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 65 individuals attended the meeting (16 members, 2 contract personnel, and 47 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.

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

Members of the ETG not in attendance:
R. Michael Anderson, Asphalt Institute (Co-Chairman)
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 in attendance included:
John Casola, Malvern
Ervin Dukatz, Mathy Construction Company
Bob Kluttz, Kraton Polymers
Ramon Bonaquist, Advanced Asphalt Technologies
Stacy Glidden, Payne and Dolan
CJ DuBois, DuPont
Kevin Carlson, Jebro
Bharath Rajaram, TA Instruments

Lorena Garcia Gucalon, TAMRO
Codrin Daranga, Ergon
Dennis Muncy, Ingevity Pavement Technologies
Jeff Shoger, Flint Hills Resources
Cassie Castorena, North Carolina State University
Dave Mensching, FHWA
Ann Baranov, InfraTest USA
Dan Staebell, Asphalt Pavement Alliance (APA)
Dennis Bachman, FHWA – Illinois
Brian Pfeifer, Illinois DOT
David Jones, UCPRC
Richard Duval, FHWA
Thomas Ludlum, Holly Frontier
Punith Shiraprasad, Shell Bitumen
Tim Aschenbrener, FHWA
Mike Hemsley, Paragon Technical Services
Shihui Shen, Penn State University – Altoona
Larry Larson, ICL
Al Palmer, Kleen Performance Products
Doug Zuberer, Zydex
Darin Hunter, Anton Paar USA
Joseph Podolsky, Iowa State University
Benjamin Roujolle, Colas Solutions
Tien Dao, Cannon Instrument
Andy Cascione, Flint Hills Resources
Jason Bausano, Ingevity
David Porter, Payne and Dolan
Lisa McDaniel, FHWA - Iowa Division Office
Mark Homer, AJAX Paving
Salman Hakimzadeh, Reliable Asphalt Corporation
Hassan Tabatabaee, Cargill
Jack Youtcheff, FHWA
Chris Wagner, FHWA
Pavel Kriz, Imperial Oil/ExxonMobil
Andrew Hanz, Mathy Construction
Frank Fee, Frank Fee, LLC
Kevin VanFrank, CMRTG
Howard J. Anderson, Utah DOT
Rebecca McDaniel, North Central Superpave Center

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

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DAY 1: Wednesday, May 3, 2017

1. Call to Order

Gaylon Baumgardner called the meeting to order at 8:00 AM.

2. Welcome and Introductions

Matthew Corrigan welcomed everyone to the meeting and asked everyone to introduce themselves. Corrigan acknowledged Chris Williams for hosting the ETG meeting. Williams welcomed everyone to Ames and Iowa State University.

3. Review Agenda/Minutes Approval & Action Items, April 2016 Meeting [Amir Gol]

Corrigan noted that the technical report from the last meeting was distributed to members.

Corrigan stated that the Action Items from the September 2016 Asphalt ETG meeting are included on the agenda for this meeting. The following is a listing and status of the Action Items from the last meeting.

- Action Item #201609-1. A new Task Force created on ground tire rubber (GTR) Testing Standard Development with the objective 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)
  - Darin Hunter (Anton Paar)
  - Amir Golalipour
  - Joe DeVol
  - Either David Jones or Zia Alavi (UCDavis) (potential)
  - Additional State DOTs will be identified as participants (potential – Caltrans, PA, FL)

  Update: Item is on the agenda.

- Action Item #201609-2. Tom Bennert will report on NJ field evaluation data on high performance thin overlay (HPTO) mixtures at next ETG meeting.

  Update: This item will be moved forward to the next meeting as Bennert was unable to attend.

- Action Item #201609-3. ETG members will review and provide comments on multi-stress creep and recovery (MSCR) proficiency sample data concerns presented by AASHTO re:source (formerly AASHTO Materials Reference Library (AMRL)) directly

to John Malusky (AASHTO re:source) and cc: Matthew Corrigan (FHWA) and Mike Anderson (AI).
Update: Item is on the agenda.

- Action Item #201609-4. Dave Anderson will send the three finalized 4 mm dynamic shear rheometer (DSR) documents to Corrigan for distribution and comment by the ETG and will finalize a written report documenting the Task Group efforts prior to the next ETG meeting.
  Update: Item is on the agenda.

- Action Item #201609-5. Dave Anderson will finalize a written report documenting the pressure aging vessel (PAV) Degassing Task Group work prior to the next ETG meeting.
  Update: Item is on the agenda.

- 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:
  - Peter Moore
  - Joe DeVol
  - Karl Zipf
  - Pamela Marks
  - Tanya Nash
  - Dave Anderson
  - Geoff Rowe
  - Codrin Daranga

  Update: Item is on the agenda.

- Action Item #201609-7. Geoff Rowe will finalize the re-refined engine oil bottoms (REOB) white paper recommendations and address any ETG comments by mid October 2016.
  Update: Item is on the agenda.

- Action Item #201609-8. A new Task Force was created to investigate a global solution addressing low $J_{nr\ diff}$ results utilizing MSCR. Members include:
  - John D'Angelo (lead)
  - Codrin Daranga
  - Amir Golalipour
  - Gerry Reinke
  - Mike Anderson
  - Bob Kluttz

  Update: Item is on the agenda.

4. GTR: Binder ETG – DSR Concentric Cylinder Task Force [Amir Golalipour, ESC, Inc.]

Presentation Title: Ground Tire Rubber: ETG – DSR Concentric Cylinder Task Force

Summary of Presentation:
Golalipour began the presentation by acknowledging the task force members. The task force was created on GTR modified asphalt testing standard development with a goal to develop a draft provisional AASHTO standard using the concentric cylinder geometry (cup and bob). The work items for the task force included geometry fixture and details (cup and bob size, and temperature control), equilibrium time needed for concentric cylinder geometry, calibration of concentric cylinder for controlled shear stress (CSS) and controlled shear rate (CSR) factors, and draft of a standard.

A questionnaire was distributed to DSR vendors. The results showed that the concentric cylinder geometry is based on DIN EN 1302 and ISO 3219 standards. The range of ratio of cup radius over bob radius was 1 to 2. If the ratio is above 1.085, it is a relative measurement as the shear distribution is non-linear and requires further analysis. The amount of material needed for testing is 20-30 ml and Peltier technology is used for the heating and cooling system. A temperature calibration kit is available. Procedures used to calibrate and verify the geometry vary by vendor and include the Cannon standard and FE simulations using oil/binder sample only to verify.

The equilibrium time is important and the entire sample should be at the same temperature. A document prepared by David Anderson was shared with the ETG members. Three labs participated in testing a few binders following the provided procedures for equilibrium time. Determination of criterion for specimen thermal equilibrium (C_{se}) is based on the difference in modulus from the average. When the C_{se} is less than or equal to 1.0 percent the specimen is in equilibrium. The wait time is equal to the time to specimen thermal equilibrium plus two minutes where the added two minutes may be considered a cushion, or a factor of safety.

Golalipour presented an example graph for an original binder where the soaking time was 28 minutes and the time to equilibrium was 21 minutes. The rolling thin film oven (RTFO) aged binder had a soaking time of 24 minutes and an equilibrium time of 18 minutes. Golalipour presented a second example of a binder containing rubber. With this sample, it took longer to reach testing temperature but once reached, the time to equilibrium was 12 minutes for original binder and 14 minutes for RTFO aged binder. The soak times were 24 and 29 minutes for original and RTFO aged binders, respectively. Golalipour presented a summary of the results based on five binders tested in three laboratories. For original binder, the total soaking time was 20 to 30 minutes with a conservative equilibrium time selected as 30 minutes. For RTFO aged binders, the total soaking time was 18 to 30 minutes with a conservative equilibrium time selected as 30 minutes.

The objective of the calibration of concentric cylinders was validation of geometry factors (CSS and CSR). All of the asphalt binder DSR manufacturer were represented and provided suggestions. Preliminary testing was conducted on unmodified PG 64-XX and one modified binder (either polymer or terminal blend rubber-modified) with PG 64-XX or PG 70-XX grade.

Testing was conducted using both concentric cylinder and parallel plates (25-mm) with 1.0-mm gap setting. The testing results of the concentric cylinder and parallel plates on neat, original binder showed the same performance grade (PG) with percent differences ranging between 0.5 to 8 percent. Similar results were observed at multiple temperatures. Results for neat binder, RTFO aged, showed the same PG grade and similar results overall with percent differences between 0.5 and 9.5 percent. The phase angle differences were less than 5 percent. No significant differences were observed between the two geometries. Factors contributing to some of the differences include trimming, edge effects in parallel plates, and CSS and CSR factors.

The next action is to provide a highly polymer modified binder to all participating laboratories by UC-Davis. Frequency sweep testing will be conducted using both concentric cylinder and parallel plates (25-mm) with 1.0 mm gap setting with frequencies ranging from 0.01 to 10 Hz. The list of measured frequencies must have 1.59 Hz (10 rad/sec). Testing should be performed at 46 ºC, 58 ºC and 70 ºC. The rheological parameters such as R-value, cross over frequency, etc. will be compared.

The goal of the task force is to develop a draft of a standard. A draft of the standard: Determining the Rheological Properties of Asphalt Binder Containing Ground Tire Rubber Particulates Using Concentric Cylinder Geometry in the Dynamic Shear Rheometer (DSR), has been created and refinement is ongoing. The draft is being distributed within the task force. Golalipour presented topics of discussion including the title and temperature range.

Action Item #201705-1. Matthew Corrigan will distribute a draft of the provisional test standard using concentric cylinder geometry for comments. The goal is to have a draft standard to Lyndi Blackburn for the AASHTO SOM.

ETG Comments, Questions, and Discussion:
Williams asked how Einstein's equation for suspended solids was verified to show that the material is behaving as a Newtonian liquid since rubber swells and asked if the amount of swell in rubber was measured. Golalipour agreed that rubber swells; however, Golalipour stated that is a part that should be graded. Williams responded that with rubber, it is looking at the polymer of rubber to asphalt. John D'Angelo agreed that it is a non-Newtonian fluid but that how the rubber particles act is important as they are flexible and move. He also mentioned that the rubber particles have a different effect on the mixture and that it is not a true measure of the modulus of a liquid but more of mastic to evaluate what is happening in the mixture. Williams asked if anyone had done microscopy. D'Angelo responded that it is hard to do microscopy, but they had looked at multiple sizes of rubber to evaluate the swelling and interaction with both concentric cylinder and parallel plates. For an 80-mesh material with swell in general range, uniform results can be obtained. Williams asked how the assumptions were checked?

John Casola commented that those factors apply but the effects of particles are significantly higher at mixing temperatures and these temperatures are lower than mix temperatures. Therefore, the effect is significantly less.

Geoff Rowe commented to consider a stiffness range to conduct the test instead of a temperature range for developing the standard. Golalipour responded the standard has a stiffness range as well, but it was challenging as there are different types of material supplied across the country to develop a range that encompasses all possible combinations of materials.

D. Anderson asked during thermal equilibrium if shearing was continuous and whether the reference fluid with time, as well as binder, was considered. Anderson stated that he was concerned with the structural change with the rubber (or mastic) and asked whether it was cooled up or down. Golalipour responded if the material is cooled up and then down, more thermal strain is added. D'Angelo responded that it has been done by Ergon and California. Anderson responded that it should be independent of ramp up or ramp down.

Gerry Reinke commented the implication is that the rubber in a concentric cylinder is reacting but that the reaction has already happened and it is not going to happen during the test. Reinke asked how much thermal aging would occur at 70-90 ºC for that short period of time?.

Bob commented that tire rubber and asphalt is a two-phase system and is temperature dependent. When the temperature is changed, the properties are also changed.

Chris Wagner asked if any correlation between the cup and bob and the Brookfield Viscometer had been tested similar to that of the parallel plate and concentric cylinder?. Golalipour responded the parallel plate is more accurate than viscosity with the rotational viscometer (RV) and that it was out of the scope for the project as it related more to how the RV is performing.

It was asked if the size of the rubber was measured. Golalipour responded 20 mesh rubber was used as it is the largest size used. It was asked if the gap in the cup and bob would be changed. Golalipour responded that the gap size from the cup wall to the surface of the wall is sufficient for the typical range of rubber particle sizes used even if the rubber swells.

5. **GTR: UC Davis/CalTrans Research, Findings, Recommendations and Implementation [David Jones, University of California Pavement Research Center, Davis.]**

<u>Presentation Title:</u> Development of Asphalt Rubber Binder Specifications in California: Project Update

<u>Summary of Presentation:</u>
Jones began the presentation by acknowledging Zia Alavi's efforts on conducting the study and also acknowledge CalTrans for funding the project. Jones stated the presentation would be an update of the one given at the September 2014 ETG meeting. Jones recapped the use of asphalt rubber in California stating that AB338 (2005) requires Caltrans to use asphalt rubber in at least 35 percent of all asphalt concrete (AC) placed. Terminal blend rubber binder is considered in the PG-M specification. Caltrans mandated in 2015 that all surface courses placed below 3,000 ft. require asphalt rubber mixes. Previously, Jones presented the Phase 1 study that compared the concentric cylinder with parallel plate on laboratory-produced AR binders. The concern was the ratio between the rubber particles size and gap influencing the result considering a ratio of 1 to 3 or 1 to 4. The plate gap was 1 mm or 2 mm depending on the particle size. Testing on 3mm and 4mm gaps were limited due to trimming and slump issues. A plot comparing the $G^*/\sin\delta$ for

concentric cylinder and parallel plate showed that as the rubber sizes increased, the correlation worsened.

Jones presented the background for Phase 2 of the study which focuses on plant-produced binders and mix. AR binders were tested with 3mm gap on 25-mm and 8-mm plates. Conventional binders were tested with 1-mm gap on 25-mm plates and 2-mm gap on 8-mm plates. Mix testing was conducted to interpret rheological properties. Parallel studies included a Caltrans/industry task group study on 3-mm parallel plate gap and round robin testing by 16 laboratories. The task force group report is in preparation. Caltrans will then decide which approach to use.

The Phase 2 experimental plan includes five AR binder sources, five AR mixes (beam fatigue, semi-circular bend (SCB), dynamic modulus, flow number and thermal stress restrained specimen test (TSRST)), two PM binders, and two TR binders.

The temperature when the crumb rubber modifier (CRM) was added to the asphalt binder plus extender oil was 375 ºF to 440 ºF. The mix production temperature was 375 ºF and 425 ºF. Conventional mixes are typically between 290 ºF and 320 ºF. The current RTFO testing temperature (163 ºC) is based on short-term aging of unmodified binders with no particulates. The current RTFO test method was not considered appropriate for the studies AR binders because aging temperature does not simulate AR binder temperature during mix production, aging of the AR binder is non-uniform due to incomplete coating of the bottles, and quantity of binder available after aging is often insufficient for both DSR and bending beam rheometer (BBR) testing.

Jones presented the proposed changes to the RTFO test method including a temperature of 190 ºC and increasing the sample size to 25 grams of the base binder (e.g., 45 grams of AR binder with 20 percent CRM). The results showed poor coating of the bottle at 163 ºC and 35 grams. Better coating was observed at 190 ºC and 35 grams; however, this does not result in a large enough binder sample for testing. Aging at 190 ºC with 45 grams resulted in good coating, good distribution of particles and enough binder was produced for testing.

Comparison of the G*/sinδ for the various aging methods for various binders (base binder, base binder with extender oil, 60 mesh, 8 mesh and Caltrans spec (T2-8)) showed a jump in G*/sinδ resulting in a PG grade bump. This is expected because that is what the mixes are being produced at. The difference between the volume was small.

The key findings from the phase were presented as follows:

- Conditioning at 163 °C does not appear to be appropriate for AR binders due to poor bottle coating; conditioning at 190 °C considered to be more representative.
- Higher binder stiffnesses at 190 °C, as expected (increased high PG temperature by up to 9 °C).
- Larger sample volume did not significantly affect results, but did help for DSR/BBR material quantity requirements (can be adjusted to suit).
- No spillage noted with 45-gram sample (oven was not tilted).

The recommendation is dependent on the remaining tests, but will likely suggest RTFO test at 190 °C.

High temperature tests considered the testing geometry (concentric cylinder with a 17-mm bob and a 6-mm gap), test methods (binder viscosity, PG grade, MSCR test, frequency sweep test) and both original and short-term aged binders. The results of the concentric cylinder and parallel plates showed differences, as expected on two out of five samples. The difference and variability depend on the rubber particle size. No recommendation is made until the binder and mixture testing is completed.

Intermediate temperature tests used a modified concentric cylinder geometry based on a study with Anton Paar where a 10-mm diameter spindle was used. Testing was performed on RTFO plus PAV aged binder. Comparison of the concentric cylinder and parallel plate on all binders tested showed possible shrinkage or confinement in concentric cylinder and possible trimming effects in parallel plate. Further testing is required before conclusions can be drawn but refinement of the test method may be required. No recommendation is made until binder and mixture testing are completed.

Jones presented the low temperature test modifications of using a modified bending beam rheometer (BBR) mold to remedy issues associated with pouring the AR binder and preparing a uniformly shaped BBR test specimen beam. The low temperature tests used the revised RTFO test method. The modified BBR beam was easier to extract from the mold, produces better quality specimens than the conventional mold and results appear to be realistic. The likely recommendation is to consider modified molds for AR binders.

The path forward for the project includes the following:

- Complete testing of plant-produced AR binders and mixes (3 complete, 2 in progress)
- Compare performance-related properties of mixes with rheological properties of their corresponding binders (3 complete, 2 in progress)
- Evaluate PG grading criteria for AR binders
- Report, provisional test methods, interpretation, and suggested specification language (Sept. 2017)

<u>ETG Comments, Questions, and Discussion:</u>
Casola asked if a vibratory surface had been considered for pouring the conventional BBR mold. Jones responded that they had tried that but it was still difficult. D'Angelo commented that using the modified BBR mold for testing with rubber showed improvement in low temperature properties.

Rowe asked whether a note should be included for the standard on pouring BBR specimens stating the conventional mold does not work with certain materials (e.g., rubber)? Jones agreed.

Darren Hazlett asked whether producing mixes at 375 ºF was allowed with air pollution permits at production locations? Jones responded there have been some problems and limit the amount of time the rubber can be added; or warm-mix asphalt (WMA) is used to reduce the production temperature.

Kluttz asked if the flash point limit was increased since the mixing temperature was increased to 225 ºC and that AASHTO M 320 has a flash point limit. Jones responded that he would have to check on that. Kluttz responded that it is a safety concern .

It was asked how mix design with AR binders was done and what binder volume was used. Jones responded they use a combined binder and typically use about 8 percent binder content.

D. Anderson asked about the repeatability with the modified BBR beam and asked if they had tried flipping the beam? Jones responded that they are still testing the beam per the standard required geometry but they are only pouring the AR binder into the mold in the wide side of the mold rather than the narrow side. Anderson asked if the thickness was reduced. Jones responded that they are not changing the beam and it is the same size beam and the test is performed the same. The modified mold filling procedure produces more repeatable beams. Anderson commented that it may be more repeatable but not more accurate. Jones responded that excess binder is trimmed from the top and that they feel confident about the beam. Rowe commented that checks such as weight could be implemented to check the beam. Jones responded that they did many tests and there was good consistency.

Baumgardner commented that they have had poor results with both beams, but the flat beam pouring procedure resulted in a better result.

Action Item #201705-2. Dave Jones will provide recommendations from the GTR study with Caltrans and the 2017 Final Report. Dave Jones to provide an update at the next ETG meeting.

6. NCHRP 20-07 Task 400: Effect of Elevation on RTFO Aging of Asphalt Binders [Ramon Bonaquist, Advanced Asphalt Technologies, LLC]

Presentation Title: NCHRP Project 20-07/Task 400 Effect of Elevation on Rolling Thin Film Oven Aging of Asphalt Binder

Summary of Presentation:
Bonaquist began the presentation by acknowledging those that had helped with the project including Dave Anderson, Jim Rosenberger, Gayle King, John Malusky, Shauna Teclemariam and the volunteer laboratories. The objectives of the project were to confirm or refute previous studies showing an elevation effect in properties of RTFO residue and if there is an effect and it is of engineering significance then to improve the AASHTO T 240 procedure to minimize differences in physical properties of RTFO residue obtained at different elevations. The approach was to perform a statistical and engineering analysis of available data – Western Cooperative Testing Group (WCTG) and AASHTO re:source proficiency sample; select a method to minimize the elevation effect; design, execute and analyze an experiment to confirm viability of the selected method and to prepare documentation of recommended modification to AASHTO T 240 and a report. The WCTG observations are a good range of elevations that were uniformly distributed (12 to 6,720 ft.). The AASHTO re:source data consisted of four binders (two neat and two modified), 213 laboratories (two replicates), 1700 observations and an elevation range of 0

to 6,295 ft. but with 68 percent of the laboratories below 1,000 ft. The statistical analysis considered the original G*/sinδ, RTFOT G*/sinδ, aging index, $J_{nr3.2}$, $R_{3.2}$ and mass change. The statistical analysis approach developed by Rosenberger assembled the data, included a graphical analysis with systematic identification of outliers followed by a final regression analysis. An initial regression analysis as a function of elevation allowing binder dependent slopes and intercepts identified outliers as data having standardized residuals exceeding plus or minus 2.5.

The WCTG binder data showed there is no elevation effect for the original binder and that there is a decrease in G*/sinδ as elevation increases for RTFOT. The J_{nr} increases with increasing elevation. The mass change data was noisier. The AASHTO re:source data was weighted more toward lower elevations. There was again a decreasing trend of G*/sinδ, increasing J_{nr}, decreasing mass change and decreasing recovery with increasing elevation. Bonaquist stated this was not binder specific and the entire data set was used for the analysis. The slope and intercept changed as a function of binder type.

Bonaquist summarized G*/sinδ are significantly different by binder type, the mass change has higher variability and a binder effect was not found. For the two data sets, the slopes differed by almost a factor of 6 to 8 based on the binder type. Thus, Bonaquist stated one correction factor for elevation would not work.

Bonaquist next presented the engineering significance of the difference in G*/sinδ as a function of elevation showed up to a 35 percent difference and noted for more sensitive binders, this is of engineering significance. The engineering significance of J_{nr} showed that the least sensitive binders had a difference of 5 percent while more sensitive binders had a difference of about 30 percent which shows that it is both statistically and engineering significant.

The options to address these differences include modifying the RTFOT to condition at a constant pressure, relate elevation effect to other measured binder properties, vary RTFOT temperature with elevation or vary RTFOT time with elevation. Bonaquist stated that modifying the RTFO equipment would be expensive and therefore likely not a viable option. As a result, the relation of elevation to other binder properties was considered. The G*/sinδ elevation effect was a significant function of the viscosity of the binder where higher viscosity binders had less of an elevation effect but lower viscosity binders had a significantly higher slope. However, this relationship was a best fit line and looking at the data, this did not remove the elevation effect and significant differences were still observed.

Therefore, varying the RTFOT temperature and time with elevation were considered viable options. The effect of time on RTFO residue properties was assessed. The RTFO conditioning time was extended (by 10, 20 and 30 minutes) to estimate the required times for various elevations required based on the effect of G*/sinδ, J_{nr}, mass change and percent recovery. For the range of time being considered, the relationships were fairly linear. The relationships showed that as time increased, G*/sinδ increased, J_{nr} decreased, mass change decreased and percent recovery increased. As a result, it is possible using this type of data to counteract the elevation. The change in G*/sinδ or J_{nr} as a function of time and elevation graph shows a linear relationship of 1.6 minutes/1,000 feet of elevation for four binders tested. This was done to get a range of time that laboratories in the experimental design would be asked to condition RTFO residue at different elevations.

Bonaquist presented the estimate of additional RTFOT conditioning time table based on elevation. An 11-minute change in conditioning time is required for 7,000 feet elevation, which is reasonable.

The next step is to complete the experimental design to confirm or improve the additional time estimate. There will be 24 laboratories in eight different elevation ranges (0 to 2,500 ft., 2,500 to 5,000 ft., and greater than 5,000 ft.), eight binders including neat and modified, two RTFOT conditioning times, and four responses measured ($G^*/\sin\delta$, J_{nr}, mass change and percent recovery).

Bonaquist asked for volunteers for conditioning of four binders at 85 and 115 minutes. The volunteers would measure the mass change and then return the residue to Bonaquist so that all rheological testing will be conducted at one location. It was estimated that this would require about 16 man-hours. Suggestions for binders to use up to eight binders (both neat and modified) should be sent to Bonaquist.

<u>ETG Comments, Questions, and Discussion:</u>
Kevin Van Frank commented this was trying to standardize laboratories so that laboratories [at higher elevations] did not fail AASHTO re:source accreditation. However, RTFO is to simulate the aging in the plant and that laboratories are measuring in the same altitude as the plant. Therefore, it would be better to adjust the results of the laboratory to standardize for AASHTO re:source than to adjust the procedure to correct to sea level. Bonaquist stated it was an excellent question and stating that if the goal was to remove the elevation effect from proficiency data, that is easily done through statistical analysis of data. However, the issue is when producing asphalt at one location and using asphalt at another location and there being a difference in the acceptance due to the elevation. Bonaquist stated these are not mutually exclusive.

D. Anderson commented this affects the PAV test results as well and there is more significant than only RTFO. Bonaquist agreed and stated as you go further down the line, the variability is going to mask the effect being studied. This study is looking at the best way to address elevation effect for the RTFO.

Buncher commented the RTFO simulated the aging during mixing and compaction and the effect of elevation occurs at the plant where it is produced. Buncher asked if the approach of extending time based on elevation addressed the binder dependency from 5 to 35 percent and how that was considered. Bonaquist responded that he could not look at that with this data as it was the change in $G^*/\sin\delta$ for four binders, but he is not sure whether the additional time will narrow the spread of the data for a wider range of binders as it did for the four binders tested. Binders that are more sensitive are more sensitive to elevation effect and whether this attenuates the noise enough will need to be determined through the experiment.

Jack Youtcheff asked what binders were being used in the experiment. Bonaquist responded the binders had not been selected yet but that a wide range of binders was desired.

Gerry Reinke asked if stratification based on mass loss was considered since there is more of an elevation effect with greater mass loss. Bonaquist replied that it was considered; however, the mass change did not relate well to the slope of the elevation effect. Mass change as a function of elevation is noisier and more variable, and the binder type does not have an effect (i.e., the binder slope was not statistically different). Reinke asked if for a softer, less stiff binder there was a way to stratify between -34 ºC and -16 ºC grades. Bonaquist responded that he did not look at those other than for the original binder because there is an elevation effect in all data that is collected. Bonaquist stated that they could go back and look into this and asked if there was anything else that they could do? Reinke asked if viscosity was performed at 135 ºC. Bonaquist confirmed that the data were collected as part of the normal certification (yes). Bonaquist stated they are trying to see if there is a way to improve the difference seen between laboratories.

D. Anderson commented there is mass change due to both oxidation and volatilization and it is unknown which one is taking place. It was thought that mass change would be a good indicator but it is complicated and it is binder dependent. Gayle King responded that volatilization happened quickly in the process and that by the end of oxidation the volatiles were gone. King stated it is a different trend than what he expected and it is dependent on the binder. The oxidation is overcoming the volatilization. D. Anderson responded there was a big difference between the volatiles found between different source binders. The difference between the two is release of the water versus hydrocarbons.

Frank Fee asked if the AASHTO re:source data could be stratified by elevation. Bonaquist responded if the goal is to grade laboratories, once the proficiency data is collected, a regression can be used to correct for elevation to a common elevation. Bonaquist stated this is an easy solution for grading laboratories but the harder solution is for a manufacturer making binder at sea level and selling at a higher elevation.

Van Frank commented that the laboratories they contract with are remote and at different elevations. As a result, producers in Utah have to boost G* more so that the elevation difference does not have an effect. Pavel Kriz responded that they have encountered this across the country and that the effect may not only be elevation but also humidity as well. Asphalt in different locations have different aging factors. Baumgardner agreed with Kriz stating that when producing the materials, it is unknown where it will be shipped and how to test the material.

D'Angelo commented RTFO aging for simulating short-term aging is only a simulation but where this effect creates an issue is with buy-sell specifications. Marks commented that high elevation production locations often have long hauls from the plant and as a result overheat at the plant in order to have the correct temperature for placement.

Bruce Morgenstern echoed what others had said; and in Wyoming, the laboratory in Cheyenne is at a higher elevation than the rest of the laboratories in the State. This can cost money if producers send a sample for testing and the elevation causes it to not be acceptable.

Kluttz commented if offset is developed for RTFO then an offset should be developed for PAV. Bonaquist agreed that other tests should consider this effect.

J. P. Planche asked how big of a difference there was in continuous grade. Bonaquist responded that he would perform calculations to see how a continuous grade would be graded, assuming it was RTFOT controlled.

Rowe commented binders that age at different rates should be used. Bonaquist agreed and stated that King will help selecting the potential sources.

Action Item #201705-3. Ray Bonaquist is soliciting volunteer laboratories for the NCHRP 20-07/Task 400. Those interested should reach out to Ray Bonaquist with contact information. Bonaquist to provide an update at the next ETG meeting.

To date, volunteers include:

- Bruce Morgenstern, Wyoming DOT
- Lyndi Blackburn, Alabama DOT
- Howard Anderson, Utah DOT
- Andrew Hanz, Mathy Construction Company
- Benjamin Roujolle, Colas
- Codrin Daranga, Ergon
- Joseph Devol, Washington DOT
- Flint Hills Resources
- PRI Asphalt
- Marathon
- Asphalt Liquids
- Kevin Carlson, Jebro
- Hassan Tabatabaee, Cargill

7. PAV DSR: Precision and Bias [Karl Zipf, Delaware DOT]

Presentation Title: Is It Time to Revise the Precision and Bias Sections in T313, T315, and T316?

Summary of Presentation:
Zipf began the presentation by stating that the precision estimates for the AASHTO Test Method T 308 and M 320 were based on a study from 2005 (NCHRP Project 09-26). The study used the AMRL proficiency sample results for the PG graded asphalt binder. The sample sets were from 181-196 covering the years 2000-2004. The data in the AMRL reports were further tightened and it became the precision and bias for several AASHTO standards. The report for AASHTO T 315 PAV residue became the basis for the precision and bias statement which has single operator one sigma limit in percent (1s percent) of 4.9 and difference two sigma limit in percent (d2s percent) equal to 13.8. The multi-laboratory 1s percent equals 14.2 and the d2s percent equals 40.2. The average and standard deviation for the PG asphalt binder proficiency samples were compiled from 2000-2016. The 1s percent (percent coefficient of variation (COV)) was calculated and

plotted. The graph of the percent COV versus PG binder sample number showed that there is an improvement over time until 2006/2007. Two possible reasons for this improvement for PAV DSR include transitioning from water circulating system after 2006 and in 2000, the binder technician certification program was established. As a result, in 2006, there was better equipment and better technicians. In 2006, the average percent COV was about 10 percent for single standard deviation. Results for the percent COV versus sample number for PAV residue of the BBR test showed the same effect. A wide difference of percent COV led to a change in equipment. The RV scatter for percent COV also leveled out after 2006. Zipf presented a comparison of multi-lab d2s percent using newer AMRL data (2006–2016) to the AASHTO precision and bias which shows the data from 2006-2016 is better.

Zipf recommended that is it time to complete another study using the AMRL proficiency sample data from the last decade to update the precision and bias in AASTHO. The most dramatic effect will be with the DSR test (AASHTO T 315). The improvement probably reflects the labs retiring the circulating water systems and switching to Peltier units. Zipf also recommended that the precision and bias statement be reconsidered every 5 to 6 years.

ETG Comments, Questions, and Discussion:
Casola commented that there are still a lot of water baths being used in the field and that the largest change is a result of a change from AASHTO TP 5 to AASHTO T 315 where the language allowed for larger changes and larger variability which sparked the time thermal equilibrium study and time equilibrium improved data. Zipf agreed that the major rewrite was in 2004 and it normally takes a couple years for agencies to incorporate.

It was asked of the group if there was interest in having this updated. By a show of hands, the group responded yes.

Baumgardner commented that this is an AASHTO function and that Lyndi Blackburn’s SOM tech section group would look at it and see if there is any action on it.

D. Anderson commented that new specifications are needed as there are significant changes that should improve DSR and BBR.

Corrigan commented the ETG should engage Blackburn, ALDOT and AASHTO SOM TS2b chair and John Mulusky, AASHTO re:source on a possible re:source PSP data mining effort. Zipf confirmed that was the procedure performed previously to generate the precision statements.

Devol commented that AASHTO T 350 lacks a precision and bias statement and asked if it would be appropriate to look into this as well. Corrigan responded it was appropriate and that item should be discussed with the AASHTO SOM Technical Section what needs to be done to get this moving forward.

Action Item #201705-4. Lyndi Blackburn to inquire with the SOM and AASHTO re:source on the ability to data mine the PSP data to update the PAV precision and bias statement.

8. Update: Binder ETG – J_{nr} Task Force [John D'Angelo, Consultant]

Presentation Title: Multi-Stress Creep and Recovery Test Method New Specification

Summary of Presentation:
D'Angelo began the presentation by stating that the development of AASHTO M 320 took 10 years to complete. D'Angelo stated that the $J_{nr\ diff}$ was included in the standard because during development when different stress levels were used, at higher stress, there was yielding of the material, or shear thinning. This resulted in more variability and is representative of what happens in a roadway. The relationship is mostly linear until stresses near 10,000 Pa. However, with a two-phase system (e.g., polymers) there are two phases, the continuous phase (neat binder) and then the polymer network within the asphalt. Depending on the stiffness of the neat binder, the polymer network and stiffness of the polymer network, more yielding is observed at higher stresses and higher temperatures.

D'Angelo next discussed a previous ETG study of wax modified WMA binders that showed the increase in M 320 grades. Using the MSCR, some of the materials showed good performance at low stress but at higher stress, there was significant yielding. D'Angelo stated that this was the driver of J_{nr}. Highly modified binders also have issues where there is greater than 100 percent recovery due to the polymers. D'Angelo explained this was caused from the polymer pulling back and causing the percent strain to go below zero. The J_{nr} changes with stress increase of the material and there is yielding of the polymer structure.

D'Angelo presented the correction to $J_{nr\ diff}$ using two approaches. The first approach increases the low stress from 0.1 to 0.8 kPa and is still in the linear range for most AC. The second approach considers the J_{nr} slope based on the Arizona procedure. It is also possible to waive the $J_{nr\ diff}$ for E grade binders. The $J_{nr\ diff}$ slope is similar to $J_{nr\ diff}$ but is divided by the change in J_{nr} (either 3.1 of 2.4) instead of the J_{nr} at 0.1 kPa. The Arizona procedure shows that materials where $J_{nr\ diff}$ fails, there is improvement and fewer failures using $J_{nr\ diff}$ slope. D'Angelo stated he has not done a lot on this item, and this is preliminary data. The next steps are to collect data on J_{nr} slope and J_{nr} at 0.8 kPa to calculate both the $J_{nr\ diff}$ and slope.

ETG Comments, Questions, and Discussion:
Rowe commented the polymer results presented were outside the norm of results seen and asked if it should not be treated as such. D'Angelo responded that materials such as these are being supplied in the field so it needs to be considered.

Rowe commented that he had issues with using stress of 0.8 kPa since a stress of 0.1 kPa is known to be in the linear region and comparable to $G^*/\sin\delta$. At stress of 3.2 kPa, the effects of the polymer network are observable. If the stress used is 0.8 kPa, some of the material types will lose this observed effect. D'Angelo responded that at 0.8 kPa there are some changes and that the effect is still captured. Rowe responded that the difference in recovery needs to be considered and where the problem is occurring. D'Angelo responded that this occurs with high polymer percentages and high recovery and yielding polymer networks. Changing the stress to 0.8 kPa can address both. Rowe asked why not remove $J_{nr\ diff}$ as was recommended. Baumgardner commented that some of these issues are seen without highly modified binders where there is a

Hamburg requirement and it would not be eliminated without $J_{nr\ diff}$. Rowe agreed to the importance of $J_{nr\ diff}$. D'Angelo reiterated previous ETG discussions and recommendation to waive the $J_{nr\ diff}$ on E grade binders.

Kluttz commented that with the Arizona slope proposal, the slope is a function of how well the material is behaving but also the initial $J_{nr;}$ should the slope be divided by J_{nr} at 0.1 kPa instead of J_{nr} at 3.2 kPa? D'Angelo responded that it would have to be re-evaluated.

Codrin Daranga commented that this was overcomplicated. Daranga suggested that if J_{nr} is below 0.25, it is not useful to look at the difference since percentage wise, the differences are large. An easy fix is to test at six degrees higher temperature so that it will not be stress sensitive. D'Angelo responded that this would be difficult in a purchase specification.

Reinke stated that for binders with bad $J_{nr\ diff}$, an increase in temperature did not result in increased $J_{nr\ diff}$. Reinke would rather evaluate if there is stress sensitivity. D'Angelo responded that with low grades, you are below the grade and if one grade stiffer is supplied, how this is quantified?

Rowe commented that J_{nr} should be plotted on log basis and not linear as it is similar to viscosity.

Kluttz commented on the use of the term yielding in the context of this discussion, stating that polymers do not yield; but they are thinning based on strain. D'Angelo agreed. D. Anderson agreed that yielding has a different meaning since this test is stress controlled and are run at different strain rates.

Action Item #201705-5. John D'Angelo to present options for addressing $J_{nr\ diff}$ and provide recommendations from the Task Force at the next meeting.

Jack Youtcheff, Matthew Corrigan, and Andrew Cascione were added to the Task Force.

9. **Asphalt Institute's Technical Advisory Committee (TAC): PAV-DSR Task Force Efforts [Pavel Kriz, Imperial Oil/ExxonMobil]**

Presentation Title: DSR-PAV Test Improvement 2017 Status Update

Summary of Presentation:
Kriz began the presentation by acknowledging the members of the AI TAC TF – Gerry Reinke, Mike Anderson, Wes Cooper and Dave Anderson. Kriz then revisited the presentation from the September 2016 ETG meeting stating that the DSR-PAV variability is too high; by comparing the quality control sample to plant production data which showed the variability. The Gauge R&R scale shows whether the measurement is able to measure the variability in the process. Based on the six sigma and the Gauge R&R the resolution of the measurement versus the process resolution should be less than 10 percent to be acceptable. However, 57 percent of the variability is from the test which indicates that the test is not measuring what it is trying to control. The study initially presented indicated that the test strain and plate sizes are likely contributors to the

DSR-PAV variability which led to the TF being formed within the AI TAC. Seventeen laboratories volunteered to participate in the round robin to collect data for the study.

Kriz next presented the developments of the study since the last ETG meeting. The TF expanded the scope to include DSR conditioning time. The first stage was to determine the appropriate conditioning time followed by the second stage to test the effect of strain and plate size variability. AI developed and distributed two PAV asphalt samples (NC-B, NC-D). Test protocols were developed and shared. A diverse set of DSR and temperature control systems were included to ensure a broad applicability. A spreadsheet was developed and shared to collect and analyze data for stage 1. Two PAV aged asphalts and a Cannon standard fluid were tested.

The test protocol for stage 1 included samples aliquoted to small tins by AI and distributed, standardized approach on sample heating and loading, cooling from 46 ºC to target temperature between 13 ºC and 25 ºC depending on the sample and system at a constant cooling rate. The cooling was done by the instrument control system capabilities. Dynamic data was collected in 30 second interval during cooling and isothermal portion for 30 minutes in total.

The current standard conditioning time is 10 minutes once the temperature is within 0.1 ºC of the target temperature. The objective of stage 1 was to verify that the current 10-minute time is appropriate across a variety of systems. The analysis required a complex approach which D. Anderson will present later. If during the conditioning period the temperature oscillated outside of 0.1 ºC, the time was reset. Asphalt can suffer steric hardening and it is a challenge to find conditioning time after temperature was reached until the inside of the asphalt sample is at equilibrium without encountering static hardening and an artificially high measured value.

Data analysis of stage 1 has been completed for 8 of the 17 laboratories. Some of the DSRs were unable to run the test to collect the data needed and two labs were identified as outliers with values greater than three sigma difference. The data showed that cooling to the temperature occurs relatively fast. DSRs differ in the time equal to zero determination after reaching the target temperature within 0.1 ºC resulting in testing at different thermal histories.

Kriz presented examples of data collected on the fluid for both 8-mm and 25-mm plates at 13 ºC and 25 ºC. There was more variability for the 8-mm plate, which could be due to low viscosity or that there is not enough torque response. The 25-mm plate showed good data results. The heat diffusion with the 1-mm gap is faster and the sample gets to target temperature faster. The data for the different asphalts showed variability for both the 8-mm and 25-mm plates. However, after 10 minutes, the $G^*\sin\delta$ lines are parallel. Little hardening was observed with NC-B samples and the conditioning time seems to be adequate. There was a fast rate of hardening observed with the NC-D sample. The NC-D sample had a high ΔTc (4 or 5 ºC).

Kriz presented the early observations from the study as follows:

- Older instruments challenged with experiment
- Instruments differ in approach to conditioning time
- Conditioning time for 25-mm plates shorter than for 8-mm
- Hardening/conditioning time is not a major factor in variability
- Cannon standard fluid data are less variable than asphalt data

The TF agreed that sufficient data was provided (10 out of 17 laboratories) for stage 1 and recommended using the 10-minute conditioning time. The next steps for the TF include communicating with laboratories with conditioning time for stage 2, execute state 2 testing, analyze data and propose updates to AASHTO T 315 and report findings at the next ETG meeting.

ETG Comments, Questions, and Discussion:
None

Action Item #201705-6. Based on analysis of isothermal conditioning for ten of the participating labs, the PAV DSR Task Force will provide guidance to all the participating labs in the round-robin program to conduct testing using a 10-minute equilibrium time after the test temperature is reached (±0.1°C). Results will be requested by no later than mid-July. The Asphalt Institute's Technical Advisory Committee (TAC): PAV-DSR Task Force will report on the results of the round-robin program at the next ETG meeting.

10. Update: PAV Degassing & Pan Warping Issues [David Anderson, Consultant]

Presentation Title: PAV Pan Warpage and Film Thickness Effects on Properties of Residue

Summary of Presentation:
D. Anderson began the presentation by stating that reports of warped PAV pans have surfaced again. This has been a long-standing issue which is recognized by ASTM but not AASHTO. Pan dimensions are left-over from the thin film oven (TFO) method. The means for specifying and measuring allowable warping in PAV pans is needed. The pan dimension need to be revisited and the levelness of the PAV rack also warrants attention.

The statement of the problem is whether potential variations in PAV film thickness are sufficient to affect the physical properties of PAV residue. Likely reasons of variations in film thickness include pan warpage, dimension of rack, levelness of supporting rack, re-entrant radius at pan circumference and pan diameter. The items that need to be addressed include determining how important these variations are, how the effect of varying film thickness can be measured, determining the appropriate limits for warpage and to verify the estimate effects with a limited testing program.

Existing methods for measuring pan warpage include the spinning method; the method recommended by AI MS-25. The spinning method is qualitative and not definitive. The MS-25 method is simple and non-qualitative but no limits are given. The flatness check for downward bow presses on one side of the pan and the opposite side should not raise by more than 0.2 mm and this is repeated once the pan is rotated 90º. The flatness check for upward bow includes inverting the pan and checking for a gap at the center of the pan using a straight edge. Neither of these procedures account for non-coplanar warpage at the circumference.

The previous methods do not address warpage. The support method may also affect film thickness. The levelness of the individual pans cannot be measured with the alternative design of the support shelf. Profiling should be done with support consistent with equipment in laboratory where pans are used. The profile can be measured using a profile gage but can be expensive and may be excessive. The re-entrant corner could be checked with a go/no-go radius gage but this may also be excessive. Pan thickness should also be specified uniformly.

A pan supported on a rotating glass plate the same size as the pan simulates the shelf support in the oven. A dial gage rides on a linear track carried by a carriage and measures within ±0.0003 inch.

The SHRP viscosity results showed a linear relationship between thickness and viscosity. The effect of variations in film thickness is a function of thickness squared. With the exception of warpage, this is easily estimated from geometry. Warpage needs to be measured from actual warped pans and the orientation needs to account for the support system. An approach to measurements with an inventory of warped pans is to simulate both edge and shelf support and to determine the profile. The shelf support is simulated by a three-point support. The weighted effect of different thicknesses is determined by dividing the area of the pan into six concentric circles and subdividing each circular area into 20 segments of approximately equal area. The profile at the center of each area is determined and the weighted average is determined as the sum of areas multiplied by the thickness ratio squared.

PAV rack levelness can cause different results. Levelness of the oven is not reliable and warping of the vessel can affect rack levelness. Pans should be measured as they sit on the support but it is not possible with the shelf support installed inside the PAV.

Anderson finished the presentation by stating the tasks that remain:

- Update pan dimensions
- Develop method for profiling pans – prototype measurement jig available
- Compare profile measurements with other recommended methods
- Assortment of warped pans has been collected
- Evaluate effectiveness of profile gage compared to other methods
- Estimate tolerances based on assumed binder aging ratios
- Verify estimated aging with measurements of binders aged with the measured/profiled pans
- Expect to be able to make recommendations at next ETG

<u>ETG Comments, Questions, and Discussion:</u>
Utah DOT asked about the barometric pressure reported by laboratories stating that if barometric pressure versus elevation is plotted, there is a considerable difference. The effect of daily pressure is only a fraction of the effect of elevation. The data showed two groups, one group that had no effect of elevation (horizontal) and the other shows barometric pressure changing with elevation. Barometric pressure from weather stations is corrected to sea level. Laboratories need to be aware of this and report the correct barometric pressure.

D. Anderson stated they need some volunteers for the study.

Action Item #201705-7. Dave Anderson to investigate pan warpage levelness.

Volunteers include:

- Matthew Corrigan, FHWA
- Andrew Hanz, Mathy Construction Company
- Karl Zip, DelDOT

11. 4mm DSR Testing: Low Temperature Thermal Equilibrium Analysis of Peltier Systems [Gerald Reinke, MTE Services]

Presentation Title: A discussion of Peltier Cooling Compared to Chilled Air Cooling and 4 mm DSR Results

Summary of Presentation:
Reinke began the presentation by providing the statement of the problem. In the course of working with a laboratory trying to implement the 4 mm DSR, comparative testing between the two laboratories was performed. One laboratory used a DSR with a Peltier temperature control system and the other DSR used a chilled air system. There was significant variation in results when testing the same binder samples. This resulted in an investigating into the factors causing the variation.

The data for a PG 64-22 PAV aged binder showed good agreement between two samples with a variability of 0.4 percent each. The ΔTc were -4.9 ºC and -4.6 ºC. Results from the same sample using the Peltier DSR for the critical temperature were -32 ºC for stiffness, -25.9 ºC for m-value and -6.4 ºC for ΔTc, which is almost 2 ºC difference. A direct comparison of the differences of Peltier and chilled air showed the Peltier was providing colder temperatures (3.4 ºC for stiffness, 1.8 ºC for m-value and 1.6 ºC for ΔTc). The Peltier system showed lower stiffness at lower temperatures.

PAV residue of a PG 58-28 binder was used to compare BBR to 4-mm DSR using both Peltier and chilled air system. The results showed similar findings that the Peltier system was providing lower temperatures. A master curve of the complex modulus at -30 ºC between the chilled air and Peltier systems with increased compliance showed that at colder temperatures, the temperatures were artificially increased. The temperatures diverged as the temperature was warmer (-6 ºC). The master curve values are overlaying at the warmer temperatures and shows that Peltier systems are controlling closer to the appropriate temperature. Comparison for individual isotherms for the two systems showed that the modulus for the Peltier system at -30 ºC does not match the chilled air system isotherm until -21 ºC, implying a 9 ºC differential which is 6 ºC different from the average. At warmer temperatures, the isotherms are closer showing a difference of -6 ºC which is 3 ºC different from the average.

A compliance correction is essential for obtaining accurate results at low temperatures. If the temperature is wrong, the compliance correction cannot fix the issue. As frequency decreases the compliance correction decreases. Torques and displacements are also lower. Depending on the machine compliance, the correction importance diminishes at around 0 ºC for the 4-mm test. Compliance correction is machine and geometry dependent.

The solution to the issue of uniform and accurate Peltier temperatures must be addressed by the DSR manufacturers. A reliable method of temperature calibration is needed down to -40 ºC. Peltier appears to have unique issues with respect to uniformity of temperature between lower plate and upper geometry. The chilled air system provides uniformity of cooling but calibration is still important. The BBR result is the basis of the comparison.

A uniform method of data analysis needs to be developed and used as there cannot be multiple relationships between the BBR and 4-mm. The impact of minor changes in the slope critical value has minimal effect on the low temperature grade but almost a degree difference for ΔTc. The slope value is a sensitive value. Inaccurate test temperatures will result in incorrect relaxation moduli and slight changes in the slope determination will impact the determination of the final binder grade. The issue is also true for the BBR, where temperature control and mechanical factors will affect the BBR slope value.

Reinke summarized the presentation as follows:

- Compliance correction is needed for the lowest temperature
- Validation of Peltier data against a chilled air system is recommend until reliable Peltier temperature can be obtained
- Important at low temperatures where displacements are low and torques can be high
- Becomes negligible at 0°C and above (at least for machines tested)
- 4 mm is a valuable tool for forensic analysis, thin film emulsion residue testing, material screening
- May not be suitable for everyone
- Not a replacement for BBR for routine PG QC testing

<u>ETG Comments, Questions, and Discussion:</u>
John Casola asked why the frequency sweep was conducted high to low. Reinke responded it was conducted from high frequency to low frequency. Casola responded that it could have heat transfer and thermal hysteresis within the sample since the data has better agreement at higher frequencies. Reinke agreed and stated that the Peltier data crossed over isotherms, indicating that there is a temperature gradient across specimens but it is unsure whether it is uniform or if the specimen continues to cool.

D'Angelo asked whether testing with a longer time had been conducted and whether the data came together. Reinke responded that it had not.

Casola commented that at thermal equilibrium the gradients are not changing but if the gradients were still changing there will be variability. Reinke responded that shorter and longer times were tested.

D. Anderson commented that people often ask why there is a requirement for the BBR test for checking the difference between the estimated and measured values at different times. If it is off systematically, then there is an error in the m-value. D. Anderson commented that this needs to be left in the test method. Reinked responded that the S value equivalent is simple to get but the m-value is more difficult. D. Anderson responded this difference needs to be looked into.

Rowe commented that precise testing is needed. Rowe added, the values for the time used for G(t) and S(t) have changed over the years. Reinke stated that originally the value was 7200 seconds but by 2012 the value had changed to 60 seconds. The values are 143 and -0.28. Rowe commented that 143 seemed high and asked what it relates to as far as temperature and that using S(t) of 111 and consider the temperature differences in equilibrium targets. Reinke responded that changing the value to 111 would affect the numbers considerably, especially for comparison to BBR, and believes that 143 is a good value. Reinke added that the relationship on m-value is not always that good with some materials such as with shingles, but the value cannot fluctuate.

Corrigan asked what the ETG can do to continue to move this forward recognizing the importance of geometry? Reinke responded that manufacturers of Peltier systems need to look into this issue and that his lab was willing to compare test results. Corrigan asked what the manufacturers could do? Darin Hunter commented that this needs to be investigated more and that it is being assumed that there is a systematic error across all Peltier systems. Bharath Rajaram commented that a difference of 6-9 ºC is not a calibration issue. Reinke responded that it does not mean that the temperature is 9 ºC off; but the stiffness is, as if it was measured at that temperature. Corrigan responded it is important to advance the testing methodology. D. Anderson commented that thermal gradients can be significant and that heating up versus cooling down can also have an effect.

Casola stated that standard operating procedures can mask problems as you can get reproducible bad data. In respect to temperature, although the sample is always conditioned in the same way, that does not mean it is correct; but the data is reproducible. Casola commented that effects of thermal hysteresis can be seen. Understanding the hysteresis is important. Casola presented an example of increasing the temperature where the modulus decreased and decreasing the temperature causing the modulus to increase. Casola stated that the change is significant. In order to remove this effect, the thermal conductivity of the sample needs to be improved. Since asphalt is a good insulator, the middle of the sample remains the same temperature and enough thermal capacity is needed to change the temperature in the middle of the sample. There can be a 20 percent change in modulus per degree Celsius. Thermal gradients in the sample are the issue. The thermal capacity of the machine can be checked by testing the top and bottom of the cannon wafer and whether the temperatures are the same.

Baumgardner commented that this is an instrument manufacturer issue and we will depend on the manufacturers to make suggestions to the ETG. The problem needs to be identified in order to address.

It was asked why master curves from BBR data are not compared to master curves from 4 mm data since BBR is the golden standard. Rowe commented that full master curves were used as part of the evaluation.

12. Update: Thermal Equilibrium [David Anderson, Consultant]

Presentation Title: Thermal Equilibrium, A Status Report

Summary of Presentation:
Anderson began the presentation by providing a historical observation of the DSR test method. Early on, it was recognized that thermal gradients and thermal equilibrium can affect test measurement repeatability. Thermal gradients are currently accounted for with a temperature measurement between test plates. Thermal equilibrium is addressed in the current AASHTO and ASTM test methods by a finite wait time of 10 minutes. The current test procedure is built around specification measurements at 10 rad/s based on early generation DRSs, many of which used water to maintain temperature control.

The ETG task group on thermal equilibrium was concerned that the 10-minute waiting time was insufficient to obtain specimen thermal equilibrium. There is no procedure for determining instrument-specific thermal equilibrium. Based on extensive series of tests, the following was reported to the ETG:

- dG*/dt time was recommended as the preferred criterion for determining when the test specimen approaches thermal equilibrium
- 10-minute waiting time appeared to be excessive
- Waiting time may be instrument- and fixture-specific
- Test window should include both a “start” and “stop” time

It is anticipated this will be adopted in both the ASTM and the AASHTO DSR test methods but it is time to reconsider the issue.

Factors that can affect equilibrium include design of temperature control system, difference between starting and target temperature, heating/cooling rate and fixture geometry. DSR equilibrium does not come to mechanical equilibrium as there are hysteresis with time. DSR measurements will vary with time during isothermal testing. Understanding the amount of variation that is acceptable for the application of the test is needed.

Specimen thermal equilibrium implies specimen mechanical properties (G*, δ) are constant with the assumptions that DSR is at thermal equilibrium, DSR components are stable, and binder properties are unchanging with time (e.g., steric and physical hardening is minimal with time). The proposed procedure for estimating the approach of specimen thermal equilibrium was to monitor changes in G* with 30-minute time sweep and identify equilibrium as time when dG*/dt is a limiting value. The procedure has been under development for several years and the limiting value is still being refined.

Anderson presented the 5-point average deviation criteria based on the time after DSR reaches the target test temperature. The following variables were defined:

- AD^{L} − Limiting Average Deviation that defines approach of specimen thermal equilibrium
- $t^{L}-1$ − Last time when Average Deviation of 5 measurements is greater than AD^{L}
- $t^{L}+1$− First time when Average Absolute Deviation of 5 measurements is less than AD^{L}

- t^{ose} − Time interpolated to AD^{L}
- t_{C} − Cushion (Factor of Safety)
- t^{BEGIN}− Beginning of test window
- t^{END} − End of test window
- t^{W}− Test window

The G* is measured at 30-second intervals during a 30-minute isothermal time sweep. The measurements are smoothed using a 5-point moving average to minimize noise. It is assumed that equilibrium is approached a t^{ose} which is defined as the time when the moving average deviation reaches a limiting value, AD^{L} (AD^{L}) is approximately 0.5 to 1 percent change in G*/min. Find the longest time when the 5-point moving average deviation for all previous sets of five consecutive points is greater than SL and the shortest time when the 5-point moving average deviation for all subsequent sets of five consecutive points is less than S^{L}. Interpolate to find t^{ose} as time slope equals assumed limiting AD.

Other equilibrium criteria include using a fixed time as per current standard but review 10-minute value. The measurements should be smoothed using the 5-point moving average to minimize noise. The minimum allowable slope at which thermal equilibrium occurs should be defined. The hypothesis is that the slope will become zero. This will minimize thermal effects but will enhance steric hardening effects.

A measurement window that offers the best compromise between the effects of thermal equilibrium and time-dependent changes in binder properties should be selected. The compromise must consider the following:

- If test too early then thermal equilibrium will be the dominant effect on measurement repeatability
- If wait too long then changes in binder will be the dominant effect
- If test window varies between laboratories then the change in binder properties may affect variability in measured properties

An approximate thermal equilibrium time using simple quantitative measurements is recommended that can be performed with a spreadsheet or incorporated into the DSR software.

The analysis is now underway and reviewing previously reported times that were as small as a few minutes and considering whether a single time or device-specific temperature time should be specified. The analysis should recommend a test window that is a compromise between the effects of thermal equilibrium, DSR drift and time-dependent changes in binder properties.

Anderson next presented some results. The reference fluid phase angle does not change much. The best sensitivity is the change in G* and the three different criteria are close. The plateau occurs within the test window, the data is flat with a slight slope. The 5-point slope and AD showed the temperature change and plateau occurred before 10 minutes. The variability in the data percent change as percent of the value at onset of thermal equilibrium shows 1 percent change in value up to the plateau region. The results for the asphalt binder showed that instead of coming to a plateau, the G* was increasing and the phase angle was mostly constant. G’ and G” were constant. Anderson stated that there is a lot of analysis still to be done to look at the onset of thermal equilibrium. With a fixed wait time, if the plateau or slope occurs at the very end it could be an indication of the amount of structure in the asphalt binder.

ETG Comments, Questions, and Discussion:
None.

Action Item #201705-8. Dave Anderson to provide an update on temperature and thermal equilibrium efforts at the next meeting. The documents will be distributed to the ETG for comment.

13. Update: Binder ETG – REOB Task Force REOB White Paper Recommendations and Status [Geoff Rowe, Abatech]

Presentation Title: New Methods for Assessing Rheological 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 presented the objectives of the presentation. These objectives were to provide an update on the document development, information on ΔTc from the Christensen-Anderson (CA) model and thoughts on point versus shape parameters. Rowe acknowledged the members of the Task Force which are listed in attachment B.

The new methods for assessing rheology data such as ΔTc and Glover-Rowe (G-R) parameter and their relationship to performance of REOB in asphalt binders and other materials document has been redrafted with input from the task group members and forwarded for circulation to the ETG for final review. Additional background is provided in the document and details on ΔTc calculation from CA model added with a worked example using data from Anderson et al. (2011).

The CA model defines rheology in the region of 105 to 109 Pascals to a good accuracy. From this it is possible to calculate the G-R and ΔTc from BBR or DSR data. Rowe presented the equation for CA within RHEA. The determination of ΔTc from the CA equation provides the slope, m(t), where the time is set and the time, t(m) when the slope is set. In this formulation, it is assumed an Arrhenius function which is appropriate for BBR data in stiffer region of master curves.

By combining the CA and Arrhenius equations, two further equations can be developed for the stiffness at a temperature, T, which corresponds to a loading time of 60 seconds and temperature, T, that corresponds to a stiffness defined at 60 seconds. These steps can be used to calculate ΔTc using a stepwise process. Rowe stated that he had a spreadsheet for the equations.

Rowe next presented what is defined as a point property versus a parameter that defines the shape of the master curve, or part of the master curve. ΔTc defines the slope of the stiffness curve in the temperature domain which is a shape parameter in the higher stiffness region related to temperature susceptibility and rheological index. G-R defines a point within black space plot of G* versus phase angle. This is a point property in a similar manner to S, m, G*sinδ, G*/sinδ, J_{nr}, etc. Point versus shape parameters will not necessarily correlate since they are defining different parameters. The initial relationship shown for ΔTc versus G-R does not apply to many materials. In the existing specifications, a shape parameter has not been used without a point parameter. Rowe ended the presentation by stating that more work is needed.

ETG Comments, Questions, and Discussion:
D. Anderson commented that during development of SHRP specifications, they were aware of the need to have a shape parameter but the technology was not available at the time. D. Anderson stated that he tries to convince people to relate to distress as a point property. Rowe responded that having two empirical point properties can define a shape and that you cannot rely on a shape parameter alone without a point property. Anderson responded that point properties cannot be used alone either. Gayle King asked whether a shape factor was needed if there is an effective point value.

D'Angelo commented that the G-R does not capture all of that; can move across black space and yet result in the same number. Rowe responded that two point properties are needed and cannot do it with one property. Planche agreed and stated he had an issue with a binder cracking in the field where there were low critical temperatures for m and S and very low ΔTc. Rowe confirmed his point, and stated that there needs to be careful consideration in how the new parameters are included in the specifications as there are different relationships and that the specification should capture those relationships.

Kluttz commented that ΔTc as a shape parameter of a master curve can be shifted by other behaviors that fall under performance and would be a challenge to use ΔTc without acknowledgment of how other materials could shift the behavior. Rowe agreed that ΔTc is in the stiffness region and there are a few others in strength parameters.

Reinke commented that ΔTc is a three-dimensional problem since time also has to be considered and it is not only two-dimensional and two materials. This is why ΔTc can often report good values and then at some point changes for the worse. Rowe agreed.

Action Item #201705-9. Matthew Corrigan will distribute documents, white paper and spreadsheet from the REOB Task Force from Geoff Rowe for comments and finalization. The original goals of the Task Force would then be completed.

14. Update: Binder ETG – Binder Ageing Task Force [John D'Angelo, Consultant]

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

Summary of Presentation:
D'Angelo began the presentation by stating that there are issues within the industry to certify materials. With age, asphalt pavements experience raveling, fatigue cracking and low temperature cracking. The current Superpave binder specifications consider aging with

construction, short-term through RTFO and long-term with PAV aging. D'Angelo asked if there were some indications of things that can be used to identify when there will be problems.

D'Angelo discussed several new criteria being considered for durability and fatigue. The first criteria is ΔTc which is intended to capture brittle cracking. The Glover-Rowe (G-R) $G^*(\cos\delta)^2/\sin\delta$ parameter is intended to capture ductility at 15 ºC 0.005 rad/s. The CAM model R-value defines the shape of the master curve indicating if binder has higher G* or lower δ. The BBR measured stiffness and m value where the m value measures relaxation of the binder at cold temperatures. As binder ages the m value continues to decrease indicating loss of relaxation properties while the stiffness increase levels off. The difference in temperature where S equals 300 MPa and m-value equals 0.3, is ΔTc and it is an indicator of embrittlement. The current ductility testing is conducted on unaged or short-term aged binders at one temperature and does not relate well to cracking. Glover investigated recovered binders for the roadway and correlated ductility at 15 ºC to cracking. The surrogate property rheological property G'(n'/G') measured at 15 ºC and 0.005 rad/s correlated to ductility. Rowe recalculated the Glover property to $G^*(\cos\delta)^2/\sin\delta$ which can be plotted in black space. Glover's study indicated that ductility of 5 cm indicates onset of cracking and ductility of 3 cm will exhibit cracking.

D'Angelo next presented that the current 20-hour PAV aging does not represent long enough aging condition to identify critical condition. The options to address this are to extend the 20-hour PAV to 40-hour PAV which requires a longer time to grade, use thinner films in the PAV which reduces the material for testing, or use extremely thin films in an oven which results in very small amounts of material; primarily used for 4-mm DSR testing. D'Angelo stated that longer aging times are being studied to identify embrittlement and longer times are needed. D'Angelo asked if aging ratios could be used to identify the same issues which allows for more tests and the same time for grading binder. Mathy Construction Company has conducted a small preliminary study regarding whether one 40-hour PAV provides similar results to two 20-hour PAV conditioning back to back. D'Angelo presented the difference in low temperature grade between two 20-hour PAV and one 40-hour PAV aged binders which showed a difference ranging from about -2.25 to 1.1 ºC with the average being negative indicating that 40-hour PAV is more severe. The difference in low temperature grade for two 20-hour PAV and 40-hour PAV based on S and m-value showed scatter ranging from -0.5 to 1 ºC and was not conclusive. D'Angelo indicated that North East Asphalt User Producer Group (NEAUPG) is conducting a study investigating this and the data should be available soon.

D'Angelo next presented the relationship between crossover frequency and ΔTc as ΔTc is related to field performance; however, the correlation between the two was 0.5843. The relationship between R-value and ΔTc had a correlation of 0.6379. The relationship between G-R to ΔTc had a correlation of 0.6755. Parameters will continue to be investigated.

D'Angelo asked if the 20-hour PAV data can be used to extrapolate and predict the 40-hour PAV value based on comparing the 20-hour PAV value with the change from the original binder to 20-hour PAV results. There are indications that the 20-hour PAV and the change from original aging provides an indication if the 40-hour PAV result will fail ΔTc. The rate of change of RTFOT ΔTc to 20-hour PAV divided by the 20-hour PAV is used to project to 40-hour PAV.

The 40-hour ΔTc is predicted based on the rate of change in ΔTc from RTFOT to 20-hour PAV. Data was presented on a wide range of materials. Aging ratios were used to predict the ΔTc for 40-hour PAV. Although some differences between the actual 40-hour PAV ΔTc and the 40-hour predicted ΔTc differed by as much as 2.2C, the predicted was able to identify the materials that exceeded the ΔTc limit. The aging ratio can indicate if there is an issue with binders.

D'Angelo concluded the presentation by stating that longer aging times are needed; but binder aging ratios may capture the issue without longer aging times. The Task Force will continue to evaluate more materials and different criteria to determine if poor materials can be identified without longer aging.

<u>ETG Comments, Questions, and Discussion:</u>
Reinke commented he was not surprised by the lack of correlation between ΔTc and crossover frequency because the other parameters are material dependent and ΔTc is not. The relationship for unaged binder may show good correlation but polymer modified binder would not have good correlation. D'Angelo agreed.

Rowe commented crossover frequency is a measure of stiffness of the binder and in frequency domain, as you move from right to left the material ages which indicates it is moving the position of master curve. Casola stated that at lower frequency, it relaxes over a slower period and there is more risk of cracking to the left. Rowe responded that crossover frequency is a point property.

Bob Klutz commented he would like to see the relationship between crossover frequency and ΔTc as the basis for low temperature PG grade. Rowe commented it should be the crossover modulus. D'Angelo commented one must be careful because there can be soft and brittle materials or hard and flexible materials. There is a relationship where at low stiffness it does not relax at all and vice versa.

Rowe stated the crossover modulus is directly related to the R-value as it represents the glassy modulus minus the R-value and both are shape parameters. Therefore, the two parameters correlate nicely. Rowe then stated crossover modulus does not capture the stiffness. D. Anderson commented that a very soft and a very hard material could have the same ΔTc.

Action Item #201705-10. John D'Angelo will provide the Binder Aging Concern Task Force update at the next ETG meeting.

D'Angelo asked Martin Jasso, University of Calgary to share his presentation and his comments on Glover and Glover-Rowe coefficient

Jasso began by providing an introduction of the Glover parameter stating that it is related to ductility at 15 ºC and 1 cm/min. Attempts for dynamic measurements at crossover frequency equal to 0.005 rad/s was impractical so the crossover frequency was shifted to 10 rad/s and temperatures greater than 15C. The hypothesis was that the Glover parameter is a good aging/hardening indicator for conventional as well as modified asphalt binders.

The next hypothesis was that larger Glover or G-R parameters lead to more brittle binder that is prone to cracking. The problem was setting a meaningful value for the Glover and G-R parameters. Since the aging of asphalt leads to harder material, the Glover parameter might also be an indicator of aging. Jasso asked the questions whether the Glover or G-R parameters could be used for prediction of cracking of modified and straight run asphalts and if aging could be characterized by one parameter?

The modified G-R parameter shows that the variables are the magnitudes of $|G^*(\omega)|$ and $\delta(\omega)$. In the linear viscoelastic range, there is one independent variable: frequency. Partial master curves of dynamic material functions were developed.

Jasso next presented the G-R parameter for 80/100 Pen Grade asphalt obtained from master curves of dynamic materials functions at 15 ºC. Based on the assumption that the Glover parameter is a parameter for assessing the aging properties of asphalt binders, then dimension of the g parameter expressed in basic dimensions mass, length and time has the same dimension of stress power.

For the linear viscoelastic region, based on sinusoidal shear flow with small amplitude oscillatory shear experiments ($\gamma_o \ll 1$), an important property is $\tan\delta(\omega)$. If there is (and there will be) a need for a vertical shift factor (b_t) for the construction of master curves of G'(w) and G"(ω), this factor does not appear in the loss tangent. The dependence of the loss tangent on the aging time should also be carefully investigated. Phase angle should also be considered.

<u>ETG Comments, Questions, and Discussion:</u>
Rowe commented that tanδ is the same as contained in the G-R. In the black space diagram, the tanδ line crosses the G-R line at about 45 degrees and $3X10^4$ Pa. Rowe believed this was the same thing and did not see what the effort was adding to the subject. Jasso asked what the point of using black space was. Rowe responded that engineers can visualize it. Jasso commented that at high frequency, black space diagram can have tails which would show this.

D. Anderson commented that there is a problem if the linear viscoelastic region does not follow the line in black space.

Gayle King said the point was well taken and that tanδ has been discussed since the beginning of SHRP. Moving forward with G-R, ductility needs to be verified and compared to mixture failure data.

D'Angelo commented that G-R also sets another parameter based on where it is located on the frequency curve.

Rowe commented the difference between tanδ and G-R is miniscule.

15. A Supplier's Experience with MSCR $J_{nr\ diff}$ [Andy Cascione, Flint Hills Resources]

Presentation Title: A Supplier's Experience with MSCR $J_{nr\ diff}$

Summary of Presentation:
Cascione explained that Flint Hills Resources has one refinery and 12 terminals throughout North Dakota, Nebraska, Minnesota, Iowa, Wisconsin and Illinois. Most of the states will be implementing the MSCR specification. The transition to this specification has gone smoothly except for $J_{nr\ diff}$. Cascione explained they are seeing high variability with $J_{nr\ diff}$ and that some DOTs which they supply materials are not experiencing rutting issues with pavements that are failing the $J_{nr\ diff}$.

The $J_{nr\ diff}$ limits the upward trend of the stress versus compliance curve. North central States are at a disadvantage because of the use of softer binders. Binders with wide temperature ranges or soft base binders are susceptible to high $J_{nr\ diff}$ values.

Cascione referenced a 2017 Transportation Research Board (TRB) paper by Jeff Stempihar that demonstrated that $J_{nr\ diff}$ may not adequately represent binder stress sensitivity. E-grade binders waive the $J_{nr\ diff}$ requirement. Cascione stated that they are experiencing issues with H- and V-grade binders.

The PG58-28 H- and V-grade binders were comfortably below the 75 percent $J_{nr\ diff}$ threshold. However, the PG 58-34 H- and V-grade binders had higher variability. Cascione stated that as a supplier, it is challenging to manage the variability and meet the $J_{nr\ diff}$ threshold of less than 75 percent. The COV for $J_{nr\ diff}$ was greater for DSR results, ER, J_{nr} and percent R. In order to determine if the binder was stress sensitive since it was out of specification, stress sweep tests were conducted by running 10 cycles at stress levels 0.005, 0.1, 1.0, 3.2, 5.0, 10.0, and 11.0 kPa on two binders. The J_{nr} was averaged at each stress level. The $J_{nr\ diff}$ was calculated based on the stress level and J_{nr} of 0.1 kPa. The results show the V-binder, which passes $J_{nr\ diff}$ at 3.2 kPa, appears to be more stress sensitive at higher stress levels than the failing H binder according to the $J_{nr\ diff}$ equation. The slope of the exponential trend line is also steeper for the V-grade binder. However, the difference is very small (0.112 versus 0.119) indicating minor difference in stress sensitivity; but one binder is failing and one is passing.

Cascione next presented the difference of $J_{nr\ diff}$ based on the revised AASHTO procedure adopted in 2014 in which 10 warm-up cycles were added to the test. Large differences in $J_{nr\ diff}$ values were observed post-2014 when the software was updated with the 10 warm-up cycles. An experiment was conducted in which the same technician conducted MSCR tests on splits of RTFO aged residue using the same DSR. One split was tested using the old software version without the 10 warm-up cycles, and the other split was tested using the current software version that includes the warm-up cycles. The binders passed the $J_{nr\ diff}$ criteria without the warm-up cycles while testing with the warm-up cycles increased $J_{nr\ diff}$ almost 40 percent and all binders failed the $J_{nr\ diff}$ criteria. The cause of this is the J_{nr} measurement at 0.1 kPa decreasing during the first 10 cycles before leveling off while the J_{nr} values at 3.2 kPa remain the same resulting in a larger $J_{nr\ diff}$ value. Cascione asked if it was possible to waive $J_{nr\ diff}$ so that the binders complied?

There was no clear trend between $J_{nr\ diff}$ and polymer content meaning that $J_{nr\ diff}$ cannot be controlled by formulating polymer content as with other PG parameters (e.g., %R, G*, phase angle). A reacting polymer experiment was conducted. The laboratory procedure included blending four different types of polymer in a highly compatible PG 58-28 binder. The MSCR was tested before and after reacting the polymer at a test temperature of 58 ºC. The percent recovery increased after reacting the polymer indicating a good polymer network in the asphalt. Reacting the polymer caused the $J_{nr\ diff}$ to increase.

A fluorescence microscope was used to capture images of a polymer modified asphalt at different stages of laboratory processing. At each stage, the sample was tested in the MSCR at 58 ºC. The first image shows individual particles of polymer floating separately within the asphalt. The neat binder is black under the microscope, and the polymer is green. At this stage, the polymer is fully melted and mixed in the asphalt, but it is not properly reacted. As the reaction is conducted, the percent recovery increases, the J_{nr} decreases, but the $J_{nr\ diff}$ also increases. At some point during the reaction $J_{nr\ diff}$ does decrease, but it has an overall increase between unreacted and fully reacted conditions.

A round robin was conducted in 2016 where a CSBG PG 64-28 binder was provided. The $J_{nr\ diff}$ average was 25.3 percent with a COV of 25.7 percent. When the same laboratories tested the CSBG PG 58-34 binder, the average $J_{nr\ diff}$ was 47.5 percent with a COV of 32.4 percent. It is possible that a laboratory would determine this binder is out of specification. Results of a CSBG PG 64-34 binder showed that the more modified binder had more variability but similar $J_{nr\ diff}$. The $J_{nr\ diff}$ average was 50.8 percent but COV was 73.8 percent.

Cascione closed the presentation by presenting the following considerations:

- The stress sensitivity of polymer modified asphalt is an important consideration but more research is requested before a parameter is implemented.
- Should $J_{nr\ diff}$ be reconsidered as a specification in AASHTO M 332 if:
    - Round-robins (CSBG) and supplier data show high variability
    - 10 warm-up cycles are causing binder to fail the $J_{nr\ diff}$
    - Lab results cannot be replicated at the terminal level
    - Asphalt suppliers are unable to control the parameter

<u>ETG Comments, Questions, and Discussion:</u>
King commented that this is a problem as more soft asphalts and polymer modified asphalts are being made. King stated that in extreme climates, eliminating soft materials is not an option. King stated that shear problems have not been observed as a problem on the road. King commented that northern States are not enforcing $J_{nr\ diff}$ and as long as the binder passed the rutting test then $J_{nr\ diff}$ is not considered.

Amir Golalipour commented that the comparison of the difference of the J_{nr} with and without the 10 warm-up cycles is the reason for the warm-up cycles since the J_{nr} changes dramatically at 0.1 kPa and then plateaus after 10 cycles. Warm-up cycles are not used at 3.2 kPa because there are only 10 cycles. Golalipour continued by stating that based on the material science, when the polymer structure is loaded, it is shocked and the 10 cycles are giving time for the structure to reach a steady state. Golalipour recommended instead of eliminating the 10 warm-up cycles at 0.1 kPa, maybe 10 cycles should be added at 3.2 kPa so that it reaches steady state.

Codrin Daranga commented that after 10 cycles at 3.2 kPa the material is damaged so adding more cycles is not an option. D'Angelo commented that this is an issue with soft materials and that these behaviors are not observed with E-grades. The averaging makes a difference.

Golalipour commented that it does make a difference for $J_{nr\ diff}$. It was recommended that 10 warm-up cycles be added for both loading levels but cycles were only added at 0.1 kPa. By adding the warm-up cycles at 3.2 kPa, the $J_{nr\ diff}$ would be more repeatable. Cascione agreed to the point and stated that the rutting resistance performance would be the same.

D'Angelo commented that they observed no change in variability with stress build-up in the binder. D'Angelo commented that it does not add to repeatability and recommended that the Task Force consider.

Golalipour commented that the other tests presented are measuring material in the linear viscoelastic region and therefore should be more repeatable. Test conducted out of the linear viscoelastic region are causing damage.

Corrigan adjourned the meeting Wednesday at 5:02 PM.

DAY 2: Thursday, May 4, 2017

16. Call to Order

Baumgardner called the meeting to order at 8:00 AM.

17. Update – Impact of Long Term Ageing on RAS Binder Properties [Gerry Reinke, MTE Services]

Presentation Title: Extended Aging of RAS Mixes with Rejuvenator – An Update

Summary of Presentation:
The motivation for the work presented by Reinke were that high levels of binder replacement, especially from recycled asphalt shingles (RAS) can cause durability concerns and materials used to soften asphalt can have unintended consequences. These risks are not apparent until after long-term aging and therefore the work was to evaluate different long-term aging methods. The current long term aging protocols use one PAV aging cycle for binders and 5 days at 85 ºC for compacted mix aging. The study focused on extended aging to identify aging susceptible materials in the mix (RAS) or binder (softening additives) since under current specifications most of these materials appear acceptable. The objectives were to compare the aging stability of bio-based rejuvenator modified binders to conventional performance grading (PG) asphalt and to evaluate the effects of multiple aging methods and conditioning times on physical properties and composition.

The materials used in the study included tear-off shingles from a commercial source in central Wisconsin, PG 58-28 and PG 52-34 asphalt binder, an experimental product (EP) additive, bio-based oils (BO#1 and BO#2). A blend of PG 58-28 with 5 percent bio oil was used to target a final grade of PG 52-34. Binder testing on the virgin binder and binder blends was conducted for the high temperature grade (unaged), low temperature grade (long-term aged with 20-hour and 40-hour PAV) and ΔTc (20-hour and 40-hour PAV). The ΔTc were at or below -3.1 ºC. The RAS binder properties were 146 ºC high temperature, low temperature of 4C, ΔTc was -31.4 ºC, S(60) of -25.4 ºC and m(60) was 6.0 ºC. The RAS AC content was 22.1 percent.

The mixture aging study used 5.7 percent asphalt with 19.4 percent binder replacement from RAS. The aging methods used in the study included loose mix aging of as-recovered binders after 2 hours at 135 ºC plus PAV and double PAV; loose mix aging for 12 hours and 24 hours at 135 ºC; and compacted mix aging at 85 ºC for 5, 10 and 20 days. The results of DSR testing on the recovered residue was presented during the 2016 September ETG meeting and were not re-presented during this meeting.

Torsion bar modulus on 20-day and 10-day compacted mix samples aged at 85 ºC were conducted. Aging additional mixes with no RAS and RAS plus additional 0.5 percent binder were also considered to show that there is a difference with additional binder content. The torsion bar testing was conducted at -40 ºC to 40-80 ºC depending on the mixture stiffness. G* master curves were determined and interconverted to relaxation modulus master curves and black space plots for mixtures. The master curves for binder mixture produced binder with PG 58-28 and 5 percent BO#1 were plotted. The mixture had 5 percent RAS. The mixture modulus is about 1 order of magnitude greater than the binder modulus.

Reinke next presented on the question if testing of recovered binder from aged RAS mixtures was meaningful. To evaluate, the relaxation modulus of recovered binder from 20-day aged at 85 °C compacted mix was compared to the relaxation modulus of the 20-day aged mix based on torsion bar testing. Reinke stated that the homogenization observed from extraction is not taking place in the mix. There has been discussion that no blending is occurring and that RAS is acting as a black rock. Reinke stated that at the very least, it should be expected that the relaxation modulus would rank order the same for the recovered binder and the mix. The comparison of the plotted relaxation modulus showed the average of five specimens recovered binder. The graph showed that the BO and EP reduced the stiffness. The relaxation modulus of the compacted mix obtained using torsion bars tested on DSR were noisier but followed the same trend. The slope of relaxation modulus curves for the mixes at a reduced time of 1 second showed better relaxation for the mixtures with PG 52-34 binders.

A plot of ΔTc of recovered binder to predict the slope of mixture relaxation modulus curve at 1 second had a correlation of 0.85. The observed relationship was that as ΔTc becomes less negative; better slope values are observed. As ΔTc worsens, the slope values increase. This shows that something is happening in the mix and also in the binder.

The black space plot of the same materials showed the highest values in black space have the lowest modulus. The plots for the various binders were similar. A plot of the complex modulus at the cross over frequency of 45 degrees phase angle as a function of ΔTc had a correlation of

0.96. It was believed that a unique relationship between binder recovered from the RAS containing mixes and a property measured on the mix itself supports the position that the RAS is indeed participating in the mix aging and not only functioning as black rock.

Reinke next presented the R-value plotted versus ΔTc that had a correlation of 0.947. The circled points on the graph with higher R-values and worse ΔTc values was mix aged for 24 hours at 135 °C while the rest of the points were aged for 12 hours at 135 °C.

Reinke next presented a plot of R-value versus ΔTc for mixes with 5 percent RAS plus 4.5 percent virgin AC and mixes with no RAS and only 4.5 percent virgin AC. The challenge tested was if the mix was deficient for AC, then the same aging would produce the same results as for the RAS mix. The relationship for the mixture containing no RAS is shifted down. If aging were the same, the points and relationship would be even. This shows that starving the mixture of binder does not produce the same results. A plot comparing the virgin mix (no RAS/low binder) results paired with the same mix with RAS showed an intermediate result where the BO was in the same region as the virgin asphalt. The mixture with 5 percent RAS plus 0.5 percent binder moves the aging along the same aging line connecting the original RAS mixture and the reduced binder virgin only mixture.

A plot of the Colloidal Index versus ΔTc showed two unique relationships – one for RAS containing mixtures and one for virgin materials. The comparison of Colloidal Index versus high temperature PG grade of binder recovered from mixture aged 2 hours and binder aged in RTFO at 135 °C shows different compositional properties. The comparison of Colloidal Index as a function of ΔTc of these binders had a correlation of 0.96 and showed a continuum for these materials.

Reinke next presented additional mixtures and binders that were aged. Binders were aged in PAV pans in 135 °C oven to ascertain comparison to loose mix aging. The mass varied from 50 grams to 17 grams and the times varied from 52 hours to 20 days. Loose mix aging was conducted for 20 days at 95 °C based on Dr. Richard Kim’s recommendation at the 2016 ETG meeting. Both virgin and mixtures containing RAS were included. Virgin binder and binder plus 20 percent recovered shingle binder were used. The Colloidal Index versus ΔTc showed that for all these materials the relationship between binder compositional changes and change in ΔTc generated a uniformly changing relationship. The correlation was 0.96. The virgin binder had the best ΔTc and highest Colloidal Index while the low end of the relationship was a result of 17 grams of binder with RAS aged for 20 days.

Reinke concluded the presentation with the following summary:

- It appears RAS is participating in the mix and it contributes negatively to the mixture aging properties
- Accelerated aging at 95 °C for longer periods of time yields changes in asphalt compositional properties and ΔTc (also R-value) similar to those caused by shorter term aging at 135 °C
    - The goal of the work was to produce mixes and binders aged to a condition matching the aging in the surface ½ inch of the field mix

<u>ETG Comments, Questions, and Discussion:</u>
Rowe commented that the ΔTc and slope are at different points on the master curve with higher stiffness. Reinke responded that the number was used because it was at 1 and appeared reasonable. Rowe stated that at 25-30 °C, some of the material is not behaving in a thermally logical simple relationship and there is displacement between the phase angle and G*. Reinke responded that he was not concerned about the ΔTc temperature issue because it is more related to intermediate fatigue than low temperature failure properties.

Rowe commented the complex modulus plot versus ΔTc should use log scale on the vertical axis.

Kluttz asked how Colloidal Index was determined. Reinke responded iatroscan.

Buncher asked how many years of aging was targeted for the surface ½ inch in the field. Reinke responded that would vary with climate, unfortunately. Aging of 12-24 hours is about 8 years in the field, however, this would be shorter in a warmer climate.

King asked how long and at what temperature aging for loose mix should be conducted? Reinke asked if this was to evaluate mixes for production? King clarified that it is to induce a state of damage in the mixture if performing the test for a research study. Reinke responded that aging was routinely between 12-24 hours but that 24 hours seemed to be too harsh. King asked if 12 hours may not be in the damage state. Reinke responded that he did not think 135 °C was an excessive temperature; and the question is about the amount of time that is appropriate for where the mixture will be placed. King asked what would be the equivalent aging at 85 °C and 95 °C? Reinke responded they did not investigate that; but estimated that it would be a much longer time. Reinke continued that film thickness is significant; and in the laboratory, using 50 grams for aging the thickness is about 3 mm; while in mixtures the thickness is 8 to 10 microns.

Rowe commented everything is following the same trend and there is nothing in the datasets that challenges the concept of R-value linking to ΔTc to Colloidal Index. Reinke responded that he thought aging at 95 °C would produce something different as the chemistry is different as represented by the Colloidal Index.

D. Anderson asked what would be done for specification purposes and whether more than 40 hours of aging would be possible? D. Anderson continued asking what kind of aging to simulate long-term field aging could be conducted and if industry would accept it? Reinke responded it depends on what is being aged. For aging binder, 40 hours was an issue raised numerous times and it is possible that the ETG task force work to provide extrapolation from 20-hour PAV to check materials may provide additional insight. Reinke also mentioned they have done a limited amount of testing using reduced amount of material in the PAV. This changes the chemistry but it can approximate 40-hour PAV aging. This effort is worth investigation to continue the aging at 20 hours. Reinke stated in order to test material when there is only 10 to 12 grams in a pan, a lot of pans will be needed. King stated if 40-hour PAV is needed, the damage state needs to be understood and that making the specimen thinner is probably the best option. In that case, there would not be much material to test but it could be solved using the 4-mm DSR plate for testing.

Reinke commented that he included a wrong slide and would correct the presentation to show black space before the presentation was made available.

18. BBR Creep Compliance & Stress Controlled Strength Test to Obtain Failure Properties at Low Temperatures [Mihai Marasteanu, University of Minnesota]

Presentation Title: New Method to Obtain Strength Properties of Asphalt Binder at Low temperature using the BBR

Summary of Presentation:
Marasteanu began the presentation by stating that there is an AASHTO provisional standard for this procedure. The NCHRP Idea Project 151 performed between 2010-2012 tested asphalt binder and miniature asphalt mixture specimens at low temperatures to obtain bending strength. This has the potential to replace indirect tensile test (IDT) and direct tension test (DTT). An upgraded testing device, the BBR Pro, had a modified BBR frame with proportional valve that offers complex control of the pressure in the air bearing system (including cycles of loading/unloading), capable of applying loads at different loading rates, and a bigger load cell for asphalt mixture three-point bending strength. The goal is to conduct tests on both binder and mixtures.

A previous investigation of DTT versus BBR strength concluded the following:

- Only potassium acetate and air are appropriate cooling media for failure tests
- DTT and BBR strength methods provide similar information about the failure properties of asphalt binders at low temperature
    - Different volumes of material tested in the two different methods need to be accounted for

Marasteanu next presented the diffusion of cooling medium in BBR samples. Fluorescence spectra were thereafter obtained for THF solutions of BBR samples after washing off the cooling solvent containing FL on the surface. Only the THF solution of the asphalt was extracted from the BBR mixture bar immersed in EIM has an emission shoulder at about λ_{em} equal to 515 nm characteristic to FL solution. The absence of a shoulder in the fluorescence spectrum for PA samples indicates no FL diffusion. Therefore, the cooling agent affects strength values.

To better understand the limitations and benefits of the DTT and BBR strength, linear viscoelasticity concepts were used to analyze the experimental data obtained on two binders PG64-28 and SBS-modified PG 64-28. The binders have similar creep properties, as indicated by the similar performance grade, however, the DTT responses were quite different. The DTT stress-strain curves at -18 ºC and -24 ºC showed large differences. The modified binders performed better in terms of fracture and stress at failure. The DTT limitations are that the 3 percent per minute strain rate is almost never attained. A stiff loading frame would be required to pull the binder with 3 percent per minute, which is not the case. Therefore, the loading rate is not constant and not 3 percent per minute. Since the strain rate is not constant, the properties using linear viscoelastic properties cannot be predicted. If different strain rates with DTT were used, the curve would collapse, and that is not the case.

The BBR stress-strain curves show similar differences between unmodified and modified binders but much higher stress at failure. There is higher stress and strain at the lower temperature (-24 ºC), which is a positive result. The BBR strength results for all binders varied between 2 and 10 MPa and never went above 12 MPA. This can be set as the upper limit to be reached within a reasonable period of time. Similar to the approach used for the DTT, a loading rate such that 12 MPa is reached in 60 seconds can be set. In some cases, beams do not break, which means higher loading rate (or lower test temperature) must be used. To be able to calculate a loading rate that would result in less than the maximum deflection of 7 mm (equivalent to a strain of 2.6 percent), prior information related to the strain evolution with time is needed.

To determine the loading rate for BBR strength, use linear viscoelasticity in a test in which the stress is increased linearly starting from zero, the resulting strain will reflect the superposition of a series of retarded compliances. This also means that if creep compliance is known, the variation of strain with stress is known for a constant loading rate test. If the loading rate is known, then the entire stress-strain curve can be determined for a given stress rate.

To determine the loading rate for the BBR strength test, first a BBR creep test is performed and the creep compliance is calculated as a function of time. Based on the assumption that creep compliance, D(t), follows a power law, the hypothetical BBR strength test performed using constant stress rate, the stress at any time can be calculated as the stress rate multiplied by time. The creep compliance from the BBR creep test is related to stress from BBR strength test using a power law equation where the coefficients a and b can be simply calculated from fitting an equation to creep compliance versus stress plot, for an assumed loading rate. The loading rate is required to match the times for the creep compliance (vertical axis) and the stress data (horizontal axis).

The calculated stress-strain curve versus measured was compared for modified and unmodified binders. By running the creep test and making assumption of the loading rate, the stress-strain curve can be predicted which is helpful in determining if 7 mm of deflection within a minute will be achieved.

The procedure for BBR strength test is as follows:

- Perform BBR creep tests at two temperatures, according to the current specifications, to determine the grade of the binder.
- Use experimental creep compliance to predict stress-strain curves for a stress rate of 0.53 N/s which will limit the duration of the test to 1 minute or less
- Use stress-strain curves to determine if the 2.6 percent strain limit is reached within 1 minute. If the limit is reached, increase the stress rate accordingly. If the strain is less than 2.6 percent, perform strength test using the 0.53 N/s rate.
- Perform BBR strength tests and obtain stress-strain curves and the stress and strain at failure

Marasteanu stated that this approach can only be used to select the best binder out of a group of binders that have similar PG lower limit based on creep data. The research in progress is to determine a limiting parameters and criteria that would allow selecting an asphalt binder based on a limiting criterion, similar to the current PG specification. Investigation of a new fluid for testing, low temperature polysiloxane (silicone oil) bath fluid with a viscosity of 2-5 cSt at ambient temperature (used in low-temperature kinematic viscometer baths down to -40 ºC).

ETG Comments, Questions, and Discussion:
D'Angelo asked if when performing testing at lower temperature for the second beam for strength, it was conducted on the same beam or another set? Marasteanu responded it can be conducted either way. Marasteanu added they have looked at beams run separately and beams tested for creep compliance first. D'Angelo asked how that affects time? Marasteanu responded the strength beams are tested the same way; the easiest way is to perform creep test and leave the beam in place. D'Angelo asked if the beam was flipped for the second test? Marasteanu responded that they did not look at flipping the beam but it was a valid question.

Kluttz commented the silicone oil was not a good idea as it can affect the properties. Marasteanu responded it was recommended by a chemist. D'Angelo commented the issue is with the silicone oil being used in the lab and being spilled on material and not being able to remove it. D. Anderson said that the idea should be abandoned. Marasteanu responded that Cannon uses the oil to standardize and they did not have any issues and it looked like there was no effect.

Reinke asked if they had considered using low molecular weight polyethanolgycol. Marasteanu responded he was not sure; the feedback was good and they could try other fluids. The results of BBR creep compliance have slightly different results using ethanol and potassium acetate. There is also an effect on m-value.

Marasteanu requested suggestions be emailed to him and that he would be happy to report at the next meeting.

19. Ontario's Binder Analysis Efforts: Findings to Date [Pamela Marks, Ontario Ministry of Transportation]

Presentation Title: Innovative Testing of Ontario's Asphalt Materials

Summary of Presentation:
Marks began the presentation by providing background of the Ontario Ministry of Transportation (MTO). The MTO was 100% Superpave mix design by 2005 which has mitigated rutting but cracking is still a concern. The MTO is establishing mix performance testing for design and acceptance of placed mix remains a goal.

Marks next presented the MTO asphalt cement test innovations such as ash content test, extended bending Beam Rheometer (ExBBR) test, double edge notched tension (DENT) test, MSCR, X-Ray Fluorescence (XRF), and Fourier Transform Infrared (FTIR) Spectroscopy. The MTO implemented the ash content test in 2008 to prevent over-modification with REOB. There was good correlation between ash content and estimated REOB content as well as between 5-year pavement cracking and ash content. The DENT test is used for acceptance as a measure of asphalt cement's elasticity, ability to stretch and resist cracking. AASHTO TP 113 specifies silicone molds with aluminum end pieces and testing at 25 ºC. Ontario uses brass molds and tests at 15 ºC for PG XX-28 and -34 grades and 4 ºC for PG XX-40 grades.

Ontario's pavement performance concerns have focused on premature cracking and not rutting. The percent recovery from the MSCR test is used as an indicator of the presence of an elastomeric polymer. Ontario's AC specifications include $J_{nr\text{-}3.2}$ and percent recovery for acceptance on modified grades since 2012. $J_{nr\ diff}$ is conducted for informational purposes only. Marks presented a comparison of MSCR J_{nr} and percent recovery to assess elastic response. The unmodified PG 58-28 binders fall below the acceptable range as they are traditionally not modified. The use of MSCR specification for high temperature is limited in Ontario but they have conducted a trial to evaluate the ability of MSCR high temperature grading to resist rutting to MTO's PG AC bumping practice. There have been concerns raised by AC suppliers that PG 52H-40 may rut.

The ExBBR determines if the AC meets the low temperature performance grade after a physical hardening process that occurs with extended conditioning at cool temperatures. The ExBBR determines low temperature grade over 72 hours versus the 1 hour for standard grading. The MTO developed a multivariate regression formula to predict the 72 hour ExBBR test based on 1 and 24 hour properties using over 330 ExBBR tests. The predicted m-value and S can be used to estimate ExBBR low temperature limiting grade that could be useful for quality control purposes. The MTO has limited ΔTc data from BBR/ExBBR testing but they are beginning to consider it.

The XRF detects the elemental content of a sample and it is used by MTO to identify over-modification of REOB in asphalt cement. The elemental intensity peaks obtained are all relative to other elements found, so calibration curves are required for each element in a material to be quantified. The four key elements and levels detected in a REOB sample are Calcium (10,000 ppm), zinc (3,000 ppm), molybdenum (300 ppm) and copper (100 ppm). The MTO created calibration curves from base asphalt cement samples with varying percentages of REOB. A linear regression curve was created for each element. FTIR detects the infrared energy absorbed in a sample. Comparison of FTIR spectra of an unknown sample to a standard sample can be used to spot modifications made to the unknown sample. The FTIR also provided information on the molecular bond and functional groups of modifications that are made to a material. The MTO has found a unique FTIR absorbance peak corresponding to REOB near wavenumber 1229 cm^{-1} believed to correspond to polyisobutylene, an additive used in engine oil. MTO is estimating the percent REOB in AC with XRF. The FTIR peak and XRF percent REOB showed agreement. The correlation between five-year pavement cracking performance and XRF estimated REOB content was 0.87.

Marks next presented some highlights of MTO's mixture testing. The MTO conducts moisture sensitivity testing by assessing stripping by Static Immersion Test which determines the stripping susceptibility of the different components of an asphalt mix. Aggregates are blended with asphalt cement and the blended material is submerged in distilled water at 49 ºC for 24 hours. The stripping susceptibility of the asphalt mix is assessed visually based on the percentage of the retained coating on the aggregate. Consistency between the people conducting the test is important. The percent coating of various samples can be compared to determine what aggregate, AC, and anti-stripping treatment (AST) combination, provides better moisture resistance. The minimum satisfactory value for this test is 65 percent retained coating. Three alternative products were approved as an alternate to hydrated lime after the static immersion test showed the percent retained coating was as good or better as hydrated lime.

The Tensile Strength Ratio (TSR) determines the change in tensile strength resulting from moisture conditioning followed by a freeze-thaw cycle of compacted asphalt mixtures. The test is used during mix design to determine susceptibility of an asphalt mix to moisture damage. However, in some cases, it is insufficient and an anti-strip agent is specified to minimize risk of stripping.

The Moisture Induced Stress Tester (MIST) is an alternative moisture conditioning process to the TSR's freeze/thaw conditioning. MIST conditioning time is over 10 times less than the TSR's and MIST can be used to evaluate specimens based on sample swelling by comparing the bulk relative density prior and after MIST conditioning. The moisture sensitivity test results showed that the sample with the lowest retained coating, also had the lowest TSR, MIST-TSR and highest swelling value. Alternately, the diabase (a non-stripping aggregate) had greatest retained coating without AST, the highest TSR, MIST-TSR and lowest swelling.

The Hamburg Wheel Tracking (HWT) test is used to evaluate mixes made with various antistripping additives, evaluate specialty mixes (e.g., fiber reinforced HMA) and to investigate premature pavement failure. The MTO has not used the HWT test to evaluate mixes before they are used in production or to evaluate mix during production. The MTO uses an Asphalt Mixture Performance Tester (AMPT) for dynamic modulus, flow number, simplified viscoelastic continuum damage (S-VECD) and Texas Overlay testing.

The MTO is purchasing a Dynamic Testing System (DTS-30) that can perform dynamic modulus, flow number, S-VECD, Texas Overlay, four-point bending, SCB, Disk-shaped compact tension (DCT), IDT creep compliance and strength, resilient modulus and Thermal Stress Restrained Specimen Test (TSRST). The MTO has just acquired a bitumen bond strength (BBS) test that can measure the moisture resistance of the asphalt-aggregate interface for different combinations of materials.

The MTO purchased a Fraass testing device and are developing a testing program to compare the results with BBR and ExBBR. In this test, a 0.4-gram sample of asphalt binder is applied to a metal plate at an even thickness. This plate is subjected to a constant cooling rate and flexed repeatedly until the binder layer breaks. The temperature at which the first crack appears is reported as the FRAASS breaking point. The testing is conducted according to European EN 12593. Studies have shown that FRAASS correlates with BBR results. Other future work includes refining recovery protocol for characterizing recovered binders from loose mix, determining if there is a relationship between double PAV BBR ΔTc and Ontario's pavement performance, and establishing a mix testing program to evaluate best options for predicting cracking of mixes placed.

Marks concluded the presentation with the following summary:

- Strong correlation was found between pavement cracking, estimated REOB and ash content.
- A relationship between ΔTc and estimated REOB content was found to be poor.

- Equations developed to predict ExBBR results after 24 hours, correlated well with actual test data and can be used for quality control (QC) purposes based on grades currently used in Ontario.
- FTIR spectroscopy can detect REOB.
- REOB content in asphalt can be estimated using XRF spectroscopy.

<u>ETG Comments, Questions, and Discussion:</u>
Kluttz asked regarding the REOB analysis whether anyone has tested the 10 most popular motor oils and 10 random samples of waste oil and performed the analysis to determine what kind of range of the various components are observed? Marks responded that Ontario had not. Youtcheff responded that Terry Arnold, an FHWA chemist, has done that. Kluttz commented that the life in the engine will change these components; and asked if all oil used polyisobutaline? Marks responded that they have seen the content of REOB change with time and the estimate has variability.
King was impressed by the work presented and commented on the correlation between ΔTc and REOB since the crude from the Canadian pipeline has variability. King stated the fact that there is a large range of ΔTc and is crude dependent shows that REOB can make it worse. King stated he expects a lack of correlation. King also asked about the tank sample numbers provided? King commented if those materials are not high in REOB, the numbers are extraordinary and would be cause for immediate removal and replace. King commented that assuming the numbers are correct, the numbers may not be from REOB and was concerned that extracted binder from shingles was being used which could cause the ΔTc value to be that poor. Marks responded the suppliers do not tell them how they formulate and produce the asphalt and they use different sources. King commented that these numbers are of real concern. Marks agreed; especially in their climate.

D'Angelo asked how ΔTc was performed on the tank and if it was on unaged material. Marks responded it was a PG 64-28 binder, which is the grade with the most problems, and the binder had been PAV aged, not double PAV. They have this testing because suppliers were using shingles and MTO had concern of what was in the mix.

Rowe commented the stiffness in the intermediate region should be tested. If other materials are coming into the market, this test may not be detecting everything through ΔTc because the relationship does not always line up. Marks responded that she would follow-up with Rowe as she planned to do intermediate region testing.

Golalipour asked how the BBS test was checked? Marks responded that the BBS was only tested to make sure it worked. Golalipour asked what MTO was going to use the test for? Marks responded they would use it on additives and also polished glass.

Reinke commented the ΔTc of -7.9 ºC or -9 ºC material could include some shingle or REOB and by looking at the R-value, materials with shingles are usually between 2.4 – 2.6. If the ΔTc values are that high but the R-value is not, then it could only be REOB and recommended looking at R-value as an indicator if shingles are in the binder. Marks agreed. Rowe agreed saying that was in-line with his comment and that R-value is effectively a stiffness at crossover frequency; an intermediate stiffness point.

Golalipour commented it is strange for tank data and that there is little change afterwards. Marks responded that the data came from a QA lab that has little variability. King agreed with Golalipour's point stating there should be change between BBR and ExBBR. King stated this is more evidence that it may not be REOB; more likely a roofing material source that is highly aged.

20. Automated Binder Extraction Equipment: Data Collection Efforts [Stacy Glidden, Payne & Dolan Incorporated]

Presentation Title: Automated Extraction of Asphalt Binder

Summary of Presentation:
Glidden stated that she is looking to receive feedback whether automated binder extraction equipment would be beneficial to the industry.

Glidden presented the Automated Extraction system. The system consists of a washing chamber, washing chamber heating system, inspection window, centrifuge, centrifuge motor, condenser, pump, outlet valve, solvent pump, integrated cooling system, dirty solvent tank, distillation unit heating system and clean solvent tank. The sample is placed in the washing chamber. The study worked with two manufacturers and Glidden commented that any other manufacturers interested could be involved by contacting her. The equipment uses a centrifuge cup in the center that acts like a washing machine and washes the binder off the aggregate. Most of the binder is recovered.

Glidden next presented results from an internal evaluation comparing automated extraction to reflux extraction. The error bars are based on AASHTO T 164 for a single lab. The Iowa DOT draft report compared the centrifuge percent binder to the InfraTest percent binder and showed a correlation of 0.9909. The AASHTO re:source PSP binder extraction data for two separate labs fell within the required d2s.

The internal evaluation for gradations based on AASHTO R 30 showed four samples comparing the automated extraction, ignition oven and reflux extraction. The error bars were based on AASHTO R 30 d2s and all cases fell within the specification requirements.

AASHTO re:source PSP data for samples 83 and 84 for gradation for four samples showed the PSP data fell within the expected range of the d2s including the passing number 200 sieve. The PSP data for samples 85 and 86 also fell within the expected d2s range. Glidden commented that all labs would have received ratings of 4 or 5.

The instrument verification using repeatability and AASHTO T 164 showed good repeatability based on three samples. Repeatability was also conducted on aggregates and results were within the acceptable limits.

Wisconsin Highway Research Program (WHRP) 16-02 study considered ignition ovens, centrifuge, reflux extraction and automated extraction system. A ruggedness study is using eight triplicate samples with four labs performing testing. The reflux method is being used as the control. Glidden stated she was looking for input on data to collect. The ASTM ILS is intended after the ruggedness study; including solvent pH and Alkalinity, aggregate drying, percent fines in binder solution, percent binder, aggregate gradation and PG grading of recovered binder. Glidden stated she would like recommendations regarding the variables to consider.

ETG Comments, Questions, and Discussion:
D'Angelo commented doing PG grading of recovered binders usually do not meet requirements because of effects from the solvents used. D'Angelo asked if Glidden was trying to change the requirements? Glidden responded that would be the goal if it works. D'Angelo commented that a more extensive experiment is needed. A completely clean solvent would need to be used as well as with a recycled solvent; but asked what the control would be? Glidden responded the control would be the extraction method and asked if that would be adequate. D'Angelo agreed.

Golalipour asked if the equipment produced binder or binder plus solvent? Glidden responded that it was binder percent by weight but that final recovery of the equipment provided effluent must still be performed. Golalipour asked if they have tested with GTR modified binders? Glidden responded there is a manufacturer with a GTR option but they do not own that type of equipment and therefore have not. Golalipour commented it could affect the results. Glidden agreed and stated it could be part of the round robin investigation.

Reinke asked if recycled solvent could be used in the centrifuge in order to record data? Reinke commented using the centrifuge could indicate if recycled solvent affects the properties. D'Angelo commented both recycled solvent and reagent grade solvent would have to be evaluated. With recycled solvent, it depends on how many times it is going to be recycled. If the machine is constantly recycling the solvent, it is going to be hard to compare it to other solvents. Ann Baranov, InfraTest commented they could monitor alkalinity and Ph of solvent in order to keep at reagent grade throughout. Although the solvent is being recycled, it can be kept at the proper quality.

Glidden commented they would like feedback on what is an appropriate way to get materials retained on the P200 sieve and what is an appropriate amount to restrict this too. Baumgardner commented it may be an experimental aspect that needs to be developed. Glidden asked if there would be information from the development of AASHTO T 164? It was recommended Glidden contact Frank Fee with the question.

Glidden asked what was suggested for the next step? The response was that it was up to the research team. The ETG could review and provide comments.

Corrigan commented FHWA had investigated the equipment for use on the mobile asphalt testing trailer program and it would require custom modifications for use due to the trailer's specific electrical power requirements and solvent used. Corrigan stated there could be value when processing a lot of material to determine asphalt content instead of characterizing the extracted binder afterward since final recovery of the binder is still necessary. Corrigan asked if it is envisioned for this to be used to determine production quantity and asphalt binder content in lieu of repeatedly recovering material for binder characterization?. Glidden responded it is primarily for determining percent binder content and that characterizing the binder would be a bonus if successful. Corrigan stated there is a need to ensure there is clarity provided on any extra steps or limitations for characterizing the binder when the ruggedness and precision and bias are conducted.

Action Item #201705-11. Stacy Glidden and research group to prepare draft report for ETG review and comment.

21. Summary of Action Items

Action Items:

Action Item #201705-1. Matthew Corrigan will distribute draft of the provisional test standard using concentric cylinder geometry for comments. The goal is to have a draft standard to Lyndi Blackburn for the AASHTO SOM Tech Section.

Action Item #201705-2. Dave Jones will provide recommendations from the GTR study with Caltrans and the 2017 Final Report. Dave Jones to provide an update at the next ETG meeting.

Action Item #201705-3. Ray Bonaquist is soliciting volunteer laboratories for the NCHRP 20-07/Task 400. Those interested should reach out to Ray Bonaquist with contact information. Bonaquist to provide an update at the next ETG meeting. (refer to minutes for list of volunteers)

Action Item #201705-4. Lyndi Blackburn to inquire with the SOM and AASHTO re:source on the ability to data mine the PSP data to update the PAV precision and bias statement.

Action Item #201705-5. John D’Angelo to present options for addressing $J_{nr\ diff}$ and provide recommendations from the Task Force at the next meeting.

Action Item #201705-6. Based on analysis of isothermal conditioning for ten of the participating labs, the PAV DSR Task Force will provide guidance to all the participating labs in the round-robin program to conduct testing using a 10-minute equilibrium time after the test temperature is reached (±0.1°C). Results will be requested by no later than mid-July. The Asphalt Institute’s Technical Advisory Committee (TAC): PAV-DSR Task Force will report on the results of the round-robin program at the next ETG meeting.

Action Item #201705-7. Dave Anderson to investigate pan warpage levelness. (refer to minutes for list of volunteers)

Action Item #201705-8. Dave Anderson to provide an update on temperature and thermal equilibrium efforts at the next meeting. The documents will be distributed to the ETG for comments.

Action Item #201705-9. Matthew Corrigan will distribute documents, white paper and spreadsheet from the REOB Task Force from Geoff Rowe for comments and finalization. The original goals of the Task Force would then be completed.

Action Item #201705-10. John D'Angelo will provide the Binder Aging Concern Task Force update at the next ETG meeting.

Action Item #201705-11. Stacy Glidden and research group to prepare draft report for ETG review and comment.

22. Next Meeting Location and Date

The next meeting date will be coordinated with the Asphalt Mixture ETG. Members were asked to consider the week of September 11, 2017 and September 18, 2017 with the preferred date being the week of September 18, 2017.

23. Meeting Adjournment

Baumgardner and Corrigan thanked all attendees for their participation on the ETG and attending the meeting. The meeting was adjourned at 11:25 AM.

ATTACHMENT A – AGENDA

Asphalt Binder Expert Task Group
Ames, IA
May 3-4, 2017
Meeting Agenda – Final

DAY 1: Wednesday, May 3, 2017

8:00 am	Welcome and Introductions	**Baumgardner**
8:10 am	Review Agenda, Minutes & Action Items	**Corrigan**
8:15 am	GTR: Binder ETG – DSR Concentric Cylinder Task Force	**Corrigan**
9:00 am	GTR: UC Davis/CalTrans Research, Findings, Recommendations, and Implementation	**D. Jones**
9:45 am	**Break (30 minutes)**	
10:15 am	NCHRP 20-07 Task 400: Effect of Elevations on RTFO Aging of Asphalt Binders	**Bonaquist**
11:00 am	PAV DSR: Precision and Bias	**Zipf**
11:45 am	Update: Binder ETG – J_{nr} diff Task Force	**D'Angelo**
Noon	**Lunch Break**	
1:00 pm	Asphalt Institute's Technical Advisory Committee (TAC): PAV-DSR Task Force Efforts	**Kriz**
1:45 pm	4 mm DSR Testing: Low Temperature Thermal Equilibrium Analysis of Peltier Systems	**Reinke**
2:00 pm	Update: PAV Degassing & Pan Warping Issues, and Update: 4 mm DSR Testing	**D. Anderson**
2:45 pm	**Break**	
3:15 pm	Update: Binder ETG – REOB Task Force REOB White Paper Recommendations and Status	**Rowe**
3:30 pm	Update: Binder ETG – Binder Ageing Task Force	**D'Angelo**
4:15 pm	A Supplier's Experience with MSCR $J_{nr\ diff}$	**Cascione**
5:00 pm	**Adjourn for the Day**	

DAY 2 – Thursday, May 4, 2017

8:00 am	Update: Impact of Long-Term Aging on RAS Binder Properties	**Hanz**
8:45 am	BBR Creep Compliance & Stress Controlled Strength	**Marasteanu**
9:30 am	**Break (30 minutes)**	
10:00 am	Ontario's Binder Analysis Efforts: Findings to Date	**Marks**
10:45 am	Automated Binder Extraction Equipment: Data Collection Efforts	**Glidden**
11:30 am	Summary of Action Items Schedule Next Meeting	**Baumgardner/Corrigan**
5:00 pm	**Adjourn – Safe Travels!**	

ATTACHMENT B – ETG MEMBER LIST

FHWA Asphalt Binder Expert Task Group Members

Chairman: **Gaylon Baumgardner** Executive Vice President Paragon Technical Services, Inc. 2829 Lakeland Drive, Suite 2000 Jackson, MS 39232-7611 Phone: 601-933-3217 Cell: 601-842-3743 Fax: 601-933-3363	Co-chairman: **R. Michael Anderson** Director of Research & Lab Services Asphalt Institute 2696 Research Park Drive Lexington, KY 40511-8480 Phone: 859-288-4984 Fax: 859-422-1301 manderson@asphaltinstitute.org
Secretary: **Matthew Corrigan, P.E.** Asphalt Pavement Engineer U.S.DOT - Federal Highway Administration 1200 New Jersey Ave, SE HIAP, Rm E73-465 Washington, D.C. 20590 Phone: 202 366-1549 matthew.corrigan@dot.gov	
Members :	
David A. Anderson Professor Emeritus of Civil Engineering Penn State University 736 Cornwall Road State College, PA 16803 Phone: 814-863-1901 daa@psu.edu or da.sc@comcast.net	**Lyndi Davis Blackburn** Asst. State Materials & Test Engineer Alabama DOT 3700 Fairground Rd. Montgomery, AL 36110 Phone: 334-206-2203 Cell: 334-850-6437 blackburnl@dot.state.al.us
John D'Angelo Consultant 8528 Canterbury Drive Annandale, Virginia 22003 Phone: 571-218-9733 Johndangelo@dangeloconsultingllc.com	**Joseph DeVol** Asst. State Materials Engineer - Materials Testing Washington DOT 1655 S. 2nd Avenue Tumwater, WA 98512 Phone: 360-709-5421 DeVolJ@wsdot.wa.gov

Darren G. Hazlett Deputy Director Construction Division Texas Department of Transportation 125 E. 11th Street Austin, TX 78701-2483 Phone : 512-416-2456 darren.hazlett@txdot.gov	**Gayle King** GHK, Inc. 10327 FM 3005, Unit 5PH1 Galveston, TX 77554 Phone: 281-576-9534 Cell: 832-741-2815 gking@asphaltscience.com
Bruce Morgenstern Materials Lab Wyoming DOT 5300 Bishop Blvd Cheyenne, WY 82009-3340 Phone: 307-777-4271 Bruce.morgenstern@wyo.gov	**Ioan I. Negulescu** Professor, DTAM Louisiana State University 232 Human Ecology Baton Rouge, LA 70803 Phone: 225-578-1684 Cell: 225-747-3565 inegule@lsu.edu and ioannegulescu@yahoo.com
Jean-Pascal Planche Vice President Asphalt & Petroleum Technology Western Research Institute 3474 N. 3rd Street Laramie, Wyoming 82072 Phone: 307-721-2325 jplanche@uwyo.edu	**Gerald Reinke** MTE Services 915 Commercial Ct. P.O. Box 563 Onalaska, WI 54650 Phone: 608-779-6304 Fax: 608-781-4694 Cell: 608-317-0242 gerald.reinke@mteservices.com
Geoff Rowe Abatech, Inc. P.O. Box 356 Blooming Glen, Pennsylvania 18911 Phone: 215-258-3640 Cell: 267-772-0096 Fax: 772-679-2464 growe@abatech.com	**Karl Zipf** Delaware DOT Chief Chemist DelDOT Adm. Center 800 S. Bay Road Dover, Delaware 19901 Phone: 302-700-2380 karl.zipf@state.de.us

Liaison Members:	
Mark S. Buncher Director of Engineering Asphalt Institute 2696 Research Park Drive Lexington, KY 40511-8480 Phone: 859-288-4972 Cell: 859-312-8312 Fax: 859-288-4999 Mbuncher@asphaltinstitute.org	**Audrey Copeland** Vice President, Engineering, Research and Technology National Asphalt Pavement Association 5100 Forbes Boulevard Lanham, MD 20706 Phone: 301-731-4748 Fax: 301-731-4621 Audrey@asphaltpavement.org
Edward Harrigan Transportation Research Board 500 5th Street, NW NA 487 Washington, D.C. 20001 Phone: 202-334-3232 Fax: 202-334-2006 eharrigan@nas.edu	**Pamela Marks** Head Bituminous Section Materials Eng. & Research Office Ministry of Transportation Building C, Room 238 145 Sir William Hearst Avenue Downsview, Ontario M3M 0B6 Phone: 416-235-3725 Cell: 416-779-3724 Pamela.Marks@ontario.ca
Evan Rothblatt Associate Program Manager, Materials AASHTO 444 North Capitol Street, NW Washington, D.C. 20001 Phone: 202-624-3648 Fax: 202-624-5469 erothblatt@aashto.org	

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
3	Concentric Cylinder	Matthew Corrigan (Lead): Zia Alavi, John D'Angelo, John Casola, Darin Hunter, Andreas Lutz, Bharath Rajaram, Codrin Daranga, Bill Buttlar, James Meister, David Mensching, Amir Golalipour, Joe Devol, Steve Landers, Steve Davis, Al Vasquez, Tim Ramirez, Troy Lehigh, and Jay Sengoz
4	Ground Tire Rubber	Matthew Corrigan (Lead): Codrin Daranga, John D'Angelo, John Casola, Bharath Rajaram, Darin Hunter, Amir Golalipour, Joe Devol
5	$J_{nr\ diff}$	John D'Angelo (Lead): Codrin Daranga, Amir Golalipour, Gerry Reinke, Mike Anderson, Bob Kluttz, Jack Youtcheff, Matthew Corrigan, and Andrew Cascione