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Performance of warm mix asphalt containing *Moringa oleifera Lam* seeds oil: Rheological and mechanical properties

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HIGHLIGHTS

- It investigates the use of Moringa oil in asphalt binder.
- Rheological behavior of asphalt binder was studied.
- Mechanical performance os mixtures with asphalt binder was studied.
- The performance of modified binder was greater when compared to the traditional asphalt binder.

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ABSTRACT

The existence of an environmental crisis resulting from the unbalanced exploration of natural resources is a concerning situation and entails the need for sustainable development. In the paving sector, warm asphalt mixtures, which are produced in lower temperatures than conventional mixtures, reduce the impacts to the environment and workers health, and the energy consumption. Among the techniques developed to the production of warm mixtures, it is highlighted the addition of an oil, usually organic, to the conventional binder, decreasing its viscosity. *Moringa oleifera Lam* seeds have an oil content varying between 38 and 40% and have antioxidant and lubricant properties. The present work aimed to analyze the rheological properties of asphalt binder and the mechanical properties of asphaltic mixtures using modified binders by the addition of Moringa oil in the contents of 0.5 and 1.0%. It was performed the physical characterization of binders and aggregates used. The Marshall Mix design method was performed and specimens for mechanical tests were produced. The results for Marshall Stability, Flow, Cantabro Loss, Indirect Tensile Strength, Resilient Modulus, Fatigue Life and Dynamic Creep tests were satisfactory when compared to results for the reference sample (using pure binder).

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1. Introduction

Asphalt pavement accounts for >80% of highway in the world [8], with asphalt binder being one of the major constituent of hot-mix asphalt (HMA). For the production of this type of mixture, it is necessary to heat the asphalt binders to temperatures close to 150/160 °C, which may cause oxidation and premature aging of the binder.

This fact coupled with the need of sustainable development and greater energy efficiency in the paving sector has attracted the study of asphalt binders mixed at temperatures lower than the conventionally used [7].

Until recently, the effort has been towards increased use of emulsified asphalt technologies in order to reduce the carbon footprint of the highway construction industry. However, these technologies have limitations that prevent their use in a large scale. Therefore, over the last decade, researchers around the world have started exploring the incorporation of warm mix additives to conventional asphalt binder [4].

Until recently, studies focused on the use of emulsified asphalt technologies in order to reduce the carbon footprint of the highway construction industry. However, this technology has limitations, which prevents its use in a large scale. Therefore, over the last decade, researchers around the world have started exploring the incorporation of warm mix additives to conventional asphalt

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binder [4]. The warm-mix asphalt can reach temperature reductions of 30 to 50 °C when compared to conventional mixtures [1,6,13].

Studies in Europe have concluded that WMA performance was the same as or better than the performance of conventional mixtures, in laboratory test and 3 years of field performance data [3]. [4] reported that warm-mixture additives have reduced the aging rate of asphalt binders. It was also reported that the mixtures prepared with some additives, like Sasobit, give higher stiffness, a higher dynamic modulus rutting parameter, and a higher fatigue cracking parameter than HMA [17].

Furthermore, the WMA reduce CO2 emissions due to the decrease of the asphalt binder mixing and compaction temperatures. This allows to minimize the amount of energy required, and it also reduces emissions and odors and improves the welfare of workers Morea et al., [12]). The use of WMA also allows paving in cooler temperatures, to haul the mix longer distances, to compact the mixture with less effort and the possibility to pave and open to traffic in a short time period [16].

Nowadays, there are three methods to produce WMA: adding organic or chemical additive, using emulsified asphalt and foamed asphalt technologies. Lots of researches were conducted for WMA, and most of them were focused on the validation of road performance, determination of the additive dosage and the construction technologies [2,18].

In Brazil, the studies and applications of these types of "green" technologies started together with research institutes, where they are developed, mostly in laboratories with new technologies and academic purposes.

The Moringa oil is originated from a renewable and biodegradable source and can be used as a "green additive". Due to its antioxidant characteristics and surface-active properties, it shows to be promising to reduce the high viscosity of neat binders and polymer-modified binders, reducing plant costs, in addition to increasing stability to storage and adhesiveness in the mixing with aggregates. Therefore, the Moringa oil shows to be potentially useful to be employed as an additive to improve the properties of asphalt cements as well as to reduce their production temperature. Silveira et al. [14] verified temperature reductions close to 10 °C with addition of 0.5% and 1% castor bean oil without compromising the physical properties of the binders.

The main objective of this study is to analyze the effects of Moringa's oil on the rheological properties of asphalt binder and the mechanical properties of stone mastic asphalt. The modified binders were evaluated by dynamic shear rheometry (DSR). Thereafter, the WMA were evaluated by Dynamic Creep, Indirect Tensile Strength, Fatigue, Resilient Modulus and Cantabro Tests.

2. Testing program

The objective of this study was to observe changes in the rheological properties of asphalt in samples from three different mixes: HMA without the additive and WMA (with additives) while reducing their mixing and compaction temperatures. These properties were analyzed in a Dynamic Shear Rheometer (DSR). At the same time, rutting and mechanical performance tests were evaluated for the different asphalt mixtures.

2.1. Materials

The *Moringa Oleífera Lam* seeds were manually peeled with the help of a pestle. Afterwards, the seeds were placed in a drying oven at 40 °C to eliminate the water contained, for a period of 24 h to maintain mass constancy. After this step, the samples were placed in a hydraulic press in a container protected by cotton to avoid the contact of the solid particles of the seeds with the oil extracted. A 30-ton load was then applied for the extraction of the Moringa oil. Characterization of the Moringa seed is shown in Table 1. The results show that the oil undergoes breaks in its triglyceride chains, releasing their main constituents and retarding oxidation (acidity index); it is an oil of unsaturated compounds (iodine index). The other results indicate the presence of oleic acid (>70%) in the oil, which means that it has a low unsaturation content. Therefore, oils rich in oleic acid are more stable to oxidation both at storage temperatures and at high temperatures (present in the mixing of asphalt binders). The addition of oleic acid to the asphalt binder is an alternative to reduce its viscosity during mixing and compaction, improving workability. However, it is necessary to study the best content to be used in order not to damage the mechanical properties of the asphalt mixtures.

The modified asphalt binders were prepared with the selected modifiers using a laboratory-scale mixing device with a four-blade impeller. The mixture which binder was modified with oil was stirred with a lab mixer set at 400 rpm and 135 °C, and the desired amount of oil was slowly added to the asphalt. The mix was stirred for 20 min and removed from the mixer. The additive percentages of oil in the base binder were selected as zero (Pure asphalt – PA), 0.5 (named 0.5 MO) and 1% (named 1.0 MO) by weight of the binder based on the outcomes of previous studies [14]. Its engineering properties are presented in Table 2.

The aggregates used in this research are of granitic origin, and show maximum diameters of 9.5 and 19 mm. Physical properties of the aggregate samples were evaluated. These evaluations included coarse flat/elongated particles, coarse and fine aggregate specific gravity and absorption, and Los Angeles abrasion (Table 3).

2.2. Test procedures

2.1.1. Rheological tests

In the DSR, the following tests were performed:

- *Viscoelastic parameters evaluation tests:* the parameters complex modulus ($G*$) and phase angle (δ) were monitored under temperature and frequency sweeps. Temperature sweep was performed in the range of 46 to 82 °C, with increases of 6 °C, and 10 rad/s frequency. In the frequency sweep, range of 0.1 to 100 Hz, tests were performed at 60 °C.
- *The Multiple Stress Creep Recovery (MSCR) procedure:* this test was performed at maximum PG temperature using a specimen of 25 mm in diameter and gap of 1 mm between plates. A one-

Table 1
Physicochemical analysis of the Moringa seeds [11].

Analysis	Method	Result
Acidity index (mg KOH/kg)	AOCS ca-5ª-40	7,95
Iodine index (g/100 g)	EM 14111	85,71
Saponification index (mg KOH/kg)	ASTM D 445	181,58
Kinematic viscosity at 40 °C (mm^2/s)	NBR 14854	45,26

Table 2
Physical properties of the studied asphalt binders.

Test		Binder		
		PA	0.5 MO	1.0 MO
Softening Point (°C)		49.60	47.75	46.50
Penetration 0.1 mm (100 g, 5 s at 25 °C)		56.2	76.4	79.4
Penetration index (PI)		−1.024	−1.420	−0.994
Rotational Viscosity (cP)	135 °C at 20 rpm	406.25	393.75	368.75
	150 °C at 50 rpm	203.00	196.50	187.00
	177 °C at 100 rpm	74.75	71.00	69.00

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