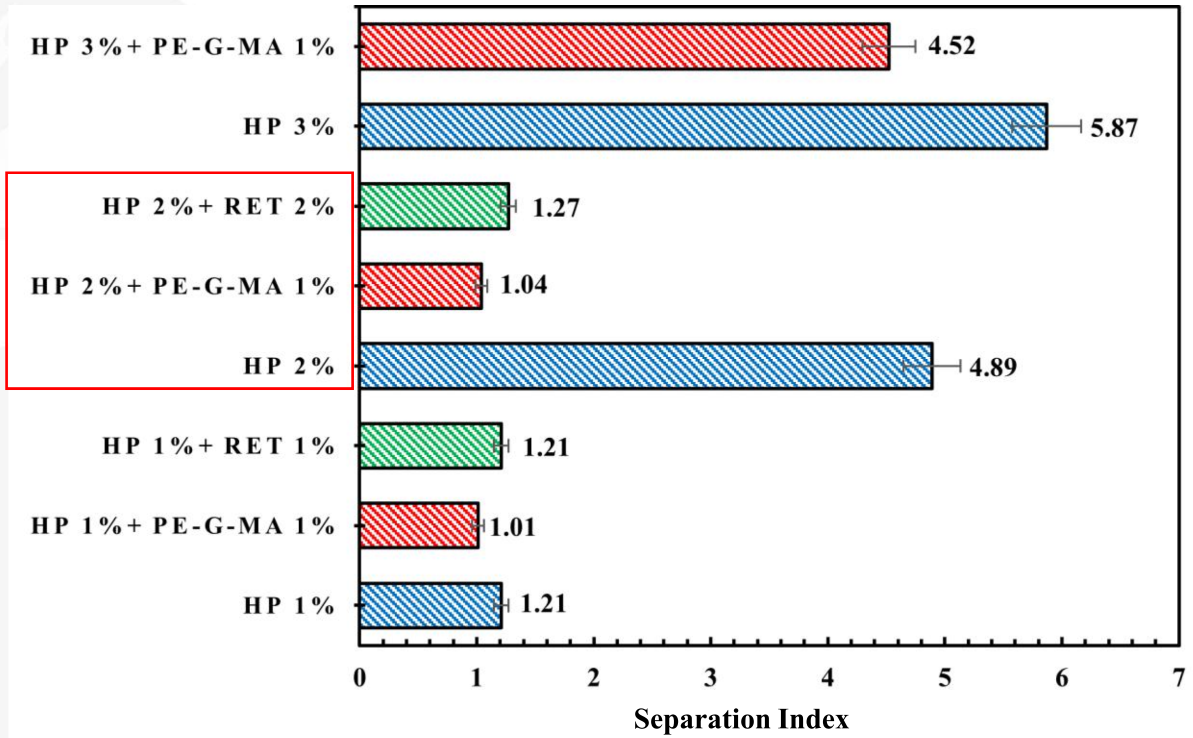
Plastic Sample	Plastic (%) by weight of binder	Stabilizer	Stabilizer (%) by weight of binder	Section	G*/Sinδ	SI
HP	2	PE-g-MA	1	Top	3271.0	1.04 (4.89)*
				Bottom	3153.0	
HP	2	RET 4170	2	Top	8809.0	1.27 (4.89)*
				Bottom	6913.0	
LHP	2	PE-g-MA	1	Top	3271.0	1.24 (5.81)*
				Bottom	3153.0	
LHP	2	RET 4170	2	Top	8809.0	1.27 (5.81)*
				Bottom	6913.0	

*** The SI values of plastic-modified binder without any stabilizers**

Separation Index of Plastic Modified Binder (Cont.)



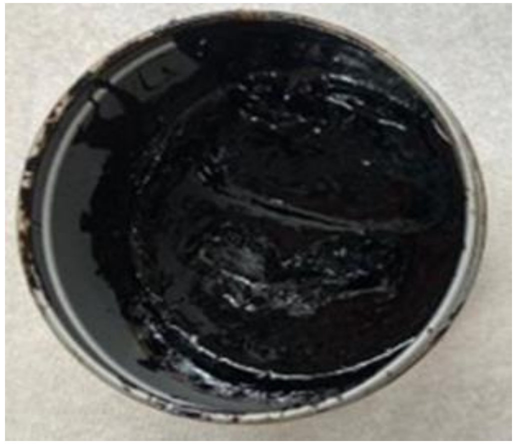
Separation Index of LHP Modified binders



Separation Index of HP Modified binders

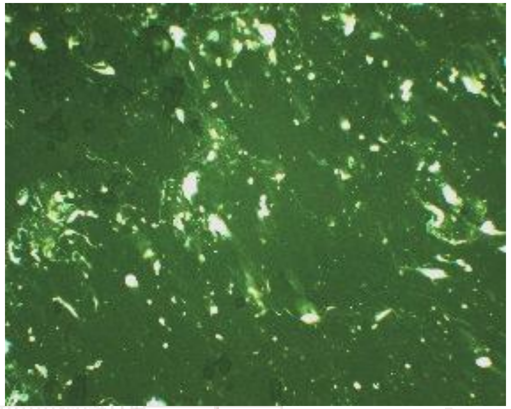
Maleic Anhydride and RET 4170 showed a noticeable improvement in storage stability in lower dosages (2%) of plastics.

Morphology Analysis

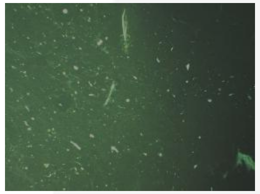
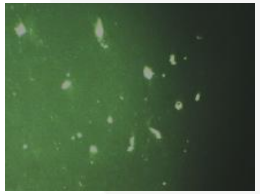
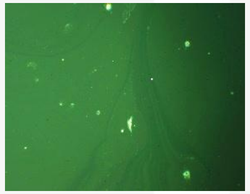
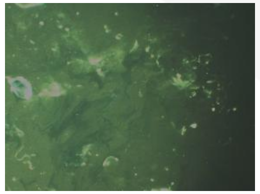
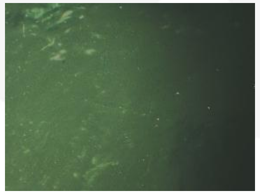


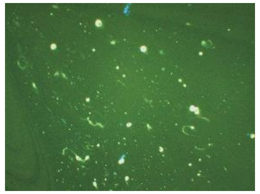
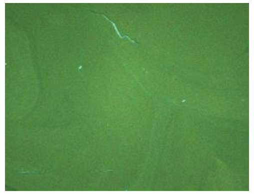
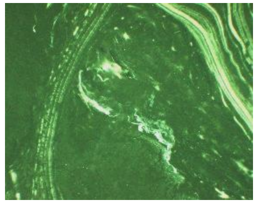
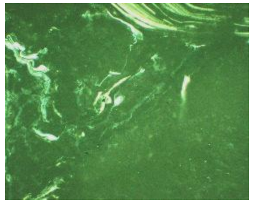
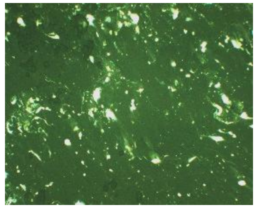
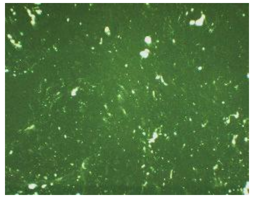
Top

Bottom



Fluorescence Microscopy Comparison

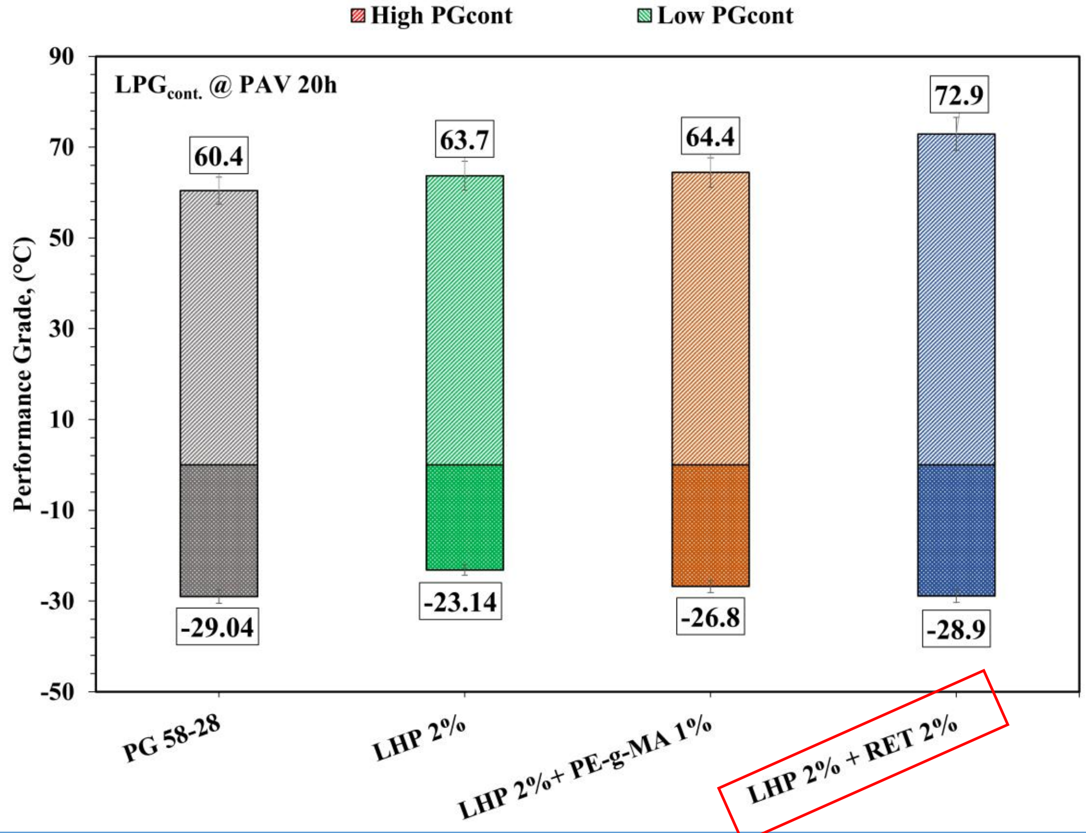
Sample Name	SI	Top	Bottom
HP (2%)	4.89		
HP (2%) + 1% PE-g-MA	1.04		
HP (2%) + 2% RET 4170	1.27		

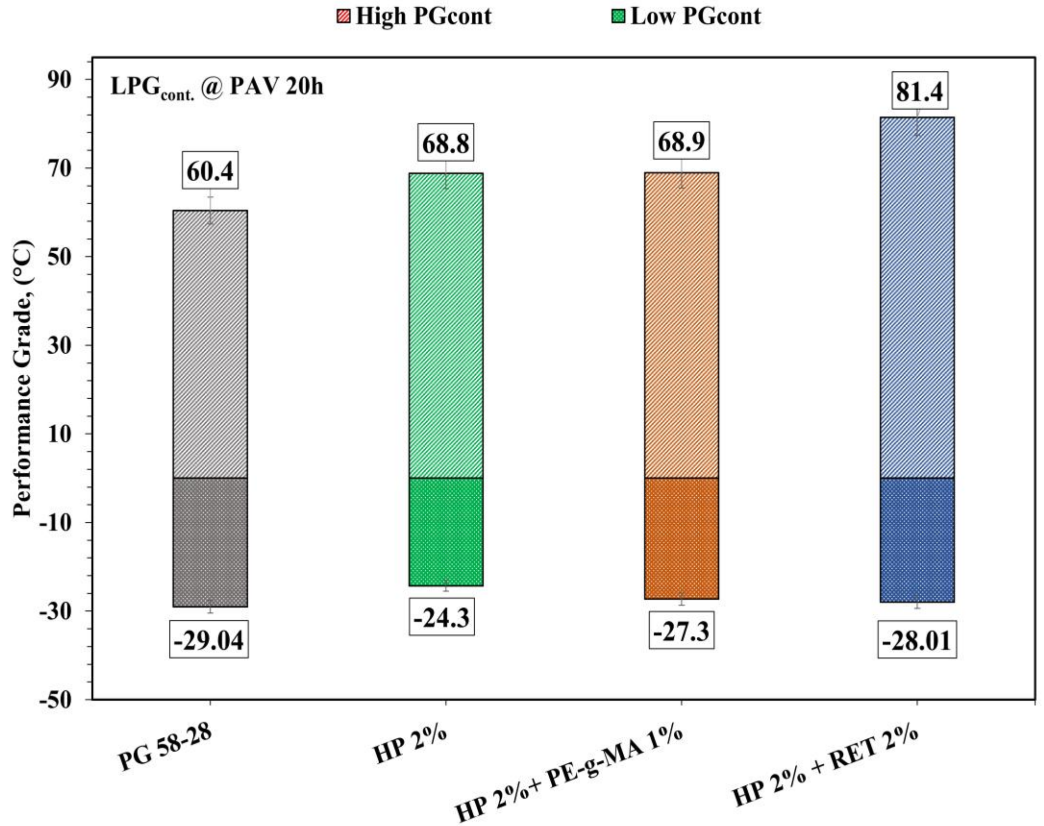
Sample Name	SI	Top	Bottom
LHP (2%)	5.81		
LHP (2%) + 1% PE-g-MA	1.24		
LHP (2%) + 2% RET 4170	1.27		

LHP 2% of plastic is showing more improvement with RET in comparison to HP 2% modified binder.

Laboratory Performance Evaluation

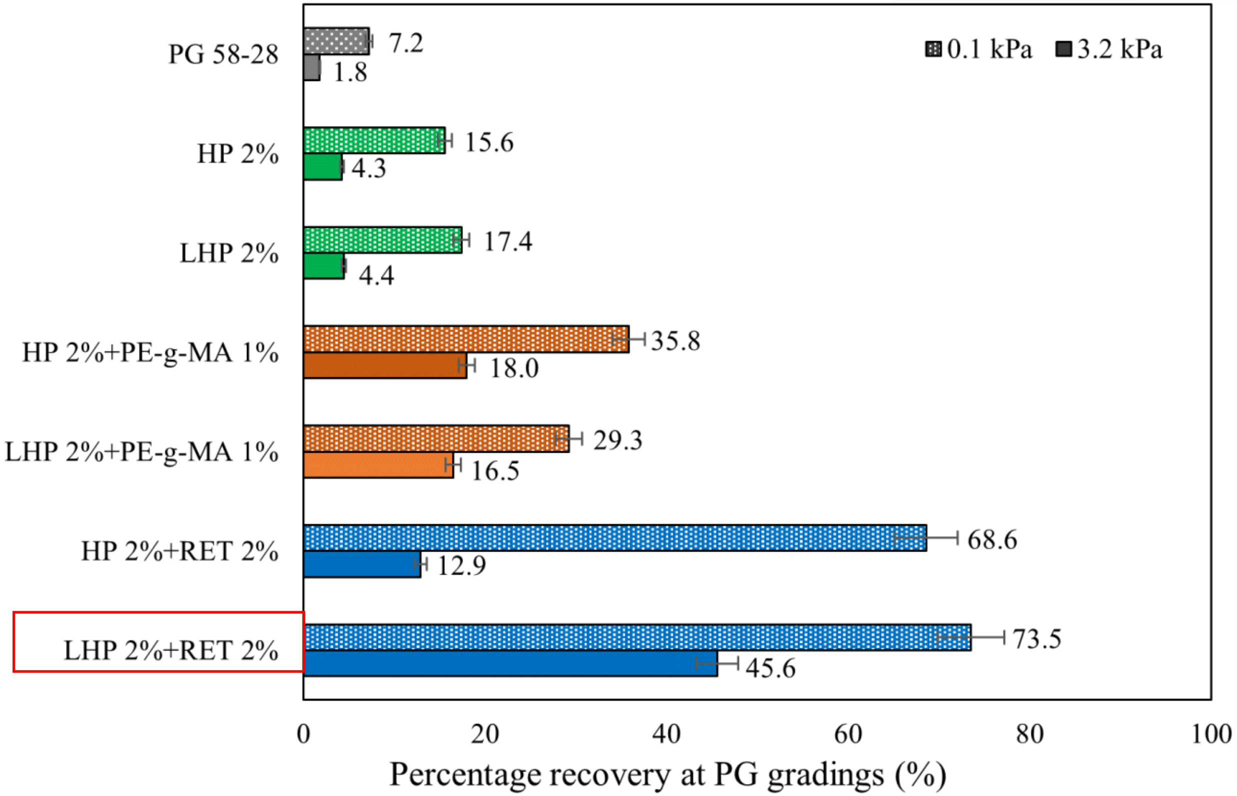
Continuous PG Grading of Binders

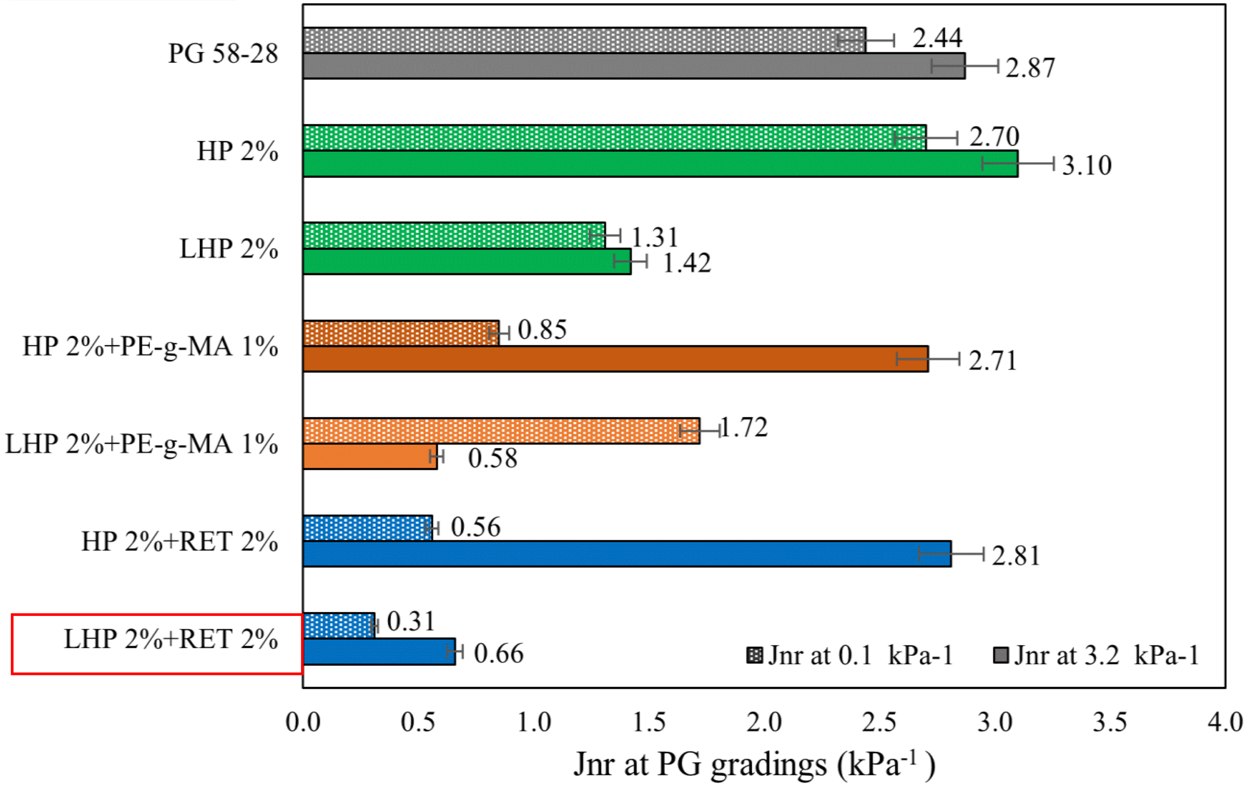




RET 4170 showed a noticeable increment of both HP and LHP plastic modified binders in both High and low PG grade.

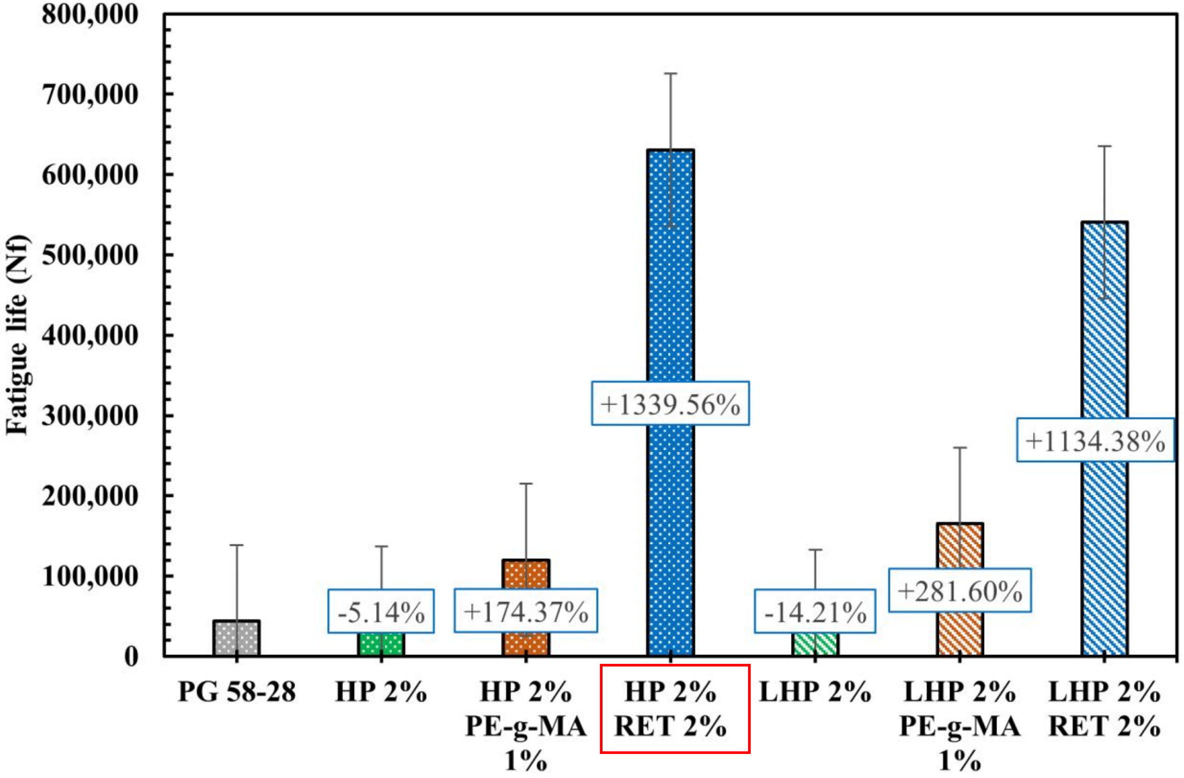
Rutting Characteristics of Plastic Modified Asphalt Binders



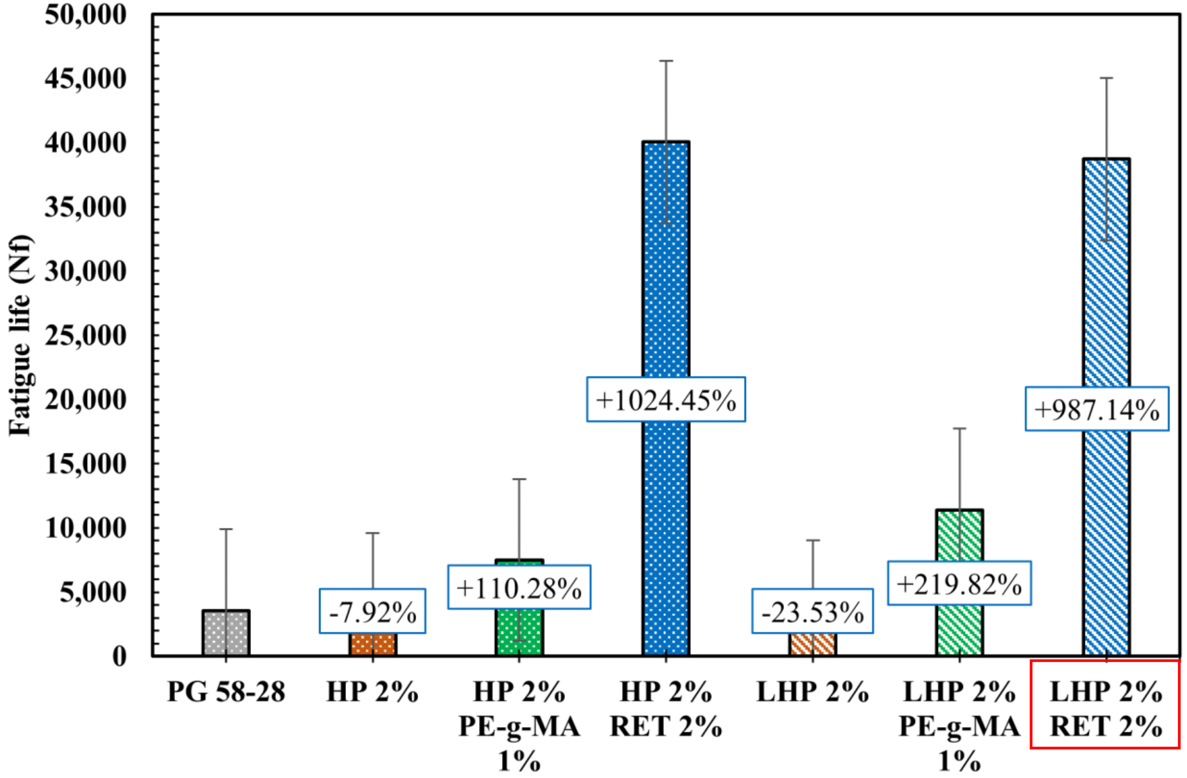


RET 4170 exhibited lower Jnr and higher percent recovery, indicating enhanced rutting resistance across various stress levels.

Fatigue Life of Composite Plastic Modified Binders



(a)



(b)

RET 4170 enhanced fatigue resistance, which increases flexibility in the modified binder matrix, thereby promoting better crack resistance.

Conclusions

- Homogenous distribution of plastics has been identified for 2% of composite plastics with Maleic Anhydride and RET 4170 combinations.
- RET 4170 showed a noticeable improvement in High and low PG grade, enhanced rutting and fatigue resistance comparing to plastic modified binders.
- Plastic-RET modified binders showed enhanced rutting, higher fatigue life, improved stress relaxation capacity and thermal cracking resistance compared to conventional polymer (SBS) modified binders.

Next Steps..

- Stabilizers need to be further explored to evaluate the compatibility in plastic modified binders with ageing.
- Storage stable and high-performance binder combinations can be evaluated at the asphalt mixture level to confirm their effectiveness in real world pavement applications.
- Monitoring long term performance data and conducting a life cycle cost analysis for storage stable plastic modified binders.

Enhanced Benefit to NJDOT

Enhance performance: Improved rutting and cracking resistance in asphalt pavement.

Extend lifespan: Increased pavement service life and reduced maintenance cost.

Sustainability goals: Incorporating composite waste plastics, preventing environmental pollution and supporting circular economy mandates.

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Thank You!

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