FHWA Asphalt Binder Expert Task Group (ETG)

Asphalt Binder ETG Purpose
The primary objective of the Federal Highway Administration (FHWA) Expert Task Group is to provide a forum for the discussion of ongoing asphalt binder technology and to provide technical input for research, development and implementation.

A total of 68 individuals attended the meeting (16 members, 2 contract personnel, and 50 visitors). Attachment A is the meeting agenda, Attachment B includes a listing of the Asphalt Binder ETG members, and Attachment C is a listing of the Binder ETG Task Force members.

Member of the FHWA Asphalt Mixture ETG in attendance included:
Gaylon Baumgardner, Paragon Technical Services, Inc. (Chairman)
R. Michael Anderson, Asphalt Institute (Co-Chairman)
Matthew Corrigan, FHWA (Secretary)
David A. Anderson, Penn State University
John D'Angelo, D'Angelo Consulting
Joseph DeVol, Washington DOT
Darren G. Hazlett, Texas DOT
Gayle King, GHK, Inc.
Bruce Morgenstern, Wyoming DOT
Ioan. I. Negulescu, Louisiana State University
Jean-Pascal Planche, Asphalt & Petroleum Technology
Gerald Reinke, MTE Services
Geoff Rowe, Abatech, Inc.
Karl Zipf, Delaware DOT
Pamela Marks, (Liaison) Ministry of Transportation

Members of the ETG not in attendance:
Lyndi Davis Blackburn, Alabama Department of Transportation (DOT)
Mark Buncher, (Liaison) Asphalt Institute
Audrey Copeland, (Liaison) National Asphalt Pavement Association (NAPA)
Edward Harrigan, (Liaison) National Cooperative Highway Research Program (NCHRP)
Evan Rothblatt, (Liaison) American Associations of State Highway Transportation Officials (AASHTO)

"Friends" of the ETG that were in attendance included:
Tanya Nash, PRI Asphalt Technologies
Jack Youtcheff, FHWA, TFHRC
Jason Bausano, Ingevity
Andy Cascione, Flint Hills Resources
Darin Hunter, Anton Paar USA
Pauya Teymourpour, Rock Road Companies
Sebastian Puchalski, Kraton Polymers
Bob Kluttz, Kraton Polymers

Scott Veglahn, Mathy Construction
Andrew Hanz, Mathy Construction
Codrin Daranga, Paragon Technical Services
Gerry Huber, Heritage Research Group
Chris Strack, Sonneborn
Kevin Nelson, Seneca Petroleum
CJ DuBois, DuPont Elvaloy
Amir Golalipour, ESC, Inc.
Ronald Corun, Axeon Specialty Products
Ted Flanigan, Wright Asphalt Products Co.
Ollie-Ville Laukkonen, University of Massachusetts
Shauna Teclemariam, U.S. Oil & Refining Co.
Alan Rawle, Malvern Instruments Inc.
Giovanni Onnemso, Innoplus Inc.
Ann Barana, Infratest USA, Inc.
Ahmed Faheen, Temple University
Howard Anderson, Utah DOT
Lee Gallivan, Gallivan Consulting, Inc.
Denis Boisvert, New Hampshire DOT
Beran Black, New Hampshire DOT
John Casola, Malvern
Walaa Mogawer, University of Massachusetts/HSRC
Ramon Bonaquist, Advanced Asphalt Technology
Bob McGennis, The Holly Frontier Companies
Thomas Ludlum, The Holly Frontier Companies
Peter Moore, Pike Industries
Paul Montenegro
Jon Pepyne, All States Materials Group
Jen Penner, Husky Oil
Bharath Rajaram, TA Instruments
Bryon Engstrom, Massachusetts DOT
Stacy Glidden, Payne & Dolan
Hua Qin Liu, Bitumax
Maximie Florant, Bitumax
Marc Joyal, New Hampshire DOT
Pavel Kriz, Imperial
Salman Hakimzadeh, Asphalt Liquids, LLC
John Malusky, AASHTO Re:source
David Howley, Connecticut DOT
Mark Brum, Massachusetts DOT
Matthew Teto, P.J. Keating Company
Frank Fee, Frank Fee, LLC

Meeting Coordinator: Carol Fisher (Amec Foster Wheeler)
Meeting Technical Report: Beth Visintine (Amec Foster Wheeler)

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DAY 1: Monday, September 12, 2016

1. Call to Order

Gaylon Baumgardner called the meeting to order at 1:02 PM.

2. Welcome and Introductions

Matthew Corrigan welcomed everyone to the meeting and asked everyone to introduce themselves. Corrigan acknowledged Walaa Mogawer for hosting the ETG meeting.

3. Review Agenda/Minutes Approval & Action Items, April 2016 Meeting [Matthew Corrigan, FHWA]

Corrigan announced that minutes would be distributed and asked for any revisions or corrections to the technical report to be sent to him.

Corrigan reviewed the Action Items from the April 2016 Asphalt Binder ETG meeting. The following is a listing and status of the Action Items from the last meeting.

- Action Item #201604-1: Dave Anderson will work with the labs participating in the Pressure Aging Vessel (PAV) Degassing experiment to finalize the data collection and analyze data in advance of the next ETG meeting. Based on the results of the experiment he will provide recommendations to the ETG for AASHTO consideration.
  Update: Item is on the agenda.

- Action Item #201604-2: Dave Anderson will work with the 4-mm DSR Task Group to complete the draft sample preparation, testing and compliance protocols and distribute to the ETG.
  Update: Item is on the agenda.

- Action Item #201604-3: Geoff Rowe will work with the REOB Task Force to complete the “white paper” on the subject. The document will be extended to include discussion on the relevance/use of the ΔT_c parameter.
  Update: Item is on the agenda.

- Action Item #201604-4: ETG members to provide comments to the Binder Aging Task Force led by John D’Angelo on the direction the task force should take going forward.
  Update: Item is on the agenda.

- Action Item #201604-5: John Casola and Dave Anderson to provide guidance on how to standardize Dynamic Shear Rheometer (DSR) temperature to meet the AASHTO Accreditation Program (AAP) requirements.
  Update: Item is on the agenda.

4. NCHRP 09-59: Relating Asphalt Binder Fatigue Properties to Asphalt Mixtures Fatigue Performance [Don Christensen, Advanced Asphalt Technologies, LLC]

Presentation Title: NCHRP 9-59 Update

Summary of Presentation:
Christensen stated that he would present the preliminary results of the project and that there was still much work to be done. The presentation was not comprehensive of the total project, but a snapshot of the important parts. Christensen stated that it was important to obtain feedback from the group. The outline of the presentation included objectives, problem, generalized failure theory, typical failure envelope, fracture/fatigue performance ratio, results to date and future work.

The objectives of NCHRP 9-59 are to develop a test or tests that will help to effectively and efficiently control the properties of asphalt binders that contribute to the fatigue resistance of asphalt mixtures.

Christensen presented examples of issues as severe raveling, surface distresses and longitudinal cracking. The problem to address included whether $|G^*|\sin\delta$ can be improved, added to or replaced, the effect of modulus on fatigue performance, the relationship between fracture and fatigue performance, and binder versus mix.

Christensen presented the generalized failure theory for fatigue strain capacity (FSC). The number of cycles to failure is the ratio of FSC to the strain of the binder raised to an exponent that includes the phase angle for binder. To apply this theory to the mixture, the strain for the binder is replaced by the strain of the mixture divided by the effective binder content divided by 100. The summation of the damage is presented for when the strain is not constant.

Christensen presented the typical failure envelope as the relationship between the failure strain or FSC, % versus the secant modulus divided by three. On the graph, data from various projects were plotted and fit the envelope nicely. The Heukelom failure envelope compares well with this fatigue envelope. The data points that did not fit the failure envelope as well were polymer modified asphalts, which is capturing the effects of the polymer as opposed to the asphalt since it was tested at low stiffness.

The fatigue/fracture performance ratio (FFPR) was presented as the ratio of observed to expected failure strain. Standard unmodified binder data was used to develop this preliminary equation. Polymer modified and mixture fatigue data were not used. FFPR values significantly above 1 are good while FFPR values below 1 are poor.

Christensen next presented the binder test methods considered under the project including the Dynamic Shear Rheometer (DSR) frequency sweep (R-value), modified double edge notched tension (MDENT), linear amplitude sweep (LAS), single edge notched bending (SENB) and various others from existing data such as direct tension. At this time, the SENB testing has not been started.

The MDENT test was used as the DENT test required six specimens which uses a lot of material that was extended aged. The MDENT test uses standard ductility batch and the molds/specimens are the same as those used for forced-ductility but with a double 2.5-mm notch. The sensitivity to the notch is important. The test is performed at 50 mm/minute at a temperature between 10°C to 20°C.

The MDENT test was analyzed as a tension test and true stress and strains were used. This method is appropriate when there is high strain and high extensions. The relaxation modulus from the master curve was compared to the tangent modulus of the MDENT test, which should be equal. The results showed that the comparison was close and that the assumptions were reasonable.

Christensen next presented preliminary results from the testing of Accelerated Loading Facility (ALF) binders. Most of the binders for the first and second ALF fatigue experiments were tested including PG 70-22, air blow binder, terpolymer, SBS-LG, crumb rubber binder, AC 5 and AC 20. The binders were short-term aged using the rolling thing film oven test (RTFOT). Christensen presented the correlation between various binder testing FFPR as:

- LAS versus DENT – 82%
- LAS versus Direct Tension – 79%
- Direct Tension versus DENT – 65%

The ALF binder correlation between cycles to 25 meters of cracking and FFPR was presented as:

- DENT – 90%
- LAS – 94%
- Direct Tension – 90%
- Binder R-value – 57%

Many of the binder tests correlated to the ALF fatigue performance. Christensen next presented the testing plans to determine whether this approach will work for the new binders considered under the project and if the binder and mixture test data will correlate. The project will test 16 different binders. At this time, three binders have been tested – PG 76-22 with SBS/PPA, PG 64-22 and a PG 58-28 with REOB.

The mixture testing conducted under the project included the uniaxial fatigue (SVECD), Texas Overlay Test (OT), and bending beam fatigue for which there is no data to date. The mixture design used in the testing included a 9.5 mm nominal maximum size, blend of granite, limestone and sand, 6.0% binder content, designed at 4.0% air voids at 80 gyrations and compacted to 7.0% air voids for most tests.

The laboratory aging used included RTFOT plus 40-hour pressure aging vessel (PAV) for the binders and standard short term aging followed by loose mix aging at 95°C for five days for the mixture. The goal was to have equivalent binder and mixture aging which was based on data available at the start of the project. The mixture and binder laboratory aging was compared by determining the temperature where the loss modulus was 5,000 kPa. The comparison included testing on extracted binder from the mixture and laboratory aged binder from NCAT and AAT. The results showed that the laboratory aging although close was a little low.

Christensen next presented the preliminary test results for the three binders tested to date. The MDENT test results followed expected trends with the SBS binder having an FFPR above 1, the PG 64-22 having an FFPR around 1 and the REOB binder having an FFPR below 1. Christensen noted that there had been problems running the LAS test and that the results would be revisited. The uniaxial fatigue and Texas OT showed the same trends as the MDENT. For the Texas OT, although the cycles to failure are greater for the REOB binder than the PG 64-22 binder, the measured fatigue strain capacity needs to be considered. The differences in the expected FSC are due to the differences in modulus which is taken into consideration during the analysis, which shows that the REOB binder does not perform better than the PG 64-22 binder.

The FSC versus G* or Stiffness (divided by 3) to approximate shear modulus was plotted for the various tests and binders. As compared to the typical failure envelope, the SBS binder fell above, the PG 64-22 was close and the REOB binder was below. There is concern that the fatigue test was performed at too low of a temperature.

Christensen next presented correlations between the FFPR of the uniaxial fatigue and the various binder testing as:

- MDENT – 85%
- Energy-based MDENT – 93%
- LAS – 61%
- R-value – 38%

The correlations between the Texas OT and the various binder testing was:

- MDENT – 92%
- LAS – 46%

The uniaxial fatigue data was slightly lower when compared to the binder testing. As stated previously, there might have been problems with the LAS testing and it is planned to revisit the data. Christensen also stated that he expected the correlation of the R-value to be higher.

Christensen presented the interim findings as:

- The proposed general failure theory and failure envelope appear to provide a powerful tool for evaluating the fatigue and fracture resistance of asphalt binders and mixtures.
- The RTFOT plus 40-hour PAV binder aging appears to produce a similar degree of aging as the five day loose mix aging at 95°C, but much more research is needed to verify and fine tune these aging protocols.
- The MDENT test correlates very well to both field fatigue performance in the FHWA ALF studies and in laboratory test conducted in the first stage of NCHRP 9-59 testing.
- The LAS test is also promising but some adjustments may be needed.

Christensen presented the future work of the project as testing the additional 13 binders and the SENB test, healing study, parametric study on relationship between modulus and fatigue performance and validation testing. Christensen ended the presentation by acknowledging those from whom he borrowed data, support of NCHRP, the NCHRP panel, industry suppliers, Nam Tran from NCAT, and his associates at AAT.

ETG Comments, Questions, and Discussion:
D'Angelo asked why a 9.5 mm mix with 4% air voids was used as this is not a typical mix that has fatigue issues. D'Angelo noted that volume of effective binder is critical to fatigue performance and asked that since the 9.5 mm mix would have high binder were significant changes in performance seen. Christensen responded that the focus should be on different binders and not mixes. D'Angelo stated that using this type of mix may mask some differences in binders. Christensen stated that he did not think that performance would change if a different mixture was used. Kluttz added that using a coarse mixture could introduce more variability as a result of difference in plus/minus binder content than a finer mix.

Amir Golalipour asked for clarification because as test temperature is increased, FFPR should also increase. The MDENT test data showed that as temperature is increased from 15°C to 20°C for the PG 76-22 SBS binder, FFPR increased as expected. However, for the neat binder, FFPR decreased with the same increase in temperature. Christensen responded that it is failure strain that should change with temperature and that it should increase as temperature increases. The FFPR should be independent of temperature and modulus and should be the same between varying temperatures. FSC should increase with increasing temperature. Christensen noted that as very low modulus values are considered, the graph flattens out and there is less dependency on temperature.

Golalipour asked whether the project was going to consider self-healing and relaxation after the test. Christensen responded that this was considered and the project is only considering healing in a limited manner by allowing rest periods after mixture fatigue testing.

Rowe asked that since the equation presented contained the binder phase angle and it is known that for certain values of G*, phase angle is directly related to the R-value how to reconcile the poor correlation between R-value and FSC. Christensen responded that although phase angle is part of the equation, FSC should be independent of phase angle and R-value. He continued that better performance is seen with higher R-value and lower phase angle in the field but that cannot be observed in these values in the lab and he hopes to obtain these results in the parametric study and establish the dependence on temperature and loading. Rowe asked whether he considered instability flow and true cracking. Rowe pointed out on the graph with the Heukelom curve that it is in the asymptotic region where there is instability but that the binders do come together as stiffness increases and one moves down the curve. Christensen agreed that testing should not be conducted in the instability region and that there should be a minimum stiffness value for test to be valid. He continued that testing at either low temperature or heavily aged mixes will likely be a recommendation.

Pamela Marks stated that temperature does impact DENT results and notches are required. For example, with softer asphalt or lower loads, larger notches give better repeatability. It is more difficult to observe repeatability with smaller notches. Marks noted that the test does require a significant amount of material and that it does need to be aged and for that reason she has considered a slightly smaller mold to use less material. Marks also stated that when testing stiffer asphalt, failure is not only failure of asphalt but failure of the specimen and the mold adhesion. Christensen responded that using a larger notch can help prevent the failure between the specimen and the mold. Christensen also responded that maybe he should consider using larger notch for reasons Marks mentioned. He continued that they are testing 40-hour PAV aged binder, which are quite stiff. However there are some problems testing RTFO aged binder and getting to a low enough temperature. Marks responded that they had to test down to 4°C without problems.

It was asked why the SBS and PG 64 binders were tested at 15°C and 20°C while the PG 58 REOB binder was tested at 10°C and 15°C. Christensen responded that he was trying to have similar stiffness values instead of similar temperatures since these are differences we can account for at different temperatures.

Gayle King stated he was surprised R-value did not correlate better to FFPR and asked how R-value was calculated. Christensen responded that it was calculated from the entire master curve. The inherent fatigue is embodied in the failure envelope, separate from the R-value. It was cautioned to cut off the R-value beyond 15°C as started to see melts above 15°C.

5. **Update: GTR: Field Project Experience and Lessons Learned [Amir Golalipour, ESC Inc.]**

Presentation Title: Ground Tire Rubber: Field Project Experiences and Lessons Learned – Part 2

Summary of Presentation:
Golalipour began the presentation by noting that at the previous ETG meeting he presented the different challenges they had faced in the testing and conditioning of ground tire rubber (GTR). Golalipour noted that this presentation would focus on solubility, separation and DSR testing using the concentric cylinder and parallel plate geometries.

The challenges of GTR modified binder testing include aging: RTFO and long term conditioning, solubility, separation, DSR testing – different gap sizes, concentric cylinder testing and low temperature specimen preparation. The focus of this presentation will be solubility, separation and what the best practices are for DSR testing.

Golalipour presented the first project from Arizona that included open graded friction course (OGFC) mixtures with three different terminal blended asphalt binders. The hybrid binders included GTR and SBS including PG 70-22 SBS, PG 70-22 TR+ (8% GTR plus 2% SBS, solubility limit of 97%), and PG 70-22 TR+ S92 (8% GTR plus 2% SBS, solubility limit of 92%).

The solubility testing used three different methods – AASHTO T 44, AASHTO T 44 using Toluene, and AASHTO T 44 using two filters (Celite and DE) – showed some differences in solubility. Statistical analysis using F-tests and t-tests showed that the analytical filter made some differences in results but that there was not a statistical difference between AASHTO T 44 and AASHTO T 44 using Toluene.

Separation tests were conducted following ASTM D7173 where the samples are stored in vertical tubes in an oven at 163°C for 48 hours. The test specimens taken from the top and bottom of the vertical storage tube are measured using AASHTO T 315. GTR is separating and sinking to the bottom of the separation tube. Results showed significant separation for the S92 binder from bottom to top which needs to be considered when using this material and constant agitation and constant temperature is necessary to make sure the material is homogeneous.

Golalipour next presented the test results of the PG grade testing of G*/sinδ for the original and RTFO aged binders that compared the parallel plate geometry using 1 and 2 mm gap and the concentric cylinder (CC) geometry using bob size of 17 which produces a 5 mm gap. This geometry was selected based on previous research. The binder tested using the CC was conducted almost a year after the parallel plate testing. For the S97 binder, there were not significant differences between the results but the stiffness from the CC was slightly higher, perhaps due to shelf-aging of material. This difference is less for the RTFO aged binder. The CC geometry has smaller standard deviation. This geometry also provides a technical advantage such as not having to trim the specimen and no edge or sample geometry effects. For the S92 binder, the parallel plate using 1 mm gap shows different material behavior. The higher stiffness and more elastic type behavior may be due to possible particle interactions with the plate. The parallel plate with 2 mm gap and CC showed similar results. Comparison of the PG grade on original binder for the parallel plate with 1 and 2 mm gap showed that although it resulted in the same grade, there were differences of 15-20%. The results showed that when there is an interaction of the rubber particles with the testing plates, an increased gap results in decreased variability, decreased complex modulus, and increased phase angle. Therefore, there is a lower G*/sinδ and phase angle for the 1 mm gap. For the RTFO aged S92 binder, the differences are decreased but there still may be possible particle interactions with the plate for the 1 mm gap. The differences between the geometries were compared for the original and RTFO aged S92 binders for two different temperatures. The least difference was observed between the 2 mm gap and the CC. The differences between the geometry is decreased with the aged material.

Statistical analysis using the F-test was performed to assess the effect of the 1 mm increase in gap for the parallel plate geometry. Only PG 70-22 TR+ (S92) original binder show effects consistent with particle interaction. When used to test binders modified with GTR, the 1 mm gap is too small to accommodate the rubber particles and the CC setup is needed as the testing geometry for these materials.

Multiple Stress Creep Recovery (MSCR) testing of the S92 binder at two temperatures show J_{nr} differences are increased with increasing temperatures and the 1 mm gap parallel plate has possible particle interactions with plates.

Golalipour presented the summary of findings from the Arizona project as follows:

- Toluene was found to be an acceptable alternative to Trichloroethylene as a solvent for solubility testing.
- GTR, due to its higher specific gravity than neat asphalt binder, is separating and sinking to the bottom of the separation tube. Separation of TR+ (S92) binder during non-agitated long-term storage should be expected.
- DSR Testing results indicate that particle interaction with the plates likely occurs when testing the PG 70-22 TR+ (S92) using the parallel plate geometry.

Golalipour next presented a project in Florida that used hot mix asphalt (HMA) produced with an asphalt rubber binder (ARB). The binder was PG 76-22 ARB. The Florida Department of

Transportation (FDOT) Section 916-1 required ARB to contain at least 7% GTR by weight of asphalt binder. There is no solubility requirement.

Separation tests were conducted following ASTM D7173. The test specimens taken from the top and bottom of the vertical storage tube were measured using AASHTO T 315. Results showed that GTR is separating and sinking to the bottom of the separation tube and needs to be considered.

DSR testing of the binder comparing original and RTFO aged binders, tested at two temperatures and three geometries (1 mm gap parallel plate, 2 mm gap parallel plate and CC) resulted in the same PG grade. The CC had slightly higher $G^*/\sin\delta$ values. There was no indication of significant particle interaction with plates which was due to a finer mesh size and low percentage of rubber. The results were similar.

Golalipour presented a comparison of long term conditioning between PAV 20-hour and 40-hour conditioning time using AASHTO M 320 Table 1 Intermediate Temperature Continuous Grade, AASHTO M 320 Table 1 Low Temperature Continuous Grade, AASHTO M 320 Table 1 ΔT_c, AASHTO M 320 Table 2 Critical Cracking Temperature, Asphalt Binder Cracking Device (ABCD) Low Temperature Grade, and ABCD AASHTO TP 92 Cracking Temperature. Results showed reasonable agreement between the three measurements for 20-hour PAV conditioning. The ΔT_c after 40-hour PAV aging exceeds the recommended -5.0 degrees C proposed cracking limit. The ABCD was less sensitive than the other two tests to conditioning time. By doubling the PAV conditioning time, the cracking temperature increased 1.1°C, 3.2°C and 1.9°C for ABCD, Table 1 and Table 2, respectively.

Comparing the Master Curve for the original, RTFOT, 20-hour PAV and 40-hour PAV showed that more conditioning causes the master curves to become flatter with R-value increasing and the crossover frequency (ω_c) decreasing.

Golalipour presented the summary of findings from the Florida project as follows:

- Separation of PG 76-22 ARB during non-agitated long-term storage should be expected.
- DSR testing: Results show no indication of particle interaction with the plates when testing the PG 76-22 ARB using the parallel plate geometry due to finer mesh size and low percentage of rubber.
- For extended PAV conditioning, binder behavior becomes highly m-value controlled.
- 40-hour PAV conditioning reveals more information about material behavior.

Golalipour presented the takeaways (from limited studies) as:

- Separation needs to be considered for asphalt rubber material (ASTM D7173)
- In DSR testing, not all asphalt rubber binders are the same. Some may work with parallel plate and some do not. Concentric cylinder geometry is a scientific and practical solution.
- Extended PAV conditioning may better differentiate between different materials in terms of low temperature cracking.
- RTFO challenges need to be considered include material creeping out of bottle.

- DSR testing has parallel plate issues such as trimming, edge effect, particle interactions, rubber swelling, rubber mesh size and percentage. CC does not require trimming and has exact volume filling with no sample geometry or edge effect. The downside to CC is the longer equilibrium time required compared to parallel plate due to the increased volume of material required (25 to 30 minutes versus 15 minutes).
- The thickness in the PAV as used with rubber modified asphalt may need to be further investigated.

ETG Comments, Questions, and Discussion:
It was asked what prompted the use of 5 mm for the cup and bob and not a larger gap. Golalipour responded that although larger gap can be used, when larger gap is used, the measurement changes from absolute to relative measurement which increased the calculations to take into account the shear distribution. Golalipour continued that they felt the 5 mm gap size was sufficient for the material tested to have enough room to eliminate particle interaction but noted that they were not provided the rubber size. The participant stated that assuming a 30 mesh rubber and that it swells two to three times, there would still be particle interaction with the 5 mm gap size. It was suggested that instead of stating that particle interaction is eliminated to state that particle interaction is less than other test methods but that larger gaps may be needed to eliminate particle interference. Golalipour responded that the CC is a better solution. The gap size may need to be increased upwards of 10 mm for some specific spec requirements but that may cause compliance issues with the equipment.

Corrigan stated they encountered the percent concentration issue and that the concentric cylinder geometry gave more flexibility than the parallel plate geometry in this aspect.

Golalipour stated that there has been some discussion on increasing gap size on parallel plate, however, this creates an issue with loss of material and ability to maintain sample geometry; and would require changes to the equations.

6. GTR: Practical Considerations for Cylinder System Measurements [Darin Hunter, Anton Paar USA]

Presentation Title: GTR: Practical Considerations for Cylinder System Measurements

Summary of Presentation:
Hunter began the presentation by stating that the focus would be on PAV residue since this can be difficult to test with GTR. Hunter then provided the background of why the cylinder system should be used over the parallel plate. The cylindrical measuring geometry was proposed over 5 years ago to address the practical challenges associated with GTR modified binder measurements. The cylindrical measuring geometry eliminates edge effect inaccuracies associated with trimming, sagging (flow) of the sample and provides the truest rheological data. The problems to address include swollen GTR particles impact results, reliable trimming and gap filling (more influence with small diameter plates) and flow and sagging of sample out of the measuring gap. Solutions to these problems include increasing the measuring gap (parallel plate geometry with gaps up to 4 mm) or concentric cylinder geometry.

Considerations for original and RTFO materials for the concentric cylinder geometry are that heating temperature is a little higher than for neat binders, loading of the sample can because some skill is needed to prevent air bubbles and determining the correct volume (18 mL). Considerations for PAV materials for the concentric cylinder geometry include temperature, loading the sample (air bubbles) and determining the correct volume (23 mL). The issue is that the sample is loaded at a higher temperature than the test temperature which results in shrinkage and contraction as it cools to test temperature which cause normal forces to pull down on the bob. This results in an incorrect volume. A possible solution is to use a sample plug from a mold. This makes it easier to load the sample in the cup, provides the best conditions for an accurate fill and accommodates the bob volume best. The sample plug is smaller in diameter and taller than the cup which requires trimming. There are molds that include positive image of the bob detail or the mold can have the bob in the bottom. Once the sample plug is placed in the cup, it is warmed slightly to allow the material to adhere to the sides.

The benefits of the cylinder geometry mold are it provides a well-controlled sample volume, accommodates for volume change, and is convenient to create replicates. However, this process does add some time to the process.

Hunter concluded the presentation by stating that the concentric cylinder geometry provides practical consideration for reproducible cup filling as it addresses shrinkage/contraction of GTR PAV materials, eliminates need to hastily load sample cup and is straight forward and easy. Currently collaboration partners are working on developing mold design and best practice for PAV materials.

<u>ETG Comments, Questions, and Discussion:</u>
D'Angelo commented that at intermediate temperatures for PAV binders, there is not an issue keeping materials between the plates and that he has used up to 30 mesh rubber and 4 mm gap at the intermediate temperature and results correlated well to the torsion bar results. The issue is trimming and maintaining the correct sample geometry. King asked whether the issue with the larger gap was with original binder. Hunter responded that it was original and RTFOT that had issues of the sample sagging out and that there was not as much of an issue with the PAV binder. King asked if this method should be used on original and RTFOT binder. Hunter clarified that the concentric cylinder is for both original and RTFOT. King stated he was not understanding the target of the work as PAV is difficult to work with and hard to remove air bubble, and that the target should be original and RTFOT. D'Angelo stated that the cup and bob is used with PAV binders as well but that the issue was with potential compliance of the equipment when testing these stiffer materials and need to conduct compliance corrections for phase angle.

Gaylon Baumgardner asked whether making pycnometer with the cell would be too easy to measure volume of asphalt. Hunter responded that it is the shrinkage that causes the issue as it causes normal forces to pull down on the bob causing a change in the geometry.

Rowe stated that the BBR works nicely at lower stiffness. D'Angelo commented that rubber binders are always softer based on $G^*\sin\delta$ but that there is no information for other tests. Rowe responded that it is known there are interconversions that work and that relaxation modulus or another parameter that is related in the same way could be used and other geometries could be used. Casola stated that using PAV binder with a large surface area causes high compliance. Casola suggested that when using this method and following the standard, to ignore the bottom and then load the sample at the required temperature and allow normal forces to control as it shrinks. It is not the volume that is important but the distance of the gap and this would allow for auto loading. Hunter responded that they have done this but a deeper volume is needed. Corrigan acknowledged that preparing BBR samples with these materials is not easy either.

Gerald Reinke commented that since D'Angelo stated that the 4 mm gap correlated well with the torsion bar that there was no need to modify. Corrigan responded that it is difficult to trim and maintain specimen geometry with larger plate gaps; especially for large particle size and large percent concentrations of rubber. Reinke stated that if the specimen is molded to a diameter and slightly greater than 4 mm depth and the sample was allowed to shrink down, the height being 4 mm does not matter as long as the diameter is known. Casola responded that it would be hard for a quality control (QC) specification especially with different operators. If that was done by mass it may be possible.

Corrigan stated that UC Davis has been engaged on the subject as well. Caltrans is considering this concentric cylinder geometry and are interested in moving away from the recipe specification requirements. This is the best geometry approach moving forward to nationally accommodate a variety of rubber specifications used across the country..

7. GTR: ETG Discussion on Draft AASHTO PG Binder Standard Utilizing Concentric Cylinder Geometry (cup and bob)

Corrigan led the discussion on the draft AASHTO PG Binder standard utilizing concentric cylinder geometry. Corrigan stated he was looking for others to work with FHWA in developing the draft standard so that a holistic approach to the specification could be taken. .

Corrigan stated that he was looking to formalize a task group to help advance this and move forward to a provisional standard.

Reinke asked whether only the cup and bob should be evaluated or whether the 4 mm gap should also be evaluated. Corrigan responded that the goal was to advance the concentric cylinder provisional standard as a solution for performance grading these materials. Maybe the two different geometries are better served with separate efforts?. This decision could be part of the continued dialogue with stakeholders. Hunter responded that he would be hesitant to use 4 mm gap with parallel plates as it limits use to smaller mesh size rubber and lower concentrations than what is used in certain States.

Corrigan asked for volunteers for the task force and emphasized the importance of having all the major DSR manufacturers engaged on this item.

Action Item #201609-1. A new Task Force created on GTR Testing Standard Development with goal to develop a draft provisional AASHTO test standard using the Concentric Cylinder (cup & bob) geometry. Members include:

Matthew Corrigan (lead)
Codrin Daranga
John D'Angelo
John Casola (Malvern)
Bharath Rajaram (TA Instrument)
Darin Hunter (Anton Paar)
Amir Golalipour
Joseph DeVol
Zia Alavi (UCDavis)
Additional State DOTs will be identified as participants

8. **Binder Fracture Energy (BFE) Test, and Using BFE Testing to Evaluate GTR Modified Binders [Reynaldo Roque, University of Florida]**

Presentation Title: Determining the Fracture Energy Density of Asphalt Binder Using the Binder Fracture Energy (BFE) Test

Summary of Presentation:
Roque began the presentation by presenting the background. The fatigue resistance of asphalt binder strongly influences the fatigue performance of asphalt mixture and pavement. A study in Florida found none of the existing test methods for asphalt binder (original and recovered from field) were able to provide parameters consistently correlated with relative cracking performance of mixtures including DSR ($G^*\sin\delta$), Elastic Recovery (ER), and Force-Ductility (FD).

Roque stated that fracture energy is a good indicator of fatigue resistance of asphalt mixtures. The cumulative energy to failure from FD results showed improved ability to predict cracking performance at intermediate temperatures. FD was not optimized to determine fracture energy accurately. A test deigned to obtain fracture energy could provide a better parameter related to fatigue resistance of binder. Traditional Direct Tension (DT) test has limitations. Some of these limitations include the long middle part with uniform area of the test specimen where the specimen may crack anywhere causing high deviation in measured failure strain; often results in premature failure; difficult to apply high enough strain rate to reduce excessive deformation; and may exceed loading rate capacity of equipment without fracture.

Roque stated that there is a need to develop a new DT test that allows for accurate determination of stress-strain relationships and fracture energy density (FED) of binder at intermediate temperatures. The UF research group developed a binder fracture energy (BFE) test with specially designed specimen geometry and data interpretation procedure.

The specimen geometry was intended to represent the curvature where aggregates would reside. The specimen geometry should also make the specimen fail where failure location was desired. The stress concentration factor was around 11.0. The problem with the specimen was that the adhesion between the asphalt and loading head was less than the cohesion of asphalt. Since pure asphalt is stronger than the mixture based on strains (in tension) the shape of the specimen needed to be modified.

Roque presented the second specimen geometry which was a more traditional dog bone. This geometry created fairly uniform stress concentration area at the center. The stress concentration factor was greater than 5. The adhesion between the asphalt and loading head was less than the cohesion of asphalt. This required the connection between the asphalt and loading head to be strengthened and any high stress at the corners of loading head to be reduced.

A third specimen geometry was presented by Roque. This specimen geometry was fork shaped at the loading head to increase adhesion. This specimen had fairly uniform stress concentration at the center and the stress concentration at contact surface of loading head was eliminated. This specimen geometry resulted in failures at the center.

The data interpretation included FEW modeling and large strain deformation to account for ductile cracks that clearly exhibit necking because of larger deformation to failure. Roque explained that relationships were developed to relate the extension (measured in mm) up to the first stress peak, to true strain and cross-sectional area to determine true stress. At the first stress peak, the change in length and cross-sectional area can be determined using FEA with large deformation formulation.

Roque continued the presentation of the data interpretation by focusing on the 3 mm portion in the center of the specimen before testing where the stress strain analysis will focus. This length at the first stress peak is labeled L_1. After the first stress peak, this middle part undergoes necking, which requires a different type of analysis. Assuming that most of the strain occurs in the middle 3 mm of the specimen, and using large strain deformation, after the first stress peak, the true stress is equal to force divided by area. The area is equal to the quantity of A_1L_1 divided by L. The true strain is equal to the natural log of L divided by L_1.

Roque presented the stress strain diagram. Large deformation FEA is used until the first stress peak followed by large strain formula. After applying these calculation procedures, the point of initial fracture is clear. The post-peak energy after the point of initial fracture should not be considered. The fracture energy is the area under the curve.

At low temperatures and/or faster loading rates, any imperfection of the specimen may result in premature failure. Premature failure can be identified based on geometric characteristics of failed specimen, fracture energy density, and true stress-strain curve. The implication is that there is an optimal combination of temperature and loading rate range to consistently obtain fracture energy of binder. Roque presented an example of a premature failure where the specimen failed in a brittle manner due to loading too quickly. Roque stated that it was not an appropriate test for the intermediate temperature.

Roque presented the preliminary tests. The tests were run on the MTS machine at temperatures of 0, 5, 10, 15, and 20°C. The loading rate varied depending on the test temperature. The test used PAV-aged binder – PG 67-22 (unmodified) and PG 76-22 (SBS Polymer modified). The fracture energy density at 15°C for the two binders was presented which was consistent for the same binder at different loading rates. This showed that the test clearly differentiates between SBS-modified and unmodified binders with the FE of modified binders being better. Next, Roque presented the average FED at various temperatures which were consistent for the same binder at different temperatures. Again, the difference in FED between the SBS-modified and unmodified binders was clear.

A summary of preliminary tests showed that 15°C appeared to be the optimal test temperature for both PG 67-22 and PG 76-22. An optimal or acceptable range of loading rate should be used to obtain consistent and accurate FE to avoid premature fracture and excessive deformation.

Roque presented on binders recovered from Superpave section that included unmodified binders (AC-30, AC-20, and PG 64-22), SBS polymer modified binder (PG 76-22) and rubber modified binder (ARB-5). Since recycled asphalt binder (RAP) is routinely used in Florida, RAP binder was present in the recovered binders. The recovered binders were tested at 15°C and multiple loading rates. FED was consistent at the different loading rates. The BFE test clearly distinguished between different types of binder with the FED being highest for the SBS-modified binders, followed by the rubber-modified binders and the lowest for the unmodified binders. When the rubber was not recovered from the rubber-modified binders, the same FED value as the unmodified binders was achieved.

BFE testing was conducted on PAV residue of three types of hybrid binders (rubber and SBS) and one highly SBS modified binder. For the same binder, the FED was consistent. The difference between the different hybrid binders was clear. The hybrid binders with more polymer modification had a higher FED. The FED of the PG 82-22 was consistent regardless of loading rate and temperature. The FED results showed that FED increases for unmodified binders, rubber-modified binders, SBS-modified binders, hybrid binders and the PG 82-22. The hybrid binders are variable based on the makeup of the hybrid.

Roque presented the results of a statistical analysis that showed the BFE test effectively differentiated between binders in terms of FED. For the same binder, the FED is independent of loading rate and temperature in a certain range. This indicated that FED is a fundamental property of binder and it can be determined by tests performed at a single temperature and loading rate.

Roque has developed a provisional standard. The testing for the standard development included binder conditioning (RTFO and PAV according to AASHTO T 315) and displacement rate of 500 mm/min at 15°C testing temperature on a broad range of asphalt binders. Roque presented typical true stress – true strain curves for unmodified, rubber modified, hybrid and SBS modified binders. Unmodified binders has one single peak and drops off fairly quickly with no extension. Rubber modified binders extends the curve over higher strain but does not increase strength. SBS modified binders increase strain and stress tolerance. Hybrid binders are between rubber modified and SBS modified and some stretching is noticeable.

The FED values lined up really well based on the binder type with the unmodified binders ranging from 354 to 488 psi; the rubber modified binders ranging from 698 to 720 psi; the hybrid binders ranging from 944 to 1,062 psi; SBS modified binders ranging from 1,199 to 1,260 psi and highly SBS modified binders ranging from 1,684 to 2,431 psi.

The conclusions of the presentation were that the BFE test and data interpretation system developed suitably measures FED of asphalt binders, including unmodified binder, modified binder (rubber, polymer, hybrid) and binder recovered from pavement (except rubber).

Roque recommended that the BFE test may be an effective tool for binder specification by state highway agencies to identify the presence of modifiers and provide a quantitative assessment of relative binder performance based on FED values. However, this is only half of the input to fatigue performance. LAS results could be combined to provide the rate of damage with this value and that combination would provide a more comprehensive answer on fatigue performance.

<u>ETG Comments, Questions, and Discussion:</u>
Rowe asked whether Roque had looked at the load deformation curve instead of the true stress and true strain curve. Roque responded that he has not considered this, as he does not see an advantage. Roque stated that it may be possible to consider this way, but that it would be a total energy measurement instead of an energy measurement right past the central part of the specimen. Although in theory this is the same, in reality it is not the same.

Christensen stated that they have seen the same thing with good failures and premature failures in their testing. He noted that brittle failures are important and asked whether Roque was disregarding important information. Roque responded that there is good information to be gained from a brittle failure and if the problem is a brittle failure problem, then it would be the correct test. However, given that the testing was at the intermediate fatigue repeated loading, it happens by considerable loading over time. For example, low temperature cracking being a brittle failure, FED is not an important property because what matters is the compliance and there is very little that can be done with FE which could not be increased by polymers. For fatigue cracking in intermediate temperature range, brittle failures are not expected to occur if tested properly. Christensen responded the good failures is what they are trying to relate to good performance in the field, but the brittle failures are the binders that will not work in the field. Roque responded that it was reasonable. If the binders are tested the same way and one binder is brittle, that binder is not as good as the other binders. Roque is looking for a number to assess the relative resistance of binder of the way it fails.

Marks commented that fatigue does not only happen at intermediate temperatures but that it can also occur due to freeze/thaw cycles at other temperatures. The Ontario MOT use -34°C and -40°C testing temperatures. Marks stated that at -20°C there could still be fatigue cracking if the binder is not ductile enough. Roque agreed and said that is part of the difference between being in Florida and Ontario and that Marks' most appropriate temperature would be different. Roque stated that at lower temperatures, both load and thermal stresses are involved. In Canada, they typically use softer binders whereas in Florida, below 0°C, the binder is stiff and brittle. Marks asked whether 15°C was an intermediate temperature for a PG 76-22. Roque responded that the intermediate temperature can be between 0°C and 20°C and the intermediate temperature range is variable. In colder regions, the range would be lower and the binders will be different. Roque explained that 15°C was selected because for the binders tested, the variance was least at that temperature. Roque noted that the damage rate will also affect this a lot.

Corrigan stated Roque presented this at the SOM technical section 2b mid-year meeting and it was balloted as a technical section ballot. Corrigan asked whether Roque received comments. Roque responded that it was well received and that the comments and questions received were very good. Roque stated that they provided extensive responses through the Florida DOT.

Corrigan adjourned the meeting for Monday at 5:05 PM.

DAY 2: Tuesday, September 13, 2016

9. Call to Order

Baumgardner called the meeting to order at 8:02 AM.

10. Micro-Mechanical Evaluation of the Interaction between RAS and/or RAP Virgin Asphalt Binders [Munir Nazzal, Ohio University]

Presentation Title: Micro-Mechanical Evaluation of the Interaction between RAS/RAP and Virgin Asphalt Binders

Summary of Presentation:
Nazzal began the presentation by providing background of the project stating that though the benefits of using RAS and higher amount of RAP in new mixes are high, it presents a concern that resultant mixture may be prone to more cracking. Recent studies indicate that the properties of this interfacial blending zone between RAP and virgin asphalt binder might dictate the performance of the RAP asphalt mixtures. At the current time, the interaction between the RAS and virgin binder is unclear. Nazzal stated that examining the properties of the interfacial zone between RAP and virgin asphalt binder is imperative to understanding the cracking resistance of mixes containing RAP/RAS and to identify the factors that affect it. This will also help in identifying if poor or no blending occurs between the RAS and virgin binders. Nazzal stated that it has been found that there is a blending zone between asphalt binder and aged RAP binder but that the mechanical properties of the zone and the factors that affect those properties are unknown. The interfacial zone is between 50 and 100 microns.

Nazzal presented the objectives as to study the interaction between RAP/RAS and virgin asphalt binders and evaluate the adhesive and micro-mechanical properties of the interfacial zone between these binders and to examine the effect of the properties of RAP and virgin asphalt binders on their blending. To date, blending of the RAP binder has been documented but the interaction of RAS is unclear.

The materials used in the project included three types of binder (PG 58-28, PG 64-22 and PG 64-28). RAP materials with different rheological and mechanical properties were selected. Different tear off and manufacturing waste RAS materials were selected. RAP/RAS binders were extracted and recovered using AASHTO T 164 and AASHTO T 170 procedures. Nazzal stated that in Ohio, the contractors own the RAP and it is hard to know the origin of the RAP in stockpiles so the RAP used in the project was obtained as it was milled from the roadway after processing. The viscosity of the RAP binder was determined by the contractor and then the project performed continuous grade testing. Two RAP binders were selected that had different properties but that had the same aggregate (limestone). The two RAP binders selected (IR-70 and US-33 2015) had viscosity of 6,838 Pa*s and 10,234 Pa*s, continuous high temperature grade of 83.5°C and 90°C, continuous low temperature grade of -19.1°C and -16.1°C from the BBR and -19.25°C and -17.6°C from the ABCD, respectively. Two RAS tear offs have been selected to date. The first RAS material had a high temperature grade of 176.1°C and a low temperature grade of 5.3°C while the second RAS material had a high temperature grade of 169.2°C.

For the sample preparation, slides were cut into two pieces. Very thin film of asphalt binders were prepared of the slide and the edges were cleaned. Slides were put together on a hot plate for about 3 minutes at the mixing temperature where one side of the slide contained RAP or RAS binder and the other side of the slide contained virgin binder.

An Atomic Force Microscopy (AFM) was used in the project. The AFM uses a cantilever with a tip at the end to scan through the sample. Forces between the tip and the sample lead to a deflection of the cantilever. The deflection is measured using a laser spot reflected from the cantilever collected by a detector. This allows for the determination of interaction forces and interaction between aggregate and asphalt binder. Using the AFM Force Spectroscopy, the sample is probed at a fixed spot on the surface. The measurement is performed as an approach-retraction cycle. The total force exhibited at the tip during the process is monitored. The relationship of Force (nN) versus distance (nm) is plotted. The retraction cycle will inform what the adhesion properties are.

Nazzal stated that since it is known where the interface between the RAP and virgin binder is on the slides, the AFM is started in the RAP binder and continues into the virgin binder. The spacing used was 10 microns to capture the interface zone.

The indention depth should be selected to minimize the surface effect. The test should be carried out with a grid of a constant size. The indention depth was a constant depth less than 200 nanometers. This allows to capture zones less than 3 microns.

Nazzal stated that the adhesion properties of the binders were obtained based on the total adhesion energy needed to separate the tip from the asphalt binder. The energy, $E_{bonding}$, is determined as the area under the curve.

The $E_{reduced}$ versus the spacing from the AFM were plotted and fit with a sigmoidal model which informs about the slope of the curve. The relationship between bonding energy and spacing between the RAP and virgin binder was fit with a negative sigmoidal model as the RAP material had much lower bonding energy than the virgin binder. The k values from the sigmoidal models were evaluated and compared how it changed between the binder and RAP sources. Results showed that as the binder changed, the k value changes where softer binders had higher k values. The k value was lower for the stiffer RAP binder. Stiffness and adhesive properties may not be the same and it is important to understand both properties to understand how it will affect the performance.

The AFM test results of $E_{reduced}$ showed that the stiffness of the interface (blending zone) was dependent on the virgin binder. For the PG 64-22 binder, the interface was similar to the virgin binder whereas with the PG 64-28 and PG 58-28 the interface was more similar to the RAP binder and had larger variability. The interface was dependent on the initial RAP value. The bonding energy was more affected with virgin asphalt binder as compared to the RAP properties.

Nazzal presented a statistical analysis of the AFM test results that showed the stiffness ($E_{reduced}$) was affected by the RAP binder, virgin binder and the interaction of the RAP and virgin binders while the Bonding energy was only affected by the virgin binder. The RAP concentration was higher for the reduced modulus and less for the PG 64-22 binder.

A cluster analysis was performed to determine the number of phases in the interfacial zone. The analysis forced three phases and showed the reduced modulus is different than the Bonding Energy and that there was very high variation. This analysis informs how many phases between the materials there are and shows that within the interface zone, there is more than one phase. There were one, two and three blending zones for the PG 64-22, PG 64-28 and PG 58-28 binders, respectively.

Nazzal presented the preliminary AFM test results for the RAS. The results showed that even with moving with a spacing of less than 20 microns, there is a drop and there is not a blending zone. The RAS film has a rougher surface as compared to the virgin film.

Nazzal next presented a study of the RAP testing at Interstate 270 where the existing pavement was milled, processed and used in the new mixture for the overlay. Cores from the intermediate and surface course mixtures were collected. Plant produced samples of the intermediate and surface course mixtures were collected. Aggregates, RAP and binders used in producing the field mixes were obtained to prepare and test the control mixture (no RAP), control mixture with 25% RAP, 35% RAP and 50% RAP, control mixture with RAS and control mixture with RAS and RAP. Mixture testing included low temperature cracking (asphalt concrete cracking device (ACCD)), fatigue cracking (SCB) and durability (AASHTO T 283).

Nazzal presented the conclusions of the presentation as:

- The AFM force spectroscopy results showed that the RAP binders blended with virgin binders in a blending zone.
- The blending zone properties varied based on the virgin binder and RAP binder being used.
- The RAP and virgin asphalt binder properties significantly affected the reduced modulus of the blending zone.
- The adhesive bonding of the blending zone was mainly affected by the virgin binder being used.

<u>ETG Comments, Questions, and Discussion:</u>
Pavel Kriz commented that when fitting the data, it is done at one time (3 minutes) and may want to consider using different times and one temperature to put into a physical meaning. Also, the physics behind the interface and interfraction is complicated and maybe something to look at. Kriz continued that the reason why diffusion of the RAS was not detected was because the rate

of diffusion is an order of magnitude slower for RAS. This would take about 10 hours. Nazzal responded that they were trying to simulate what was happening in the asphalt plant and that is why 3 minutes was selected. Although he agreed that more time was needed, that is not what the current practice is.

A participant asked that with a manually trimmed edge, how was it known that the two plates were actually touching each other. Nazzal responded that the joining was done under the microscope and that within the AFM, the size of the crack can be checked. Once joined, the slides are moved to the plate.

Rowe stated that the k-value reported with the sigmoidal equation should be related to other rheological values such as the R-value and that it is known that the sigmoidal shape is related to binder properties. Rowe suggested that comparing the AFM k-values to recovered binder properties may be of interest.

King commented that the phase angle is more important than the modulus for the interface. Nazzal responded that with the AFM, the phase angle can be obtained through the image. Rowe also responded that the phase angle is buried in the data of the sigmoidal curve but may need some manipulation.

Nazzal stated one important note was that they were using stiffness measurement but that the adhesive properties in asphalt binder is missing from the specification. Rowe stated that a component of the properties are contained in the complex modulus. Nazzal argued that although stiffness was similar, bonding energy was different through studies on PG grade testing with the AFM.

11. Impact of Long Term Aging on RAS Binder Properties [Andrew Hanz, Mathy Construction]

Presentation Title: Extended Aging of RAS Mixes with Rejuvenator

Summary of Presentation:
Hanz presented the motivation for the study as cracking is the most prominent state agency concern. High levels of binder replacement, especially from RAS can cause durability concerns and that materials used to soften asphalt can have unintended consequences. In addition, these risks are not apparent until after long-term aging. Therefore, different long-term aging methods were evaluated. There are current long term conditioning protocols in specifications – binder (AASHTO M 320 and M 332) for 1 PAV aging cycle; mixture (AASHTO R 30) for 5 days compacted mix aging at 85°C. The focus of this study is on extended aging to identify aging susceptible materials in the mix (RAS) or binder (softening additives) because under current specifications most of these materials appear acceptable.

Hanz presented data from MnRoad that showed that cracking increased by a factor of 9 after 5.5 years of service to show why long term aging is needed.

The objectives of the mix aging study were to compare aging stability of bio-based rejuvenator modified binders to conventional PG asphalt and to evaluate the effects of multiple aging methods and conditioning times on physical properties and composition. The study included tear-off shingles for RAS, two asphalt binders (PG 58-28 and PG 52-34), an experimental product rejuvenator and two bio-based oils. The PG 58-28 with 5% bio oil was used to target a final grade of PG 52-34. The high temperature PG grade for the binder blends ranged from 48.3°C to 59.6°C. The low temperature grades ranged from -29.7°C to -36.5°C for 20-hour PAV and -25.1°C to -35.6°C for 40-hour PAV. The ΔTc were all below -0.4 and -3.1 for 20-hour PAV and 40-hour PAV, respectively. The RAS binder properties had an R-value of 6.03, a high temperature grade of 146°C, a low temperature grade of 6.0°C, a ΔTc of -31.4, S(60) of -25.6 and a m(60) of 6.0. The RAS AC content was 22.1% and all mixes used in this study included 5% RAS by weight.

The mix design for the study represented a normal surface course used for intermediate traffic levels in Wisconsin, used a 12.5 mm NMAS fine gradation with 5.7% AC with 19.4% binder replacement from RAS.

Three aging methods used in the study included the following:

- Loose Mix + PAV
    - As- recovered (after 2 hours at 135°C)
    - As-recovered + PAV (blending chart)
    - As-recovered + 2PAV
- Loose Mix
    - 12 hours at 135°C
    - 24 hours at 135°C
- Compacted Mix
    - 5 days at 85°C (AASHTO R 30)
    - 10 days at 85°C
    - 20 days at 85°C

After the prescribed aging protocol asphalt binder was extracted and recovered from the mix. The recovered residue was evaluated using DSR 25 mm and 4 mm parallel plate and iatroscan to determine composition. Future work will include use of torsion bar modulus on compacted mix samples.

The effects of additives and aging on physical properties were assessed using low temperature properties (PG grade) and durability (ΔTc). Two analysis cases were developed – softer binder grade versus rejuvenating additives and do nothing.

The results of the low temperature PG for the intermediate aging (20-hour PAV, 12-hour loose and 10-day compacted) and extended aging (40-hour PAV, 24-hour loose, and 20-day compacted) showed that the difference between materials almost doubled with the exception of the compacted specimens.

Results of the low temperature PG testing for PG 52-34 showed that the loose mix aging slope began to drastically increase after 12 hours. The results for PG 52-34, PG 52-34 + EP#1, PG 58-28 + BO#1 showed that all three mixes for the PAV aging was similar. However, the compacted mixes after 20 days were about 3-4°C difference for the BO#1 and the loose mix differentiation between EP#1 and BO#1 was about 10°C. The change in low temperature grade between the various binders for each type of intermediate aging showed that the EP#1 maintained or improved the PG grade while the BO reduced the PG grade slightly. For the extended aging, this difference is increased.

Hanz presented the case study summary for the low temperature grade as follows:

- PAV aging at both conditions did not discriminate between materials as well as loose mix or compacted mix aging.
- EP#1 maintained better low temperature grading relative to PG 52-34 control and other additives, even with extended aging.
- Combination of EP#1 and BO#1 performed best.
- No benefit to additives observed in maintaining low temperature PG with extended aging. BO#2 was worst in most categories, PG 52-34 was marginally better than BO#1 at intermediate aging and substantially better after extended aging.

Results of the ΔTc testing showed similar values for the intermediate aging ranging from -1.6°C to -3.2°C while results for the extended aging showed a difference for the 24 hour loose mix aging where the ΔTc was -11.1°C while the 40-hour PAV and 20 day compacted were -3.7°C and -4.6°C, respectively. The results for PG 52-34, PG 52-34 + EP#1, PG 58-28 + BO#1 showed that the materials do not show much difference except for the loose mix aging. The change in ΔTc for the intermediate aging ranged from 2.6°C to 3.5°C while the change in ΔTc for extended aging ranged from 3.5°C to 9.9°C. The ΔTc for the extended aging was also mostly beyond the -5.0°C limit.

Hanz presented the observations from the ΔTc testing as follows:

- Significant differentiation was observed after extended aging, particularly loose mix.
- EP#1 improved ΔTc at all aging conditions
- BO#1 and BO#2 resulted in worse values of ΔTc relative to using a softer binder grade.

Hanz next presented the "Do Nothing" alternative to evaluate the effectiveness of using rejuvenators versus not changing the PG. The control was PG 58-28 and additives BO#1 and BO#2 were used. The target climate for the mix was -28°C. The intermediate aging for the low temperature grade showed improved performance for the binders with additives while after extended aging, the BO#2 reverted back to the same condition as not using oil at all. The low temperature grade for intermediate aging ranged from -27°C to -33°C for 20-hour PAV, from -24°C to -29°C for 12 hour loose mix and -26°C to -31°C for 10 day compacted. The low temperature grade for extended aging ranged from -23°C to -28°C for 40-hour PAV, from -12°C to -15°C for 24 hour loose mix and -20°C to -26°C for 20 day compacted. The intermediate aging for the ΔTc ranged from -1.5°C to -3.5°C for 20-hour PAV, from -3.0°C to -5.0°C for 12 hour loose mix aging and -2.5°C to -4.0°C for 10-day compacted mixes. The extended aging for the ΔTc ranged from -4.2°C to -5.5°C for 40-hour PAV, from -13.0°C to -15.5°C for 24 hour loose mix aging and -5.°C to -8.5°C for 20 day compacted.

Hanz presented the observations from the Do Nothing case as follows:

- Diminishing returns in using rejuvenating additives.
    - LT PG: Softening due to use of additives remains after intermediate aging. Additive effect diminished after extended aging for BO#2.
    - ΔTc: No significant benefit of additives for most aging conditions.
- Extended aging needed to evaluate additives used to soften the binder.

Hanz presented a comparison of aging methods. SARA analysis showed the asphaltenes were higher for the 24 hour loose aged mix. The Colloidal Index versus R-value showed that the asphalt mixes performed similar and that the addition of oil increased the R-value and decreased the colloidal index.

A field study at MnRoad was commissioned to evaluate the effect of asphalt binder source on performance and how laboratory aging protocols evaluated related to the field. A control section with PMA PG 58-34 with 20% RAP was used. Test sections included binder sources of PMA PG 58-34, PG 58-28 Canadian Blend, PG 58-28 Middle Easter Blend with REOB, and PG 58-28 Venezuelan. None of the mixes contained RAS.

The ΔTc were compared for the binder recovered from aged loose mix at 12 and 24 hours at 135°C to binder recovered from the top ½ inch of 8 year old field cores. To represent 8 years of field aging, laboratory aging at 135°C falls between 12 and 24 hours.

Hanz presented the conclusions as follows:

- Aging Methods
    - Both compacted mix and loose mix aging methods were more severe than PAV aging. Related to film thickness?
    - Presence of RAS impacted extended aging behavior. In MnDOT study 40-hour PAV and 24 hour loose mix aging were similar, for the RAS mixes differences were significant.
    - 12 hour loose mix aging and 10 day compacted mix aging produced similar results. 24 hour aging was very severe and could not be replicated by any other aging protocols.
- RAS:
    - Mix aging methods showed a significant deterioration of properties with extended aging.
    - Revisions to PP78 were intended to address RAS durability risks, PAV vs. mix aging issue requires further investigation.
- Rejuvenating Additives
    - EP#1 demonstrated an ability to retard aging. Low temperature PG and ΔTc were better relative to the PG 52-34 across multiple aging conditions.
    - The softening effects of BO#1 and BO#2 diminished with aging, ΔTc was worse than the PG 52-34.
    - When compared to the “do nothing” alternative of using PG 58-28 with RAS mixes, similar ΔTc values were observed after aging. LT PG was within ~one grade.

The future work includes finishing the current study including compacted mix aging after 5 days and chemical analysis, to expand the mixes tested including lower RAS loadings and designs with high RAP and conventional RAP dosages, and to verify extracted binder results using torsion bar testing and analysis.

<u>ETG Comments, Questions, and Discussion:</u>

Rowe asked where the sample came from. Hanz responded that the sample was from the top half inch. Rowe cautioned that there could be a gradient at that location.

King commented that this PAV aging was conducted at 100°C for a climate of -34°C where the difference of lab versus field would be about 2 degrees if 90°C was used for 20-hour PAV aging.

Golalipour asked for clarification regarding statement that compacted and loose mix aging were more severe than PAV aging since graphs showed PAV and compacted aging were similar. Hanz responded that PAV aging has much smaller spread than compacted or loose mix aging and therefore was not able to differentiate between materials. Golalipour stated that BO1 and BO2 PAV aging looked similar but were different in the mix and asked whether any chemical analysis on the oils was conducted or if there was an explanation for the change. Hanz responded that there was limited chemical data, but that there was a lower colloidal index with increased aging and that the oil decreased the colloidal index.

Reinke added that this was the second round of testing conducted on at least one of these oils. Initially it was thought that there was volatility loss. The second round of testing showed similar results and was repeatable but now the thought is that it is not due to volatility loss.

Marks commented that Ontario tried to use 12.5 grams in the PAV pan and age for 20-hours and the result was more severe than 40-hours PAV aging. She continued that 40-hour PAV and loose mix correlate well with 6 year performance in the field.

A participant asked if there is diffusion within the compacted sample aging and whether the assumption was that the entire binder within the sample is aging. Hanz responded that the whole sample does not age and that the torsion bar modulus testing will be used to answer this question later.

Golalipour asked how torsion bar samples were fabricated. Hanz responded that the sample was cut in half longitudinally and sliced out at the top or near the middle.

Sebastian asked whether correlation was observed between SARA and d-critical. Hanz responded that the correlation was not really strong.

Corrigan commented more of this work is needed; and we are severely over predicting performance, i.e. the materials perform better, by not having longer term aging during evaluations. A longer term laboratory conditioning protocol is needed. Longer term aging will help differentiate additives that are not beneficial to performance in the long term. Corrigan questioned what should be the target number of years to simulate long term aging for performance testing, whether current target of simulating 8 years was sufficient or if it should be 10 to 12 years or longer. Hanz responded that some LTPP sites could provide more insight if forensic analysis was conducted.

Reinke stated that the MN data was based only on virgin binders and when RAS or high RAP is used in the mixture, the virgin binder ages more rapidly. This needs to be considered when working towards a conditioning protocol.

12. MSCR vs AASHTO M 320 – High Temperature Grade for HPTO [Tom Bennert, Rutgers University]

Presentation Title: MSCR vs AASHTO M 320 – High Temperature Grade for HPTO

Summary of Presentation:
Bennert presented the background stating that in 2006, NJDOT began using High Performance Thin Overlay (HPTO) which was a performance-based design requiring Asphalt Pavement Analyzer (APA) (AASHTO T 340) rutting requirements. The general design of the HPTO included 4.75 mm NMAS, at least 7% asphalt content, design air voids of 3% and design gyrations of 50. There were some issues in 2015 regarding failing HPTO mixtures specifically those using PG 64E-22 asphalt binder. Prior to use of PG64E, there had been minimal issues. MSCR was adopted in 2015 which showed some issues with the HPTO designs. The asphalt suppliers were asked for more robust asphalt. MSCR testing showed that Jnr values greater than 0.16 resulted in failing APA rutting. The RTFO PG grade greater than 79°C resulted in failing APA rutting while the original PG grade greater than 82°C resulted in failing APA rutting. MSCR percent recovery less than 77% resulted in failing APA rutting. Original phase angle greater than 67 degrees at 76°C resulted in failing APA rutting.

Bennert stated that in 2015 Rutgers was working with the Port Authority of New York and New Jersey (PANYNJ) on high temperature binder issues. For this, 31 cores were taken from areas where failed binder retains occurred and Rutgers recovered the asphalt for PG grading and MSCR testing. The binder specified for the job was PG 76-22. Testing showed that all 31 cores failed the high temperature of 76°C with 28 of the cores resulting in 70°C and 3 cores resulting in 64°C. However, 28 of the 31 cores passed for a PG64E-22. Of the 31 cores, three failed the percent recovery versus Jnr for the existing PG 64E limit.

During MSCR implementation, northeast states tested binders, which at the time, met the current PG grade. MSCR results were compared to PG grades to help establish equivalent M332 traffic level. NJDOT agreed that PG 64E should be the same as the previous PG 76-22. Bennert posed the question now that MSCR has been implemented, are states that are used to getting previous binder performance, still receiving those binders or has binder modification now changed to meet M332, creating binders that no longer compare to what states were previously receiving under M320.

Bennert presented where the MSCR Jnr grading divisions were originally stated as discussed with D'Angelo. Jnr for neat binders in regional climates is usually around and under 4.0 to 4.51 kPa^{-1}. During mixture testing, every 50% reduction in permanent deformation was approximately a 50% reduction in Jnr. The original divisions went from 4.0 to 2.0 to 1.0 to 0.5. Bennert asked whether the Jnr divisions should be revisited.

Bennert presented the laboratory testing program to compare M332 versus M320 HPTO binder specification. The testing program included eight binders from different suppliers consisting of different sources and modifications. The PG grade was determined according to M320 and M 332. Binders were used in a NJDOT approved HPTO mix and conducted testing after volumetric conditioning and STOA conditioning. The testing included APA at 64°C (standard for HPTO specification) and Flow Number at 54°C (using NCHRP 9-33 protocols). Binder and mixture performance were compared to determine if current MSCR requirements are appropriate for NJDOT HPTO.

Bennert presented an example of a NJDOT mix design that uses high asphalt content and high VMA to address fatigue. Five different asphalt suppliers provided the eight binders that were formulated differently.

Bennert presented the binder test results according to AASHTO M 320 including the original and RTFO high temperature grade, the original phase angle at 76°C, the ratio of RTFO to original high temperature grade and the difference of RTFO and original high temperature grade. Only one binder did not grade to a PG 76, but was a PG 70-22. The binder test results according to AASHTO M 332 showed that all eight binders fell within the E range when tested at 64°C while three binders fell outside of the E range when tested at 70°C. The change in Jnr versus the change in PG grade test temperature was fairly linear through zero and showed that an increase in test temperature (from 64°C to 70°C) reduced Jnr by 62%. Additional changes in temperature were tested for another 14 binders to check on the consistency of Jnr change. On average, when increasing test temperature by 6°C, Jnr reduces by 60%, or becomes 40% of the previous test temperature's value. Bennert hypothesized that since 6°C intervals are still used for testing, whether the Jnr divisions should be modified to represent how the binder is performing within the test temperatures. Bennert presented revised Jnr divisions based on PG temperature bump that uses the 40% of previous grade as 4.5, 1.8, 0.7 and 0.3 for traffic designation S, H, V and E, respectively.

Bennert next presented the mixture test results for APA testing and Flow Number for both volumetric and STOA conditioning. The APA rutting versus Jnr at 64°C showed that a Jnr of 0.37 would fail APA rutting for production. The Flow Number versus Jnr at 64°C showed that Jnr greater than 0.35 would fail for traffic greater than 30 MESAL. APA rutting results were plotted within the percent recovery versus Jnr. In order for the Jnr threshold to capture the APA rutting failures (greater than 5.0 mm), Bennert proposed reducing the existing 64E Jnr limit from 0.5 to 0.3.

Bennert presented the study conclusions stating that it appears that the current M332 divisions may need to be modified for NJDOT HPTO mixtures. APA rutting for volumetric conditioning showed Jnr less than 0.37 for production APA rutting and less than 0.23 for design APA rutting. The flow number for STOA conditioning showed Jnr less than 0.35 for traffic levels greater than 30 MESALs. The MSCR Jnr limit of 0.3 kPa^{-1} was able to differentiate passing/failing HPTO mixtures using production tolerance.

Bennert presented the NJDOT recommendations as follows:

- For NJDOT's HPTO, it was recommended to change the Jnr value from < 0.5 to < 0.3 kPa^{-1}.
- NJDOT considering changing current MSCR Jnr to < 0.3 kPa^{-1} for all mixes using PG 64E-22.

Bennert concluded the presentation by providing the final thoughts. In adopting MSCR for high temperature, many states looked at how their PG binders were fitting into the MSCR system. For example, NJDOT acknowledged that the previous PG 76-22 would have fell into the 64E designation (Jnr < 0.5 kPa^{-1}). However, how the binders received now (modified to meet MSCR) fit into the previous PG system remains to be seen and the impact on performance.

<u>ETG Comments, Questions, and Discussion:</u>
D'Angelo commented that the Jnr divisions were developed for typical mixes, not specialty mixes. D'Angelo stated that the binder suppliers for the HPTO mixes were probably limited and likely closer to PG 82. Bennert replied that the high temperature grade was close to 79°C. Bennert stated that they were seeing binders a few years ago that were higher than they are now. D'Angelo responded that the performance criteria is about the same, but that the material used to be stiffer. If NJ wants and/or need a stiffer material, it will need to be required since when specifications are changed, suppliers change the formulations slightly. Suppliers are now modifying binders to meet AASHTO M 332.

Rowe stated that the work was trying to understand how temperature ties into change of binder properties. Jnr is a pseudo stress dependent property and it is not always perfectly related to $G^*/\sin\delta$ for all materials. With a change in parameters, one should be able to determine the relationship between the two and calculate what the divisions are. Rowe stated he would like to look at the data.

Christensen asked whether any actual performance problems with the HPTO mixes had been reported. Bennert responded that a field evaluation would be conducted in a couple of weeks which will include looking at the first four sections that failed after only about a year. The perspective from NJDOT is that they had not seen failures in the past with previous criteria. Christensen responded that part of the problem is in the mixture test and not in the binder test of specification. Bennert agreed and stated that they had seen some issues when APA rutting was less than 4 mm.

Frank Fee commented that it was important to state that the PG 76-22 was a plus specification with stringent elastic recovery. Fee stated that it is important to note that failing the rut test, had a recovery less than 80 and that this should be considered rather than stiffness alone.

Kluttz responded to Rowe's comment stating that when moved from $G^*/\sin\delta$ to much higher, no longer in linear range for the binder. When the test temperature at high strain is changed, there is an added level of risk of what you are specifying versus what you are receiving.

Corrigan stated it isn't ideal to use the APA rational to make changes to MSCR without having the field performance to support any changes. The APA criteria was not considered during development of the original MSCR requirement. Corrigan asked what was the time line for the field evaluation? Bennert responded the deadline for the field performance was the end of September.

D'Angelo commented that there was a stringent recovery portion which requires to have a stiffer material. D'Angelo suggested setting requirements on recovery and that recovery could be increased and Jnr would still decrease. Bennert responded that he did not want to get stuck on Jnr deviations or specialty mixes, but that they do need to go back and look at what they are getting now compared to before.

King commented that the difference between two grading systems was not related to the APA test. The change in 6°C testing temperature increments was not 50% and that the 40% differences may show that Jnr is changing a little more. King also commented that when the plus specification was removed, the formulations were changed. There is more risk for rutting if APA is showing more deformation.

D'Angelo stated that it was critical how the differences are evaluated. D'Angelo continued that changes in grades in Jnr are based on tests, not temperatures. With the MSCR, there are four from S to E and you have to look at it correctly.

Baumgardner commented that binders are changing due to the MSCR specification and that agencies need to get used to these new MSCR driven formulation of binders.

Rowe commented that three grade bumps using G*/sinδ was equated to three grade improvements using MSCR. Bennert has pointed out these yield different values. D'Angelo commented he was not against a New Jersey specific threshold but would need the details of why the two are not the same. There is a difference between changing the Jnr threshold for New Jersey versus for the entire country or for AASHTO. Rowe stated that he was not recommending to change AASHTO but that agencies need to know what they are getting based on AASHTO M 332 instead of AASHTO M 320. D'Angelo commented to ask for higher recovery instead of asking for a Jnr of 0.3.

Action Item #201609-2. Tom Bennert will report on NJ field evaluation data on HPTO mixtures at next ETG meeting.

Reinke asked whether Bennert could get cores from the field evaluation to determine the binder grade. Bennert stated that he could try.

13. Update: MSCR: Evaluation of MSCR Data in the AMRL Proficiency Sample Program (PSP) [John Malusky, AASHTO Re:source]

Presentation Title: Evaluation of Laboratory Performance in MSCR Testing (T350/D7405) Using AASHTO Re:source PSP Data (Continued)

Summary of Presentation:
Malusky presented a review of the statistically significant differences for the PGB Rounds 241/242 (64-28p). Out of the six reporting parameters in T350/D7405, statistical differences existed between manufacturers (A, B & C) for these four test parameters: percent recovery at 0.1 kPa (A-B), percent difference in recovery (A-B), Jnr at 0.1 kPa (A-B) and percent difference in Jnr (A-B-C). Malusky presented the actions taken as a result of the differences. AASHTO Re:source are continuing to solicit for test data for all reporting parameters in the MSCR (T350/D7405). The Administrative Task Group has been informed of the situation. AAP's proposal to the ATG is to not evaluate the percent difference in recovery and percent difference in Jnr for accreditation purposes but to still evaluate data for percent recovery and Jnr values at 0.1 and 3.2 kPa, respectively. In addition, AASHTO Re:source will continue to evaluate the data after each PSP round and look for issues such as model and software version.

Malusky presented the results from PGB 243/244 (PG 64-22) where there were statistical significance between manufacturers for the following parameters:

- % recovery at 0.1 kPa (all manufacturers)
- % recovery at 3.2 kPa (all manufacturers)
- % difference in recovery (all manufacturers)
- % difference in Jnr (all manufacturers)

Malusky presented the scatter plots for the percent recovery at 0.1 kPa. The results looked good although quadrant three was a little heavier than the others. The scatter plot for the percent recovery at 3.2 kPa showed a bi-modal distribution based on manufacturer. Although the analysis is robust enough and would not affect the rating, the ratings were suppressed. The scatter plot for the percent difference in recovery also show a bi-modal distribution and the ratings were suppressed. The scatter plot for the percent difference in Jnr showed that the manufacturers were clustered more but that quadrant three was again heavier. It is possible that there is a systematic error due to the spread of the results in quadrants 1 and 3.

Malusky presented the issue of the different DSR software versions. Out of 240 participants, there were over 40 different software versions reported. The DSR manufacturers were contacted to cross reference the reported software version. The communication indicated that the laboratories are not certain on what type of software they have. AASHTO Re:source assessments included identifying devices without the most current software and reviewing data to determine if conditioning cycles are being used.

Malusky presented several options to open the discussion including the following:

- Collect data based off of the correct software version.
- New RTFO sample vs. tested RTFO DSR sample with "rest" period (AASHTO and ASTM allow both).
- Revise the standards to require most current version of software from the manufacturer.

ETG Comments, Questions, and Discussion:
Casola stated that AMRL used to require the software version to be recorded and that if it was required again, it may help with the issue.

Golalipour stated that requiring the most current version of the software in the standard may be difficult since there are different vendors and updates may not be helpful and could create some challenges. Golalipour stated that sometimes looking at the raw data from different machines and software, the raw data is acceptable, but there are some issues with the calculations. Looking at the raw data should be considered.

D'Angelo stated that most of his work was with the raw data. D'Angelo did have an issue where the time was off for one manufacturer which caused issues with the calculations. The data from the equipment needs to be reviewed to make sure that it is correct. Malusky asked whether D'Angelo would require raw data to be visible on the final report. D'Angelo responded that the manufacturers need to go over the data. Golalipour added that the manufacturers should be asked to bring the raw data and software templates and to show how the calculations are performed.

Corrigan stated there are challenges with the raw data from the implementation standpoint and capabilities of users from accreditation standpoint. Corrigan asked, as an agency, what they can do to help strengthen the overall program. There would be value to the community if the manufacturer could give assurance the version of software that needs to be used with each type or model of equipment in use. Malusky agreed. Malusky stated that if he was to reach out to the manufacturers and ask what software version was applicable to the machines, AASHTO Re:source could check whether the software being used was acceptable.

Casola stated that manufacturers could issue to AASHTO Re:source the current version of the software. Corrigan responded it would help educate the community on what they should be doing and could be a tool as part of the proficiency samples or assessment. Corrigan stated, if it was reasonable to ask that of the manufacturers, it would help narrow down the issue.

Golalipour stated that AASHTO Re:source may not want to ask users to provide all raw data, but only data for strains of 0, 1 and 10 seconds for each cycle in a table.

Bonaquist asked whether the data was showing that it was a software issue only, and asked whether the issue was with the calculations since the data is bi-modal. Bonaquist believed that there was a bigger difference than simply the software version. Malusky responded that it was possible and that there is a lot of education that needs to happen.

M. Anderson asked what Malusky was looking for on how to move forward. Malusky responded that from an AASHTO Re:source perspective, they would like to know whether or not to enforce the standard.

Action Item #201609-3. ETG members will review and provide comments on MSCR proficiency sample data concerns presented by AASHTO Resource (formerly AMRL) directly to John Malusky (AASHTO Resource) and cc: Matthew Corrigan (FHWA) and Mike Anderson (AI).

14. Update: 4 mm DSR Testing and PAV Degassing Issues [David Anderson, Consultant]

Presentation Title: Update: 4 mm Update

Summary of Presentation:
The task group has found that new procedures are needed for sample preparation to ensure adhesion between plates and binder. In addition, fixture-specific machine compliance is needed for low-temperature testing. As an ancillary activity, verification of time required for specimen thermal equilibrium was determined and will be incorporated in forthcoming update of DSR test method. Working draft test protocols are now ready for general distribution to the ETG and beyond.

The two protocols appear to give similar results. Since equilibrium occurs rapidly (i.e., within few minutes) the time to equilibrium is not an issue. Physical hardening is binder dependent as expected. This can be significant and the test protocol needs to account for physical hardening. If physical hardening is unaccounted for, test variability may be unacceptable. Depending on the purpose of testing, physical hardening may be an issue.

D. Anderson presented the remaining issues that were beyond the scope of the task group as follows:

- Specifying linear region – broader than first expected.
- Testing sequence – increasing or decreasing temperature steps and increasing or decreasing frequency.
- Consideration of physical hardening – test sequence and data correction by extrapolation to zero time.
- Ruggedness testing.
- Training and subsequent round robin testing.
- Algorithms for specification use.

D. Anderson stated that all test data for the main experiment is complete and the work needs to be documented in a comprehensive final report. D. Anderson stated that the original goals of the task force on 4 mm are essentially complete. This includes having a protocol that can be used and that can form the basis of ruggedness and round robin testing. D. Anderson suggested that the task group look into the 8 mm repeatability and that it is possible that the material is not being heated enough.

ETG Comments, Questions, and Discussion:
Golalipour, in reference to physical hardening, asked whether the period of time for system to change from temperature control to high temperature for DSR testing was considered. D. Anderson responded that it needs to be considered, but that the task group did not have time to consider this. D. Anderson also noted that many do not consider thermal history when doing master curve analysis.

Action Item #201609-4. Dave Anderson will send the three finalized 4 mm DSR documents to Corrigan for distribution and comment by ETG; and will finalize a written report documenting the Task Group efforts prior to the next ETG meeting.

Shauna Teclemariam asked whether the 4 mm method would be added to current specification. D. Anderson responded that it was composed so that it could be inserted in the current DSR test specification.

Presentation Title: Update: PAV Degassing

Summary of Presentation:
D. Anderson stated that the task group addressed whether vacuum degassing was necessary prior to conducting rheological measurements with the BBR or DSR. The requirements for degassing vary with ASTM and AASHTO. There was a recent proposal to eliminate vacuum degassing based on historical studies but some, especially west coast agencies at high altitudes, reject this proposal. A multi-laboratory study was established to address the question. Historically, the degassing procedure was added post SHRP when direct tension test was adopted as a result of small bubbles that were a source of flaws that reduced the tensile strength. The degassing time was recently increased from 10 to 15 minutes. No ruggedness testing was done to establish vacuum level or temperature.

The degassing experiment laboratory work, initial data analysis and initial draft report are complete. This presentation focuses on a review of the experimental work, describe ancillary work and discusses recommendations for updating the test method.

D. Anderson stated that the linearity of pressure release rate was reviewed as a possible cause of excessive bubbles. The study showed that the Prentex equipment releases linearly in series of small bursts while the ATS releases non-linearly with 50% release in the first 90 seconds. Neither of these equipment pressure release methods meet the original intent of the test method. This was verified by data from several laboratories. As a result, the release rate and uniformity of the release rate may need to be addressed in the test method which should include continuous-linear release rate with nonlinear or short bursts.

The experiment design included four binders, including a modified binder as these are reported as more difficult. Eight laboratories were included and were selected to give different elevations and devices. The rate of PAV pressure release was either device controlled or manual (linear).

For the measurements, the original binder samples were sent to each participating laboratory where each laboratory then performed RTFOT and PAV conditioning. The RTFOT residue was blended and then PAV aged. The PAV conditioned binder was then split between degassing and no degassing conditions. Study variables included differences in elevation, vacuum gage reading, and pressure release device.

The measurements on the PAV residue included 8 mm DSR at specification temperature closest to intermediate specification temperature and BBR at grading temperature. The intent was to analyze the relative change in property when degassed and non-degassed. This was to minimize laboratory to laboratory bias. If the difference between degassed and non-degassed measurements was less than replicate samples (2ds% for operator error), it was assumed that there was no effect from degassing.

The measurement of residual pressure when vacuum is applied is poorly understood in many laboratories. It was recommended to measure absolute pressure as it gives pressure relative to a perfect vacuum and there is no need to correct for ambient pressure. The specification should be simplified to require pressure gage reading as a function of laboratory elevation. Instrument manuals vary with respect to adjustments for barometric pressure which is not always clearly understood in the field. D. Anderson stated that the estimate of gage pressure versus elevation should use the linear regression equation and not what the manufacturer provided.

The recommended specification wording was:

> When using a vacuum gage to control the degassing pressure, the gauge readings given by Eq. 4 calculated using the laboratory elevation to the nearest 100 feet shall be used to control and report the vacuum during the degassing cycle. Equation 4 accounts for changes in atmospheric pressure with elevation. No additional corrections for laboratory barometric pressure, temperature, humidity, etc. shall be applied to the vacuum gage reading regardless of instructions supplied by any vendors, instrument software, or other source. The vacuum gage reading shall be reported and controlled to the nearest 0.5 inches Hg (0.2 k Pa).

The tolerance in the specifications needs to be changed in order to match what is on the dial gage. It is recommended to change the specification to 15-19 kPa and 11-14 nh Hg.

The data analysis centered on calculating the ratio of degassed to non-degassed for modulus, phase angle and m-value for various combinations of study variables. The data were tabulated by grade. Results showed that there was a lot of variability for G*sinδ and that sometimes degassing was higher while other times it was lower, which was not expected. Stiffness results were also similar. Binder source or laboratory elevation effects could not be identified. The percent change in PG 58-28 and PG 78-28 with degassing for device and manual control showed mixed results from the expected.

The observations from this study were that there was no clear change in properties as consequence of degassing and that qualitative evaluation of data does not warrant degassing. However, until anecdotal information claiming vacuum stiffens binder is verified, degassing should be allowed as optional but with referee of the method. Observations also showed that degassing may decrease test to test variability but more data is needed to validate this claim. There were bubbles observed in non-degassed and degassed specimens.

D. Anderson presented the conclusions and recommendations as follows:

- Test method should be revised with specifications regarding determination of vacuum gage pressure.
- Specification values for gage pressure should be revised to match gages in use and to be compatible with gage readability.
- Some binders never stop outgassing.

D. Anderson stated that there was no definitive answer whether degassing should be required but that it may reduce repeatability. The recommendation was that degassing PAV residue is optional when conducting a non-destructive property test such as G* but is required when performing a destructive test such as the DTT. In addition, degassing is required for all reference testing. An appropriate note must be added to each property method.

Action Item #201609-5. Dave Anderson will finalize a written report documenting the PAV Degassing Task Group work prior to the next ETG meeting.

ETG Comments, Questions, and Discussion:
Casola commented that degassing made some samples stiffer but other samples softer. Since air bubbles in the system act as hard spheres, removing the air bubbles should reduce stiffness. When stiffness is increasing, there may be some other issue occurring during degassing. D. Anderson responded that it may be more of an issue with more exotic binders.

Beran Black asked whether AMRL data was considered since it is noted whether degassing is used. Malusky responded that about 90% of laboratories continue to degas although it is not required. Malusky continued that the repeatability and reproducibility did decrease, but it was not significant.

15. Improvements to DSR-PAV Test Method [Pavel Kriz, Imperial]

Presentation Title: DSR-PAV Test Improvement

Summary of Presentation:
Kriz stated that the DSR-PAV is too variable. He presented one sample of SQC data with about 100 results over one year where the reproducibility was 40.2%. The Gauge R&R scale shows whether the measurement is able to measure the variability in the process. Less than 10% falls into the acceptable range, between 10% and 30% is acceptable with limits and above 30% is unacceptable. 57% of the variability of the DSR-PAV test process is from the test itself and is unacceptable.

Kriz presented an approach to DSR-PAV variability improvement. Kriz stated that the sample RTFO and PAV aging was shown insignificant to DSR-PAV variability. The study focused on the DSR test improvement itself. The first step was to standardize within T315. This included sample preparation using direct pour with plates at 46°C, trimming and gap setting with plates at 46°C and conditioning with fixed cooling rate and fixed wait time. This still conforms to the test method but does not allow room for interpretation. This provided minor improvement in variability. The second step was to review the science in T315 for contributions to variability. The test variables were placed in a Statistical Design of Experiment (DoE).

The statistical DoE considered five factors at two levels for a total of 32 individual test settings. The five factors and levels were as follows:

- Thermal – direct transfer or mold
- Geometry – 8 mm parallel plate with 2 mm gap or 25 mm parallel plate with 1 mm gap
- Strain (%) – 0.1 or 1

- Sample – naphthenic or waxy
- Operator – new or experienced

The test matrix was generated and randomized with each setting repeated four times in order to calculate standard deviation. A half of the design (16 settings) was performed for a total of 64 individual DSR measurements.

Kriz next presented the standard deviation comparison for each factor and level. A horizontal line represented the methods were equivalent, while the steeper the line, signifies a larger difference between the two methods. This showed that strain was a major factor affecting variability. Kriz showed that linear viscoelasticity is challenged at 1% strain. For the 8 mm parallel plate, the modulus increases with strain likely due to edge effect. For the 25 mm parallel plate, the modulus is constant until about 1% strain. There is better repeatability at lower strain because there is no difference in geometry. Kriz stated that the variability may be cut in half by using 0.1% strain and 25 mm geometry.

Kriz stated that the high test strain and 8 mm plate geometry was an artifact of circa 1990s DSR equipment capability where the 0.1% strain would challenge the capability of the machine. However, current instruments are capable of much lower torque. Older instruments could still be compliant with 25 mm geometry and 0.1% strain.

Kriz stated that the 5,000 kPa limit was suggested on limited data developed from tests on asphalts used in the Zaca-Wigmore Test Road. Kriz showed with his data that the cycles to failure are scattered with little correlation up to 10,000 kPa.. Kriz suggested that increasing the limit to 6,000 kPa would make a difference in their ability to meet the standard. Kriz stated that it is this specification that limits them in their production.

Kriz presented the conclusions of the presentation as follows:

- DSR-PAV test is not easily able to distinguish quality
- High variability is partly driven by the test method parameters
- Lower strain and higher plate diameter-to-gap ratio is desirable

Kriz recommended to adopt a 0.1% (or lower) strain and allow the 25 mm parallel plate for DSR-PAV testing. In addition, Kriz recommended to increase the specification limit to 6,000 kPa to ensure DSR (original/RTFO) and BBR (m or S) are PG limiting specifications. Kriz suggested this would allow for improved asphalt production without impacting the binder performance.

Kriz presented an approach to improve the test method in AASHTO T 315. The approach included a round robin using various binder samples to compare the existing and suggested test setup (strain level, plate size, load T). Analysis of the data would be used to develop an updated AASHTO T 315 test method. The target timeline for data analysis is the April 2017 ETG meeting.

Kriz next stated that his objective to increase the DSR-PAV limit in AASHTO M 320 to 6,000 kPa needed the ETG input.

<u>ETG Comments, Questions, and Discussion:</u>
Black asked for clarification regarding the sample Kriz presented with the variability over a year and asked whether it was over various laboratories. Kriz responded that it was from one laboratory. Black asked how to not alter samples and prepare samples with no variation in the samples. Kriz responded that they used 200 pails that were each numbered and the data cross validated. The pails are put through the same heating process and data has shown that properties do not changes when stored in large pails. Black stated that the NHDOT experience was that the DSR-PAV rarely failed and that BBR failure was more likely. Kriz responded that it could be because of the suppliers in the specific state.

D. Anderson stated that one has to be careful comparing binder tests of different grades and test temperatures. D. Anderson stated that binder and mixture tests should be done at the same temperature.

King stated that the intermediate temperature task force is already recommending some changes and that he would rather see efforts put there for an alternative predictor for fatigue cracking than into this. King stated that if some changes are needed, he might agree with a temporary change to 6,000 kPa. Kriz responded that he would support developing a new specification but worried that it would take many years for that to happen and that changing the limit to 6,000 kPa would alleviate some pressure now.

Rowe cautioned about removing the specifications for the intermediate temperatures because it helps control the shape of the master curve. Rowe stated that one has to be careful when changing specifications. King agreed and stated that it helps reduce oxidation of material. However, in Canada, this hurts more than it helps. D. Anderson stated that non-standard grades do bump the limit up to 6,000 kPa.

Marks stated that PG 58-28 are the only binders that ever fail this for her agency (Ontario). Marks stated that in those cases, she looks at the binder and normally allows it. However, she would not want to change this limit for all other grades.

Corrigan stated that
in context of the presentation, there are other causes for variability that are not easy to control; to ensure there is enough data to make a definitive case for making this change would need to be conducted to move forward any recommendation. Corrigan stated the discussion and generating data to further discussion was good, but wants to make sure that they would be focusing on advancing a better alternative. Kriz responded that they support research for advancing alternatives. However, he stated that they did not have the 5 to 10 years it would take for a new method.

John Bukowski stated, as FHWA, they are always willing to take something to AASHTO. However, they also consider the likelihood of passage. It requires justification and data to convince the ETG members and AASHTO members; data is important.

King asked whether there was any way that they could qualify the results with R-value. For example, if you exceed 5,000 kPa, you must have an R-value less than “X.”

Rowe asked that with MSCR changes, what are all the differences on G*sinδ that would be seen. Rowe stated that there are some differences between MSCR and the old specification because the intermediate test temperature was changed, which will give a different value.

Marks stated that with the PG 58-28 that failed, the binder was tested as if it were a different grade and the parameter did not change the grade much. Once the temperature was changed, the problem went away. It is sensitive to slight temperature differences.

Teclemariam stated that in California many binders exceed 5,000 kPa. These binders are then tested at 3 degrees higher and then must pass.

Black asked what the standard deviation was for the 8 mm test AMRL proficiency samples since those have been tested for years. Black asked if there was an issue with variability, would it not show up there. Malusky responded that the individual sample reproducibility d2s was in the 30's while the single operator d2s was in the low teens. Malusky noted this was consistent for years.

It was asked whether the variability was from the test or more related to asphalt and crude itself. With extended PAV aging, what will the effects be that will differentiate different asphalts. Baumgardner responded that it is due to both.

D'Angelo stated that the d2s for DSR-PAV is very high and it is variable. If one can reduce variability then they may be able to shift up some.

Howard Anderson stated that UDOT was concerned about cracking and asked how moving the limit from 5,000 kPa to 6,000 kPa would affect the cracking potential?

Reinke asked whether the limit was increased to 6,000 kPa for s-graded binders if that provided relief. Kriz responded yes. It was suggested that the scope be narrowed to s-graded binders.

D. Anderson asked whether it was the variability in the 8 mm measurement or the 5,000 kPa limit. Kriz responded both. However, these are two separate issues.

Corrigan stated that activities starting through the AI task force would be able to present findings and recommendations to the ETG; whichwould then review and provide additional comments. If there is enough interest to have a separate task force, although there would be some crossover, a task force could add some additional or differing viewpoints.

Action Item #201609-6. Pavel Kriz will report ongoing work by the newly formed Asphalt Institute PAV DSR Task Group at the next ETG meeting. ETG members and friends interested in supporting AI's Task Group efforts are:

a. **Peter Moore**
b. **Joe DeVol**
c. **Karl Zipf**
d. **Pamela Marks**

e. **Tanya Nash**
f. **Dave Anderson**
g. **Geoff Rowe**
h. **Codrin Daranga**

16. Update: Binder ETG – REOB Task Force, Final REOB White Paper Recommendations; Relevance and Use of ΔTc [Geoff Rowe, Abatech]

Presentation Title: New methods for assessing rheology data such as ΔTc and G-R Parameter and their relationship to performance of REOB in asphalt binders and other materials.

Summary of Presentation:
Rowe stated that at the last meeting, the ETG members had asked the Task Group to summarize the information from the ΔTc discussions, background of information and related parameters and to format it into a document including the REOB discussions. The document is 19 pages long and covers introduction, development of ΔTc and G-R relationships with other parameters, use of CA equation to estimate DTC, assessment of REOB material and other materials, and REOB materials. This document was distributed to a small group for review the week of September 5, 2016. The group has been asked to provide comments by the end of September. The plan is for the Task Group to finalize the document in early October and to submit to Baumgardner and Corrigan.

ETG Comments, Questions, and Discussion:
Corrigan stated the documents from task group need to be finalized. Once completed, the documents will be distributed to the ETG. Any issues or comments from the ETG will be addressed and then the documents may be published. The goal is to have this completed by years end.

Action Item #201609-7. Geoff Rowe will finalize the REOB white paper recommendations and address any ETG comments by mid October 2016.

17. IS-235 – "State-of-the-Knowledge, The Use of REOB/VTAE in Asphalt" [Mike Anderson, Asphalt Institute]

Presentation Title: State-of-the-Knowledge Document on the Use of REOB/VTAE in Asphalt

Summary of Presentation:
M. Anderson stated that the Asphalt Institute has published the State-of-the-Knowledge document. M. Anderson stated that there were corrections identified shortly after the document was announced and that if anyone downloaded the original document, they may want to download the revised document. The document is available for download at asphaltinstitute.org/re-refined-engine-oil-bottom/

18. ΔT_c TFHRC Research [Jack Youtcheff, FHWA]

Presentation Title: Update of Ongoing Binder Activities

Summary of Presentation:
Youtcheff stated that the binder activities included the REOB round robin characterization, WRI/ARC field validation sites, binder QC tester update and the ΔTc Range and magnitude.

Youtcheff stated that the binders have changed as a result of high crude oil process and new blends, modifications and materials including REOB, RAP, hybrid (CRM+Elastomer), Waxes and other polymers, and PPA. There are also new methods for extracting crudes.

Youtcheff presented the approach used that included collecting State DOT low temperature BBR verification data, calculating ΔTc using data mining techniques and obtaining performance data if available. The purpose of this was to use data to provide recommendations on an acceptable ΔTc and to specify S where m-value is 0.3.

The rule of thumb for ΔTc prediction from a single point BBR data states that the S value at 60s doubles every 6°C and the m-value changes by 0.036 every 6°C. A second method to predict ΔTc from a single point BBR data is to collect a robust database of BBR S and m-values for different PG grades and calculate the PG specific prediction rules for S and m-value. This should be validated using an independent database of S and m-value. A third method is to predict ΔTc based on PG specific changes in S and m-value.

Data from Maine DOT showed that the ΔTc bands reported were narrow, from 2003 to 2015. Delaware DOT data shows that the majority of the ΔTc values are between 6 and -4°C. The range of ΔTc values also narrows with time. By separating the results for the different PG grades, you can look at the different skewness for each binder.

Youtcheff presented the findings to date as follows:

- ΔTc may be predicted using simple rules based on PG averages
- Error in prediction is within ± 1°C for most grades and binders
- Data mining effort
    - ΔTc is mostly skewed to negative ΔTc (m-controlled) for the six State DOTs analyzed
    - ΔTc can range from as low as 3.6°C to as high as -14.6°C for the six State DOTs analyzed

The future plans include collecting more datasets from researchers where S and m-value data for both temperatures for BBR are available to fine tune the ΔTc prediction method and improve the PG based method error. In addition, collection of performance data from State DOTs, especially for State DOTs showing high values of ΔTc, will be completed. Finally, possible ΔTc limits for binder specification will be recommended.

ETG Comments, Questions, and Discussion:
Kluttz stated that he had never seen stiffness temperature exceed the m-value by so much. Youtcheff responded that the S values did not seem to change with time.

D. Anderson commented that a small amount of good data is better than a lot of poor data.

19. Update: Binder ETG – Binder Aging Concerns Task Force [John D'Angelo, Consultant]

Presentation Title: Asphalt Binders and Aging 20-hour or 40-hour PAV

Summary of Presentation:
D'Angelo stated that the task group has been considering aging ratios. D'Angelo had presented at the previous ETG meeting the change in ΔTc from RTFOT to 20-hour PAV which showed the trend of the material. The task group only received one comment on the work presented which stated that running BBR on RTFOT material can be a challenge. D'Angelo stated that the other approach is to run G-R on RTFOT and PAV. If the ΔTc on 20-hour PAV is close to -5^{o}C he recommended running a 40-hour PAV. If G-R aging ratio is low and ΔTc less than -3^{o}C than no 40-hour PAV aging is needed. If G-R aging ratio is high and ΔTc is -3^{o}C, run 40-hour PAV aging.

D'Angelo next presented on the MSCR specification. D'Angelo stated that using percentages on small values results in high variability and is not a factor of whether the material is stress sensitive or not. The other problem is when there are tests with very low Jnr values, when the material is relatively stiff, that it is not stretching the polymers.

D'Angelo stated that the peak point in the strain graph for determining Jnr is irrelevant since the Jnr value is calculated at the end of the graph.

D'Angelo stated that neat binders are typically linear up to 3.2 kPa or higher. On the other hand, with a PG 82-22 binder, stress sensitivity increases with temperature. The graph showed that at 70^{o}C, there was little stress sensitivity but at 82^{o}C, it was very stress sensitive. With SBS modified binders, compliance values increase with temperature and stress. The rate of increase with stress increases with increased temperature.

A study on wax modified warm mix binders showed that at 0.1 kPa stress, it is like a rock. However, once stress is increased beyond that, the binder falls apart

Arizona State uses a new procedure where instead of percent difference, the slope is used. With this method, some of the smaller numbers do not have as large of an effect. With this, 0.8 kPa can still be used.

D'Angelo presented the correction to Jnr difference as increasing the low stress from 0.1 to 0.8 kPa, which is still in the linear range for most binders and to consider going to Jnr slope similar to Arizona's procedure.

ETG Comments, Questions, and Discussion:
D. Anderson was concerned this becomes an empirical specification because these are just index values. Rowe commented that the values that would be reported would be G* and phase angle and that you would have data if you wanted to use it.

Kriz stated that since 40-hour PAV is stringent to ask for in a specification, maybe consider what was done in Austria. Austria did RTFO for three times the time and then if the grade increased more than 16 degrees, the asphalt was rejected.

Golalipour commented that they have been testing some materials from field projects where the slope of aging from RTFO to PAV was very similar but then from 20 to 40-hour PAV aged was totally different. Golalipour referred to the data Hanz presented, where up to 20-hours PAV aged was similar, but after 40-hour PAV aged the performance was different. D'Angelo agreed and stated that he will have to look at it.

Teclemariam stated that she had concerns about 40-hour PAV aging. She asked whether D'Angelo had looked at lowering the amount (of residue) in the PAV pan and keeping the aging time at 20-hours. D'Angelo responded that there are significant problems doing that because the level in the pans is critical. This makes the flatness of the pans more of an issue, which people are still working on.

Corrigan responded too often the term "practical" is used instead of the term "simple". This results in not using robust data and solutions to allow distress prediction, quantify performance, and make the link to long term field performance. The majority of the billions of dollars spent for highway construction goes to pavements and there needs to be a balance and consideration given to being "inconvenienced" by materials and testing requirement versus the value they provide which results in longer life pavements for the traveling public. Finding this balance requires the understanding that the goal is to prevent premature failure resulting in significant savings to the public.

Marks commented that Ontario MOT preheats the PAV pans and adds 12.5 grams of binder and then moves the pans around so that the binder covers the whole pan.

Reinke commented that 40-hour PAV aging can identify problem materials and problem additives. Reinke also noted that the Glover-Rowe parameter is worth consideration. He added that finding a method to approximate 40-hour aging is also time and money well spent. The 40-hour PAV aging is providing valuable and useful information not known before.

D. Anderson asked whether 40-hour aging was the upper limit. Reinke responded that 40-hour aging was enough to determine problematic materials.

Black stated that prior to adding the conditioning steps they did not have issues of binders having percent difference under 75%. D'Angelo responded that the conditioning was added to address softer asphalts that were not activating the polymer networks that caused stress buildup in the specimens. By adding the conditioning cycles, there was greater uniformity. This was not a problem for stiffer asphalts. D'Angelo stated that if the stress was increased (to 0.8) this effect would not occur. Black asked if the difference would still be under 75%. D'Angelo responded that he thought so but would have to do some testing.

Klutz commented that polymers are not activated, but rather they are stretched. D'Angelo agreed that it was inducing stress in the polymer.

Darango suggested that a solution for the issue with the percent difference between Jnr for low numbers was to ignore differences if the Jnr was below 0.5 or 0.25 but if needed to test at a higher temperature. D'Angelo agreed.

Baumgardner asked what the recommendation to ETG was. D'Angelo responded that he would like to form a task group.

Action Item #201609-8. A new Task Force was created to investigate a solution addressing low $J_{nr\ diff}$ results utilizing MSCR. Members include:

a. John D'Angelo (lead)
b. Codrin Daranga
c. Amir Golalipour
d. Gerry Reinke
e. Mike Anderson
f. Bob Kluttz

20. DSR Temperature Standardization to Satisfy Laboratory Accreditation Requirements [David Anderson, Consultant]

Presentation Title: PAV Pan Warping

Summary of Presentation:
D. Anderson began this presentation by stating that reports of warped PAV pans have surfaced again although it is a long-standing issue. This issue is recognized in ASTM but not AASHTO. The pan dimensions are left-over from the TFO method. D. Anderson stated that a means for specifying and measuring allowable warping in PAV pans is needed. The pan dimensions need to be revisited. The levelness of the PAV rack may also warrant attention. The pans warp due to residual stresses created during manufacture and expansion of the pan bottom during filling.

D. Anderson stated that the levelness is important because the effect of PAV conditioning depends upon the thickness of the binder film. The aging is diffusion controlled and thus a non-linear function of thickness. The aging varies with the thickness squared.

There is a need for a method of establishing warping and levelness in PAV pans and rack. Currently, the spinning method can be used to determine warpage or the method recommended in Asphalt Institute MS-25. However, MS-25 is simple and non-qualitative and no limits are given.

The flatness check for downward bow states that after pressing on one side of the pan the opposite side should not raise by more than 0.2 mm. The flatness check for upward bow states that the inverted pan should not have more than a 0.2 mm gap at the center of the pan with a straightedge. D. Anderson stated this was ad hoc and very approximate.

D. Anderson suggested a go-no go gage that the PAV pans can be placed in to determine whether it is warped too much. If the pan touches the gage on either side or the bottom, the pan is warped too much. D. Anderson would like to manufacture a gage and test how it works.

The PAV rack levelness had requirements given in the initial version of the test method. The varying rack design complicates the measurement. For one of the PAV manufacturers, an electronic level can be used to measure the angle. It is also possible that there is warpage in the bottom of the vessel.

D. Anderson stated that tolerances based on data of aged property versus thickness should be established. D. Anderson also suggested collecting an assortment of warped pans to evaluate the effectiveness of the gage design.

<u>ETG Comments, Questions, and Discussion:</u>
Karl Zipf commented that his lab had seen warping the first time a pan was used. Zipf added that warpage is seldom symmetrical, especially for convex pans. Testing can be complicated as it is not a uniform radius across the pan.

<u>Presentation Title:</u> DSR Thermometer Validation Study

<u>Summary of Presentation:</u>
At the April 2016 Asphalt Binder ETG meeting, it was claimed that AMRL had been requiring that the Canon wafer be certified annually. The questions were raised whether this was required by AASHTO D 315 and whether it was a change in AMRL practice, and if it was necessary. The long-standing common practice was to have the reference thermometer calibrated annually. Then to use the reference thermometer or outside agency to standardize the portable thermometer (Canon wafer + CPU as a unit) every six months. The Canon wafer was used to verify the DSR thermometer every six months. As an alternative, the reference thermometer can be used to verify the DSR thermometer, although this is not recommended. The intent of this was to avoid excessive number of calibrated thermometers.

According to TAI MS-25 – portable thermometer standardization, there are specific instructions for standardizing working thermometer (silicone wafer) along with the following cautions: battery charge, heat transfer medium, equilibrium time and probe contact. Many of these are not given sufficient attention.

D. Anderson stated that AASHTO Re:source was not changing the practice but that there was misunderstanding by the inspectors. The change was a matter of interpretation of poorly worded tested methods for both AASHTO and ASTM. This has been corrected by Maria Knake. The use of the Canon wafer and reference thermometer will be allowed in the future and this is consistent with past practice. If the Canon wafer is used as the reference thermometer, then it must be calibrated with a certificate of uncertainty. AASHTO Re:source will verify the policy in communication to inspectors. Laboratories should no longer be penalized if the reference thermometer is used to verify the DSR thermometer.

21. Rheology and Use of DSR Reference Fluid [David Anderson, Consultant]

Presentation Title: Using DSR reference fluid to verify DSR

Summary of Presentation:
D. Anderson began the presentation by stating the purpose of the presentation was to review the history and intended use of the reference fluid, provide a comprehensive characterization of the reference fluid, correct some basic misunderstandings, and offer recommendations on proper use of fluid based on characteristics of the fluid and its intended use. D. Anderson stated that the Cannon Viscosity Standard is recommended.

The DSR test method was developed expecting that manufacturers would supply “calibration” fixtures. Reference fluid was suggested as an alternative in AASHTO T 315. A round robin test program was sponsored by NEAUPG in 1997. The findings of the NEAUPG round robin were to restrict use to 10 rad/s and 10% strain at 58°C and 64°C. At 58°C and 64°C the round robin test results showed a 3% difference between reference viscosities and Cox/Merx viscosities. The problem was not high viscosity but that the fluid is shear thinning. Comparison of the referenced viscosity versus the measured viscosity as a function of temperature resulted in recommended testing at 64°C. Errors become large at lower temperatures while binder flows from the plates at higher temperatures.

Measuring viscosity in the DSR, the torque must be known. Since it is impossible to verify the torque with the reference fluid, verification should be of the overall operation of the DSR. Items that might affect the accuracy of the DSR measurements using fluid include measurement temperature, fluid expiration date, heating the fluid, and improper test specimen preparation.

Reference values determined with capillary viscometer in region of Newtonian flow. The viscosity is independent of shear rate and shear rate is not given on reference fluid container. When the reference fluid is calibrated, the supplier must exercise same cautions used when DSR measurements are made such as staying in the Newtonian (linear) region and avoiding shear thinning (non-Newtonian region).

The reference fluid cannot be used to validate torque transducer and measurement at single torque level (single temperature) is sufficient.

The flow characteristics of the fluid were evaluated for self-heating and instability flow. The Reynolds number defines the relative importance of the viscous and inertial forces. The Weissenberg number defines the ratio of elastic to viscous behavior. The effect of self-heating considered whether heat generated by non-recoverable deformation cause a rise in temperature sufficient to affect measured values. The study showed that self-heating was not an issue.

D. Anderson presented the findings from the study as follows:

- Reference fluid is Newtonian within limited range and measured values are in excellent agreement with reported values.
- Reference fluid is viscoelastic in region where it is used in ASTM D7175 and AASHTO T 315.

- Measured and reported viscosities disagree when tested at 10 rad/s and within temperatures ranging from 52°C to 76°C.
- Difference between reported and measured viscosities are due to viscoelastic effects only
- Machine compliance and self-heating are non-issues.

The observations from the study showed that many factors affect values measured with the DSR. The DSR fluid measurements verify overall operation of the DSR.

D. Anderson presented the conclusions and recommendations as follows:
- Viscosity standard is useful as a reference fluid.
- Perform verification measurement at single temperature, strain and frequency.
- Reference fluid provides a known torque that allows verification of overall operation of DSR.
- Revise ASTM D7175 and AASHTO T 315 to require reference fluid viscosity as measured by DSR to be within 3% of the test variability.
- Revise ASTM D7175 and AASHTO T 315 to require standardization when measured value falls outside limits.
- Weekly reference fluid measurements should be maintained in quality control chart.
- If DSR viscosity equals reference viscosity DSR is likely working correctly and verifying that the torque transducer standardization is verified.
- If DSR viscosity differs from reference viscosity something is wrong.

ETG Comments, Questions, and Discussion:
Golalipour asked why a weekly check with the standard was recommended and if it was expected that the instrument was changing within a week. D. Anderson responded that it can help prevent the instrument from drifting.

Casola commented that the fluid should be used to check the instrument and not to calibrate the instrument. If the instrument check shows anything out of specification, the instrument needs to be checked further and evaluated by the manufacturer.

22. MSCR: National Implementation Status Update [Mike Anderson, Asphalt Institute]

Presentation Title: Implementation of the MSCR Test and Specification

Summary of Presentation:
M. Anderson began the presentation by stating that this topic was discussed during the last fall ETG meeting. The MSCR test is covered in AASHTO T 350. The PG Specification using MSCR is covered in AASHTO M 332. The draft practice of “Practice for Evaluating the Elastic Behavior of Asphalt Binders Using the MSCR Test” has been submitted to the AASHTO SOM.

M. Anderson presented the concerns, questions and challenges with the specification as follows:
- Inconsistent implementation by specifying agencies
- Grade names in AASHTO M 332

- Variability of MSCR test
- Selection of appropriate test temperature
- Leadership/champion
- Use of recovery-Jnr curve for evaluating elastic response

Some agencies are using the recovery-Jnr curve as is, while other agencies are specifying a minimum recovery 3.2 value. The recovery 3.2 becomes the determining factor.

The percent recovery should also be tied to the Jnr value for the binder. To assure the percent recovery response is primarily from the polymer network and not from just a stiffening of the base binder, the minimum percent recovery should be increased as the Jnr value of the binder decreases.

Using the recovery-Jnr curve for evaluating the elastic response showed that the lower ER values are below the curve. However, some ER values that are higher are below the curve and this is an issue. The question is if tied to Jnr, how to specify recovery. One possibility is to change to the coefficients of the curve. This can be done, but not sure that it is what should be done.

The use and relevance of the Jnr-Diff as a specification requirement is indicative of stress-sensitive binders. This is a problem for some current formulations, but not a problem for the majority of modified binders. This is caused by very low Jnr value at 0.1 and much higher Jnr value at 3.2.

The AMRL proficiency data showed higher recovery with higher ER. The data showed that as Jnr-Diff begins to increase, the values fall further from the projected line.

Next M. Anderson presented the use and relevance of Jnr-Diff as a specification requirement. The experiment included a standard 9.5 mm NMAS mixture using 5.4% AC with lose mix conditioning for 4 hours at 135°C. The specimens were tested using the AMPT Flow Number test. The results showed that for the recovered binder, the PG 65 recovery was dropping off faster. The Jnr-Diff plot showed that temperature matters for the Jnr-Diff. Binder A showed the Jnr-Diff at 52°C and 54°C were below 60% but jumped to 85% and 171% for 58°C and 64°C, respectively. Jnr at 3.2 was added to the Jnr-Diff plot. This showed that all materials for binder A were below 0.5 and the Jnr-Diff requirement could be waived. For binder C, although the Jnr – 3.2 goes above 0.5, it is still below the Jnr criteria.

M. Anderson presented that the proposal to AASHTO SOM Tech Section 2b was that if Jnr-3.2 was less than or equal to 0.5 kPa^{-1}, then the Jnr-Diff requirement is waived.

Analysis of the 2015 PCCAS MSCR Task Group data showed that all failed the Jnr-Diff but this was done at PG testing temperature. However, seven of the ten have Jnr-3.2 values less than 0.5. When the test temperature was dropped 6 degrees, many of the binders had Jnr-Diff less than the 75% criteria. Of the binders that were not below the 75% criteria, there was only one binder that did not get waived by having Jnr-3.2 less than 0.5 kPa^{-1}.

The takeaways from the study was that testing at the proper temperature matters and guidance needs to be given of what the temperature should be.

23. Summary of Action Items

Action Items:
Action Item #201609-1. A new Task Force created on GTR Testing Standard Development with goal to develop a draft provisional AASHTO test standard using the Concentric Cylinder (cup & bob) geometry. Members include:

Matthew Corrigan (lead)
Codrin Daranga
John D'Angelo
John Casola (Malvern)
Bharath Rajaram (TA Instrument)
Darin Hunter (Anton Paar)
Amir Golalipour
Joe DeVol
Zia Alavi (UCDavis))
Additional State DOT's will be identified as participants

Action Item #201609-2. Tom Bennert will report on NJ field evaluation data on HPTO mixtures at next ETG meeting.

Action Item #201609-3. ETG members will review and provide comments on MSCR proficiency sample data concerns presented by AASHTO Resource (formerly AMRL) directly to John Malusky (AASHTO Resource) and cc: Matthew Corrigan (FHWA) and Mike Anderson (AI).

Action Item #201609-4. Dave Anderson will send the three finalized 4 mm DSR documents to Corrigan for distribution and comment by ETG; and will finalize a written report documenting the Task Group efforts prior to the next ETG meeting.

Action Item #201609-5. Dave Anderson will finalize a written report documenting the PAV Degassing Task Group work prior to the next ETG meeting.

Action Item #201609-6. Pavel Kriz will report ongoing work by the newly formed Asphalt Institute PAV DSR Task Group at the next ETG meeting. ETG members and friends interested in supporting AI's Task Group efforts are:

a. Peter Moore
b. Joe DeVol
c. Karl Zipf
d. Pamela Marks
e. Tanya Nash
f. Dave Anderson
g. Geoff Rowe

h. Codrin Daranga

Action Item #201609-7. Geoff Rowe will finalize the REOB white paper recommendations and address any ETG comments by mid October 2016.

Action Item #201609-8. A new Task Force was created to investigate a solution addressing low $J_{nr\ diff}$ results utilizing MSCR. Members include:

a. John D'Angelo (lead)
b. Codrin Daranga
c. Amir Golalipour
d. Gerry Reinke
e. Mike Anderson
f. Bob Kluttz

24. New Version of LTPPBind

Corrigan stated beta testing of the LTPPBind software was underway and asked the ETG for feedback. Corrigan sent out documents to the ETG last week. LTPP has also asked for feedback regarding the interest of pursuing mobile applications for the software with a focus on an improved graphical user interface.

ETG Comments, Questions, and Discussion:
D'Angelo stated that he liked the software overall online but questioned the applicability of having a mobile application although it could be nice to have.

Corrigan stated that there is an increasing use of LTPPBind to determine the test temperatures for an array of testing protocols. From this perspective, there could be a need for a mobile application.

Reinke stated that it would not be useful on a phone but iPads and tablets are becoming more prevalent tools and it may make sense to have an application for those devices.

Marks stated that although she does not know where they will be in a few years, the agency does not want others specifying the test temperatures and they have computers.

Hazlett stated that in Texas, decisions are made on a regional basis and not by individual users. Although this may change with time, it is likely that this will still be specified by policy.

DeVol stated that he did not understand the need from a pavement designer perspective for a mobile application and did not think that it was practical.

Scott asked whether development of a mobile based website instead of a mobile application would be more efficient.

Rowe stated that the software is good for a computer but was unnecessary for a tablet or phone.

25. Next Meeting Location and Date

The next meeting date will be coordinated with the Mixture ETG. Members were asked to consider the weeks of April 24, 2016 and May 1, 2016.

26. Meeting Adjournment

M. Anderson and Corrigan thanked all attendees for their participation on the ETG and attending the meeting. The meeting was adjourned at 4:45 PM.

ATTACHMENT A – AGENDA

Asphalt Binder Expert Task Group
Fall River, MA
September 12-13, 2016
Meeting Agenda – Final

DAY 1: Monday, September 12, 2016

1:00 pm	Welcome and Introductions	**Baumgardner/M. Anderson**
1:10 pm	Review Agenda, Minutes & Action Items	**Corrigan**
1:15 pm	NCHRP 09-59: Relating Asphalt Binder Fatigue Properties to Asphalt Mixture Fatigue Performance	**D. Christensen**
2:00 pm	Update: GTR: Field Project Experience and Lessons Learned	**Golalipour**
2:30 pm	**Break (30 minutes)**	
3:00 pm	GTR: Practical Consideration for Cylinder System Measurements	**D. Hunter**
	GTR: ETG *discussion on draft AASHTO PG Binder Standard utilizing concentric cylinder geometry (cup and bob)*	
4:15 pm	Binder Fracture Energy (BFE) Test, and Using BFE Testing to Evaluate GTR Modified Binders	**Roque**
5:00 pm	**Adjourn for the Day**	

DAY 2 – Tuesday, September 13, 2016

8:00 am	Micro-Mechanical Evaluation of the Interaction between RAS Dry Process Crumb Rubber Modified Asphalt	**L. Mohammad**
8:30 am	Impact of Long Term Aging on RAS Binder Properties	**A. Hanz**
9:00 am	Update: PAV Degassing Issues, and Update: 4 mm DSR Testing	**D. Anderson**
9:45 am	MSCR vs AASHTO M320 – High Temperature	**Bennert**
10:15 am	**Break (30 minutes)**	

DAY 2 (continued) – Tuesday, September 13, 2016

10:45 am	Update: MSCR: Evaluation of MSCR Data in The AMRL Proficiency Sample Program (PSP), and	**Malusky/M. Anderson**
	MSCR: National Implementation Status Update	**M. Anderson**
11:30 am	Improvements to DSR-PAV Test Method	**Kriz**
Noon	**Lunch Break**	
1:00 pm	Update: Binder ETG – REOB Task Force Final REOB White Paper recommendations; relevance and use of ΔT_c	**Rowe**
1:30 pm	IS-235 – "State-of-the-Knowledge, The Use of REOB/VTAE in Asphalt"	**M. Anderson**
2:00 pm	∆Tc TFHRC Research	**Youtcheff/Arnold**
2:30 pm	**Break (30 minutes)**	
3:00 pm	Update: Binder ETG – Binder Ageing Concerns Task Force Proposed future direction of the Task Force	**D'Angelo**
3:30 pm	DSR Temperature Standardization to Satisfy Laboratory Accreditation Requirements	**Casola/D. Anderson**
4:15 pm	Rheology and Use of DSR Reference Fluid	**D. Anderson/Casola**
4:45 pm	Summary of Action Items New version of LTPPBind Schedule Next Meeting	**Baumgardner/Corrigan**
5:00 pm	**Adjourn**	

ATTACHMENT B – ETG MEMBER LIST

FHWA Asphalt Binder Expert Task Group Members

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ATTACHMENT C – TASK FORCE MEMBERS AND ASSIGNMENTS

Task Force Members and Assignments
FHWA Asphalt Binder ETG

Task Force Identification:		Members Assigned to Force:
1	REOB	Geoff Rowe (Lead): Bill Ahearn, Imad Al-Qadi, Dave Anderson, Thomas Bennert, Mark Buncher, Matthew Corrigan, John D'Angelo, Nelson Gibson, Pamela Marks, Louay Mohammad, Walaa Mogawer, Jean-Pascal Planche, Gerry Reinke, and Laci Tiarks-Martin
2	Binder Aging Concern	John D'Angelo (Lead): David Anderson, Darren Hazlett, Jean-Pascal Planche, Bob Klutz, and Geoff Rowe