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Differences in asphalt binder variability quantified through traditional and advanced laboratory testing

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HIGHLIGHTS

- Asphalt binder (AB) variability could induce uncertainty in the behaviour of asphalt mixtures.
- Variability of a Pen 60–70 AB was quantified through both traditional and advanced asphalt testing.
- Advanced testing captured higher variability than traditional testing used during production.
- Results encourage the need of new strategies to reduce current AB variability.

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ABSTRACT

The variability in the properties of asphalt binders used for road construction could induce uncertainty in the response, performance, and degradation of flexible pavements. Although in the last 25 years some countries have adopted performance-based classification systems and stricter quality control procedures to reduce the variability of the material during its production, the reality is that most countries—including emerging economies that are extensively investing in road infrastructure—continue using classification techniques based on traditional indexes (i.e. penetration and viscosity). The objective of this paper is to assess the variability of traditional indexes and fundamental properties among eighteen asphalt specimens produced in the same refinery and classified as penetration 60–70 $^{1}/_{10}$ mm. The results show that the variability of the fundamental properties (i.e. rheological, thermodynamic, and chemical) among specimens is substantially higher than that of traditional asphalt-tests indexes (i.e. penetration, softening point, and penetration index). These results support the necessity for enhancing current classification and production practices in those countries that still use these traditional indexes.

1. Introduction

The service life of an asphalt pavement depends on different factors, including the properties of the materials, the design of the structure, construction and quality control processes, management strategies, operational conditions, and the occurrence of extreme weather or loading events. Regarding the role of the materials, the properties of the asphalt binder (or asphalt) are of paramount importance to ensure proper performance and durability of both asphalt mixtures [1] and asphalt surface treatments [2,3].

In terms of the production of the asphalt binders, a common practice at several refineries consists in loading the distillation towers with crude oils from different field sources, in proportions or ‘recipes’ that change as a function of the individual production rates at each oil field, market demand conditions, and/or specific technical requirements related to the refinery operation processes. The quality control system used during these processes is expected to guarantee a reduced variability of the material through time, which is crucial in determining the structural reliability of the pavement structure and corresponding durability of road networks. However, those control procedures are highly dependent on the specific asphalt classification system used in each country. Indeed, after demonstrating that traditional quality assessment, classification, and specification systems based on traditional indexes (e.g. penetration, softening point, ductility, and viscosity) were not sufficient to assure proper field performance of the

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asphalt mixtures, several countries have adopted new performance-based systems to control and classify these materials. These procedures, among which the Superpave system developed in North America [4] is the most popular, aim at classifying asphalt binders based on fundamental material properties so that they can fulfil the required performance in a specific road project.

Nevertheless, the reality is that with the exception of North America and some few other countries, classification systems based on traditional indexes continue being the most extended practice in the world [1]. This is particularly concerning in emerging economies, like those in Asia and Latin America, that are currently allocating unprecedented investments in the construction of road infrastructure. In the case of Colombia, for example, despite the fact that the asphalt binders comply with the penetration specifications adopted by the National Roads Institute (INVIAS by its acronym in Spanish) [5], changes in both the recipes and operation conditions at the refineries are believed to cause significant variability in the chemical, mechanical, and thermodynamic properties of the material. As a matter of fact, several main road contractors in the country have manifested variations in the workability, response, and/or performance of asphalt mixtures fabricated with virgin asphalts classified within a single penetration category. This situation motivated the Colombian Infrastructure Chamber to fund a study to quantify the chemical fraction composition of two asphalts (i.e. penetration 60–70 and 80–100 $^{1}/_{10}$ mm) produced in two local refineries [6]. The results demonstrated that asphalts produced under the same category during several consecutive days presented significant differences in their chemical composition.

Within this context, the objective of this paper is to quantify and compare the differences in the variability of traditional indexes and fundamental properties among several specimens of an asphalt binder produced at a single refinery using the penetration classification system. Asphalt variability, quantified using a penetration 60–70 $^{1}/_{10}$ mm asphalt (or Pen 60–70 asphalt), was evaluated through: (*i*) traditional characterization tests, (*ii*) rheological characterization of both unaged- and short term aged-asphalts, (*iii*) determination of surface free energy (SFE), (*iv*) computation of energy-based parameters derived from SFE measurements (i.e. adhesion quality and wettability of asphalt-aggregate interfaces), and (*v*) chemical characterization by means of asphalt Fourier Transform Infrared spectroscopy (FTIR).

It is important to stress that several of the properties quantified in this work were not evaluated during the development of the SHRP program that resulted in the Superpave methodology [4], since they were not available or used at the time. In addition, there are few published works that have evaluated the variability of asphalt binders using either traditional or advanced characterization asphalt testing (e.g. [6,7]). Therefore, the results obtained from this work offer relevant and up-to-date data that could be used to support improvements in current asphalt production practices and strategies in several countries and, consequently, they constitute a relevant contribution in the area of pavement engineering.

2. Materials and test methods

2.1. Experimental materials

Asphalt sampling was performed at two secondary facilities that continuously received Pen 60–70 asphalt produced at the main refinery in Colombia, located at the north-east of the country. In this manner, eighteen asphalt specimens were gathered between March 2013 and January 2017 for laboratory characterization. Specimens were collected at the secondary facilities within few days after receiving the asphalt from the refinery, shipped to the laboratory and kept until testing in a freezer at −18 °C to minimize aging effects. This procedure helped assuring undisturbed materials in order to obtain reliable results. In addition, six Colombian aggregates, commonly used in road projects in the country, were used to evaluate the quality of the adhesive bond that they develop with the asphalt binder specimens.

2.2. Asphalt traditional characterization tests

The asphalt specimens were subjected to the following tests—used in several countries, including Colombia—to quantify the variability of the traditional characterization indices used to control and classify the material: softening point (INV E 712-13), penetration (INV E 706-13), and ductility (INV E 702-13) [5]. In addition, the penetration index (I_p)—a quantitative measurement of the changes in asphalt consistency due to changes in its temperature—was determined in accordance with the testing method INV E 724-13 [5]. This computation is based on the eq. 1, proposed by Pfeiffer and Van Doormal [1].

$$I_p = \frac{20 - 10f}{1 + f} \tag{1}$$

where f is calculated as per Eq. (2), using the values of both penetration at 25 °C (P; $^{1}/_{10}$ mm) and softening point (T_{SP}; °C) of the asphalt binder.

$$f = \frac{50\ Log\left[\frac{800}{P}\right]}{T_{SP} - 25} \tag{2}$$

2.3. Asphalt rheology characterization

Rheological characterization was conducted on the asphalt specimens to quantify the variability of the linear viscoelastic material properties (i.e. dynamic shear modulus, $|G^*|$, phase angle, δ, and shear viscosity, μ) through Dynamic Shear Rheometer (DSR) testing, using a TA2000ex rheometer. Thus, strain-controlled oscillatory shear tests were conducted at frequencies ranging between 1 Hz and 20 Hz, and temperatures ranging between 25 °C and 75 °C, in intervals of 1 Hz and 10 °C, respectively. In addition, the impact of aging on the magnitude and variability of these properties was assessed by testing the asphalts in two different conditions: (*i*) unaged, and (*ii*) short-term aged—obtained through the Rolling Thin Film Oven test or RTFO (AASHTO T240 [8]).

2.4. Asphalt- and aggregate-surface free energy (SFE) and Energy-Based parameters

The SFE properties of the asphalt specimens and of some selected aggregates were determined, and these values were used to compute several energy-based parameters to quantify the variability in the adhesion quality at the asphalt-aggregate interfaces. The SFE is defined as the work required to create a new unit of surface in a material, under vacuum conditions [9]. In this research, SFE was computed by applying the Good-Van Oss-Chaudhury theory [10], which defines three SFE components as follows: nonpolar or Lifshitz-van der Waals, Γ^{LW}; monopolar acid, Γ^{+}; and monopolar basic, Γ^{-}. The combination of these components yields the total SFE, Γ, of a material (e.g. asphalt or aggregate) through Eq. (3).

$$\Gamma = \Gamma^{LW} + 2\sqrt{\Gamma^{+}\Gamma^{-}} \tag{3}$$

These SFE components were computed for the asphalt specimens by means of the Wilhelmy plate method, which allows measuring the contact angle between a probe liquid (i.e. liquid with known SFE components) and a solid asphalt surface [9]. Following existing recommendations [9], the liquids used in this study were formamide, ethylene glycol, distilled water, and glycerol; and the laboratory procedure corresponded to that proposed by Hefer et al. [9]. In addition, the aggregates SFE testing was conducted through the methodology proposed by Bhasin and Little [11], using the Universal Sorption Device (USD).

Based on the known SFE components of both asphalts and aggregates, several energy-based parameters were computed as indicated in Table 1. The first parameter is the asphalt work of cohesion, W_{AA} (i.e. energy required to fracture an asphalt material creating two new surfaces of unit area), which can be computed using the asphalt (subscript A) SFE components in Eq. (4). The work of adhesion between aggregates and asphalts in both dry condition (Eq. (5)), W_{AS}^{dry}, and wet condition (Eq. (6)), W_{WAS}^{wet}, can be calculated using the SFE components of asphalt, aggregate (subscript S), and water (subscript W). The work of adhesion in dry condition is defined as the energy required to propagate an existing crack at the interface of two materials by creating two new surfaces of unit area, whereas the work of adhesion in wet condition refers to the work done to disrupt, in a unit area, an asphalt-aggregate interface by the water. The calculation of the interfacial energies (i.e. γ_{AW}, γ_{SW}, and γ_{AS} values in Eq. (6)) was performed through Eq. (7) as a function of both the total SFE and SFE components of water, asphalt, and aggregate.

Eq. (8) was applied to determine the ER_1 index [12], to quantify the moisture damage susceptibility of the asphalt-aggregate interfaces. In general, higher values of this index are desirable, since they represent asphalt-aggregate systems that simultaneously develop good quality adhesive properties in dry conditions and that are more resistant to the deleterious action of water. In addition, the asphalt wettability was assessed by means of both the spreading coefficient (Eq. (9)) [13] and the ER_2 index (Eq. (10)) [12]. The spreading coefficient evaluates the wettability, or ability of the asphalt to coat the aggregate, while the ER_2 index allows identifying material combinations that can develop simultaneously proper wettability and resistance to moisture damage.