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Drying path of a Water Retention Curve (WRC) on asphalt mixtures

Trayectoria de secado de una Curva de Retención de Agua (WRC) en mezclas asfálticas

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ABSTRACT

Keywords:

Water Retention Curve,
Suction,
Asphalt mixtures.

The unsaturated behavior of bituminous materials has yet to be studied at present. However, the atmosphere-asphalt layer interaction in terms of humidity changes has forced different specifications or world standards to consider it appropriate to link in the designs the variable that controls this response, known as suction. This phenomenon is because it is the layer most exposed to atmospheric changes, therefore with a particular susceptibility to significant hygrometric changes. The construction of a water retention curve (WRC) is required to observe the changes in specific suction moisture ranges, which indicates the unique tandem suction-moisture value for a given material. The suction in the specimens of this research has been measured using a traditional filter-paper method, widely used in other types of soil engineering materials. Until now, suction on asphalt mixtures has only been measured using psychrometers, inducing invasive processes within the sample that can alter the results. The filter paper method only allows obtaining the drying path of the material; therefore, the probable hysteresis of the WRC cannot be obtained. Extensive experimentation time and experience in interpreting the tests was required because it is a technique that has not been used before for asphalt mixtures. The results show a restricted curve in moisture values and the suction spectrum. However, they reveal suction values that should be considered in stages of understanding the mechanical behavior of the material, especially for design purposes.

RESUMEN

Palabras clave:

Curva de Retención de agua, Succión, Mezclas asfálticas.

El comportamiento no saturado de los materiales bituminosos ha sido poco estudiado en la actualidad. Sin embargo, la interacción atmósfera-capa asfáltica en cuanto a los cambios de humedad, ha obligado a diferentes especificaciones o estándares mundiales a considerar oportuno vincular en los diseños la variable que controla esta respuesta, conocida como succión. Esto se debe a que es la capa más expuesta a los cambios atmosféricos, por lo tanto, posee cierta susceptibilidad a grandes cambios higrométricos. Para observar los cambios en ciertos rangos de humedad de succión, se requiere la construcción de la curva de retención de agua (WRC), que indica el valor único del tándem humedad-succión para un material dado. La succión en los especímenes de esta investigación se ha medido utilizando un método tradicional de papel de filtro, ampliamente utilizado en otros tipos de geomateriales. Hasta ahora la succión en mezclas asfálticas solo se ha medido con psicrómetros, induciendo procesos invasivos dentro de la muestra que pueden alterar los resultados. El método del papel filtro sólo permite obtener la trayectoria de secado del material; por lo tanto, no se puede obtener la histéresis probable del WRC. Los resultados muestran una curva restringida, tanto en valores de humedad como en el espectro de succión. Sin embargo, revelan valores de succión que nunca son considerados en las etapas de entendimiento básico del comportamiento mecánico del material, especialmente para fines de diseño.

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Introduction

In a stratigraphic horizon, the first layers often closely interact with the atmosphere. In dry weather, the environment allows the soil to gradually increase in depth, its natural moisture. If there is a water table nearby, the surface remains close to zero saturation, and, in extreme cases of dry weather, the groundwater level may drop. The upper, partially saturated stratum retains greater thickness and high susceptibility to alter its ability to resist shear failure by varying suction values or depending on the in-situ soil typology. In times of high humidity (rainy), the stratigraphic profile tends to be constantly saturated, minimizing the impact of suction on the soil [1]. This aspect is what eventually happens in a natural stratigraphic profile. Therefore, it is important to analyze the effects of artificial structures modifying natural soil conditions.

To obtain the characteristics of the partially saturated layer, it is necessary to estimate, by theoretical or empirical methods, the moisture change with respect to suction at a degree of saturation from 0 to 100%. These techniques are typically used for soils in which the pore size distribution (PSD) allows obtaining suction values that have an important influence on the mechanical-hydraulic behavior of the soil [2]. Thus, it is possible to deduce that only soils ranging in particular diameters from fine sands to clays are susceptible to being influenced by the suction generated in an unsaturated stratum.

Other types of geomaterials, which may eventually become part of the ground, have yet to be subjected to studies that evaluate their mechanical-hydraulic behavior, so they may present grain sizes where suction develops in the pore. On the other hand, they are sufficiently superficial to undergo state modifications, given the interaction between the particles and the atmosphere. For asphalt pavements, where void ratios are low, exposure to weathering processes generates pathologies associated with the suction ranges present in the particular microstructure.

In this study, the intrinsic framework of the water retention curve (WRC) of a hot asphalt mix (MDC-19) is evaluated to know the suction potential of this geomaterial for a restricted moisture spectrum since saturation is reached at low moisture contents. The filter-paper method was used, which is generally used for natural earth materials without any modification [3]. The filter paper was left in direct contact with the asphalt mix, so it was prioritized in the exclusive estimation of the matric suction. The results show reasonable and promising suction values, according to the state-of-the-art investigated [4-7]. Similarly, a mathematical adjustment of the water retention curve (WRC) is exposed using conservative models for fine-grained soils [8-10]. This adjustment analyses if the classical trend of this type of curve for soils can be adapted to the retention curve of these asphalt materials.

Background

The approach to the concept of suction in asphalt mixtures is relatively new. Normally the suction mobilization in an argile-material is conditioned by several aspects, such as pore size distribution (PSD), material gradation, ion exchange capacity, fabric, etc. [11]. Some factors are equally characteristic of asphalt mixtures and dictate part of their mechanical behavior.

It is widely known that the water content in asphalt mixtures (WMA) affects the cohesion of asphalt cement and, consequently, the loss of adhesion with the aggregate [12]. Suction in materials can be defined and understood from several frames of reference. Like many physical laws, molecules prefer to mobilize from high to low energy states. Water is no exception and moves more readily from a wet or partially saturated macropore condition to a dry, more minor pore condition. This notion ultimately articulates the concept of capillarity, which is related to suction, due to a latent free energy state causing water movement [2]. Of course, this phenomenon in partially saturated materials is also governed by the unsaturated hydraulic conductivity (ku) [13-16].

The term suction is not generally associated with asphalt mixtures. Its application is currently more a part of agricultural and geotechnical engineering. Within road engineering, most of the studies related to this subject have evaluated suction in (unbound) granular layers of a high specification [11]. However, there are some promising advances regarding the inclusion of environmental factors in pavement designs, which are directly related to suction. [17-18] investigated the influence of water content and saturation degree on the value of the secant and resilient modulus of unbound granular materials. These results confirm the influence of the unsaturated response on the mechanical behavior of these materials. However, the influence on asphalt materials (hot mix asphalt) has yet to be sufficiently studied. Different proposals have also provided knowledge in the study of suction on the strength of road materials, especially granular [5,7] [19-23].

According to the analyses performed by [24], which were mentioned in the introduction of this paper, the upper layers of flexible pavements are subjected to environmental factors such as relative humidity gradient. These cycles of atmospheric attacks end up being critical on these layers affecting the mechanical behavior. Some research similar to the methodology advanced in the current study showed the possibility of obtaining the water retention curve (WRC) of different asphalt mixtures [25,26].
Materials and Methods

Characterization of the material

Table I contains the physical variables of the asphalt binder used in this research. This bituminous material is associated with 60-70% asphalt of penetration, which satisfies the requirements for manufacturing hot asphalt mixes (MDC-19) defined in Colombian regulations.

Table I. Asphalt cement properties

Test	*Reference*	*Unit*	*Requirements Min / Max*	*Result*
Penetration (25°C, 100 g, 5 s)	[27]	0.1 mm	60 / 70	62
Penetration index	[28]	-----	-1.0 / +0.1	-0.1
Softening point	[29]	°C	-----	56
Specific gravity	[30]	-----	-----	1.02
Viscosity (60°C)	[31]	Poises	1000 / -----	1200
Inflammation Point	[32]	°C	232 / -----	230
Ductility (25°C, 5 cm/min)	[33]	cm	100 / -----	125

The aggregate properties listed in Table II allow the analysis of the interlocking between the material itself and the interaction with the bitumen surrounding the aggregate particle. Natural aggregate and asphalt binder (AC 60-70, penetration range according to [27,28]). These characteristics are shown in Tables 1-2, according to the guidelines recommended by INVIAS standard (2022). The tests carried out for the bitumen were penetration [27], penetration index [28], softening point [29], viscosity [31], Inflammation Point [32] and ductility [33]. In contrast, the aggregate materials were analyzed by the following standards: Los

Angeles machine [34], Micro-Deval [35], fractured particles [36], specific gravity / absorption [37,38]. The parameters of the materials used in the MDC-19 consider the specifications highlighted by Colombian standards consigned by INVIAS [39].

Table II. Aggregate test results

Test	*Reference*	*Unit*	*Requirements Min / Max*	*Result*
Wear resistance L.A. machine	[34]	%	25 /35	29.9
Microdeval	[35]	%	----- / 25	21.2
Fractured Faces	[36]	%	70 / 85	75
Bulk specific gravity	[37]	g/cm3	-----	2.62
Sg saturated superficially dry	[37]	g/cm3	-----	2.67
Absorption	[37]	%	-----	1.2
Fine aggregate specific gravity	[38]	g/cm3	-----	2.60

Regarding the particle size distribution, in order to guarantee the adequate mechanical behavior of the MDC-19, it was preferred to use the considerations of the INVIAS specifications [39]. These describe the curve that must remain within the required thresholds. These are shown as dashed lines in Figure 1. It can be seen that the curve fully complies with the recommendations of the Colombian regulations, since special care was taken in the preparation of the sample, in order to achieve the midpoint of the range shown.

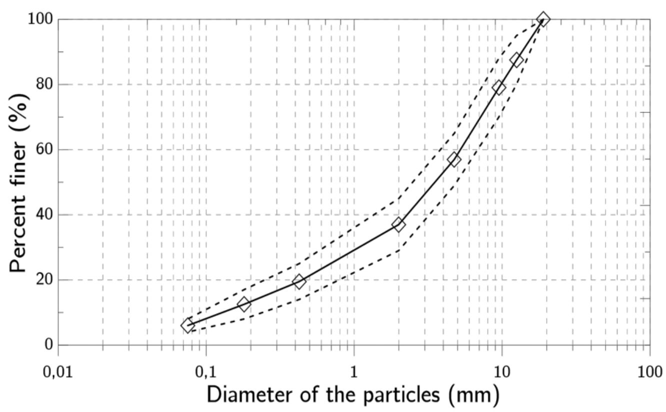

Figure 1. Particle size of distribution of the MDC-19 under analysis

Experimental program

The development of the samples was advanced by means of reference UNE-EN-12697-33 [40], which validates the manufacture of specimens in block geometry for hot asphalt mix materials employing a compacting roller. With this technique, it is possible to reproduce the compaction in situ adequately. The asphalt mixture was cut in cylindrical dimensions to establish similarity with the unaltered samples obtained in a shelby tube for soils. The ASTM standard dictates that the samples must be subjected to equilibration with filter paper for a minimum period of 7 days. Given the limited literary scope of adaptations with this test, a four-month interaction was allowed to ensure physical exchange between the materials (Figure 2). Additionally, the small moisture range required greater precision in the measurement data, so high-precision scales (0.0001 g) were used.

The test campaign was mainly oriented to estimating the water retention curve (WRC) in the asphalt mixtures used as analysis material. The specimens were compacted employing a roller that allows obtaining a continuous rectangular plate of the required thickness, adapting the procedure to asphalt mixtures, as described in the standard [3]. Subsequently, the specimens were cut to ensure a cylindrical shape with a height of 2.54 cm and a diameter of 5.5 cm since Whatman No. 42 filter paper comes from the factory with the indicated diameter.

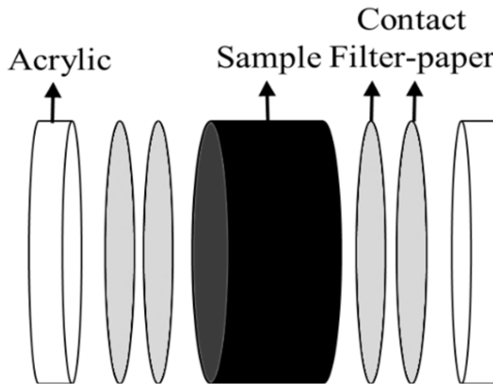

Figure 2. Configuration of the assembled samples

Figure 2. Configuration of the assembled samples

The technique chosen to obtain the matric suction was filter paper by direct contact with the sample (Figure 2). Since the filter paper methodology is commonly applied to clayey materials, its application to bituminous materials has practically never been studied. A calibration stage was necessary where the samples were left in equilibrium for 16 weeks (Figure 3). Equilibrium is the time necessary for adequate interaction between the filter paper and the soil sample. This time guarantees that the filter paper can absorb all possible moisture from the soil and subsequently obtain suction through the calibration chart shown in the standard [39]. The latter specimens revealed better response ranges, revealing reasonable suction values similar to those obtained by [4,5,7]. Samples left for short periods showed inconsistent results. At this stage of the process, it is important to highlight that great experience is required in developing the test and constructing the WRC.

For the construction of the WRC, a range of humidity must be artificially attributed to the asphalt mix sample. For this particular research, it was decided to saturate all the samples in a pool for one (1) week of immersion. They were then placed in the oven at a temperature of 40°C and gradually withdrawn at different times until 15 samples with a moisture range between 0.5% and 2.5% were obtained (Figure 4). The value of 2.5% moisture was calculated to be close to 100% saturation. This procedure adopted is complex, added to the four months of equilibration of the sample with the filter paper, but it ensures the imposition of the required moisture in the samples. Extensive knowledge is required in the development and interpretation of the laboratory test, since many of the samples may show erroneous results and must be discarded. In some cases, sample data from different batches of curves were adjusted in order to successfully achieve the final result.

The ASTM D5298–10 Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper standard [41] and studies such as that of [42] recommend samples of a maximum of 2.54 cm because a sample of considerable thickness may influence an adequate balance of the filter paper-soil system. The filter paper does not have enough time to drain water from the soil specimen if a thicker sample is used and indirectly registers incorrect suction.

Figure 3. Sample assembly procedure

Results

Water Retention Curve

Figure 5 shows the three water retention curves obtained for the asphalt mix tested. It is essential to bear in mind that the asphalt mix used has low porosity, so it reaches saturation with low humidity. In other words, the moisture range in which significant suctions are reached is very restricted, similar to what can be obtained in compacted soils. This specific behavior demonstrates the importance of evaluating the susceptibility of asphalt layers to environmental contact since they can develop high suction levels with little moisture change.

Figure 4. Samples in the oven

The suction values reached when the sample is desaturated are close to 5 pF (104 kPa). These results show that upper layers of flexible pavements, which are closely interacting with atmospheric changes of a dry nature, can accommodate significant suction that is not considered in any pavement design. Since the filter paper technique cannot cover the whole spectrum of measurable suction values, it was necessary to make mathematical adjustments to the WRC using the models proposed by [8-10] to obtain all the theoretical values. In the literature, these equations have been used for earth materials. However, it is observed in Figure 2 that the applied methodologies adequately address the water retention behavior revealed experimentally.

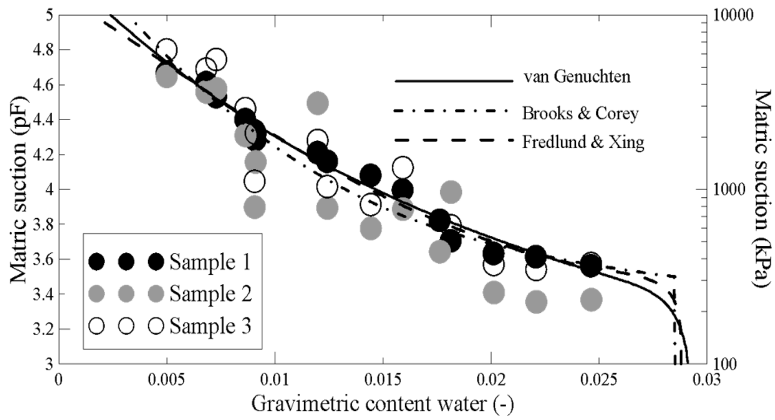

Figure 5. Water Retention Curve of asphalt mixture

Conclusions

It was possible to estimate the dry path of the WRC for this type of bituminous material using the filter paper technique. However, to achieve the equilibrium between the material under study and the filter paper, a considerable time is required (minimum three months) since generating a higher degree of effectiveness is possible.

It is essential to know that this technique is usually used for other types of geomaterials, which requires high skill in the execution of the test and in interpreting the results obtained. It is recommended to explore other techniques such as the Dew-point method, in order to obtain spectrums of suction values that the filter paper method cannot cover.

The theoretical adjustment curves, using the techniques of Brooks & Corey, van Genuchten and Fredlund & Xing, proved to be appropriate for use in this type of asphalt material. Their use is typically limited to soils of fine character.

The most important conclusion of this study is based on obtaining important suction values for this type of layer, which little was analyzed previously in the available literature in other studies. For small moisture ranges, suction levels were estimated that yielded promising data to continue studying these materials' water retention properties for different parameter variations, both in the asphalt binder and the aggregate used.

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