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Assessment of the asphalt mixtures properties subjected to a flexural strength

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Assessment of the asphalt mixtures properties subjected to a flexural strength

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Abstract. Fatigue cracking by loading is one of the main mechanisms of damage to asphalt mixtures in service. Several studies worldwide have been conducted to try to understand the response that hot-mix asphalt undergo under this mechanism of damage. Despite the above, the fatigue phenomenon in asphalt mixtures is still not fully understood. The current research hypothesizes that the response under repeated loading of asphalt mixtures in fatigue tests can be more clearly understood through the one obtained under monotonic loading. For this reason, this study presents the results of the first phase of the research in which beams of asphalt mixtures were subjected to flexion using monotonic loads. The above, to correlate the evaluated properties with those obtained in a second phase where the response of the beams under repeated load (fatigue) will be measured. Beams made of two hot-mix asphalt mixes, two asphalt contents, and two different thicknesses were subjected to flexural strength tests. From the tests, the modulus of rupture, the maximum monotonic load that supports the beams in the failure state, the displacement in the failure state, and the relation between load and displacement were obtained. As a general conclusion of the study, it was obtained that the response experienced by the beams subjected to monotonic load has a broad correlation with the reported in the reference literature.

1. Introduction

One of the primary damage mechanisms of asphalt mixtures is fatigue cracking [1-3]. In Asphalt pavements, fatigue cracking due to loads occurs when high accumulated tensile strain values are generated in the lower area of the asphalt layer due to the loads imposed by the traffic (repeated loads). It is considered that around the 1940s, the exponential increase in vehicles began in the world [4]. Practically, since that date, it has been reported that the asphalt layers begin to fail at minimal strains (deflections), close to 0.5 mm [5].

The continuous action of traffic typically exceeds the flexural strength in these materials. This effect is revealed with the appearance of cracks at the end of the lifespan [6]. The continuous movement of vehicles causes the asphalt layer to flex. This repetition of loading makes the asphalt mix lose stiffness and causes the appearance of tensile plastic strains, which simultaneously leads to the formation of microcracks. Due to the continuity of the load repetitions and the decrease in stiffness, the microcrack coalescence occurs, leading to the formation of a visible fissure (macrocrack) at ground level. Once the crack appears superficially, the life of the pavement decreases exponentially because water and air penetrate more quickly [7].

Despite the large number of research carried out on the subject, the phenomenon of fatigue in asphalt mixtures is still not fully understood, due to the multiple variables that affect the response that these materials undergo under repeated load. Some of them are the magnitude and speed of the load, the type of aggregates and asphalt, temperature, stiffness, and dimensions of the mixture, effects associated with aging and moisture damage, among others [8-12]. The test methods used to measure the fatigue resistance of asphalt mixtures can be grouped into the following categories [13]: Simple bending tests, bending tests with supports, direct axial tests, diametric tests, triaxial tests, and track tests.

In the previous tests (under controlled stress or strain), the number of load cycles that the material can resist until failure can be estimated [14,15]. Among the simple bending tests, one of the most used to evaluate the fatigue life of asphalt mixtures under repeated load is the bending beam test [3] (generally with load in the center of the beam or thirds). The present study hypothesizes that these tests of fatigue resistance on beams can be understood more clearly through the response of asphalt mixtures subjected to monotonic loads. Therefore, an experimental phase was designed to correlate the response obtained from flexural beam tests under monotonic load with the one obtained from fatigue resistance tests under repeated load.

For that purpose, the study was divided into two phases; this document presents the results of the first phase of the study, in which flexural resistance tests were carried out under monotonic load on beams made with two hot mix asphalt (HMA), two asphalt contents, and two different dimensions (varying the beam height). The current study is the first point of analysis for long-term research, which seeks to analyze the fatigue failure in beams of asphalt mixtures subjected to repetitive loads. Similar research to the one described in the present study were not found in the literature consulted. In this sense, the present document contributes to the state-of-the-art.

2. Methodology and materials

In Table 1 and Table 2, the asphalt AC 60-70 (0.1 mm) and aggregate properties used in the fabrication of beams are shown. These materials meet the established requirements by [16] to be used in manufacturing mixtures HMA.

Table 1. Physical characteristics of asphalt AC 60-70.

Characteristics	Specification	Measure	AC 60-70		
			Minimum	Maximum	Result
Penetration	[17]	0.1mm	50	70.0	67.00
Penetration index	[18]	-	-1.2	0.6	-0.59
Softening point	[19]	°C	48	54.0	49.60
Specific gravity	[20]	-	-	-	1.021
Viscosity Absolute 60°C	[21]	P	1500	-	2172
Flashpoint	[22]	°C	230	-	302
Ductility	[23]	cm	100	-	135
Loss of mass	[24]	%	-	0.8	0.40
Penetration, in% with refence to the original penetration	[17]	%	50	-	57.50
Increase of softening point	[18]	°C	-	9.0	7.80

Table 2. Physical characteristics of aggregate.

Characteristics	Standard	Measure	Value	Specification
Sand equivalent	[25]	%	66.0	min 55.0
Abrasion in Los Angeles	[26]	%	21.0	max 50.0
Form index	[27]	-	0.7	min 0.5
Soundness of aggregates by use of magnesium sulfate	[28]	%	7.0	max 12.0
Bulk specific gravity coarse	[29]	-	2.6	-
Bulk specific gravity saturated- surfaced –dry coarse	[29]	-	2.6	-
Absorption coarse	[29]	%	0.8	-
Specific gravity of fine aggregates	[30]	-	2.6	-

2.1. Marshall test

Marshall tests [31] were carried out to obtain the asphalt percentages to use in the manufacturing of the beams. The particle size distribution (Figure 1) recommended by [16] was used to manufacture the Marshall samples HMA-19 and HMA-25. In order to measure the volumetric composition of the mixtures (air void content (Va), voids in mineral aggregate (VMA), and the voids filled with asphalt (VFA)), and the strength parameters under monotonic load (stability (S), flow (F), and stability-flow ratio (S/F)) (see Table 3).

Five samples of 1200 g were manufactured for each percentage of asphalt of 4.5%, 5.0%, 5.5%, and 6.0% (concerning the total mass). Each sample was compacted by applying 75 blows per face. Mixing and compaction temperatures were 150 °C (asphalt viscosity = 170 cP) and 140 °C (asphalt viscosity = 280 cP), respectively. The results of the Marshall test are presented in Table 1. The optimal asphalt contents (OAC) of the HMA-19 and HMA-25 mixtures are 5.3% and 5.0%, respectively. Therefore, the decision to manufacture the beams with asphalt contents of 5.0% and 5.5% were made in both HMAs.

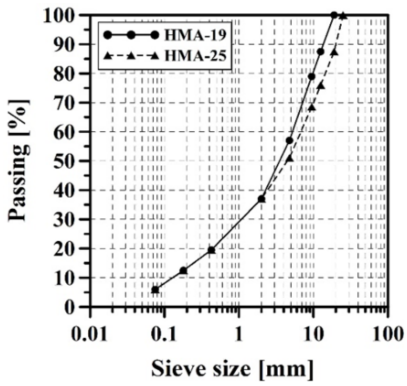


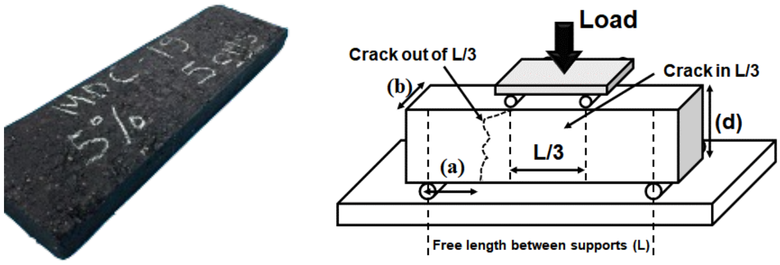
Figure 1. Particle size distribution curves of HMA mixtures.

Table 3. Marshall test.

Asphalt (%)	S (KN)	F (mm)	S/F (KN/mm)	Bulk density (g/cm^3)	Va (%)	VMA (%)	VFA (%)
HMA-19							
4.5	11.3	4.06	2.8	2.305	6.0	16.30	63.0
5.0	12.5	3.98	3.2	2.321	4.7	16.20	70.9
5.5	12.8	3.94	3.3	2.329	3.7	16.30	77.6
6.0	11.5	4.15	2.8	2.323	3.2	17.00	81.2
HMA-25							
4.5	11.9	3.76	3.2	2.285	4.6	14.77	68.8
5.0	13.7	3.80	3.6	2.284	4.0	15.25	74.0
5.5	13.5	3.84	3.5	2.288	3.1	15.53	80.1
6.0	12.9	4.14	3.1	2.325	0.9	14.63	94.2

2.2. Beams manufacturing and flexural strength test

To carry out the flexural strength tests, 32 beams were manufactured: 4 samples for each asphalt content (5.0% and 5.5%), beam height d (5 cm and 10 cm), and type of mixture (HMA-19 and HMA-25). The length and width (b) of each beam were 42 cm and 15 cm, respectively. The length between supports (L) was 38 cm. The particle size distribution (Figure 1) and the mixing and compaction temperatures to manufacture the beams were the same as the Marshall test (150 ° C and 140 °C, respectively). The beams were compacted by applying a monotonic load on their surface until achieving Va, obtained from the Marshall test. The above process was performed by trial and error on beams that were not failed (*i.e.*, beams manufactured only to achieve the standard dimensions and Va). An example of a fabricated beam is presented in Figure 2(a).



(a) (b)

Figure 2. (a) Example of manufactures beam; (b) test scheme.

The flexural strength tests on the beams were carried out following the guidelines established by [32]. Each beam was subjected to bending, applying a monotonic load (P) until failure; beam height (d) (5 cm and 10 cm), and type of mixture (HMA-19 and HMA-25). The length and width (b) of each beam were 42 cm and 15 cm, respectively. The length between supports (L) was 38 cm (see Figure 2(b)). According to [32], the displacement in a failure state (D) in mm, the distance between fracture line and closest support (a), were measured in the central area of each beam. With the results obtained from the tests, load-displacement ratio (P/D) (which can be understood as an indirect parameter of flexural stiffness under monotonic load) and the modulus of rupture (MR) were calculated using Equation (1).

$$MR = \frac{P \cdot L}{b \cdot d^2}. \quad (1)$$

In preliminary calibration tests, it was observed that the equipment is susceptible to loading speed. For very high speed, the record of maximum load P could occur suddenly during the test. For this reason, the speed was decreased to a value of 1.27 mm/min. Figure 2(b) shows the setup of the test.

3. Results and discussions

The average values (Av) with their respective standard deviation (SD) of the measurements and parameters obtained from the beams tested are shown in Table 2. It is observed that the MR tends to be higher in the HMA-25 mixtures. The above is perhaps due to the higher S/F ratio these mixtures undergo (greater stiffness and resistance under monotonic load) than HMA-19. This greater stiffness in tension as a product of the greater stiffness of the asphalt mix is coherent with other studies (*e.g.* [33,34]). Regardless of the above, the trend of the P/D relation is not clear. HMA-25 beams with a thickness of 10 cm undergo a higher P/D than HMA-19. However, when the thickness was 5 cm, the behavior was contrary. These results could help understand the response of asphalt mixtures in fatigue tests since the literature recommends tests with thin asphalt layers (≤5 cm) to carry out tests under controlled strain, while for thick asphalt layers, tests under controlled stress [35,36]. In both types of tests, the fatigue resistance of asphalt mixes is contrary. In fatigue tests under controlled strain, the mixtures that undergo better fatigue resistance are the minor stiffness. Nevertheless, under controlled stress, those with the increased stiffness [37,38]. On the other hand, it is evident that as the asphalt content increases, the D in the beams increases. Because when presenting a higher asphalt content, the mixtures tend to be more ductile. Also, HMA-25 mixes show higher D in the failure state as a product of the lowest Va and highest VFA.

4. Conclusions

This article shows the results of the first phase of a study to correlate the response that hot mix asphalt beams undergo in flexural strength tests under monotonic load. The above, to correlate this response with the one obtained under repeated load in fatigue tests in the future. Based on the results obtained, it is concluded that the beams manufactured with hot mix asphalt-25 undergo higher modulus of rupture compared to hot mix asphalt-19. The previous is perhaps due to the increased stiffness under monotonic load (S/F ratio) of the hot mix asphalt-25. This greater stiffness allowed the beams with hot mix asphalt-

25 and thickness of 10 cm to develop greater load-displacement ratio than those made with hot mix asphalt-19. A contrary behavior was experienced by the beams when the thickness was 5 cm, explaining the fatigue resistance in thin and thick asphalt layers, in which the strength is contrary (in thin asphalt layers, the mixtures experience less resistance to fatigue when their stiffness increases, while in thick the opposite occurs). Also, hot mix asphalt-25 mixes allow significant strain before failure, perhaps due to their lower air void content, and higher voids in mineral aggregate than hot mix asphalt-19. The higher the asphalt content, the more significant displacements are allowed in the failure, which is associated with increments in the mixture's ductility.

References

[1] Masad E, Castelo Branco V, Little D N, Lytton R 2008 A unified method for the analysis of controlled-strain and controlled-stress fatigue testing *International Journal of Pavement Engineering* **9(4)** 233
[2] Nejad F M, Aflaki E, Mohammadi M A 2010 Fatigue behavior of SMA and HMA mixtures *Construction and Building Materials* **24(7)** 1158
[3] Sudarsanan N, Arulrajah A, Karpurapu R, Amrithalingam V 2020 Fatigue performance of geosynthetic-reinforced asphalt concrete beams *Journal of Materials in Civil Engineering* **32(8)** 04020206
[4] Li N 2013 *Asphalt Mixture Fatigue Testing. Influence of Test Type and Specimen Size* (Delft: Delft University of Technology)
[5] Porter O J 1943 *Foundations for Flexible Pavements* (Washington: Proceedings Highway Research Board)
[6] Nijboer L W, Van der Poel C 1953 A study of vibration phenomena in asphaltic road constructions *Asphalt Paving Technology* **22** 197
[7] Rondón Quintana H A, Reyes F A 2015 *Pavimentos: Materiales, Construcción y Diseño* (Bogotá: ECOE)
[8] Moreno F, Rubio M C 2013 Effect of aggregate nature on the fatigue-cracking behavior of asphalt mixes *Materials and Design* **47** 61
[9] Moon K H, Falchetto A C, Marasteanu M O 2014 Investigation of limiting criteria for low temperature cracking of asphalt mixture *KSCE Journal of Civil Engineering* **18(1)** 172
[10] Meena P K, Saha G, Biligiri K P 2016 Estimation of fatigue life using resilient moduli of asphalt mixtures *Journal of Testing and Evaluation* **44(1)** 424
[11] Alinezhad M, Sahaf A 2019 Investigation of the fatigue characteristics of warm stone matrix asphalt (WSMA) containing electric arc furnace (EAF) steel slag as coarse aggregate and Sasobit as warm mix additive *Case Studies in Construction Materials* **11** e00265
[12] Ziari H, Amini A, Goli A 2020 The effect of different aging conditions and strain levels on relationship between fatigue life of asphalt binders and mixtures *Construction and Building Materials* **244** 118345
[13] Tangella S R, Craus J, Deacon J A, Monismith C L 1990 *Summary Report on Fatigue Response of Asphalt Mixtures* (Berkeley: University of California)
[14] Saha G, Biligiri K P 2015 Fracture damage evaluation of asphalt mixtures using semi-circular bending test based on fracture energy approach *Engineering Fracture Mechanics* **142** 154
[15] Zheng M, Li P, Yang J, Li H, Qiu Y, Zhang Z 2017 Fatigue life prediction of high modulus asphalt concrete based on the local stress-strain method *Applied Sciences* **7(3)** 305
[16] Instituto Nacional de Vías (INVIAS) 2013 *Mezclas Asfálticas en Caliente de Gradación Continua (Concreto Asfáltico), Artículo 450-13* (Colombia: Instituto Nacional de Vías)
[17] American Society for Testing and Materials (ASTM) 2020 *Standard Test Method for Penetration of Bituminous Materials, ASTM D5M-20* (United States of America: American Society for Testing and Materials)
[18] Centro de Estudios y Experimentación de Obras Públicas (CEDEX) 1999 *Indice de Penetración de los Betunes Asfálticos, NLT-181/99* (España: Centro de Estudios y Experimentación de Obras Públicas)
[19] American Society for Testing and Materials (ASTM) 2000 *Standard Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus), ASTM D36-95* (United States of America: American Society for Testing and Materials)
[20] American Association of State Highway and Transpotation Officials (AASHTO) 2009 *Standard Method of Test for Specific Gravity of Semi-Solid Asphalt Materials, AASHTO T 228-09* (United States of America: American Association of State Highway and Transpotation Officials)
[21] American Association of State Highway and Transpotation Officials (AASHTO) 2013 *Standard Method of Test for Viscosity Determination of Asphalt Binder Using Rotational Viscometer, AASHTO T 316-13* (United States of America: American Association of State Highway and Transpotation Officials)

[22] American Society for Testing and Materials (ASTM) 2019 *Standard Test Method for Flash Point of Cutback Asphalt with Tag Open-Cup Apparatus, ASTM D3143M-19* (United States of America: American Society for Testing and Materials)
[23] American Society for Testing and Materials (ASTM) 2017 *Standard Test Method for Ductility of Asphalt Materials, ASTM D113-17* (United States of America: American Society for Testing and Materials)
[24] American Society for Testing and Materials (ASTM) 2019 *Standard Test Method for Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin-Film Oven Test), ASTM D2872-19* (United States of America: American Society for Testing and Materials)
[25] American Society for Testing and Materials (ASTM) 2009 *Standard Test Method for Sand Equivalent Value of Soils and Fine Aggregate, ASTM D2419-09* (United States of America: American Society for Testing and Materials)
[26] American Society for Testing and Materials (ASTM) 2006 *Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine, ASTM C131-06* (United States of America: American Society for Testing and Materials)
[27] Departamento Nacional de Estradas de Rodagem (DNER) 1994 *Agregado - Determinação do Índice de Forma, DNER-ME 086/94* (Brazil: Departamento Nacional de Estradas de Rodagem)
[28] American Society for Testing and Materials (ASTM) 2005 *Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, ASTM C88-0*5 (United States of America: American Society for Testing and Materials)
[29] American Society for Testing and Materials (ASTM) 2007 *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate, ASTM C127-07* (United States of America: American Society for Testing and Materials)
[30] American Society for Testing and Materials (ASTM) 2007 *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate, ASTM C128-07a* (United States of America: American Society for Testing and Materials)
[31] American Association of State Highway and Transpotation Officials (AASHTO) 2015 *Standard Method of Test for Resistance to Plastic Flow of Asphalt Mixtures Using Marshall Apparatus, AASHTO T 245-15* (United States of America: American Association of State Highway and Transpotation Officials)
[32] American Association of State Highway and Transpotation Officials (AASHTO) 2018 *Standard Method of Test for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loagind), AASHTO T 97-18* (United States of America: American Association of State Highway and Transpotation Officials)
[33] Molenaar A A A, Li N 2014 Prediction of compressive and tensile strength of asphalt concrete *International Journal of Pavement Research & Technology* **7(5)** 324
[34] Teltayev B, Radovskiy B 2018 Predicting thermal cracking of asphalt pavements from bitumen and mix properties *Road Materials and Pavement Design* **19(8)** 1832
[35] Elseifi M A, Flintsch G W, Al-Qadi I L 2003 Quantitative effect of elastomeric modification on binder performance at intermediate and high temperatures *Journal of Materials in Civil Engineering* **15(1)** 32
[36] Muniz de Farias M, Quiñonez F, Rondón H A 2019 Behavior of a hot-mix asphalt made with recycled concrete aggregate and crumb rubber *Canadian Journal of Civil Engineering* **46(6)** 544
[37] Rondón-Quintana H A, Ruge-Cárdenas J C, Bastidas-Martínez J G, Velandia-Castelblanco M Y, Muniz de Farias M 2020 Use of thermally treated bentonite as filler in hot mix asphalt *Journal of Materials in Civil Engineering* **32(5)** 04020070
[38] Bastidas-Martínez J G, Rodríguez-Joaquín N, Torres-Daza H D, Rondón-Quintana H A, Ruge-Cárdenas J C 2020 Behavior of a draining mixture composed by recycled concrete aggregates and rubberized asphalt concrete *Respuestas* **25(1)** 96