Improvement of Porous Pavement System for on-site Stormwater Management

Introduction

One of the priority topics in A National Green Building Research Agenda, developed by USGBC, is to “develop or improve best management practices for on-site stormwater management, including effective utilization, treatment, infiltration and storage (USGBC 2008).” A potential technology recommended by the Agenda is “porous pavement systems,” which offer advantages such as “reducing downstream flooding, limiting surface water pollution, recharging aquifers, and—in certain urban areas—reducing the frequency of combined sewage overflow problems (USGBC 2008).”

The types of porous pavements include porous asphalt, porous concrete, and several types of pavers. A successful porous pavement system retains or even improves the site infiltration capacity while not sacrificing its structural or functional requirements. There have been many studies and publications on porous pavements. One of the pioneering studies was performed by Franklin Institutes Research Laboratories in 1972. The study concluded that properly constructed porous pavements will satisfy the necessary strength and drainage requirements (FIRL 1972). However, the widespread interest on porous pavements is more of a recent trend, coinciding with the momentum of green buildings. Particularly, the use of porous pavements can assist an owner in gaining more than one LEED® credit if he or she is interested in receiving green building certification from USGBC. In 2003, the National Asphalt Pavement Association has published a guide for porous asphalt pavements (NAPA 2003). More recently, the National Ready Mixed Concrete Association also published a guide on pervious concreter pavements (NRMCA 2008). There is also a book specific on different aspects of porous pavements (Ferguson 2004).

As recognized by the Research Agenda of USGBC, porous pavements still have many unknown issues that need to be investigated (USGBC 2008) and great potential to be further improved. For example, the porous pavement system is often designed according to empirical parking lot design procedures, which simply recommends default material proportions and thicknesses, without considering the variations in climate, traffic loading, and material properties. The purpose of this study is to use innovative techniques to improve porous pavement materials as well as to refine porous pavement design process. It is expected that the study will advance knowledge on porous pavements and make them more durable, economical, and environmentally friendly.
RESEARCH GOALS AND OBJECTIVES

The primary goals of this project are to: (1) improve porous pavement technology by making pavements stronger, more durable, more affordable, and more environmentally friendly; and (2) develop a comprehensive design and operational guide for two types of porous pavement systems--porous asphalt and concrete. The goals will be achieved through the following itemized objectives:

1. Optimize pavement material selections and proportions to make the pavement system more economical without degrading its functional and structural capacity.
2. Test the use of fibers made of recycled tires or plastics to increase the strength of porous pavements.
3. Test the use of a layered base containing waste or recycled materials to make pavements more affordable.
4. Improve solar reflectance index (SRI) of asphalt pavements by adding color modification agent to asphalt surface. (Color modification agents had been recently used on conventional asphalt race track. The impact of the agent on pavement porosity needs to be investigated)
5. Develop a hydrological map based on historical precipitation data in different areas that assists pavement designers in sizing pavement thickness and storage capacity.
6. Develop recycling strategies for porous pavements when they approach to the end of life.
7. Develop a design, construction, and maintenance guide that includes both pavements and ancillary features.

If the proposal were accepted, it is anticipated that 80% of the research effort will be dedicated to goal one and its associated objectives 1, 2, 3, and 4. Figure 1 shows the types of improvements that will be investigated in the study.
Figure 1. Proposed Improvements on Porous Pavements.

**Project Narrative**

**Research Needs**

As an environmentally friendly alternative to conventional pavements, porous pavements can reduce post-development peak discharge as well as pollutant loadings. The use of porous pavements is a viable solution in places where stormwater best management practices are interested or required. In addition, if an owner plans to achieve LEED® certification for new construction, the use of porous pavements may assist the owner in receiving credits on both stormwater quantity control and quality control. However, several obstacles hinder the widely adoption of porous pavements.

One of the primary concerns for porous pavements is the higher installation cost. It is reported that porous asphalt costs 10 to 15 percent higher than regular asphalt and porous concrete about 25 percent higher than regular concrete (FHWA 2002). Since porous pavements typically require a thicker base and special site preparation (FHWA 2002), the actual cost may be even higher. Another concern is the durability of porous pavements. Higher air voids in porous asphalt pavements increase the oxidization of asphalt and make it susceptible to water damage. If porous pavement is saturated, freeze-thaw can accelerate the deterioration. The
maintenance of porous pavements is also a concern. The effectiveness of porous pavements relies on the interconnected voids in the pavement structure. If the voids are clogged, the infiltration capacity of the pavement will be reduced. Therefore, the pavements need to be maintained periodically to restore their porosity. If these concerns can be adequately addressed, the owners may be more willing to use porous pavements on their projects.

This study will develop innovative techniques to address some of these concerns and improve the overall performance of porous pavements. The first technique is to use fibers made of recycled tires or plastics to reinforce porous pavements. Recycled tires have been experimented on conventional concrete, but not on porous concrete (Siddique 2004). Traditionally, there are two technologies to use rubber from recycled tires in asphalt pavements: wet method and dry method (Rebala et al 1995). The wet method uses liquid rubber as a type of binder while the dry method uses crumble rubber as a supplement to aggregates. In this study, it is expected that rubber fibers will reinforce the pavement structure to make it stronger. As a result, the overall strength of pavement structure will be improved if pavement thickness does not change; or the thickness can be reduced if the strength requirement remains the same. In addition, the use of fibers can solve one of the constructability issues in porous asphalt pavements: draindown of asphalt binders. The second technology is to use an inexpensive material to modify the surface color of pavements. The technology had been successfully used in a project one of the researchers had managed in the past -- an F1 trace track in Canada. It is expected that the use of the material will improve Solar Reflectance Index (SRI) and make asphalt pavements less susceptible to rutting in the summer time. However, since the material has not been used on porous pavements, how to maintain the porosity of pavements needs to be examined. The third effort is to optimize material design (grade proportion and binder content) and structural design to make pavements more economical.

With a concerted effort, the new porous pavements can assist an owner in receiving additional LEED® credits. Since recycled fibers and reclaimed aggregate will be used, the credit on the use of waste materials may be obtained. By changing SRI, the credit on the reduction of heat island effects may also be achieved. Therefore, by both reducing construction cost and potentially achieving two additional LEED® credits, the owner may be more motivated to adopt porous pavements.

Research Approach

The goals and objectives of the research will be achieved through three related stages: theoretical analysis, laboratory analysis, and onsite testing. The general framework of the research methodology is shown in Figure 2. At stage one, the researchers will review the typical proportions of porous pavement materials and design new mixtures and base materials. Fibrous materials made from recycled tires and plastics will be considered for the surface
materials, while reclaimed or waste aggregate will be considered for the base materials. Several trial mixtures and base materials will be designed before they are prepared in the lab.

Figure 2. Framework of Research Methodology

At stage two, trial mixtures and base materials will be prepared and tested in laboratories. Superpave gyratory compactor will be used to prepare porous asphalt mixtures;
and porous concrete will be prepared and cured by researchers following industry standards. The prepared specimens include both commonly used porous pavement mixtures and those modified in this study. Then the surface materials will be tested for strength, durability, and permeability. To examine the strength loss of specimen after freeze-thaw, the researchers will apply multiple freeze-thaw cycles to the porous pavement materials and then test the change of their strengths. For compacted asphalt mixtures, static creep test will be used to examine its susceptibility to rutting, while indirect tensile strength test will be applied to both freeze-thaw conditioned specimens and unconditioned ones to investigate their strength and durability. For porous concrete specimens, both compressive and tensile strength tests will be performed. Freeze-thaw resistance tests on porous concrete will also be conducted. In addition, permeability tests will be performed on each type of specimen to examine their infiltration capacity. The results from these tests will be recorded and compared. If a new mixture does not meet performance requirements, it may be redesigned and retested. After stage two, the successful mixture formula will be used for field experiments. In addition, the material properties obtained from experiments, along with precipitation data from national weather stations, will be used as inputs for porous pavement thickness design.

At stage three, field tests on porous pavements will be conducted. An experimental test site will be constructed. The materials used for construction are those materials successfully passing the lab tests at the stage two. Observation PVC tubes will be installed when the pavements are constructed. The horizontal part of the PVC tubes will be perforated and placed on the top of undisturbed soil. Color modification agent will be applied to the test strip made of porous asphalt pavements. After the test sites are constructed, several in-situ tests will be performed, including:

- The strength of pavement structure, tested by Falling Weight Deflectometer (FWD). FWD is commonly used to evaluate the physical properties of a pavement. When performing the test, a dynamic load is applied by the device; and then several deflection sensors measure the deformation of the pavement in response to the load at different locations. The deflections are indicators of the overall strength. Additionally, the deflections can be used to backcalculate the dynamic moduli of different layers.
- Effectiveness of asphalt color modification agent. Temperatures of the modified asphalt surface and unmodified surface will be recorded and compared. The potential adverse effect of the agent, primarily clogging pavement voids, will be investigated through drainage test. A remedial measure, vacuuming following the application of the color modification agent, will be investigated.
- Infiltration speed of pavements. A sprinkler system mimicking rainfall will be used on top of test strips. The speed of water reaching the bottom of pavements will be recorded by using the observation tubes.
If these tests are successful, they will be used to develop porous pavement design guidelines. Otherwise, causes of underperformance will be further investigated. If it is due to material properties, pavement materials will be examined and redesigned. If it is due to insufficient thickness, thickness design procedure will be reviewed and modified. Along with these tests, constructability issues and construction cost will be recorded, which will serve as references for actual projects.

For other maintenance issues, the researchers plan to survey users of porous pavements on the maintenance issues they encountered and evaluate the effectiveness of maintenance activities.

This project will be implemented through close collaboration between East Carolina University (ECU) and Barnhill Contracting Company. The research team at ECU consists of a principle investigator, a co-principle investigator, a key researcher, and a student assistant. Barnhill Contracting is specialized in pavement construction and is ranked #166 in Engineering News-Record’s List of the Top 400 Contractors in the year of 2000. The company will provide essential assistance to laboratory tests and onsite construction. Figure 3 shows the project organization structure. The principle investigator will be responsible for overall experimental design, testing, and reporting. The Co-PI will be responsible for material processing and testing. The key researcher will be responsible for construction and coordination with Barnhill Contracting. The student assistant will be responsible for preparing test specimens, data collection, and processing. At Barnhill Contracting, the managers of the company will provide advice to the implementation of the project. The engineer will assist ECU research team in finalizing mix design and pavement structure design, while the lab technician will help prepare test specimens. The construction manager and crew will help build the actual porous pavement structure for testing.

![Figure 3. Organizational Structure of the Project](image)
An advisory board for this study will be formed. The advisory board will consist of a professor from academia who is familiar with pavement materials, the chief engineer of stormwater management program in Greenville, North Carolina, the vice president of an asphalt construction company, and material engineers from NC Department of Transportation.

Research Outcomes

It is anticipated that the study will improve the performance of porous pavements and encourage more building owners to adopt them. Pavement materials developed in this study will have different components and properties than the currently used porous pavement materials. The expected research outcomes include:

1. New porous pavement mix formula that include a certain percentage of fibers from recycled tires or plastics;
2. New base design that uses a certain percentage of aggregate from reclaimed concrete, steel slag, and other sources;
3. Optimized design procedure for porous pavement surface thickness;
4. Material and application procedure that assist modifying the color of asphalt pavement surface to reduce heat island effect;
5. A porous pavement design, construction, maintenance, and recycling guide.

Table 1 shows the contributions of these outcomes to the advancement of construction science and market transformation, their impacts on construction practices, and relationship to LEED® topics.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Knowledge Building</th>
<th>Immediate and Quantifiable Impact</th>
<th>Relevant to LEED-NC Rating Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>• Quantify reinforcing capacity of fibers from waste materials.</td>
<td>• Improved strength of pavement</td>
<td>Recycled content</td>
</tr>
<tr>
<td></td>
<td>• Identify optimum proportions of porous pavement mixtures.</td>
<td>• Use of recycled materials</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>• Quantify the strength of aggregate from waste materials in pavement base</td>
<td>Use of waste materials</td>
<td>Recycled content</td>
</tr>
<tr>
<td></td>
<td>• Identify the drainage capacity of base made from this type of aggregate</td>
<td></td>
<td>Construction waste management</td>
</tr>
<tr>
<td>3</td>
<td>• Improve pavement thickness design procedure</td>
<td>Reduction of construction cost</td>
<td>N/A</td>
</tr>
<tr>
<td>4</td>
<td>• Develop new technique to apply color modification agent on porous asphalt</td>
<td>Increase of SRI</td>
<td>Heat Island Effect: Non-roof</td>
</tr>
<tr>
<td>5</td>
<td>• Develop a comprehensive guide as an effective tool for practitioners</td>
<td>N/A</td>
<td>N/A</td>
</tr>
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</table>
Due to the lack of data, it is difficult to quantify the impact of research outcomes at this time. However, if the use of fibers in asphalt mixture can cause one inch reduction in surface thickness, the savings for a three inch surface course would be around 33% and savings for a four inch surface course would be around 25%. If 0.8 percent (by weight) of fibers is introduced to the surface mixture, it is estimated that an 100 ft by 100 ft lot with 3 inches of asphalt would consume around 100 recycled tires (assume that the unit weight of porous asphalt mixture is 110 lb/ cu ft and the average weight of recycled tires is 20 lb). Based on a study performed in 1980s in Washington D. C. area (MWCOG 1983), the pollutant removal efficiency of porous pavements for several common pollutants are: total suspended solid (TSS), 95%; total phosphorus (TP), 60%; total nitrogen (TN), 88%, and metals, 99%. Due to the large number of parking lots being built and rehabilitated every year, the study will have significant impact on stormwater quality even if it causes a slight percentage of increase in using porous pavements.

**Research Tasks and Milestones**

It is anticipated that the objectives of this study will be accomplished by completion of the following tasks but they may be modified as more information is obtained.

1. **Design Porous Pavement Mixtures and Bases**
   The researchers will study the commonly used mixtures and base materials and design new fiber-based mixtures and alternative base materials.
   Duration: 1 month   Expected expense: $3,876   Grand Request from USGBC: $500

2. **Process/Purchase Materials and Devices for Lab Test**
   The researchers will process materials, particular fibers, used for further laboratory test. Unavailable materials and test devices will be purchased.
   Duration: 3 months   Expected expense: $14,626   Grand Request from USGBC: $4,259

3. **Perform Lab Test**
   The trial surface and base materials will be tested in a lab.
   Duration: 2 months   Expected expense: $14,651   Grand Request from USGBC: $4,300
4. Analyze Data Based on Lab Test Results and Re-design if Necessary
   The lab test data will be compared and analyzed. If the test results do not meet
   performance expectations, the researchers will redesign the mix and base materials.
   Duration: 3 months   Expected expense: $19,200   Grand Request from USGBC: $8,690

5. Design Porous Pavement Structures for Onsite Test
   The research team will design porous pavement structures based on different assumptions
   on traffic loading, precipitation, and subgrade soil conditions.
   Duration: 2 months   Expected expense: $16,400   Grand Request from USGBC: $9,900

6. Process/Purchase Materials and Devices for Onsite Test
   The researchers will process and purchase materials for onsite test as well as purchase or
   rent equipment for onsite test.
   Duration: 3 months   Expected expense: $27,845   Grand Request from USGBC: $15,400

7. Construct Experimental Test Sites
   Barnhill Contracting Company will construct experimental test sites according to design.
   Duration: 2 months   Expected expense: $58,200   Grand Request from USGBC: $8,179

8. Conduct Onsite Experiment
   The researchers will conduct experiments such as testing strength and infiltration rates.
   Duration: 2 months   Expected expense: $17,831   Grand Request from USGBC: $5,900

9. Analyze Data Based on Test Results
   The researchers will analyze test data from onsite experiments. If the performance does not
   meet expectations, the materials and structures may be redesigned.
   Duration: 2 months   Expected expense: $24,500   Grand Request from USGBC: $14,234

    The researchers will develop this guide based research results and existing literature
    Duration: 2 months   Expected expense: $14,145   Grand Request from USGBC: $8,910

11. Prepare Quarterly Reports
    Every quarter, a progress report will be prepared according to USGBC requirements.
    Duration: 1 week   Expected expense: N/A   Grand Request from USGBC: N/A

12. Prepare Final Report
    At the end of the study, a detailed final report will be prepared.
Duration: 2 months  Expected expense: $10,740  Grand Request from USGBC: $10,570

Schedule

Table 2 lists the schedule of the project based on the expected tasks.

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
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<td></td>
<td></td>
<td>Q4</td>
<td>Q1</td>
<td>Q2</td>
</tr>
<tr>
<td>1</td>
<td>Materials Design</td>
<td>1/1/2008</td>
<td>1/31/2008</td>
<td>🟢</td>
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<tr>
<td>3</td>
<td>Prepare Quarterly Report</td>
<td>1/1/2009</td>
<td>1/7/2009</td>
<td>🟢</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Prepare Quarterly Report</td>
<td>7/1/2009</td>
<td>7/7/2009</td>
<td></td>
<td>🟢</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Construct Test Site</td>
<td>9/1/2009</td>
<td>10/30/2009</td>
<td>🟢</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Conduct Onsite Test</td>
<td>11/2/2009</td>
<td>1/29/2010</td>
<td>🟢</td>
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</tr>
<tr>
<td>12</td>
<td>Prepare Quarterly Report</td>
<td>1/1/2010</td>
<td>1/7/2010</td>
<td></td>
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<tr>
<td>13</td>
<td>Analyze Onsite Test Results</td>
<td>2/1/2010</td>
<td>3/29/2010</td>
<td></td>
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<td></td>
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<tr>
<td>16</td>
<td>Develop Quarterly Report</td>
<td>7/1/2010</td>
<td>7/7/2010</td>
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<tr>
<td>17</td>
<td>Prepare Final Report</td>
<td>8/16/2010</td>
<td>9/30/2010</td>
<td>🟢</td>
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<td></td>
</tr>
</tbody>
</table>

Table 2 Schedule of the Project

Qualifications of PI and Research Team

Dr. Yuhong Wang, PE, Principal Investigator

Dr. Yuhong Wang is an assistant professor in the Construction Management Department at ECU. He has strong interest in sustainability and has also developed extensive experience in pavement materials when he worked as a material research engineer at Kentucky Transportation Center. He was principal investigators for several pavement related studies sponsored by Kentucky Transportation Cabinets. He had published several papers on pavement design and made four presentations on International Transportation Research Board conference. He had developed and taught a class named “Sustainability in Construction.” Dr. Wang had collaborated with researchers on two sustainability related studies: sustainable
development planning for Hengshui Lake area in China (Sponsored by World Bank) and pollutant analysis of bridge deck runoff from NC Currituck bridge (by the Turnpike Authority).

**Dr. George Wang, PE, Co Principal Investigator**

Dr. George Wang is currently an assistant professor in the Construction Management Department at ECU. Before joining ECU, Dr. Wang had more than 20 years of research and industry experience in construction materials, industrial solid waste utilization and pavement engineering. He also conducted many storm water management studies for industrial distribution centers, residential and commercial parking areas, airport runway, taxiways when he worked as a principal research engineer. Dr. Wang published many papers on asphalt pavement materials and acted as course leaders in domestic and international seminars in pavement technology.

**Dr. David Batie, Key Researcher**

Dr. David L. Batie is an associate professor in the Construction Management Department at ECU. As a licensed architect, he has a long history and interest in sustainable construction, and is currently pursuing the LEED certification for Existing Buildings. He had extensive industrial experience in construction, including managing design and construction of the Universal Studios’ studio-theme park in Florida. He is engaged with other faculty members to develop a Center for Sustainable Construction at ECU.

**Budget**

The budget for this project is $222,014. The research team requests a grant of $90,842 from USGBC (40.9%), while ECU will be matching $71,172 (32.1%) and Barnhill Contracting will be matching $60,000 (27.0%). The grant from USGBC will be primarily used to support testing, a student assistant, and partial summer salaries of researchers. The matching fund from ECU will be used to release class time for researchers. The matching fund from Barnhill Contracting will be used to purchase testing materials, prepare lab samples, and construct onsite test sections.

**Human Subjects Review**

N/A

**References**


Rebala, S R and Estakhri, C K. 1995. laboratory evaluation of crumb rubber modified mixtures designed using txdot mixture design method. Transportation Research Record, Iss. 1515, p1-10
