TEXAS TECH UNIVERSITY
Multidisciplinary Research in Transportation

PROJECT SUMMARY

Texas Department of Transportation

0-6868 (Phase I): Novel Material Systems for the Next Generation of Flexible Pavement Structures

Background

This research project was funded under TxDOT RFP #15-1 *Leadership in Transportation Innovation—Technical Area 1: Enhanced Durability and Asset Life of Existing and New Infrastructure*. This research project was designed to be conducted in three phases: Phase I–Design and Demonstration (18 months), Phase II–Integration Component Demonstrations (24 months), and Phase III–Final Demonstrations (12 months). Phase I was intended to demonstrate any associated high-risk technologies, including the use of material systems to extreme service temperatures in the pavement surface layer, and to improve the quality and performance of layers supporting it. Phase I concluded with the construction of exploratory field test sections containing novel materials systems. Research activities were carried out by seven research groups at Texas Tech working on pavement material systems, chemical processes, molecular simulation, geotechnical support systems, energy and service condition optimization, constructability and cost-benefit analysis, and sustainability-based life-cycle assessment (LCA), respectively.

What the Researchers Did

The chemical processes group investigated polymeric modifiers for asphalt binders to provide enhanced rheological properties in the temperature range of 50 to 70 °C, which is most relevant to rutting problems in Texas roadways. In addition, microencapsulated phase change materials (PCMs) were investigated for their feasibility to lower the maximum temperature of a flexible pavement surface layer. The molecular simulation group conducted dynamics simulations to study the rheological properties of asphalts modified with atactic polypropylene (aPP) and the heat transfer properties of asphalt containing encapsulated PCM. The geotechnical support systems group focused on the development of strong and stable base/subbase systems and innovative stabilizers to minimize moisture-induced swelling and sulfate heave of highly-plastic clay soils.

The energy condition optimization group studied the heat transfer and maximum surface temperature in flexible pavement systems that include PCMs. In addition, they performed energy and exergy-based analyses to quantify the heat loss and exergy destruction during material production and construction of flexible pavements. The constructability and cost-benefit analysis group reviewed the flexible pavement construction processes containing both conventional and novel material systems. Furthermore, this group conducted a comprehensive life-cycle cost analysis (LCCA) using a framework developed in this study for conventional and novel pavement systems. The sustainability-based LCA was conducted for both conventional and novel material systems using a proprietary software package that contained a comprehensive sustainability database and an analysis framework. Data input interfaces were developed to integrate five processes within the flexible pavement life-cycle and the proprietary software system to easily incorporate LCA to evaluate various pavement design alternatives. The pavement material systems group coordinated and conducted the systems integration of all the activities described above, conducted planning and construction of exploratory field test sections at the end of Phase I and assisted in the design and installation of the field data acquisition system.

What They Found

Pavement system simulations conducted using available protocols revealed that controlling extreme pavement surface temperatures in flexible pavements can significantly extend pavement service life. From three polymeric modifiers studied, including polydimethylsiloxane, poly(n-butyl acrylate), and a polyolefin copolymer, the polyolefin copolymer was

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found to have the greatest potential to function as a cost-effective rheological modifier for asphalt binders. From two encapsulated PCM materials studies, a hydrocarbon wax (melting point 43 °C) encapsulated by micrometer-sized polymeric shells was selected as the best material for mediating temperature fluctuations. Both materials have been incorporated in exploratory field test sections. Molecular simulations showed that the addition of aPP did not change the glass transition temperature of asphalt but increased its viscosity and stiffness at high temperatures. The interfacial thermal resistance in asphalt cement containing encapsulated PCM is small and can be added to asphalt without concern for a reduction in the heat transfer rate in the system. Two mix designs for flowable fill base materials were developed based on laboratory findings. These mixes were incorporated in high and low conductivity environments (i.e. with and without metal geocells) to study their influence on heat transfer in the pavement system. Among the soil stabilizers tested, one that was synthesized by mixing Class C fly ash and an alkaline activator solution showed the best promise to stabilize high-plastic weak, subgrade soils containing sulfates.

Heat transfer simulations showed that novel pavement systems containing PCM yield lower surface temperatures compared to conventional systems. Furthermore, a higher temperature drop through the PCM-embedded asphalt layer was observed compared to a pavement without PCM. The simulation also showed that increasing PCM volume fraction beyond 60% results in higher surface temperature values. This may be due to PCM having a lower thermal conductivity than other components in the asphalt-concrete. The energy/exergy analyses revealed several possible ways to reduce energy consumption during the flexible pavement construction process.

The constructability review indicated that precast pavement technology is a possible option to meet the need for rapid construction and repair of asphalt concrete layers. The review also recommended a long-term performance monitoring system for novel flexible pavement material systems since flexible pavements are subjected to traffic and environmental loads that are repeatedly applied over their life cycles. The LCCA shows that initial construction cost, discount rate, length of first performance period and rehabilitation cost are critical inputs in the analysis. The comparison between conventional and novel pavement systems shows that all novel designs cost more than conventional ones. However, provided the length of first performance period increases, novel designs with added polymer could become economically competitive. Twelve exploratory flexible pavement test sections using novel material systems were considered for further monitoring before full-scale pavement sections are constructed during a second phase of this research and six of them were constructed and instrumented at the field test site. They are being monitored using a comprehensive, automatic data acquisition system designed and installed by the research team.

What This Means

Several novel material systems were identified as feasible options to significantly extend the service life of flexible pavement systems. These include the use of a novel polymer modification protocol for asphalt using polypropylene, use of phase change materials to control extreme pavement surface temperatures, use of innovative flowable fill systems that can improve constructability and heat transfer efficiency in the pavement system, and novel materials that can stabilize high-plastic clay soils in Texas to mitigate pavement damage. Furthermore, two custom-developed protocols developed in Phase I are ready to be tested to conduct LCCA and sustainability-based LCA to enhance the pavement design process that can result in cost-effective, sustainable flexible pavement systems capable of significantly extending pavement service life. It is important that the exploratory work conducted in Phase I needs to be extended to an industry-scale testing phase to continue refinement of novel material systems already developed, and to calibrate the LCCA and LCA protocols.

For More Information

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