Arkansas Transportation Summit-2025

TRRWDGP 2023

Sustainable Use of Rice Husk and Scrap Tires as Construction Materials of Transportation Infrastructures

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Part A

Rice Husk Ash (RHA) as Subgrade Soil Stabilizers

Introduction

- Soil stabilization is a **chemical, physical, biological, mechanical, or combined** technique that improves the stability of weak soils to achieve engineering goals.

- This study aims to evaluate the effectiveness of using **reclaimed fly ash (RFA)** and rice husk ash **(RHA)** as stabilizing soil agents.

Example Pavement Failures Due to Weak Subgrade Soils

Source: Google.com

Background

- **Hydrated Lime (HL)** is a traditional stabilizing agent. However, the cost is **high**.
- This study explores Rice Husk Ash (**RHA)** as a potential alternative to lime.
- RHA primarily consists of **67–70% silica**, along with cellulose and lignin.
- Per **USDA (2024)**, **Arkansas produces about 50% of the U.S. rice**, yielding approximately **110 million cwt** out of **220 million cwt** nationwide. (1 cwt=100 lb.)
- As an agricultural by-product, **RHA offers a cost-effective and sustainable solution**.

- **Reclaimed Fly Ash (RFA)** (recovered from landfills of coal-fired power plants) is another alternative.
- RFA can effectively improve soil stability.

Objectives

- Assess **performance** of stabilized soils and evaluate the **individual and combined effects** of the stabilizing agents.

- Determine **optimum percentages** of **RHA** and **RFA**, and a blend of **Lime and RHA**

Materials

Soil Sample

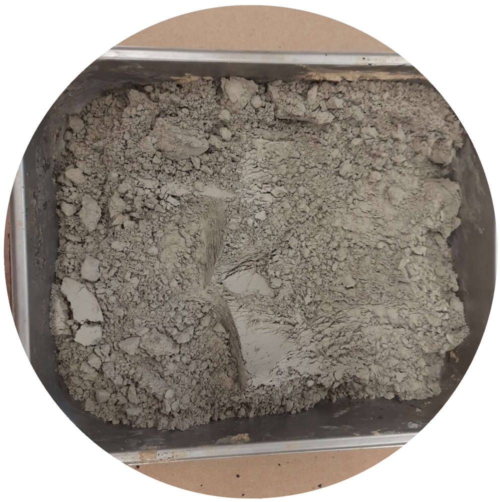
AR-1 Soil

AR-2 Soil

- **AR-1:** Collected from **I-555 State Highway,** Jonesboro, Craighead County, AR.
- **AR-2:** Collected from **Prospect Road,** Jonesboro, Craighead County, AR.
- Both samples were taken from **5–7 ft** below ground.

Materials

Stabilizer



RFA Sample

- Meets ASTM C618-15 specifications

RHA Sample:

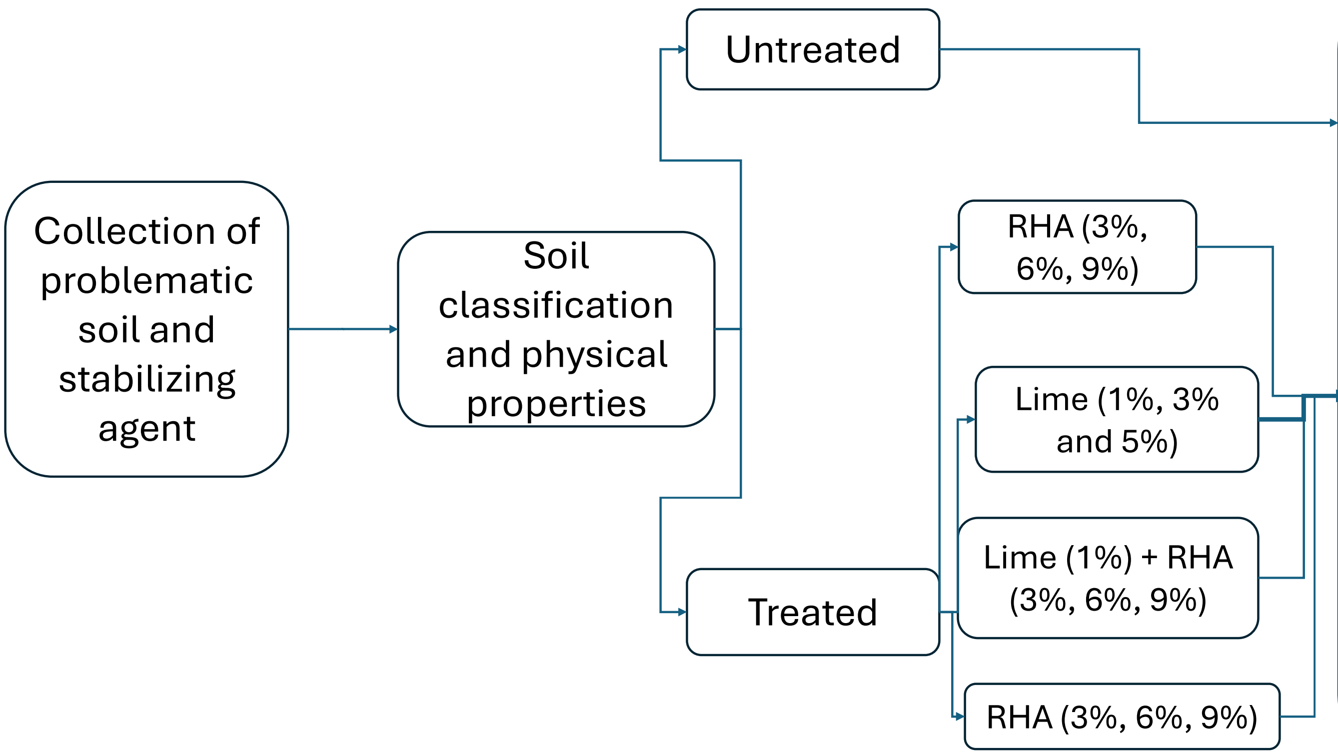
- 44µm
- Meets AASHTO M 321–04 and ASTM C618-15 specifications

Lime Sample:

Arkansas Lime Co.

Methodology

Experimental Plan (RHA)



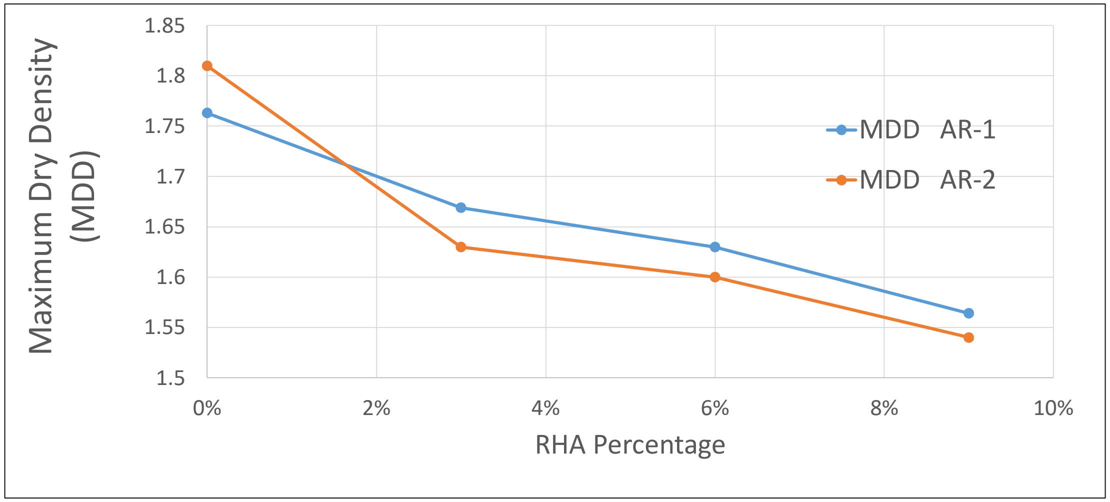
Test	Standard/Procedure
Gradation Analysis	ASTM D6913 (Sieve), ASTM D7928 (Hydrometer)
Specific Gravity	ASTM D854
Atterberg Limits	ASTM D4318
Modified Proctor Test	ASTM D1557
Unconfined Compressive Strength Test	ASTM D2166
California Bearing Ratio (CBR)	ASTM D1883
Free Swell Test	ASTM D4546
pH Measurement Test	ASTM D4972
Soil Resistivity Test	AASTHO T 288

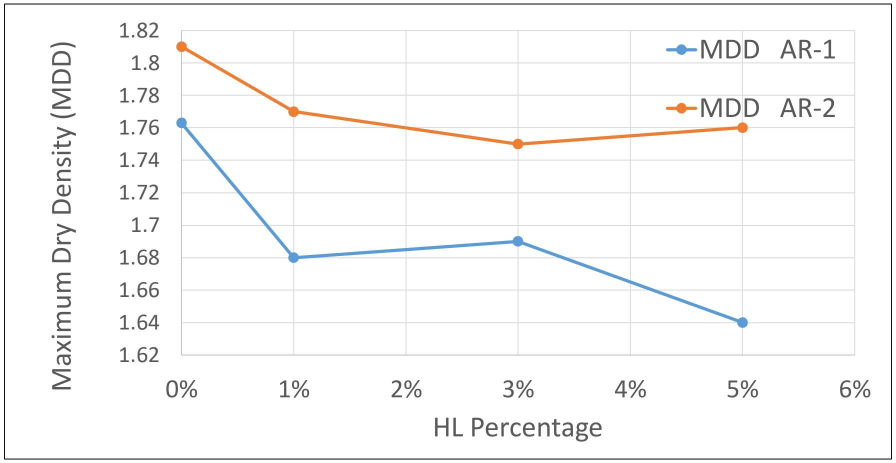
Result and Discussion

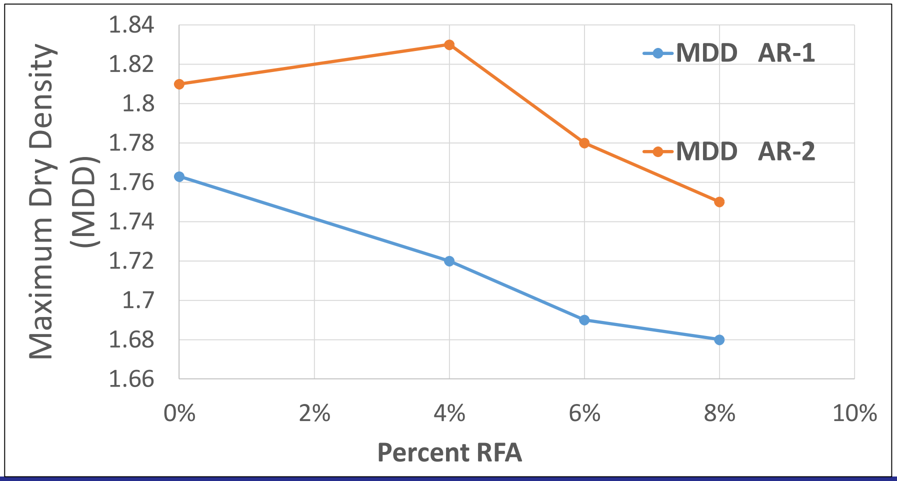
Soil Classification

Index Properties	AR-1	AR-2
Liquid Limit LL, %	36	27
Plastic Limit PL, %	25	23
Plastic Index, PI %	11	4
Specific Gravity	2.61	2.63
Gravel (Larger than 4.75mm) %	2	1
Sand (0.075 to 4.75 mm) %	43	47
Slit (0.002 mm to 0.075 mm) %	21	43
Clay (Less than 0.002 mm) %	34	12
Soil Type (AASTHO)	A-6	A-4
Soil Type (USCS)	CL	ML
Group Index, GI %	4	0.345

Maximum Dry Density

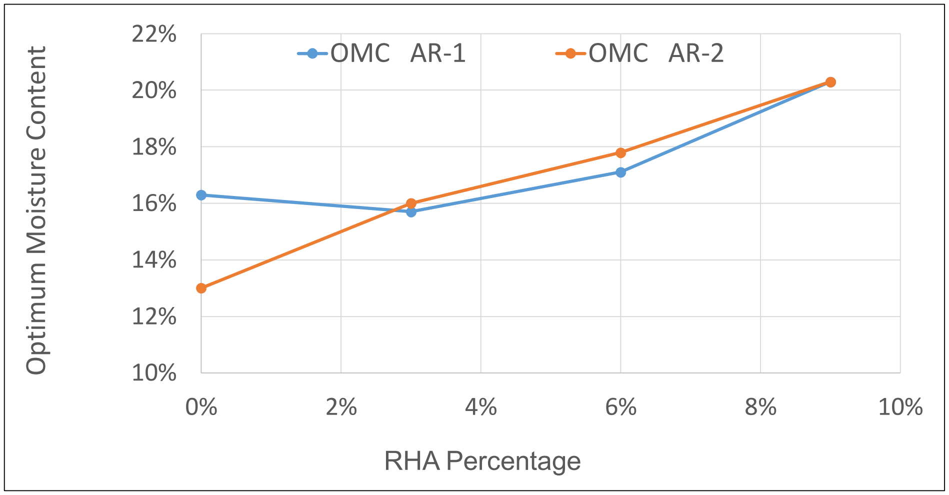


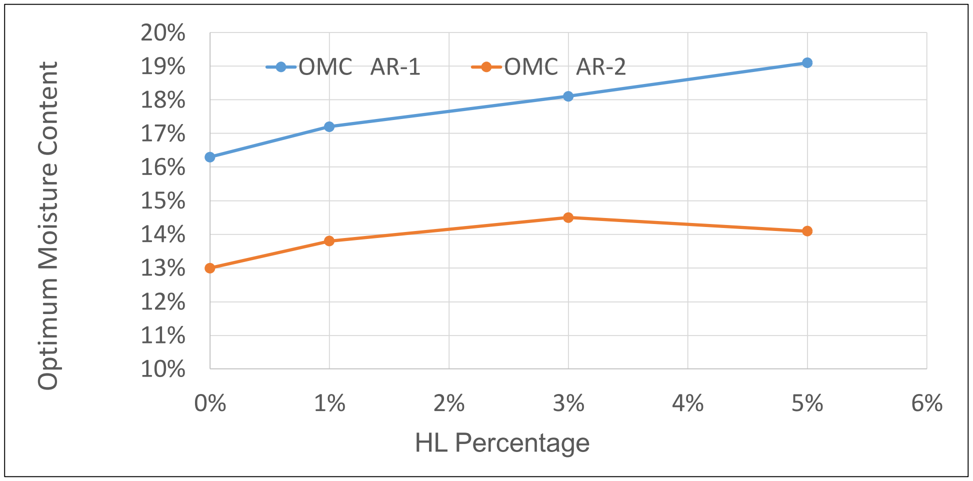


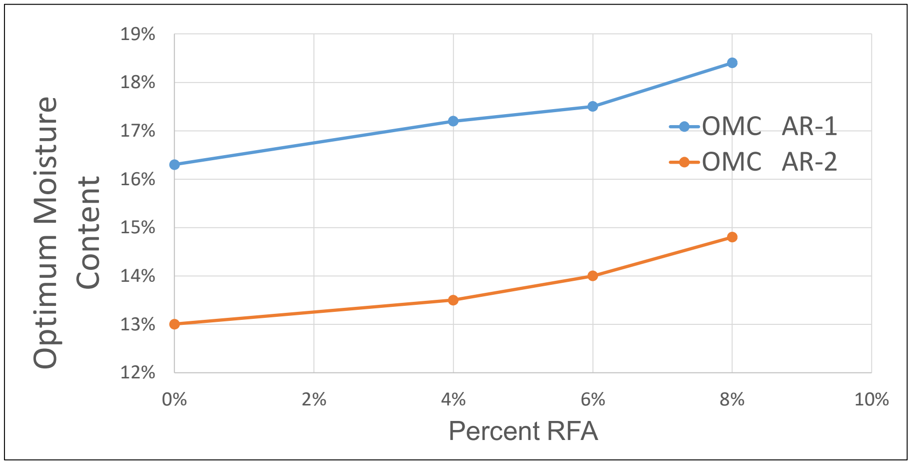


MDD decreased with the addition of all stabilizer.

Optimum Moisture Content

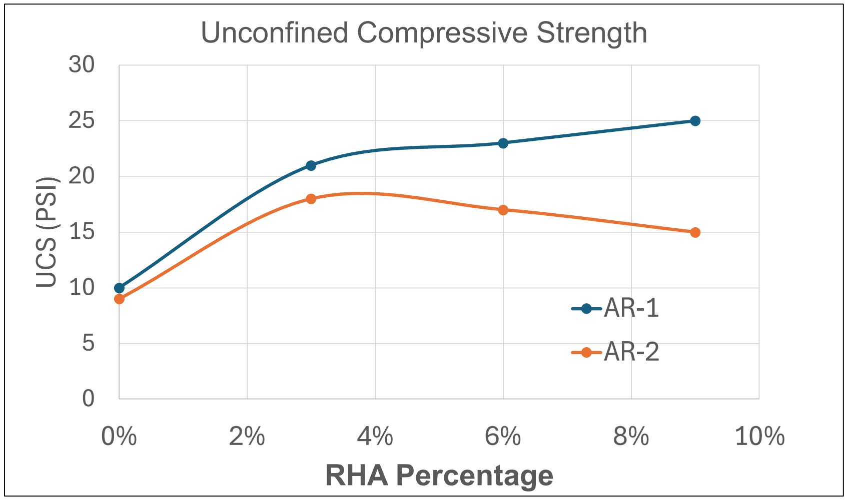


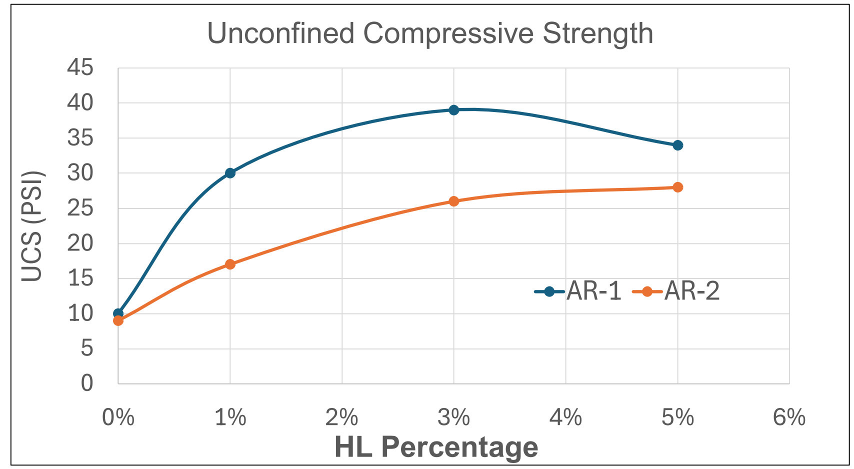


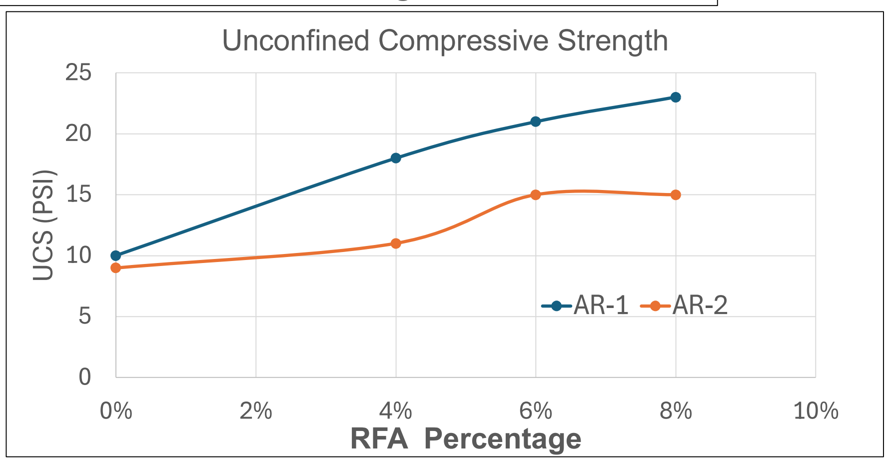


OMC increased with the addition of RHA, HL, and RFA

Unconfined Compressive Strength

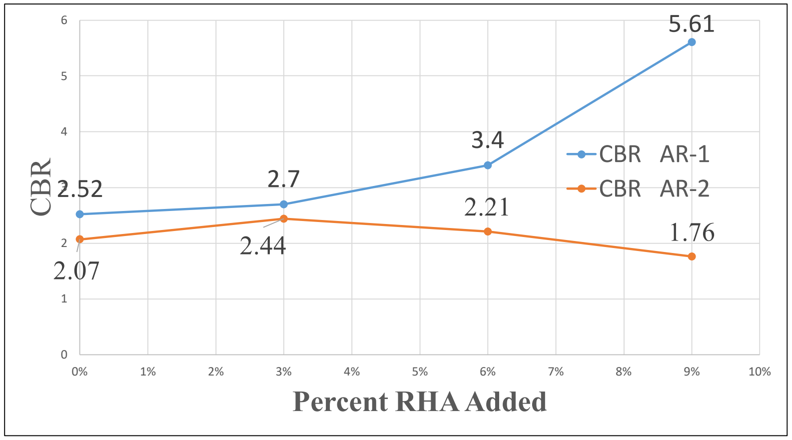


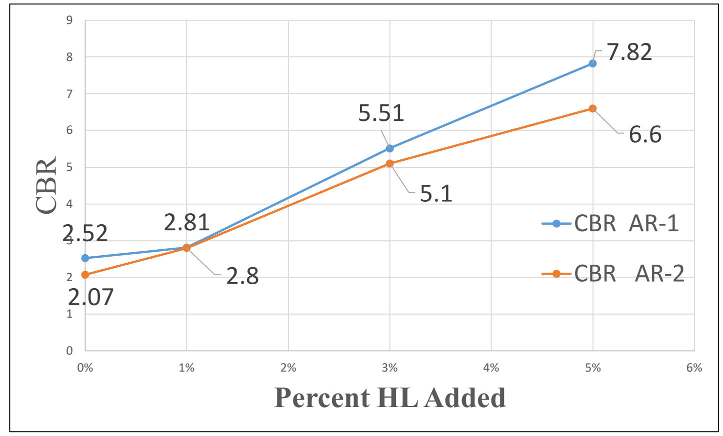


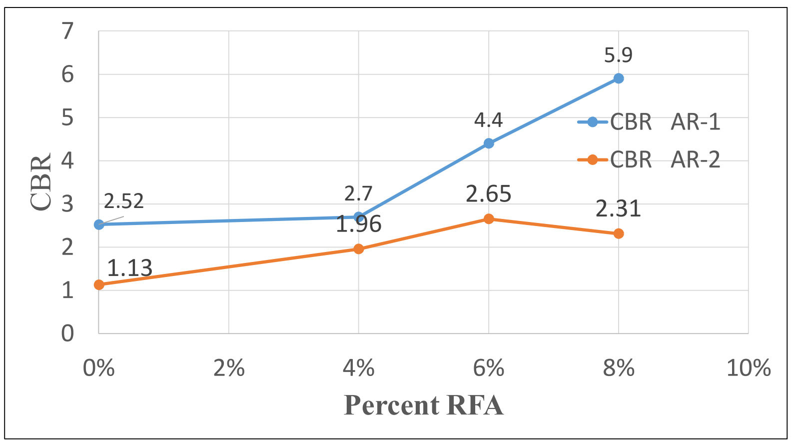


HL provided the Highest UCS for both soil
RHA shows better performance in AR-1 soil than in AR-2 soil.
Strength development correlates with the CBR test

California Bearing Ratio



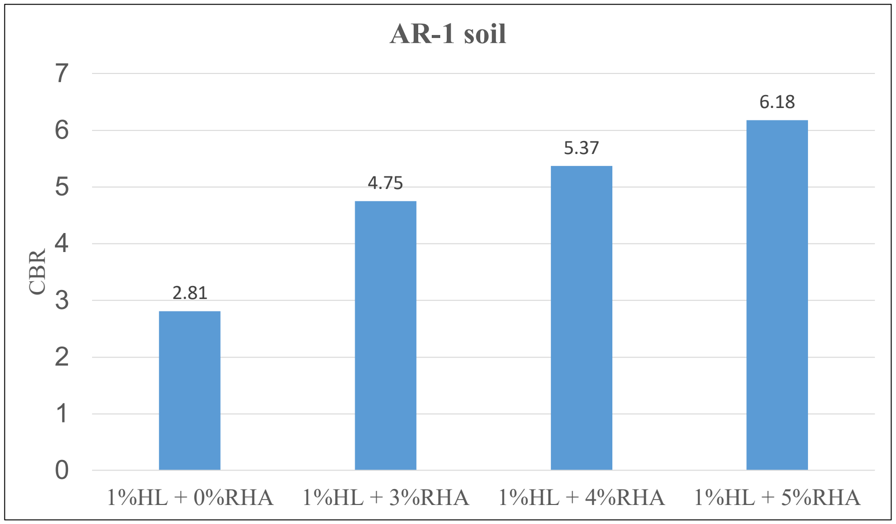




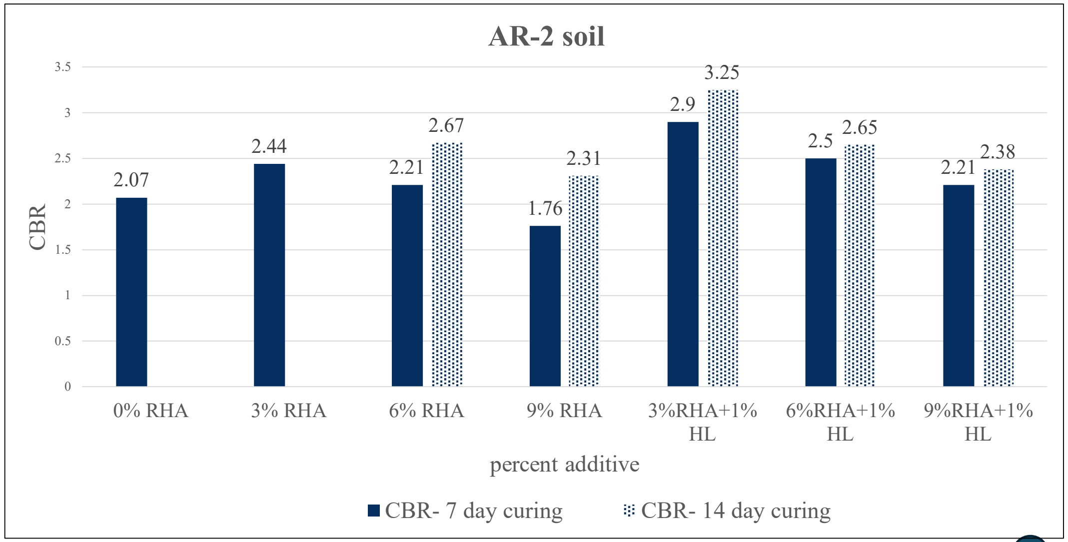
All stabilizer improves the CBR value.
RHA and RFA show better performance in AR-1 soil.
HL shows consistent results for both soils

California Bearing Ratio (cont.)

Combined Treatment of RHA and HL in **AR-1 Soil**



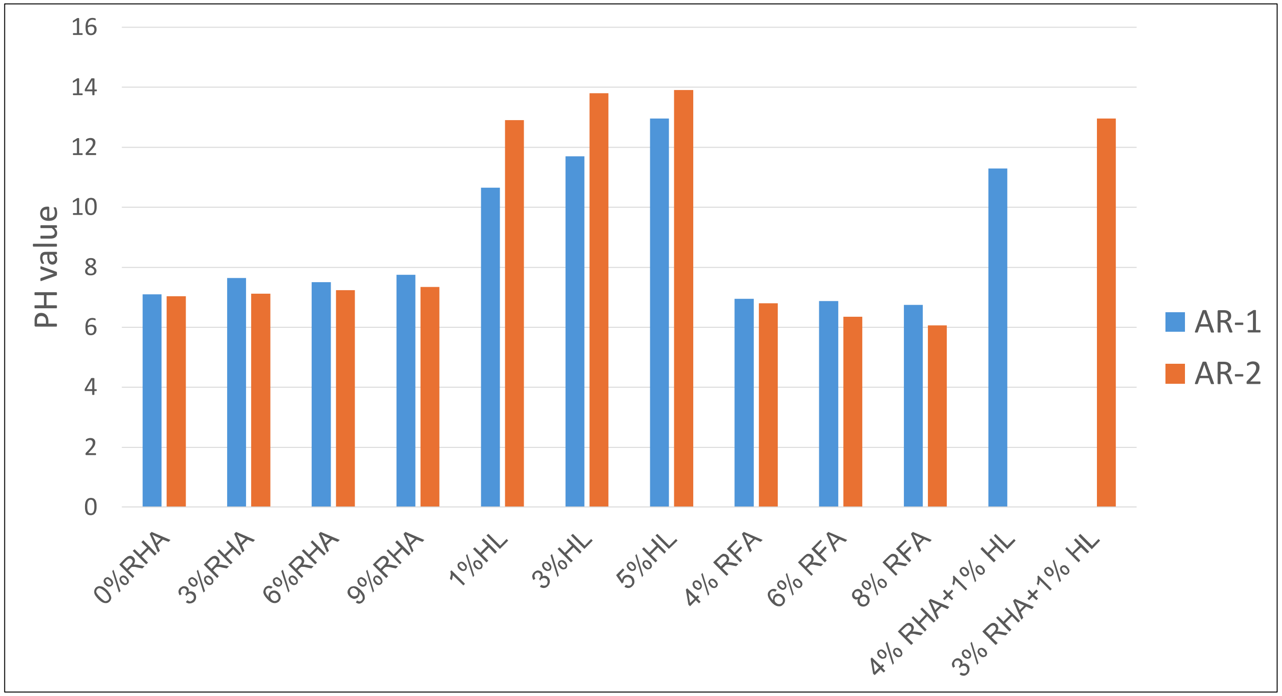
Combined Treatment of RHA and HL in **AR-2 Soil**



A combination of 1%HL and RHA shows improved performance than RHA alone.

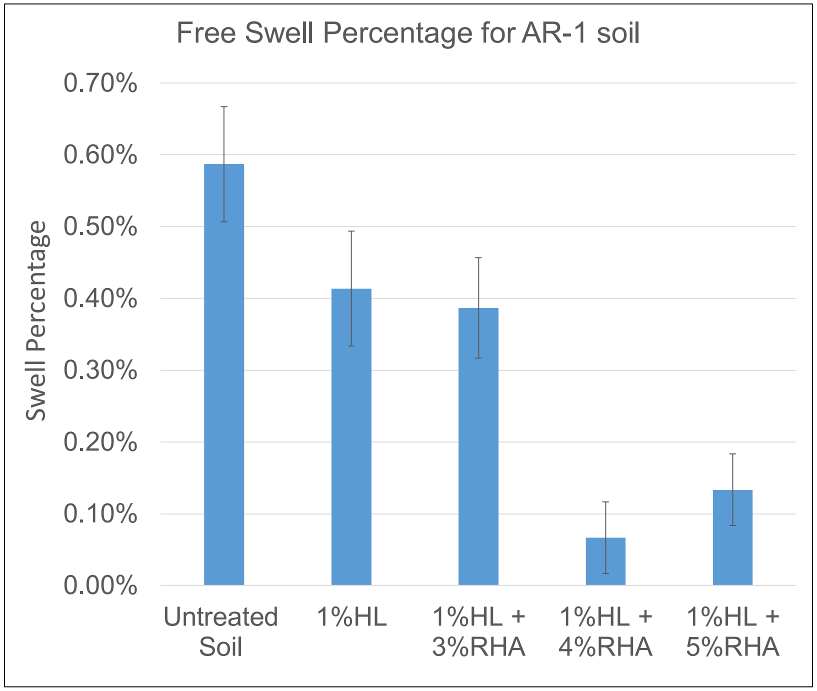
- A combination of 1% HL and RHA shows improved performance than RHA alone.
- 14-day cured specimen shows improved performance over 7-day cured specimen.

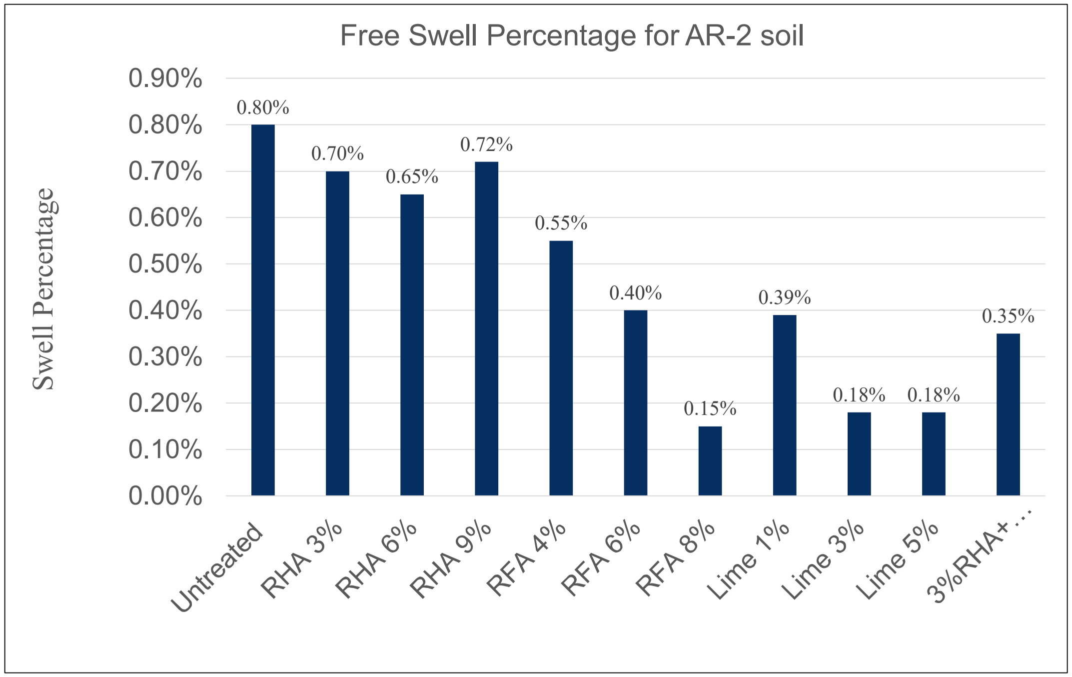
pH Measurement



HL-treated soil shows high pH.
Combined HL and RHA also shows a high pH value (desired 10 to 12).

Swell Behavior





Swell percentage reduced significantly for AR-1 soil when added with HL and RHA blend.

- For AR-2 soil, HL and RFA both significantly reduce the swell percentage. 1% HL + 3% RHA also shows pronounced swell reduction.

Conclusion and Recommendation

- **Both RHA and RFA improved subgrade soil properties**—including strength, bearing capacity, and swell behavior
- **Hydrated Lime (HL)** showed the **highest strength improvement** but was **costly**.
- **RHA performance was soil-dependent** and improved when blended with **1% HL**.
- Curing period is a significant factor in gaining soil strength.
- **Reclaimed Fly Ash (RFA)** improved strength and reduced swell but required higher dosages, increasing cost.
- **Recommendation:**

✓ **AR-1 (A-6):** 1% HL + 4% RHA → reduced swell by **89%** and improved CBR.

✓ **AR-2 (A-4):** 1% HL + 3% RHA → balanced strength and swell reduction

Part B

Micronized Rubber Powder (MRP) as an Alternative to Polymer Modifiers in Asphalt Pavement

Background

- About **300M waste tires/yr** are generated in the US=> env. Challenges
- **AR** incurs tire management costs of over **$3M/year.**
- In recent years, waste tires have gained significant attention as a modifier for asphalt in the form of **crumb rubber modifier (CRM).**
- To enhance the durability of asphalts, **polymeric modifiers** (SBS, SBR, Natural rubber, etc.) have been used.
- **SBS** is the most widely used modifier, improving **elasticity, fatigue resistance, and rutting performance**, but it has drawbacks such as **high cost**, **increased viscosity**, and uncertain long-term behavior.
- **CRM in the form of Micronized Rubber Powder (MRP)** can be an alternative to SBS

Waste tire landfill.

Photo Source: google.com

Background

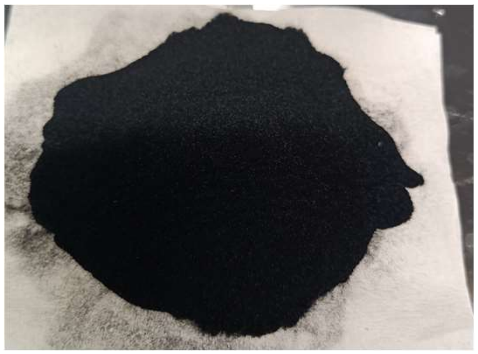
- **CRM** offers a **sustainable, and cost-effective alternative**, reducing environmental
- **Mixing process (dry/wet), CRM amount & size** influence the properties of rubber-modified asphalt.
- **Large particle size** is responsible for the separation problem, and dry process doesn't provide good compatibility bet. asphalt and rubber
- Most studies have focused on particles size ranging **from 9.5 mm to 75 μm**
- **V**ery few have investigated mesh sizes **less than 75 μm.**
- In this study, **Micronized Rubber Powder (MRP, <75 μm)** was incorporated (**wet method**) into a **virgin PG 64-22** binder to evaluate its performance and then compared with that of a **SBS-modified PG 70-22**.

Objectives

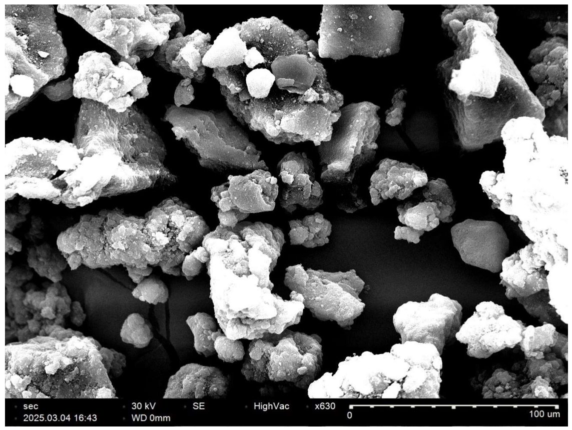
- Assess the feasibility of modifying asphalt using **MRP as an alternative to SBS polymer.**
- Observe the **rheological properties**, including viscosity, complex modulus, creep recovery, and low temperature stiffness of **rubber powder modified asphalt (RPMA).**
- Observe the **storage stability** of RPMA and moisture susceptibility
- Evaluate the **cracking, rutting, and fatigue resistance** of the asphalt mixture made with RPMA binder.
- Determine the **optimum dose** of rubber powder to get the expected performance.

Materials

Micronized Rubber Powder



MRP



SEM image of MRP

- MRP was collected from Entec Inc., Indiana.

Parameters	Approximate Value	Test Method
Acetone Extractables	4.0-25%	ASTM D6370
Ash Content	8.0%	ASTM D6370
Carbon Black	26-38%	ASTM D6370
Natural Rubber	10.0-45.0%	ASTM D6370
Rubber Hydrocarbon	42.0%	ASTM D6370
Moisture Content	1.0%	ASTM D1509
Bulk Density	25 lb/ft^3	ASTM D1513
Specific Gravity	1.15	ASTM D297

- According to ASTM D 5644, its maximum particle **size was 75 µm (99% passing #200 mesh).**

- Virgin PG 64-22 and SBS modified PG 70-22 were collected from **Ergon Asphalt & Emulsions Inc.**

Materials | Aggregates

1. 1/2" Sandstone (744105) -Vulcan Materials Co., Judsonia, AR.
2. 1/2" Sandstone (80869)-Vulcan Materials, Black Rock, AR
3. 1/2" Screenings (74752)-White River Materials, Inc. - Cord AR
4. 1/4" Screenings (116862)-Capital Quarries - Pocahontas, AR
5. Man. sand (116863)-Capital Quarries - Pocahontas, AR
6. Concrete Sand –(116971)- Capital Sand Co. - Harrisburg South AR
7. RAP (265) -Atlas Asphalt, Jonesboro, AR

Sieve Size (mm)	Aggregates SL No.							Job Mix
	1	2	3	4	5	6	7	
12.5	100	100	100	100	100	100	100	**100**
9.5	90	94	95	100	100	100	92	**95**
4.75	21	33	68	90	90	97	68	**62**
2.361	5	8	45	57	55	82	47	**40**
1.18	2	3	29	36	30	70	34	**27**
0.6	1	3	19	24	18	51	26	**19**
0.3	1	2	11	13	6	1	12	**10**
0.15	1	2	11	13	6	1	12	**7**
0.075	0.5	1.9	9.4	10.5	4.1	0.2	9.2	**5.2**
Cold Feed %	24	8	14	13	9	12	20	
Gsb	**2.616**	**2.766**	**2.716**	**2.731**	**2.745**	**2.619**	**2.695**	

Methodology

Nomenclature

PG 64-22: Virgin PG 64-22 (control)

MR 05: control with 5% MRP

MR 10: control with 10% MRP

MR 15: control with 15% MRP

PG 70-22: 2% SBS Modified

Blending Protocol

- Blending protocol: **170 °C, 1000 rpm, Mixing duration: 60 min**
- Based on several trials and corresponding literature reviews

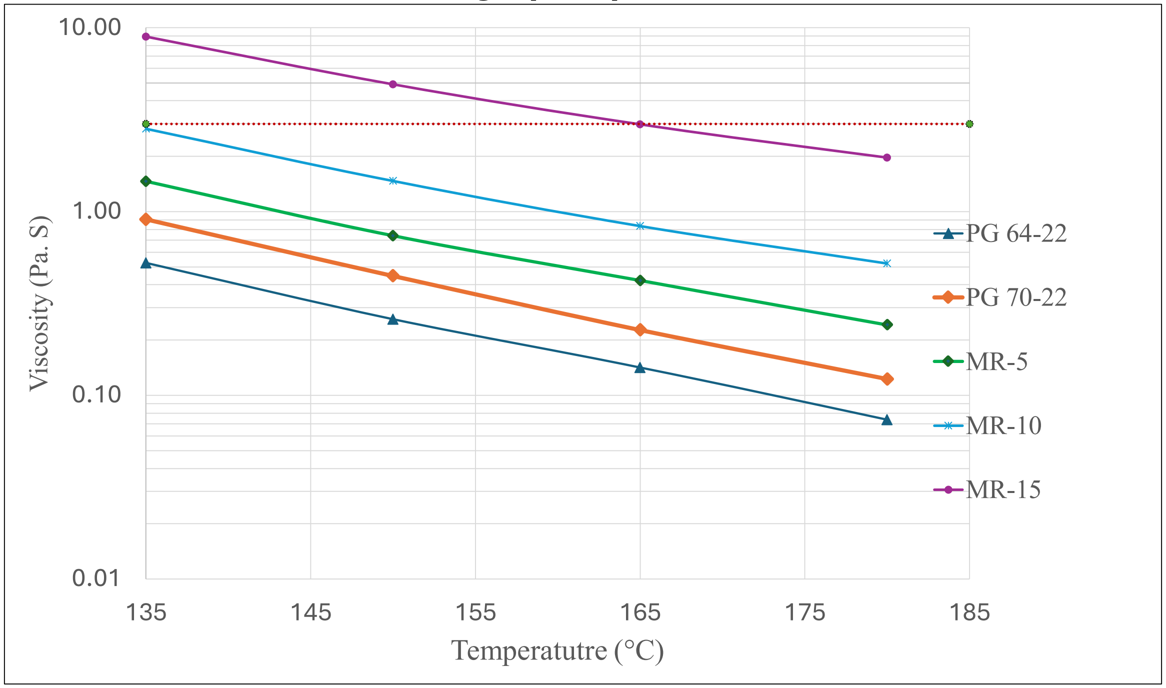
RPMA -rubber powder modified asphalt

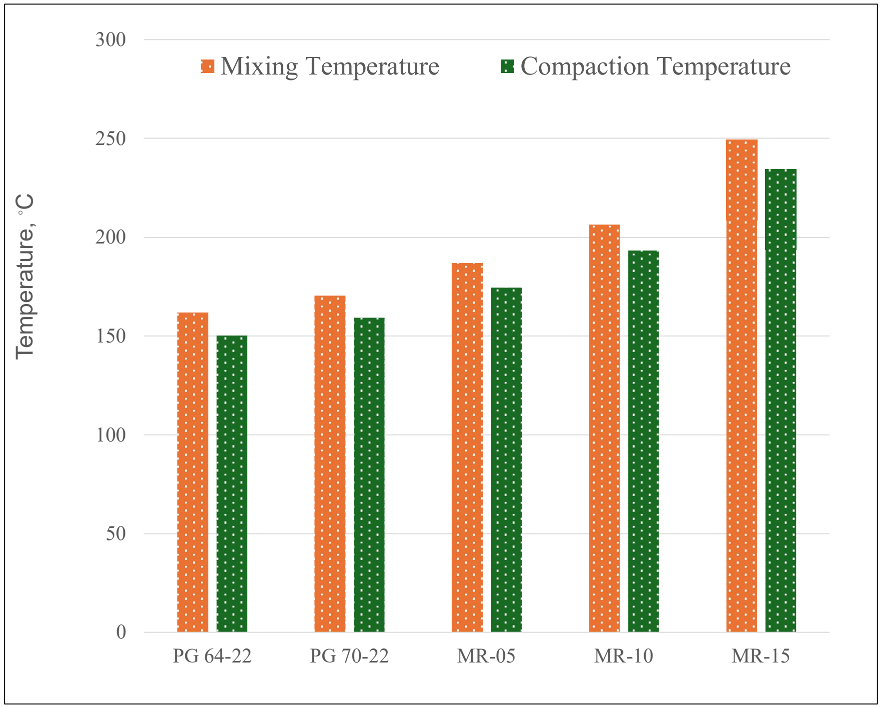
SMB- SBS modified Binder

Tests	Standard	Conditions
Short-term Aging	AASHTO T 240	RTFO, 163 °C, 85 mins
Long-term Aging	AASHTO R 28	PAV,100°C, 2.10 MPa pressure, 20 hours
Viscosity	AASHTO T 316	20 rpm, 135 to 180°C with 15 °C interval
DSR	AASHTO T 315	Unaged, RTFO, and PAV aged
MSCR	AASHTO T 350	RTFO sample, 0.1 kPa and 3.2 kPa
BBR	AASHTO T 313	PAV aged, -12 °C and -15 °C
Elastic recovery	AASHTO T 301	unaged and RTFO, 25±0.5 °C,
Storage Stability	ASTM D7173	163°C for 48 hours, cooled at –10°C for 4 hours, and cut into three parts
IDEAL CT	ASTM D8225	2 hours at 25°C,
IDEAL RT	ASTM D8360	at 50 °C for 2 hours.
AFM	Literature	$CaCO_3$ and SiO_2 modified Probes.
FTIR	Literature	KBr substrate, 50 scans, humidity 5%

Result and Discussion

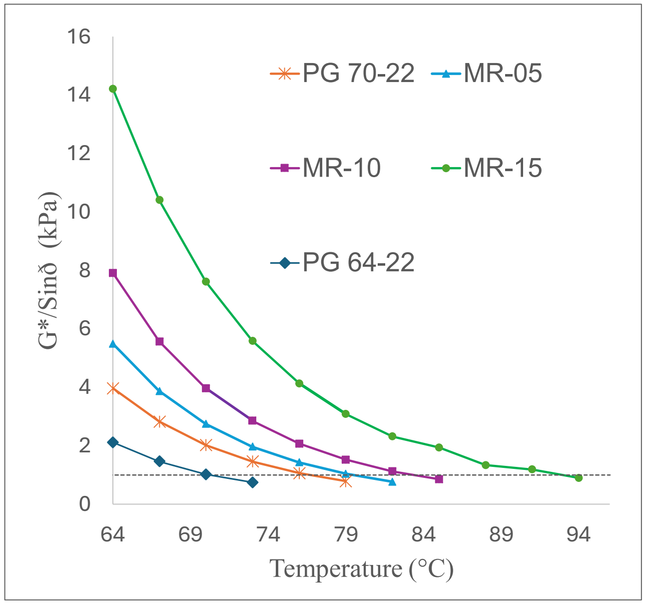
Rotational Viscosity (RV) Test



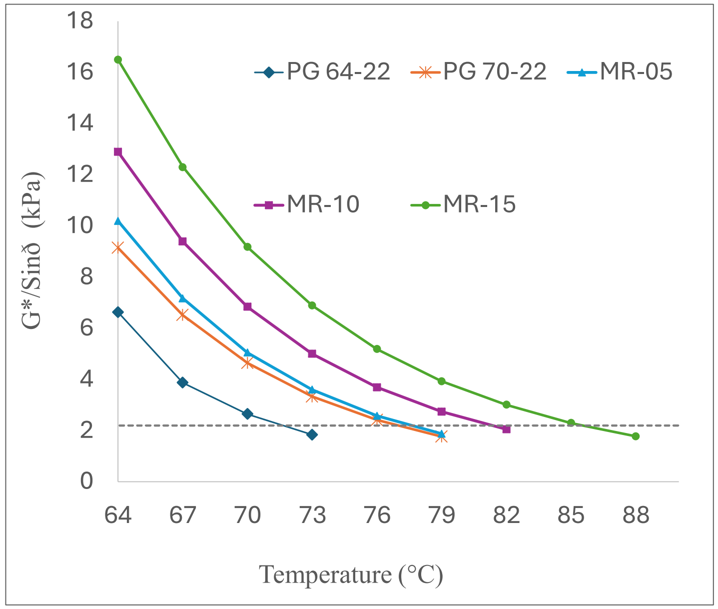


- Viscosity is increased with the increase of rubber content.
- MR-15 binder exceeds the maximum Superpave viscosity limits of 3.0 Pa.s at 135 °C
- Asphalt Institute report advises that laboratory mixing temperature should not exceed 177 °C

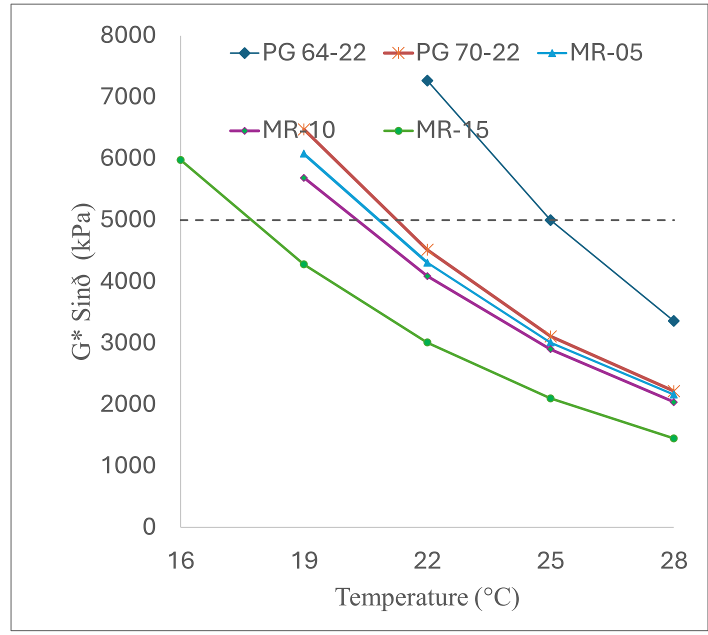
Dynamic Shear Rheometer Test



Unaged



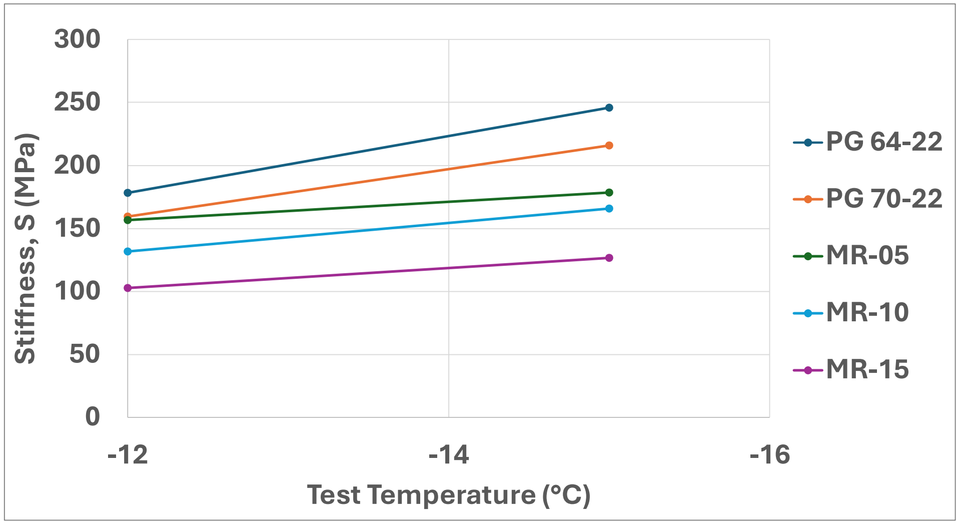
RTFO



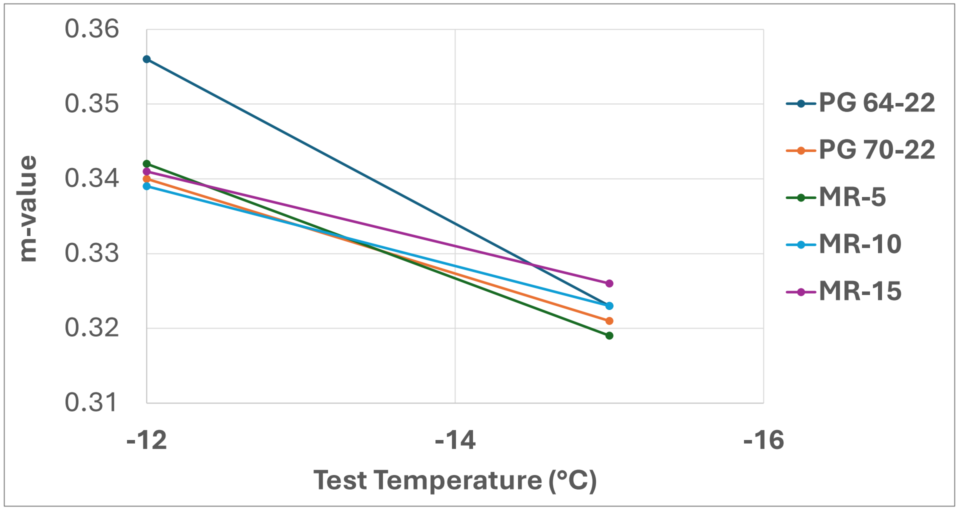
PAV

- G* /sinð values are increased significantly with the increasing concentration of MRP
- Complex (favorable) physical interaction between rubber and asphalt is attributed to this phenomenon.
- MRP-modified binder showed higher rutting resistance than SBS-modified binder.
- MRP-modified binder showed better fatigue resistance than SBS-modified binder

Bending Beam Rheometer (BBR)



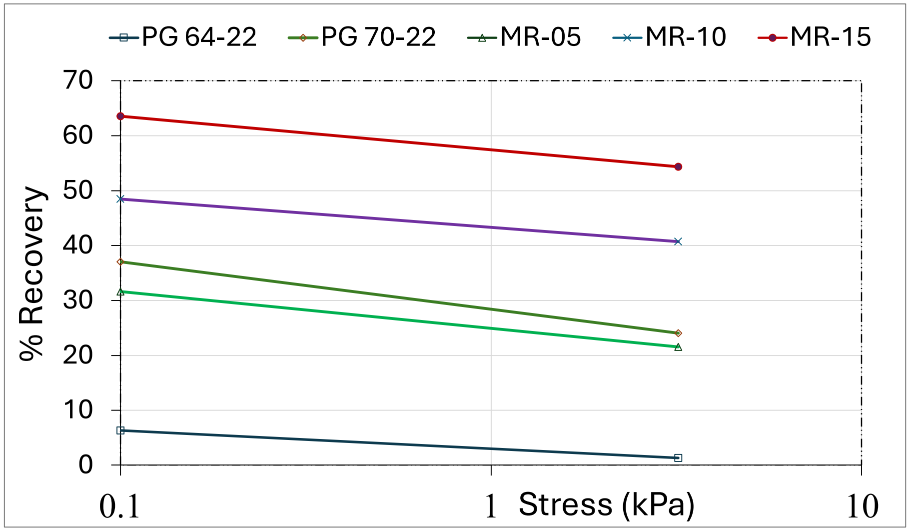
low temperature stiffness

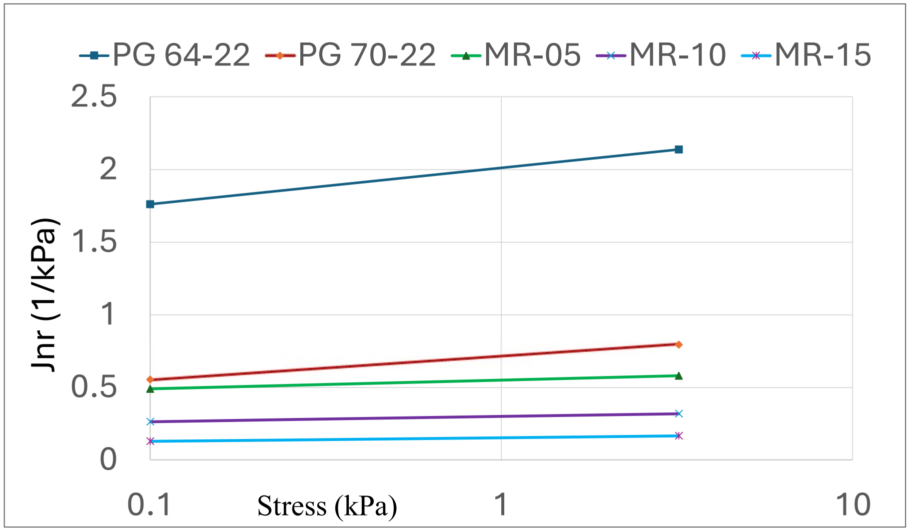


Variation of m-value

- Stiffness value declined by **11%, 21%, and 37% at -12 °C** with **5%, 10%, and 15%** MRP, respectively
- RPMA-binder had relatively lower stiffness than the SMB and control binders.
- All passed the m-value; a slight deviation in the trend was observed. This phenomenon has occurred due to the **elastic nature** and **stress-relaxing** capacity of rubber.

Multiple Stress Creep Recovery (MSCR)





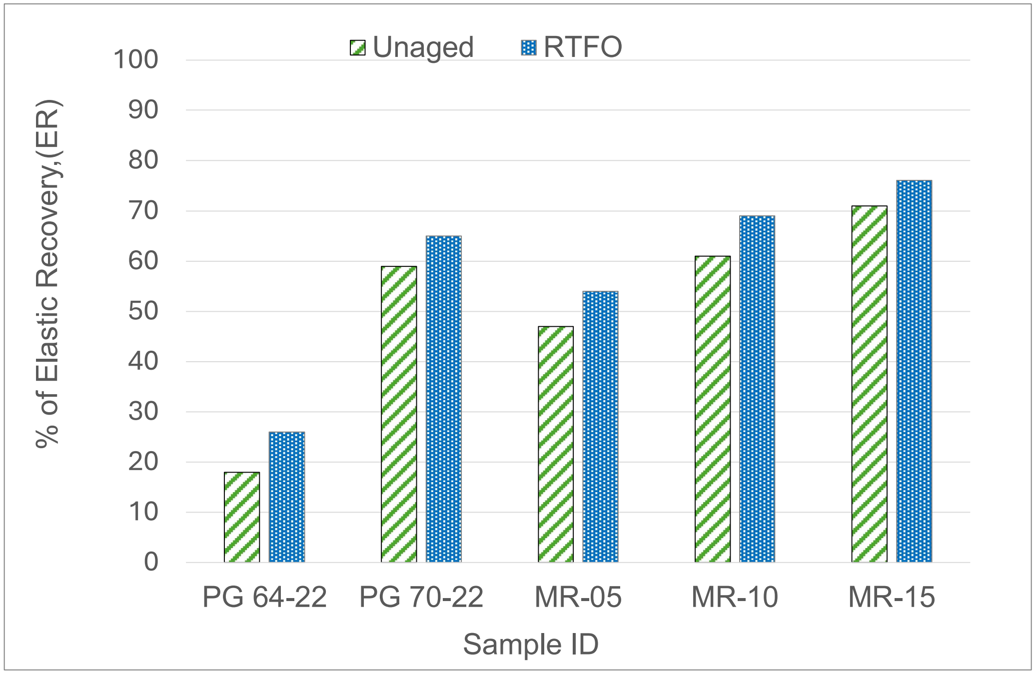
- Adding rubber into asphalt increases the recovery potential as well as reduces the J_{nr} value.
- This phenomenon may be attributed to the higher elasticity and shock-absorbing capacity of the rubber.
- RPMA can endure greater stress and release that stress more quickly than unmodified asphalt and SBS-modified binder.

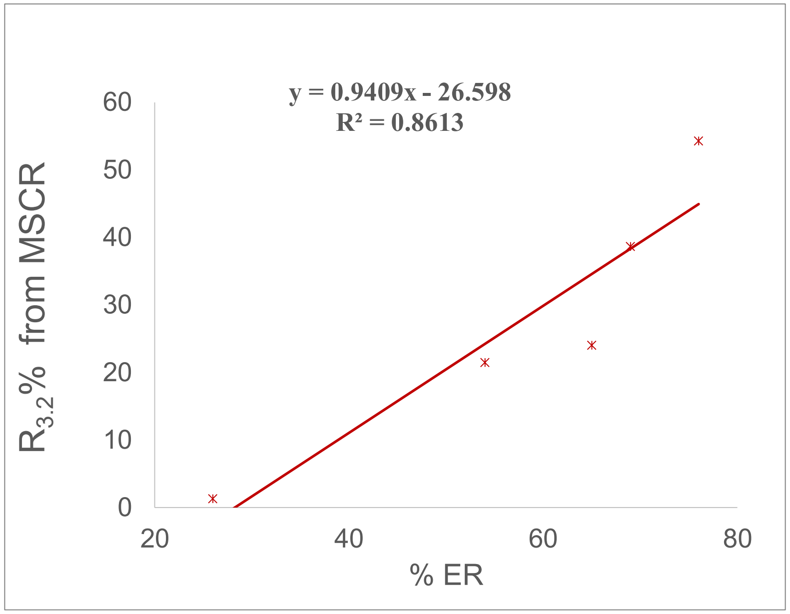
Performance Grade (PG)

Sample Name	Superpave acceptance criteria of the rutting factor			Superpave acceptance criteria of Low temperature				Overall PG grade (°C)	Based on MSCR test results		
	Unaged (°C)	RTFO (°C)	High PG (°C)	Critical Temp. (S>300 MPa)(°C)	Critical Temp. (m<0.3) (°C)	Failure Temp. (°C)	Low PG (°C)		Meet AASHTO TP 70	Meet AASHTO MP 19 (Jnrdiff<75%)	Traffic Level
PG 64-22	64	70	**64**	-18.54	-17.09	-27.09	**-22**	64 -22	NO	YES	**H**
PG 70-22	70	76	**70**	−19.48	-17.21	-27.21	**-22**	70 -22	NO	YES	**V**
MR-05	76	76	**76**	−31.65	-17.4	-27.4	**-22**	76 -22	NO	YES	**V**
MR-10	82	76	**76**	−26.82	-19.8	-29.8	**-28**	76 -28	YES	YES	**E**
MR-15	88	82	**82**	-36.71	-20.2	-30.2	**-28**	82 -28	YES	YES	**E**

- High PG grade is increased by two grades for MR-5 and MR-10, and three levels for MR-15, respectively.
- MR-10 and MR-15 achieved one grade higher low-temperature PG of –28 °C in contrast to the control and SBS Modified.
- MR-10 and MR-15 passed the minimum recovery criteria.
- PG 70-22 as "**V**" (very high traffic), **MR-10 and MR-15** are in the " **E**" category, extreme traffic capacity exceeding 30 million ESALs

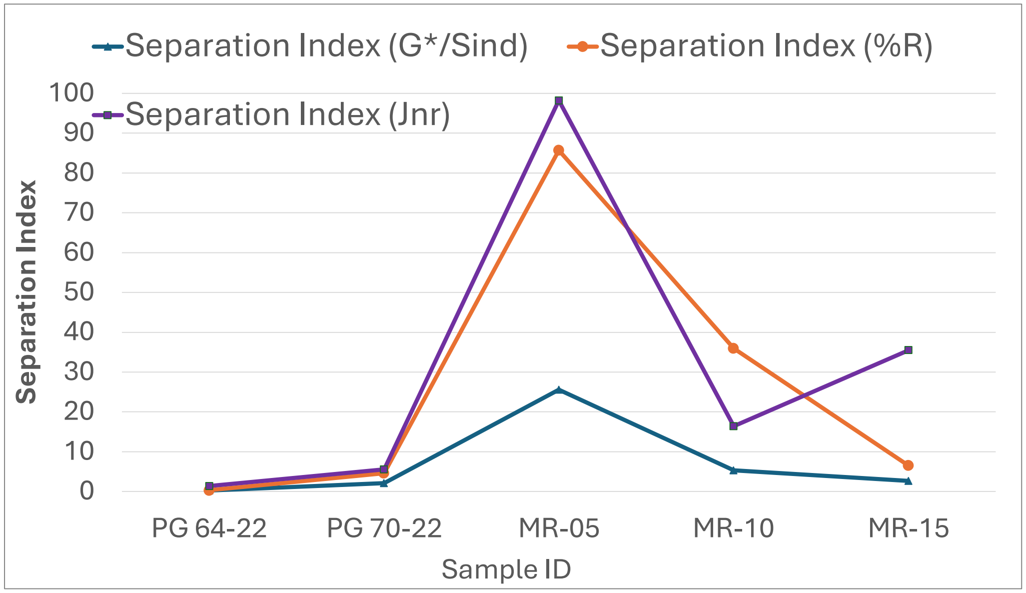
Elastic Recovery





- RPMA asphalts increased strain recovery potential with the rising percentage of MRP
- Except PG 64-22, all RTFO-aged binders passed the minimum recovery criteria (40%) of AASHTO T301
- Unaged **PG 70-22 shows 59% recovery**, whereas **MR-15 shows 76%.**
- A **strong correlation between the MSCR recovery and the elastic recovery** is found

Storage Stability



Cigar Tube Sample

- MR-5 exhibited the highest Separation Index among the modified binders, indicating poor storage stability
- **MR-10 and MR-15, despite containing higher MRP, showed lower SI values.** This is attributed to the reduced inter-particle distance at higher MRP contents, which enhances structural stability

Mixture Performance

IDEAL CT Mixture Properties

Mix ID	G_{mm}	G_{mb}	Air Void	Specimen Height	Diameter
PG 64-22	2.467	2.303	6.6	61.9	150 mm
PG 70-22	2.482	2.314	6.8	62.4	
MR-5	2.486	2.311	7.0	62.2	
MR-10	2.495	2.331	6.6	62.2	
MR-15	2.508	2.341	6.7	62.1	

Mix Design Parameters

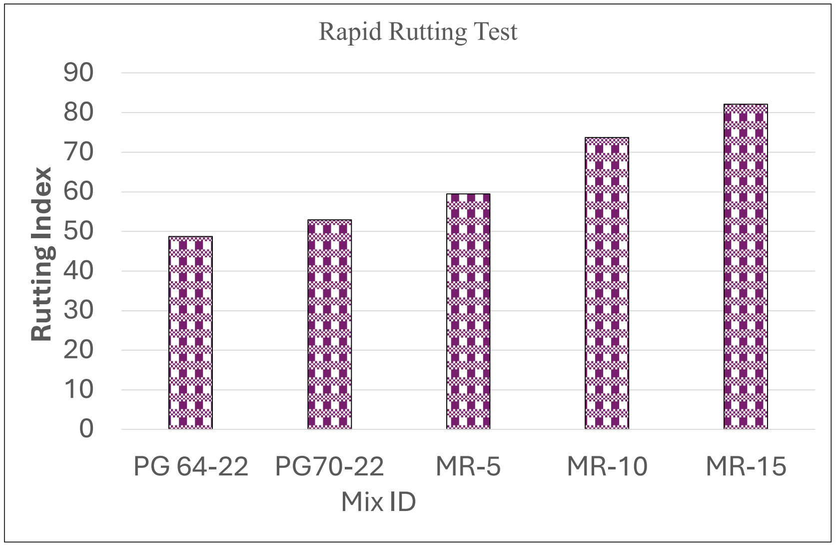
Parameters	Value
Total Asphalt Content:	5.8 %
RAP AC :	5 %
New Asphalt Content%:	4.8 %
Air Voids (Va):	3.5 %
N_{des}:	60
Fines to Asphalt Ratio:	0.95
VMA:	16.2 %
VFA:	78.3 %

- A **9.5 mm ACHM** surface course mixture was prepared.
- **Binder content was the same** in all samples
- One set of samples was conditioned in a **water bath for 24 hours at 25°C**, and another set for **2 hours at 25°C** to observe the effects of prolonged conditioning.

IDEAL CT test sample

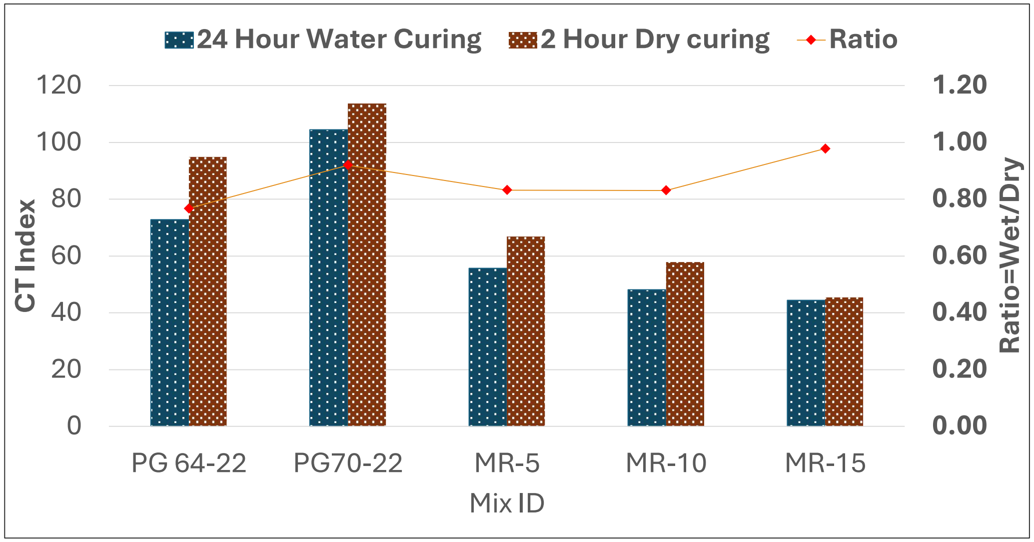
Mixture Performance

IDEAL RT Test Results



This trend suggests that incorporating <u>MPR enhances the asphalt mixture's ability to resist permanent deformation</u>. It is attributed to the elasticity and stress-absorbing capacity of rubber

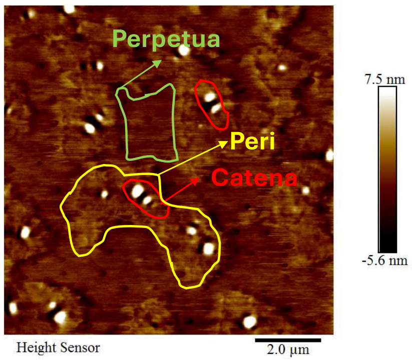
IDEAL CT Test Results



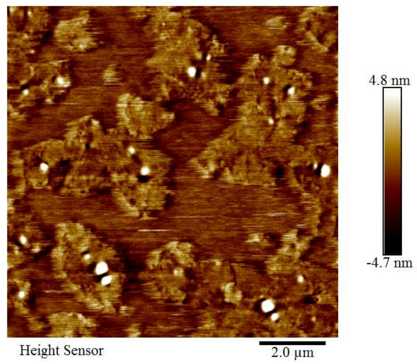
- Construction-phase thresholds 72–97 for good durability
- A common goal is a CT index> 30 for reheated mixes
- The overall lower CT Index of RPMA mixtures may be attributed to weak bonding

AFM Test Results

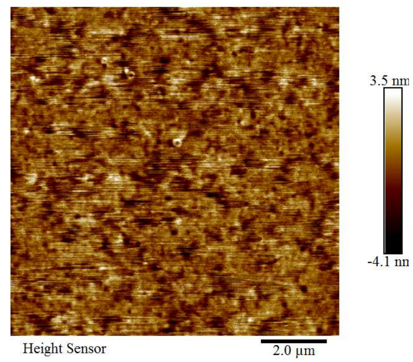
Height Sensor



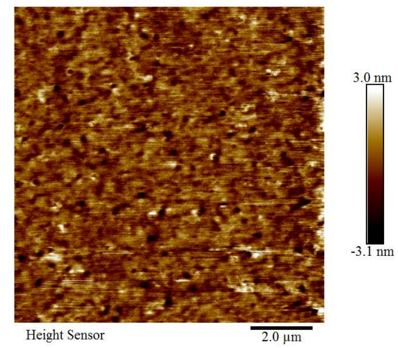
PG 64-22-Unaged Dry



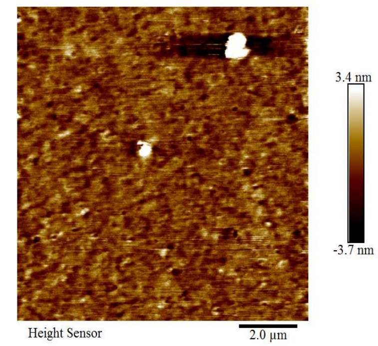
PG 70-22-Unaged Dry



MR-5-Unaged-Dry



MR-10-Unaged Dry



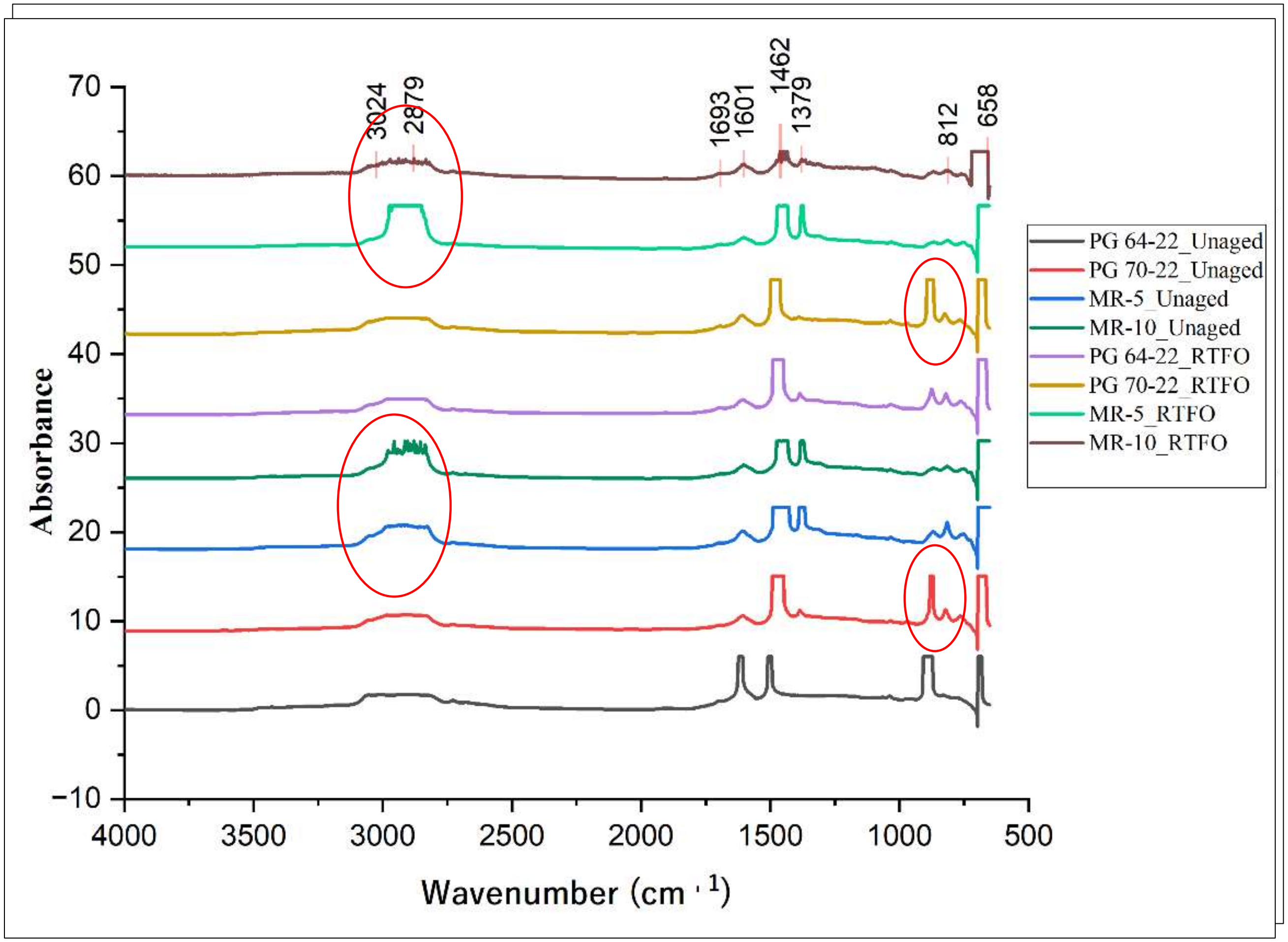
MR-15-Unaged Dry

- The height sensor reveals that surfaces of the RPMA binders are relatively smoother than PMB and control binder.
- For PG 64-22 and PG 70-22, the catena and peri phase are dominating and clearly visible. MRP prevents the elimination of VOCs from the binder surface, thereby minimizes the roughness.

FTIR Test Results

FTIR Test Results

- 3000 cm-1 the C-H stretch (aromatics).
- Higher peak at 960 cm^{-1}, indicating SBS's presence in PG 70-22
- At 880 cm-1, C=C; at 1380 cm-1, C-H (bend) show the component of MRP in RPMA.
- Most % of the IRs were absorbed by the MR-15 sample during the test, resulting in a very irregular spectrum



Conclusions

- All MRP binders show increased viscosity
- **MRP-15 exceeds Superpave limits**, indicating higher mixing/compaction temperatures.
- Higher **G*/sin δ**, better permanent deformation resistance, and **upgraded high-temp PG**.
- Lower stiffness → improved stress dispersion and **upgraded low-temp PG level**.
- MR-10 and MR-15 met AASHTO MSCR criteria, with **better elastic recovery** under **extreme traffic**.
- MRP-15 shows better thermal stability (cigar tube test); higher rubber content **reduces sedimentation**.
- Amount of larger "Bee-like" wax structures reduced, but tiny bee structure increased; consequently, the **surface roughness also was reduced**.
- From FTIR, **no chemical reaction** was observed; only physical interaction between MRP and binder
- Higher rutting resistance but lower cracking tolerance compared to SMB due to weak chemical bonding.
- Up to date, **RPMA binder outperforms SBS-modified PG 70-22** in most aspects;
- **15% MRP** is optimal for further research and field performance evaluation.

Future Works

i) Additional mixture performance tests.

ii) Assessment of field performance through pilot-scale project.

iii) Performing life cycle and cost analysis.

iv) Further research on long-term performance, under extreme conditions, and higher percentages of modifier.

v) Prepare the standard protocol for the agency towards field implementation.


Thank You all