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Studying the impact of biomodifiers produced from agroindustrial wastes on asphalt binders

Silvia Caro [a,*], Natalia Vega [a], Johana Husserl [a], Allex E. Alvarez [b]

[a] Department of Civil and Environmental Engineering, Universidad de los Andes, Carrera 1 Este # 19A-40, Edificio ML Piso 6, Bogotá D.C., Colombia
[b] Program of Civil Engineering, Universidad del Magdalena, Carrera 32 # 22-08, Bloque VIII, Piso 2, Santa Marta D.T.C.H., Colombia

HIGHLIGHTS

- Biomodifiers were produced using three agroindustrial wastes through solvolysis.
- They were used to modify an asphalt binder at two doses and two aged conditions.
- They hardened the asphalt and affected its chemical and adhesive properties.

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ABSTRACT

This work explores the impact of using biomodifiers produced from three different agroindustrial wastes (i.e., sugarcane bagasse, corncobs, and rice husk) obtained through solvolysis, on the chemical, rheological, and thermodynamic properties of an asphalt binder. Two different modification doses were considered, and the binders were characterized in both unaged- and aged-conditions. Results showed that the biomaterials contain several hydrophobic and hydrophilic functional groups that modified the chemical properties of the asphalt binder. Besides, the biomaterials produced a hardening effect on the asphalt binder, and strongly affected the adhesive bond quality with aggregates.

1. Introduction

The search for alternative bio-renewable materials that could be used as full or partial replacement for conventional petroleum-refined asphalt binders in the construction of road infrastructure has significantly increased in recent years. There are several reasons explaining the interest in these materials—which are commonly called biobinders or biomodifiers—including the recognition that regular asphalt binders are obtained from a non-renewable source, the irregular changes in oil prices, and the possibility of reusing agroindustrial and other biological wastes in the construction of road infrastructure.

The importance of the use of natural wastes in the area of pavement engineering is easily demonstrated by the number of studies that have been published on this topic in the last six years. In general, these works have aimed to characterize the chemical and rheological properties of asphalt binders modified with different materials obtained from biological wastes. Some of these studies have focused on evaluating the use of swine manure as a potential modifier for asphalt binders [9,10,17,7,11]. The first study in this direction was conducted in 2011, and it explored the production, modification, and characterization of a biobinder obtained from the residue of a bio-oil generated from swine manure through a thermochemical liquefaction process [9]. To evaluate the compatibility of the produced biobinder with a regular PG 64-22 asphalt binder, a chemical study that included SARA tests, nuclear magnetic resonance (NMR), and gas chromatography-mass spectrometry, among others, was performed on the biobinder. Also, some basic rheological tests were conducted on asphalt binders modified with 2, 5, and 10% of biobinder by weight of asphalt. Although the rheological results showed that the dynamic shear modulus ($|G^*|$) of the asphalt binder decreased with the addition of the biobinder, the authors concluded that this material could be considered chemically compatible with regular asphalt cements, and that it

* Corresponding author.
E-mail addresses: scaro@uniandes.edu.co (S. Caro), n.vega152@uniandes.edu.co (N. Vega), jhusserl@uniandes.edu.co (J. Husserl), allexalvarez@yahoo.com (A.E. Alvarez).

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could be used to improve the low-temperature cracking properties of the asphalt binder or as a warm mix asphalt application.

The rheological properties of an asphalt binder modified with the same biobinder were further studied in subsequent works [10,17]. These studies evaluated the impact of several percentages of biomodification on the rheological properties of a PG 64-22 asphalt binder. These properties included rotational viscosity, $|G^*|$, creep stiffness, and cracking susceptibility [10]; as well as the impact of aging on the biomodified asphalt binder [17]. It was observed that the use of the biobinder reduced the viscosity of the asphalt binder; this reduction was 29% and 63% higher for the short- and long-term aging conditions in comparison to the unaged condition, when 5% of the biobinder by asphalt weight was used. It was also observed that the cracking temperature decreased in proportion to the amount of biobinder, and that $|G^*|$ significantly decreased for doses of biomodifiers higher than 5%. According to the authors, although some of these effects could be beneficial to reduce mixing and compaction temperatures and/or to improve the low-temperature cracking susceptibility of the asphalt binder, the impact of the softening effects at intermediate- and high-temperatures required further evaluation.

Due to the softening effects produced by this biobinder, its potential application as a rejuvenator for asphalt modified with wet processed reclaimed asphalt shingles (RAS) was evaluated [7]. This study included the determination of the rotational viscosity and $|G^*|$ of a PG 64-22 asphalt binder modified with four percentages of RAS (5, 15, 30, and 40% by total weight) and 10%, by weight, of the swine manure-based modifier. As expected, although the introduction of RAS increased the viscosity of the control binder, the addition of the biobinder strongly reversed this effect. Furthermore, the addition of the biobinder to the RAS modified asphalt binders reduced $|G^*|$, even below the modulus of the original unmodified binder. This, in turn, improved the ductility and fracture energy of the material.

More recently, Fini et al. [11] expanded their work by studying the effects of other types of biobinders. In this opportunity, besides the swine manure-based modifier, they also evaluated three other biomodifiers produced from natural wastes: mescanthus pellet (MP), corn stover (CS), and wood pellet (WP). The chemical and rheological properties of a control PG 64-22 asphalt binder modified with these four materials were studied. Although all the biomodifiers generated a softening effect on the base binder, the results varied significantly as a function of the biomodifier used (i.e., reductions of $|G^*|$ between 18 and 48% at 10 Hz). Also, significant differences were observed in the aging susceptibility of the materials.

Some other efforts to evaluate the use of biomodifiers in asphalt binders include the work by Xue et al. [23], who used two biomass materials (rice husk ash, RHA, and wood sawdust ash, WSA) as asphalt binder modifiers. The results showed that the ashes properly blended without chemically reacting to the asphalt binder, and that they resulted in modified binders with an increased viscosity and $|G^*|$. In a different effort, Williams and McCready [22] studied the asphalt antioxidant properties of lignin-containing co-products obtained from ethanol production from cornstarch.

In terms of studies that have used vegetable- and animal-based oils, Raouf and Williams [18] characterized the rheological properties of bio-oils generated from switch grass, while Yang and You [25], Yang and Suciptan [24], and Lei et al. [16] evaluated the role of different bio-oils generated from waste wood on the rheological properties of asphalt binders. Also, Su et al. [21] investigated the impact of encapsulated waste cooking oil as a binder rejuvenator, and Guarín et al. [13] conducted a comprehensive study that included the rheological, chemical, and thermodynamic characterization of an asphalt binder modified with bio-oils obtained from rapseed oil and fish oil.

These previous works demonstrate that the use of biomodifiers is a promising area that requires further study. Within this context, the objective of this work is to evaluate the possibility of using biobinders obtained from three agricultural wastes as modifiers for an asphalt binder. Specifically, the work investigates if sugarcane bagasse, corncob, and rice husks could be used as raw material to produce asphalt biomodifiers through a solvolysis procedure. Besides describing the methodology for the generation of the biomodifiers and the results of their chemical characterization (i.e., Fourier-transform Infrared Spectroscopy, FTIR, and Gas Chromatography-Mass Spectrometry, GC-MS), this paper also investigates the impact of two modification doses (1 and 2% by asphalt weight) on the rheological and thermodynamic properties of a Colombian control asphalt binder, in both original and aged conditions.

This work is particularly pertinent in Colombia, since the country produces over 70 million metric tons of agricultural wastes every year [8]. These wastes include more than 490,000 metric tons of rice husks, 370,000 metric tons of corncob, and 7,000,000 metric tons of sugarcane bagasse per year. Handling these wastes, which are commonly incinerated to reduce its volume, increases production costs. Therefore, it is expected that these biomodifiers will produce materials with similar or better properties than the control asphalt binder, so they can provide an effective alternative use to these residues, and an option for the partial replacement of the non-renewable asphalt binders used in the construction of road infrastructure.

2. Methodology

This work followed a four-stage process:

1. Three different agroindustrial waste materials were selected and used to produce biomodifiers by solvolysis.
2. Samples of asphalt binder modified with two different percentages of each biomodifier, in unaged- and short-aged conditions, were prepared for further characterization.
3. The modified asphalt binders were characterized experimentally to determine their rheological properties (i.e., dynamic shear modulus using the Dynamic Shear Rheometer, DSR), and thermodynamic properties (i.e., surface free energy, SFE). Besides, FTIR and GC-MS tests were conducted to characterize the chemical properties of the biomodifiers and the biomodified binders, to better understand their impact on the control asphalt binder.
4. Experimental results were analysed to conclude about the effects of adding biomodifiers on the chemical and viscoelastic material properties of the asphalt binder, on the cohesive properties of the biomodified binders, and on the adhesive-bond properties they could develop with aggregates when used in the fabrication of paving asphalt mixtures.

The following sections explain in detail each one of the stages previously described.

3. Materials

3.1. Asphalt binder

The control asphalt binder used in this study is classified as penetration 60–70 (1/10 mm), and it was obtained from the refinery of Barrancabermeja (Colombia). Specifically, the asphalt binder