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Temperature implications on rheological-mechanical behavior and design of high modulus dense asphalt mix

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HIGHLIGHTS

- A research on the rheological-mechanical behavior of high modulus dense asphalt mix is carried out.
- All the materials, parameters and models to formulate the asphalt mix tested are defined.
- Complex modulus, fatigue resistance and numerical simulations are the main evaluation scopes.
- Critical energy dissipation temperature is a decisive parameter to design asphalt pavements.

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ABSTRACT

The main aim of this paper is to evaluate the influence of temperature on mechanical-rheological behavior and design of high modulus dense asphalt mix. Analytical procedures were conceived based on the French rational methodology. The asphalt mix formulated was tested through two point bending complex modulus and fatigue tests. Numerical simulations using Huet-Sayegh viscoelastic linear model and computerized tools Viscoanalyse and Viscoroute were proceeded to design asphalt pavement structures. The results obtained indicate the critical energy dissipation temperature verified in complex plan has decisive influence on the asphalt mix behavior and must be analyzed particularly for designing asphalt pavement structures.

1. Introduction

Understanding rheological-mechanical properties of asphalt mixes at different temperatures and loading frequencies is essential, due to influence they exert directly on the viscoelastic linear behavior of these materials [7,18,21,15].

The constant need of formulating asphalt mixes able to support the growing, continuous and intense loading axle levels of the traffic fleet worldwide, have been leading to research the effect of high consistent asphalt binders in increasing the stiffness dynamic (or complex) modulus and resistance to fatigue, which is the main phenomenon responsible for the rupture of pavement structures in the field [11,20].

French methodology was chosen to proceed the technical analyses of this research, due to present narrow field/laboratory ratios scientifically attested, thus, supplying credibility to the results obtained. And in its technical context for designing pavement structures, the complex modulus value determined at 15 °C and 10 Hz is assumed, as well as the admissible fatigue strain to 10^6 loading cycles obtained at 10 °C and 25 Hz [16].

For complex modulus, the temperature of 15 °C is taken into account, in order to be the equivalent temperature for weather conditions in France. However, equivalent is not the same of air temperature, but that measured along a given period at different temperature conditions in the bottom of the asphalt layer subjected to repeatable tensile strains caused by the traffic loading applications, which are capable to lead the asphalt mix, and subsequently the pavement, to collapse. Frequency of 10 Hz is adopted because it is close to that regarding the monitored strain amplitude signal generated in the bottom of the deepest field asphalt layers during heavy vehicles loading applications (above 50 kN) [14].

Concerning fatigue resistance tests, the temperature of 10 °C and frequency of 25 Hz are adopted, due to represent the most usual unfavorable conditions related to mechanical performance of traditional asphalt mix formulations, mainly of those produced

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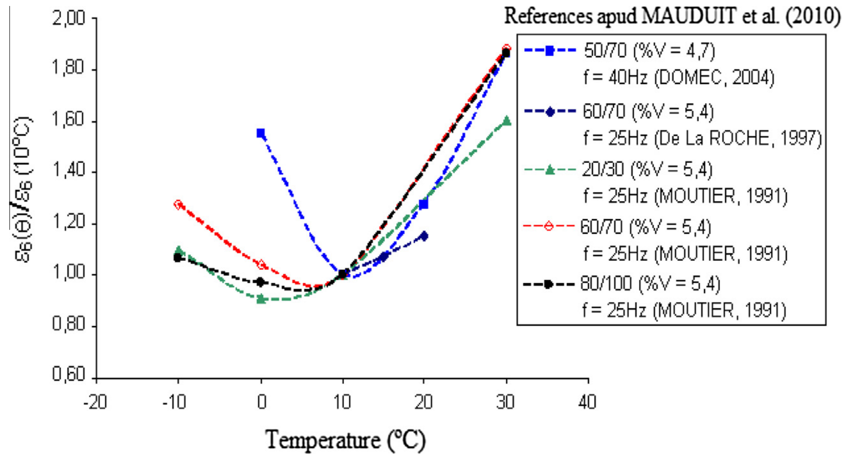

Fig. 1. Evolution of strain at 10^6 cycles of loading applications (ε_6) related to temperature [17].

with ordinary commercial asphalt binders [17] as illustrated in Fig. 1, while 25 Hz is the frequency chosen in order to accelerate the occurrence of fatigue phenomenon in laboratory.

However, every change related to the nature of asphalt binders can alter significantly the critical rheological behavior of the asphalt mixes formulated, affecting directly the temperature value considered as the most unfavorable to evaluate their mechanical performance in fatigue tests.

Therefore, this research investigates the effect of adding high consistent asphalt binder 10/20 in high modulus dense asphalt mix formulation, taking into account the temperature intensity with regards to critical energy dissipation by internal viscous friction in the complex plan so-called Cole-Cole, and its respective impact not only on the mechanical performance of that asphalt mix, but also on the pavement structure design by numerical simulations, according to the standardized principles of the French methodology.

2. Materials and methods

2.1. Asphalt binder

The high consistent asphalt binder 10/20 used to formulate the asphalt mix tested in this research has the characteristics indicated in Table 1 and Fig. 2.

The optimum asphalt binder content of 5.7% was based on the research carried out by Quintero et al. [19], which used the same sample of asphalt binder 10/20, as well as the same aggregate source and gradation curve proposed in this manuscript, considering performance evaluation levels predicted in Manuel LPC [16], such as: conformity to compacting process at Giratory Shear Press, resistance to action of water in Duriez test at 18 °C, resistance to rutting by pneumatic cyclic loadings at 60 °C, complex modulus and fatigue resistance.

2.2. Aggregate gradation curve

The aggregate gradation curve of the asphalt mix was calculated with use of the Eq. (1) from Füller and Thompson [13], which was formulated entirely by granitic crushed rock particles, being fixed the maximum diameter (D) as 15.9 mm and the percent passing through sieve size 0.075 mm (%p) as 7.0%, with power (n) 0.50, which confirms the characteristic of dense asphalt mix (Fig. 3).

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

Table 1
Characteristics of the asphalt binder 10/20.

Test	Standard procedure	Result
Penetration	Abnt Nbr 6576 [2]	10 (0.1 mm)
Softening point	Abnt Nbr 6560 [1]	66 °C
Real specific gravity	Abnt Nbr 6296 [3]	1.02

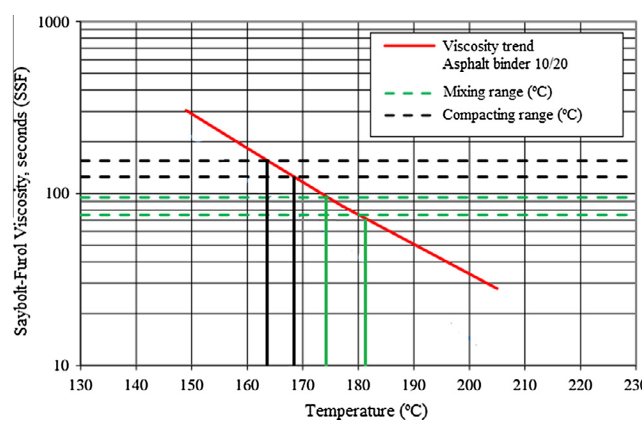

Fig. 2. Viscosity trend of the asphalt binder 10/20.

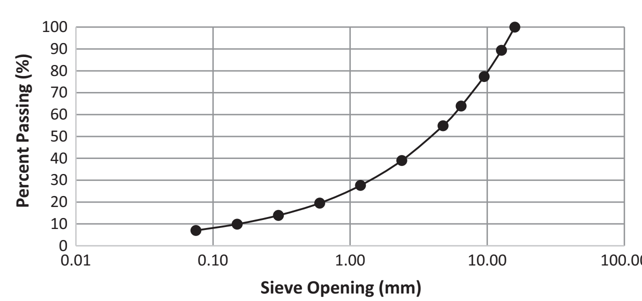

Fig. 3. Aggregate gradation curve.

where '%p' is the percent in weight which passes through a given sieve opening of the aggregate gradation curve; a = constant, taken as 100; 'd' is a given sieve opening along the series of the aggregate gradation curve (mm); 'D' is the maximum diameter of the aggregate gradation curve (mm); and 'n' is the power of the aggregate gradation curve.