ASPHALT MATERIALS & PAVEMENTS PROGRAM

Development of Bio-Based Polymers for Use in Asphalt – Phase II

tech transfer summary

The Iowa Highway Research Board (IHRB) recognized that the development of biopolymer technology for asphalt paving was high-risk/high-potential-pay-off research that Iowa is uniquely positioned to address and possibly capitalize on.

Problem Statement

Due to the environmental, safety, and economic concerns related to using petroleum-derived polymers, there is a rising demand for biopolymers that are sustainable, biodegradable, environmentally friendly, cost-effective, and less toxic than petroleum-derived polymers (Zhu et al. 2014, Kowalski et al. 2016).

Project Goals

The overall goals of this research were to develop and optimize the formulation of biopolymers to maximize performance in asphalt modification and ensure the successful large-scale production of biopolymers in Iowa State University's biopolymer pilot plant. In addition to these two areas of focus, the other main focus was to combine biopolymers with rejuvenators (in liquid form) for use with reclaimed or recycled asphalt pavement (RAP) and recycled asphalt shingle (RAS) mixtures and utilize this material for field demonstrations while characterizing binder and mix performance.

Biopolymer pilot plant capable of producing 10 tons of polymer per week that was built just west of Iowa State University at its BioCentury Research Farm as part of this research project

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RESEARCH PROJECT TITLE
Development of Bio-Based Polymers for Use in Asphalt – Phase II

SPONSORS
Iowa Highway Research Board
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The Asphalt Materials and Pavements Program (AMPP) at InTrans specializes in improving asphalt materials and pavements through research and technology transfer and in developing students' technical skills in asphalt.

IOWA STATE UNIVERSITY
Institute for Transportation

Project Objectives

- Demonstrate how biopolymers are produced using non-food soybean oil
- Evaluate how laboratory-produced biopolymers perform rheologically in asphalt against the performance of commonly used petroleum-derived polymers
- Optimize the formulation of the biopolymer based on the performance grading results that can modify a neat asphalt binder from performance grade (PG) 52–34 to PG 64–28 for warm climate region pavement applications
- Verify the modification effects of the optimized biopolymers with proposed polystyrene (PS) parameters by conducting performance grade tests
- Produce 600 gallons of biopolymer from the biopolymer pilot plant and have the biopolymer-modified asphalt mixture paved on the National Center for Asphalt Technology (NCAT) Test Track at Auburn University in Alabama
- Formulate biopolymer/rejuvenator dosage combinations for use in field trials and perform mix characterization tests on the field-produced mixes from trials

Background

The rheological properties of an asphalt binder have a significant impact on asphalt pavement performance (Liang et al. 2016). Primary pavement distresses such as rutting at high temperature, thermal cracking at low temperature, and fatigue cracking due to repeated traffic loading are related to the rheological properties of the asphalt materials in pavement construction (Chen et al. 2002, Liang et al. 2015, Moreno-Navarro et al. 2015).

To improve the performance of asphalt binders, modifiers or additives such as styrene-butadiene styrene (SBS), styrene-butadiene rubber (SBR), and ethylene-vinyl acetate (EVA) have been used to modify asphalt (Isacsson and Lu 1995).

Triglycerides are known as the most important renewable resources for producing biopolymers due to their special chemical structure that consists of three fatty acid chains connected by one glycerol center (Grishchuk and Karger-Kocsis 2011, Habib and Bajpai 2011, Salih et al. 2015). Triglycerides can be polymerized with flexible and rubbery properties to replace the petroleum-derived butadiene in styrenic copolymers (Yan et al. 2016).

Such high-value materials derived from vegetable oil can be produced within the Midwest and create tremendous economic opportunity to replace a dangerous and carcinogenic material, such as butadiene, which is derived from crude oil petroleum. The majority of butadiene is imported to use for subsequent production of polymers or is contained in polymers imported to the US.

Since the conclusion of the first phase of this study in April 2014, a ton-per-day pilot plant was designed and built at Iowa State University's BioCentury Research Farm, west of Ames, at a cost of more than $6 million. The pilot plant was installed in late 2015, winterized for the 2015–2016 winter, and reopened in Spring 2016.

The research team worked since the completion of the Phase I IHRB project in getting the pilot plant working and correctly calibrated. The Bio-Polymer Processing Facility underwent rigorous troubleshooting and upgrades during 2016 and became capable of producing biopolymers in sufficient quantities to conduct field demonstration paving projects. This effort was vital in determining the technical and economic feasibility of producing the biopolymers to use in asphalt modification.

Research Description

The use of polymers to improve asphalt performance is currently commonplace in the US, especially given the concerns about certain distresses (rutting, fatigue cracking, and thermal cracking at low temperatures). For this phase of the project, biopolymer evaluation was conducted through the creation of the various biopolymers considering the base asphalt and mix factors.

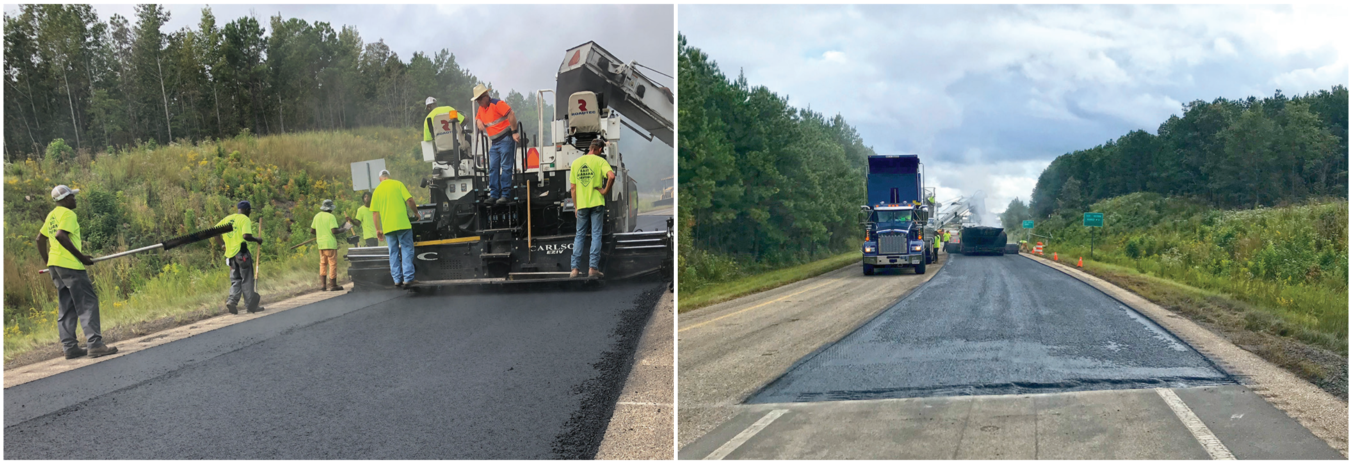
The various biopolymers would all be blended the same way with the same binder and then put through a complete rheological characterization test plan. More than 30 different blends were created in the laboratory to explore the impacts of changing doses or other variables.

The test plan included collection of dynamic shear test results for both unaged and rolling thin-film oven (RTFO) short-term aged modified asphalt blends and bending beam rheometer test results for long-term aged binders to determine the optimum amounts needed in the biopolymer to obtain maximum performance from polymer-modified asphalt.

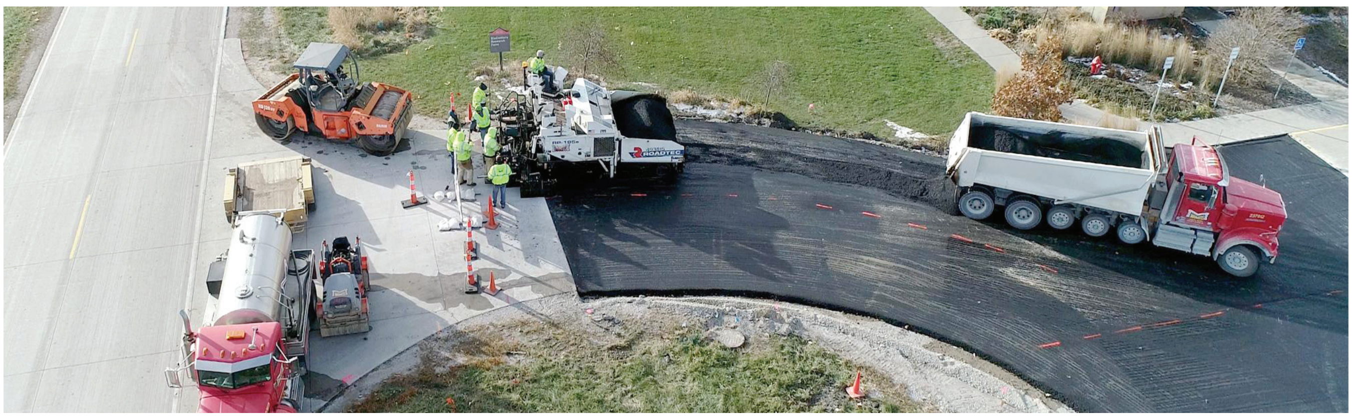
After determining the optimized parameters for the biopolymer, trial-optimized biopolymers were produced, and rheological characterization results were verified with regression model and master curves, and black space diagrams were produced and analyzed. After this step was the production of 600 gallons of biopolymer from the biopolymer pilot plant with optimized PS parameters.

Further research for this project entailed the development of a biopolymer and rejuvenator combination named BioMAG for mixtures utilizing RAP and switching the operation of the pilot plant over to produce this material. This material was then used to formulate dosages for three different field sections.

Mix performance testing for the field-produced mix was then conducted for three field test sections, which included placement of the biopolymer-modified asphalt mixture in pavement at the NCAT Test Track and at two sites in Iowa.



NCAT Test Track paving and compaction using first generation of BioMAG (biopolymer-modified asphalt mixture)



Second field demonstration site paving in Iowa at the University's BioCentury Research Farm after using a newer blending procedure called a master batching process

Key Findings

NCAT Test Track Paving

- Test track paving at NCAT was a success given it proved that the biopolymer could be produced on a large scale and blended into an asphalt binder at asphalt mix facilities currently doing paving.
- The NCAT test also demonstrated that the biopolymer-modified asphalt mixture can be easily compacted and paved in a manner similar to other commercial polymer-modified asphalt mixtures in construction.
- After 14 years of simulated wear from heavily loaded semi-trailers in a three-year period, less than 3 mm of rutting was experienced by the test section.

Iowa Field Demonstration Formulations and Blending

- The final outcomes achieved better performance using BioMAG in Iowa than were expected—reaching a performance grade (PG)58-28V with the RAP binder included—given the elastic recovery was significantly higher due to the master batching procedure.
- The low temperature was able to be reduced from -23.0°C to -29.9°C, even with the inclusion of RAP, while also improving the high temperature performance, illustrating the unique benefit of using BioMAG and blending it in an integrated manner at the facility.

Mixture Formulation and Blending

- It was shown that, with ideal blending conditions, the asphalt binder can reach very high levels of performance by improving the elastic behavior and decreasing the thermal cracking potential at the same time.
- Even under less-than-ideal blending conditions, the BioMAG blends were able to meet the goals of the formulation.
- Detailed findings on the mixture formulation results are included in the Conclusions chapter of the final report for this project.

Implementation Readiness and Benefits

The biopolymers developed by Iowa State University were found to be an excellent alternative to the polymers currently used. Much was learned from the execution of the demonstration projects, and many useful industry connections were made with contractors and terminal suppliers.

This project is beneficial in demonstrating that the performance of the biopolymers developed meet expectations and have cost advantages. The outcome will be the development of a biopolymer that has cost and performance advantages for use on roads in Iowa. This project will also be beneficial in the development of new materials produced from Iowa feedstock materials (e.g., vegetable oil) and produced in Iowa.

This research has the potential to have a substantial impact on the Iowa economy through job creation, future tax revenue, and the export of a high-value specialty product, which has also shown success in numerous other applications, including adhesives, coatings, and packaging materials.

In the future, additional demonstration projects will be completed with even greater amounts of RAP, and the projects will be conducted in more diverse climates and conditions throughout the nation. Achieving the goals of this Phase II project will further the development and growth of biopolymer-modified asphalt mixtures and help enable the use of these mixtures throughout the US in the future.

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