

**FHWA Expert Task Group**  
**Asphalt Fundamental Properties and Advanced Modeling**  
**September 17-18, 2009**  
**NuStar Center**  
**San Antonio, TX**

**ETG Objective and Purpose**

The primary objective of the FHWA Asphalt Fundamental Properties and Advanced Modeling Expert Task Group is to provide a forum for the discussion of ongoing asphalt research and also to provide technical input for future research related to fundamental properties and advanced modeling.

The meeting of the FHWA Asphalt Fundamental Properties and Advanced Modeling (Models) Expert Task Group (ETG) was held on, 2009 in San Antonio, Texas. A total of 44 members and friends of the ETG attended the meeting.

Chairperson A. (Tom) Scarpas with the Delft University of Technology, Co-Chairperson Dallas N. Little with the Texas Transportation Institute and Secretary Katherine Petros of the Federal Highway Administration (FHWA) conducted the meeting. Ms. Lori Dalton with SME and Mr. Harold L. Von Quintus of Applied Research Associates, Inc. were present with Mr. Von Quintus acting as Secretariat and Ms. Dalton assisting with the meeting. Attachment A is the meeting Agenda and Attachment B includes a listing of the ETG members.

*The following members of the FHWA Asphalt Models ETG **were** in attendance:*

A. Tom Scarpas, Delft University of Technology (Chairperson)  
Dallas N. Little, Texas Transportation Institute (Co-Chairperson)  
Katherine Petros, Federal Highway Administration (Secretary)  
Imad L. Al-Qadi, University of Illinois at Urbana-Champaign  
Jo Sias Daniel, University of New Hampshire  
Jon Epps, Granite Construction  
Gayle King, GHK, Inc.  
Julie Kliewer, Arizona DOT  
Bob Klutz, Kraton Polymers  
Charles Schwartz, University of Maryland - College Park  
Linbing Wang, Virginia Polytechnic Institute and State University (Virginia Tech)

*The following members of the FHWA Asphalt Models ETG **were not** in attendance:*

Michael Anderson, Asphalt Institute (Liaison Member)  
William Buttlar, University of Illinois at Urbana-Champaign  
Edward Harrigan, NCHRP (Liaison Member)  
Magdy Y. Mikhail, Texas DOT  
Dave Newcomb, NAPA (Liaison Member)  
Bob Statz, Consultant

The following “*friends*” of the FHWA Asphalt Models ETG were in attendance:

Michael Arasteh, FHWA	Rong Luo, Texas A & M University
Rashid K. Abu-Alrub, Texas A&M University	Robert L. Lytton, Texas A&M University
Hussain Bahia, University of Wisconsin	Amy Epps Martin, Texas A&M University
Satish Belagutti, FHWA-HIPT	Eyad Masad, Texas A&M University
Amit Bhasin, Texas A&M University	Karissa Mooney, NuStar Asphalt
Don Christensen, AAT	Steve Mueller, FHWA
Audrey Copeland, FHWA	Tom Papagiannakis, UTSA
Samer Dessoury, UTSA	Troy Pauli, WRI
Frank Fee, NuStar Asphalt	Geoff Rowe, ABATECH
Nelson Gibson, FHWA	Fred Ruiz, University of Texas at San Antonio
Michael Greenfield, University of Rhode Island	Alexander Schmits, Delft University of Technology
Gerry Huber, Heritage Research	Monte Symons, Auburn University
Richard Kim, North Carolina State Univ.	Eric Weaver, FHWA
Sang Soo Kim, Ohio University	Jack Youtcheff, FHWA
Yong-Rak Kim, Univ. of Nebraska at Lincoln	
Saradhi Koneru, University of Texas A&M	
Niki Kringos, Delft University of Technology	

## SUMMARY OF HANDOUTS AT THE MEETING

1. White paper entitled: *Practical Approaches to Continuum Damage Fatigue Analysis*.
2. FHWA Report entitled *Development of a Multiaxial Viscoelastoplastic Continuum Damage Model for Asphalt Mixtures*, FHWA-HRT-08-073, Sept. 2009 [Authors: Richard Kim, M.N. Guddati, B.S. Underwood, T.Y. Yun, V. Subramanian, S. Savadatti]; not provided at ETG but acknowledged in meeting.
3. ARC Modeling End Products Description and Timeline, April 2009.
4. ARC Validation Plan and Timeline, April 2009 (Validation of ARC Models and Test Methods).
5. A summary of the data included in the Nottingham database and a write up on the FHWA ALF Test Results – NCSU; both of these will be used in the validation phase of the project.

## DAY 1 (Thursday, September 17, 2009)

Frank Fee (NuStar Asphalt) opened the meeting with some announcements, and Kirissa Mooney (NuStar Asphalt) made some announcements regarding the meeting logistics including; internet connections, lunch, breakfast, and other items. NuStar Asphalt sponsored the meeting location.

### 1. Call to Order—Tom Scarpas (Delft University of Technology)

Chairperson Tom Scarpas called the meeting to order at 8:20 AM and welcomed all in attendance. Co-Chairperson Dallas Little also welcomed everyone to Texas, and asked everyone to introduce themselves around the room.

**Welcome and Introductions** – Tom Scarpas (Delft University of Technology)

Chairperson Scarpas reviewed the meeting agenda sent to all ETG members prior to the meeting, and summarized those agenda items that will be presented. Chairperson Scarpas noted that the agenda was changed. Chairperson Scarpas overviewed the goals for this meeting. One of the goals is to brief the ETG on work completed within year 2 and summarize what is planned for year 3. A second goal of this ETG meeting is to establish the needs and criteria to evaluate what the ARC is finding and what is needed for the future. In other words, defining what the deliverables are and start interacting with the public or users of the system. A third meeting goal is to start interacting between the researchers and ETG in terms of the vision of the product within the next 3 years, and start evaluating/discussing what we are getting from this research.

Scarpas asked if there were any attendees that had not attended any of the previous ETG meetings. None were noted.

**Review and Approval of September 17 & 18, 2008 Meeting Minutes**—Dallas Little (Texas A & M University)

Minutes from the previous meeting were submitted to the ETG prior this meeting. Co-Chairperson Little asked for discussion of the minutes and if there were any corrections or additions to the minutes. No revisions or corrections to the minutes were identified and no discussion of the minutes from the ETG. Hearing none, Co-Chairperson Little asked for a motion to approve the minutes. Chuck Schwartz made a motion to approve the minutes and Gayle King seconded the motion. Co-Chairperson Little asked for a verbal vote to approve the minutes. The meeting minutes were unanimously approved.

**Attendance List and Sign-Up Sheet**

The list of member information and participant sign up sheet were passed around the room for participants to log their attendance. Chairperson Scarpas requested that the ETG members mark or notate any changes to their contact information on the list of members being passed around the room. No changes were recorded on the membership contact information that was returned to the chair.

**2. Simplified Fatigue with Continuum Damage Theory**—Eric Weaver (FHWA)

Co-Chairperson Dallas Little introduced this subject and presentation; *Practical Approaches to Continuum Damage Fatigue Analysis*. He acknowledged the authors of the white paper—Don Christensen (who lead the effort), Eyad Masad, Richard Kim, Dallas Little, and Yong-Rak Kim. Katherine Petros noted that copies of the white paper were being passed out at the meeting. This white paper was also distributed prior to the meeting.

Co-Chairperson Little noted that the plan is to have a workshop in the spring to demonstrate these simple models summarized in the white paper. A latter workshop would then be held to demonstrate the more complex models that are currently under development. Little then introduced Eric Weaver who presented the white paper.

Presentation Title: *Fatigue Testing with Basis in Continuum Damage Theory*

Presentation Summary:

Eric Weaver presented a summary of the work that FHWA has been sponsoring in the fatigue testing and mixture characterization area. He noted why this work was being done and provided an overview of the simplified approaches. Weaver requested advice or feedback from the ETG on specific issues or questions that were included at the end of the white paper.

Weaver provided an overview and summary of the different characterization techniques for HMA. These included the (1) reduced cycles for ranking, endurance and AMPT; (2) the simplified VECD that can be used for ranking, endurance and input for the FEP++, and (3) DMA (dynamic mechanical analysis) used for ranking, compatibility and moisture damage. Weaver noted that there is a table in the white paper that summarizes the attributes, features, and conditions of each method.

Weaver gave an overview of how each of these characterization methods will be evaluated. He acknowledged the support from Bob Klutz (Kraton Polymers) for providing some of the highly polymer modified mixtures that were placed at NCAT test track and can be used for this evaluation and comparison. Weaver also referred to the table in the white paper that summarizes the testing conditions for each of the different approaches (temperature, load level, replicates, etc.). The purpose of this work is to get the research into practice, make it practical for use, and someday convert the model for use into a performance based specification. Weaver ended the presentations with a listing of questions to be considered by the ETG, which are:

- Is this an advantage?
- Is the testing plan appropriate?
- If so, what material sources may be considered?
- Should a workshop be planned?
- What is the scope and target audience?
- Should all 3 approaches be considered at this time?

ETG Comments, Discussion, and Questions:

Tom Scarpas wanted to understand the sequence of events, as noted in the white paper. Specifically, he wanted to clarify if only one model was to be selected. Weaver; not necessarily, there could be multiple models selected.

The discussion moved towards the timing of the workshop and factors that may have an impact on its timing. Scarpas asked; what is the purpose of the workshop—he believes that the workshop should not be planned until the models have been selected. Doing the workshop now may be too early; as an example, what if one model is eliminated from consideration for some reason?

Joe Daniel; when is the testing and evaluation going to be completed? Weaver responded by giving a summary of the schedule; sometime in the spring is when the testing and analysis will be on-going but nearing completion. Jo Daniel agreed with that time schedule. She would like to have the data available at the workshop so that the participants can manipulate and use the data at the workshop. Weaver; agreed, but noted that the word “workshop” may be an incorrect term to use.

Gayle King thought that individuals need to be invited to the workshop. Jo Daniel believes that those invited to the workshop should be those that have not been directly involved in the development of the methods.

Frank Fee commented that what we need is to identify the procedures that we need right now so that data can be collected. Second – trying to optimize properties of the materials and how do we characterize the materials. We definitely need this tool and must understand and use some tool for fatigue testing and characterization. Need a tool to rank the mix for fatigue. What he needs is a tool to work in the sand box. They have the sand box but needs the tool. Dallas Little clarified what you need is the protocol or test procedure – Frank Fee agreed; he needs the tool to run the test. Gayle King questioned whether we are putting the “horse before the cart.” Frank Fee disagreed with that comment. His opinion is that we need something to take to the field to make fundamental decisions (thin or thick or stiff versus flexible pavements, etc.). Frank Fee opinion is that we need the protocols written up so that they can be used, at least to start the effort.

Eric Weaver noted that there is a protocol from AAT. They are waiting on some of the software to ensure that they are compatible.

Tom Scarpas; Page 5 in the white paper is an interesting statement; “...the laboratory evaluation method should consider the pavement structure in which an asphalt mixture will be used” because “...the pavement structure and the stiffness of the asphalt layer affect the magnitudes of stresses and strains that the asphalt layer experience in the pavement”. Scarpas has a problem with these statements, because the material characteristics are not known before testing so that they can be used in the evaluation of engineering properties necessary for any type of analysis on the basis of which the stresses and the strains in the asphalt layer can be evaluated.

Jon Epps; thanked Eric Weaver for bringing this to light and trying to get this into practice. These approaches seem to have merit but his opinion is that it will be difficult to pick one. In terms of where the material sources are; NCAT, WesTrack, MnROADs are excellent sources for the materials testing and characterization for predicting the cracking that has occurred. The important item is not to rank the materials but to predict the performance of these mixtures to ensure that we can predict the observed cracking. Frank Fee; do not forget the states test sections that have been instrumented. Jon Epps agreed with comment, but the difficulty is in getting the original materials. Epps is concerned about getting the materials rather than the methodology.

Dallas Little summarized the basis of where we need to go. All excellent comments, but he asked Don Christensen; where we go from here? Don Christensen; we are requesting comments from the ETG of what materials we use for the testing. He agreed that maybe we need to do the testing prior to the workshop. He agreed trying to find the materials and start the testing is a good place to start with the discussion. Obviously, the pavement structure will have a large impact on performance. We should know what the structure is based on where the mixtures were used. Jo Daniel and Geoff Rowe had suggested a colloquium, but Christensen responded that he does not know the difference between the colloquium and a workshop. Christensen noted that it is important to do the testing on materials with proven performance—must have the cracking data in which they were used.

Bob Kluttz commented about the testing conditions; he is hearing the strain level and temperatures or test parameters are totally dependent on where the materials are being used. Christensen replied not necessarily so, because the models will predict the performance over a wide range of conditions. That was Kluttz's question, how "wide is wide?" Christensen replied that you could designate the test conditions for complete materials characterization. Tom Scarpas; going back to "wide"—most of these methods use small strain levels, so are we really considering a wide range of conditions. Christensen; they typically use standard ranges but can go much higher strain levels; however, the failure at high strain levels occurs very rapidly. Scarpas commented at this point; we have to know what we are after and the theory being used—they must be compatible. Christensen; it is not that the limits of the test method, it is the method we are using. There was a large discussion between Scarpas and Christensen in terms of confusing flaws and how they can be represented in the methods or models.

Amy Epps Martin; we should be cautious about selecting the evaluation criteria. She also agrees that we need to select materials and projects that have good data but you can not go crazy about selecting a wide range of conditions. If the main goal is to compare fatigue predictions, why do you want to limit it to just three; shouldn't others be considered? Richard Kim commented on the issue of small versus large strain levels. They have been successful in predicting performance or cracking by using the test protocol proposed. He disagrees with the comment about the large versus small flaws, and noted that temperature is an issue that should be considered.

Dallas Little commented that we are beginning to get in the theoretical discussion of continuum damage theory, rather than getting Eric Weaver an answer to his questions. He requested that the ETG focus on the questions that Weaver presented at the end of his presentation. Little asked for one final comment.

Eyad Masad; Referenced or referred to the sequencing of events and trying to short cut what needs to be done. Masad noted that there is no substitute for simulating the actual conditions or in place state of stress for predicting cracking, anything else is a short cut. These approaches or the evaluation is to look at which shortcut is the better approach and how do we evaluate the shortcuts? We tend to evaluate the models by output, which may or may not be the better evaluation technique. He encouraged the workshop to be held earlier rather than later. Masad's opinion; judging the model solely by output may eliminate an appropriate model for the wrong reason. He also cautioned eliminating all but one model; as an example, by eliminating a very good procedure because it has a glitch in it that can be fixed with additional work—that glitch might eliminate it in terms of predicted versus observed cracking measurements. Weaver; can we point out these shortcuts or identify any potential glitches that may exist within the models at the time? His point was that we are discussing two different scales. The shortcut being discussed today is using a test method that has a theoretical basis to "speed up" the fatigue analysis and cracking prediction, while the other scale is using the complex theoretical model for predicting performance—this is a separate item or discussion topic.

Chuck Schwartz; regarding one of the questions you asked, do we include all three approaches? The DMA is good for mastic but we are looking for mixtures. If you are looking for a way to simplify the workshop, that would be a way to remove one—the DMA model. Dallas Little agreed that it could be eliminated or not included. Nelson Gibson also agreed. Jack Youtcheff

commented that he had a problem with that suggestion, because the other models do not include or consider environmental conditions. The DMA can include the environmental factors.

Dallas Little asked Eric Weaver for any closing comments. He does not want to move on if anyone has further comments. Eric Weaver summarized what he heard from the conversations:

- Get the materials from projects where you have observed performance.
  - Consider the test tracks for materials.
- Select the testing conditions from the following items.
- Do the evaluation and put the results out to the group, such as the ETG.
- Find out what we have and develop a plan to move one.
- Define the criteria for selection/evaluation of the methods or approaches.
- Limit the scope just to the extremes so that the plan does not get enormous.

Eric Weaver wanted to come back to Scarpas' comments about the size of the flaw. This comment resulted in a lot of discussion between Scarpas and Christensen. Christensen; the methods tell you what is going to happen before the large flaws occur but do not tell you anything after the large flaws occur – visible failure. Scarpas' concern was exactly what Christensen had discussed about before and after the flaw. Christensen opinion; the methods can tell you what happens after the flaw but was not positive of this fact.

Tom Scarpas; why do we not engage or ask the developers themselves why one method was developed or selected over the other? Richard Kim noted that was the original purpose of the workshop. Scarpas agreed. Chuck Schwartz noted some of that information is in the white paper. Scarpas disagreed; there is insufficient information in the paper. Weaver noted that was the original intent of the white paper—to present why one method was selected or developed, why the developers selected one theory over the other, etc. He also agreed that was the reason for the workshop. Dallas Little commented; that controversy between the methods of what was important and the reason for the white paper and workshop. Richard Kim; the other reason for the workshop was to demonstrate why one method worked and was selected.

Gayle King; You need to think of the customers that these methods will have to serve. Gayle King and Frank Fee are the customers. Right now the mixture and binder guys work very well together in terms of rutting and thermal cracking, because we have good tests. But for fatigue we are just going to use the cheapest section possible.

Frank Fee; do you have a task group that looks at validation? He noted that he has a project in New Jersey and he can do anything. There are a number of these projects like this—there are a “lot of sand boxes to play in.” He suggested that there be a validation task group that can identify these projects for use in fatigue cracking studies. Fee believes that this task group can identify these projects or sand boxes. At construction, it is cheap to get additional materials for use in testing and characterization.

Hussain Bahia commented; right now we have nothing to assist us in making a decision. There is no tool to help in a decision making process. The real issue, tell me whether to accept or reject the mixture.

Bob Kluttz commented on the experimental design; this may be a pipe dream, but is it possible to get material from where it has been used in extreme conditions? That would be huge to see how well the model can interpolate and extrapolate. Richard Kim opinion; It would be better to get one material/structure in one controlled environment—that is the best method to evaluate the models, because we do not have the transfer functions to date. So we should not expand the experiment to include many different environments or structures.

Dallas Little had to cut the discussion off because of time, and thanked everyone for the detailed and good discussion on this topic. He also thanked Eric Weaver for his efforts in making the presentation and leading the discussion.

**Action Item (1): Dallas Little requested that the ETG get the comments on the white paper back to Eric Weaver within a month or two.**

### **3. Modeling Compaction**—Saradhi Koneru (Texas A&M University).

Co-Chairperson Little introduced Saradhi Koneru and the modeling compaction project, which is being conducted by some members of the ETG and models team. Saradhi Koneru acknowledged the individuals that have been working on this topic (Eyad Masad and K.R. Rajagopal at Texas A&M University; and Tom Scarpas, Cor Kasbergen, and Xueyan Liu at Delft University of Technology). He also acknowledged the sponsor for the work—FHWA.

Presentation Title: *Modeling of Hot Mix Asphalt Compaction*

#### Presentation Summary:

Saradhi Koneru provided an introduction to the issue and reason for this study. He then noted or summarized the challenges in trying to model compaction. This was a detailed presentation showing the concepts, material models, and mathematical processes used to simulate mix compaction in the laboratory (gyratory compaction) and field. He identified the model parameters that are being used in the simulation model selected for HMA – a nonlinear viscoelastic model. The material model selected for this work was a thermodynamic based viscoelastic model. Koneru had a simulation movie that showed the gyratory sampled being compacted. He also included a simulation on how the model predicts the compaction process. He concluded with a summary of their findings or conclusions to date, which are:

- A systematic method was developed to determine model parameters from gyratory compaction curves.
- The model is capable of simulating the gyratory compaction process at different compaction angles.
- The model has good potential to capture both laboratory and field compaction processes.

#### ETG Comments, Discussion, and Questions:

Most of the discussion occurred during the presentation itself. The following notes the discussion that took place during Koneru's presentation.

Koneru overviewed some of the factors that affect the compaction simulation in terms of time of compaction in the gyratory mold and angle of gyration. He showed a couple of plots with the

simulation curves for different angles of gyration. These were to calibrate the model parameters. After the model compaction parameters were derived from the gyratory, he then moved onto field compaction modeling. Koneru showed a simulation of field compaction.

Gerry Huber; for the simulation slide, was the parameter on the slide density? Koneru; the parameter on the slide was density.

Linbing Wang; Can you model the air voids in the structure? Koneru; Can not model air voids because of the model selected for simulating compaction or densification of the mix.

Steve Mueller; How thick is the HMA in the simulation? Koneru; It is 3 inches.

Koneru showed the comparison of field density measurement at three points along the drum versus the percentage compaction from the experiment or simulation. He pointed out that the boundary conditions are important in terms of matching the field density results. After the initial results they ran a sensitivity analysis of the simulation model. Koneru showed an additional simulation regarding the longitudinal joint compaction. This showed the number of passes and stresses resulting from those passes. The next simulation showed a different set of passes.

Imad Al-Qadi; what type of load was used, static or vibratory? Koneru; only static-compression loads were considered for these simulations. They are now simulating vibratory loads. Al-Qadi; was the field validation effort also restricted to static loading conditions? His comment was that the stresses can be substantially different than for the static condition. Koneru; yes. Eyad Masad noted or responded to the question on vibratory loading conditions – it will be added in the future.

Linbing Wang; did you consider the vibratory rollers? Koneru; no, but in the future they plan to consider vibratory loadings.

Tom Papagiannakis comment; this would be a good tool to explain the stress and segregation of the mix inside the gyratory mold. Are there any features that would force segregation through the model? Papagiannakis also noted that this model is not a viscoelastic model because the deformation does not go back to zero; this is really a viscoplastic model. Koneru; no related to the question on segregation because the model simulated the material as a continuum. In order to simulate segregation, a discrete modeling approach would be needed. This will render the model inappropriate for field simulations because of the large finite element meshes that would be required. Eyad Masad revised Koneru's response related to the predictions of stress.

Michael Greenfield; why was the decay in density relationship smooth for the lab but oscillating for the field information or simulation, and what would explain or cause that in the model? Koneru; this was related to the boundary conditions. Tom Scarpas also responded to the question and noted his concern in that when you apply rotational forces on an element you no longer have uniform stress conditions.

Co-Chairperson Little had to cut the discussion off because of time, and asked that any additional questions be directed to Koneru after the meeting. There were no specific action items relative to this presentation.

After the break, the next part of the meeting was directed or focused on the following topic—  
**Multiscale Models and Tests: How will they contribute to the ARC final deliverables?**

**4. US/International Cooperative Efforts on Multiscale Modeling**—Tom Scarpas (Delft University of Technology)

This part of the ETG meeting was a four part presentation on multi-scale modeling efforts. Chairperson Scarpas gave the first presentation to introduce the topics for the remaining presentations.

**4.1 Chemo-Mechanics of Bituminous Materials Workshop Summary**

Presentation Title: *International Workshop on Chemo-Mechanics of Bituminous Materials*

Scarpas reminded the ETG that the Irvine ETG meeting focused on the larger scale models. This meeting was to focus on the attempts of the ARC researchers and others on the smaller scale models. Scarpas acknowledged the international workshop that was held in the Netherlands on June 10-12, 2009 in concert with ISAP and the ARC. This was a three-day meeting and the primary outcomes were; [1] a volume of proceeding that summarizes all of the presentations from the workshop, [2] the realization that there is enough momentum to produce a journal special issue on the topic, [3] the decision to organize, in the near future, a course on asphalt chemistry .

Delft University of Technology have set up already a private consortium on Chemo-Mechanics of cracking, aging, and healing processes in bituminous materials—the Delft Healing Consortium. The idea for this consortium is how to identify and quantify the effects of chemistry on the mechanical characteristics of an asphalt mix. Scarpas noted that representatives of FHWA and Western Research Institute had also been invited as observers He provided an overview of the work schedule of the Delft Healing Consortium. Phase 1 (2006 and 2007) focused on chemistry, Phase 2 (2008 until recently) attempts to relate or interpret the mechanical response of bitumen to the chemistry, and Phase 3 (the most significant one) to relate the chemistry to the mix response. Ideally this shall enable, in the future, the customer to specify the desired mix response and, on the basis of this, the bitumen supplier to identify the appropriate binder characteristics.

Scarpas then turned it over to Troy Pauli (WRI) who summarized the effort of a new ARC group whose focus is the chemistry and mechanics part of asphalt concrete.

**4.2 Troy Pauli (WRI) – Asphalt Research Consortium.**

Presentation Title: *Microscale Physicochemical Characteristics of Asphalt Binders*

Troy Pauli presented the focus topics within the consortium, and summarized what was being done to fill in the gaps. He noted or acknowledged the support from FHWA on this topic and acknowledged all members of the consortium (WRI, TTI, UWM, UNR, and AAT). He then focused on the research scope for WRI, which is to export the fundamental properties into flexible pavements or putting the applied research into practice. He noted that the consortium or ARC is focusing on specific research elements, which include: moisture damage, fatigue damage, high-performance materials, technology development, research and development validation, and technology transfer.

He also listed the asphalt microstructure model team members. The intent of this work is to eventually determine what type of polymers and additives will be needed, if any, for an asphalt binder for use under specific conditions of the in place pavement. This presentation was an overview of what is expected from the work that will be on-going under the asphalt consortium. The asphalt microstructure model team includes:

- National Institute of Standards and Technology (NIST)
- University of Rhode Island
- Virginia Tech
- Western Research Institute

He noted that Delft University of Technology, have been invited as observer in this effort.

Pauli's presentation included visual aids that demonstrated the nano-scale interpretation of neat asphalt and modified asphalts through their molecular structure and how properties can be used to predict the response of mixtures; both in the laboratory and field. In summary:

- The overall purpose is to measure and model, at a fundamental level, the processing, microstructure, and properties, including degradation properties of infrastructure materials.
- The measurement goal is to use standard tests that will measure fundamental properties of infrastructure materials, enabling scientific understanding and control of the use of these materials.
- The modeling goal is to simplify the material design of infrastructure materials so that this can be done without the use of quantitative computer models such as finite element methods.

#### **4.3 Molecular Simulations of Bitumen** – Michael L. Greenfield (University of Rhode Island)

Chairperson Scarpas then introduced Michael Greenfield for the next presentation.

Presentation Title: *Molecular Simulations of Bitumen*

##### Presentation Summary

Michael Greenfield overviewed how the molecular structure and properties can fit into and be used within the microstructure modeling and finite element modeling for pavements. In other words, going from the nano-scale to macro-scale. Greenfield noted and defined the different parts of the modeling effort; going from simulation to theory to correlation. He then defined what is meant by each of those terms and noted the advantages and disadvantages of each (simulation, theory, correlation) in terms of the underlying physics and chemistry, computational requirements, and extrapolation of results.

Greenfield then defined and turned his attention to the molecular simulation part. In summary, we must know how molecules fit and work together; thus, simplification is not considered. Simulations take a large amount of time to consider the interactions of the molecules. This part of the presentation included many slides that provided a lot of detail on molecular dynamics

simulation that was overviewed by Greenfield. This was focused towards the ARC task to devise an improved model asphalt.

The other key point presented or overviewed was the impact of polymers on the relaxation properties of the asphalt binder in terms of how does polymer affect asphaltene dynamics. A benefit on the use of this technology or modeling effort is to explain some of the anomalies that are observed within the macro structure. (In other words, insights from simulation results – what could explain these slow relaxations?).

In summary; Greenfield provided a summary of his comments related to the simulations and time for the simulations regarding making extrapolations in terms of time, which included:

- Molecule rotations provide information about viscosity.
- Rotational relaxation time is a more easily converged surrogate for viscosity effects and changes.
- Asphaltene, polymer rotation rates slow dramatically as temperature decreases.
- Zero shear viscosity predictions are consistent with ranges observed for real asphalts in experiments.
- Unoccupied volume has possible use for correlating model asphalt viscosity.

Greenfield concluded with acknowledging the different individuals and organizations that have been involved in this work.

#### ETG Comments, Discussion, and Questions:

Bob Kluttz made a couple of suggestions; it might be worthwhile to make one run at 100% c22 crystallization because the rate of crystallization is so dependent on dilution you might get a better handle on crystallization and the effect of temperature dependence on it by going to the higher c22 percentage. Greenfield commented; that is a good suggestion. Kluttz agrees with work on going related to polymers, but the problem is with the heterogeneous structure of polymers. His opinion is that the material is one or two orders of magnitude too small to pick up the effects or changes in the material. His suggestion for improving on the experimental part of the modeling effort going from the emerging phases to the aggregate-bitumen composite part is to put in a lot of polystyrene. One of the items that drives the processing and viscosity effects is the formation of polystyrene domains. To determine or see how your simulation excludes those small molecules from the polystyrene short chains is to put in 80% of your polystyrene short chains and 20% of others. Greenfield commented; agrees with the suggestion for one simulation – focusing on the smaller polystyrene smaller phase. Kluttz expects that the polystyrene chains will all come together and the small molecules will be excluded. This will allow your simulation or model to confirm that it will identify that effect. Greenfield commented; excellent suggestion.

Gayle King; related to aging and molecular structuring (aging is becoming a molecular relaxation problem); historically we have looked at the high temperature viscosity phase, but we probably should be looking at the lower temperatures phase to characterize the material in terms of molecular relaxation. Have you looked at aging and its effect on relaxation properties on the low temperature side? Greenfield; not really, but we have thought about the issue. Greenfield believes that this is a good suggestion to look at. It is something that can be done and should be

looked at. There was additional discussion between Gayle King and Michael Greenfield related to the impact or effect of aging or molecular relaxation on the other material properties.

Gayle King; can your model predict cracking without any external loading or stress? Greenfield; we can certainly calculate volume being open, but would hesitate to say that they can predict cracks. Depends on how small cracks can be defined. There have been simulations using different strain rates to see the effect.

Alex Schmets; how do you do the computations of the polymer molecular structure of the simulation—are the cracks an artifact of the simulation? Greenfield; cracks are an absence of the molecular structure or molecules, but there is insufficient time to answer the question in terms of a demonstration of the computations made.

Chairperson Scarpas had to cut the discussion off because of time, and asked that any additional questions be directed to Michael Greenfield after the meeting. There were no specific action items relative to this presentation.

#### **4.4 Structural-Property Relations at the Molecular Level** - Alex Schmets (Delft University of Technology) Group of Mechanics of Infrastructural Materials

Presentation Title: *Determination of Structure-Property Relationships in Bitumen at the Molecular Level*

##### Presentation Summary

Alexander Schmets acknowledged all of the different individuals that were involved in this work.

His presentation focused on the healing behavior of bituminous binders. Schmets noted that prior to discussion of healing properties and parameters you must define and identify the damage that is going to be healed. The first part of his presentation was related to the micro-scale mechanical testing of homogeneous specimens that result in damage to define what damage can be healed. The next part of the presentation focused on the Delft healing model.

According to this model, material memory loss is responsible for healing in bitumen. The Delft healing model is composed of three basic parts; energy fluctuations which can lead to phase separation, followed by stress concentrations that build up at the interfaces of stiffness discontinuities (microstructure locates the initial damage sites), and stress concentrations being removed by reversible phase changes (memory loss). Schmets then overviewed and explained how the microstructure is characterized in terms of the healing model. Three items or parameters were explained as part of the characterization process; aspect ratio, ridge patterns, and terracing. Terracing implies underlying crystallization.

The healing hypothesis as part of the model is a two-phase morphology or phase separation that is a bulk effect rather than a surface effect. In other words, phase separation is a bulk effect in terms of the 3-D characterization. The next part of the presentation focused on the use of neutron techniques for investigating the image or properties (crystallization) of materials for the healing model.

Schmets then defined the measurement of molecular movement or diffusion that is used in the healing model. These diffusion coefficients have to do with complete mixing versus separation of molecules. Schmets defined how the microscopic definition of the diffusion coefficient is determined or defined. Both the diffusion coefficients and the geometry of diffusion are important parameters of the healing model. Schmets ended his presentation with the conclusions from their work to date:

- A new healing model based on reversible phase formation has been developed and presented.
- Experimental justification, using AFM and small angle neutron scattering, has been provided related to the healing model.
- Bitumen might be considered a binary mix; a mix of two materials with distinct H/C ratio.
- Diffusion coefficients have been measured as a function of temperature.
- The molecular motion of the diffusing molecules is bound in space.

ETG Comments, Questions, and Discussions:

Dallas Little; when you are doing your thin slices, are you just trying to determine or define the bulk versus surface effects. Schmets; yes, that is correct. However, Schmets did note that the error bars are quite large so there are still items that are not considered or used by the model. Michael Greenfield also had a question about the slicing and the number of slices considered; were the thickness of the slices different. Schmets; no—the slices must be about equal for the analysis.

Steve Mueller; why is this important from a road building standpoint? Schmets; you have to know how the properties of the bitumen affect properties of the mixture. These results can be used to define temperature effects and effects of cooling rates on properties. Dallas Little and Tom Scarpas noted that this can also give you insight about the mechanisms of damage and material property characterization.

Bob Kluttz comment and opinion; regarding use of the term “spinodal decomposition” as opposed to nucleation, the two can be distinguished in terms of kinetics as phase separation; is there any evidence of what is being seen here is actually spinodal decomposition and not just simply nucleation? Tom Scarpas noted that from the thermodynamic point of view, the driving mechanisms are the same hence, does it make any difference between the two ? Kluttz replied, no. Scarpas agreed that it has no influence on the mathematical simulations. There was a lot of discussion between the Delft members and others on the use of these terms and how they are referred to and used in the model regarding diffusion theory.

There were no specific action items relative to this presentation.

Chairperson Scarpas adjourned the meeting for lunch at 12:30 PM. The meeting will resume at 1:30 PM. Both Scarpas and Frank Fee requested that all of the presenters in the afternoon provide Lori Dalton with their presentations so that they can be loaded before the afternoon session begins.

**5. Microscale Physicochemical Characteristics of Asphalt Binders** – Troy Pauli (WRI) and A. Beemer, J. Miller, W. Grimes, J. Beiswenger, and J.F. Branthaver

Presentation Title: *Physical Chemistry of Asphalt*

Presentation Summary:

Troy Pauli gave an overview of the process to define the asphalt properties from the molecules to asphalt. He referred to his presentation as an overview of asphalt materials science. He acknowledged the FHWA for financial support for the information from various projects (DTFH61-92-C-00170, DTFH61-07-D-00005 and DTFH61-07-H-00009) that was used in preparing this presentation. Troy Pauli overviewed seven topics as part of the presentation on asphalt materials science: fatigue and self-healing materials, molecular architecture of asphalt, physico-chemical property calculations, physico-chemical property to Rheology, interpreting compatibility parameters, asphalt fraction micro- and nano0morphology, and correlations to field data.

The first part of the presentation was focused on the method and device used to complete a SARA separation of asphalt, modified Corbett chromatography apparatus (saturates, aromatics, resins, asphaltene) and what impact these different fractions have on the binder and mixture properties – or at least what impact these fractions have on the fundamental properties. He gave examples and results using some of the SHRP asphalts. As you go from a linear molecule to a structured molecule the degrees of freedom to move around decrease. The asphaltenes are the molecules that resist flow while the resins permit flow once you heat them up. Pauli presented many of the equations that have been used to model the asphalt flow or define those properties related to flow from a molecular standpoint. He also presented measure data showing the comparison of measured to calculated values. The correspondence of the measured data to the calculated values was very good.

The next part of the presentation was the SARA fractionation and AFM Imaging of Comparative test site analysis. He showed many images of the materials from the Topography (top) phase-contrast (bottom) AFM images of the Saturates, Aromatics, Resins, and Asphaltenes from some of the different SHRP asphalts. Pauli also discussed and overviewed the “bees” structure and if it is related to the wax content of asphalts. He also overviewed what impact different materials have on the results. Conclusions from his presentation included:

- Molecular architecture of asphalt, based loosely on SatAroResAspt. IR-spectra of SARA fractions offer an interesting classification” of materials.
- Physico-chemical properties, as examples: surface energy, density, refractive index, could be calculated from molecular structure “maps” by semi-empirical simulations. Thus, present data compares well to experimental values.
- Relative viscosities (absolute viscosity) of asphalt could be determined based on models proposed by Pal-Rhodes (D-EMT solved), and Eyring (Significant Liquid Structure Theory). Our modeling approach showed that iso-octane “defined” asphaltene mass fractions linearly correlated with SEC-I mass fraction, which in turn, linearly correlated with the rheological phase angel (more particulate, less flow).
- Compatibility parameters were found to be functionally related to the ratio of isooctane to n-heptane asphaltene mass fractions. This correlation is interpreted as a measure of a molecular phase interaction “energy”.

- Bees appear to be wax related. When bees are not present in an asphalt the largest structuring is “observed” at the “nano” scale.
- Four Rochester Minnesota Comparative Test Site Asphalt were ARA fractional then analyzed by AFM. The complexity of the morphology correlated with the transverse crack map data, with the exception of one asphalt known to be a PMA (Evaloy modified).
- There may be a synergy between wax and asphaltene resulting in the development of a “micro-structure” as a possible cause of stress discontinuities.

ETG Comments, Questions, and Discussion:

There was a lot of discussion between different ETG members regarding the rheology and physical hardening effects of the asphalt with higher wax contents. Gayle King disagreed with the comment that the rheology is hidden from some of the characterization tests; his point is that the rheology is not hidden; if you do physical hardening tests, you will get crystallization. As the material crystallizes, it becomes denser, and thus stiffer. The longer you store the asphalt at lower temperatures, the harder or stiffer it will become to a degree. The wax structures are changing over time and the greater the probability that cracks will initiate at that harder microstructure of the asphalt. The more micro-crystalline structure you have, the more potential cracking the mixture will exhibit.

Geoff Rowe disagreed somewhat with Gayle King’s opinion because of their data on the damage of BBR specimens if you hold the temperature for longer periods of time. Rowe’s opinion; it goes beyond physical hardening tests.

Gerry Huber commented that an Ontario project had the same mix and same volumetric properties, but different additives or modifiers were used to result in a PG64-34 asphalt. The performance of these mixtures is significantly different. There are lots of data on binders but there is little data on the mixtures for those held at colder temperatures for longer periods of time. Huber’s opinion is that the data show that cracking is not correlated to physical hardening. Binder properties in terms of physical hardening do not correlate to the mix properties. Huber also referred to Mihai Marasteanu’s data from Minnesota and that he believes that they do not have sufficient data relating physical hardening and cracking. Huber and King agreed that there is a lot of disagreement and discrepancies on the effects of physical hardening of asphalt binders.

Nelson Gibson commented about mixtures with and without SASOBIT; no significant difference in mix properties; any comment on that observation? Troy Pauli; not enough of the hard particles or balls are present to make a difference. In other words, you are probably on getting a small particle effect—not enough to make a difference in the mix properties. Gayle King opinion; you have to store your binder four days or longer at colder temperatures and not reheat them if you are going to see any difference as related to crystallization. He suggested that Gibson change the testing conditions in order to see an effect on the mix from that additive. Nelson Gibson; what is the typical amount of wax content in asphalt? Gayle King; difficult to define wax content and is test method dependent, but it can generally be 2 to 8 percent.

There were no specific action items relative to this presentation and topic.

**6. Micromechanical Healing Model – Amit Bhasin (University of Texas at Austin)**

Presentation Title: *ARC – Micromechanical Healing Model*

Presentation Summary

Amit Bhasin provided a presentation taking us from the molecular scale to a modular scale. This relates to the micromechanics model and healing model. Bhasin covered or overviewed two items or questions; what they have done to date, basically an update, and what is planned for the future?

Completed work: Basic model of healing was overviewed first in three areas: an overview of the basic micromechanical healing model, the measurement of input material properties for a portion of the healing model, and molecular dynamics to partially support the healing hypothesis. The healing model can be separated into two steps: the interfacial wetting and intrinsic healing. The intrinsic healing is proportional to work of cohesion. Bhasin overviewed the micromechanical modeling and measurement of material properties. The material properties for the healing model and how they are measured were presented. To define healing or the ultimate healing, they take the DSR for a thick and two piece specimen, and normalize the  $G^*$  versus time relationship for the two piece specimen to the thick specimen. Healing is rest period dependent.

The second and shorter part of his presentation was directed at the future work on the healing model. Bhasin briefly went over the different tasks or items that the team plans to do. These steps were separated into three items or tasks: Cross check/validate the intrinsic healing properties measured using the DSR, evaluate the entire model for FAM, and conduct parametric analysis to recommend a form for the healing mechanism for the continuum damage model.

ETG Comments, Questions, and Discussion:

Richard Kim; what is the test temperature and were different temperatures used in the development of the healing model? Bhasin; room temperature only for now, but future plans are to do multiple temperatures. Richard Kim suggested using time-temperature superposition, because at cold temperature or short loading times, healing is small or insignificant. Bhasin noted that the accuracy could probably be accomplished by selecting a time and temperature related to healing and agreed with Richard Kim's comment.

Gayle King noted that for one of the asphalts with a flat line is asphalt AMM included in the presentation, the changes with time are probably a lack of healing rather than a lack of hardening based on the conversations between Gerry Huber and himself during the previous presentation. If the modelers could tell us, the users, more about the evolution of properties especially for the waxy materials when they are subjected to longer cooler temperatures (when they will start to stiffen) that would be beneficial. In other words, identify the location and cause of damage that would be beneficial in the long run.

Dallas Little clarification comment; what types of cracks heal? This needs to be clarified. Bhasin; these are micro-cracks that are subjected to healing, once you get to a macro-crack healing does not exist or will not occur. Bhasin did define a micro-crack as one that is less than a micron.

Richard Kim noted that the less than 10 seconds is the time that healing needs to be defined or evaluated. The longer times could be misleading and confusing good healing asphalt versus poor healing asphalt. Bhasin agreed with the comment.

Gayle King; what temperatures are you using? Bhasin; 22 to 23C. King commented that healing should be looked at different temperatures. Much cooler temperatures were initially used, -15C; temperatures at which you really see cracking problems. Gayle King suggested using colder temperatures to slow down the healing process to be more accurate and to evaluate the physical hardening process. Bhasin agreed with the comment and suggestion. Little also commented regarding the temperatures and micro versus macro-scale that should be looked. Little felt it very important to look at the molecular scale as part of this model. Bhasin agreed with the comment and briefly reviewed their current and future plans related to this area.

Troy Pauli suggestion was to always rank the materials in terms of compatibility. Bhasin agreed with comment or suggestion.

Alex Schmets; maybe you need a step 0 for the initial contact point. Bhasin agreed regarding the fracture modeling in reverse.

Nelson Gibson; when you get to the mix area, do you expect the healing to be slower or faster, and are you going to vary the asphalt content? Bhasin; going to try and match the wetting process for the binder this should be independent of binder or mix. Bhasin noted that this is controlling the rate of wetting.

Richard Kim; AAD asphalt tested went out and grabbed the fracture surface area and started deforming, while AAM was different in terms that it took much longer to grab fracture surface area. Kim's question was related to the plot and rest time period. Going below 1 minute, things might be significantly different. Kim's test results in terms of healing were different than what Amit Bhasin presented. Dallas Little noted that the results were almost in reverse of what was anticipated.

There were no specific action items relative to this presentation and topic.

Chairperson Tom Scarpas noted a change to the agenda. Amit Bhasin will give his presentation on moisture damage now which was scheduled for in the morning. Hussain Bahia's presentation was moved for tomorrow.

**7. Micro Mechanical Moisture Damage Model** – Amit Bhasin (University of Texas at Austin)  
Presentation Title: *ARC – Micromechanical Moisture Damage Model*

Presentation Summary

Amit Bhasin's presentation was grouped into two basic areas; the first part was on the completed work (ideal versus practical work of adhesion and cohesion) and the second part will be on what is planned for the future. The briefing on the completed work was focused in four area topics or tasks. These were noted as:

1. Ideal versus practical work of adhesion and cohesion; Bhasin noted that the ideal work of adhesion or cohesion refers to the quantities computed using principles of thermodynamics such as surface free energy, while practical work refers to the quantities measuring using mechanical test. Although ideal work is much less than practical work, the literature suggests that the two have a direct correlation. The micro-mechanics models require the work of cohesion and adhesion as an input – this could be the ideal work or the practical work depending on the application of the model.
2. Moisture diffusion; Bhasin summarized that the previous work has addressed moisture transport through asphalt mixes and FAM. More recently measurements of diffusivity of water through thin films of asphalt have been investigated. The need for diffusivity of water through the mixture, FAM or binder is dictated by the length scale at which the modeling is carried out.
3. DMA and analytical micro-mechanics model of moisture damage; Bhasin noted that the DMA is used in conjunction with an analytical micro-mechanics models to compare performance of different FAM in wet and dry conditions.
4. Computational micro-mechanics model of moisture damage; Bhasin reported that the first of the FE models was developed in ABAQUS with the following key features:
  - a. The composite was modeled as a combination of two phases – coarse aggregate and FAM.
  - b. Cohesive damage within the FAM was modeled in terms of the degradation of its mechanical properties as a function of moisture content.
  - c. A cohesive zone element was used to model the adhesive interface of the FAM and aggregate; adhesive damage at the interface was modeled in terms of the degradation of fracture resistance of this cohesive zone element.
  - d. A sequentially coupled approach was used to model diffusion of moisture and mechanical response of the composite.

The second and shorter part of the presentation was to summarize some of the activities that are planned for the future. Future work summarized by Bhasin included: identifying practical and ideal work of adhesion in the presence of moisture for aggregate-binder systems, determining the kinetics of debonding at the interface and hysteretic effect of moisture diffusion, confirming procedure to moisture condition FAM specimens, and integrate with the cohesion zone model to model cohesive failure in the bulk.

ETG Comments, Questions, and Discussion:

Niki Kringos; what defines wet for the samples or test specimens? Bhasin; it was vacuum saturation for a short period of time. The specimens were tested at the end point, 80 percent saturation was used to define the end point. The water in the specimen was allowed to set for a longer period of time prior to testing.

At this point there were multiple discussions and debate between Tom Scarpas, Dallas Little, Imad Al-Qadi, Eyad Masad, Amit Bhasin, and Niki Kringos related to the saturation of the test specimens and its effect on the test results. Getting the specimen to 80 % saturation was a short cut for shorter time periods and then specimens allowed to set for some time prior to testing. It was noted that higher than 80% saturation can cause damage or cracking of the test specimen, so 80% was set as an upper limit.

Frank Fee; how did you adjust the air voids? Bhasin noted that they replaced or removed aggregate, did not do anything to the asphalt or compaction. Frank Fee's point; so the 4, 7 and 10 percent air voids represent different mixtures. Bhasin; yes, that is correct. (This was related to the air voids slide.)

There was some discussion and debate between Tom Scarpas, Amit Bhasin, Eyad Masad, and Niki Kringos regarding diffusion of moisture through the asphalt and air void channels. The key discussion area or point of the debate was the importance of getting uniform moisture throughout the specimen that does not have uniform channels through the specimen. Bhasin reported that the planned process was to back-calculate the moisture profiles in the specimen to evaluate moisture uniformity. This was a major discussion item. The debate on this topic was not resolved.

Frank Fee; does film thickness play an important role in this issue? Bhasin did not want to answer related to film thickness. So Fee restructured his question related to asphalt content. Bhasin; yes. Frank Fee noted that by changing the mix to vary air voids may cause some of the problem noted. The debate on the moisture diffusion through the specimen continued after Frank Fee's question. Bhasin; they looked at and evaluated how to do this, and concluded that it would be potentially misleading regarding either way you do this. To check the model or ensure that it works correctly, it does not really matter, which is what they were focusing on here. For the future work, they plan on using nondestructive techniques, like tomography, to evaluate moisture uniformity and diffusion through the sample.

Gayle King; how are you simulating the effect of driving water through the mix from truck loads; Niki Kringos calls this "pumping". Gayle King noted that this mechanism needs to include something related to forcing water through the specimen. If it does not include that, then we will probably be missing an important part of the process. Absorption of the binder into the aggregate is also important. Bhasin noted that they are starting to test the aggregate now to know or understand how important the aggregate is. They started with steel because it is a well controlled material and easy to fabricate.

There were no specific action items relative to this presentation and topic.

## **8. Performance Prediction of Asphalt Mixtures and Pavements Based on Computational Micromechanics and Multiscale Modeling – Yongrak Kim and David Allen (University of Nebraska)**

### Presentation Summary

Yongrak Kim overviewed the problem and the expected solution to the problem. First the problem – prediction of performance and service life for complex structures with complex boundary conditions using multi-phase composites with multiple length scales. The proposed solution to the problem is to use computational micromechanics modeling approach with multi-scale modeling considering material heterogeneity, inelasticity, and fracture by cohesive zone. He identified four to five key words or questions that he will focus on throughout the presentation. These are:

- Why Micromechanics?

- Why Computational?
- Why Multi-Scale Modeling?
- Why Cohesive Zone?

Yongrak Kim then gave an overview of the concept and evolution of cohesive zone model. The cohesive zone model consists of an intrinsic model (bilinear) and extrinsic model (linear). These are two ways to simulate fracture – intrinsic and extrinsic. Yongrak Kim had a simulation in the presentation that showed how the fracture begins in the HMA mixture.

Yongrak Kim noted that within the intrinsic cohesion zone you can control the initial slope but you have to be careful because it can cause errors in the solution. He then went over some of the meaningful findings from the studies completed to date regarding the intrinsic CZ, and extrinsic CZ, and rate-dependent CZ models. Yongrak Kim then gave some overviews of the modeling approach. In terms of the microstructure characterization of the mixture there are two ways; fabrication and testing of mix specimens or imaging and a virtual characterization.

He summarized the constitutive relations being used in the FEM; the mixture micro-structure – aggregates are considered elastic and the asphalt is considered viscoelastic. For aggregate testing or characterization, they are using nano-indentation testing. Cohesive zone characterization is difficult and maybe impossible.

Interface simulations; Yongrak Kim showed the results from simulations using the uniaxial dynamic modulus testing and showed comparisons with other regression equations, as well as with the indirect tensile test specimen with damage that develop cracks. Uniaxial tension simulation was also provided. All simulations appeared to be relatively good. The FEM and the Christenson  $E^*$  model matched very well with the simulations.

Yongrak Kim provided an overview of multi-scale modeling approach in terms of the problems encountered and the local and global scale modeling. Homogenization principle must be considered as part of the multi-scale model. The validation and benefits of the multi-scale modeling effort was summarized relative to the demonstrations or simulations included in the presentation.

Yongrak Kim then demonstrated the model for showing the failure of an IDT test and a roadway prediction. He also summarized some of the challenges for each of the items discussed and summarized the items discussed. The challenges listed included: rate-dependent cohesive zone model, characterization of mixed-mode fracture properties, characterization and modeling of adhesive fracture, explicit modeling of air void structures, and extension of 2D modeling to 3D simulation.

#### ETG Comments, Questions, and Discussion:

Tom Scarpas; regarding your intrinsic model, what about the interface, do you create or simulate the interface? Scarpas noted that the intrinsic model can create a bias in the results. Yongrak Kim; yes, you create the interface or designate where the interface is located in the FEM, and it can create some bias in the results.

Richard Kim; what is the computational cost for the stiffness, dynamic modulus analysis? Yongrak Kim; about two hours for the simulation using ABAQUS. Richard Kim; what about the damage IDT simulation? Yongrak Kim; takes more time, about 2 hours (on a laptop about 16 hours). The analysis or integration is done for each nodal point. Eight processors are used and about 4 hours are required. He noted that you can not simulate 1 million loading cycles.

Nelson Gibson; what about a finer grade of mix versus a coarse or larger grade aggregate, have you looked at fine versus coarse graded mixtures on the micro-scale version? Yongrak Kim; no I have not, but it can be done.

There were no specific action items relative to this presentation and topic.

Chairperson Tom Scarpas adjourned the meeting for the day at 5:20 PM.

## **DAY 2 (Tuesday, 18 September 2009)**

**Call to Order**—Chairperson Scarpas called the meeting to order at 8:06 AM. He noted that the meeting has to be concluded by 11:30 AM so time is of the essence. Chairperson Scarpas then asked Linbing Wang to start his presentation.

### **9. Micro-Mechanical Modeling of Asphalt Mixtures – Linbing Wang (Virginia Tech)**

[NOTE: The electronic copy of the presentation was provided by Linbing Wang, but that copy could not be opened or read after the meeting.]

#### Presentation Summary:

Linbing Wang stated with an overview of the motivation for this work. He overviewed the unified approach for multi-scale characterization, modeling, and simulation for stone-based infrastructure materials – the general philosophy. Linbing Wang then summarized the different capabilities of the procedure once you have the visual image and characterization of the microstructure of the mix. Virginia Tech. developed and implemented digital specimens and digital tester technique for infrastructure of the materials. This was completed for the triaxial compression test, indirect tensile test by looking at the skeleton structure of the mixture and air void structure of the mix. This was completed for the simulation studies. Linbing Wang acknowledged the partnership that was used within this work. The following summarizes the items that were included in the presentation.

- Reviewed the parameter sensitivity and parameter optimization that was completed by using the FEM.
- Back-calculated the model parameters from selected tests for using the model to estimate the response from other tests.
- SSTS, 3-D Microstructure and simulation FE.
- SSTS, Digital test integration – the have the capability to scan the specimen during the actual testing of the specimen. The scope of the study during the simulation tests included 5, 25, and 50 % solids or aggregate in the specimen to calculate the model parameters for predicting the response of the other tests.

- Simulated the APA testing – micro-scale simulation of Asphalt Pavement Analyzer test. Compared the predicted and measured observations from the test.
- Macro and Micro Strain Measurements for predicting the rut depth of the test. Showed the predicted versus measured rut depth within the APA test. Linbing Wang discussed the differences between the micro strain which are very large and macro strains used in the laboratory testing.
- Simplified multi-scale modeling method – Linbing acknowledged the individuals that have been involved in this effort to develop the method.
- Molecular dynamic simulation procedure was reviewed, the different steps involved in the procedure.
- Inter-particle atomic simulation and use.
- Average molecular structure.
- They used 3-D DVM image to determine the interface between the aggregate and binder.
- Used the process and model to look at the interface adhesion energy regarding moisture damage. They completed two simulations, one with leaving the moisture in and one with removing the moisture

Linbing Wang then presented the discussion topics for the future and acknowledged the other individuals on the topic area.

Tom Scarpas asked for additional questions, but none were asked.

ETG Comments, Discussion, and Questions Asked During the Presentation:

Dallas Little asked how do you define the interface? Linbing Wang defined it as the where the crystals from the bitumen from the TEM image at the interface – it is basically done visually using the TEM image. It is not defined mathematically or through testing – visual location through the TEM image.

Eyad Masad asked which one of the interface adhesion energy results included the water and which row did not have the water in comparing the two.

Bob Kluttz; asked about how the water molecules was simulated or structured in the simulation. When you allow the water molecules to be included in a structure. Linbing Wang agreed with Kluttz's point. Alex Schmets also commented on how the water was simulated in the model and how that could affect the results.

Steve Mueller; asked about the mold size in the simulation and what boundary conditions and boundary effects on the results. Linbing Wang noted that it was the limitation of the machine – not able to test larger test specimens. Mueller suggested that Linbing Wang take a look at the size of the specimen and how the stresses may be affected by those small sample sizes.

Gayle King; what about permeability and how this can be used to assist in mixture design for selecting and understanding mix designs related to reducing permeability – reducing the potential for interconnected air voids. Linbing Wang replied that it would be difficult to use this in terms of mixture design and selection of mixtures. Gayle King; this could be used on a global trend,

not for mix selection, but show trends between fine versus coarse mixtures related to permeability.

There were no specific action items relative to this presentation and topic.

#### **10. Discrete Element Simulation of HMA Uniaxial Creep – Tom Papagiannakis (University of Texas at San Antonio)**

##### Presentation Summary:

Tom Papagiannakis noted the reason for the study and reviewed some of the studies that have been completed in the past regarding the DEM – Discrete Element Model. Tom Papagiannakis showed a brief outline of the methodology regarding the simulation of the permanent deformation of HMA mixtures using the DEM. The creep data came from the work done by UTEP-Soheil Nazarian for the uniaxial creep test data.

Papagiannakis presented the different mixtures that were used in the laboratory and went over the testing conditions. Loads were not left on the specimens long enough to show the flow time – no accelerated permanent deformation. Papagiannakis noted that TTIs AC X-Ray computed tomography CT images were used. He thanked Eyad Masad for the images. He noted that the images had to be cleaned because of the large amount of absorption that was present in the mixtures. This was a good learning experience.

Papagiannakis summarized the process that they used to improve the imaging process and discussed the different steps used in the process. He showed the images from each of these mixtures. The one item that stood out is that the Superpave mix or gyratory cores were significantly segregated. Papagiannakis noted that the problem was horizontal segregation and not vertical segregation in the gyratory compacted specimens. Next discussion moved towards the mastic simulation and analysis as part of the overall procedure.

Papagiannakis then showed the test results measured on the test specimens. The overall summary of results was provided. He noted that the Superpave mix did its own thing and was an anomaly. The other mixtures without segregation was found to be more reasonable or expected. The simulation ran for about 2 hours. He used ABAQUS on a desktop compute. More complicated runs required overnight runs.

Papagiannakis presented the conclusions from the study. He requested creep data from any of the ETG participants in attendance. Their team would like to expand their database or mixtures tested. Papagiannakis showed the table that had to do with the wavelength question that Imad Al-Qad asked (see discussion below). He noted that they were thinking to go near sieve no. 4 in terms of fine versus coarse aggregate. The following lists his conclusions.

- Modeling HMA micro-structure at large strains is possible with DEM (DEM has an advantage over FEM).
- HMA X-ray CT image processing is not trivial; the software developed automates the process to a large extent, while maintaining realistic volumetric properties in the discretized representation.

- Additional work need in incorporating better contact damage models to better predict the beginning of tertiary flow.

ETG Comments, Discussion, and Questions:

Geoff Rowe; asked about the load application; static or repeated. Papagiannakis; static creep loads were applied, a typical creep load.

Jon Epps asked about the cores; were these images of the cores cut from the gyratory sample so that the outside edges have already been removed? Papagiannakis; yes, but that does not explain the segregation that was observed in the images.

Imad Al-Qad; how did you decide on the wave lengths or time windows? Papagiannakis replied that they used the maximum wave length as a yard length to pick the size. The break down in size is not your choice – it only affects the number of points to be used. Al-Qad noted that he uses this procedure, but in analyzing GPR data.

Imad Al-Qadi also asked about how the data was cleaned and what type of filtering was used to clean the images. Papagiannakis noted that they used the canny operator.

Alex Schmets; did you use other methods in the calibration process for the X-ray process; you need to calibrate the process? Papagiannakis noted that it has to be nondestructive. The standard was the air voids during the mixture design. Eyad Masad noted that you calibrate one by one because of the difference between the aggregate and asphalt at the interface. Eyad Masad noted that the images were good, but asked how Papagiannakis was using the data to evaluate the interfaces different process had to be used. Papagiannakis noted that for the calibration effort this was not simple.

Monte Symons; did you did the testing before you did the images? Papagiannakis replied that they did the imaging prior to do the testing, but the images were done on the same samples as the testing.

Bob Lytton; did you predict the on set of tertiary flow? Papagiannakis; yes from the stresses or strain, but noted that it was not real because the samples did not show this.

Chuck Schwartz; question about the slides that showed the experimental results in comparison to the predicted values. Papagiannakis noted that they should have continued the test until the specimens showed the tertiary creep values. Almost none of the test results showed the tertiary values. Papagiannakis noted that in his opinion once you reach the 52% strain you call it quits for the test – the flow number; this was about 2.7 hours at 60C.

There were no specific action items relative to this presentation and topic.

**11. Micro-Macro Texture Characteristics of Asphalt Mixtures – Hussain Bahia and Enad Mahmoud (University of Wisconsin)**

Presentation Title: *Mixture Design to Enhance Safety and Reduce Noise of HMA (Task VP1-a)*

Presentation Summary:

Hussain Bahia noted that he is unsure whether his presentation or topic really fits within this multi-scale modeling approach session. His presentation will focus on the noise and friction of HMA mixtures in terms if we are comfortable in measuring these properties in terms of micro-macro texture characterization of mixes. Bahia noted the issue with the polishing of aggregates and will focus on what they have done to reduce or eliminate that issue.

Bahia presented a summary of the experimental plan and the testing conditions used in the study. He provided a brief summary of the gradation analysis that was used in the testing plan. They used a modified sand patch method for laboratory conditions. Some of the sand was lost in the voids in the mix and they had to use coax to keep the volume of sand relatively constant in the laboratory. Bahia noted he will address this issue later on in the presentation.

British Pendulum number was used to measure friction on the laboratory specimen.

All mixtures were dense graded mixtures. Bahia presented some of the test results and comparisons between the gradation values (beta index) and measured values to at least note that the system is measuring something that is logical. Bahia showed and summarized some of the interim findings from the test results.

Bahia then overviewed the polishing effects issue that he noted at the beginning. Bahia noted that the stable polishing values are achieved quickly and the stable value can be achieved quickly. Bahia then overviewed the mix design for noise reduction issue. Noise properties divided into two parts; noise reduction and absorption. Noise generation is directly correlated to the macrotexture in terms of reduction but the sand patch is insufficient to determine the macrotexture. The term that Bahia is proposing to use is the macro-texture spectrum.

The next issue is noise absorption. The researchers have discovered that the low and high frequency noise is generated by certain texture wave length of the macro texture spectrum. So that at low texture wavelengths should be reduced and high wavelengths should be increased in terms of gradation for mixtures for noise and friction optimum property conditions. Bahia briefly went over the device that they originally tried to construct for measuring noise absorption in the laboratory. But after many trials, the recommendation was to discard the device.

Summary; sand patch and laser are two successful methods, but cannot be used for noise. They are continuing with the impedance tube for noise measurements, but not sure what the correlation with the field is unsure. They are going to field sites to determine the correlations. Bahia also presented a summary of progress for the functional design, which included:

- Testing procedures are under development for measuring the following for mixture samples;
  - Macro-texture (sand patch and laser).
  - Noise absorption (impedance tube).
  - Friction (British Pendulum).
- A method for simulating traffic polishing effect was introduced using the BPN.

A summary of progress made to date includes:

- Developed procedures on already existing measuring procedures and equipment with minor modifications.
- Measurements are based on laboratory compacted asphalt mixes.
  - No large asphalt slabs are required.
  - Characteristics can eventually be included within the mix volumetric design procedures.

ETG Comments, Discussion, and Questions:

Imad Al-Qadi asked whether Bahia was using the actual binder in the mix. Bahia replied yes, it was surprising that they were able to use the high compaction temperatures, but they were successful.

Tom Scarpas asked what is the reason for the obtained relationship between gradation and BPN value? Bahia noted that his explanation was that the higher the beta values there were fewer points (more coarse) in contact with the wheel so that the friction decreased. Steve Mueller requested direction of the values on that graph in what they mean. High beta value means that it is getting coarser and higher BPN values means that friction is better or more friction. Bahia; yes, that is my understanding – a higher BPN value means higher friction values. A higher beta value, means a coarser mix.

Tom Scarpas; the end of the plateau, what does it mean? Bahia; the issue is to measure the stable or consistent values of the friction, once the asphalt binder has been removed. This obviously assumes that you do not get bleeding or flushing of asphalt. The system does not consider that condition.

Amy Epps Martin - Can the CP meter give you what you need. Bahia replied yes but the issue is the sample size. We wanted to have something to put on the gyratory sample to give you an answer.

Eric Weaver asked about the footprint on the laser in terms of the diameters or resolution. Bahia; did not know what the diameter is. 0.1 mm is the horizontal 0.5 mm is the vertical in terms of the resolution. The cost of the laser is about \$7,000.

Imad Al-Qadi; how is the noise being measured? Bahia; with the use of a microphone on the field mixtures. The information presented or included in the presentation represents field correlations.

Bob Kluttz; what about the surface texture between the field and laboratory compacted specimens, is there a difference? Bahia; they are different, that is the reason for their experimental plan and these mixtures were compacted in the field. For asphalt, one of the applications is noise reduction. The sound damping effect became part of the discussion. Noise damping is the absorption into the solid. Gerry Huber had a similar comment. Geoff Rowe noted the damping from viscoelastic materials that they have been looking at for rubber type materials.

Amy Epps Martin; are you going to run your lab test on field cores? Bahia; for noise they are measuring traffic noise in the field; whereas, for friction they are using the locked wheel for measuring friction in the field.

Tom Scarpas; the British Pendulum is an indicative test. In reality, for a given combination of pavement surface and rubber characteristics, friction depends on, pressure, moisture conditions and speed.. Steve Mueller asked Tom Scarpas which test he recommends for this condition. Tom Scarpas noted that this is the topic of a much longer discussion and outside the scope of this presentation. Scarpas' point was that the friction and noise tests presented by the speaker were not fundamental but empirical. Bahia agreed that all of these are indices but that we are taking small steps in the entire process.

Gayle King; were you looking a permeability in terms of the Weibull model analysis? Bahia; no, this was only recently considered. King's opinion is that this would be a good thing to look at considering the Weibull distribution. Amy Epps Martin commented that they can consider the Weibull distribution, but have yet to do that. King's point was that we are building mixes now that are very permeable and the maintenance people do not get this either. Permeability is a key item property to identify when fog seals and other surface seals need to be planned for. There was a lot of discussion on the permeability issue and the effects of it on mixture performance.

Chairperson Tom Scarpas noted that the discussion has to be ended because of time.

There were no specific action items relative to this presentation and topic.

## **12. ARC Deliverables** – Eyad Masad and Dallas Little (Texas A&M University/Texas Transportation Institute)

Eyad Masad made the presentation on the ARC deliverables related to the ARC modeling end products and timeline and the ARC validation plan and timeline. Masad noted that two documents were provided to the ETG as part of this presentation. These two documents include; ARC Modeling End Products Description and Timeline and ARC Validation Plan and Timeline (or Validation of ARC Models and Test Method). Masad also handed out the information that is planned for us in the validation effort – this included a summary of the data included in the Nottingham database and a write up on the FHWA LAF Test Results – NCSU.

### Presentation Summary:

The presentation was grouped into three specific topics related to the ARC deliverables. These topics included software status, calibration/validation status of the models, and documentation. Eyad Masad then provided a summary of the software and the procedure used to run the ARC deliverable continuum damage model.

He summarized the three official deliverables from the project – Computational material code linked to the commercially available finite element software ABAQUS; a set of geometrical finite element models for different pavement structures in ABAQUS software; and a set of document to include guidelines to estimate or measure the material constants associated with the constitutive equations in UMAT, a theory manual which documents the constitutive equations of the continuum damage model include din the developed computation algorithms used to implement these equation in UMAT, and a description of different pavement structures – the boundary conditions, method of applying repeated loading.

Masad provided an overview of the timeline for the specific objectives and project deliverables from the project. The next item presented and discussed was the validation plan which makes use of the Nottingham database, the ALF database, and the ARC mixture testing results. This information was also provided in text summary or memo documents at the meeting. Masad also noted that all work is being stored in a shared drive hosted at UT Austin.

Eyad Masad then overviewed and summarized the models that are under development. The presentation provided a summary of the different mixture response and performance prediction. This includes the nonlinear thermo-viscoelasticity, nonlinear thermo-viscoplasticity, strength-degradation due to damage, the damage driving force, moisture-induced damage, and coupled mechanical-moisture damage. He also reviewed the different test procedure and comparison of tests being used for verification. Masad then provided an overview of the performance simulations. The performance simulations included the contours of viscoelastic strain after different load repetitions and after multiple horizontal viscoplastic strains at different temperatures. He also identified some of the future extensions that will include aging and healing predictions.

The following summarizes some of the comments related to each of the three major topics addressed during the presentation.

#### *Software Status*

- Software is documented in two reports that were presented to FHWA. The links to documents were provided in the slide.
- How will the document look – it is an engine included in ABAQUS. The deliverables were noted on the presentation and end product description – the sets of documents.
- Eyad Masad then went over the timeline for the remaining part of the project.
- Project year ends at the end of March.

Tom Scarpas; is there going to be any interaction between Richard Kim and Eyad Masad on the damage models? Masad; the combination and interaction with Richard Kim will occur in year 4.

#### *Calibration/Validation Status to Include*

- Listing of the validation databases and a summary of the data elements – what is going to be in database.
- Nonlinear Thermo-Viscoelasticity
- Nonlinear Thermo-Viscoplasticity
- Strength Degradation due to Damage
- Damage Driving Force
- Coupled Mechanical-Moisture Damage
- Calibration to define the model parameter, none of the data used to do this is used within the verification process; using the Nottingham database.
- Verification – strain rate controlled tests.
- Performance Simulations

Under the slide comparison with Nottingham database, there was a lot of discussion on how the 2-D simplification or short cut will compare with the 3-D simulation or predictions. This discussion was centered on how to account for damage build up that will not be accounted for in the 2-D simulation and plain strain and stress for the 2-D simulation.

Geoff Rowe asked about how the viscoelastic and viscoplastic strains are being separated or combined within the evaluation process. Masad gave a quick response regarding the fitting process from multiple laboratory experiments.

Eyad Masad mentioned that a short course on Advanced Constitutive Modelling of Asphaltic Materials will begin on Monday of next week. This short course will cover many of the items and topics covered within the meeting.

*How is the effort being documented?*

- ARC annual plans, quarterly reports and responses to FHWA comments.
- Archival papers published in the open literature.
- Documentation of codes.
- All documentation is available in a shared drive hosted at UT Austin.

Chairperson Tom Scarpas asked for any questions—specifically, non-technical questions. There were no additional questions asked.

### **13. Other ETG Business – ETG/Task Force Chairs**

No other ETG business was discussed in the interest of time.

### **14. Adjournment of Meeting**

Chairperson Tom Scarpas thanked everyone for attending and to Eyad Masad for the ARC work.

Tom Scarpas noted that the next meeting will be held during the week of February 22, 2010, but topics for the next ETG meeting have not been decided to date. Gayle King noted that there is a conflict with the ETG meetings and the Rocky Mountain Asphalt Pavement Conference. It was noted that all ETG meetings will be held during that week and that there would probably be only a few conflicts between the ETG members. Thus, no change in the planned ETG meeting date was made.

Co-Chairperson Dallas Little thanked Eyad Masad for his summary and requested that if there were any additional questions, please contact the team. Chairperson Tom Scarpas and Co-Chairperson Little thanked everyone for attending and to have a safe trip home.

Chairman Scarpas adjourned the meeting at 11:30 AM.

**SUMMARY OF ACTION ITEMS FROM THIS MEETING OR SUGGESTED TOPICS FOR NEXT MEETING**

Only one action items was identified during the ETG discussion of various topics, but was not discussed or reviewed at the meeting. That action item is listed below.

1. Dallas Little requested that the ETG return any comments on the white paper back to Eric Weaver within a month or two.

DRAFT

## ATTACHMENT A

### Agenda Fundamental Properties and Advanced Models ETG September 17-18, 2009 San Antonio, Texas

#### Thursday, September 17, 2009

08:00 – 08:15 Chairs	Welcome, Introductions, Approval of Minutes	ETG
08:15 – 09:00	Modeling Compaction	Koneru
09:00 – 10:00	Simplified Fatigue	Christensen/Kim
10:00 – 10:30	<b>BREAK</b>	
10:30 – 10:45	US/International Cooperative Efforts on Multiscale Modeling	Scarpas
<u>Multiscale Models and Tests: How will they contribute to the ARC final deliverables?</u>		
10:45 – 11:30	Molecular Simulations of Bitumen	Greenfield
11:30 – 12:15	Determination of structure-property relationships in bitumen at the molecular level	Schmets
12:15 – 13:30	<b>LUNCH</b>	
13:30 – 14:15	Microscale Physicochemical Characteristics of Asphalt Binders	Pauli
14:15 – 15:00	Physicochemical Characteristics of Micro Mechanical Healing Model	Bhasin
15:00 – 15:30	<b>BREAK</b>	
15:30 – 16:15	Micro Mechanical Modeling of Asphalt Mixes	Wang
16:15 – 17:00	Cohesive Zone Model	Yong-Rak Kim
17:00	Adjourn Day 1	

**Agenda**  
**Fundamental Properties and Advanced Models ETG**  
**September 17-18 2009**  
**San Antonio, Texas**

**Friday, September 18, 2009**

08:00 – 08:45	Micro Mechanical Moisture Damage Model	Bhasin
08:45 – 09:30	Discrete Element Simulation of AC Uniaxial Creep	Papagiannakis
09:30 – 10:00	Micro-Macro Texture Characteristics of Asphalt Mixes	Bahia
10:00 – 10:30	Highly Modified Binders for Reduced Pavement Thickness	Klutz
10:30 – 11:00	<b>BREAK</b>	
11:00 – 11:45	ARC Deliverables <ul style="list-style-type: none"><li>▪ Software status</li><li>▪ Calibration/validation status</li><li>▪ How is the effort being documented?</li></ul>	Little
11:45 – 12:00	Other ETG Business	Chairs
12:00	<b>Adjourn</b>	

## ATTACHMENT B

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