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Effect of asphalt binder hardness and temperature on fatigue life and complex modulus of hot mixes

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HIGHLIGHTS

- The high hardness binders shift the critical temperature.
- Strain for one million cycles varies according to temperature and binder hardness.
- It is possible to determine the critical temperature for pavement design.
- Asphalt mixtures with higher hardness binders have a greater life fatigue.
- The Cole-Cole plane shows a parity between the fatigue and complex modulus.

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ABSTRACT

This paper deals with fatigue and complex modulus for three hot mixes. The Brazilian asphalt binders used in this work are classified by penetration grade 10/20, 30/45 and 50/70. It was observed a critical temperature variation in the Cole-Cole plane and in the fatigue test, where the smallest strain for one million cycles occurs at 30 °C for the mixture with penetration grade binder 10/20, and at 20 °C for the mixture with penetration grade binder 30/45, in relation to the mixtures prepared with conventional penetration grade binder 50/70, in which larger viscous component of the modulus normally occurs at 10 °C.

1. Introduction

Normally, the hot mixes prepared with hard asphalt binders have high stiffness modulus. However, the stiffness modulus and the fatigue resistance should be performed at different temperatures and frequencies in order to verify the critical temperature in the fatigue test. So it is very important to evaluate the effect of hard asphalt binder on the fundamental parameters of the pavement design: modulus and fatigue.

According to the French Design Manual for Pavement Structures [1], asphalt mixture fatigue properties are evaluated at 10 °C and 25 Hz. Experimental studies [2–6] point out that the bituminous mixtures fatigue properties change with temperature and frequency [7]. Asphalt mixtures with different stiffness exhibited different critical temperatures, i.e. the temperature where the smallest strain occurs for one million cycles. Moreover, the critical fatigue temperature for the asphalt mixture prepared with hard asphalt binder is higher when compared to conventional asphalt mixtures.

The high modulus asphalt mixture uses a continuous graded curve and a hardness binder. Recent researches show a high performance with gap-grade curve with a higher strain for one million cycles and high complex modulus. The fatigue resistance is influenced by arranging optimal aggregates and it is greatly influenced by asphalt binder nature [22].

The hardness influence of Brazilian asphalt binder on complex modulus in the Cole-Cole plane, and the fatigue behavior are the objectives of this paper. The results of the complex modulus are shown on the Cole-Cole plane. The complex modulus behavior is

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evaluated using the rheological Huet-Sayegh model [9,10] and rheological model 2S2P1D [23]. The complex modulus changes are discussed in relation to the fatigue test results, carried out at different temperatures.

2. Materials and methods

2.1. Aggregates

The source of the adopted aggregates is granitic rock of the Santa Catarina State, Brazil, characterized through conventional tests: Los Angeles abrasion, soundness of aggregate by $NaSO_4$ and absorption, Table 1.

The dense hot mixes gradation is obtained using the equation Fuller and Thompson [11] Eq. (1). For definition of "n", it is necessary to establish the maximum diameter of the aggregates gradation and the passing percentage through the sieve of 0.075 mm according the data showed in Table 2.

$$\%p = a \cdot \left(\frac{d}{D}\right)^n \tag{1}$$

Table 1
Properties of the aggregates [8].

Tests	Results	Test methods
Los Angeles Abrasion	19.96%	ASTM C131
Soundness of aggregate by $NaSO_4$	1.02%	ASTM C88
Absorption (%)	0.40%	ASTM D570

Table 2
Gradation of mixtures [8].

Sieved (mm)	High modulus asphalt concrete exponent of the curve (n) = 0.50 passing percentage (%)
15.90	100.0
12.70	89.4
9.50	77.4
6.45	63.9
4.76	54.9
2.38	39.0
1.19	27.6
0.59	19.5
0.30	13.9
0.15	9.9
0.075	7.0

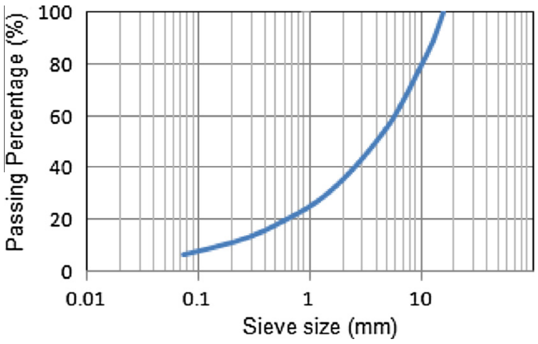

Fig. 1. Aggregate gradation curve [8].

where $\%p$ represents the weight percent that is sieved through an aperture d; a is a constant equal to 100; d is the aperture of the sieve, (mm); D is the aperture of the sieve that passes 100%, (mm); n is the exponent of the granulometric curve, Table 2.

The gradation curves for the mixture, the high modulus asphalt concrete [12] and asphalt mixture prepared with penetration grade binder 30/45, and asphalt mixture with penetration grade binder 50/70 are shown in Fig. 1.

2.2. Asphalt binder

The binder content of high modulus asphalt mixtures [8] was 5.7% using penetration grade binder 10/20 and richness modulus of 3.84. The binder content for the asphalt mixtures with both penetration grade binder 30/45 and 50/70 was 5.7%. The properties of the asphalt binders are shown in Table 3.

2.3. Specimens preparation

Three asphalt mixtures were prepared: the first, with penetration grade binder 10/20 for high modulus asphalt concrete [8]; the second, with penetration grade asphalt binder 30/45; and the third, with penetration grade asphalt binder 50/70. The mixture and compaction temperatures are shown in Table 4.

The complex modulus and fatigue tests are carried out with trapezoidal specimens sawed from slabs, produced in laboratory, with dimensions 400 mm × 600 mm × 120 mm. The slabs are sawed according to the standard NF P98-250-3 [14]. The dimensions of the trapezoidal specimens are: big base (B) (70 ± 1) mm, small base (b) (25 ± 1) mm, thickness (e) (25 ± 1) mm, length (h) (250 ± 1) mm. The specimens are selected satisfying two conditions: the standard deviation of air volume shall be less than 0.5%, and the coefficient of variation of the parameter K_ε shall be less than 1%, Eq. (2).

$$K_\varepsilon = \frac{\varepsilon_{máx}}{Z} = \frac{(B-b)^2}{8bh^2\left[\frac{(b-B)(3B-b)}{2B^2} + \ln\frac{B}{b}\right]} \tag{2}$$

where K_ε is the coefficient in function of dimensions, mm^{-1}; h is the height of the specimen (mm); e is the thickness of the specimen (mm); B is the big base of the specimen (mm); b is the small base of the specimen (mm).

2.4. Complex modulus

The complex modulus test is carried out following the French norm NF P 98-260-2 [15], the strain is in the linear viscoelastic domain (40 microstrain). This test is a two point bending-test, the solicitation type is sinusoidal signal with controlled displacement, and it was carried out in the machine of complex modulus and

Table 4
Mixture and compaction temperature.

Temperature (°C)	Asphalt mixture with pen grade binder 50/70	Asphalt mixture with pen grade binder 30/45	Asphalt mixture with pen grade binder 10/20
Aggregates	165	175	185
Binder	150	165	175
Mixture	150	165	175
Compaction	140	155	165

Table 5
Temperature of fatigue test.

Asphalt mixtures	Temperature [°C]	Frequency [Hz]
Asphalt mixture with pen grade binder10/20	10, 20, 30, 40	25
Asphalt mixture with pen grade binder 30/45	10, 20, 30	25
Asphalt mixture with pen grade binder 50/70	0, 10, 20, 30	25

Table 3
Properties of bitumen.

Properties	Penetration grade binder 50/70	Penetration grade binder 30/45	Penetration grade binder 10/20	Standard
Penetration at 25 °C, (5 s) 100 g	53 (0.10 mm)	33 (0.10 mm)	10 (0.1 mm)	ASTM D 5
Softening point	50 °C	56 °C	66 °C	ASTM D 36
Specific gravity	1.0130 g/cm^3	1.0176 g/cm^3	1.0190 g/cm^3	ASTM D 70