A Proposal to New England Transportation Consortium

NETC 13-2

HMA Mixtures Containing Recycled Asphalt Shingles (RAS): Low Temperature and Fatigue Performance of Plant-Produced Mixtures

by

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Significance of the Problem:

Transportation agencies have been recycling pavement materials for highway rehabilitation since 1915. Pavement recycling has greatly increased since the mid-1970’s, largely due to the oil embargo as well as a decrease in the availability of quality aggregates. Recent emphasis on infrastructure sustainability and Green Highway Initiatives has been driving forces beyond the significant increases observed in the use of recycled pavement materials. Several benefits arise from pavement recycling, including conservation of materials and energy, preservation of the environment, and reduction in cost. Because of these benefits, many agencies such as Federal Highway Administration (FHWA) and State Highway Agencies (SHAs) began to promote recycling (Epps 1990). It has been recognized by transportation officials that there is a vast amount of aggregate and asphalt materials already in place that can supply materials for future highway construction and rehabilitation. This recognition, in addition to the potential energy savings from not manufacturing new virgin materials and the reduction of environmental impact, has led to an increase in the use of reclaimed asphalt pavement (RAP) as an effective alternative (Lee et al. 1999; Lee et al. 2005).

Today, all 50 states accept the use of recycled pavements in some form, either as aggregate material or as a means to replace a portion of the virgin binder used in the mix (FHWA 2010). Use of RAP at levels of 20-25% by weight of mixtures is common practice and there are recent and current research projects examining RAP at higher levels. An alternate source of recycled asphalt binder, from recycled asphalt shingles, has been gaining popularity in recent years and several states are using RAS regularly at levels around 5% by weight. As a result, recycled roofing shingles (RAS) were identified as a viable replacement or supplement to RAP due to their relatively high asphalt binder content and the presence of hard mineral aggregates and fibrous filler materials (Krivit 2007). More stringent RAS processing guidelines and a better understanding of the properties of the constituent materials has led to more widespread usage of RAS materials in recent years, as 1.1 million tons of RAS were used in HMA mixes in 2010 (Hansen and Newcomb, 2011). Research on RAS has been focused on environmental and processing issues related to the material as well as studies on laboratory produced mixtures. The asphalt cement in recycled shingles is not a paving grade asphalt; it is typically highly oxidized for roofing applications. Therefore, the RAS has the potential to behave differently than RAP at typical production temperatures for RAP mixtures. This difference will have impacts on plant operations (i.e., production temperatures, mixing times, silo and transportation aging, etc.) and must be evaluated on mixtures containing RAS to optimize the effectiveness of the RAS binder. Because of the stiff nature of the original asphalt cement in shingles, the primary concern is cracking – both fatigue and low temperature. – A secondary concern is lost performance due to an effectively under-asphalted mix.

Objectives of the Research:

Plant mixtures produced with varying RAP and/or RAS will be sampled. The objective of this research will be to evaluate plant-produced HMA mixtures containing RAS to identify the critical material properties and plant operations that are needed to produce RAS mixtures with low temperature and fatigue cracking properties equivalent (or better than) typical mixtures that are produced.
Methodology:

Task 1: Literature Search for Completed and Active Research and Solicitation of Contractor Experience in the Use of RAS.

The main objectives of this project are to evaluate the critical material properties, e.g., resistances against low temperature and fatigue cracking, and plant operations, e.g., production temperatures, mixing times, silo and transportation aging, etc. that are need to produce RAS mixtures. To be consistent with the objectives of this study, a series of preliminary literature review has been conducted, and it will be continued with paying attention to recently completed and active studies, funded and unfunded research work, published and unpublished reports, journal and conference articles. Two participating universities all have the capabilities to conduct thorough literature review of the work since each university has completed a few RAP projects and have published articles/reports (Lee et al. 1998; Lee et al. 2001; Hernandez and Lee 2012).

RAS has been a developing technology for more than two decades with growing acceptance by both construction contractors and government agencies. The State of Minnesota has sponsored several research studies on the use of RAS in HMA over the past 15 years (McGraw et al. 2007). Recent literature review also indicates that Gerry Huber (2011) of Heritage Research Group presented the current state-of-the-art on RAS at the Louisiana Transportation Conference. Saman Salarie (2012) studied effects of RAS on the rheological and molecular composition properties of asphalt cement for his graduate study. Yet, one of most significant studies could be National Cooperative Highway Research Program (NCHRP) 09-55, “Recycled Asphalt Shingles in Asphalt Mixtures with Warm Mix Asphalt (WMA) Technologies.” The objective of the research being conducted by National Center for Asphalt Technology (NCAT) is to update and revise AASHTO provisional standards MP 15-09, “Use of Reclaimed Asphalt Shingles as an Additive in Hot Mix Asphalt (HMA)” and PP 53-09, “Design Considerations When Using Reclaimed Asphalt Shingles in New Hot Mix Asphalt (HMA)” to accommodate the use of RAS in WMA NCHRP 2013).

Further literature reviewed will encompass all of the significant journals that publish pavement related articles, including:

- Association of Asphalt Paving Technologists (AAPT)
- Transportation Research Record (TRR)
- Road Material and Pavement Design
- International Journal of Pavement Engineering
- ASCE Journal of Testing and Evaluation
- ASCE Journal of Materials in Civil Engineering

In addition to these articles, national and state final reports will also be reviewed, including NCHRP, FHWA, Texas Transportation Institute, NCAT, all State Department of Transportation (DOT), and others.
Task 2: Determine Potential Asphalt Mix Producers Who Might Participate in the Study By Providing Mix at the Required Designs.

Use of RAP at levels of 20-25% by weight of mixtures is common practice and there are recent and current research projects examining RAP at higher levels. An alternate source of recycled asphalt binder from RAS has been gaining popularity in recent years and several states are using RAS regularly at levels around 5% by weight. Thus, at least two asphalt plants will be identified, one or more from New England State and the other one from State of Arkansas, and HMA mixtures containing RAS will be obtained. If plants are not able to be found in these two locations, a survey of asphalt concrete plants in the New England area will be conducted to identify at least one plant that is currently utilizing RAS and RAP in their daily production. This plant will be contacted in order to obtain the proper plant produced mix for this study.

A candidate asphalt contractor would be P.J. Keating Co, which has asphalt plants in Rhode Island as well as Massachusetts. Students of the University of Rhode Island (URI) have been making field trip every spring in conjunction with Highway Engineering courses. They also have been very generous to provide all aggregates and materials whenever we need for teaching and research activities. Other favorable candidates would be D’Ambré Construction Co., Inc., J.H. Lynch & Sons, Inc., and Cardi Corporation. If needed, O’Lyn Roofing in Massachusetts and The Hudson Companies in Rhode Island will provide RAS and asphalt binders for the study, respectively.

The most likely contractor in Arkansas that will be utilized is APAC Central Inc., which has a plant in Springdale, AR, approximately fifteen miles north of the University of Arkansas (UAR). This contractor is the provider of aggregate and asphalt cement for the majority of UAR teaching and research activities, and is always willing to assist when needed.

Task 3: Identify the typical RAS/RAP Mix to be Produced and the Maximum Total Quantity of Recycled Binder that will be tested. Plant-Produced Mixes including RAS shall contain the Maximum Recommended Amount (5%).

When considering a pavement structure, there is typically a surface wearing course and a binder (and/or base) course. The wearing course is generally a 9.5mm Nominal Maximum Aggregate Size (NMAS) mixture, while the binder (and/or base) course is either a 12.5mm or 19.0mm NMAS. All three of these mixture gradations will be explored with maximum 5% RAS, and at least two levels of RAP. The anticipated amount of RAS to be tested will be 0, 2.5 and 5%. Over 20% RAP is considered a “high RAP” mixture, so one mix below 20% RAP and one mix above 20% RAP will be targeted. The anticipated amount of RAP to be examined would be 0, 15 and 25%. If it is not possible to obtain plant mixtures for all of these variations, some blends may be fabricated in the lab and correlated to field production in order to gain an understanding of RAP and RAS on gradation. Table 1 outlines the anticipated testing matrix for plant produced asphalt mixtures with RAP and/or RAS in both URI and UAR laboratoris.
Table 1. Conceptual Testing Matrix to Identify the typical RAS/RAP Mix to be Produced and the Maximum Total Quantity of Recycled Binder

<table>
<thead>
<tr>
<th>Testing</th>
<th>RAP Content, %</th>
<th>RAS Content, %</th>
<th>Number of Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superpave binder tests</td>
<td>0</td>
<td>0</td>
<td>27 specimens</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>0</td>
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<td>2.5</td>
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<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Dynamic Modulus test</td>
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<td>2.5</td>
<td>27 specimens</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0</td>
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</tr>
<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Simple Performance Test</td>
<td>0</td>
<td>2.5</td>
<td>27 specimens</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
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<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Creep Compliance and Strength Test</td>
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<td>2.5</td>
<td>27 specimens</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
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<tr>
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<td>15</td>
<td>0</td>
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<td></td>
<td>2.5</td>
<td>5</td>
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<tr>
<td></td>
<td>25</td>
<td>0</td>
<td></td>
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<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Torsion Bar Test</td>
<td>0</td>
<td>2.5</td>
<td>27 specimens</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>
Notes

1. 3 (RAP contents) * 3 (RAA contents) * 3 (specimens) = 27 (specimens) for 9.5mm Nominal Maximum Aggregate Size (NMAS) mixture.
2. 27 specimens for 12.5mm NMAS mixture.
3. 27 specimens for 19.0mm NMAS mixture.
Task 4: Identify the Performance Testing Methods to be Performed to Reveal the Critical Mix Production Temperatures of RAS Mixes that will Equal the Performance of a Typical Non-RAS Mix. Identify the Performance Properties/Relationships, Production Temperatures, etc. to be Evaluated and Describe how These Properties will be Used to Evaluate the Mixes.

Numerous laboratory tests have been developed over the years to examine performance of HMA in terms of low temperature and fatigue cracking. The combined laboratories of The University of Rhode Island (URI) and University of Arkansas (UAR) are capable of conducting all necessary tests to reveal the critical mix production temperatures of RAS mixes that will equal the performance of a typical non-RAS mix.

The URI Transportation Laboratory is equipped with most testers to characterize asphalt binder and mixtures with and without RAS. It has rotational viscometer (RV), dynamic shear rheometer (DSR), rolling thin film oven (RTFO), pressure aging vessel (PAV), and Bending Beam Rheometer (BBR), etc. to test asphalt binder. The facility contains a complete set of equipment for mixing and testing bituminous materials including Marshall, Hveem and Superpave mix design sets. In addition, it contains the Superpave Indirect Tension Tester (IDT), Automatic Asphalt Pavement Analyzer (APA), and a 25 kip servohydraulic testing system which can be used for various static and dynamic loading modes, such as resilient modulus, dynamic modulus, fatigue, flexure and creep, and Simple Performance Test (SPT). This particular system is housed in the walk-in environmental chamber, which has temperature ranges from -12° to 60°C (10° to 140°F).

The University of Arkansas is capable of performing several mixture performance tests. Specific performance test methods include the development of dynamic modulus master curves, low-temperature creep compliance and strength testing, torsion bar testing, and the Semi-Circular Bend Test (SE(B)). The dynamic modulus, creep compliance, and torsion bar test results are all indicators of rutting and permanent deformation of asphalt concrete, while the SE(B) fracture test is an indicator of cracking characteristics. Dynamic modulus (AASHTO TP 62) is a primary input into the Mechanistic-Empirical Design Guide (MEPDG) and quantifies the fundamental linear viscoelastic characteristics of asphalt concrete (Underwood et al. 2011). During this test, an axial load is applied to a cylindrical specimen that is 75mm in diameter and 90mm high. Various frequencies (as low as 0.01 Hz and as high as 25 Hz) are applied to the sample at multiple temperatures (as low as -10°C and as high as 54°C). As the load is applied, the displacement of the sample is measured, which allows for an analysis of the stress/strain characteristics of the material. This test can be used to rank the stiffness of materials, and could be entered into the MEPDG for pavement structural analysis during a Level 1 analysis.

Creep compliance (AASHTO T 322) test will determine the tensile compliance at different loading times and/or temperatures, tensile strength and Poisson ratio of asphalt mixtures using indirect loading techniques. It will provide the data required to conduct the fatigue cracking analysis at a testing temperature 20°C or less, and thermal cracking analysis using test temperatures 0°C or less with Superpave software. Specimens will be 38 to 50 mm high and 150 ± 9 mm in diameter. Creep compliance is an indicator of rutting behavior (White et al. 2002), and also can be used for low-temperature cracking analysis when it will be determined at -20, -
10 and 0°C. During this test, a constant load is applied to a sample, and the deformation is measured. These two tests may be able to differentiate between mixtures that are performing as designed and mixtures that prematurely deteriorated.

The Semi-Circular Bend test is a fracture test. During this test, samples are placed in a three-point bend testing configuration. A notch is cut into the bottom of the sample, which forces a crack to begin forming at the tip of the notch when the sample is pushed down in a load frame. By measuring the load applied during the test and the displacement of the sample, the fracture energy can be calculated. The fracture energy is an indication of how susceptible a mixture is to cracking. Higher levels of fracture energy indicate that a mix has a lower chance of cracking (Molenaar et al. 2002). Since this test quantifies the separation of material, an asphalt concrete mixture with lower adhesive or cohesive characteristics (a mixture with either low binder content or burned asphalt cement), it is anticipated that it will be able to easily differentiate mixtures susceptible to cracking.

A newer test, with the ability to run on a standard Dynamic Shear Rheometer (DSR) piece of equipment (with additional fixtures), is a torsion bar test (Reinke and Glidden 2004). This test can also indicate the rutting susceptibility of asphalt concrete using small samples sizes on a piece of equipment available in most asphalt concrete laboratories (Dave and Koktan 2011). A benefit to this test is the small sample size, which reduces the number of samples necessary to collect from the field.

Initial production (or mixing) temperatures considered would be 250, 300 and 350°F, and similar testing matrix to Table 1 will be used to reveal the critical mix production temperatures of RAS mixes.
Task 5: Identify the Test Matrix of Plant-Produced Samples that will be Tested.
Obtain Plant Produced Mix Samples, and Perform Testing to Measure Low Temperature and Fatigue Performance

The testing of each mix will include the following considerations: Superpave gyratory compaction will be used to prepare samples to be tested for the low temperature and fatigue cracking properties of HMA mixtures containing RAS.

Plant produced mix samples will be collected at least one from six New England States and the other one from Arkansas, and will be tested in accordance with the testing matrix in Task 3. The testing to examine fatigue and low-temperature cracking resistance characteristics will include Superpave binder, dynamic modulus, simple performance and creep compliance tests with/without RAS. In addition, torsion bar and the Semi-Circular Bend Test will be performed particularly to examine low-temperature cracking performance. The research team also developed a detailed possible testing matrix for fatigue and low-temperature cracking performance in Table 2 and Table 3, respectively. Final decisions will be based on results of Tasks 3 and 4, and recommendations of Technical Committee.

Table 2 Matrix for Fatigue Performance Test

<table>
<thead>
<tr>
<th>For each of the three RAP contents</th>
<th>RAS Content 1 (0% or without RAS)</th>
<th>RAS Content 2 (2.5%)</th>
<th>RAS Content 3 (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superpave Binder Tests</td>
<td>3 specimens</td>
<td>3 specimens</td>
<td>3 specimens</td>
</tr>
<tr>
<td>Rotational Viscosity DSR RTFO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic Modulus</td>
<td>18 specimens</td>
<td>18 specimens</td>
<td>18 specimens</td>
</tr>
<tr>
<td>Simple Performance</td>
<td>18 specimens</td>
<td>18 specimens</td>
<td>18 specimens</td>
</tr>
<tr>
<td>Creep compliance and Strength at 20°C or less</td>
<td>18 specimens</td>
<td>18 specimens</td>
<td>18 specimens</td>
</tr>
</tbody>
</table>

Notes: 19.0 and 12.5mm NMAS
2 (NMAS) * 3 (mixing temperatures) * 3 (specimens) = 18 (specimens)

IDT creep compliance test will be performed to measure low temperature cracking resistance in accordance with testing matrix Task 3 (Table 1). The testing will be performed in order to produce representative input data for the prediction software, e.g., TC Model. For low temperature cracking, the prediction model and/or software need material parameters. Therefore, the test will be carried out using the IDT and/or the asphalt mixture performance tester (AMPT). With the testing apparatus set up, two goals need to be accomplished. The creep compliance and tensile strength will be determined by the AASHTO procedure and given as results for the creep compliance \( D(T) \) and average tensile strength \( S_t \). On the other hand, values for the prediction software TC MODEL need to be collected.
Table 3 Matrix for Low Temperature Cracking Performance Test

<table>
<thead>
<tr>
<th>For each of the three RAP contents</th>
<th>RAS Content 1 (0% or without RAS)</th>
<th>RAS Content 2 (2.5%)</th>
<th>RAS Content 3 (5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superpave Tests</td>
<td>3 specimens</td>
<td>3 specimens</td>
<td>3 specimens</td>
</tr>
<tr>
<td>DSR</td>
<td>3 specimens</td>
<td>3 specimens</td>
<td>3 specimens</td>
</tr>
<tr>
<td>RTFO</td>
<td>3 specimens</td>
<td>3 specimens</td>
<td>3 specimens</td>
</tr>
<tr>
<td>PAV</td>
<td>3 specimens</td>
<td>3 specimens</td>
<td>3 specimens</td>
</tr>
<tr>
<td>BBR</td>
<td>3 specimens</td>
<td>3 specimens</td>
<td>3 specimens</td>
</tr>
<tr>
<td>Creep compliance and</td>
<td>27 specimens</td>
<td>27 specimens</td>
<td>27 specimens</td>
</tr>
<tr>
<td>Strength at -20, -10, and 0°C</td>
<td>27 specimens</td>
<td>27 specimens</td>
<td>27 specimens</td>
</tr>
<tr>
<td>Torsion Br Test</td>
<td>27 specimens</td>
<td>27 specimens</td>
<td>27 specimens</td>
</tr>
<tr>
<td>Semi-Circular Bend Test</td>
<td>27 specimens</td>
<td>27 specimens</td>
<td>27 specimens</td>
</tr>
</tbody>
</table>

Notes: 9.5 mm NMAS
1 (NMAS) * 3 (mix temperatures) * 3 (testing temperatures) * 3 (specimens) = 27 (specimens)

The prediction software TC MODEL is based on a variety of mathematical models which describe the material behavior. It must be mentioned that the complexity of the modeling and mathematical description is very elaborate. For instance, after applying the Laplace-transformation of the creep compliance which is described as a Prony series contains parameters from the master curve, as can be seen Equation 1.

\[
E(\xi) = \sum_{i=1}^{N+1} E_i \cdot e^{-\frac{\xi}{\lambda_i}}
\]

Equation 1

\[
\xi = \frac{t}{\alpha_T}
\]

Equation 2

Where:
- \( E(\xi) \) Relaxation modulus at \( \xi \)
- \( \xi \) reduced time
- \( t \) real time
- \( \alpha_T \) temperature shift factor
- \( \lambda \) Parameter for master curve of relaxation modulus

However, few models can describe the process of low-temperature cracking entirely without calibration of those models. This can only be achieved with practical testing and analysis of the obtained results. In this case, the creep testing over a time period of 100 or 1,000 seconds
will yield the required creep data. They will be analyzed with calculations as described in the AASHTO procedure and lead to an expression for $D(t)$. Also, the measured compliance will be put into the window shown in Figure 1.

![Thermal Cracking Input Data Window, ME PDG®](image)

**Figure 1: Thermal cracking input data window, ME PDG®**

Additionally, the tensile strength test which will be conducted at a temperature of -10°C (14°F) will determine the maximum force the material is able to bear and serve as a direct input for TC MODEL.

With this completed, the model calibration inside the software and therefore the actual prediction process can be started. Climate as well as traffic and pavement material types and layer thickness data from the site where the HMA mixtures containing RAS will be acquired and utilized for greater accuracy. Then, the prediction software will process the input data and finally deliver the output data for behavior at cold temperatures. Then, the behavior over time can be analyzed and statements about future distress and serviceability can be made.
Task 6: Develop a Plant Guideline for the Use of RAS in Virgin and RAP Mixes

Since research results are not automatically put into practice upon completion of the research, implementation is more likely when researchers and user agencies collaborate to plan for implementation. A plant guideline will be developed to include threshold values and limits on RAS usage (or RAS binder content in the mix). Upon approval of technical committee, an implementation plan will be executed. The plan will include establishment of test section(s), and the research team will participate in the performance monitoring process.

The implementation plan will also include at least two presentations at 2014 and 2015 Northeast State Materials Engineers Association (NESMEA) meetings. A project poster and recording of a project presentation will be submitted as part of the technology transfer strategy. In addition, the results will be presented at national and international conference, e.g., Transportation Research Board (TRB) etc. Then, it will be disseminated through publishing results in journals, e.g. Transportation Research Record (TRC), etc.

Task 7: Prepare a Final Report

A state-of-the-art chapter on technologies will be prepared based on Tasks 1 and 2 investigations. Results of Tasks 3 and 4 will be summarized in the sampling chapter. Data from task 5 will be analyzed statistically, and results will be included in the testing and results chapters. Chapter 6 will include a Plant Guideline for the Use of RAS in Virgin and RAP Mixes. Last chapter of the report will be conclusions and recommendations. The final report will contain an executive summary.
References


Schedule of Major Activities:

To allow for flexibility in the project start date, the schedule was prepared generically as follows:

<table>
<thead>
<tr>
<th>Task 1</th>
<th>Task 2</th>
<th>Task 3</th>
<th>Task 4</th>
<th>Task 5</th>
<th>Task 6</th>
<th>Task 7</th>
</tr>
</thead>
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</tbody>
</table>

Submission of Quarterly Progress Report to Coordinator: Quarterly Progress reports will be submitted electronically to the NETC Coordinator for distribution to the Project Technical Committee no later than three (3) working days after the end of each calendar quarter.

Submission of Draft Final Report to Project Technical Committee for Review:
The review of the Draft Final Report and resolution of review comments will be carried out within sixty (60) days.

Preparation of Final Report: After completion of the review of the draft final report, the Final Report will be prepared and submittal to the NETC Coordinator within ninety (90) days.
MEETINGS WITH PROJECT TECHNICAL COMMITTEE: To monitor the progress of the project, the research team will have a minimum of three (3) meetings with the Technical Committee. The tentative schedule will be as follows:

1. Within one month after starting the project
2. After the completion of Task 4
3. After submitting the draft final report

REPORTS: The Principal Investigator will prepare and distribute the following reports:

Quarterly Progress Reports: One (1) copy prepared and e-mailed, on a calendar quarter basis, to the NETC Coordinator. The Coordinator will forward copies to the Project Technical Committee.

Draft Final Report: Seven (7) copies of the Draft Final Report will be prepared and distributed to the members of the Project Technical Committee for review prior to printing of the Final Report.

Final Report: Upon receipt of approval from the Chairman of the Project Technical Committee to complete the Final Report, the PI will provide the following to the NETC Coordinator: 70 paper copies, bound with NETC covers and backs, and a copy in ADOBE™ Portable Document Format.

TECHNOLOGY TRANSFER STRATEGY:

Since research results are not automatically put into practice upon completion of the research, implementation is more likely when researchers and user agencies collaborate to plan for implementation. A brief practitioner guide will be developed to include threshold values and limits on RAS usage (or RAS binder content in the mix), and RAS content to minimize low temperature and fatigue cracking. Upon approval of technical committee, an implementation plan will be executed. The plan will include establishment of test section(s), and the research team will participate in the performance monitoring process, if desirable.

The implementation plan will also include at least two presentations at 2014 and 2015 Northeast State Materials Engineers Association (NESMEA) meetings. A project poster and recording of a project presentation will be submitted as part of the technology transfer strategy. In addition, the results will be presented at national and international conference, e.g., Transportation Research Board (TRB) etc. Then, it will be disseminated through publishing results in journals, e.g. Transportation Research Record (TRR), etc.
Budget and Total Cost:

The total cost for the 24 months long project would be $250,000, and the details of the budget can be found in the following separate sheet. It is anticipated that the project starts on June 1, 2014 and ends on May 31, 2016.
Appendix
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e-mail: leew@egr.uri.edu  web: www.uri.edu/cve/ritrc

(a) Professional Preparation:

<table>
<thead>
<tr>
<th>Institution</th>
<th>Field</th>
<th>Degree</th>
<th>Year</th>
</tr>
</thead>
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<td>Seoul National University</td>
<td>Civil Engineering</td>
<td>B.S.</td>
<td>1974</td>
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<td>Rutgers University</td>
<td>Geotechnical Engineering</td>
<td>M.S.</td>
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<td>The University of Texas at Austin</td>
<td>Transportation Engineering</td>
<td>Ph.D.</td>
<td>1982</td>
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(b) Appointments:

1993-present Professor, Dept. of Civil & Environmental Engineering, University of Rhode Island (URI)
1992-present Director of Rhode Island Transportation Research Center (RITRC), URI
2005-2008 Chair, Department of Civil & Environmental Engineering, URI
2007 Visiting Research Assoc., Korea Highway Corporation
1998-2002 R&D Director, Univ. of Rhode Island Transportation Center (URITC)
1996-1999 Director of Graduate Prog., Dept. of Civil and Environmental Eng., URI
1998 Visiting Professor, Rutgers Univ. and Univ. of New Hampshire
1992 & 2004 Visiting Prof., Korean Advan. Inst. of Science and Technology (KAIST)
1991 & 2007 Visiting Prof., Dept. of Civil Engineering, Seoul National Univ. (SNU)
1991 Visiting Research Assoc., Univ. of California, Berkeley
1988-1993 Associate Professor, Dept. of Civil and Environmental Eng., URI
1985-1988 Assistant Professor, Dept. of Civil and Environmental Engineering, URI
1982-1985 Asst. Prof., Dept. of Civil Eng., King Saud Univ., Riyadh, Saudi Arabia
1978-1982 Rsrch Engr. Asst., Cntr for Transportation Rsrch, Univ. of Texas at Austin
1978 Highway Construction Inspector, NJ Department of Transportation
1976-1978 Graduate Asst., Dept. of Civil and Environmental Eng., Rutgers Univ.
1976 Structural Engineer, TAMS - Engineers & Architects
1974-1976 Civil Engineer, LYON Associates Inc.
(c) Related Publications


Lee, K. W. and W. Mogawer, "Oil Spill Cleanup Debris Incorporated Into Asphalt Concrete Mixtures," Proceedings, 14th Conference of Australian Road Research Board, 1988, pp. 54-64.


(d) Synergistic Activities

Organized 26 Transportation Forums successfully including 26th RI Transportation Forum: Sustainable Transportation Infrastructure and System to Stimulate Creative Economy, October 25, 2013

Performed a Live Interactive Webinar on Practical Design for High Performing Hot Mix Asphalt (HMA) for American Society of Civil Engineers (ASCE) 2009


Received $12M University Transportation Center (UTC) Grant 1998

Established the Rhode Island Transportation Research Center at URI 1992

Founding Member of New England University Transportation Center (NEUTC) at MIT, New England Transportation Consortium (NETC), and ASCE Bituminous Materials Committee (BMC).

(e) Other Activities

• Graduate Advisors (Kennedy, T. UT Austin) and Sabbatical Sponsor (Monismith, C. UC Berkeley)

• Thesis Advisor and Postgraduate-Scholar Sponsor.

Total: Graduated 55 PhD and MS students, and supported 10 visiting scholars
Andrew F. Braham, Ph.D., P.E.
Assistant Professor of Civil Engineering
University of Arkansas
4190 Bell Engineering Center
Fayetteville, AR 72701
(479) 575-6028 afbraham@uark.edu

Education

University of Illinois at Urbana-Champaign, Urbana, IL; Civil Engineering; Ph.D., 2008
University of Wisconsin - Madison, Madison, WI; Civil Engineering; M.S., 2002
University of Wisconsin - Madison, Madison, WI; Civil Engineering; B.S., 2000

Appointments

Assistant Professor, University of Arkansas, Fayetteville, AR; 01/2011 – present
Postdoctoral Research Fellow, Southeast University, Nanjing, China; 02/2009 – 11/2010
Graduate Research Assistant, Illinois Leadership Center, Urbana, IL; 08/2007 – 05/2008

Selected Peer-Reviewed Publications

Synergistic Activities

- Creator and primary moderator of “Pavinar” webinar series (www.pavinars.uaark.edu)
- Editorial Board Member for Journal of Testing and Evaluation
- Member of Transportation Research Board committees: Characteristics of Asphalt Paving Mixtures to Meet Structural Requirements, AFK50; Committee on Pavement Preservation, AHD18; Characteristics of Bituminous Materials, AFK20
- Chair of the Newer Members Committee for the Association of Asphalt Paving Technologists
- Member of University of Arkansas committees: Transit, Parking, and Traffic Committee; Graduate Studies Committee; Sustainability Minor task group

Courses Taught

- Enhanced and taught Transportation Engineering (three semesters; junior)
- Developed and taught Advanced Materials Characterization (one semester; grad/senior)
- Developed and taught Sustainability in Civil Engineering (three semesters; senior/grad)
- Enhanced and taught Structural Design of Pavement Systems (one semester; grad/grad)
- Enhanced and taught Transportation Pavement and Materials (one semester; senior/grad)

Thesis Advisor and Postgraduate-Scholar Sponsor

- Ph.D. – Shu Yang (2011-current)
- M.S. – Sadie Smith (2013-current); Chase Henrichs (2013-current); Alex Jackson (2012-current); John Ryan (2012-current); Rob Hill (2013)
- Undergraduate Honors Thesis – Karangwa Ken Rutabana (2013-current); Sadie Smith (2013); Alex Jackson (2012)

Funding Sources

- National Science Foundation, Private industry, Hebei Province (China), Arkansas State Highway and Transportation Department, Mack-Blackwell Rural Transportation Center, University of Arkansas Department of Civil Engineering, University of Arkansas College of Engineering, Southeast University, National Natural Science Foundation of China, China Postdoctoral Science Foundation

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<th>Base Salary</th>
<th>Man Months</th>
<th>Year 1 Request</th>
<th>Year 2 Request</th>
<th>Total Request</th>
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