HOT MIX ASPHALT CYCLIC TORQUE TESTS FOR VISCOELASTIC BULK SHEAR BEHAVIOUR

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ABSTRACT

The main goal of this paper is to compare tension-compression cyclic test and alternate cyclic shear torque test. This original test for standard Hot Mix Asphalt (HMA) will lead to get shear complex modulus and Young complex modulus for each sample. Slabs core sampling is performed with one main diameter 100 mm. The experimental program is related to HMA bulk behaviour. Servohydraulic MTS device is able to perform cyclic axial and cyclic torque test to get Young complex modulus E* and shear complex modulus G* for six frequencies and two temperatures 10°C and -5°C. Interesting results complex Poisson ratio can be obtained from E* and G*. Master curve E*, G* and ν* are drawn with the same temperature shift factor. The authors have shown that cyclic torque test can be performed for HMA with core sampling in the field or in slabs for G* identification in good agreement with standard tensile-compression test.

Keywords: Complex modulus E* and G*, Cyclic Torque Tests, Cyclic Shear Behaviour.

1. INTRODUCTION

Pavement interface between surface layer and base layer are more and more subjected to damage such as debonding. New pavement technologies (thin surface layers and new asphalt materials), new tire pavement technologies and also increasing of traffic loading lead to such damage due to traffic loading. Assuming that the origin of such damage is mainly due to shear loading in the interface, this study focuses on cyclic torque tests which can reproduce such solicitation. In practical cases, bituminous materials are always considered as isotropic and have been widely studied in the mono-dimensional case with a constant Poisson's ratio. The LVE properties of the HMA are measured by means of complex modulus tests (tension–compression) at selected temperatures and frequencies.

An investigation into the linear viscoelastic (LVE) domain of HMA materials is presented in this paper, in which two loading phases have been considered: standard tension-compression test and cyclic torque test. The mechanical behaviour and test procedure validation by comparison of tension-compression test (complex modulus identification E*) widely used and such test as cyclic torque test (shear complex modulus G*) is the main original result for bulk asphalt material characterization. Complex Poisson ratio can be identified from both loading protocol. The obtained Poisson's ratios are higher than 0.5 for frequencies lower than 1 Hz. Such results reveal anisotropic properties of HMA.

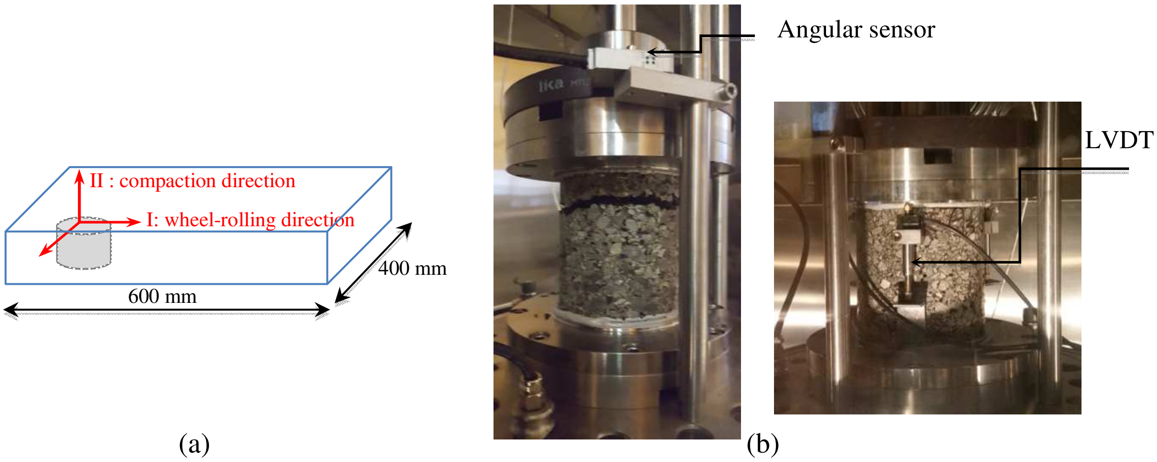
The following sections present successively the tested bituminous material and the experimental procedures, and the obtained experimental results.

2. SAMPLE AND TEST PROCEDURE

The objective of this paper is viscoelastic characterization with small strain. Cyclic torque-axial loading is proposed with cylinder core sampling in the field or on slab made in laboratory. Cyclic axial loading will give complex modulus E* and cyclic torque loading will give shear complex modulus G*. From these moduli, Poisson ratio is calculated and cyclic torque procedure is validated.

2.1 Servohydraulic Press and experimental protocol

MTS devise is able to apply a torque of 1000 N.m and axial load of 100 kN. Angle rotation is measured with a magnetic angular sensor without contact (accuracy 0,001°). Axial strains are measured with three LVDT. Angular sensor is located on the upper steel plate (Figure 1).



(a) (b)

FIGURE 1 (a) slab and cylindrical specimen material directions and (b) experimental device

Three temperatures (-5°C, 10°C and 20°C) and seven frequencies (0,01Hz, 0,03Hz, 0,1Hz, 0,3Hz, 1Hz, 3Hz and 10Hz) are chosen. Sinusoidal angular rotation signal (3.10^{-3}°) and axial strain signal (50µm/m) are controlled with servohydraulic press for torque and axial loading, respectively. In terms of distortion γ, it corresponds to amplitudes of 5.10^{-5} m/m.

For torque test on cylindrical samples, shear stress is considering linear against radius (Figure 2). If we assume elastic behaviour, we remind the relationship between torque couple T and shear modulus G with Eq. (1) :

$$G = \frac{T}{\alpha . I_p} . L \qquad \text{Eq. (1)}$$

where : L is length of the sample (mm) ; α is the torque rotation angle (rd) ; $I_p = \frac{\pi R^4}{2}$. The shear modulus G is calculated at each temperature-frequency condition.

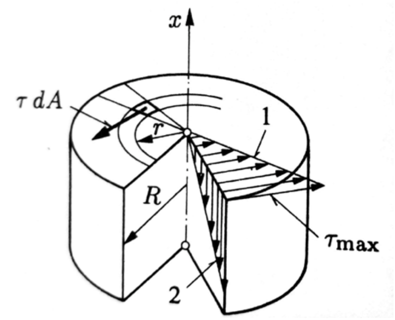


FIGURE 2 Torque test : Shear stresses distribution

2.1 material and samples tested

Both sinusoidal cyclic torque and tension-compression tests were applied on HMA (BBSG 0/10). Cylindrical specimens were 100mm diameter and 100mm high. The test conditions used for this study are summarized in table 1. Each sample has been cored from slab (60x40x16 cm^3) made with French wheel compactor (EN 12697-33). Figure 1 (a) presents the slab and the 3 identified material directions.

The axes I, II, and III are related to the specific material directions (I: rolling direction, II: vertical load direction of compaction, and III: direction transverse to the rolling wheel compaction). In this study, the cylindrical tested specimen orientation is indicated in Figure 1 where loading is applied in direction II.

TABLE 1 : Samples and materials for complex modulus

Reference	Material	Size (mm)	Test Temperature (°C)	% voids	Test type	Control mode
T-AT1	BBSG 0/10	100X100	0	8,34	Torque	Angle rotation
T-AT4			-5 10 15	6,99	Torque Tension-Compression	Angle rotation Axial strain
T-AT5			0 10	7,54	Torque	Angle rotation

3. TENSILE-COMPRESSION-TORQUE TESTS

3.1 Complex modulus isotherms curves

The $|E^*|$ and $|G^*|$ values measured in this study are summarized respectively in Figure 3 and Figure 4. The data in these figures are presented in isothermal and isochronal forms. It can be easily observed that HMA exhibits a temperature/frequency dependent mechanical behaviour.

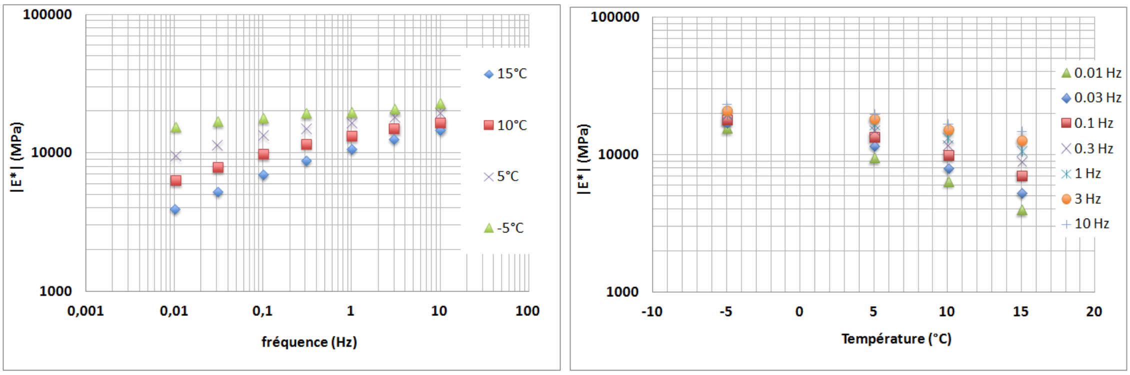


FIGURE 3 Isotherms and isochrones axial complex modulus curves

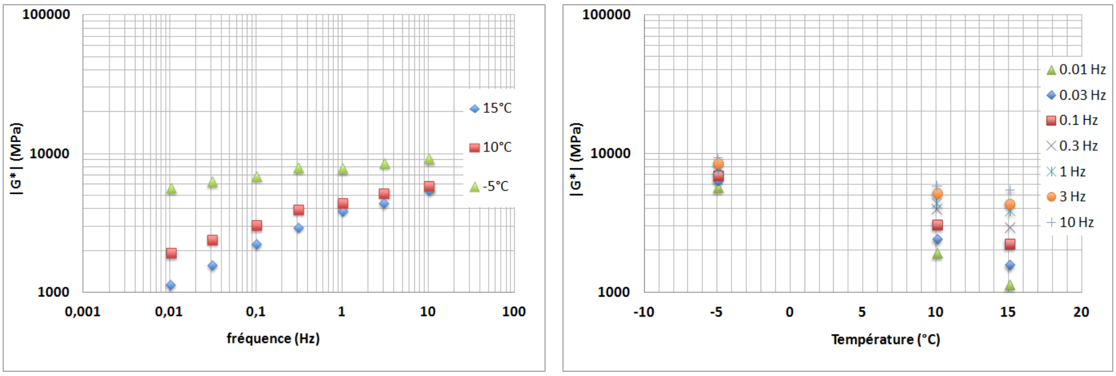


FIGURE 4 Isotherms and isochrones shear complex modulus curves

In isotropic materials, we can obtain the Poisson's ratio from the shear and Young's modulus. In viscoelastic materials, the Poisson's ratio ν may be defined in several ways. According to Tschoegl [1], the Poisson's ratio of asphalt materials is a priori complex and for a sinusoidal steady-state excitation the elastic constants should be replaced by the corresponding complex quantities. Then Poisson ratio can be deduced with Eq. (2):

$$G^{*} = \frac{E^{*}}{2(1+\nu^{*})} \qquad \text{Eq. (2)}$$

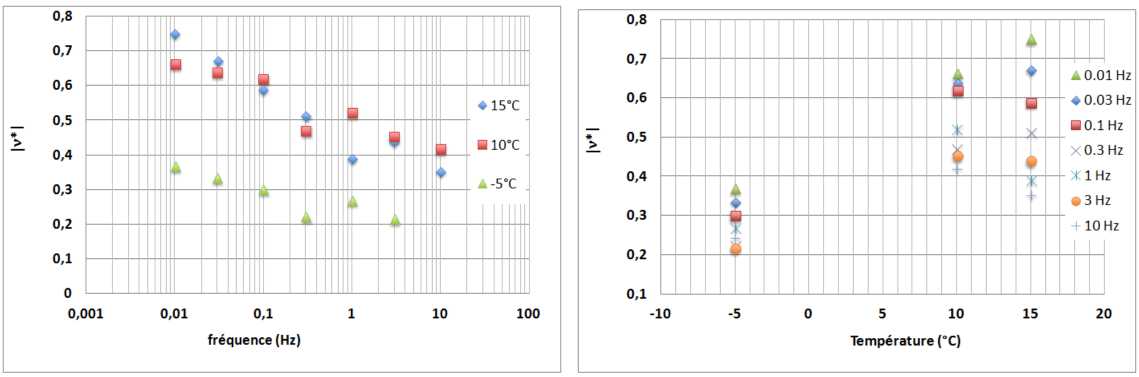


FIGURE 5 Isotherms and isochrones complex Poisson ratio

Figure 5 show the norm of Poisson's ratio |ν* | from Eq. (2). For cylindrical specimens, if the loading is applied in direction II, the Poisson's ratio is the same in the two directions III-II and I-II ($\nu^*_{III-II} = \nu^*_{I-II}$) for isotropic case and it is different for anisotropic case ($\nu^*_{III-II} \neq \nu^*_{I-II}$). In other studies, the Poisson's ratio of HMA in the direction III-II is different from direction I-II and ν^*_{III-II} varies from 0.2 to 0.7 [2-3]. It can be concluded that the obtained complex Poisson's ratio is in direction III-II.

3.2 Master curves

The time temperature superposition principle (TTSP) has been verified by many studies for unidirectional linear viscoelastic behaviour of HMA. This property allows plotting master curves of complex modulus and Poisson's ratio at any chosen temperature T_{ref}.

Figure 6 show plots of complex moduli (|E*| and |G*|) and Poisson's ratio master curves. The reference temperature chosen to build master curves is 10°C. It can be observed that the norm of Poisson's ratio is not a constant equal to 0.35, as generally admitted in literature. |ν*| varies approximately between 0.2 for high frequencies and/or lower temperature and 0.7 for low frequencies and/or high temperatures. For frequencies less than 1Hz, Poisson ratio is higher than 0.5 and it decreases while temperature decreases and while frequency increases. The same results are obtained in other studies for complex Poisson's ν^*_{III-II} [2-3]. For orthotropic materials, Poisson's ratio higher than 0.5 imposes the verification of stability of the behavior [4-5].

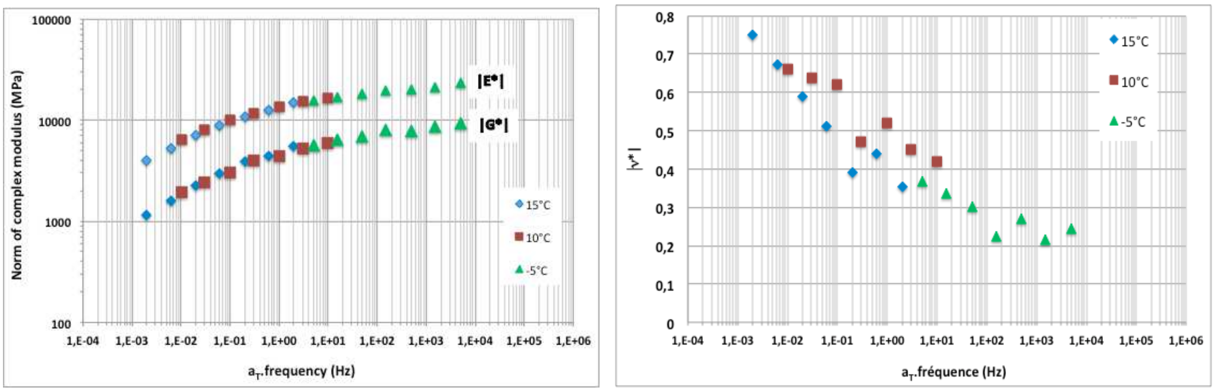


FIGURE 6 Master curves of norm of complex Young's modulus, shear modulus and Poisson's ratio

The classical Williams-Landel-Ferry (WLF) law [6], reported in Eq. (5), is used to fit shift factors:

$$\log(a_T) = \frac{-C_1\left(T - T_{ref}\right)}{C_2 + T - T_{ref}} \qquad \text{Eq. (5)}$$

where C_1 and C_2 are two empirical constants and T_{ref} is the reference temperature. Figure 7 presents the shift factor of HMA used for the construction of the master curves, approached by the WLF law.

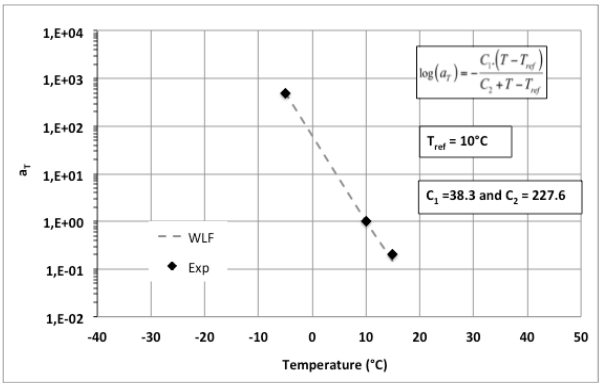


FIGURE 7 Experimental and fitting shift factors for master curves |E*|, |G*| and |ν*|.

An important result from Figure 7 is that, in agreement with TTSP, shift factors can be considered as identical for complex Young's and shear moduli and complex Poisson's ratio:

$$a_T = a_{TE} = a_{TG} = a_{T\nu} \qquad \text{Eq. (6)}$$

6. CONCLUSION

In this paper, testing and analysis of linear viscoelastic orthotropic behaviour of HMA materials are presented. It includes experimental investigation using axial cyclic tension-compression tests and cyclic torque tests. The combination of these tests gives the 3-dimensional linear behaviour of HMA.

The tested HMA is considered as thermorheologically simple, which means that the Time–Temperature Superposition Principle (TTSP) is verified. The shift factors used for the construction of the master curves were the same for the complex moduli and the complex Poisson's ratios. The obtained Poisson's ratio shows that the HMA can be considered as orthotropic. The equations assuring stability for elastic materials need to be checked for the norm of complex parameters (modulus and Poisson's ratio) on the whole frequency-temperature range.

7. AKNOWLEDGEMENT

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8. REFERENCES

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