Technical Advisory Panel (TAP) Meeting

March 28, 2024

Evaluation of Proprietary Rejuvenators

(Tasks 3.2 and 4.2: Laboratory and Field Studies' Update on Freshly Rejuvenated Test Sections)

Presented by

Tanzila Islam, *M.Sc.*
Graduate Research Assistant
Michigan State University

Research Team

Poornachandra Vaddy, *M.Tech.*
Graduate Research Assistant
Michigan State University

Dr. M. Emin Kutay, *Ph.D., P.E.*
Professor and PI
Michigan State University

Dr. Syed Waqar Haider, *Ph.D., P.E.*
Associate Professor and Co-PI
Michigan State University

Dr. Bora Cetin, *Ph.D.*
Associate Professor and Co-PI
Michigan State University

Outline of the Presentation

MICHIGAN STATE UNIVERSITY

Introduction

- Project summary
- Progress update

Field Experiments and Results

- Sand patch test
- Dynamic friction test (DFT)
- Permeability

Laboratory Experiments and Results

- ***Creep stiffness:*** Bending Beam Rheometer (BBR) test
- ***Surface friction:***

→ Hamburg abrasion test

→ British Pendulum test

INTRODUCTION

Background

- Asphalt pavements ***age with time*** → Stiffening & embrittlement of asphalt mixture
- **Spray-on Rejuvenators (SORs):** Petroleum/bio-based products sprayed on asphalt pavements to ***reverse*** *or* ***retard the aging*** of asphalt binder
- **Prospects:**
  - ✓Prolong the service life
  - ✓Reduce maintenance costs
  - ✓Enhance the flexibility of asphalt
  - ✓Seal the minor cracks in the surface layers
  - ✓Reduce the permeability of surface courses
- **Concerns:** Potential reduction in mean texture depth and pavement friction; surface softening

Field Application of SORs

- **Current project: LRRB Research Need Statement-626**
  - Contract between LRRB and MSU
- **Project locations:** MnROAD research facility and 15th street, St. Michael, MN
- **Test section IDs:** MnROAD28, MnROAD34, and 15th street
- Each test section was divided into multiple test cells; a total of ***12 different SORs*** were applied on each test cell on every test section
- The SORs are ***grouped based on the application of fine sand/gravel*** after/along with the SOR
  1. Group A: No fine sand/gravel was applied
  2. Group B: Fine sand/gravel was applied

SOR: Spray-on-rejuvenators

Field Application of SORs

Group	SORs	Composition
Group A	BioMAG™	Bio-based
	BioRestor®	
	BioRestor® Low VOC	
	Delta Mist®	
	Invigorate™	
	RePlay™	
	RPE-R	Petroleum-based
Group B	ARA1 Ti	
	CRF®	
	GSB-88®	
	Reclamite®	
	Replenify™	

Application of SOR on an asphalt pavement

Field Application Video

SOR: Spray-on-rejuvenators

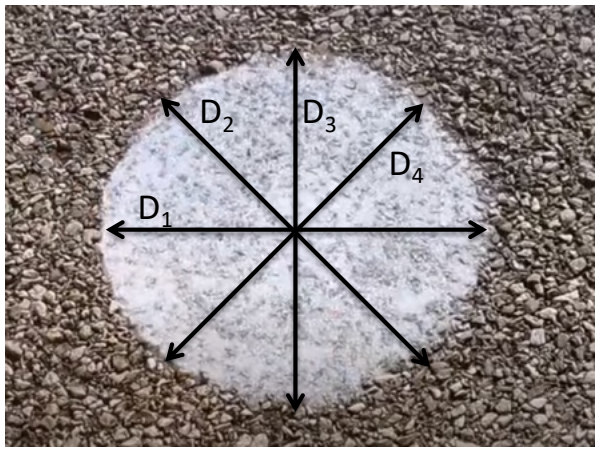
Field Experiments and Results

Sand Patch Test

- To measure the mean texture depth (MTD) of a pavement surface (ASTM E965)

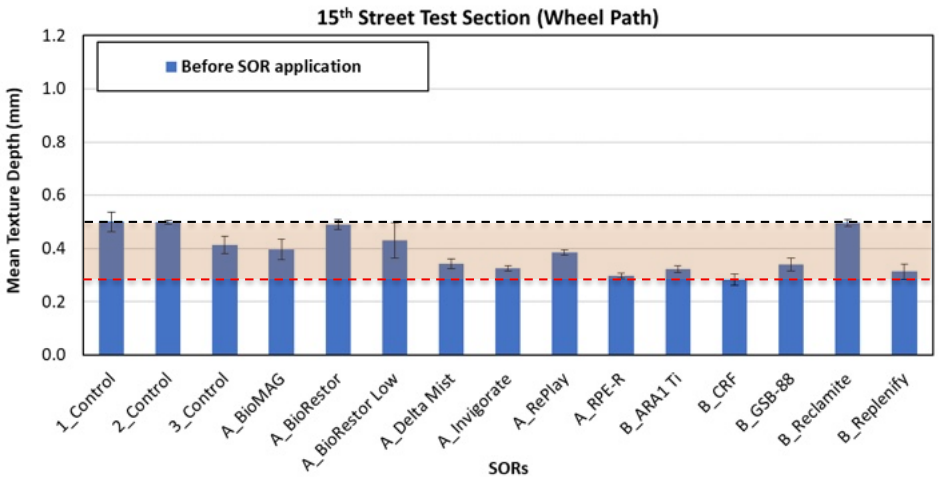
$$MTD = \frac{Volume\ of\ sand\ or\ glass\ beads}{Area\ of\ the\ patch}$$

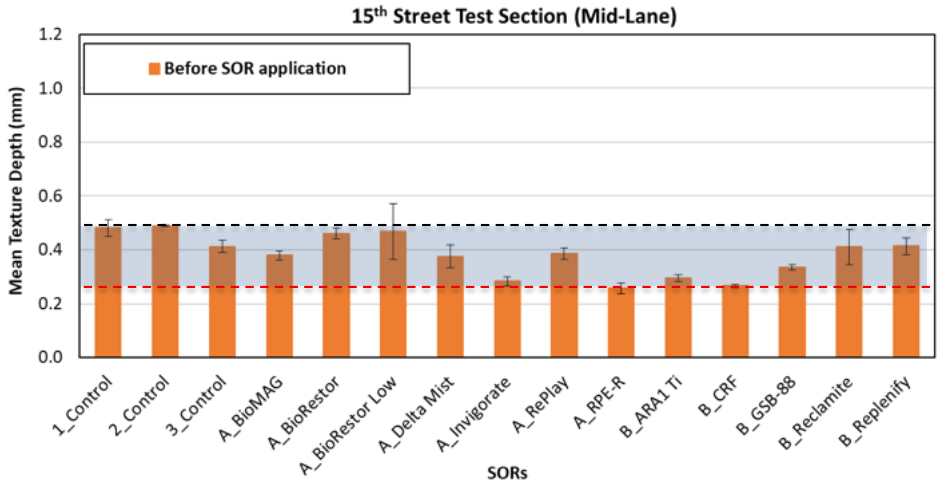
- Related to pavement friction
- Decrease in MTD is expected with the SOR application



SOR: Spray-on-rejuvenators

Sand Patch Test (15th Street)





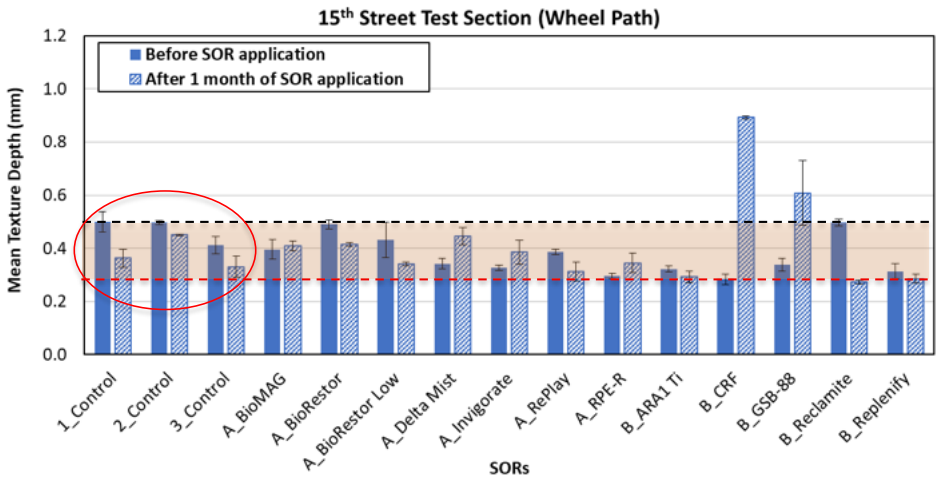
15th street test cells; before SOR application

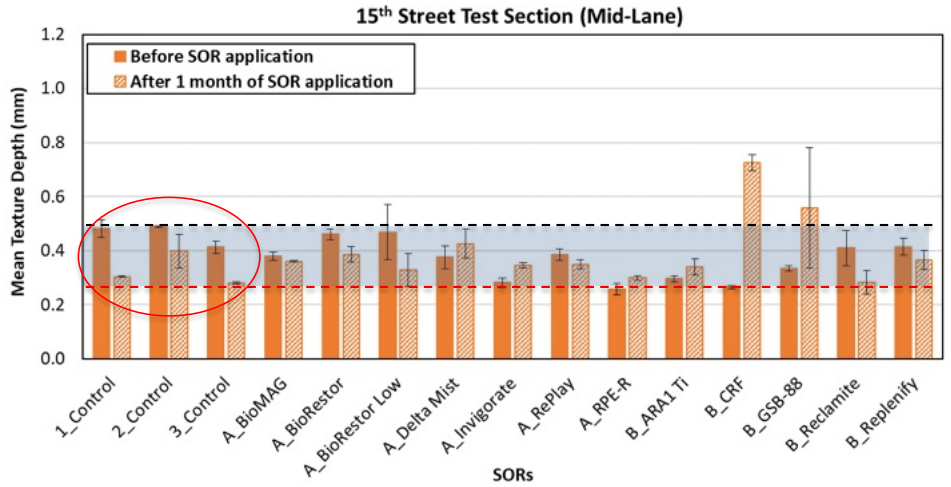
Before SOR application

- *Field variability:* MTD values varied between 0.3 and 0.5 mm
- *No significant difference* in wheel path and mid-lane MTD values

SOR: Spray-on-rejuvenators

Sand Patch Test (15th Street)





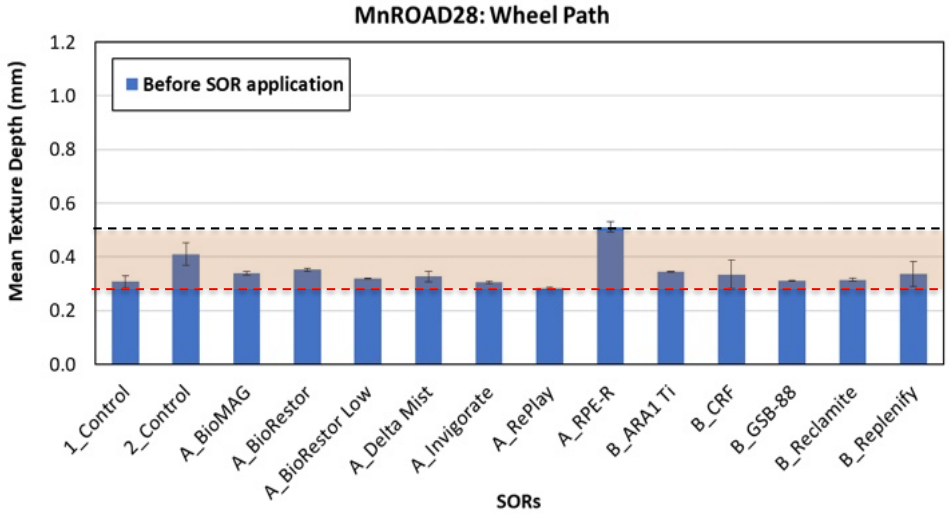
15th street test cells; before and after a month of SOR application

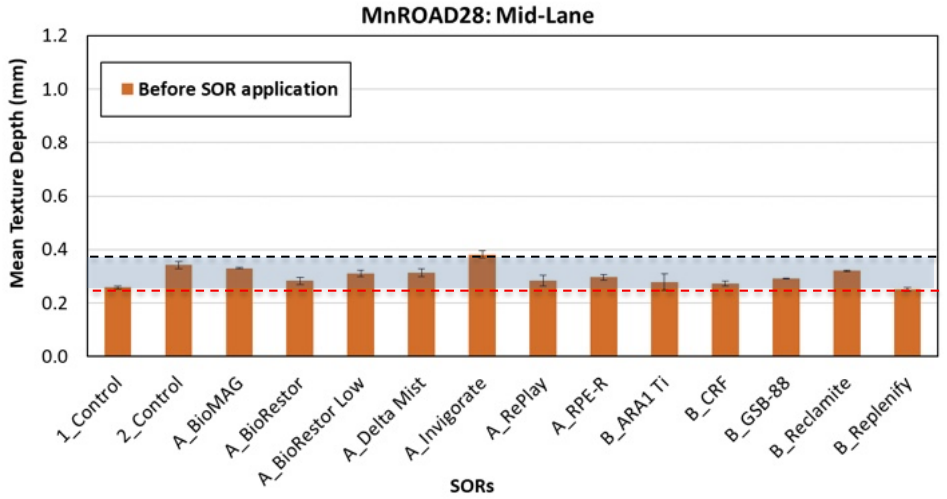
After SOR application

- *No significant decrease after 1 month of SOR application*
  - Exception: Increase in MTD in the cells treated with CRF and GSB-88

SOR: Spray-on-rejuvenators

Sand Patch Test (MnROAD28)





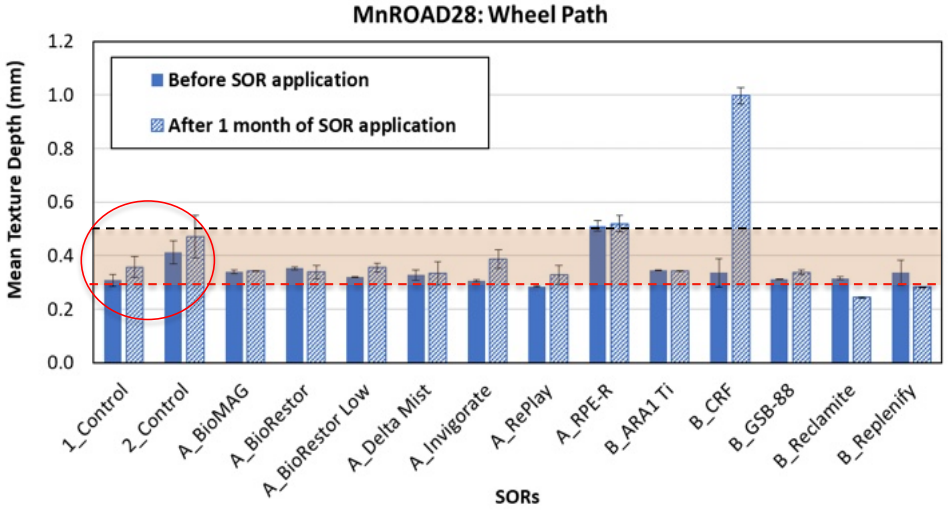
MnROAD28 street test cells; before SOR application

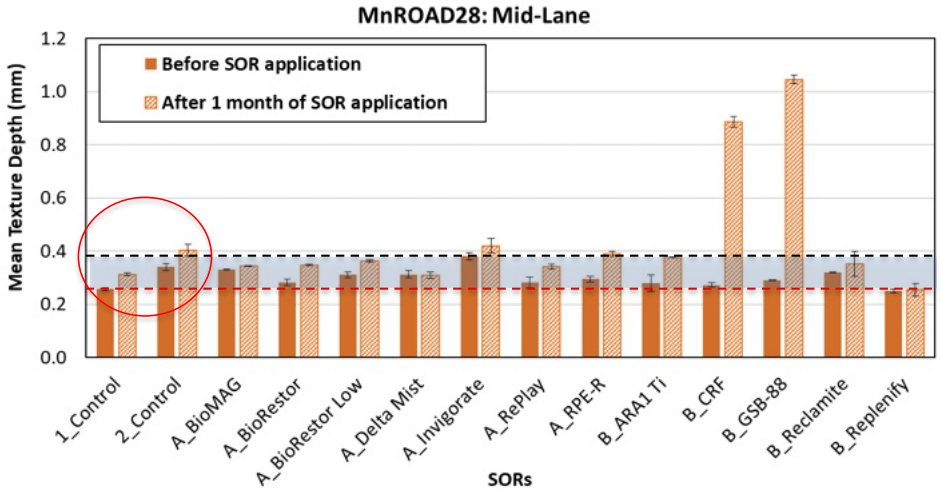
Before SOR application

- *Field variability:* MTD values varied between 0.3 and 0.5 mm
- No significant difference in wheel path and mid-lane MTD values

SOR: Spray-on-rejuvenators

Sand Patch Test (MnROAD28)





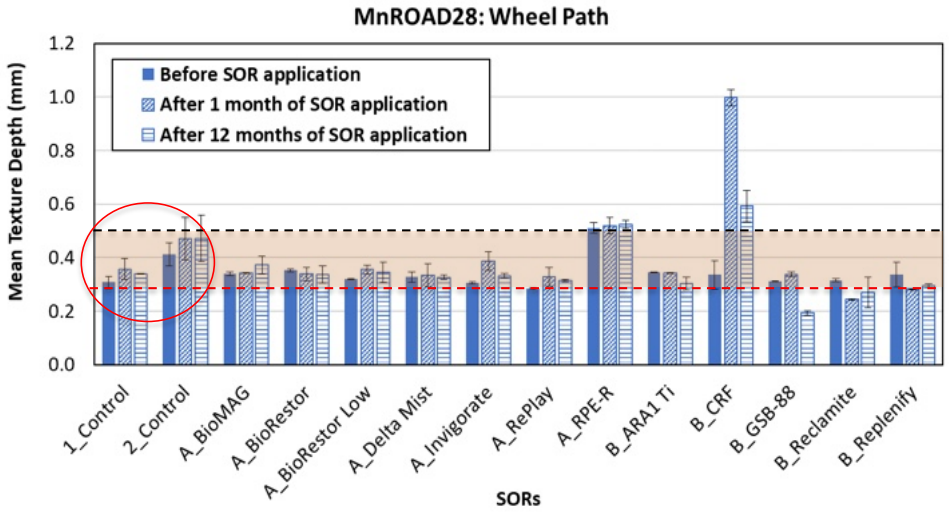
MnROAD28 street test cells; before and after a month of SOR application

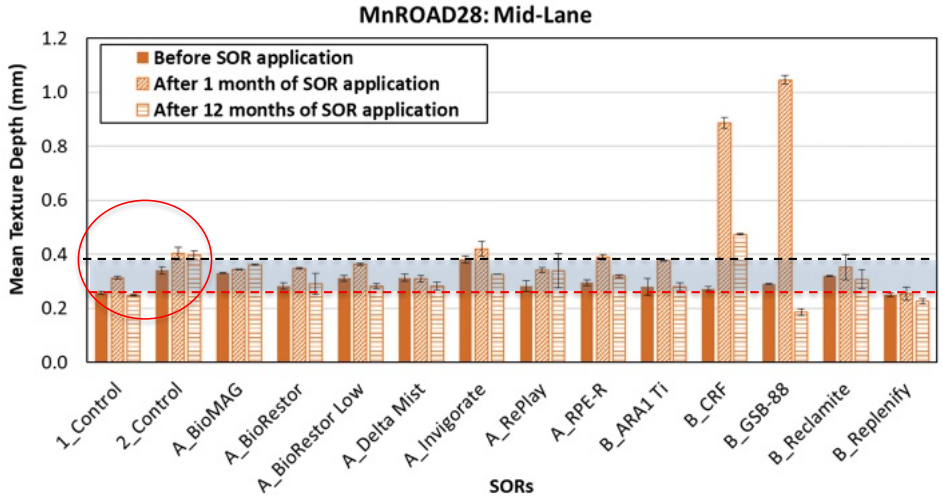
After 1 month of SOR application

- *No significant decrease* after 1 month of SOR application
- Exception: In the case of the cells treated with CRF and GSB-88
  - *Sharp increase* in the MTD

SOR: Spray-on-rejuvenators

Sand Patch Test (MnROAD28)





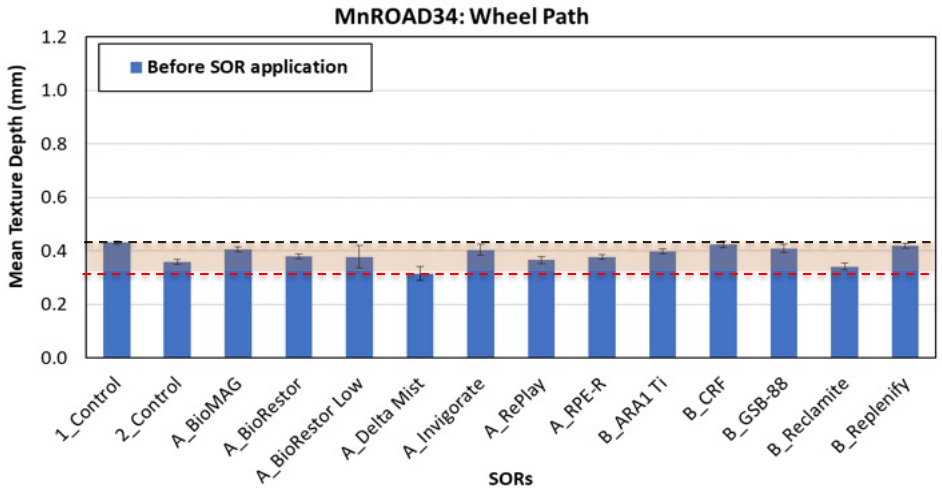
MnROAD28 street test cells; before, after a month and after 12 months of SOR application

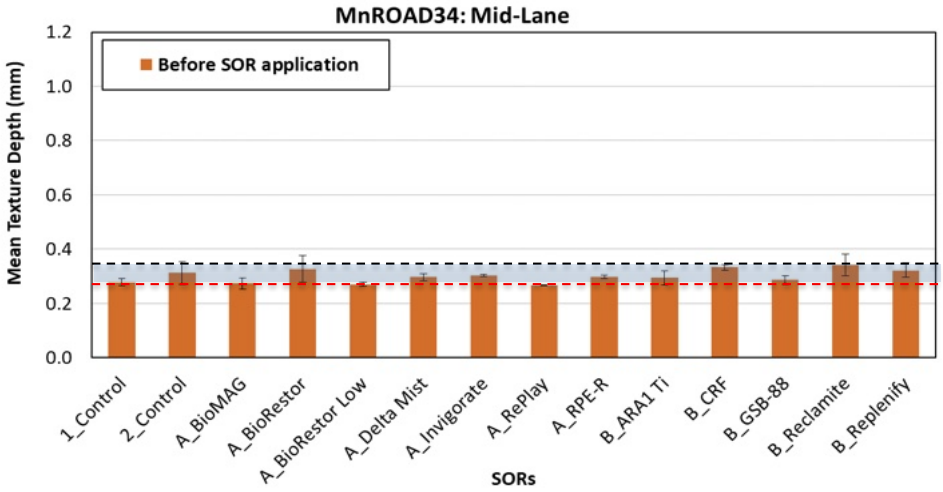
After 12 months of SOR application

- *No significant decrease* after 12 months of SOR application
- Exception: In the case of the cells treated with CRF and GSB-88
  - MTD values similar to control, possibly as the fine sand/gravel swept off

SOR: Spray-on-rejuvenators

Sand Patch Test (MnROAD34)





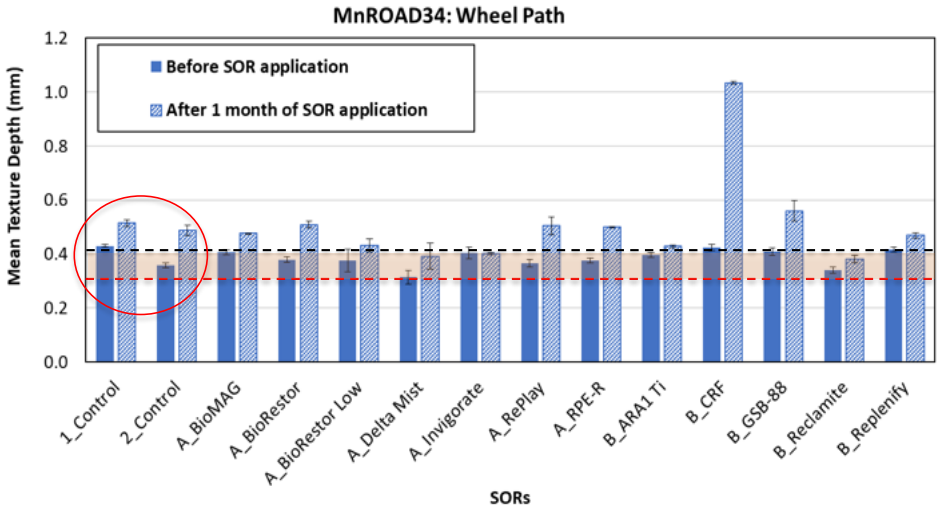
MnROAD34 street test cells; before SOR application

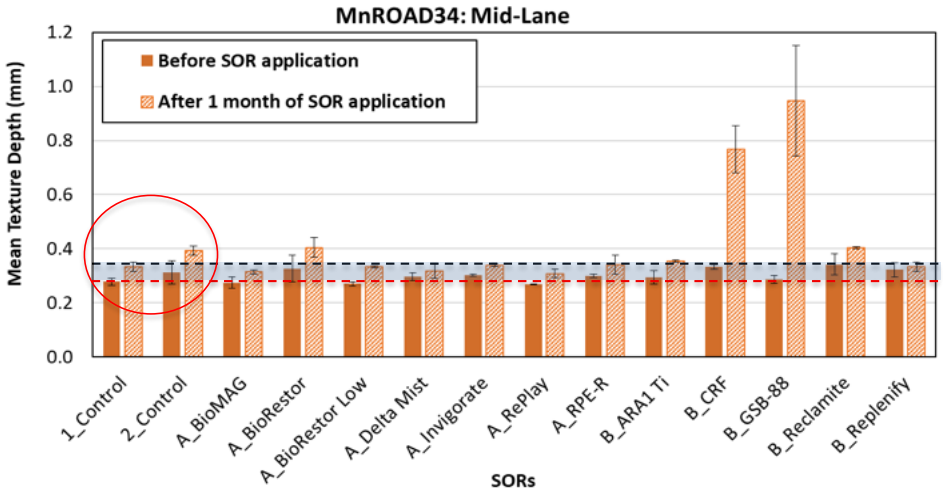
Before SOR application

- *Field variability:* MTD values varied between 0.3 and 0.4 mm
- No significant difference in wheel path and mid-lane MTD values

SOR: Spray-on-rejuvenators

Sand Patch Test (MnROAD34)





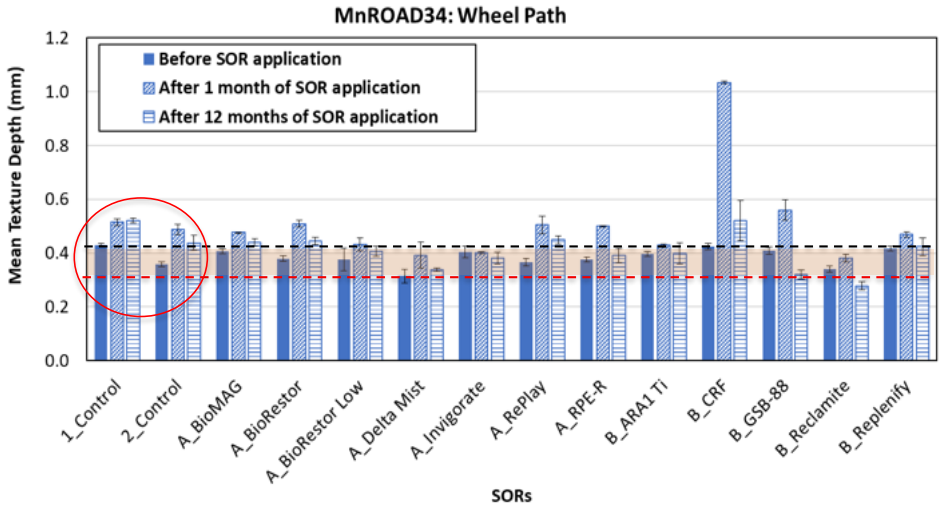
MnROAD34 street test cells; before and after a month of SOR application

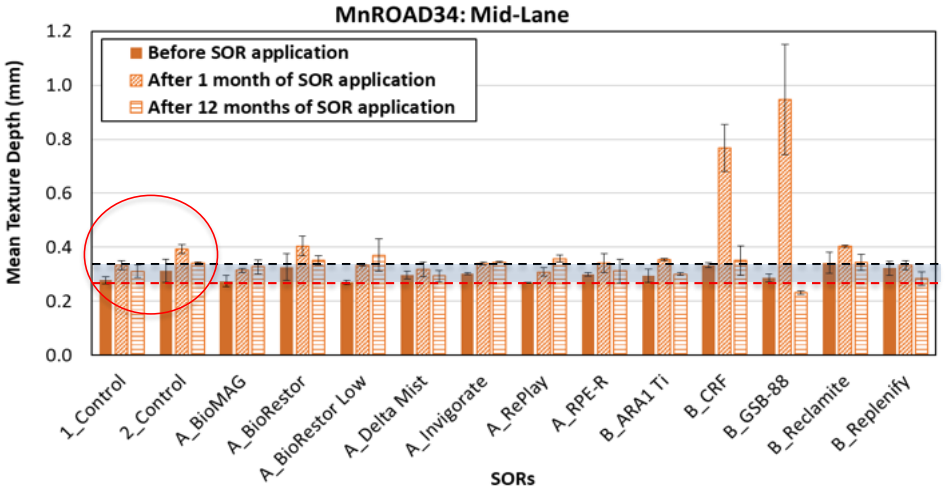
After 1 month of SOR application

- *No significant decrease* after 1 month of SOR application
- Exception: In the case of the cells treated with CRF and GSB-88
  - *Sharp increase* in the MTD

SOR: Spray-on-rejuvenators

Sand Patch Test (MnROAD34)





MnROAD34 street test cells; before, after a month and after 12 months of SOR application

After 12 months of SOR application

- *No significant decrease* after 12 months of SOR application
- Exception: In the case of the cells treated with CRF and GSB-88
  - MTD values similar to control, possibly as the fine sand/gravel swept off

SOR: Spray-on-rejuvenators

Dynamic Friction Tester (DFT)

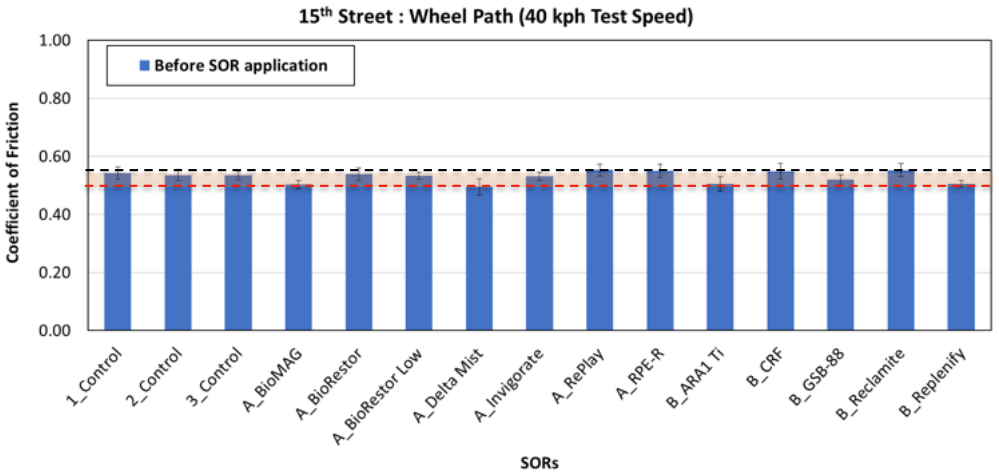
MICHIGAN STATE UNIVERSITY

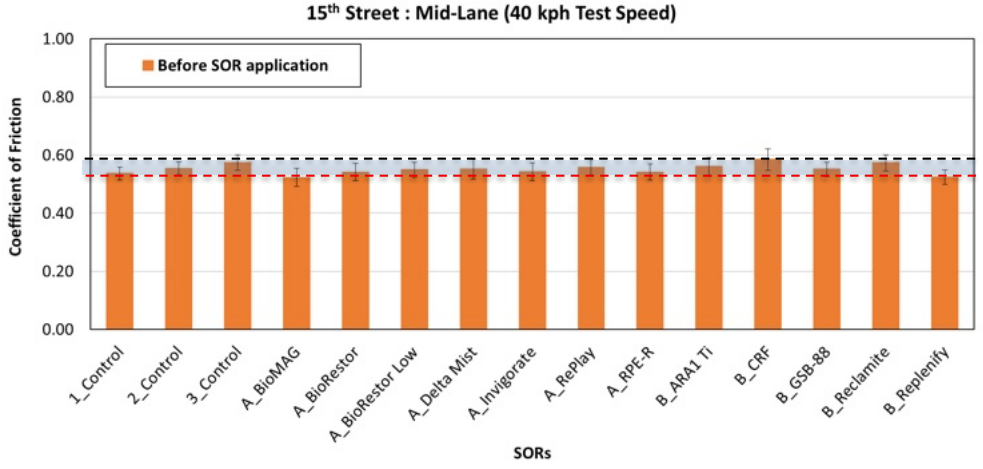
- To measure the frictional properties of pavement surfaces (ASTM E1911)
- Measurement of friction at different speeds (20, 40, 60 kph)
- ***Coefficient of friction:*** a measure of pavement friction

Dynamic Friction Test (15th Street)

Before SOR application

- *Less Spatial variability* compared to MTD



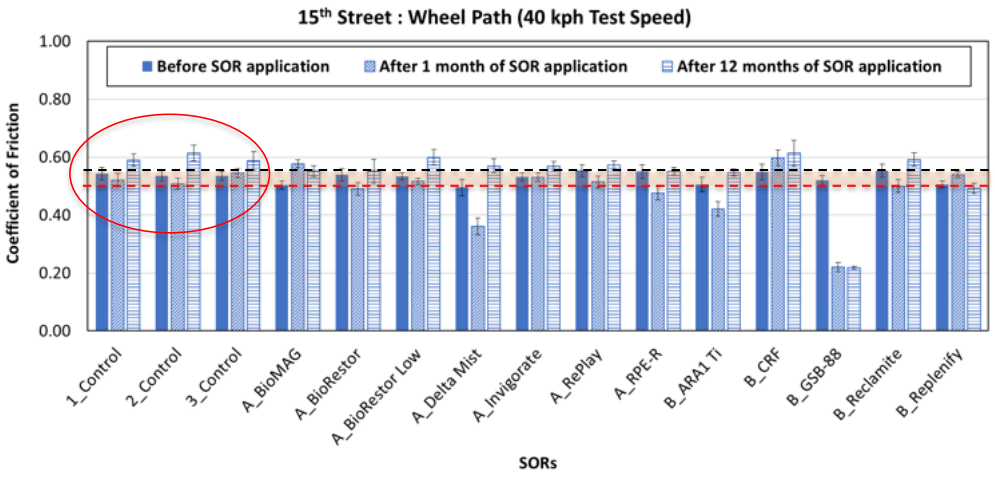


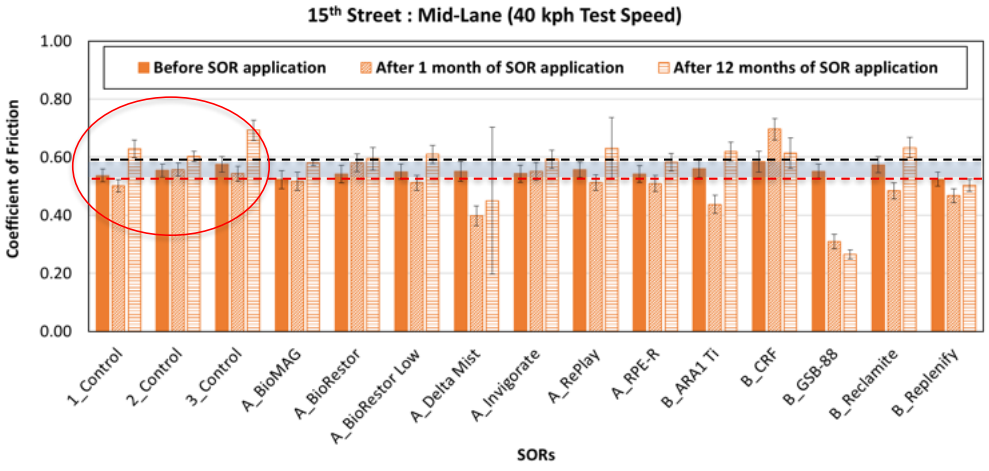
SOR: Spray-on-rejuvenators

Dynamic Friction Test (15th Street)

After SOR application

- After 1 month of SOR application:
  - Friction coefficient decreased in most of the cells in different degrees





- After 12 months of SOR application:
  - Friction values for all SOR cells were similar to pre-SOR application values
    - **Exception:** Friction coefficient stayed low in GSB-88

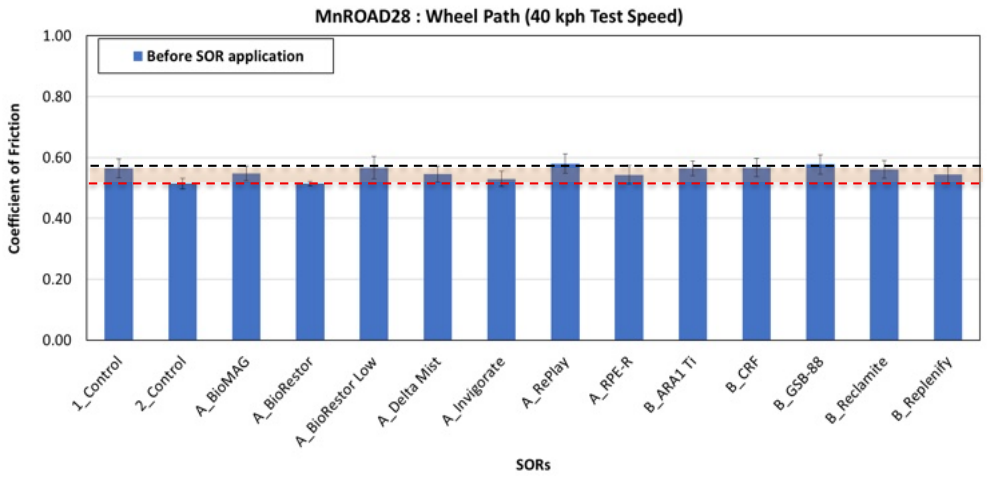
SOR: Spray-on-rejuvenators

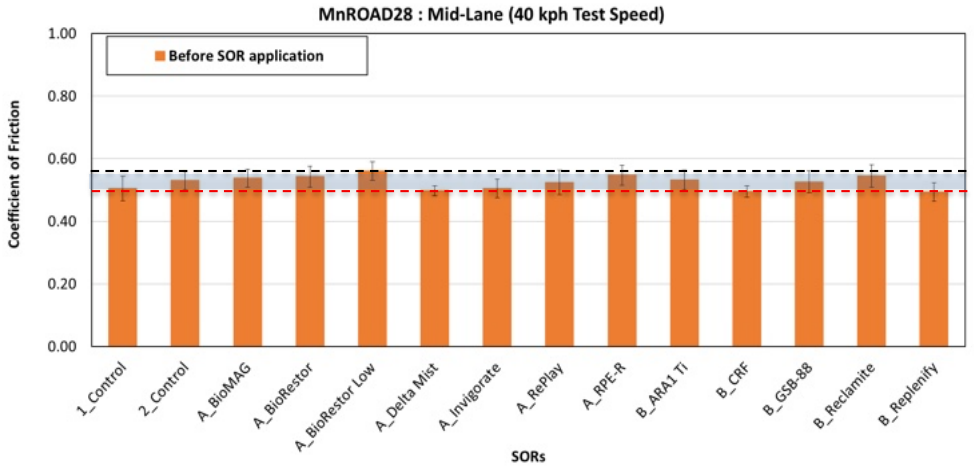
Dynamic Friction Test (MnROAD28)

MICHIGAN STATE UNIVERSITY

Before SOR application

- *Less Spatial variability* compared to MTD





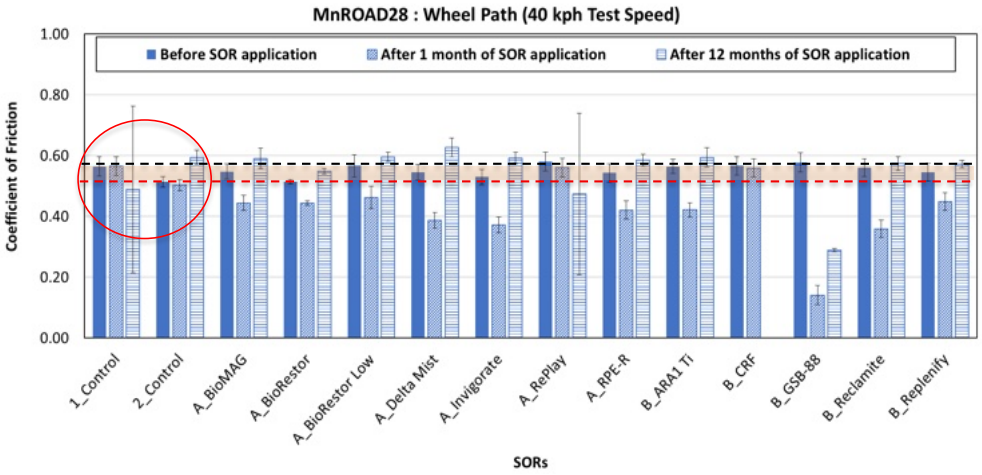
SOR: Spray-on-rejuvenators

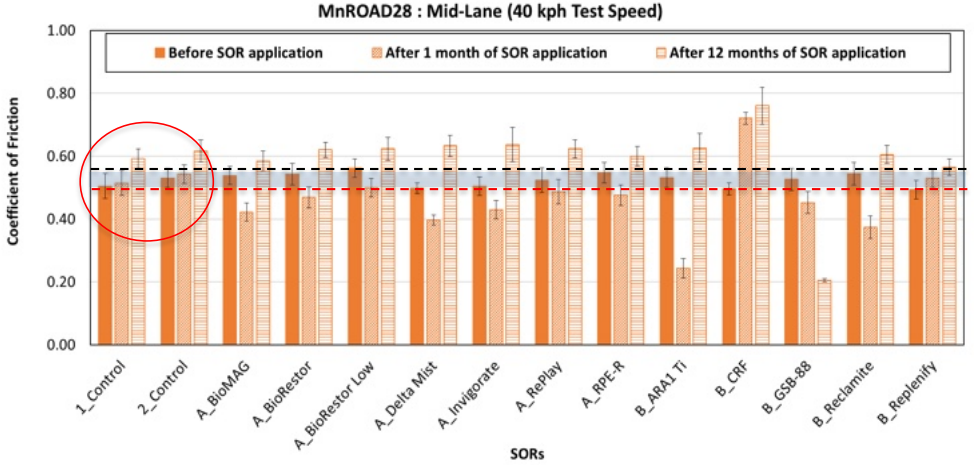
Dynamic Friction Test (MnROAD28)

MICHIGAN STATE UNIVERSITY

After SOR application

- After 1 month of SOR application:
  - Friction coefficient decreased in most of the cells in different degrees





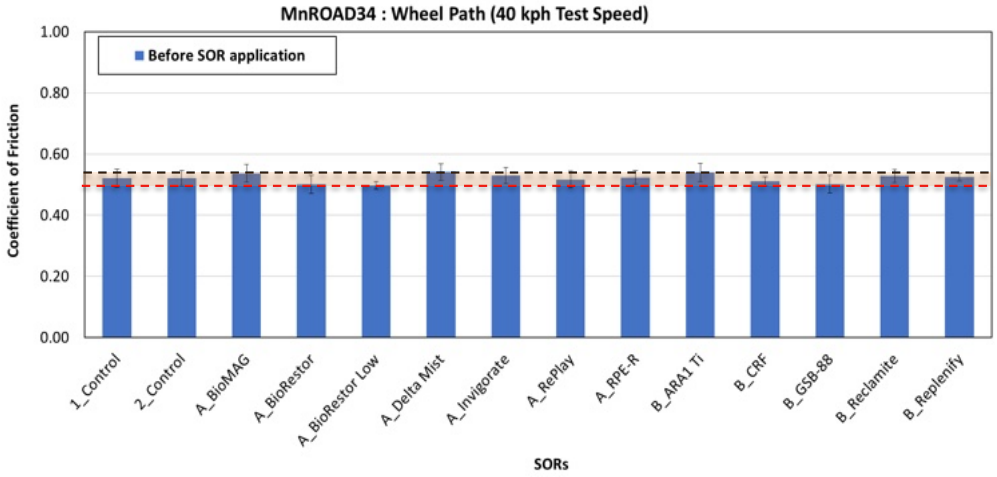
- After 12 months of SOR application:
  - Friction values for all SOR cells were similar to pre-SOR application values
    - **Exception:** Friction coefficient stayed low in GSB-88

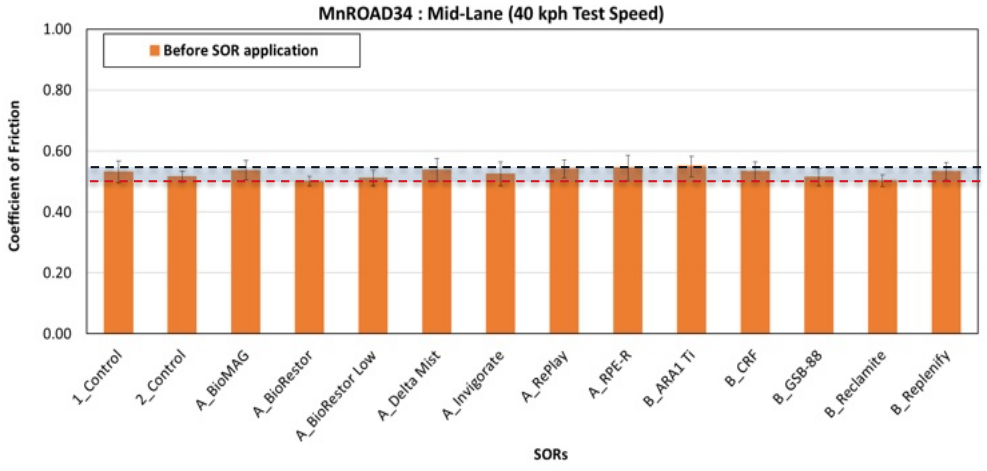
SOR: Spray-on-rejuvenators

Dynamic Friction Test (MnROAD34)

Before SOR application

- *Less Spatial variability* compared to MTD





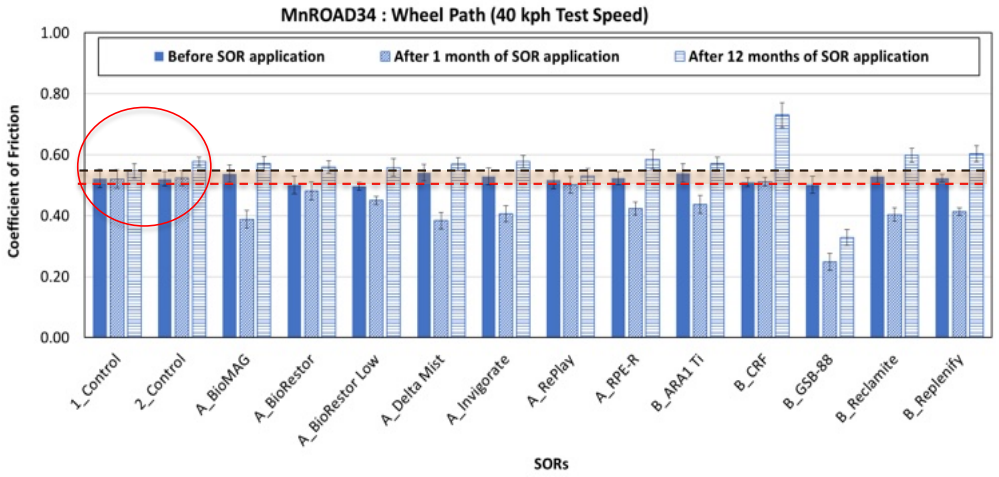
SOR: Spray-on-rejuvenators

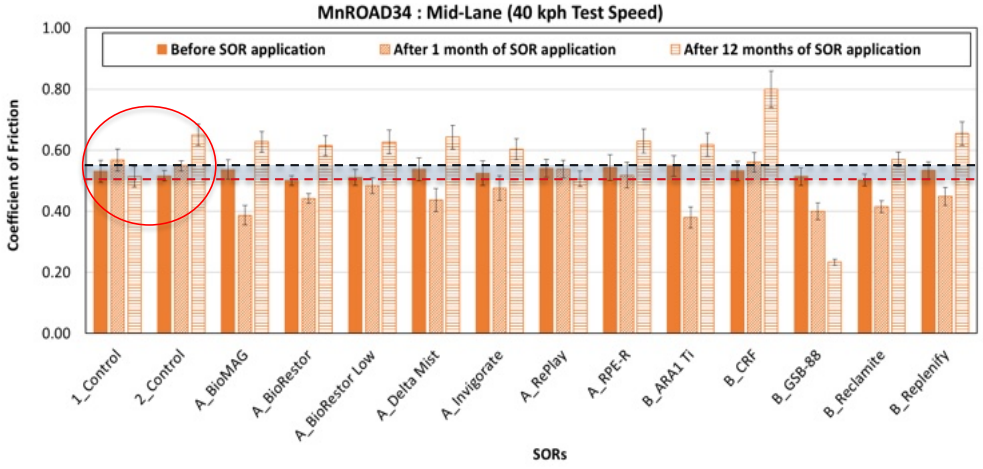
Dynamic Friction Test (MnROAD34)

MICHIGAN STATE UNIVERSITY

After SOR application

- After 1 month of SOR application:
  - Friction coefficient decreased in most of the cells in different degrees



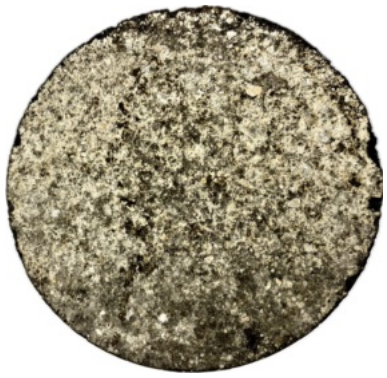


- After 12 months of SOR application:
  - Friction values for all SOR cells were similar to pre-SOR application values
    - **Exception:** Friction coefficient stayed low in GSB-88

SOR: Spray-on-rejuvenators

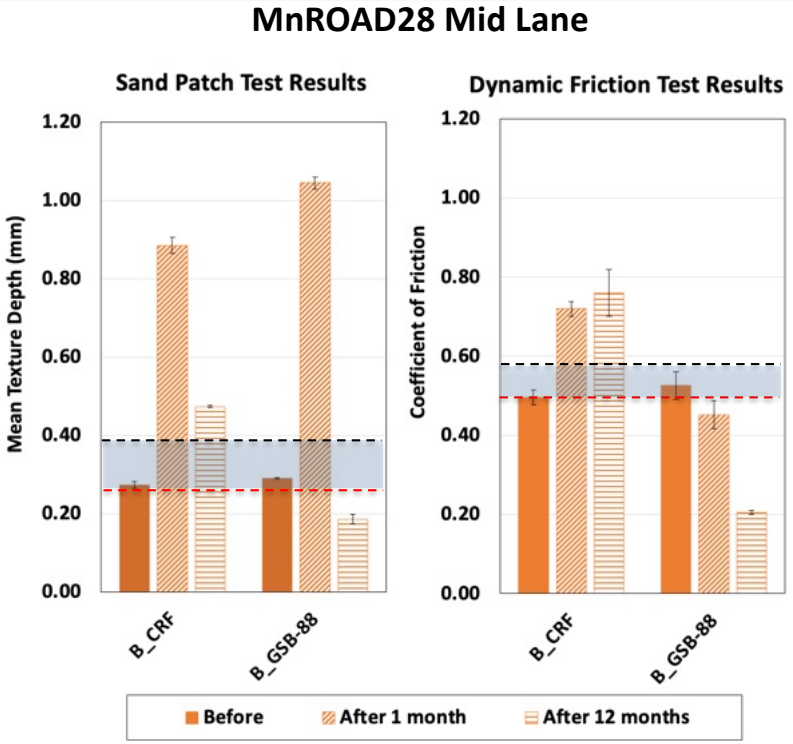
MPD vs. DFT Results

- General conception: *Higher mean texture depth leads to a higher coefficient of friction*
- Coefficient of friction and MTD values in the case of *CRF and GSB-88* do not correlate consistently
  - **Probable reasons:**
    - Non-uniform application of sand/fine gravel
    - MTD: The long-term retention of applied sand/fine gravel is unclear
    - Sand/fine gravel might have swept off during DFT



CRF

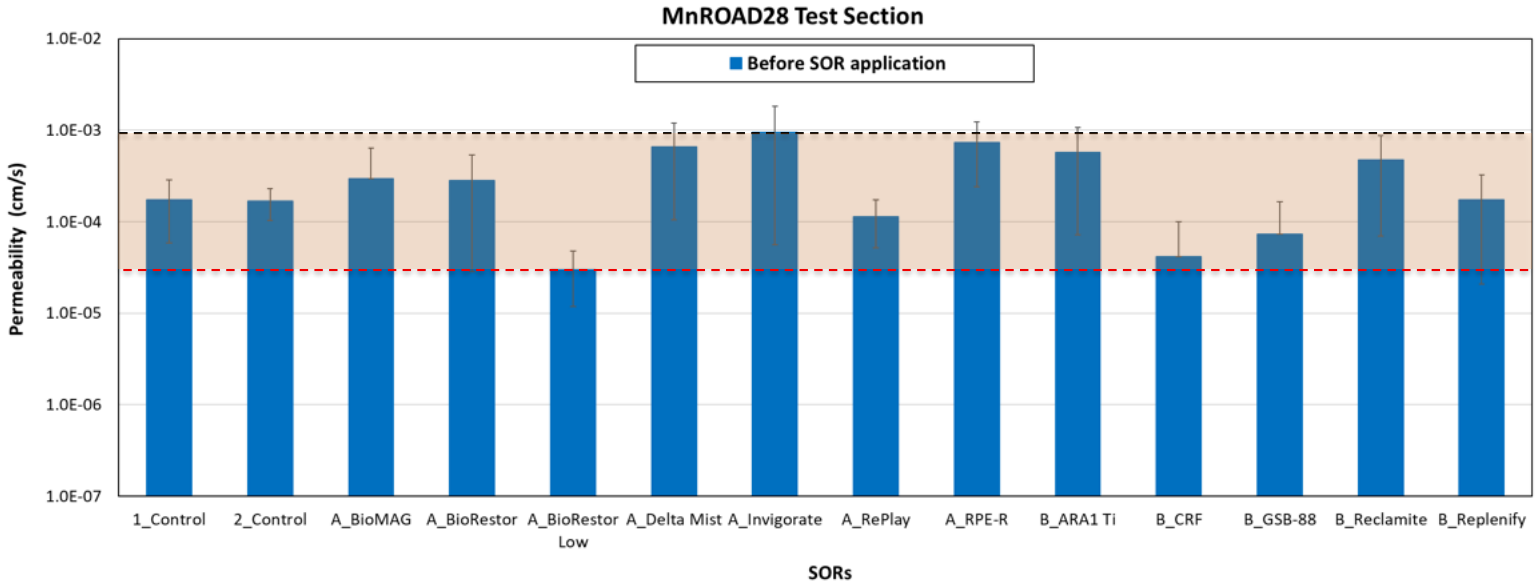
GSB-88



Which is the reliable test for Group-B SORs; Sand patch test or Dynamic friction test?

Permeability (MnROAD28)

- Measured using NCAT permeameter
- ***Before SOR application:***
  - *Spatial variability:* 9.43 × 10^{-4} cm/sec to 2.97 × 10^{-5} cm/sec (50%)

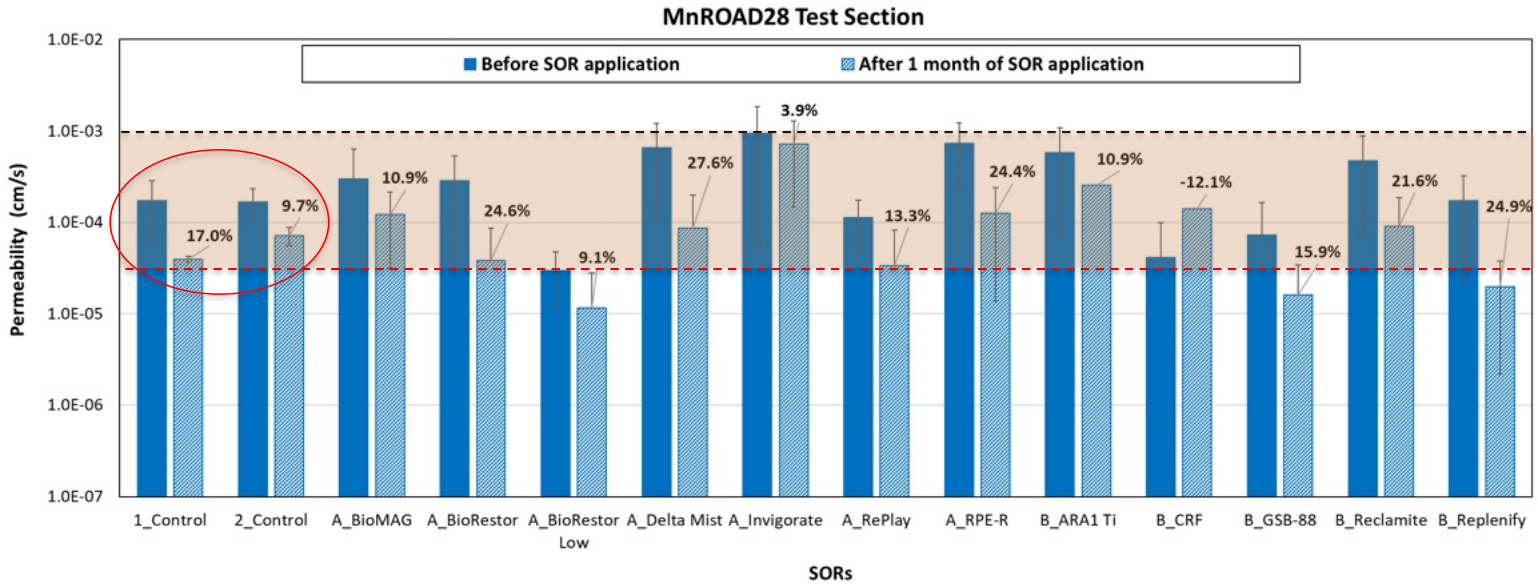


Permeability results of MnROAD28 test cells (Before SOR application)

SOR: Spray-on-rejuvenators

Permeability (MnROAD28)

- ***After one month of SOR application:***
  - ***Testing variability:*** Permeability values decreased in two control cells from 1.72×10^{-4} cm/sec to 7.2×10^{-5} cm/sec (10% to 17%)



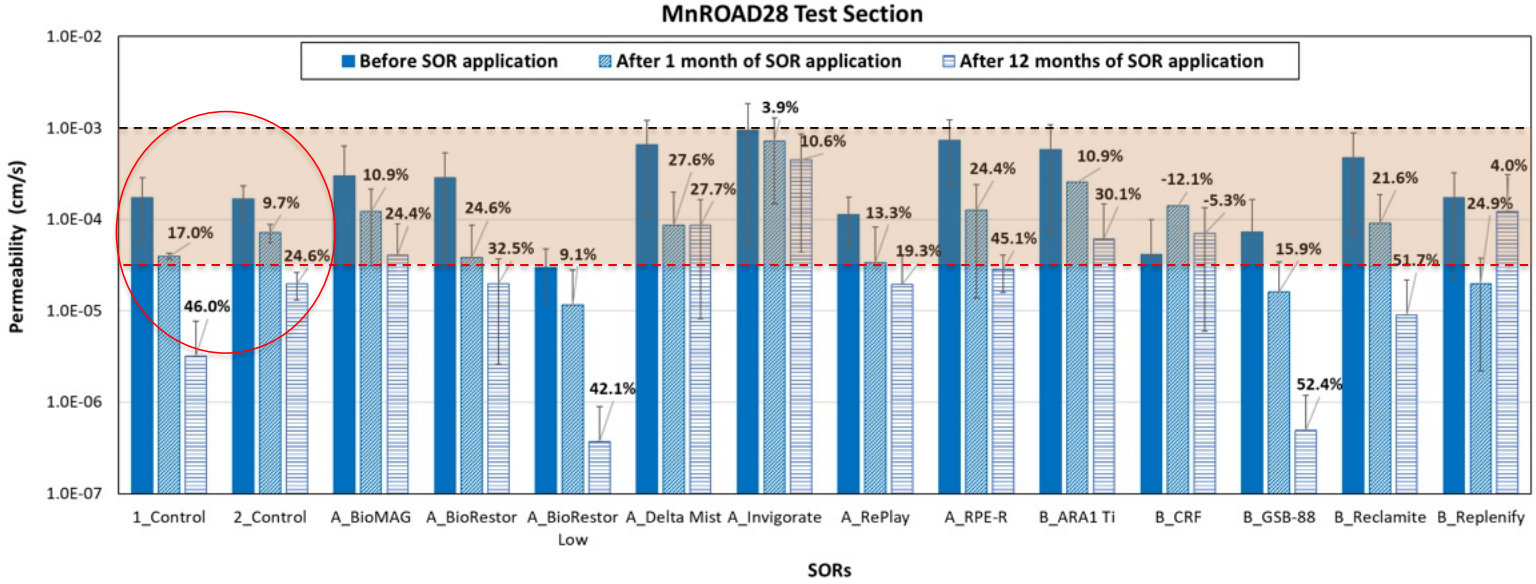
Permeability results of MnROAD28 test cells (Before and after one month of SOR application)

SOR: Spray-on-rejuvenators

Permeability (MnROAD28)

- ***After 12 months of SOR application:***
  - *Testing variability:* Permeability values decreased in two control cells from 1.7×10^{-4} cm/sec to 3×10^{-6} cm/sec (25% to 46%)
- Decrease in permeability values: Group A SORs: BioRestor Low

Group B SORs: GSB-88, Reclamite → *location variability*

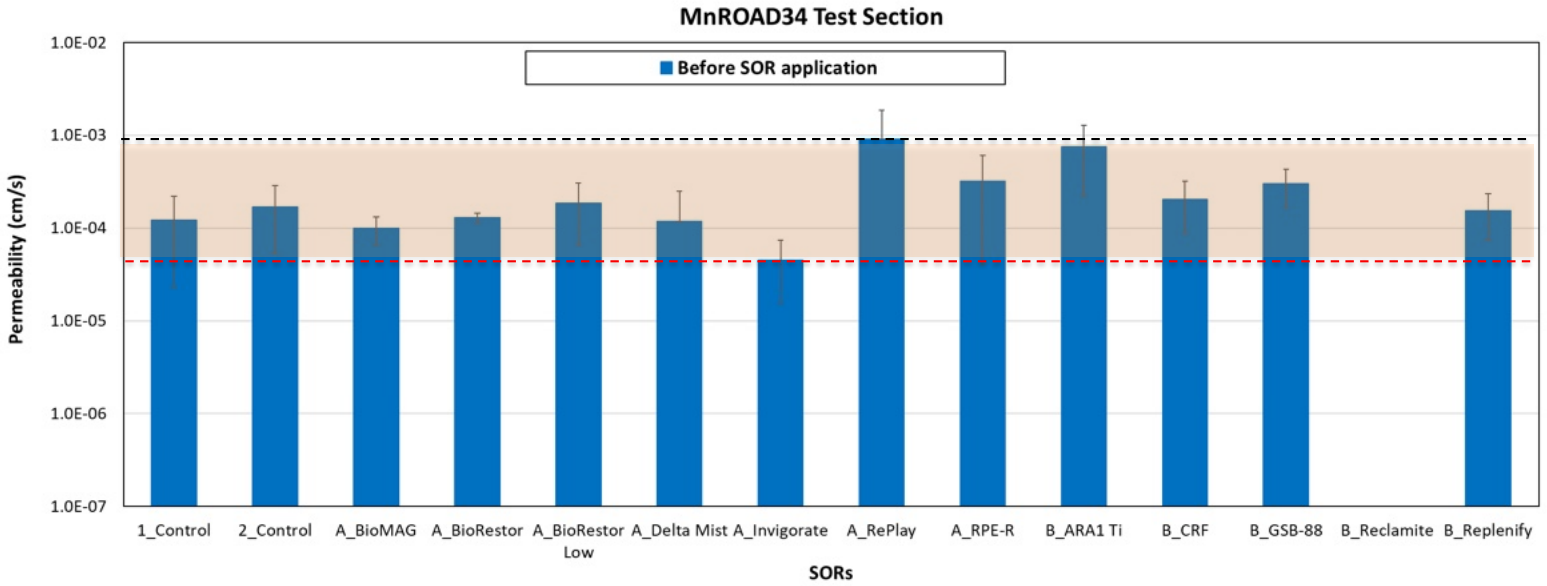


Permeability results of MnROAD28 test cells (Before, after 1 month, and after 12 months of SOR application)

SOR: Spray-on-rejuvenators

Permeability (MnROAD34)

- ***Before SOR application:***
  - ***Spatial variability:*** 9.11×10^{-4} cm/sec to 4.48×10^{-5} cm/sec (43%)

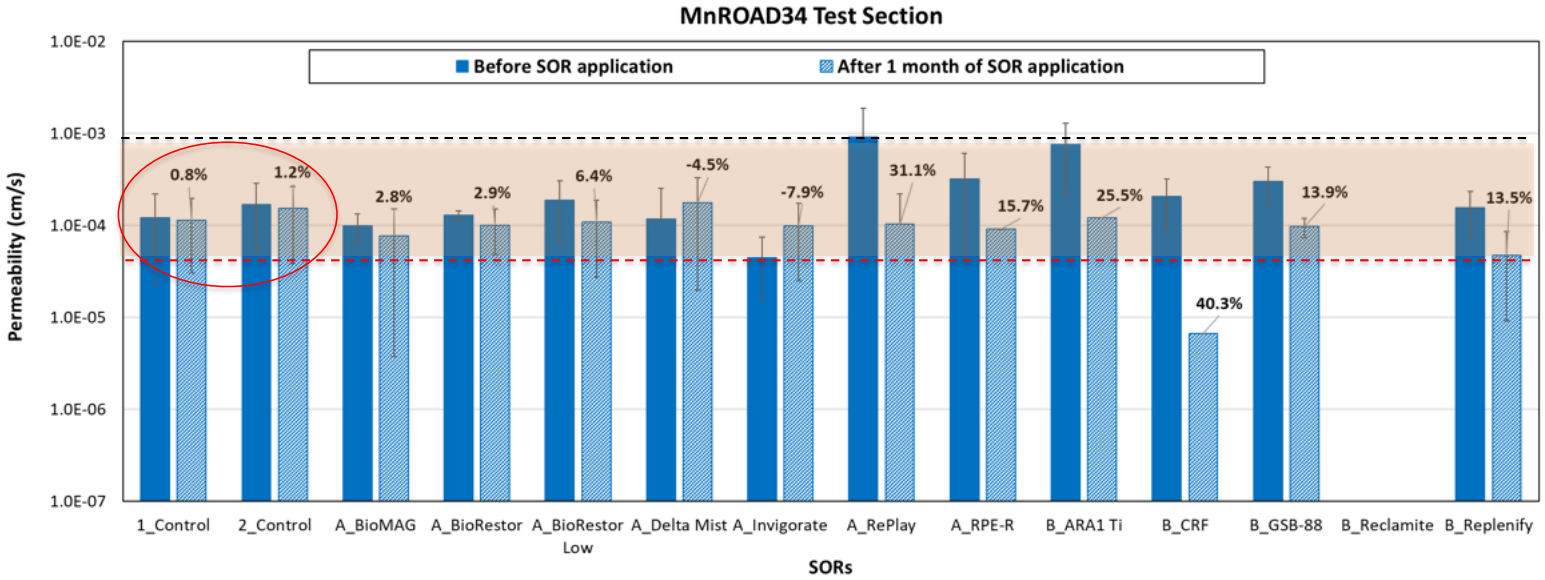


Permeability results of MnROAD34 test cells (Before SOR application)

SOR: Spray-on-rejuvenators

Permeability (MnROAD34)

- ***After one month of SOR application:***
  - ***Testing variability:*** Permeability values decreased in two control cells from 1.69×10^{-4} cm/sec to 1.13×10^{-4} cm/sec (0.8% to 1.2%) (Relatively less than MnROAD28)
  - ***Decrease in permeability:*** CRF



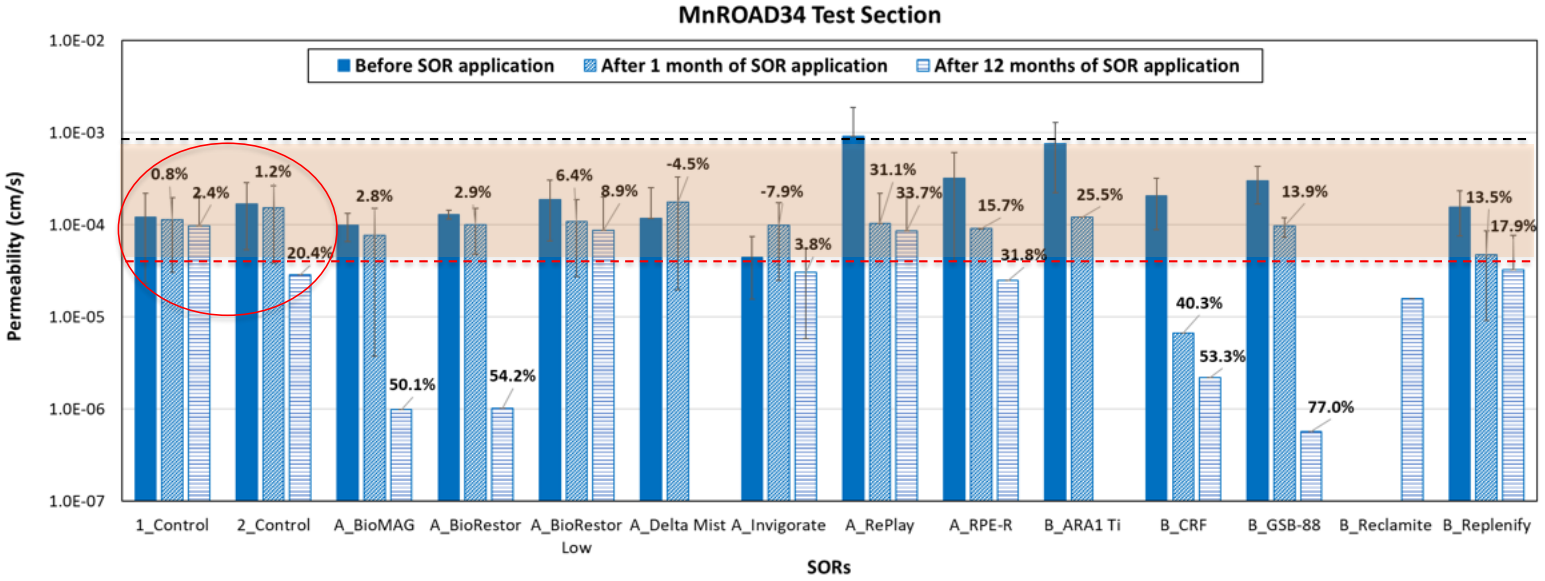
Permeability results of MnROAD34 test cells (Before and after one month of SOR application)

SOR: Spray-on-rejuvenators

Permeability (MnROAD34)

- ***After 12 months of SOR application:***
- *Testing variability:* Permeability values decreased in two control cells from 1.69×10^{-4} cm/sec to 2.89×10^{-5} cm/sec (2.4% to 20.4%) (Relatively less than MnROAD28)
- Decrease in permeability values: Group A SORs: BioMAG, BioRestor

Group B SORs: CRF, GSB-88→*location variability*



Permeability results of MnROAD34 test cells (Before, after one month, and after 12 months of SOR application)

SOR: Spray-on-rejuvenators

Lab Experiments and Results

Modified Bending Beam Rheometer (BBR)

- Marasteanu et. al. (2009): ***No statistically significant differences*** were found between the creep stiffness of the 3x, 2x, and 1x beams
- Specimen size: 127 mm × 25.4 mm × 12.7 mm (Modification of AASHTO T313)
  - Larger size beams are necessary ***to eliminate breakage of the beams and chipping of fine aggregates***
  - Width and height were modified maintaining the ***same aspect ratio (2:1)***
  - Effective penetration depth: Lee et al. (2013): **12.5 mm**; Federal Aviation Administration (FAA): **9 mm**

Figure: 1x, 2x, and 3x asphalt mixture beam specimens (Marasteanu et. al., 2009)

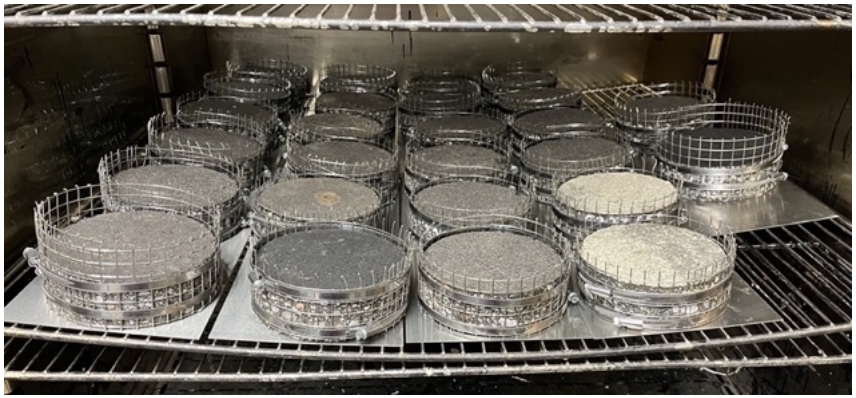
Figure: Modified BBR beams (127 mm × 25.4 mm × 12.7 mm)

Vaddy, P., Islam, T., Kutay, M. E., Vrtis, M., Haider, S. W., & Cetin, B. (2023) "Evaluating the Short-term Performance of Spray-on Rejuvenators using a Modified Bending Beam Rheometer Test Methodology", Transportation Research Record, 0(0), DOI: 10.1177/03611981231209038

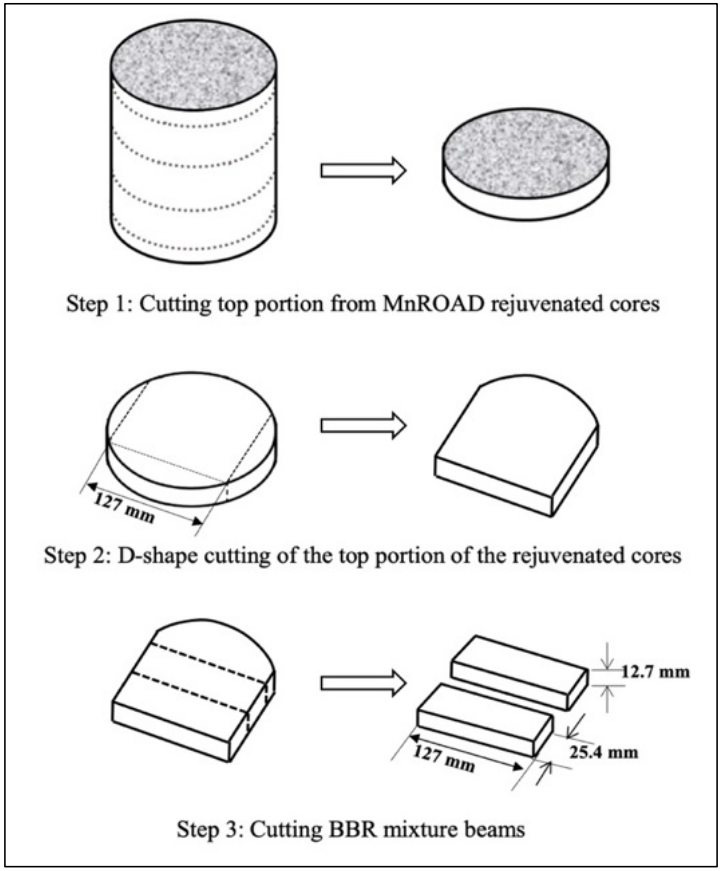
Sample Preparation

MICHIGAN STATE UNIVERSITY

- Aging of the Cores:
  - **Unaged (UA):** Collected field cores after one month of SOR application
  - **1-year field-aged (F1):** Collected field cores after 12 months of SOR application
  - **2-year field-aged (F2):** Collected field cores after 12 months of SOR application
  - **Lab-aged (LA):** Two-inch field cores aged in the oven at 95°C for 7 days to simulate long-term field aging conditions



Cores placed in an oven for lab aging



Step 1: Cutting top portion from MnROAD rejuvenated cores

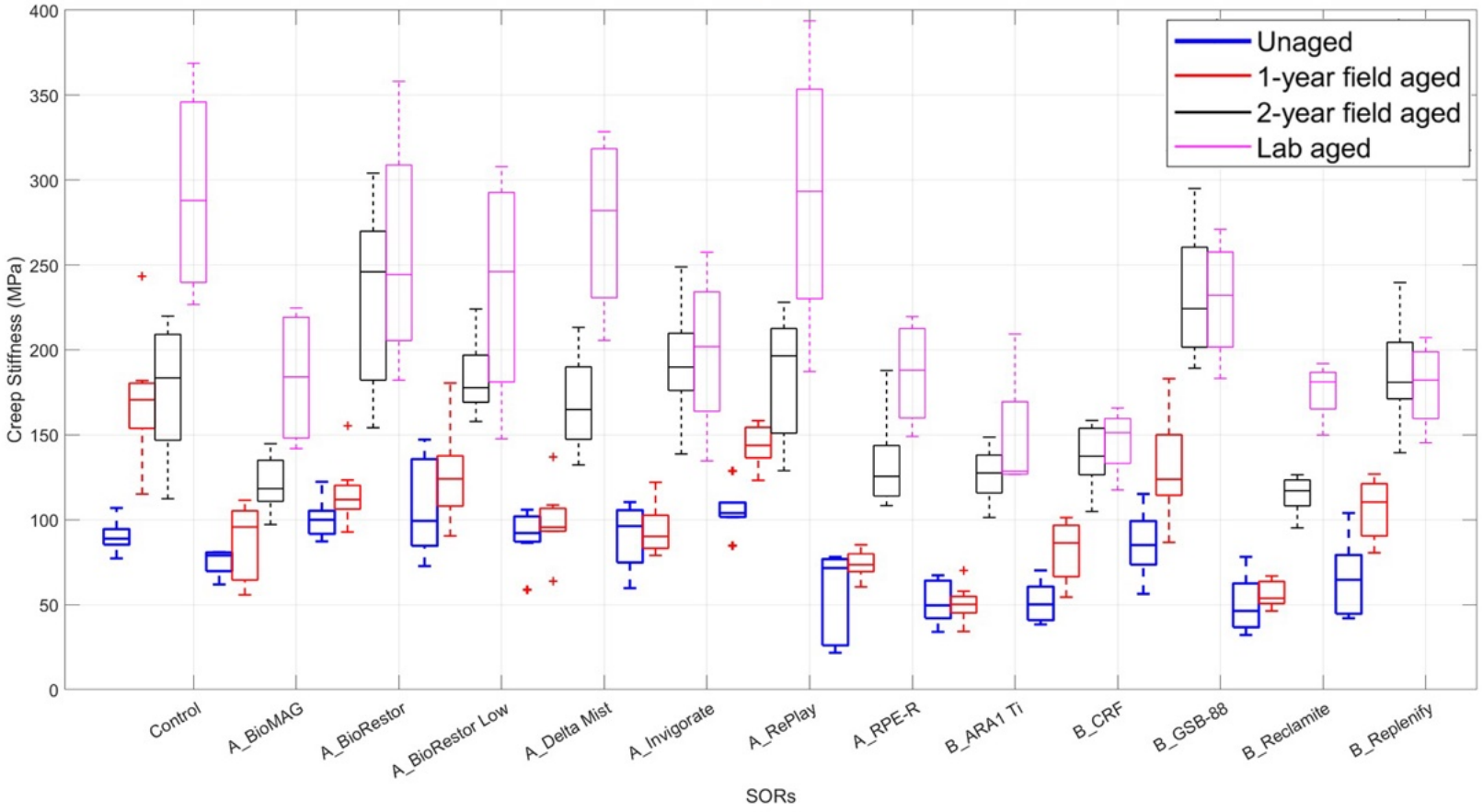
Step 2: D-shape cutting of the top portion of the rejuvenated cores

Step 3: Cutting BBR mixture beams

Preparation of BBR test samples from field-extracted cores

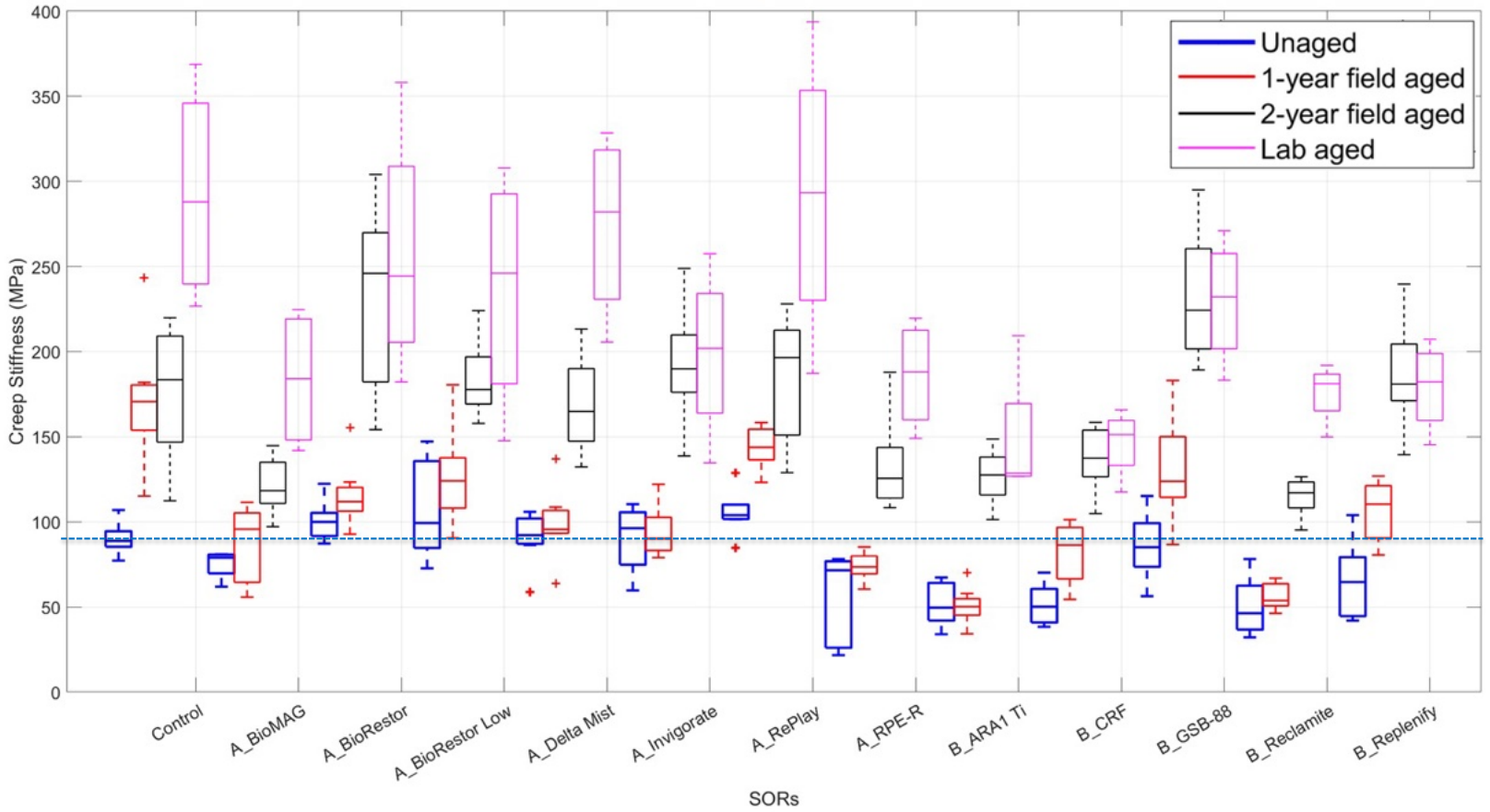
BBR Test Results (MnROAD28)

Creep stiffness @20°C



BBR Test Results (MnROAD28)

Creep stiffness @20°C

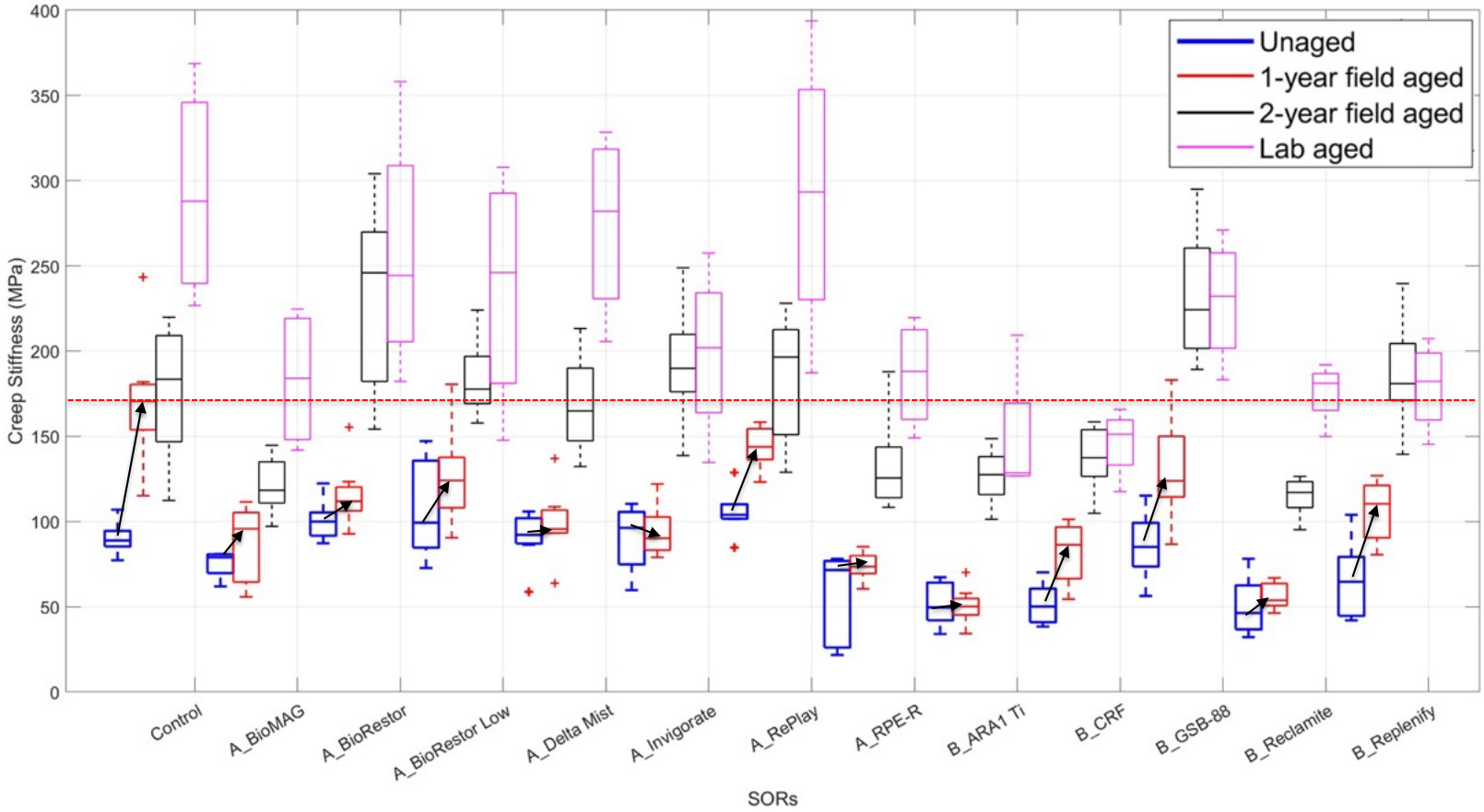


Unaged condition (blue boxes):

- **Softening effect in some SORs:** Other SORs might need some time to exert effect on creep stiffness

BBR Test Results (MnROAD28)

Creep stiffness @20°C

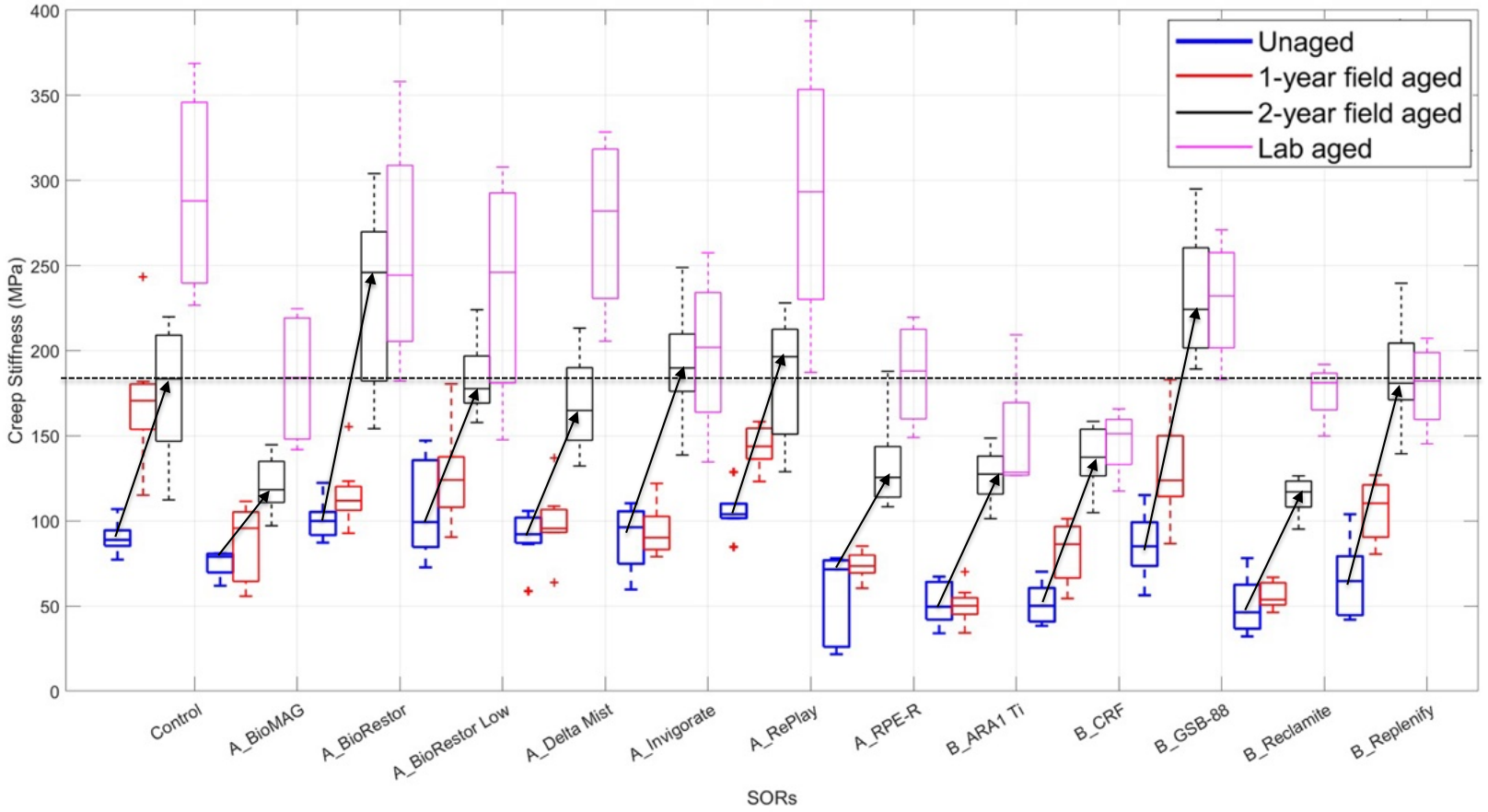


One-year field aged (red boxes):

– Most rejuvenators are effective in keeping the stiffnesses low → successfully retarded aging.

BBR Test Results (MnROAD28)

Creep stiffness @20°C

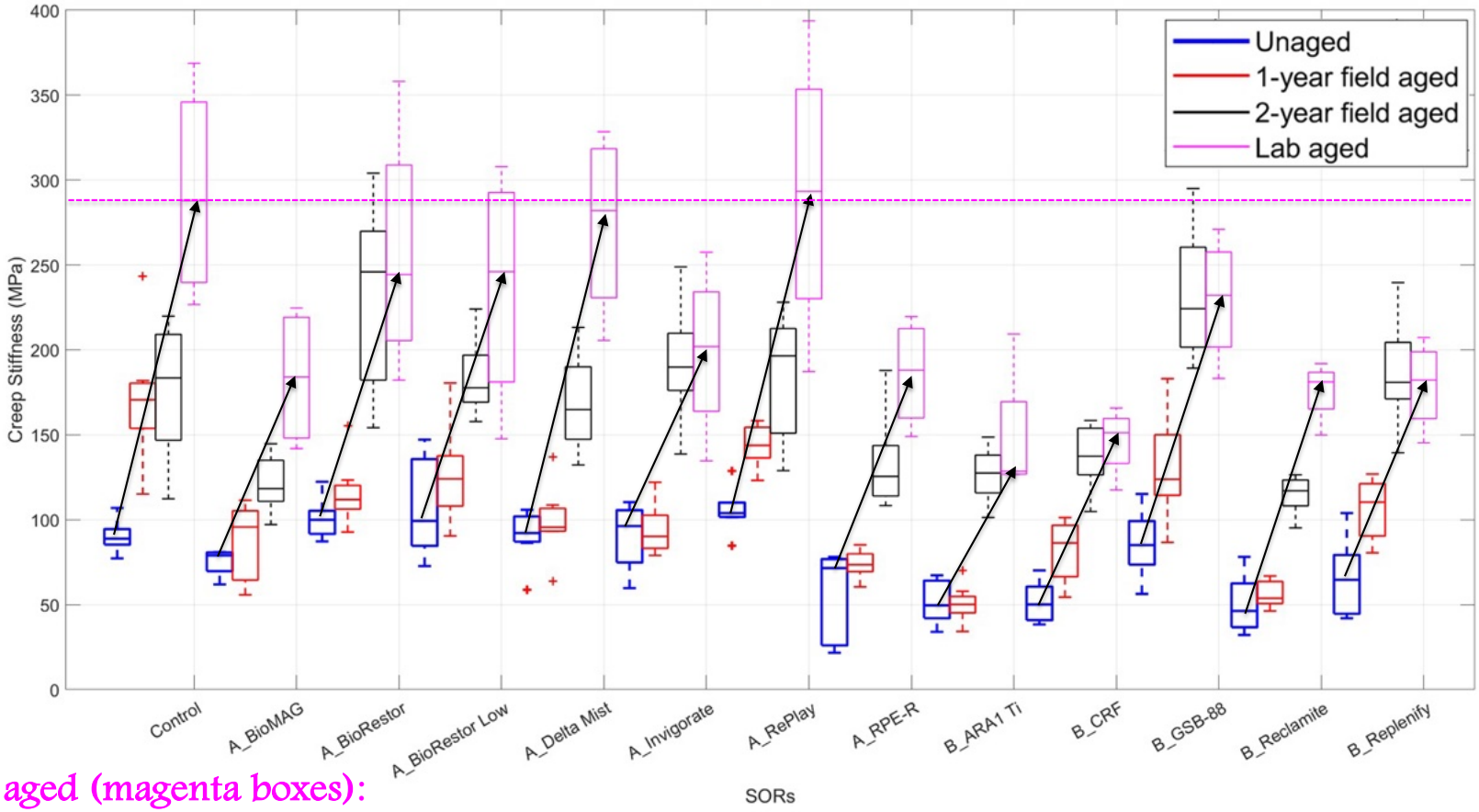


Two-year field aged (black boxes):

- A few SORs are effective for up to 1-2 years; need reapplication to continue to retard aging

BBR Test Results (MnROAD28)

Creep stiffness @20°C

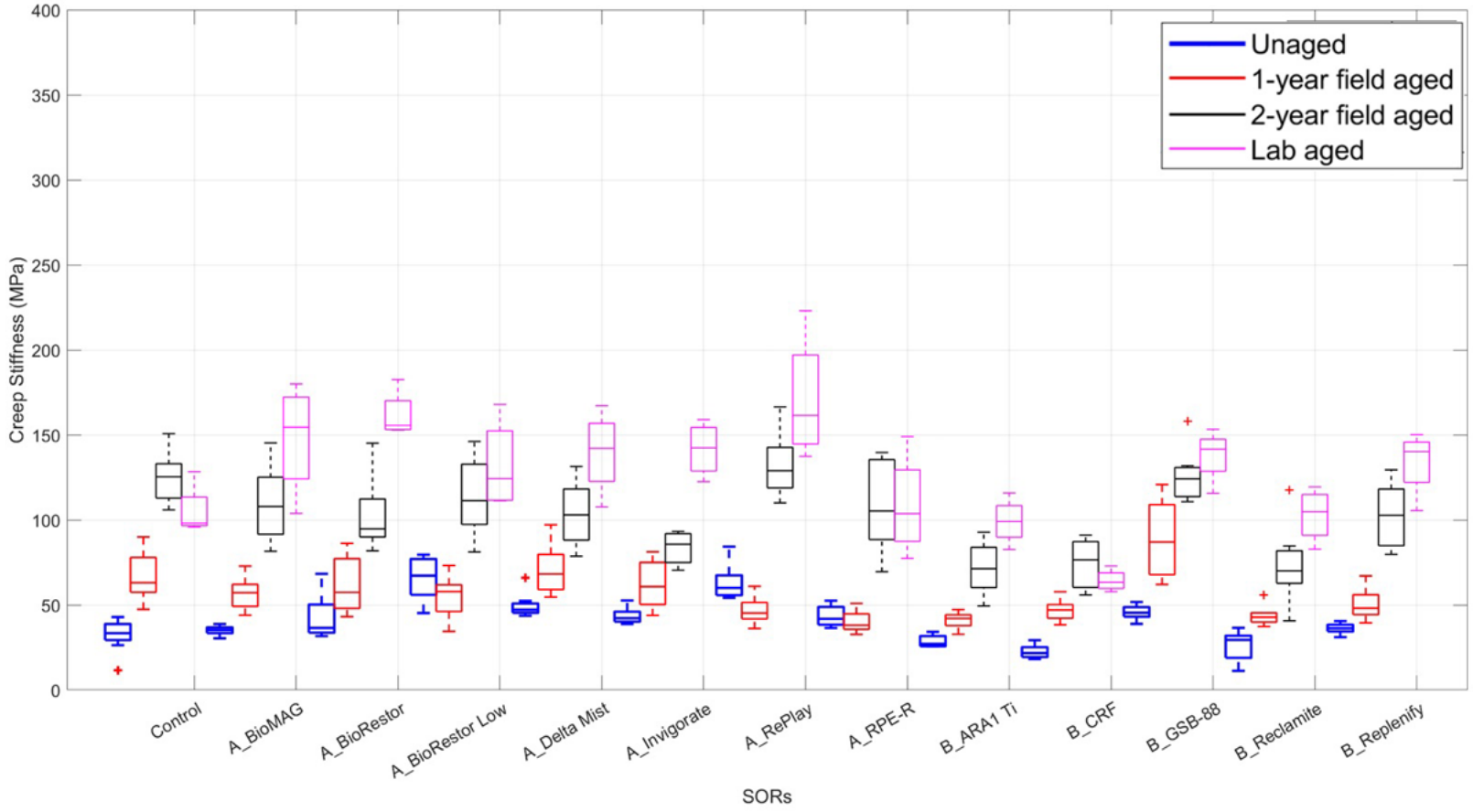


Lab aged (magenta boxes):

- Significant aging in some cores
- Aged cores: Effect of SOR application might have faded away after long period of aging

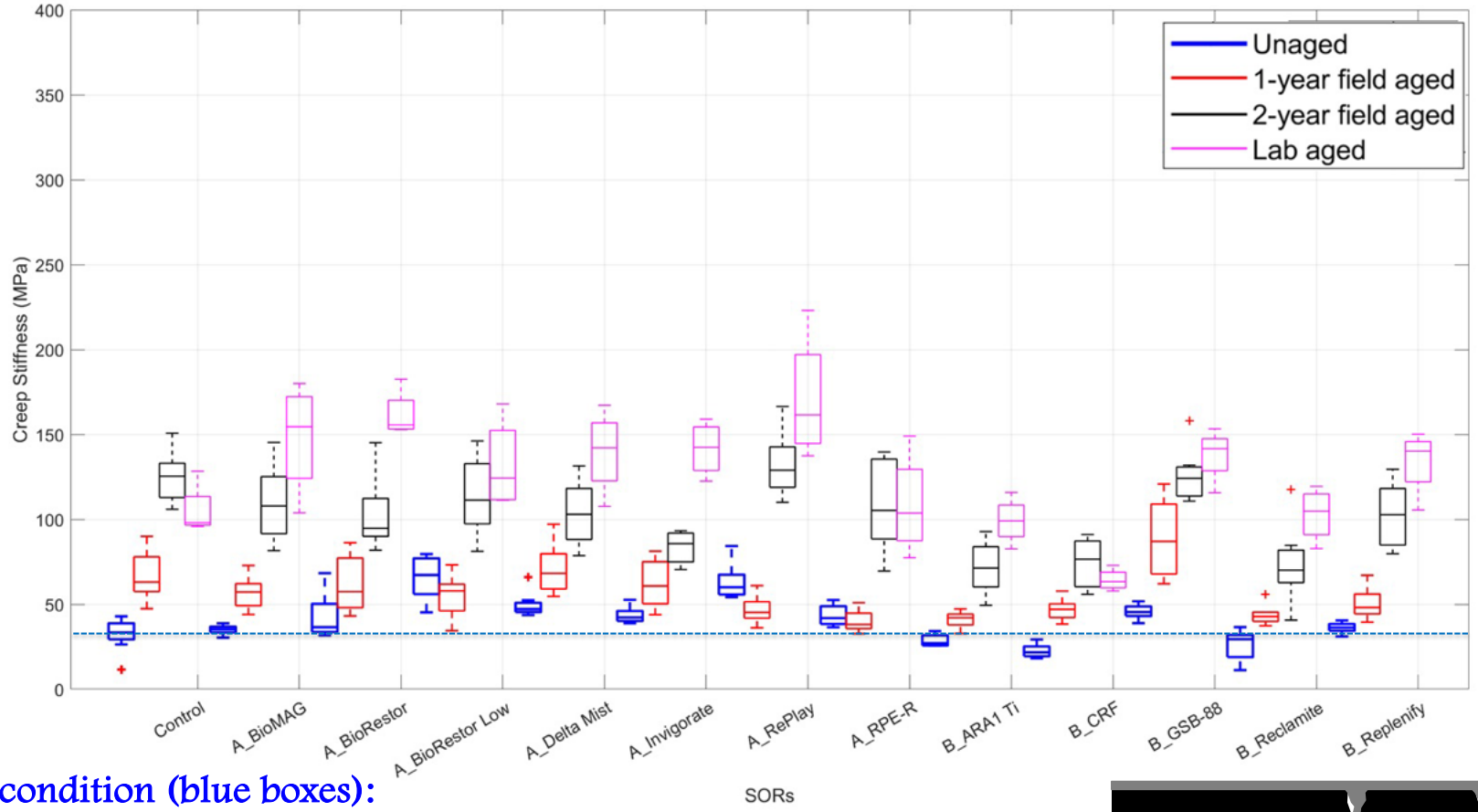
BBR Test Results (MnROAD34)

Creep stiffness @20°C



BBR Test Results (MnROAD34)

Creep stiffness @20°C

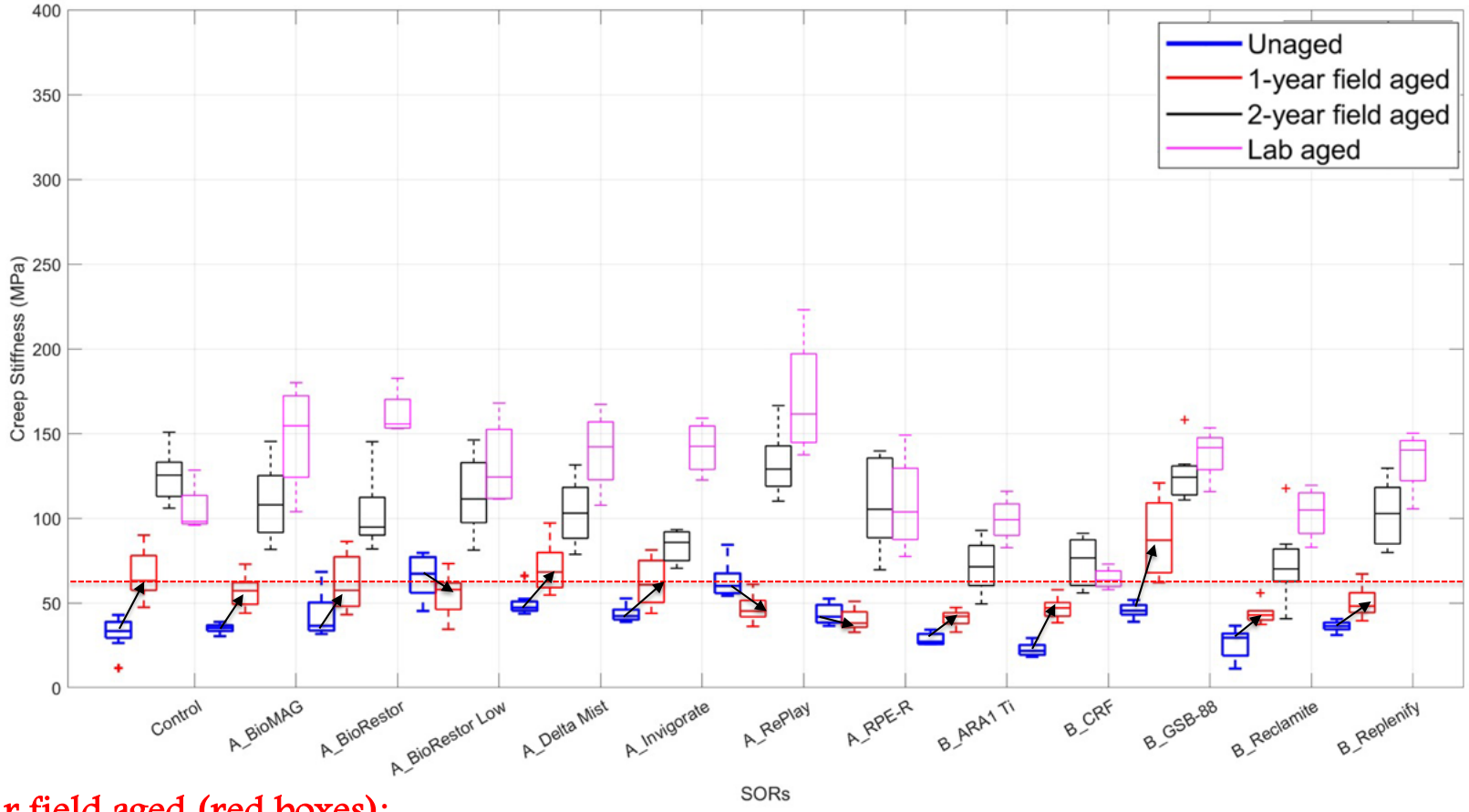


Unaged condition (blue boxes):

- Softening effect in some SORs
- Stiffening effect in some others → bridging over microcracks

BBR Test Results (MnROAD34)

Creep stiffness @20°C

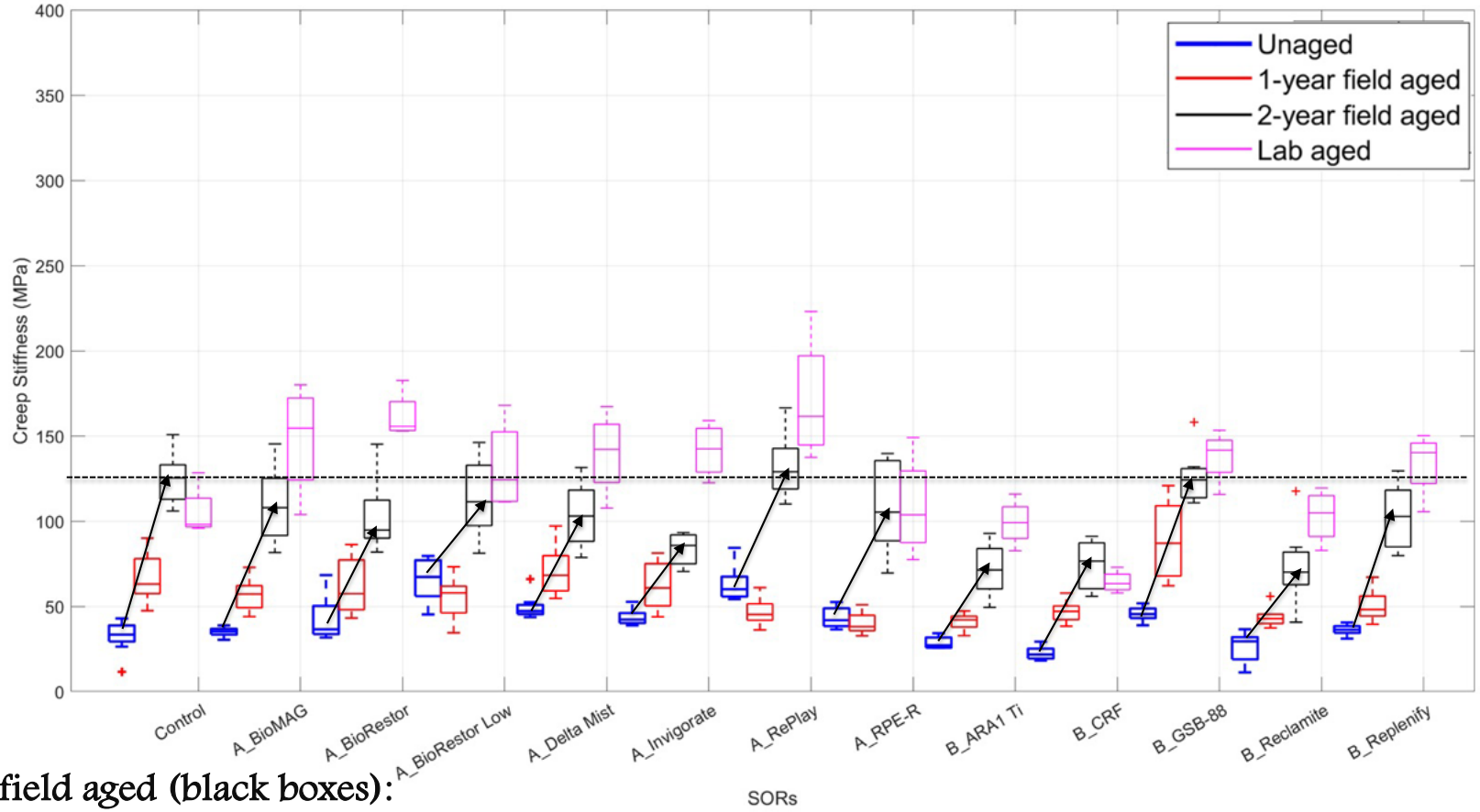


One-year field aged (red boxes):

- Most rejuvenators are effective in keeping the stiffnesses low → successfully retarded aging

BBR Test Results (MnROAD34)

Creep stiffness @20°C

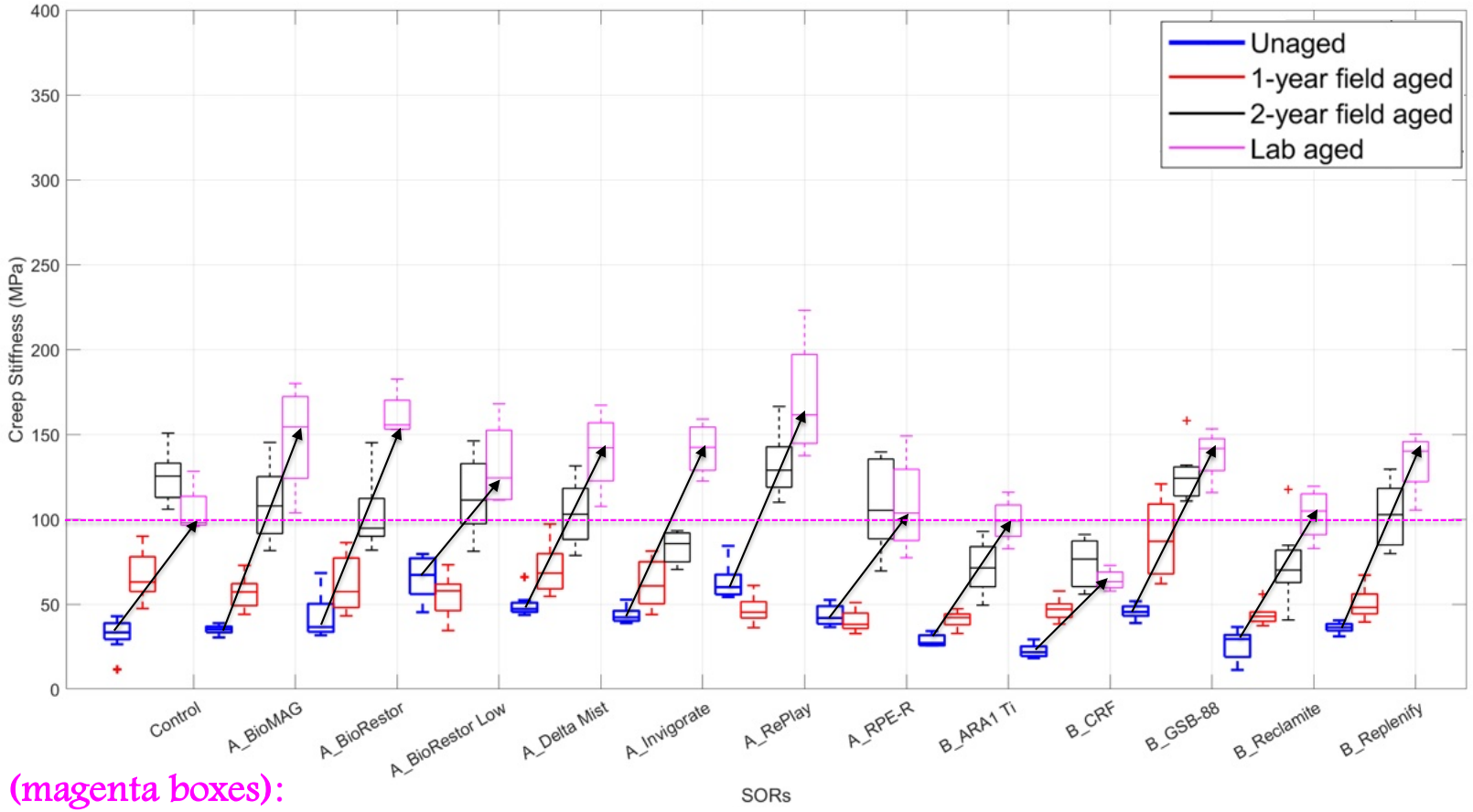


Two-year field aged (black boxes):

- A few SORs are effective for up to 1-2 years; need reapplication to continue to retard aging
- Effect of SORs could be different in pavements with surface microcracks

BBR Test Results (MnROAD34)

Creep stiffness @20°C



Lab aged (magenta boxes):

- Significant aging in some cores while others showed less aging
- Aged cores: Effect of SOR application might have faded away after long period of aging

Skid Resistance and Abrasion

MICHIGAN STATE UNIVERSITY

- **Modified Hamburg Wheel Tracking (HWT)**
  - To simulate the braking/acceleration effect on SOR-treated pavement surface
  - The steel wheel in the HWT device was replaced with a rubber wheel
  - Load level was reduced to 125 lb (ASTM D 6372)

1 2

Sample Preparation: For the identical surface level of both samples

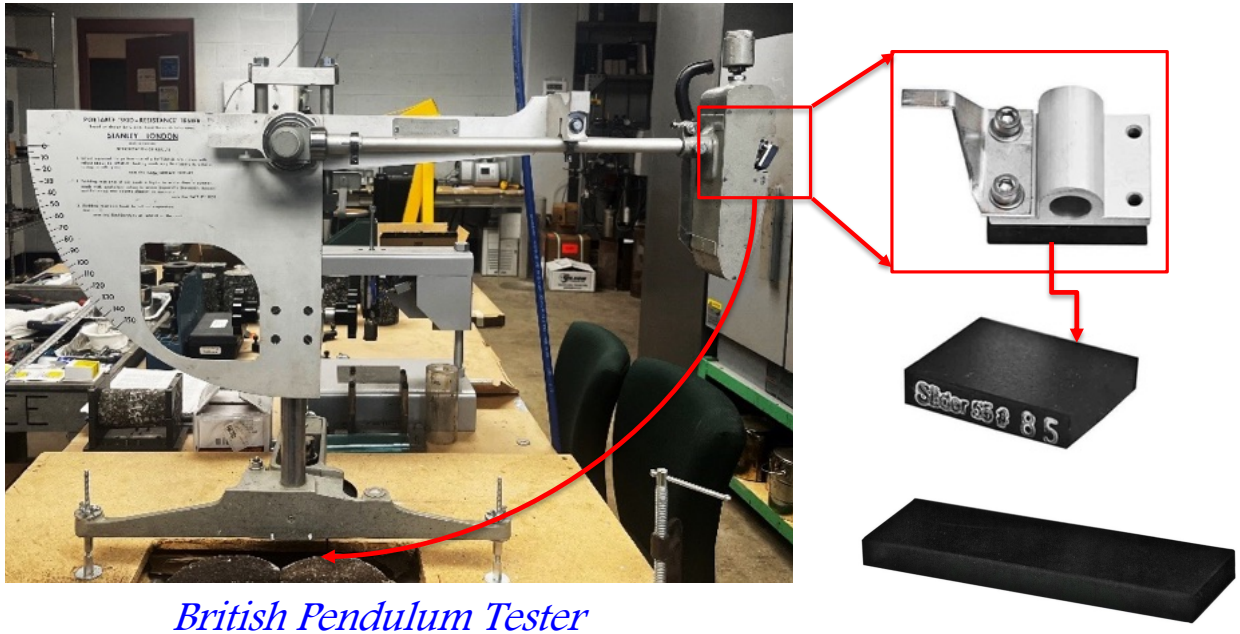
Modified Hamburg Wheel Tracking Machine

SOR: Spray-on-rejuvenators

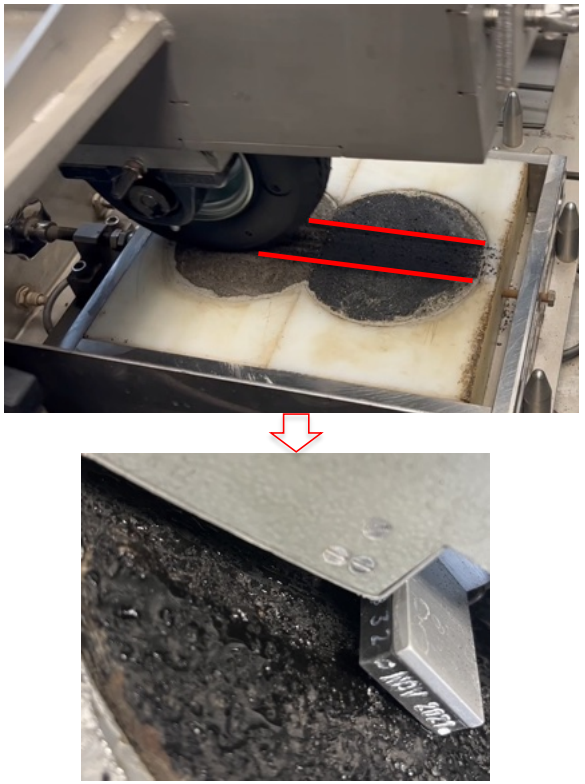
Skid Resistance and Abrasion

MICHIGAN STATE UNIVERSITY

- **British Pendulum Testing** (before and after the abrasion)
  - To quantify change in friction

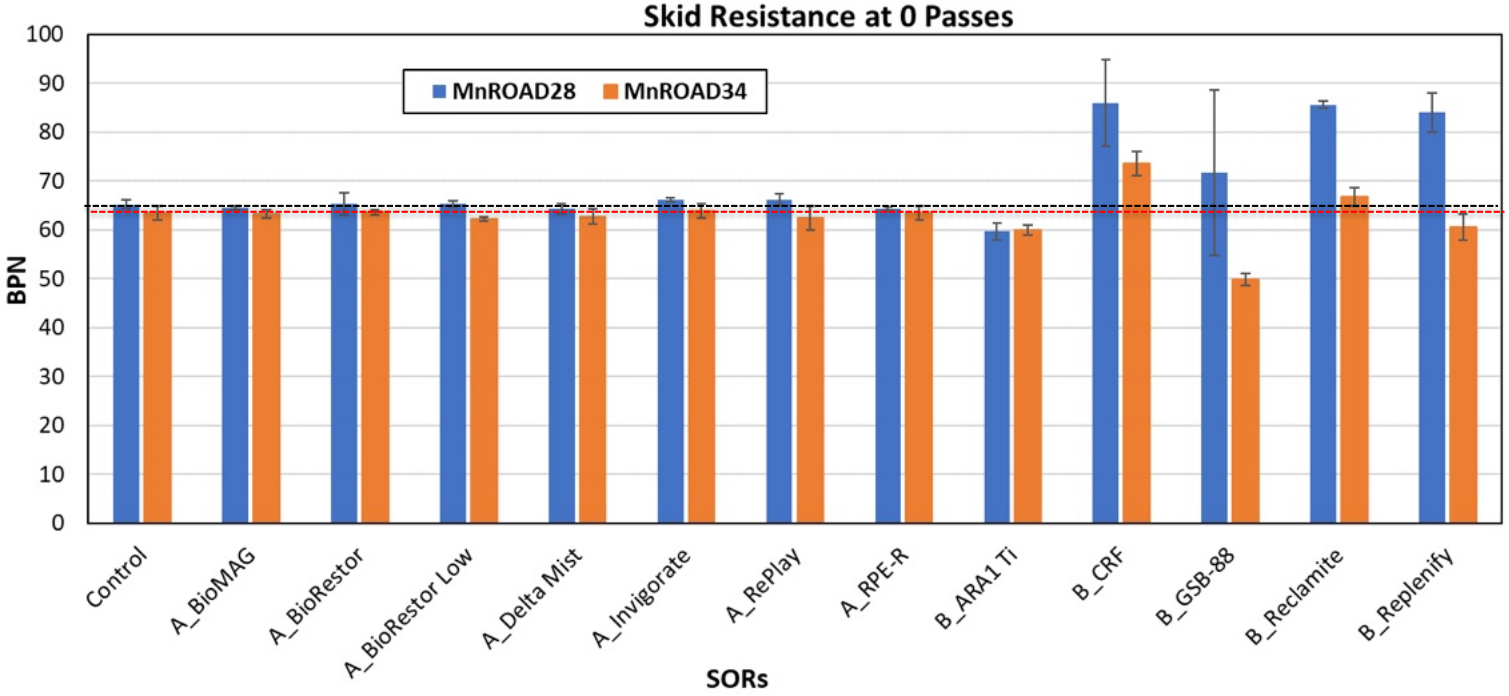


British Pendulum Tester



SOR: Spray-on-rejuvenators

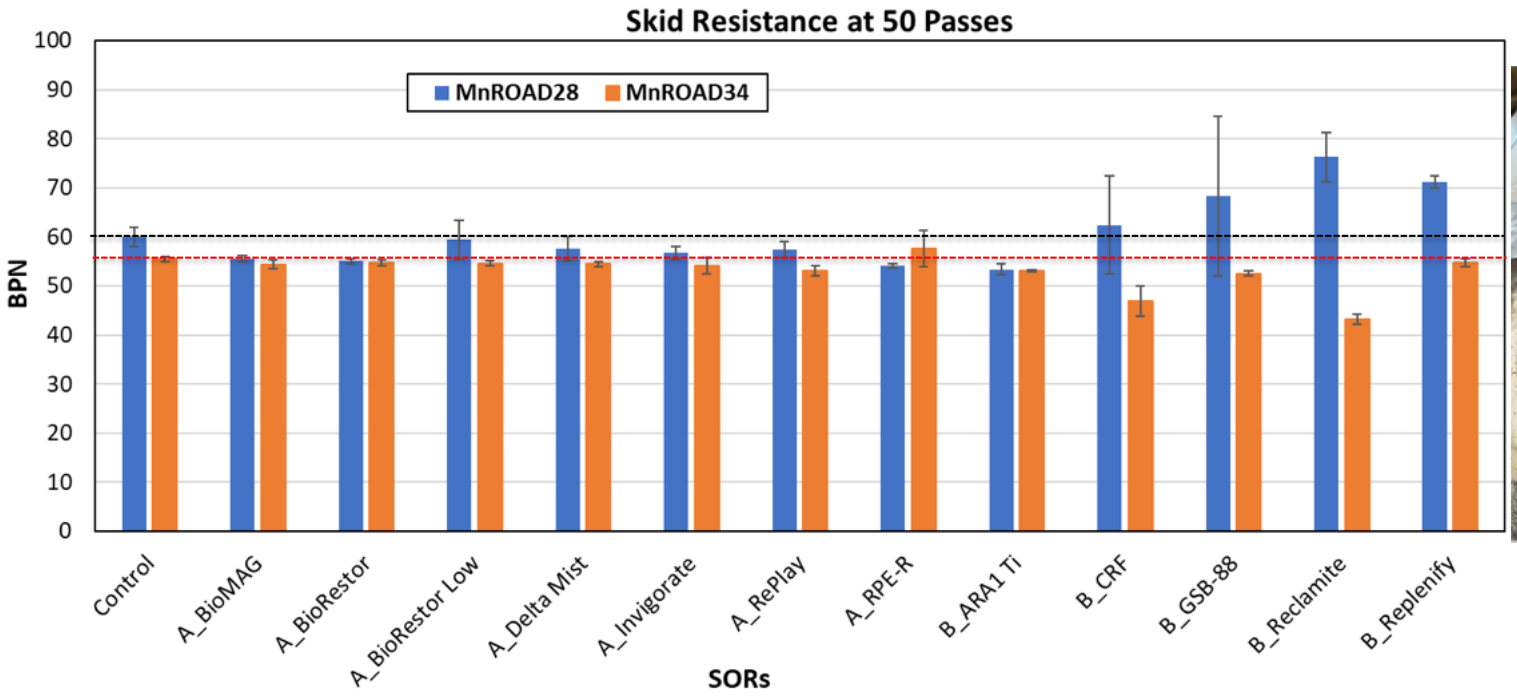
Skid Resistance



At 0 Passes:

- Similar friction values in most of the cells of MnROAD28 and MnROAD34
- Higher than control: *CRF, GSB88, Reclamite, Replenify* (MnROAD28); *CRF, Reclamite* (MnROAD34)
- Lower than control: *GSB88* (MnROAD34)

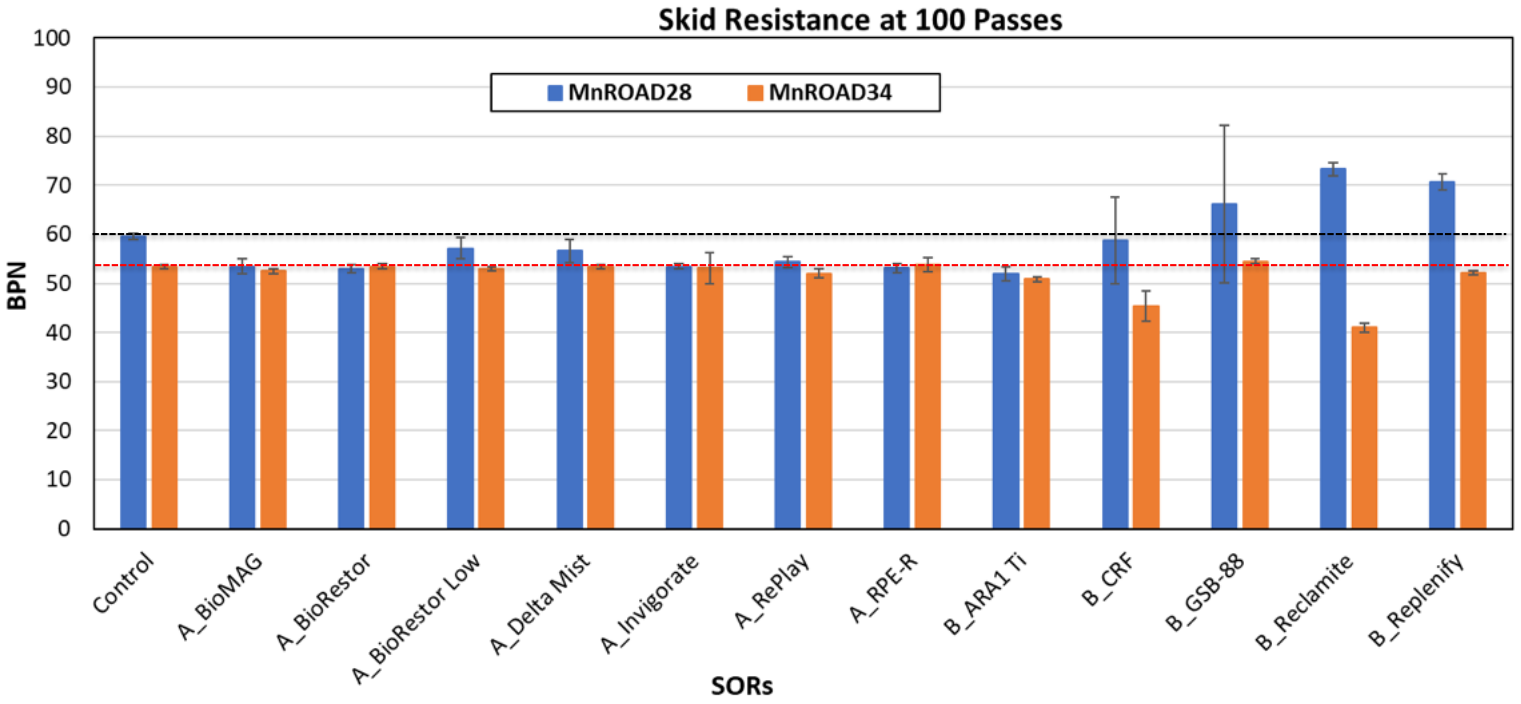
Skid Resistance

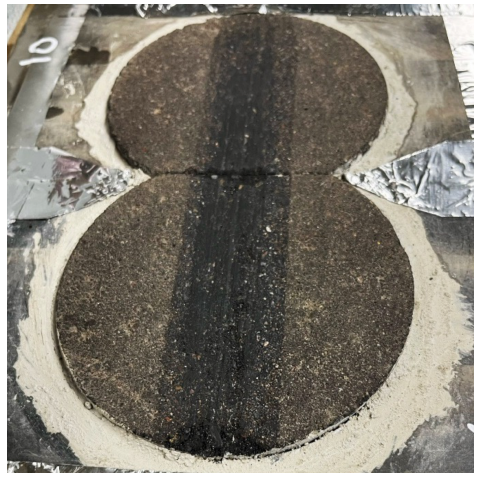


At 50 Passes:

- Friction values of all cells slightly decreased than 0 passes
- Higher than control: *CRF, GSB88, Reclamite, Replenify* (MnROAD28)
- Lower than control: *CRF, Reclamite* (MnROAD34)

Skid Resistance





At 100 Passes:

- Friction values of all cells slightly decreased than 50 passes
- Higher than control: ***GSB88, Reclamite, Replenify*** (MnROAD28)
- Lower than control: *CRF, Reclamite* (MnROAD34)

SOR Ranking

MICHIGAN STATE UNIVERSITY

- SOR ranking is determined by calculating *the percentage difference between the control cells and the different SOR-treated cells*
- Compared to the Control cells, the SORs with *lower values for creep stiffness, permeability, and rut depth and higher values for skid resistance (friction) were ranked in order*

SOR Ranking

MICHIGAN STATE UNIVERSITY

Ranking Score:

$$[(UA_{20}+F1_{20}+F2_{20}+LA_{20})+(UA_{4}+F1_{4}+F2_{4}+LA_{4})+(UA_{-10}+F1_{-10}+F2_{-10}+LA_{-10})+k+RD] - (BPN_{0}+BPN_{50}+BPN_{100})$$

In case of BBR, rut depth, permeability; lower the value from control, the better

In case of skid resistance (friction); higher the value from control, the better

% Difference between control and SOR-treated cells:

UA_{20} = Creep stiffness of unaged samples @ 20°C
$F1_{20}$ = Creep stiffness of one-year-field-aged-samples @ 20°C
$F2_{20}$ = Creep stiffness of two-year-field-aged-samples @ 20°C
LA_{20} = Creep stiffness of lab-aged-samples @ 20°C

UA_{4} = Creep stiffness of unaged samples @ 4°C
$F1_{4}$ = Creep stiffness of one-year-field-aged-samples @ 4°C
$F2_{4}$ = Creep stiffness of two-year-field-aged-samples @ 4°C
LA_{4} = Creep stiffness of lab-aged-samples @ 4°C

UA_{4} = Creep stiffness of unaged samples @ -10°C
$F1_{4}$ = Creep stiffness of one-year-field-aged-samples @ -10°C
$F2_{4}$ = Creep stiffness of two-year-field-aged-samples @ -10°C
LA_{4} = Creep stiffness of lab-aged-samples @ -10°C

k = Lab permeability test values on field extracted cores

RD = Rut depth of field extracted samples by HWT test
BPN_{0} = Skid resistance at 0-wheel passes
BPN_{50} = Skid resistance at 50-wheel passes
BPN_{100} = Skid resistance at 100-wheel passes

SOR Ranking

MICHIGAN STATE UNIVERSITY

Rank	Order	MnROAD28	MnROAD 34
Best	1	**B_Reclamite**	B_CRF
	2	**B_ARA1 Ti**	**B_Reclamite**
	3	**B_CRF**	**A_RPE-R**
	4	B_Replenify	**B_ARA1 Ti**
Better	5	**B_GSB-88**	**A_Invigorate**
	6	**A_BioMAG**	A_BioRestor Low
	7	A_RPE-R	**B_GSB-88**
	8	**A_Invigorate**	**A_BioMAG**
Good	9	**A_Delta Mist**	**A_Delta Mist**
	10	**A_BioRestor**	B_Replenify
	11	**A_RePlay**	**A_RePlay**
	12	A_BioRestor Low	**A_BioRestor**

Conclusions (Field Tests)

MICHIGAN STATE UNIVERSITY

- **Sand Patch Test:**
  - The Mean Texture Depth (MTD) of control sections: 0.3 to 0.5 mm variation
  - *No significant decrease* in the case of most of the SORs
  - CRF and GSB-88 increased the MTD after one month but decreased after 12 months
- **The Dynamic Friction Test (DFT):**
  - Slight decrement in friction coefficients after one month of SOR application
  - After 12 months, the friction values for all cells were similar to/higher than the pre-SOR application values
  - *GSB-88* showed lower friction coefficient values after one month and after 12 months of SOR application

Conclusions (Field Tests)

- **Permeability:**
  - After 1 month and 12 months of SOR treatment, slight changes in most of the SORs: might be for dust settling/spatial variability
  - Decrement in permeability: Evident in some SORs after 1 month and 12 months of SOR application

In general, SORs might have minor effects on pavement surface properties shortly after application. Over time, most of the field test parameters were restored to pre-SOR values.

Conclusions (Lab Tests)

- **Bending Beam Rheometer Test:**
  - Modified BBR test methodology was used in measuring the creep stiffness
  - MnROAD28 test section:
    - In unaged conditions, some of the SORs did not show a significant decrease in creep stiffness; true effect was seen one year after the application
    - Many SORs showed significant retardation of aging one/two years after application
    - Some SORs need reapplication after two years to continue to retard aging
  - MnROAD34 test section: *Presence of micro cracks*
    - Some of the SORs are effective in filling the cracks causing increment of creep stiffness compared to the respective control section (Bridging effect)
    - The softening effect of SORs decreased the creep stiffness
    - The resulting creep stiffness of a rejuvenated test cell in this test section is a ***combined result of softening and bridging effects***

- **Skid Resistance:**
  - *No significant reduction* in most of the SORs (specifically Group A)
  - *Skid resistance might increase in the presence of sand/fine gravel*

Ongoing Research

- Field study on performance evaluation of SORs after 24 and 36 months of application
- Measuring creep stiffness of ***three-year field-aged*** cores
- Assessment of Fatigue Resistance on two-year field-aged cores

Arthur Sickels Jr., Adrian Ricardo Archilla, University of Hawaii (2024)

Project Outcomes

MICHIGAN STATE UNIVERSITY

- **Published**
  - ***Peer-reviewed journal:***
    - ✓Vaddy, P., Islam, T., Kutay, M. E., Vrtis, M., Haider, S. W., & Cetin, B. (2023) "Evaluating the Short-term Performance of Spray-on Rejuvenators using a Modified Bending Beam Rheometer Test Methodology", Transportation Research Record, 0(0), DOI: 10.1177/03611981231209038. https://journals.sagepub.com/doi/10.1177/03611981231209038
  - ***Poster:***
    - ✓Vaddy, P., Islam, T., Kutay, M.E., Haider, S.W., and Cetin, B. (2024) "Creep Stiffness Behavior of Spray-on Rejuvenator (SOR) Treated Asphalt Pavements under Different Aging Conditions", *Presented at* 103rd Annual Meeting of the Transportation Research Board, Washington, D.C., USA.
    - ✓Islam, T., Vaddy, P., Kutay, M.E., Haider, S.W., and Cetin, B. (2023) "Evaluating the Effect of Spray-On Rejuvenators On Asphalt Pavement Surfaces", *Presented at* Graduate Research Symposium, Department of Civil and Environment Engineering, Michigan State University, USA.
    - ✓Vaddy, P., Kutay, M.E., Michael, V., Cetin, B., and Haider, S.W. (2023) "Evaluation of Short-term Field Performance of Proprietary Spray-on Rejuvenators", *Presented at* 102nd Annual Meeting of the Transportation Research Board, Washington, D.C., USA.
- **Current works in progress**
  - Performance evaluation of SORs based on field tests
  - Performance evaluation of SORs based on lab tests

Acknowledgements

- Michael Vrtis, Ph.D., P.E., MnDOT
- MnROAD Personnel – Field testing

Thank You!