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Comparison of the 3-dim linear viscoelastic behavior of asphalt mixes determined with tension-compression and dynamic tests

Jean-Claude Carret *, Alvaro Pedraza, Hervé Di Benedetto, Cédric Sauzeat

LTDS (UMR CNRS 5513), University of Lyon/ENTPE, Rue M. Audin, 69518 Vaulx en Velin, France

HIGHLIGHTS

- Dynamic tests can be used to characterize the LVE behavior of asphalt mixes.
- Asphalt mixes with 70% of RAP were tested with dynamic tests.
- Small differences exist between results from complex modulus and dynamic tests.
- Norm of the complex modulus obtained from dynamic tests is higher.
- Phase angle of the complex modulus obtained from dynamic tests is lower.

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ABSTRACT

In this paper, conventional cyclic tension-compression tests and dynamic measurements have been applied to three cylindrical specimens of asphalt mixes. The results of the two tests have been compared. For the tension-compression tests, the complex modulus was obtained from the measurements of the axial stress and axial strain. For the dynamic testing, an instrumented impact hammer and an accelerometer have been used to obtain the frequency response functions of the specimens at different temperatures. The dynamic complex modulus was then back calculated by optimizing finite element calculated frequency response functions to match the measured frequency response functions. The 2S2P1D linear viscoelastic model was used to estimate master curves of the complex modulus for the two test methods. The two tests give similar results. However, the dynamic measurements give a higher value of the norm of the complex modulus and a lower value of the phase angle compared to the tension–compression results. This result is probably explained by the nonlinearity of asphalt mixes as dynamic tests are performed at a much smaller strain level than the tension-compression tests.

1. Introduction

The complex modulus is widely known as the fundamental parameter to characterize the linear viscoelastic (LVE) behavior of asphalt mixes (AM), which is essential in pavement design. Conventional cyclic tension-compression tests are costly, complex to perform and they are not adapted for in situ measurements. Therefore, there is a need for alternative test methods that are more economical and that could be applied on field pavement structures. Dynamic measurements such as impact loadings [1,2] are economical, simple to perform and are very well known for accurate characterization of material properties in different applications [3]. Dynamic measurements can also be used for in situ quality control of pavement [4,5]. Dynamic testing of AM to determine the complex modulus have been performed through measurements of the flying time in wave propagation tests [6–8]. Resonance testing has also been used to evaluate the complex modulus of AM through the measurements of the fundamental resonance frequencies of AM specimens [9–11]. These two methods are based on simplified approximate formula that give access to the complex modulus only for a limited number of geometries and frequencies. Therefore, the frequency dependency of AM cannot be characterized through these two tests. Resonant acoustic spectroscopy intends to increase the number of frequency for which the complex modulus can be calculated [12–15]. Although, this method still not provide enough information to estimate the global master curve for AM. Frequency response functions (FRFs) measurements have been used to characterize viscoelastic materials over a wide frequency range [16–18]. Laboratory measurements of FRFs for AM

* Corresponding author.
E-mail addresses: jean-claude.carret@entpe.fr (J.-C. Carret), alvaro.pedraza@entpe.fr (A. Pedraza), herve.dibenedetto@entpe.fr (H. Di Benedetto), cedric.sauzeat@entpe.fr (C. Sauzeat).

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have showed promising results [19] and enables a direct comparison between master curves obtained from tension-compression tests and from dynamic measurements. Duttine et al. in 2007 and Ezaoui et al. in 2009 [20,21] have showed that the combination of both conventional measurements and dynamic testing is useful to improve the characterization of sands. The same approach was used on AM by Gudmarsson et al. in 2014 and 2015 [22,23] and it showed small differences between the two test methods due to the known nonlinearity of asphalt concrete [24–26] and because the applied strain levels are different in the two methods. In this paper, three specimens of the same AM containing 70% of reclaimed asphalt pavement (RAP) were tested with tension-compression tests and dynamic testing. The LVE properties of the specimens obtained with the two different methodologies were compared. The results show that the two test methods give similar results.

2. Methodology

The tests presented in this paper were performed at the ENTPE laboratory (University of Lyon). The tension-compression tests were performed first. Then the upper and lower part of the sample were sawed in order to eliminate the caps glued on the specimens for these tests. Then, dynamic tests were performed on the same specimen with a reduced length. More details on the materials and on the two different experimental procedures are presented in the following sections.

2.1. Materials

Three different specimens of the same material are considered in this paper. The material was fabricated for the IMPROVMURE project [27], a project from the French national research agency studying the environmental and mechanical impact of multi-recycling on asphalt mixes. It is a laboratory designed asphalt mix containing 70% of RAP after one cycle of recycling. Details of the three studied specimens are reported in Table 1. To simplify the notation in the next tables, each specimen is identified to its abbreviation. Tension-compression tests and dynamic tests were performed on each specimen.

2.2. Conventional characterization of the LVE behavior with complex modulus test

2.2.1. Tension-compression complex modulus tests

Cyclic tension-compression tests were used to determine the complex modulus of the three considered specimens. Cylindrical samples having a height of 150 mm and a diameter of 75 mm were used for these tests. Cyclic sinusoidal axial loadings were applied using a hydraulic press in strain-controlled mode with an amplitude of around 50 μm/m. A load cell measured the axial stress ($\sigma_1 = \sigma_0.\sin(\omega t\text{-}\varphi_E)$ or $\sigma_1 = \sigma_0.e^{i(\omega t\text{-}\varphi E)}$ in complex notation) while the axial strain ($\varepsilon_1 = \varepsilon_{01}.\sin(\omega t)$ or $\varepsilon_1 = \varepsilon_{01}.e^{i\omega t}$ in complex notation) was obtained from the average of the three extensometers placed at 120°. Finally, the radial strain ($\varepsilon_2 = \varepsilon_{02}.\sin(\omega t + \varphi_v)$ or $\varepsilon_2 = \varepsilon_{02}.e^{i(\omega t + \varphi v)}$ in complex notation) was deduced from two non-contact transducers. The tension-compression tests were performed at 9 temperatures from −25 °C to 55 °C in steps of 10 °C and at 8 loading frequencies (0.003, 0.01, 0.03, 0.1, 0.3, 1, 3 and 10 Hz). Details of the experimental set up are shown in Fig. 1 and an example of experimental data for two cycles of loading at 1 Hz and 15 °C, is presented in Fig. 2.

The complex modulus and complex Poisson's ratio at the different temperatures and frequencies were calculated according to Eqs. (1) and (2) where σ_1^*, ε_1^* and ε_2^* are the complex expressions of σ_1, ε_1 and ε_2, φ_E is the phase of the complex modulus and φ_v is the phase of the complex Poisson's ratio.

$$E^*(\omega) = \frac{\sigma_1^*}{\varepsilon_1^*} = |E^*(\omega)|e^{i\varphi_E} \quad (1)$$

$$v^*(\omega) = -\frac{\varepsilon_2^*}{\varepsilon_1^*} = |v^*(\omega)|e^{i\varphi_v} \quad (2)$$

Table 1
Details of the specimen used in this study.

Specimen	Abbreviation	Mass (g)	Height (mm)	Diameter (mm)	Density (kg/m^3)	Void ratio (%)	Bitumen content (%)
LWF-70-1-1-4	4	1293	0.123	75	2379	6.6	5.4
LWF-70-1-1-6	6	1320	0.123	75	2431	4.2	5.4
LWF-70-1-1-8	8	1330	0.123	75	2449	3.8	5.4

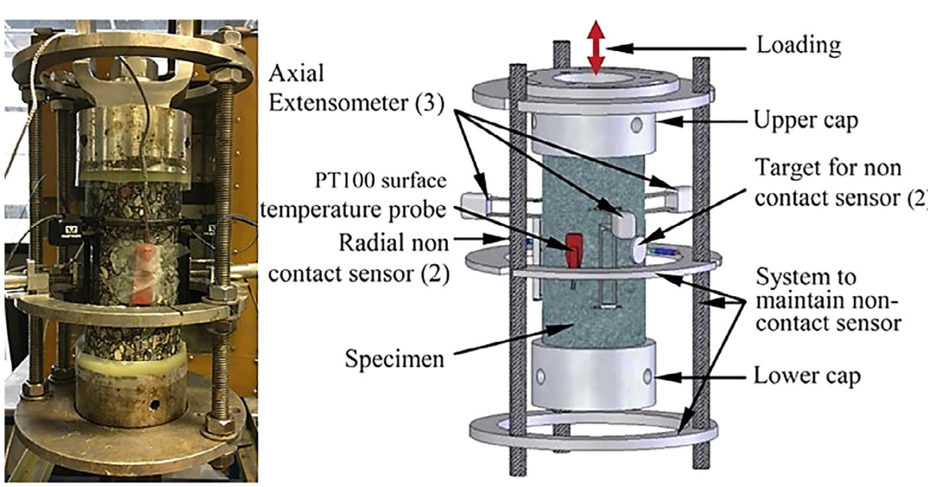

Fig. 1. (left) Tension-compression test apparatus used for tests on asphalt mixes (ENTPE laboratory, Vaulx-en-Velin, France); (right) detailed scheme of measurement devices and sample.