TRANSPORTATION POOLED FUND PROGRAM
QUARTERLY PROGRESS REPORT

Lead Agency (FHWA or State DOT): Minnesota Department of Transportation

INSTRUCTIONS:
Project Managers and/or research project investigators should complete a quarterly progress report for each calendar quarter during which the projects are active. Please provide a project schedule status of the research activities tied to each task that is defined in the proposal; a percentage completion of each task; a concise discussion (2 or 3 sentences) of the current status, including accomplishments and problems encountered, if any. List all tasks, even if no work was done during this period.

Transportation Pooled Fund Program Project # *(i.e, SPR-2(XXX), SPR-3(XXX) or TPF-5(XXX)* TPF-5(341) http://www.pooledfund.org/Details/Study/590		**Transportation Pooled Fund Program - Report Period:** ☐Quarter 1 (January 1 – March 31) ☐Quarter 2 (April 1 – June 30) ☐Quarter 3 (July 1 – September 30) ☒Quarter 4 (October 4 – December 31)
Project Title: Long-term Testing and Analysis on Asphalt Mix Rejuvenator Field Sections		
Name of Project Manager(s): PI: Jo E. Sias Co-PI: Eshan V. Dave PC: Debbie Sinclair TL: Michael Vrtis	**Phone Number:** 603 862-3277 603 862-5268	**E-Mail** jo.sias@unh.edu eshan.dave@unh.edu
Lead Agency Project ID: NRRA LT1	**Other Project ID (i.e., contract #):** MnDOT Contract No. 1036343 Work Order 01	**Project Start Date:** August 24, 2020
Original Project End Date: August 31, 2024	**Current Project End Date:** August 31, 2024	**Number of Extensions:** 0

Project schedule status:

☒ On schedule ☐ On revised schedule ☐ Ahead of schedule ☐ Behind schedule

Overall Project Statistics:

Total Project Budget	Total Cost to Date for Project	Percentage of Work Completed to Date
148,981	1,437	5%

Quarterly Project Statistics:

Total Project Expenses and Percentage This Quarter	Total Amount of Funds Expended This Quarter	Total Percentage of Time Used to Date
1%	1%	1%

Project Description:
Asphalt rejuvenators are used to incorporate higher amounts of Reclaimed Asphalt Pavement (RAP) in Hot Mix Asphalt (HMA) without detrimentally impacting the long-term performance of the pavement. Rejuvenating agents (RAs) are relatively new in the HMA industry and there are many different products marketed to transportation agencies. However, most of these products have limited field and laboratory test data available to support their effectiveness over time. Several recent research efforts have shown that some products, while effective immediately after production, show rapid decrease in effectiveness with aging. Therefore, there is a need for a better understanding of how various RAs perform over time through both laboratory and field evaluations to help guide engineers on appropriate usage of these materials.

The National Road Research Alliance (NRRA) Flexible Team constructed field test sections as part of a mill and overlay project on Trunk Highway 6 (TH6) located in Emily, MN in August of 2019. These field sections include wearing courses with 40% RAP that incorporate seven different RA products, with the dosage determined by the supplier to meet a target extracted and recovered performance grade (PG) of XX-34. In addition to the RA test sections, there are control sections with 40% RAP and 30% RAP (the maximum level allowed on remainder of this project).

The objective of this research project is to evaluate the effectiveness of the seven RA products over time and evaluate their performance as compared to the control mixtures. This will be accomplished through a combination of binder and mixture characterization and performance testing using different laboratory aging levels, field core testing, and performance monitoring of the field sections over time.

Progress this Quarter (includes meetings, work plan status, contract status, significant progress, etc.):
General: The project update meeting was conducted on November 19h, 2020. During this meeting, the mixture testing results provided by NRRA agency members and the determination of the additional long-term laboratory conditioning level were discussed. Specific progress for various study tasks is provided below.

Task 1 Technical Advisory Panel (TAP) Update/ Monitoring Coordination:
This task is currently underway. The research team is reviewing the updated NRRA Mix Rejuvenator Synthesis and conducting a thorough literature review regarding the available tools and techniques to assess various rejuvenators, especially for their long-term performance. Field cores will be taken once per year in the fall (September/October) and field monitoring will be conducted twice per year for the project duration: at the time of coring and at the conclusion of each winter season (since substantial cracking distress is expected to occur over winter months). Refinements to the recommended coring and field monitoring schedule will be done based on information from the literature review, testing results, field performance, and discussion with the TAP.

Task 2 Annual Interim Update 1st Year -Initial Construction Results.
Research team is working with MnDOT staff to transfer the pavement construction information (including the mix design information and pavement structure details, etc.) for the different field sections, gathered pavement performance data, and completed test results.

Task 3 Plant Produced Mixture and Field Core Testing.
The majority of testing to be conducted by NRRA agencies has been completed, and testing data have been received and analyzed by research team: Hamburg Wheel Track Testing (HWTT) by MnDOT; Tensile Strength Ratio (TSR) testing by MoDOT; Semi-circular Bending (I-FIT) test by IDOT; Ideal Cracking Test (CT-Index) by WisDOT. The Disk-shaped Compact Tension (DCT) testing has been delayed due to COVID-19; MnDOT plans to complete this testing during the winter. The sampled plant-produced mixtures, binders, and field cores after one-year service from the different sections are currently in transit and will be received by the research team soon.

Task 4 Binder Testing: No progress to report.

Task 5 Annual Interim Update 2nd and 3rd Year: No progress to report.

Task 6 Final Report: No progress to report.

Anticipated work next quarter:

Key activities that will be undertaken in the upcoming quarter are the following:

Task 1: The literature review will be completed and any adjustments to the coring, monitoring, or testing plan will be discussed with the TAP. The additional long-term aging condition (in addition to 6 hours @ 135°C) will be evaluated. A task report (Task-1 deliverable) will be submitted to TAP at the end of this task.

Task 2: The research team will summarize and report as-built details of each field section as well as their current performance provided by MnDOT. Binder extraction and recovery from the loose mixtures sampled during production will be conducted using ASTM D7906 procedure (toluene extraction and rotovap recovery). Rheological and chemical characterization of the recovered binders as well as the virgin and blended binders sampled during production will begin. Appropriate aging (RTFO and/or 20 hours PAV) will be conducted for grading the various binders according to the Superpave procedure.

Task 3: Additional mixture testing including the complex modulus and direct tension cyclic fatigue tests is anticipated to be performed on the sampled plant mixtures and the mixtures after 6hrs. at 135°C aging condition. Research team will continue to analyze the testing data provided by the NRRA agencies as well as the data measured from the tests performed by the research team.

Significant Results:

Significant results from this quarter are listed below:

1. Mixture testing results

The results from the testing conducted by NRRA agencies are summarized and presented below. RA1-RA7 represents the mixtures with recycling agent (RA) added that were placed on the corresponding field test sections (Cell 6001-6007). 30% RAP indicates the control section with 30% RAP mixture, while 40% RAP represents the mixtures containing 40% RAP with 40% RAP1 shows the mixture sampled from the first day of production and 40% RAP2 indicates the mixture sampled from the second day of production.

Hamburg Wheel Track Testing (HWTT):
Figure 1 and 2 below show the average results of the HWTT performed by MnDOT. HWTT was conducted on the plant produced mixture without additional aging.

Figure 1 shows the number of passes to the 12.5mm rut depth for the study mixtures. Only the RA7, 30% RAP and 40% RAP1 mixtures meet the current threshold value for rutting resistance (>10,000@12.5mm rut depth) set by MnDOT for their material selection. Comparing the three control mixtures (30% RAP, 40% RAP1 and 40% RAP2), 30% RAP mixture has lower number of passes to the 12.5mm rut depth than 40% RAP1 mixture, but higher than 40% RAP2 mixture. Generally, mixtures with RAs (except for RA7) have substantially lower number of passes to the 12.5mm rut depth value, indicating deterioration of the rutting performance by adding the RAs into the RAP mixture. The performance of RA7 is comparable to the 30% RAP mixture. Additionally, there is significant difference observed between 40% RAP1 and 40% RAP2, indicating the potential inconsistency for the mixtures sampled during two production days.

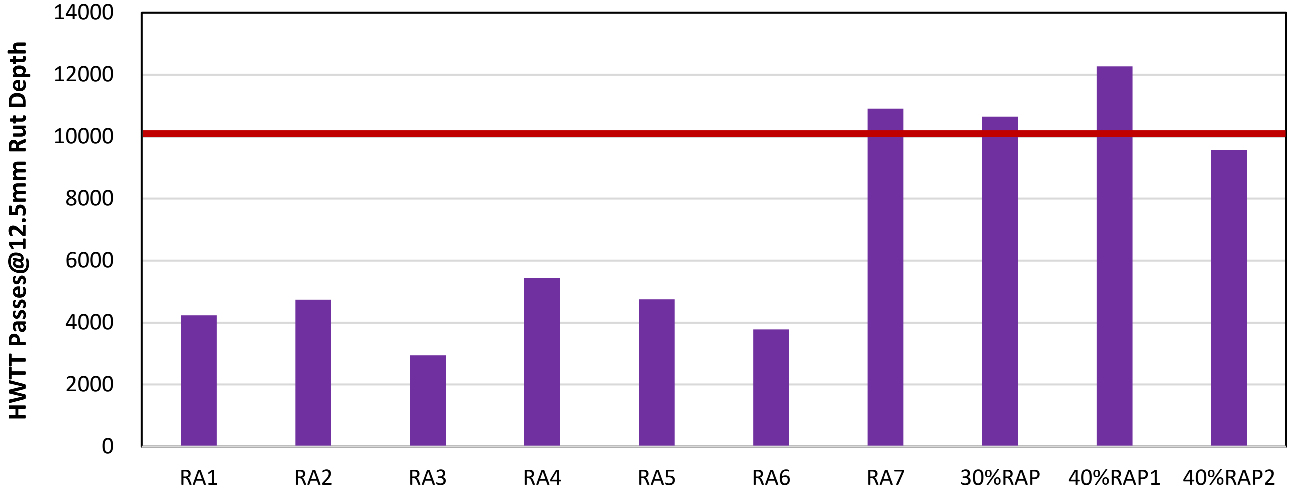

Figure 1 Number of Passes to 12.5mm Rut Depth from Hamburg Wheel Track Testing (HWTT) by MnDOT

Figure 2 shows the striping inflection point (SIP) for the study mixtures. Comparing the three control mixtures, mixture 40% RAP1 shows the highest SIP value indicating the better moisture resistance. Comparing the mixtures with RAs and the control mixtures, the three control mixtures typically have the higher SIP value than the RA mixtures (especially RA1 – RA6), which shows that the study RAs may deteriorate the moisture resistance of the mixtures with RAP. Again, there is significant difference observed for SIP value between 40% RAP1 and 40% RAP2, indicating the potential inconsistency for the mixtures sampled during two production days.

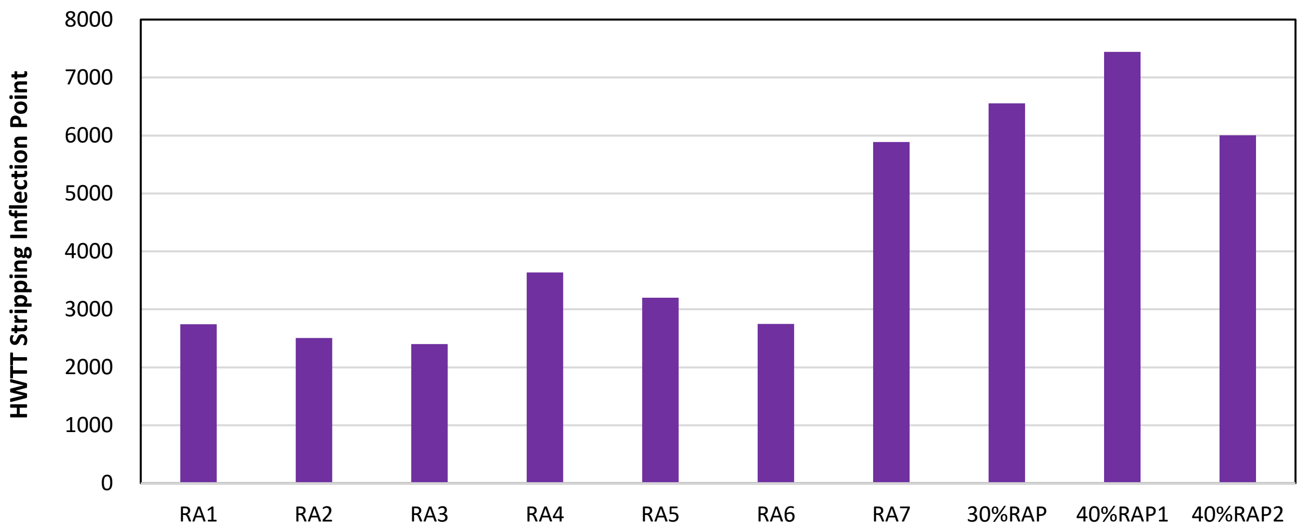

Figure 2 Striping Inflection Point from Hamburg Wheel Track Testing (HWTT) by MnDOT

Semi-circular Bending (I-FIT) test by IDOT

Figure 3 below shows the average flexibility index values for the mixtures measured from I-FIT test conducted by Illinois DOT. Tests were conducted on unaged plant mix, plant mix aged 6hrs. at 135°C in the loose condition, and compacted specimens aged 3 days at 95˚C. Aging in the loose or compacted state causes a decrease in FI value for all mixtures. All plant produced mixtures pass the threshold value of 8 set by IDOT for their material selection. Comparing the three control mixtures, mixture 30% RAP that has lower RAP content typically shows the higher FI value after each aging conditioning level as compared to the 40% RAP1 and 40% RAP2 mixtures with higher RAP content as expected. For the plant mixtures, except for RA7, other six mixtures with RAs clearly show the higher FI value than three control mixtures, while after 6hrs.

at 135°C condition, FI values for RA mixtures except for RA2 are higher than the control mixtures. After 3 days at 95˚C aging of the compacted specimen, RA1 – RA6 mixtures show the higher FI value than control mixtures. Additionally, there is no significant difference observed between 40% RAP1 and 40% RAP2 mixture as shown in Figure 3.

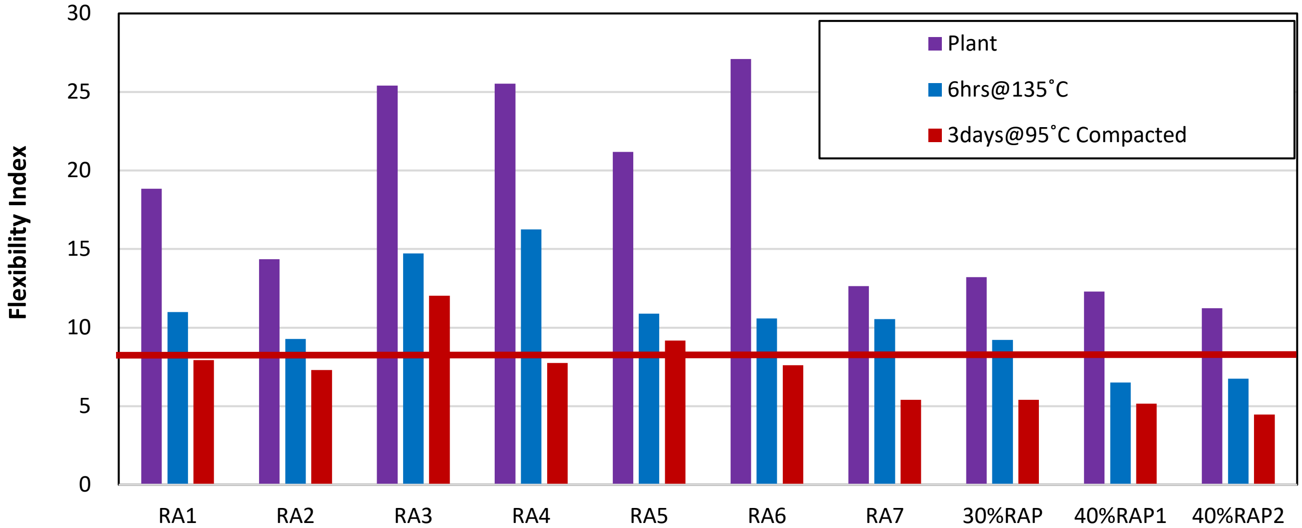

Figure 3 Semi-circular Bending (I-FIT) test by IDOT

Ideal Cracking Test (CT-Index) by WisDOT

Figure 4 below shows the CT_{Index} values for the different mixtures measured from the CT-Index test conducted by Wisconsin DOT. Tests were conducted on unaged plant mix and plant mix aged 6hrs. at 135°C in the loose condition. Aging in the loose state causes a decrease in CT_{Index} value for all mixtures. Comparing the three control mixtures, mixture 30% RAP with lower RAP content shows the lower CT_{Index} value as compared to the 40% RAP1 and 40% RAP2 mixtures for unaged condition, while after the 6hrs. at 135°C conditioning level, the CT_{Index} values for these mixtures are comparable with 40% RAP1 shows the slightly lower value than other two mixtures. Comparing the RA mixtures and the three control mixtures, mixture RA1, RA3 RA4 and RA5 clearly show the higher CT_{Index} value than control mixtures after each aging condition. Other three mixtures with RAs (RA2, RA6 and RA7) shows the comparable CT_{Index} value as compared to the three control mixtures for unaged condition. However, RA6 and RA7 have the lower CT_{Index} value than control mixtures after the 6hrs. at 135°C condition, while RA2 shows the higher value after aging. In addition, there is no significant difference observed between 40% RAP1 and 40% RAP2 mixture as shown in Figure 4.

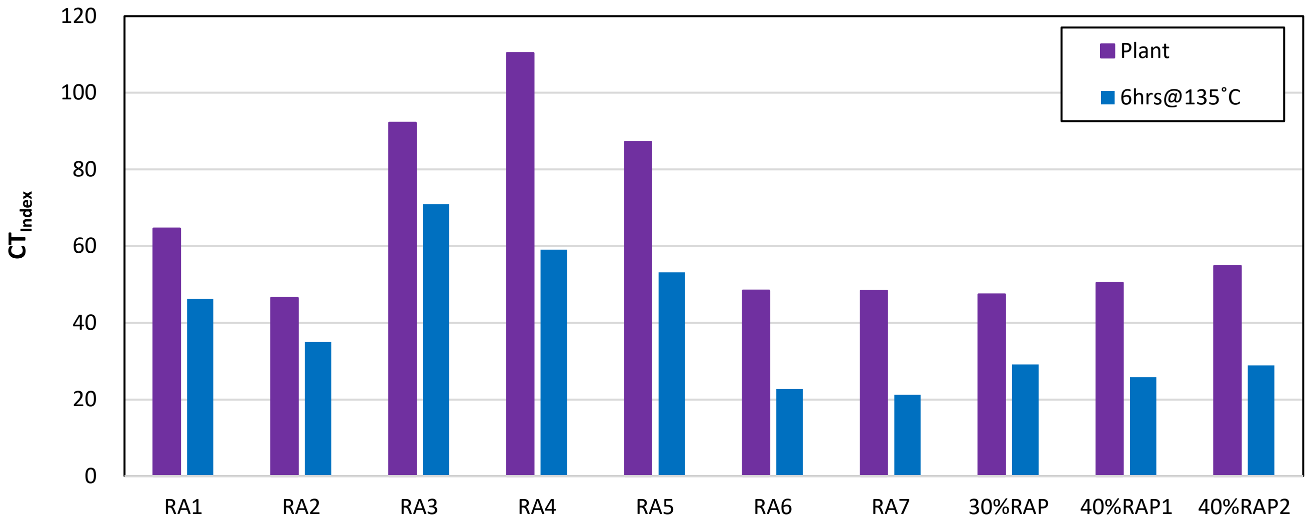

Figure 4 Ideal Cracking Test (CT-Index) by WisDOT

Tensile Strength Ratio (TSR) testing by MoDOT

Figure 5 below shows the TSR values for the different mixtures. Tests were conducted on unaged plant mix and plant mix aged 6hrs. at 135°C in the loose condition. There isn't a clear trend showing the change of TSR value with increase of aging condition. Comparing the three control mixtures, mixture with lower RAP content (30%RAP) shows the lower TSR value as compared to the mixtures with higher RAP content (40% RAP1 and 40% RAP2) for both aging conditions, indicating the higher RAP content may contribute to the moisture resistance of asphalt mixtures. This can be related to the fact that the aggregate in the recycled materials is covered and protected by the aged binder and the bonds between aggregate and aged binder is stronger than the ones between aggregate and virgin binder, making the recycled mixture less vulnerable to moisture damage (Shen et al. 2007; Hajj et al. 2009; Zhao et al. 2012). All three control mixtures do not pass the TSR threshold value of 0.8 for unaged condition, while the 40% RAP1 and 40% RAP2 mixtures meet the requirement after 6hrs. at 135°C aging condition. Comparing the RA mixtures and the three control mixtures, mixtures with RAs show the higher TSR value after STA condition (all pass the threshold value of 0.8). In addition, there is no large difference observed between 40%RAP1 and 40%RAP2 after STA, but the different becomes significant after 6hrs@135°C aging as shown in Figure 5.

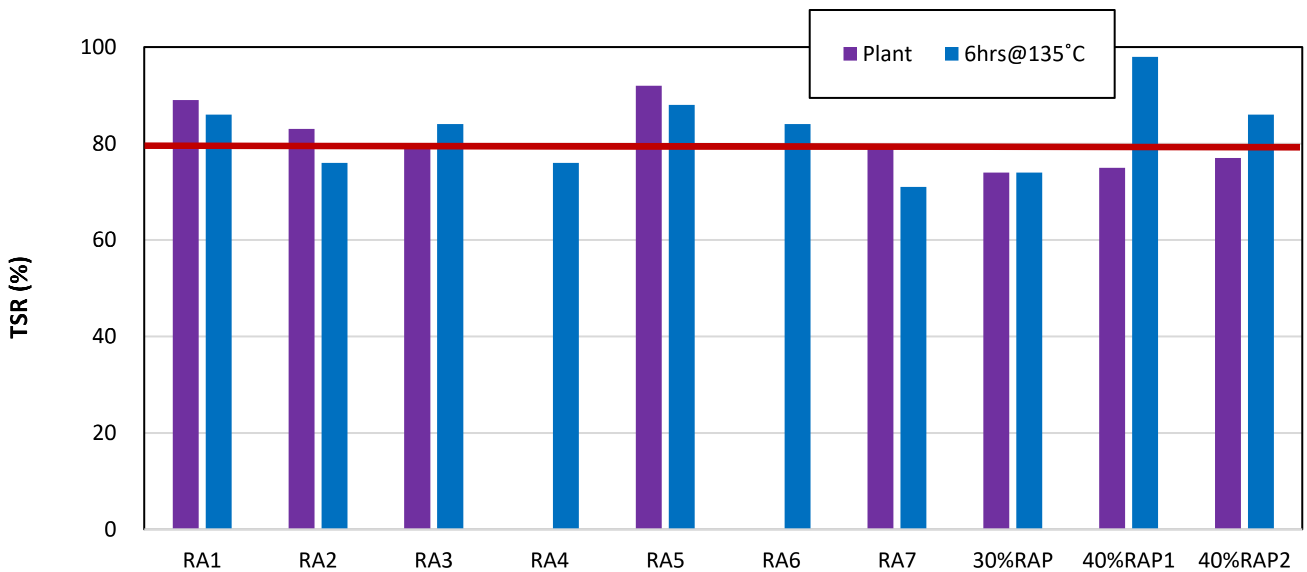

Figure 5 Tensile Strength Ratio (TSR) testing by MoDOT

2. Preliminary literature review results

In this section, the literature review results on long-term laboratory mixture conditioning methods is summarized. This information was also presented in the project update meeting conducted this quarter for collecting feedback from the project TAP.

Several asphalt mixture laboratory conditioning procedures to simulate the long-term aging of asphalt pavement in the field are documented in the literature. These procedures can be further classified based on state of mixture during aging: compacted specimen or loose mix.

The procedures documented in the literature for conditioning of the compacted mixture specimens are provided in **Table 1.**

Table 1 Studies on Accelerated Laboratory Aging Procedures Developed for Compacted Asphalt Specimens

References	Laboratory Conditioning Method	Key Findings
AASHTO R30	5 days at 85°C	Can approximately represent five to ten years of aging in the field
Brown and Scholz (2000)	4 and 5 days at 85°C	1. 5 days at 85°C can simulate long-term aging of asphalt pavements in UK; 2. 4 days at 85°C simulates 15 years old pavement in the US
Harrigan (2007); Houston et al. (2005)	5 days at 80, 85, and 90°C	5 days at 85°C simulates 7–10 years of field aging
Epps Martin et al. (2014)	1 to 16 weeks at 60°C	4–8 weeks at 60°C simulates first year of field aging
Newcomb et al. (2015)	AASHTO R30	Relates to 11-22 months of field aging depending on climate
Sirin et al. (2020)	0, 3, 7, 15, 30, 45, 60, 90, and 120 days at 85°C	45 and 75 days at 85°C simulate 5 years field aging in Middle East condition for wearing and base course, respectively
Nicholls (2006)	2 days at 60°C	Simulates around 1-year aging in the field
Van den Bergh (2011)	16 hours at 110-120°C	The method can simulate around 20 years of aging in field

Research (Collop et al., 2004; Reed et al., 2010; Kim et al., 2013; Elwardany et al., 2017; Zhang et al., 2019) has shown that aging on the compacted specimen leads to a change in air void distribution and the development of an aging gradient from the specimen's center to its periphery and can result in different aging extents for different specimen geometries. This variability complicates the interpretation of results from different performance tests on the aged mixtures.

Some studies recommend aging loose mixtures in the laboratory to simulate the aging of asphalt pavements instead of aging compacted specimens. The primary advantages of loose mixture aging over compacted specimen aging are: (1) problems associated with the conditioning of compacted specimen (e.g., change in air void distribution and aging gradient) during laboratory aging are avoided; (2) air and heat can easily circulate inside the loose asphalt mixture, which not only allows for uniform aging throughout the mix but also significantly shortens the conditioning time needed due to a larger area of the binder surface being exposed to oxygen.

The procedures documented in the literature for conditioning of the loose mixture are provided in
Table 1

Table 2 Studies on Accelerated Laboratory Aging Procedures Developed for Loose Asphalt Mixtures

References	Laboratory Aging Condition	Key Findings
Asphalt Institute (2010)	24 hours at 135°C	This method can simulate 7 to 10 years of aging in the field
Von Quintus (1989); Van den Bergh (2009; 2011)	8, 16, 24, and 36 hours at 135°C	1. STA at 130°C for 3 hours following LTA at 90°C for 168 hours; 2. STA at 134°C for 4 hours following LTA at 85°C for 168 hours 3. Two methods can be used to simulate 7 to 10 years field aging
Yin et al. (2017)	2 weeks at 60°C; 3 days at 85°C; and 5 days at 85°C	1. 2 weeks at 60°C simulates 7 to 12 months field aging; 2. 5 days at 60°C simulates 12 to 23 months field aging
Sirin et al. (2011)	0, 1, 2, and 3 days at 135°C on loose mixtures	2-3 and 1-2 days at 135°C can simulate 5 years field aging in Middle East condition for wearing and base course, respectively
Islam et al. (2015)	1, 5, 10, 15, 20, and 25 days of oven aging at 85°C	1-day laboratory aging is close to 1-year of field aging
RILEM TG5 (2009)	7-9 days at 85°C	1. Laboratory aging of loose mix provides an appropriate way to produce RAP material; 2. A more homogenous aged mix obtained from aging of loose mix

Mollenhauer and Mouillet (2011)	90°C with 2.1 MPa pressure for 20 hours; 85°C for nine days	Both can simulate 11 to 12 years field aging

Table 2 (continued) Studies on Accelerated Laboratory Aging Procedures Developed for Loose Asphalt Mixtures

Reed (2010)	Loose mix at 85°C for 5 days; Compacted sample at 85°C for 14 days	1. Uniform aging of the asphalt around each aggregate particle in the laboratory-aged loose mix; 2. Significant changes in air void content during the long-term aging of the compacted specimens
Yousefi et al. (2018)	Loose mix at 70°C, 85°C and 95°C for different durations; Loose mix at 135°C with different durations	Aging asphalt at temperatures above 100°C may: 1. disrupt polar molecular associations, which leads to the thermal decomposition of sulfoxides in asphalt binders; 2. lead to significantly different cracking performance results compared to the material testing and pavement simulations for aging below 95°C
Chen et al. (2018)	Loose mix at 95°C for different durations; Loose mix at 135°C with different durations	1. 8 hrs.@135°C can simulate an equivalent aging level as 5 days@95°C; 2. Both can simulate around 70, 000 CDD (cumulative degree-days) of field aging

The recent findings of the National Cooperative Highway Research Program (NCHRP) 09-54 project on long term aging of asphalt mixtures suggests 95°C as an optimal temperature for aging loose mix (Kim et al., 2018). The aging time varies with the geographical location of the pavement and should be adjusted based on climate conditions and pavement depth. A climatic aging index (CAI), based on a simplification of the aging kinetics model, was developed in the NCHRP 09-54 project to determine laboratory aging durations at 95°C for asphalt mixtures that best reflect the time, climate, and pavement depth for a given pavement location in the United States using Enhanced Integrated Climatic Model (EICM) hourly pavement temperature data. Zhang et al. (2019&2020) proposed that 5 days@95°C can simulate around 10 years field aging while 12 days@95°C can simulate approximately 10 years field aging based on New Hampshire historical climatic condition.

By means of the CAI model and the aging maps proposed from the NCHRP 09-54 project, **Table 3** below shows the lab aging durations that correspond to different field aging durations and pavement depths based on the Minnesota historical climatic data. The 6mm depth can be generally used as the critical depth to represent the aging behavior of the top 1/2” of asphalt pavement, while 20 mm depth and 50mm depth can be used to represent the middle 1” and bottom 1” of the surface layer, respectively.

Table 3 Laboratory Conditioning Durations Needed to Simulate the Corresponding Field Aging Durations at Different Pavement Locations

Field Aging Duration (years)	**Laboratory Conditioning Duration (days)**		
	6mm	20mm	50mm
4	2-3	1	1
8	5-6	2-3	1-2
16	11-13	5-6	3-4

3. Determination of the additional long-term aging conditioning level

To more accurately and effectively capture the performance, especially the long-term performance of project rejuvenators, several aging levels should be evaluated to characterize how the properties of the binders and mixtures change with aging and differentiate performance with respect to the control mixtures. In addition to the binder conditioning levels, and the planned mixture aging level of 6 hrs. at 135°C (simulates approximately 3-4 years in service based on Minnesota conditions (Chen et al. 2018)), an additional long-term aging conditioning level needs to be considered and evaluated.

Based on the discussion between the research team and the TAP, as well as the findings observed in the literature review (summarized and presented in **Table 1** and **2**), the multi-hours@135°C recommended by Asphalt Institute (consistent with the 6 hrs@135°C aging) and multi-days@95°C suggested by NCHRP 09-54 project are selected as the laboratory conditioning protocols that will be further evaluated in this project.

At this point, research team proposes that both hours@135°C and days@95°C protocol be used to condition selected mixtures, and the conditioning durations will be determined after evaluation of mixture and extracted/recovered binder results with the 6 hrs. at 135 conditioning level. Then a set of and mixture and binder testing (e.g. binder DSR test and SARA analysis; mixture E* test and fracture tests) will be conducted on the aged mixture and extracted and recovered binder to see if there is significant effect on the binder/mixture properties caused by aging of the mixtures at higher temperature. Also, the field cores after one-year service have been sampled and will be tested (on both mixture and extracted and recovered binders). The results from field cores will be used to compare with the laboratory aged mixtures and binders to find correlations between the laboratory conditioning durations at 135°C/95°C and the actual field aging duration. Based on these results observed from the testing and analysis, the additional long-term laboratory mixture conditioning level that will be employed in this project will be determined.

4. References

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Circumstance affecting project or budget. (Please describe any challenges encountered or anticipated that might affect the completion of the project within the time, scope and fiscal constraints set forth in the agreement, along with recommended solutions to those problems).

Nothing to report at this time.

Potential Implementation:

Nothing to report at this time.