Biofuel Co-Product Use for Pavement Geo-Materials Stabilization Phase II: Extensive Lab Characterization and Field Demonstration

tech transfer summary

Biofuel co-products are an alternative environmentally friendly construction material that can be used in place of traditional chemical additives for soil stabilization.

Problem Statement

Much natural soil doesn't provide a desired platform for pavement construction due to its poor engineering properties, so the addition of agents in soil, a practice termed soil stabilization, is necessary to make the soil strong enough to support a road.

To enhance the economic value added by the biofuel industry, new applications for its lignin-based byproducts are needed. Utilization of lignin-based biofuel co-products (BCPs) in geo-material stabilization should be investigated, because it is hypothesized that stronger road foundation layers may be achieved through this innovative approach.

Background

The effect of additives on soil stabilization is determined by the measurement of strength improvement of the soil-additive mixture. The performance of soil stabilization is influenced by many factors, the most remarkable being the physical and chemical properties of the natural soil and the additive(s) used.

Over the last couple of decades, lignin products have been studied with respect to their soil stabilization properties and are believed to benefit soil mechanical properties. Many lignin products have been commercialized and marketed over a wide range of applications including concrete admixture, asphalt modifier, batteries, pavement-surface sealing, dispersants, animal nutrition, and agriculture.

In pavement construction in particular, traditional lignin derived from the paper industry, termed lignosulfonate, has proven to have positive effects with respect to road dust control, service life, and antioxidation in the binder.

Objectives

- Evaluate the performance of BCPs in different soils with respect to engineering properties and strength properties
- Evaluate the performance of BCPs in different soils with respect to freeze-thaw durability and moisture susceptibility
- Identify the mechanisms of BCP soil stabilization through microstructural analysis
- Identify the performance and mechanism of lignosulfonate soil stabilization

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RESEARCH PROJECT TITLE
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The Program for Sustainable Pavement Engineering and Research (PROSPER) is part of the Institute for Transportation (InTrans) at Iowa State University. The overall goal of PROSPER is to advance research, education, and technology transfer in the area of sustainable highway and airport pavement infrastructure systems.

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- Conduct a field demonstration project to verify laboratory results and identify lessons learned
- Compare five different soil stabilizers with respect to their strength and durability performance by conducting light weight deflectometer (LWD) and dynamic cone penetration (DCP) tests

Research Description

Laboratory Investigation

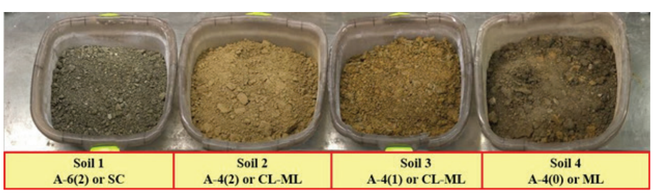
This research focused on investigating soil-BCPs and lignosulfonate mixtures through laboratory testing. Four types of soil were collected from different locations in Iowa for this study:

- Soil 1: A-6 or clayey sand (SC) soil from Calhoun County
- Soil 2: A-4 or sandy silt with clay (CL-ML) soil from Sioux County
- Soil 3: A-4 or CL-ML soil from Buchanan County
- Soil 4: A-4 or sandy silt (ML) soil from Buchanan County

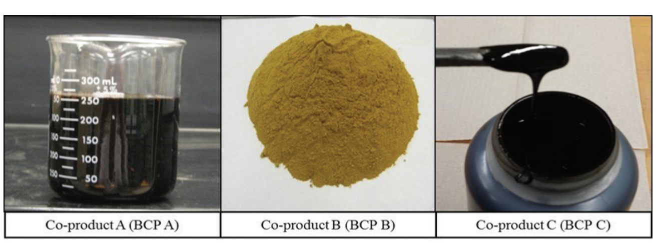
Three types of BCPs containing sulfur-free lignin were mixed with the four types of Iowa soils, and one type of lignosulfonate was mixed with the two types of Iowa soils from Buchanan County. Type I portland cement also was used as a traditional stabilizer for comparison purposes. The natural soil or soil-additive mixtures were compacted into cylinder or plate specimens for strength and durability testing.

The three types of BCP tested were as follows:

- BCP A: An oily liquid type with medium lignin content
- BCP B: A powder type with lower lignin content
- BCP C: Another oily liquid type with high lignin content



Four types of soil collected in Iowa for the research



Three types of biofuel co-products used in this research

The BCP specimens were subjected to several laboratory tests including Atterberg limits, compaction characteristics, unconfined compressive strength (UCS), direct shear, freeze-thaw durability, moisture susceptibility, and micro-structural characterization consisting of scanning electron microscope (SEM) and x-ray diffraction (XRD) analyses to evaluate their performance.

The lignosulfonate specimens were subjected to similar laboratory tests including compaction characteristics, UCS, freeze-thaw durability, wet-dry durability, lignin set time, and SEM. Freeze-thaw durability and wet-dry durability tests only considered the effect of the curing period, and the durability of specimens were evaluated based on visual images, mass loss, and volume expansion.

In the moisture susceptibility test, the specimens were soaked in water for observation of the damages from moisture. Set time tests were performed to investigate the speed at which lignosulfonate became hard at different temperatures and its mechanism. SEM and XRD were used to identify the interactions between lignin and soil grains.

Field Demonstration

Based on the laboratory test results of lignosulfonate, a field demonstration project was conducted at the site where Soil 4 was collected (in Buchanan County). A total of five soil stabilizers were applied on the aggregate road subgrade in October 2018.

A lignosulfonate test section of 300 ft was compared with 500 ft test sections using traditional commercial soil stabilizers: cement, chlorides, Claycrete, and Base One. Seasonal in situ tests were conducted and documentation (both visual and written) was collected both before and one week after construction of each section to monitor the performance of the stabilized sections and to draw the lessons learned from the practices.

LWD tests and DCP tests were conducted to compare the strength and durability performance of these five stabilizers.

Lignosulfonate test section construction

Key Findings

- The investigated BCPs are promising additives for increasing compressive strength, shear strength, freeze-thaw durability, and resistance to moisture degradation for four types of Iowa soil A-6(2), A-4(2), A-4(1), and A-4(0).
- The UCS test results determined that only a low dosage of lignosulfonate is required to improve soil strength.
- SEM and XRD analyses revealed the primary underlying mechanisms of BCP A and BCP B to be coating and binding soil grains to form strong soil structures.
- The durability test results demonstrated that lignosulfonate equally improved wet-dry durability for CL-ML soil (i.e., Soil 3) and ML soil (i.e., Soil 4) from Buchanan County, and the use of lignosulfonate also produced a significant improvement in freeze-thaw durability for CL-ML soil (i.e., Soil 3) from Buchanan County.
- The set time tests revealed that the increase from lignosulfonate's strength also contributed to the improvement of the lignosulfonate-treated soil strength.
- In the diluted lignosulfonate-treated section, the actual dosage was adjusted to 2.5%, while the designed optimum dosage was 5%. The subgrade's over-wet condition was caused by both climate and human factors. An excessive amount of water stayed in the subgrade due to the continuous precipitation prior to the construction date.

Implementation Readiness and Benefits

The application of BCPs, which are co-products of local biofuel production plants, is a cost-effective and sustainable solution to strengthen secondary road transportation infrastructure systems in particular.

In the field implementation, the lignosulfonate was diluted with too much water and applied at a larger spray rate, which should be avoided in future construction. If the moisture can be well controlled at the optimum moisture content (OMC) level (12%), the theoretical value of the subgrade elastic modulus will increase dramatically compared to the actual value measured in this study under the over-wet condition.

The following are some of the potential benefits of utilizing BCPs for soil stabilization:

- One of the most important benefits is that BCPs are a sustainable solution, particularly because co-products from local lignocellulosic biorefineries/ethanol plants can be used on nearby roads that transport biomass.
- BCPs are a safe and economical alternative to petroleum-based products and co-products from power plants for geo-material stabilization.
- Lignocellulosic BCPs are expected to be environmentally friendly as they have no oil-based contaminants.
- Apart from their utilization on low-volume roads, the use of BCPs could expand to soil stabilization of haul roads for local power plants, stockpiles, parking lots, road shoulders, military runways, etc.
- Apart from their utilization as soil stabilizers, BCPs could also be used as admixtures in concrete, antioxidants in asphalt, and for dust control purposes.
- Successful implementation will enhance the state's leadership in contributing to the long-term sustainability of agricultural-based industries in Iowa

Recommendations for Future Research

- Future studies should balance the entire laboratory test program to obtain more comparable results when additional quantities of BCPs are available.
- Field investigations should be expanded to include various BCP-treated soil foundations. Although the laboratory data showed improvements from BCP stabilization, the field condition under actual traffic loads should be evaluated for pavement infrastructure systems. Moreover, the application of lignosulfonate in the field demonstrated in this study can be a good lesson for the future construction.
- Considering traditional lignin products already have a wide range of applications in concrete and asphalt admixtures, as a dust control agent, and as a pavement geo-material stabilizer, the utilization of the new BCP types can be investigated in these applications.