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Recycled Polyethylene (RPE) Modified Asphalt Mixtures: Performance Predictions Using Pavement ME Design and Evaluation of Return on Investment

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Presentation Outline

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Introduction

- The U.S. EPA (Environmental Protection Agency) reported that only 8.7% of municipal solid waste (MSW) plastic produced in the US in 2018 was recycled.
- In 2018, China closed its borders to the import of waste plastics from other countries.
- The recent change by China and the EPA report have increased the level of interest in the United States.

Thousands of tons of waste plastics and percent recycled in the US in 2018

Type of MSW	Thousands of Tons Generated	Percent Generated	Percent Recycled
LDPE and LLDPE	8,590	***24.1%***	4.3%
HDPE	6,300	***17.7%***	8.9%
PP	8,150	22.8%	0.6%
PS	2,260	6.3%	0.9%
PET	5,290	14.8%	18.5%
PVC	840	2.4%	Negligible
PLA	90	0.3%	Negligible
Other resins	4,160	11.7%	26.7%
Total Plastics in MSW	**35,680**	**100%**	**8.7%**

LDPE = Low density polyethylene; LLDPE = Linear low-density polyethylene; HDPE = High density polyethylene; PP = Polypropylene; PS = Polystyrene; PET = Polyethylene terephthalate; PVC = Polyvinyl chloride; PLA = Polylactide.

Introduction

Recycled Polyethylene Modified Asphalt Binders and Mixtures: Performance Characteristics and Environmental Impact

RPE Source

RPE-A

RPE-B

Mixing Process

Wet

Dry

Virgin Binder Source

(Binder A) ***(Binder B)***

PG 64-22

Introduction

Results showed that

- The virgin binder source and the mixing process were significant factors in determining the critical RPE dosage.
- RPE improved the rutting resistance of the asphalt binders and asphalt mixtures.
- However, it may have adverse effects on their resistance to intermediate-temperature and non-load associated cracking.
- RPE can be used by the asphalt paving industry without having potential environmental risks.

Problem Statement

Based on the documented literature review, no comprehensive research has yet been published on how recycled plastics impact the long-term performances and life-cycle costs of asphalt pavements. The research presented herein evaluated the effect of using RPE on the return on investment (ROI) when using wet and dry mixing processes.

Research Objectives

The objectives of this study were as follows:

1. Predict the rutting and bottom-up fatigue cracking of RPE modified asphalt mixtures using Level 1 of the AASHTOWare Pavement Mechanistic-Empirical Design (PMED).
2. Conduct life-cycle cost analyses (LCCA) using FHWA RealCost to analyze the return on investment (ROI) when using wet and dry mixing processes.

Research Approach

Materials Selection and Control Mixture Design

Determination of the Level 1 Inputs for AASHTOWare PMED

AASHTOWare PMED Simulations and Distress Predictions

Perform LCCA to Determine the Effect of RPE and RPE Mixing Process on ROI

Methodology

Binder A

Develop Mixtures Incorporating RPE
0%, 2.5% (Wet process) & 10% (Dry process)

→

Test for Performance Prediction

→

Predict Pavement Performance Using AASHTOWare PMED
(Rutting& Bottom-up fatigue cracking)

↓

Select Pavement Rehabilitation/ Preservation Strategies for Different RPE Pavement Sections

←

Conduct Life Cycle Cost Analysis (LCCA) Using FHWA RealCost

←

Compare ROI of RPE Mixtures Prepared Using the Wet and Dry Processes

Performance testing for Level 1 Prediction

Asphalt Binder

Extract & Recover Binder from Different Mixtures

↓

G* & δ using a Dynamic Shear Rheometer (DSR)

M-E Calibration Models

Repeated Load Permanent Deformation Test (AC Rutting)

Flexural Bending Beam Fatigue Test (Fatigue Cracking)

Asphalt Mixture

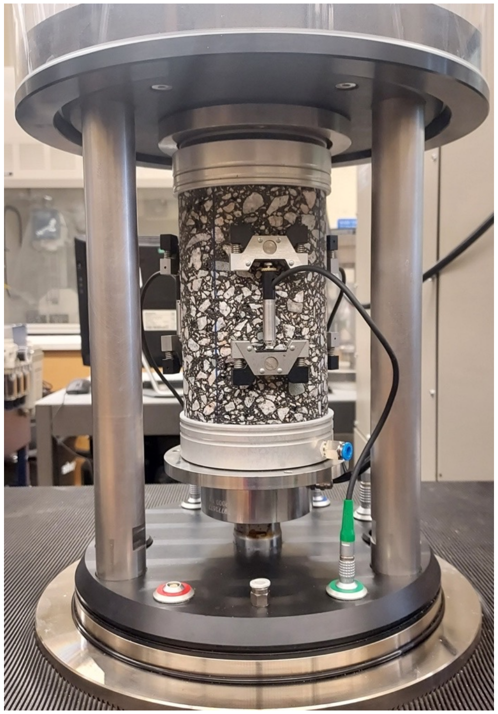
Dynamic Modulus (|E*|)

Mixture Volumetric Properties

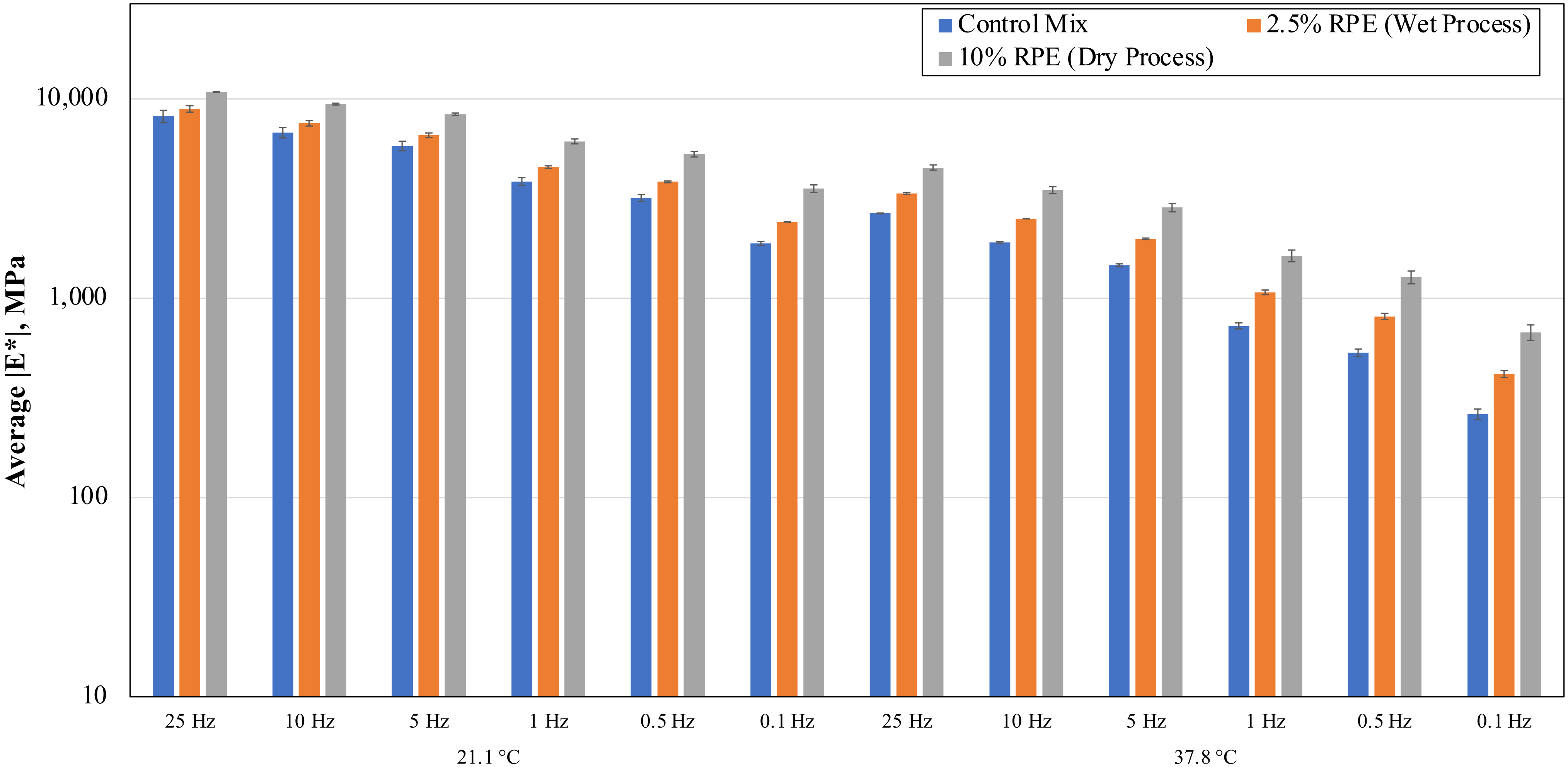
Laboratory Materials Testing

a) Dynamic Modulus (|E*|):

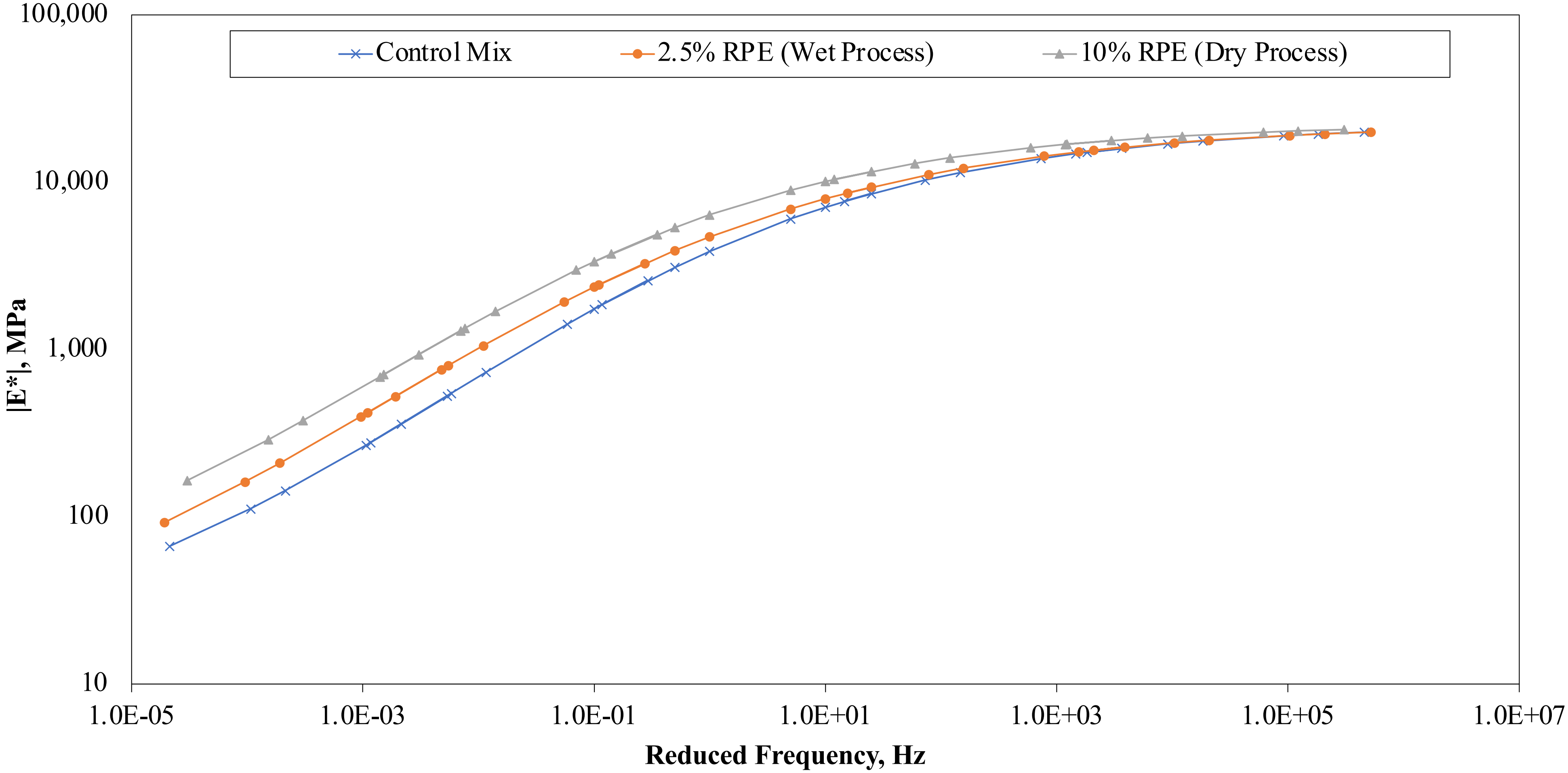
- |E*| tests samples were performed in accordance with AASHTO T 378-17
- Test samples were prepared at 7 ± 0.5% air voids
- Each specimen was tested at temperatures 4.4ºC, 21.1ºC, 37.8ºC, and 54.4ºC and loading frequencies of 25 Hz,10 Hz, 5 Hz, 1 Hz, 0.5 Hz, and 0.1 Hz
- |E*| master curve for each RPE mixture was developed according to AASHTO R 84, then the |E*| were calculated at the temperatures and loading frequencies required by AASHTOWare PMED



Close-up of |E*|Specimen within AMPT Test Device



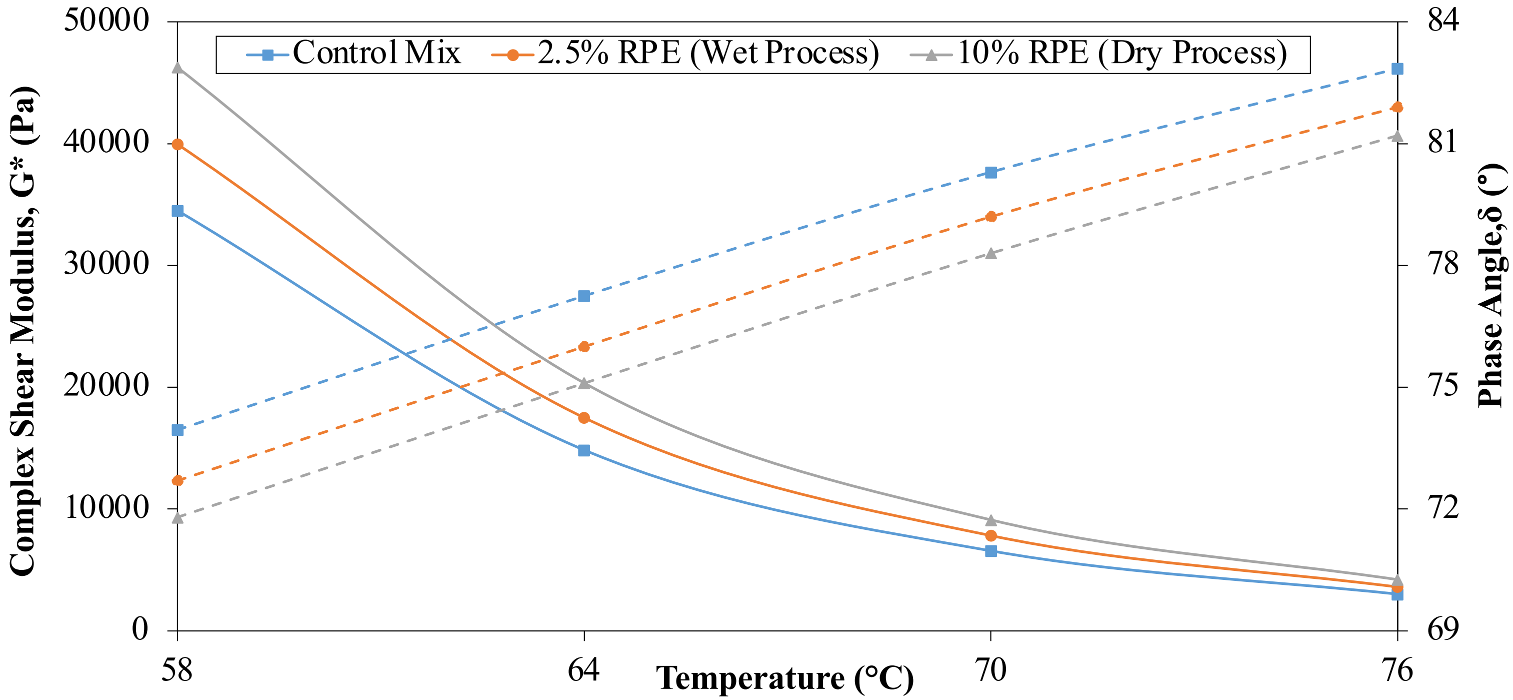
Average dynamic moduli for the different mixtures 21.1 °C and 37.8 °C



Master curves of dynamic modulus |E*| for the different mixtures at 21.1 °C

b) Asphalt Binder Characterization for AASHTOWare PMED:

- AASHTOWare PMED Level 1 requires the laboratory-measured complex shear moduli (G*) and phase angles (δ) of the asphalt binder used in the mixture.



Complex shear moduli and phase angles for the different binders

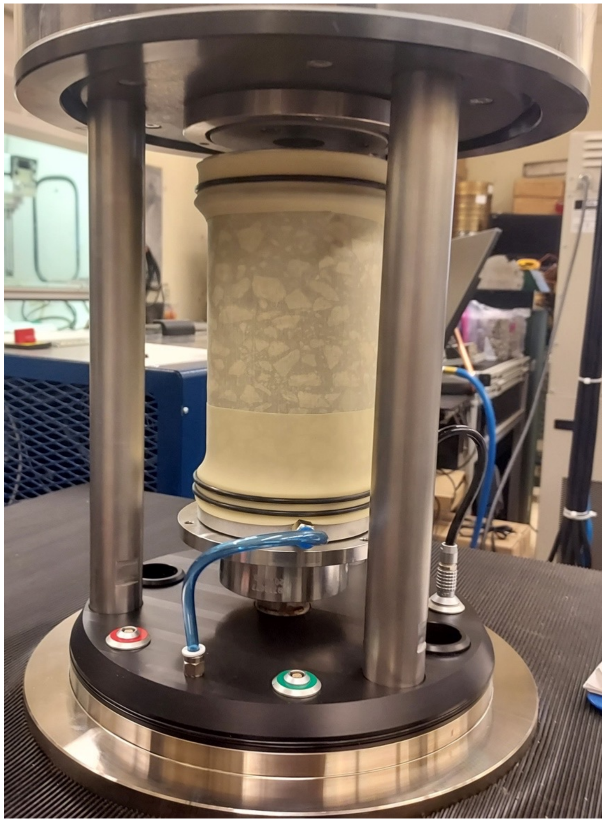
c) Repeated Load Permanent Deformation Test (RLPDT):

- RLPDT tests samples were performed following the procedure outlined in NCHRP 9-30A for deriving the permanent deformation coefficients

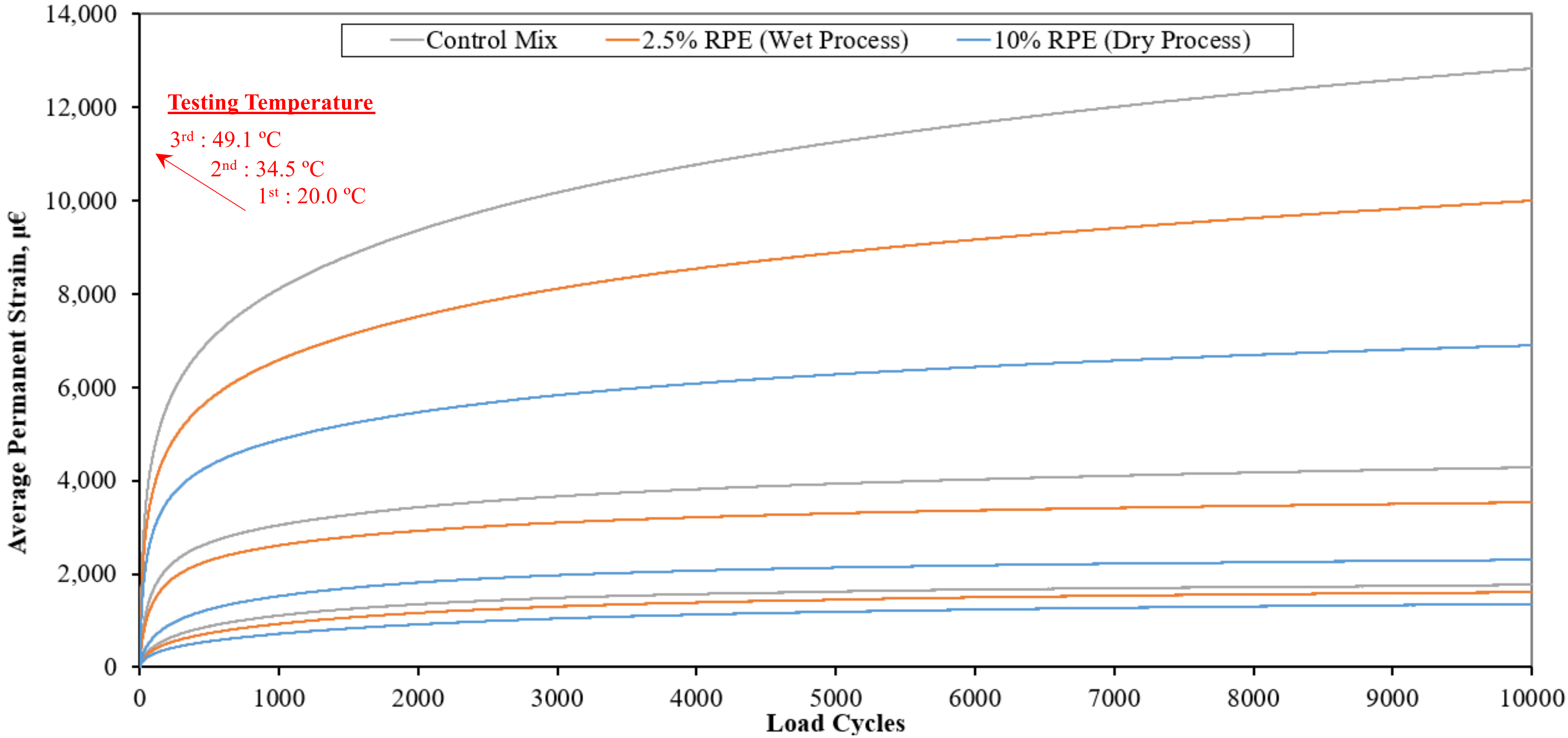
- Test samples were prepared at 7 ± 0.5% air voids

- RLPDT tests were conducted using a 482.6 kPa repeated deviator stress, 24 kPa contact deviator stress, and 68.9 kPa confining pressure

- RLPDT tests were conducted at temperatures: (1) 20 ºC; (2) 5 ºC below the 50 percent reliability high pavement temperature from LTPPBind software [54.1 °C- 5 °C = 49.1 ºC] and (3) average of these two temperatures [34.5 °C].



Specimen setup in AMPT device



Average permanent strain of the control and RPE modified mixtures at different temperatures

Determination of Laboratory Permanent Deformation Coefficients Needed for AASHTOWare PMED

- For HMA, AASHTOWare PMED predicts the rutting of asphalt sublayers using the permanent deformation model:

$$\Delta_{p(HMA)} = \varepsilon_{p(HMA)}\, h_{(HMA)} = \beta_{1r}\, k_z\, \varepsilon_{r(HMA)} 10^{k_{1r}} n^{k_{2r}\beta_{2r}} T^{k_{3r}\beta_{3r}}$$

Where:

k_z is a depth correction factor;

β_{1r}, β_{2r}, and β_{3r} are field adjustment constants; and

$\boldsymbol{k_{1r}, k_{2r}, k_{3r}}$ are permanent deformation coefficients which can be determined by fitting the RLPDT data within the secondary zone where the slope of the plastic strain curve is nearly constant using:

$$\frac{\varepsilon_{p(HMA)}}{\varepsilon_{r(HMA)}} = 10^{k_{1r}} n^{k_{2r}} T^{k_{3r}} h_{specimen}$$

- The Solver function in Microsoft Excel was executed to simultaneously optimize the k_r coefficients that minimize the sum of the squared errors between the measured and predicted permanent strain to resilient stain ratio $\left(\frac{\varepsilon_p}{\varepsilon_r}\right)$ (Bonaquist, 2019)

Calculated Permanent Deformation Coefficients for the Control and RPE Modified Mixtures and the Corresponding Goodness of Fit Parameters

Parameter	Coefficients	Control Mix	2.5% RPE (Wet process)	10% RPE (Dry process)
Permanent Deformation Coefficients	k_{1r}	-4.131	-4.193	-4.300
	k_{2r}	2.448	2.461	2.447
	k_{3r}	0.160	0.160	0.162
Statistical Goodness of Fit Parameters	Se/Sy	0.07	0.10	0.15
	R^2	0.995	0.991	0.978

d) *Flexural Bending Beam Fatigue Test:*

- The four-point bending beam fatigue procedure was performed according to AASHTO T 321

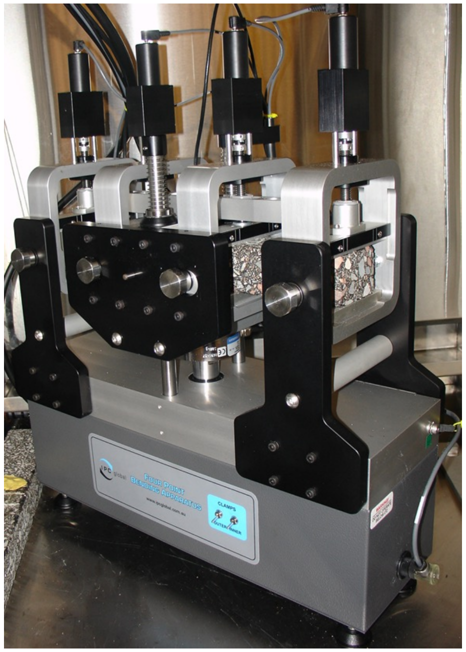
- Beam dimension: 63 mm in width, 50 mm in height, and 380 mm in length

- Test samples were prepared at 7 ± 0.5% air voids

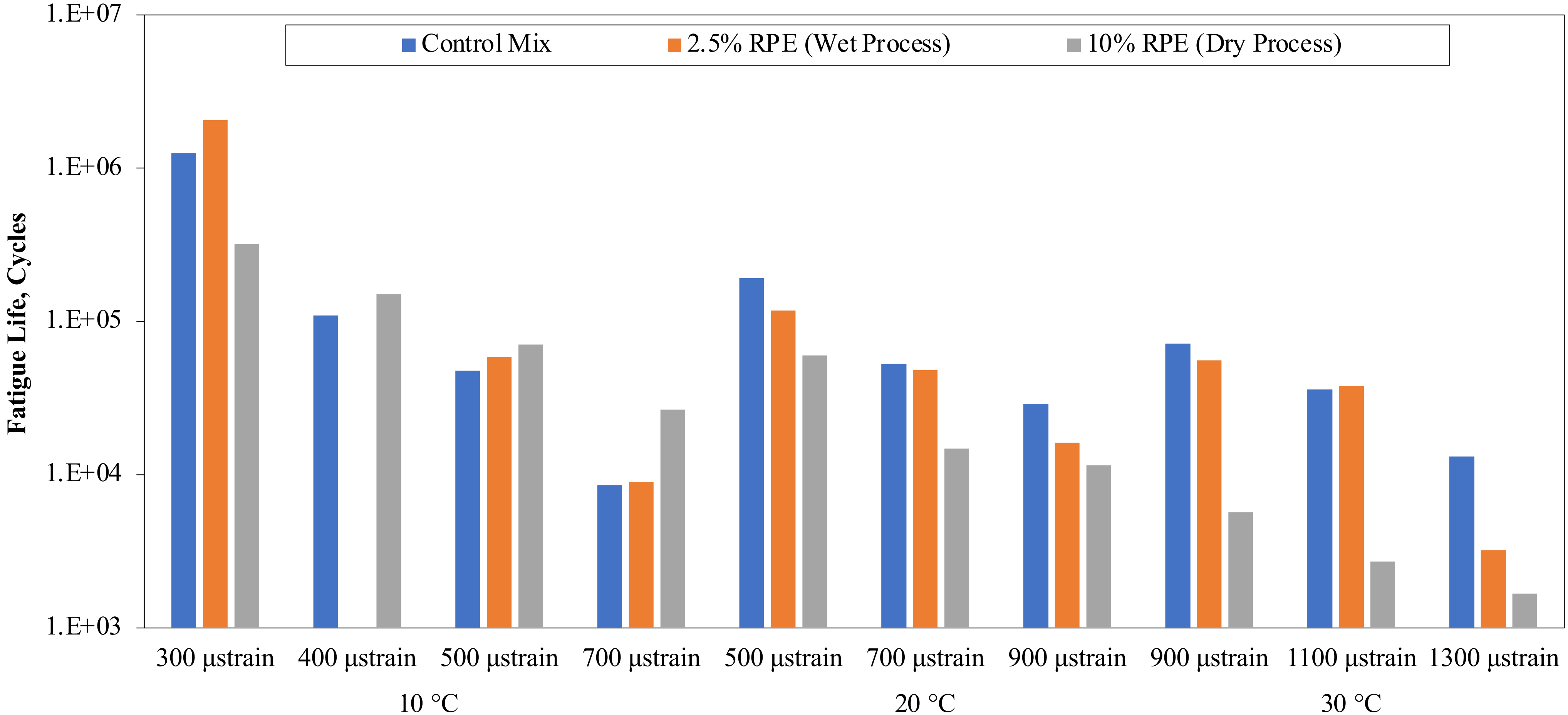
- Beam fatigue tests were conducted at temperatures of 10, 20, and 30 ºC. The strain levels were (1) 300, 400, 500, and 700 με at 10ºC; (2) 500, 700, and 900 με at 20 ºC and (3) 900, 1100, and 1300 με at 30 ºC.

Slab prepared using IPC Global Pressbox slab compactor

Beam fatigue test specimens



Specimen setup in four-point flexural fatigue test device



Fatigue life for the control and RPE modified mixtures at different strain levels and temperatures

Determination of Laboratory Fatigue Strength Coefficients Needed for AASHTOWare PMED

- AASHTOWare PMED predicts load-related cracking using an incremental damage analysis by calculating the allowable number of axle-load applications given by:

$$N_f = \boldsymbol{k_{f1}}(C)(C_H)\beta_{f1}\left(\frac{1}{\varepsilon_t}\right)^{\boldsymbol{k_{f2}}\beta_{f2}}\left(\frac{1}{|E^*|}\right)^{\boldsymbol{k_{f3}}\beta_{f3}}$$

Where:

C is mixture volumetric property factor which equals to $10^{4.84\,(\mathrm{VFA}-0.69)}$;

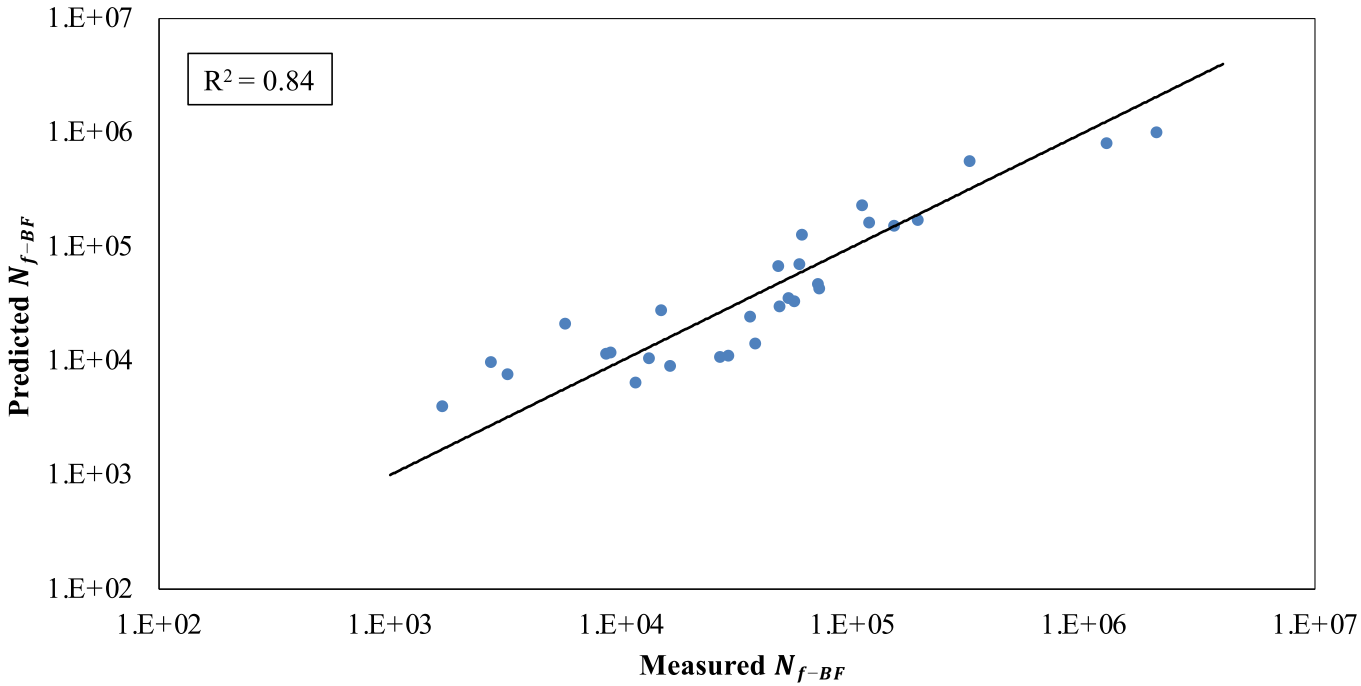
β_{f1}, β_{f2}, and β_{f3} are field adjustment constants; and

$\boldsymbol{k_{f1}, k_{f2}, k_{f3}}$ are fatigue strength coefficients which can be calculated using beam fatigue testing results by performing a linear regression analysis on:

$$N_{f-BF} = k_{f1}(C)\left(\frac{1}{\varepsilon_t}\right)^{k_{f2}}\left(\frac{1}{E_{Flexural}}\right)^{k_{f3}}$$

- The laboratory measured fatigue data were tabulated and used as inputs to a linear regression function to determine the fatigue strength coefficients k_{f1}, k_{f2}, k_{f3} (Bonaquist, 2019 and Nabizadeh et al., 2022).

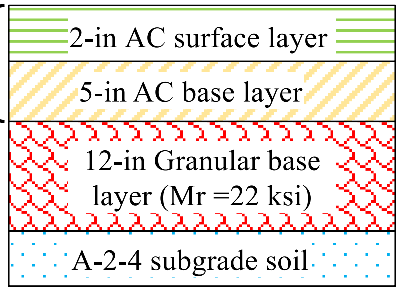
Coefficients	Intercept, k_{f1}	Strain Exponent, k_{f2}	Temperature / Modulus Exponent, k_{f3}
Global Defaults	3.75	2.870	1.460
Calculated	0.103	5.222	1.783



Predicted N_{f-BF} versus Measured N_{f-BF}

Prediction of Asphalt Concrete Rutting and Bottom-Up Fatigue Cracking Using AASHTOWare PMED

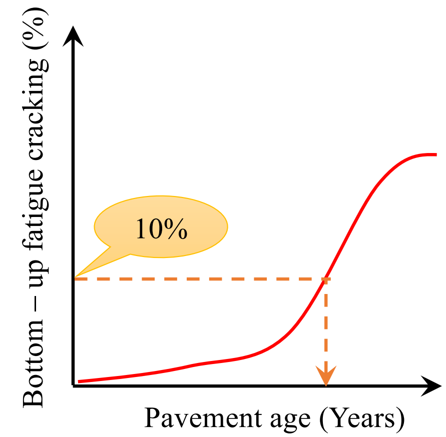
|E*| dynamic modulus master curves
G* and δ at multiple temperatures
Fatigue coefficients: k_{f1}, k_{f2}, k_{f3}
AC rutting coefficients: k_{1r}, k_{2r}, k_{3r}

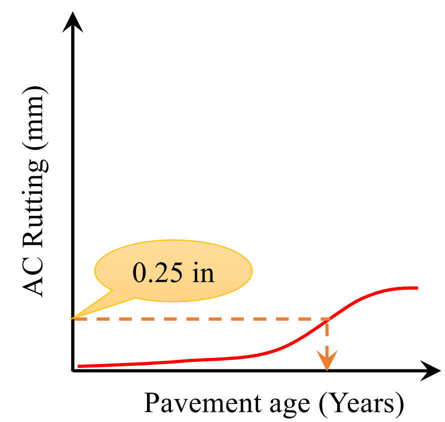


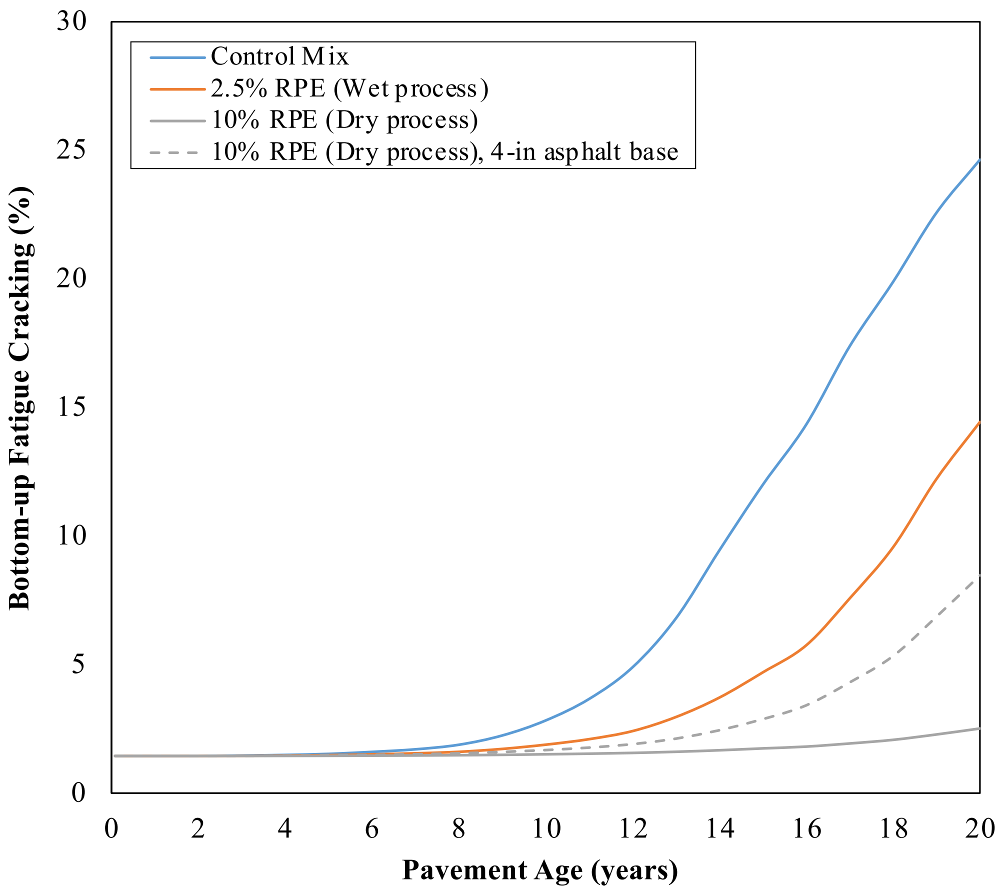
Traffic Data	
Design Life (years)	20
Initial two-way Annual Average Daily Truck Traffic (AADTT)	4,000
Number of lanes	4
Percent of trucks in design direction (%)	50
Percent of trucks in design lane (%)	85
Percent of trucks in design lane (%)	3.0

Climate Data		
Weather Station	Boston, MA	
Latitude (degrees.minutes)	• 42.50	• 42.00
Longitude (degrees.minutes)	• -71.25	• -71.25
Elevation, ft	• 134	• 148

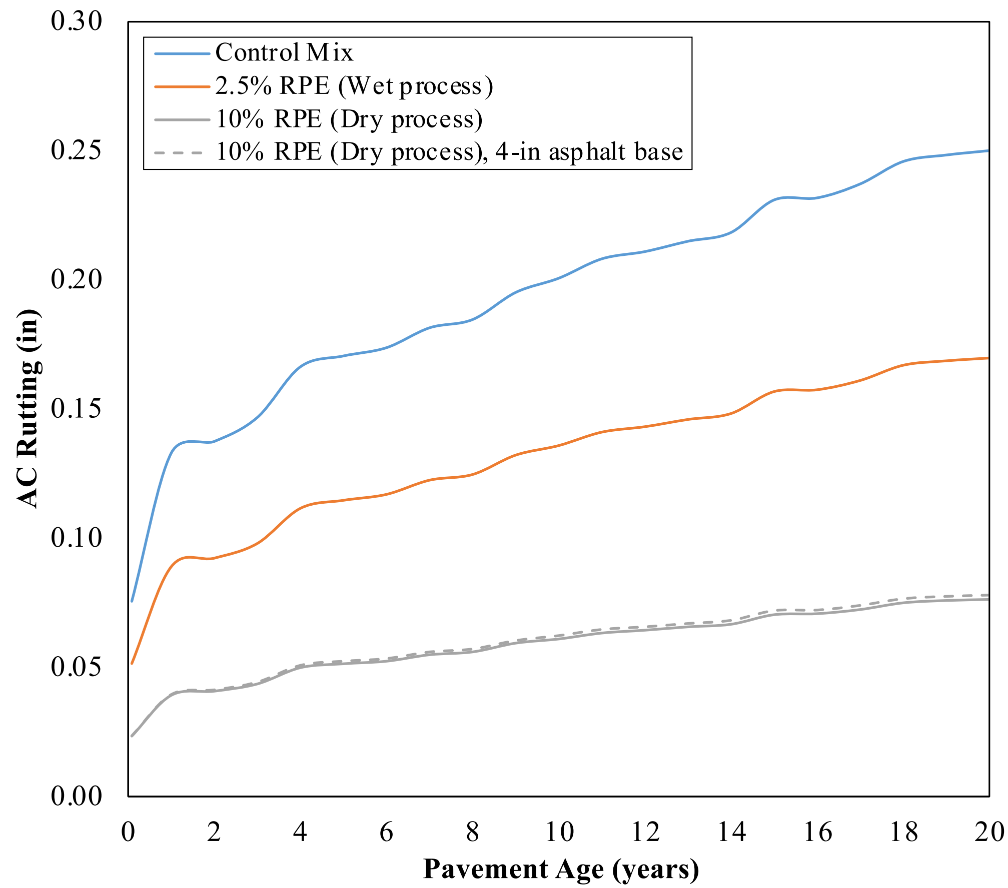
AASHTOWare Pavement ME Design







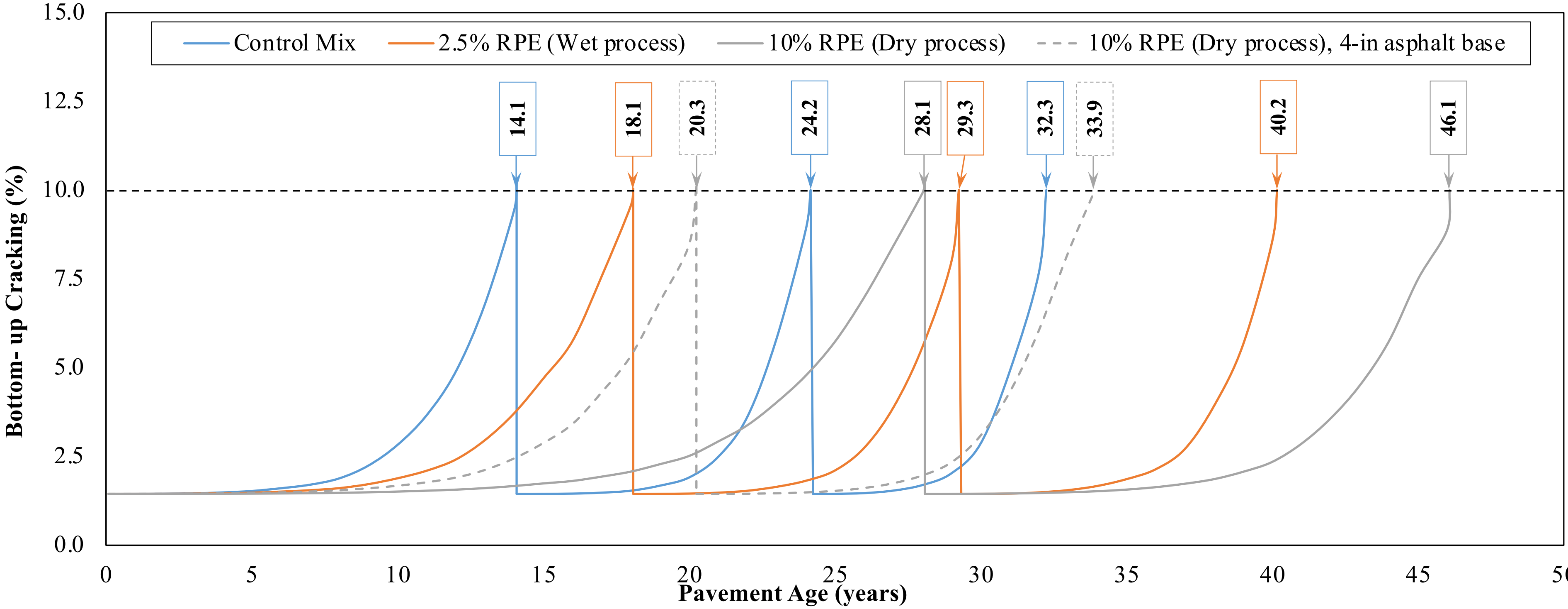
Predicted bottom-up fatigue cracking for control and RPE modified mixtures

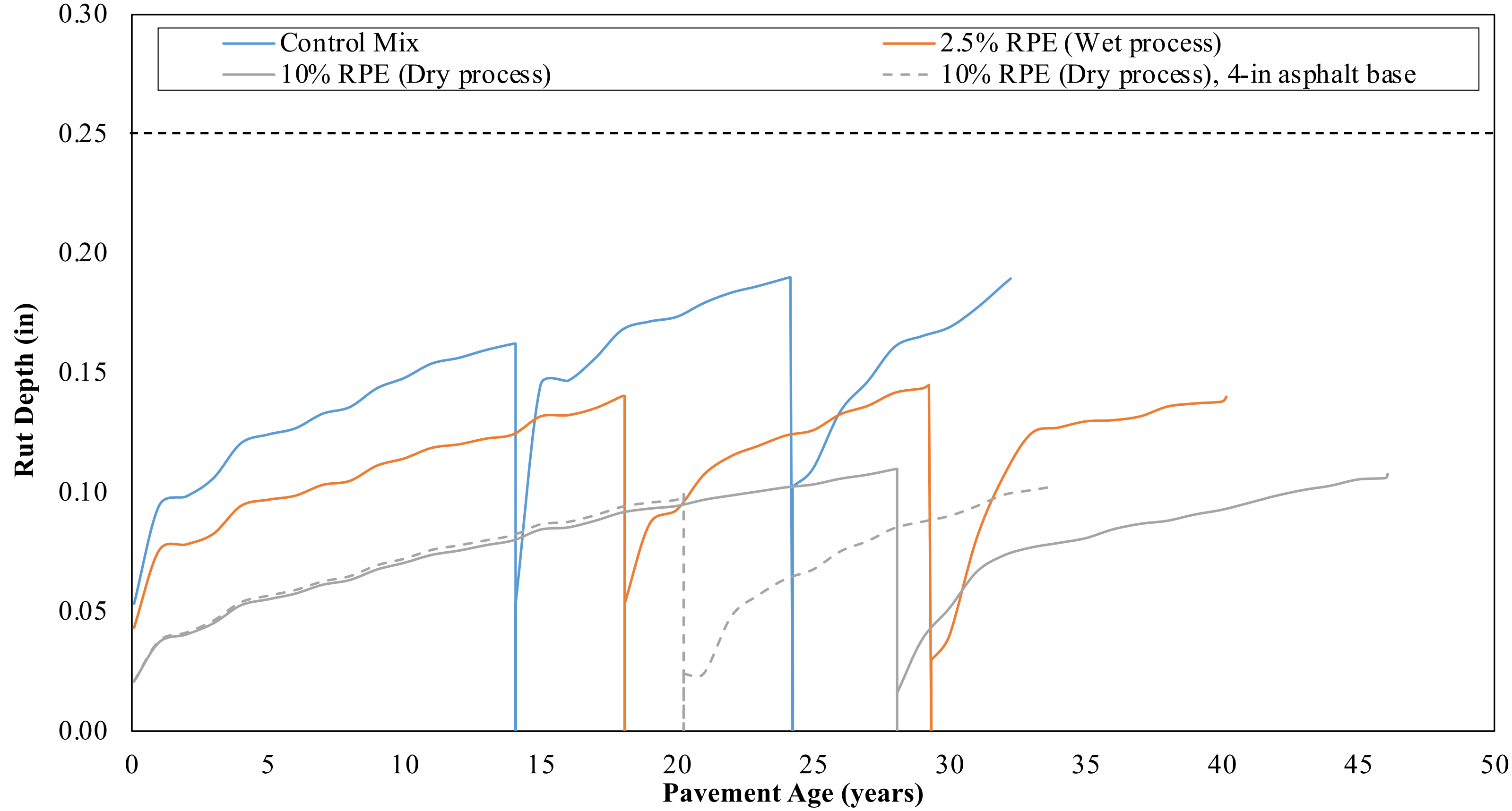


Predicted asphalt concrete rutting for control and RPE modified mixtures

Predicted Lifecycle Performance Based on Proposed Pavement Rehabilitation/Preservation Strategies

Based on pavement rehabilitation/preservation practices used in northeastern USA, the 2-in (51-mm) surface layer mixture was replaced with the same mixture when either the predicted asphalt concrete rutting or bottom-up fatigue cracking reached 0.25 in. (6.35 mm) and 10% of the lane area, respectively.





Predicted asphalt concrete rutting pavement life cycle performances for different sections

Return on Investment (ROI) for the Different Pavement Sections Using FHWA REALCost

Based on the AASHTOWare PMED outputs, Life Cycle Cost Analyses (LCCAs) were performed using FHWA RealCost:

1. A 30-year analysis period was selected.
2. The remaining service life value (RSLV) for both agency and user costs were included in each LCCA.
3. Deterministic net present values (NPV) were computed using a discount rate of 4%.

A detailed software methodology and procedures for computing the NPV for both agency and user costs are presented in an FHWA Technical Bulletin .

ROI for Agency, User, and Total Costs for the Different Mixtures

Cost	Most Economical →	to	→	Least Economical
Agency	10% RPE (Dry Process), 4-in asphalt base	10% RPE (Dry Process)	2.5% RPE (Wet Process)	Control Mixture
User	10% RPE (Dry Process), 4-in asphalt base	10% RPE (Dry Process)	2.5% RPE (Wet Process)	Control Mixture
Total NPV	10% RPE (Dry Process), 4-in asphalt base	10% RPE (Dry Process)	2.5% RPE (Wet Process)	Control Mixture

Conclusions

❑ ***AASHTOWare PMED analyses, and the ROI provided by FHWA RealCost***

- RPE pavement sections using both the dry and wet processes were more resistant to rutting and bottom-up fatigue cracking compared to the control pavement section, while the RPE pavement section using the dry process provided better performances compared to the wet process.

- The use of RPE by the asphalt paving industry is anticipated to produce pavements with higher ROI. In terms of highway agency costs, the full and reduced-thickness pavements using the dry process yielded approximately 13% and 18% NPV cost savings, respectively, when compared to the control pavement section, while the wet process yielded an approximately 6.5% NPV cost savings compared to the control pavement section.

Thanks!