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Development of Non-Petroleum-Based Binders for Use in Flexible Pavements – Phase II

R. Christopher Williams
Iowa State University, rwilliam@iastate.edu

Elvira Joana Joana Ferreira Ferreira Peralta
Iowa State University, peralta.joana@gmail.com

Ka Lai Nieve Ng Puga
Iowa State University, k_lai_ng@yahoo.com

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Abstract

Bio-binders can be utilized as asphalt modifiers, extenders, and replacements for conventional asphalt in bituminous binders. From the rheology results of Phase I of this project, it was found that the bio-binders tested had good performance, similar to conventional asphalt, except at low temperatures. Phase II of this project addresses this shortcoming and evaluates the Superpave performance of laboratory mixes produced with the enhanced bio-binders. The main objective of this research was to develop a bio-binder capable of replacing conventional asphalt in flexible pavements by incorporating ground tire rubber (GTR) into bio-oil derived from fast pyrolysis of agriculture and forestry residues. The chemical compatibility of the new bio-binder with GTR was assessed, and the low-temperature performance of the bio-binders was enhanced by the use of GTR. The newly developed binder, which consisted of 80 percent conventional binder and 20 percent rubber-modified bio-oil (85 percent bio-oil with 15 percent GTR), was used to produce mixes at two different air void contents, 4 and 7 percent. The laboratory performance test results showed that the performance of the newly developed bio-binder mixes is as good as or better than conventional asphalt mixes for fatigue cracking, rutting resistance, moisture sensitivity, and low-temperature cracking. These results need to be validated in field projects in order to demonstrate adequate performance for this innovative and sustainable technology for flexible pavements.

Keywords

Asphalt pavements, Asphalt rubber, Binders, Blends, Fatigue cracking, Flexible pavements, Laboratory studies, Mixtures, Polymers, Pyrolysis, Rheology, Rubber, Sustainable development, bio-binder, bio-oil

Disciplines

Civil Engineering

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tech transfer summary

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RESEARCH PROJECT TITLE
Development of Non-Petroleum-Based Binders for Use in Flexible Pavements – Phase II

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PRINCIPAL INVESTIGATOR
R. Christopher Williams
Professor, Civil, Construction, and Environmental Engineering
Director, Asphalt Materials and Pavements Program, Institute for Transportation
Iowa State University
515-294-4419
rwilliam@iastate.edu

MORE INFORMATION
www.intrans.iastate.edu

Asphalt Materials and Pavements Program, Institute for Transportation
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103
www.intrans.iastate.edu

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.

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In this study, the low-temperature performance of the bio-binders studied in a previous phase of this research was enhanced using ground tire rubber.

Background

The substantial increase in oil prices over the past few years has been reflected in asphalt prices. Moreover, the maximization of fuel production in refineries has reduced asphalt supply. These conditions have prompted the development of alternative sources of asphalt binders, including bio-oils derived from the fractionated fast pyrolysis of biomass that comes from agricultural and forestry residues, e.g., oakwood, switchgrass, and cornstover.

Phase I Research Findings

In 2010, the feasibility of using non-petroleum–based binders in flexible pavements was studied. These binders come from alternative sources, particularly from the waste products of bio-renewable resources, namely bio-oils. The main findings in Phase I revealed that bio-oils need a pre-heat treatment in order to be used as pavement binders and that Superpave procedures for evaluating binder performance need to be modified to accommodate the particular properties of bio-binders.

While the rheological properties of neat bio-binders differed from those of conventional asphalt binders, polymer modification of the bio-binders significantly changed their rheological properties and made their rheological behavior similar to that of conventional asphalt binders. Good high-temperature performance grades were obtained for the bio-binders, which performed similarly to conventional binders. However, low-temperature performance grades varied greatly from those of conventional binders.

Iowa State University biofuels fast pyrolysis pilot plant (Image: Bob Mills, Iowa State University Bioeconomy Institute)

Project Objectives

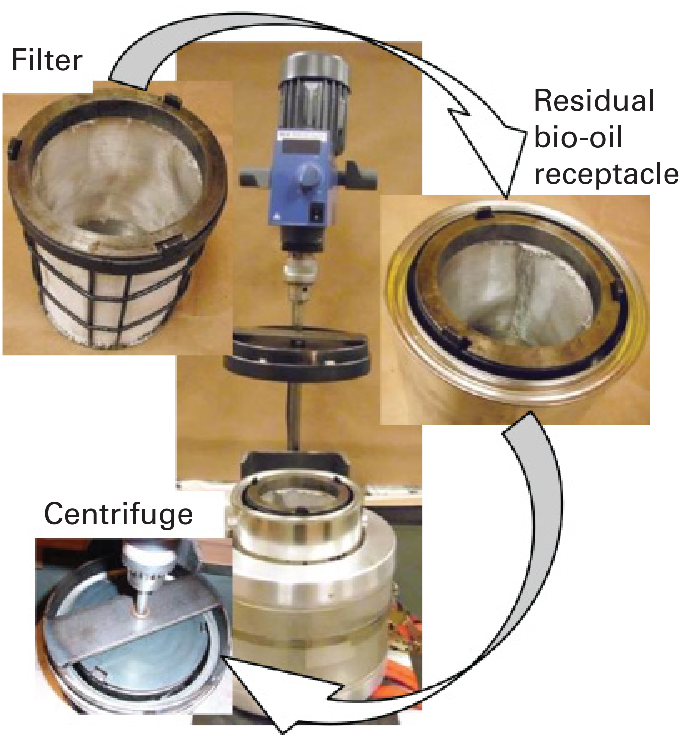
The project objectives were to improve the low-temperature performance of bio-binders by developing asphalt-rubber mixtures made from ground tire rubber and an optimized binder (using petroleum asphalt, bio-oils from fast pyrolysis of biomass, or both in combination) in order to improve performance throughout the life of the pavement and provide greater stability during the production and construction stages. These objectives were achieved by developing and evaluating the performance of laboratory mixes with the modified bio-binders.

Research Methodology

Conventional asphalt binders; bio-oil produced from fast pyrolysis of red oak (*Quercus rubra*); and ground tire rubber from two processing methods, ambient (amb) and cryogenic (cryo) grinding, were evaluated in this research.

The Fourier transform infrared (FTIR) spectroscopy method was used for the chemical characterization of the conventional binders, bio-oil, and modified bio-oils (MBO). Changes in bio-oil viscosity upon heating over time were assessed.

The binder accelerated separation (BAS) method was developed to separate the ground tire rubber from the bio-binders so that the real change in the bio-binders due to the ground tire modification could be quantified without the influence of the ground tire rubber particles. Specific gravities were determined for the bio-binders.



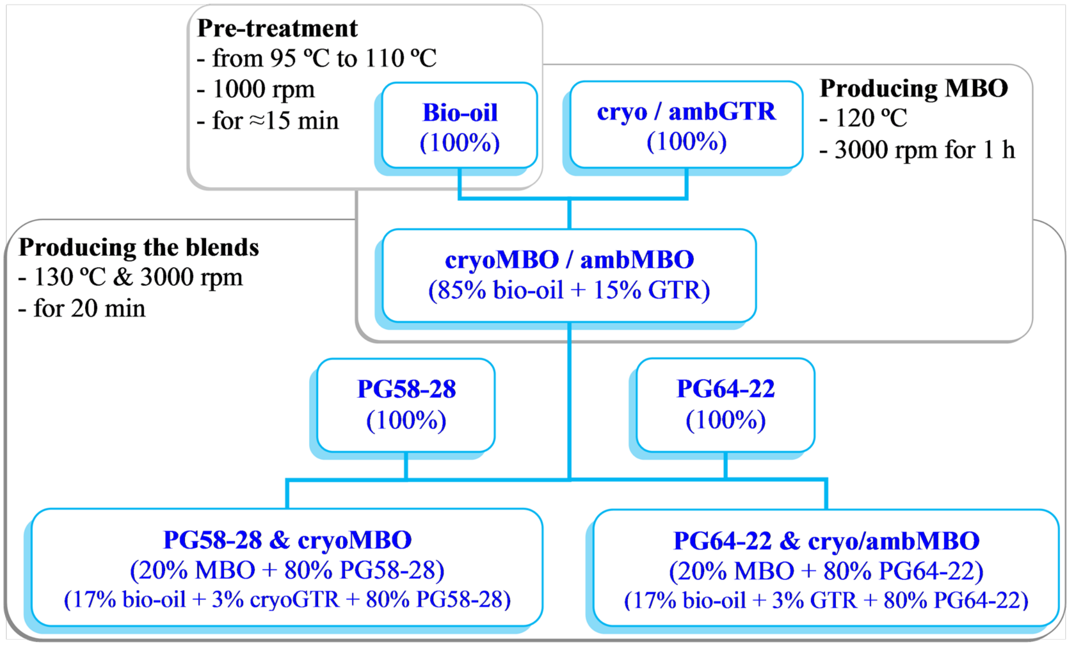
Binder accelerated separation method

Rheological testing of the materials involved the determination of their viscosities; short-term aging simulation; mass loss determination; high-, intermediate-, and low-temperature performance grading of the developed bio-binders; and storage stability or separation susceptibility testing.

The asphalt mixtures developed were compacted in a Superpave gyratory compactor. Several methods were used to assess the mixtures' performance: indirect tensile strength ratio (TSR) test to assess moisture susceptibility, four-point beam fatigue test to assess fatigue cracking resistance, dynamic modulus, flow number, and semi-circular bending test.

Key Findings

- A bio-binder consisting of fractionated bio-oil reacted with crumb rubber can produce a binder that is comparable to asphalt binders derived from crude petroleum.
- Bio-oil can successfully react with crumb rubber at 125°C, which is substantially lower than the temperature used in normal asphalt binders, typically around 185°C.
- Of the two types of ground tire rubber used in this study, the cryogenic rubber is more effective than the ambient ground rubber at producing lower temperature grades; the stiffness of the bio-binders containing the cryogenic rubber is lower than that of the ambient rubber at low temperatures.
- Overall binder grades of PG 58-22 and PG 64-22 were obtained with the bio-binders containing 10 and 15 percent cryogenic rubber, respectively. The bio-binders containing 10 and 15 percent ambient rubber produced binder grades of PG 58-16 and 64-16, respectively.
- The FTIR results indicate that the styrene butadiene rubber from the tire rubber is likely migrating and chemically combining with the fractionated bio-oil.
- The final blends had properties similar to those of conventional asphalts, except for the blend of the PG64-22 asphalt with the modified bio-oil reacted with the ambient tire rubber (ambMBO), which showed a higher susceptibility to separation during storage.



Production of PG64-22 and cryoMBO, PG64-22 and ambMBO, and PG58-28 and cryoMBO

- The mixtures with the chosen asphalt blend of a PG64-22 asphalt with 20% modified bio-oil reacted with the cryogenic tire rubber (cryoMBO) showed very good performance in all of the tests. Thus, it is not expected that rutting or early fatigue cracking distresses will occur. These mixtures should not be sensitive to moisture nor to low-temperature cracking.
- Laboratory observations indicated that the bio-binders will need agitation to avoid phase separation.
- Based on the laboratory results, it is not recommended to use particle sizes of ground tire rubber larger than #80 mesh in bio-binders to avoid higher stability/phase separation issues.

Implementation Readiness

- Accommodations need to be made for special tanks with agitation systems.
- Sufficient commercial production of fractionated bio-oil would be necessary for this technology to be readily applicable. The researchers believe there is a sufficient amount of agricultural and forestry residues for the commercial production of fractionated bio-oil.
- Pavement trials after plant production are required to provide a better understanding of the oxidative aging mechanism of these new materials.

Implementation Benefits

The economic impact of replacing asphalt with bio-oil is very significant, considering that a replacement of 25% of asphalt with bio-binder, at the current prices for paving asphalt and bio-oil, would result in direct economic savings of about 5%. If the reduction in mixing and compaction temperatures is also accounted for, the economic opportunity in using this technology is even higher.

However, the biggest gain in applying this technology is environmental. The feedstocks for the production of bio-oil are agriculture and forestry residues; thus, no additional energy is spent in collecting these materials.

A fast pyrolysis plant is less complex and often smaller than a crude petroleum refinery; plants can therefore be placed near feedstock production and, consequently, near places where the binder will be used. Fast pyrolysis units are energy auto-sufficient, and as previously noted there is no residue produced in the system.

The reduction in mixing and compacting temperatures when bio-oil is used instead of asphalt results in smaller carbon emissions. Modifying bio-oils with ground tire rubber to improve the oils' low-temperature performance is also considered a green technology.

In sum, this technology can improve pavement performance with important economic and environmental savings. The developed bioasphalt/asphalt blends using ground tire rubber have been shown to perform as well or better than the traditional asphalt mixtures using ground tire rubber.