

Stiffness Comparisons of Mastics Asphalt in Different Test Modes

H. Kim & M.N. Partl

Empa, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland

ABSTRACT: Four-point bending beam (4PB) test has been widely used for predicting the stiffness and fatigue life of asphalt materials. However, in Switzerland, coaxial shear tests (CAST) and two-point bending beam (2PB) tests have been used to obtain the complex modulus and the fatigue behavior of asphalt materials. Recently, a Swiss national research project was initiated for adopting the 4PB test and for evaluating pavement performance of Swiss highways. Based on European standards, a 4PB test set-up was manufactured in Empa and LabVIEW program was implemented to control experimental tests. This paper will discuss about experimental comparisons of various test methods, an uniaxial compression test (UCT), an indirect tension test (IDT), a co-axial shear test (CAST), and a 4PB test. As a calibration procedure, the stiffness of an aluminum bar made by Empa was reasonably predicted with different strain levels and frequencies. Mastics asphalt (MA8) specimens were tested by four different test methods. The test temperature range was from -20°C to 20°C and the range of frequency was between 0.01Hz and 10Hz. All test results were predicted and compared by Witczak's sigmoidal function.

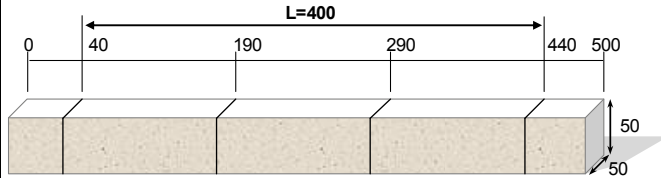
1 INTRODUCTION

Four-point bending beam (4PB) tests have been widely used in many countries to obtain complex modulus and to predict fatigue behavior of asphaltic materials. In Switzerland, two-point bending beam (2PB) tests and co-axial shear tests (CAST) have been practically used for predicting the stiffness and fatigue behavior of asphalt materials. Recently, a Swiss national research project was initiated to implement the 4PB test and to characterize highway materials and laboratory mixtures. As an initial stage, preliminary tests were conducted to verify and to calibrate a 4PB test set-up made by Empa. An aluminum bar was used and tested as a reference beam to verify 4PB tests. Also, the 4PB test was compared with several other test methods that can provide the stiffness predictions. They are an uniaxial compression test (UCT, or direct tension-compression test on cylindrical specimens (DTC-CY)), an indirect tensile test (IDT, or indirect tension to cylindrical specimens (IT-CY)), and a co-axial shear test (CAST) (EN 12697-26, 2004). All test data were predicted and fitted by Witczak's sigmoidal functions. More results and details can be seen from our presentation of the second 4PB workshop in Portugal.

2 EXPERIMENTAL PROGRAM

A 4PB test set-up made by Empa is shown in Figure 1(a) and the specimen geometry is also shown in Figure 1(b) (Junker, 1987). The 4PB test equipment has not been often used although it was made in long time ago because the 4PB test was not a standard test in Switzerland. Recently, a testing program of 4PB was implemented by LabVIEW to apply sinusoidal waves based on both strain-controlled and stress-controlled modes. The common specimen length is

500mm with 50mm width and 50mm height. The length between outer two fixing points is 400mm and the length between inner two loading points is 100mm. The geometry of aluminum bar was also same except the total length of 460mm. Four fixing and loading areas in all four sides were covered by steel plates to apply uniform forces on 4PB specimens. Fatigue tests were also conducted with different materials but they cannot be seen in this paper (EN 12697-26, 2004). The fatigue results may be seen in our presentation of 4PB workshop.



(a) 4PB test set-ups

(b) Specimen geometry

Figures 1. Test set-ups and specimen geometry of 4PB

As shown in Table 1, the geometric parameters of four different tests can be found. The height (or thickness) range was varied from 40mm to 100mm. The test conditions applied to all tests are shown in Table 2. The temperature was varied from -20°C to 20°C and the frequency was varied from 0.01 to 10Hz.

Tables 1. Specimen geometries of four different tests

Test method	Geometry (mm)
UCT	D=50, H=100
IDT	D=100, H=40
CAST	D _{outer} =150, D _{inner} =56, H=40
4PB	L=500, W=H=50

where, D is a diameter, H is a height or a thickness, L is a length, W is a width, D_{outer} is a outer diameter, and D_{inner} is a inner diameter.

Table 2. Test conditions

Temperature, °C	-20, -10, 0, 10, 20
Frequency, Hz	0.01, 0.1, 1, 5, 10

The CAST, as shown in Figure 2, was designed at Empa, in the 1980s and has been continuously developed further and improved (Gubler et al., 2005). The CAST determines the mechanical properties of ring-shaped asphalt specimens under dynamic load cycles and temperature changes. Inner and outer lateral surfaces of the specimens are sealed with epoxy resin and then glued to an internal steel core and an external steel ring respectively. Afterwards, the specimen with the steel ring is placed into the climatic testing chamber and mounted on a loading platform while the steel core is connected to the servo-hydraulic testing system.

The modulus of test specimen was calculated using the following formula and the iterative coefficient function was derived by the finite element analysis (FEA) (Sokolov et al., 2005):

$$G^* = \frac{F_a}{\delta_a} A(G^*) \quad (1)$$

where, G^* = complex modulus in shear, F_a = force amplitude along the steel core, δ_a = displacement amplitude along the steel core, $A(G^*)$ = coefficient function derived from FEA by recursive iteration. The conversion equation to convert the measured shear stiffness $|G^*|$ to extensional complex modulus $|E^*|$ were employed. Poisson's ratio of 0.38 was assumed.

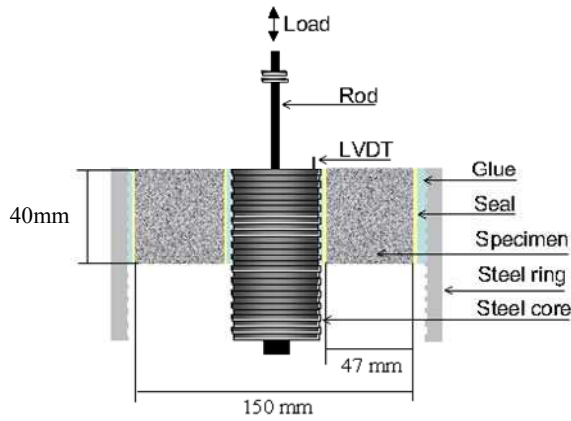


Figure 2. Test set-ups and concepts of CAST

3 EXPERIMENTAL RESULTS

4PB tests of an aluminum bar were conducted to verify the testing program and test set-ups of 4PB made in Empa. The test results and test conditions are shown in Table 3. The error percentage was 0.13%, which can be acceptable for stiffness predictions.

Table 3. Test results for an aluminum bar

Strain amplitude (μm)	Predicted Complex modulus (GPa)	Error (%)	Targeting Complex modulus (GPa)
50	72.10	0.13	72.2

Frequency (Hz): 1, 5, 10, 20, 30

The stiffness prediction of mastics asphalt (MA8) was conducted by four different test methods. All test results were fitted and compared with a sigmoidal function as shown in Figure 3 (Fonseca and Witzack, 1996).

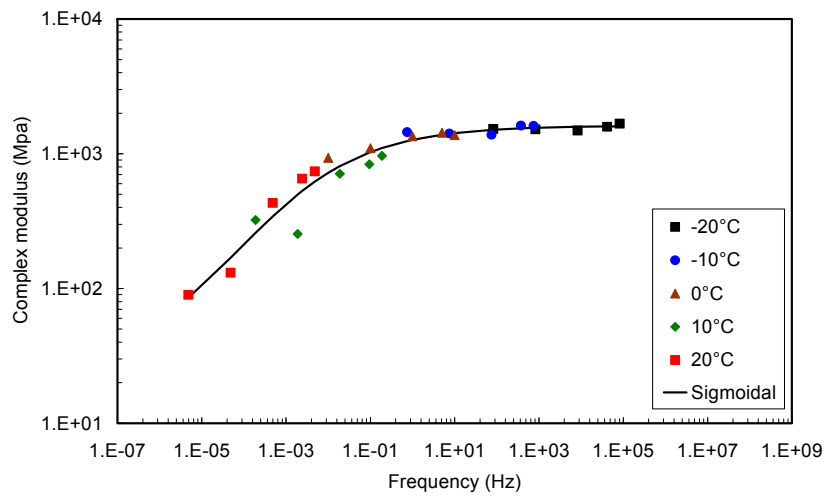
The method of time temperature superposition was used to construct master curves at the reference temperature (0°C) based on a sigmoidal function:

$$\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma(\log f_r + \log a_T)}} \quad (2)$$

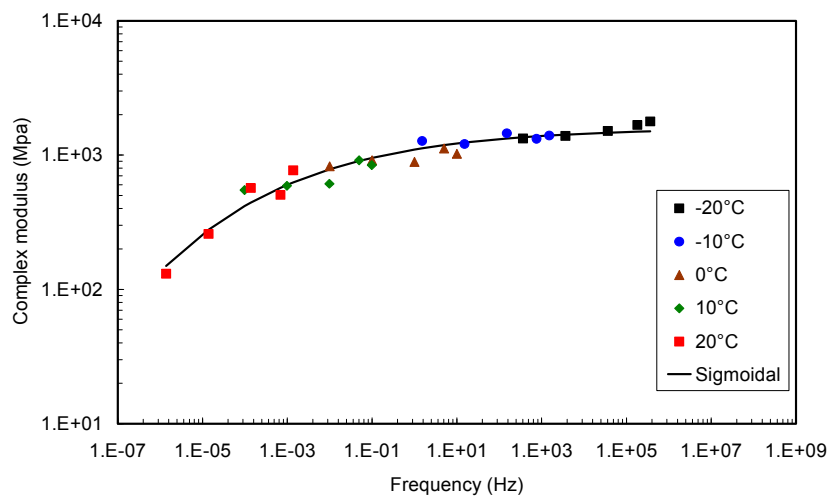
where, E^* = complex modulus, δ = parameter describing the minimum value of G^* , f_r = frequency of loading at the reference temperature, α = parameter describing the span between max and min value of G^* , β , γ = parameter describing the shape of the sigmoidal function, a_T = shift factor, determined with Williams-Landel-Ferry (WLF) relationship.

The shift factor (a_T) is determined by Eq. (3): where, T = temperature; T_R = reference temperature; C_1 and C_2 are WLF constant coefficients.

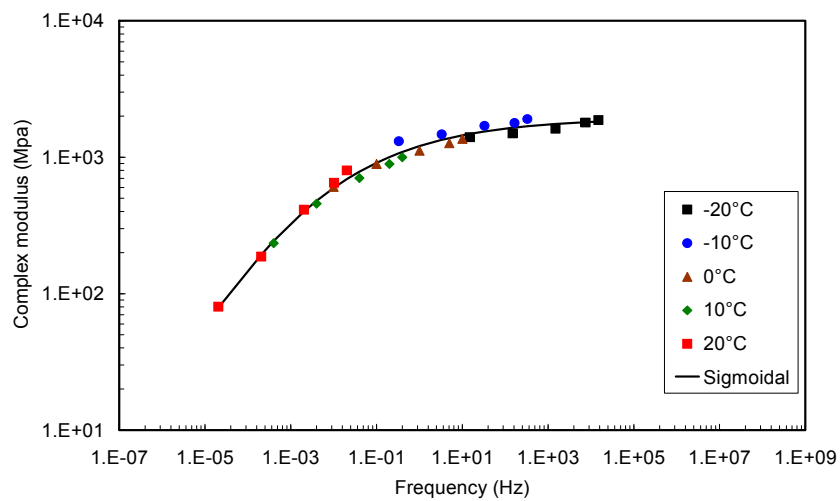
$$\log(a_T) = \frac{-C_1 \times (T - T_R)}{C_2 + T - T_R} \quad (3)$$



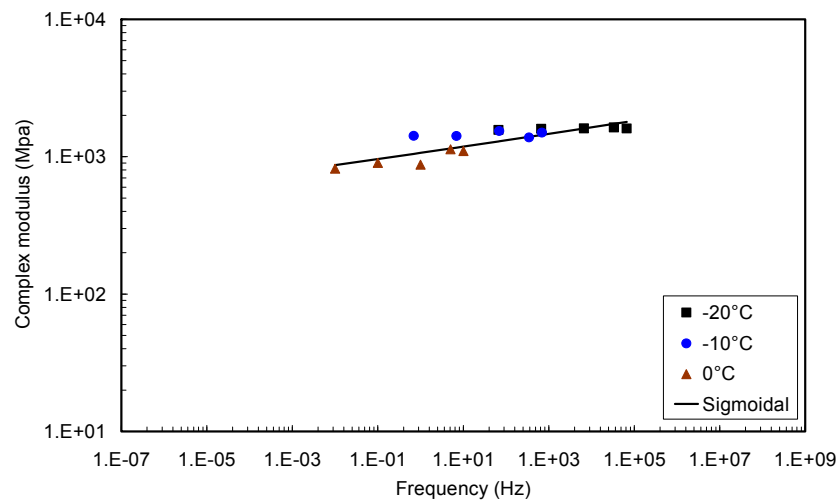
(a) UCT



(b) IDT



(C) CAST



(d) 4PB

Figure 3. Test results and fitted sigmoidal curves

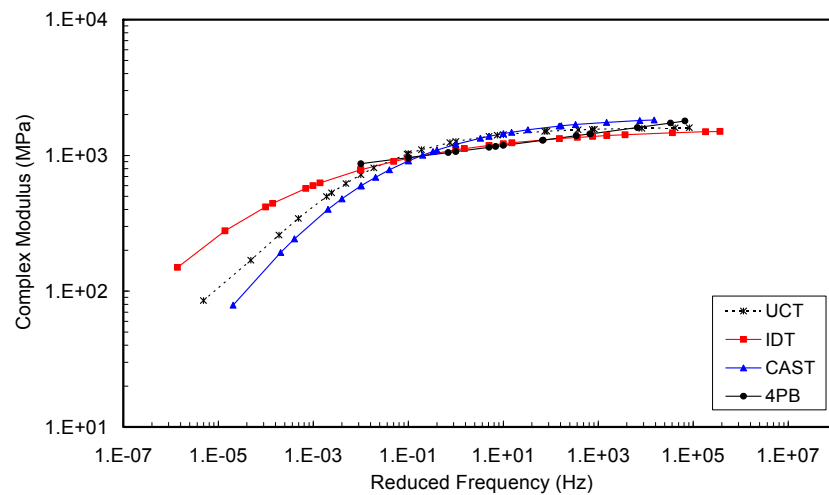
The determined sigmoidal parameters are shown in Table 4. Also, Figure 4 shows comparisons for predicted sigmoidal mastercurves and black diagrams obtained based on four different test methods. Overall, complex moduli at different temperatures and frequencies determined by different test methods show comparative results and similar range of complex modulus. The predicted complex moduli by different test methods at low temperatures show good agreements but they were varied at high temperatures.

Table 4. Determined sigmoidal and WLF parameters

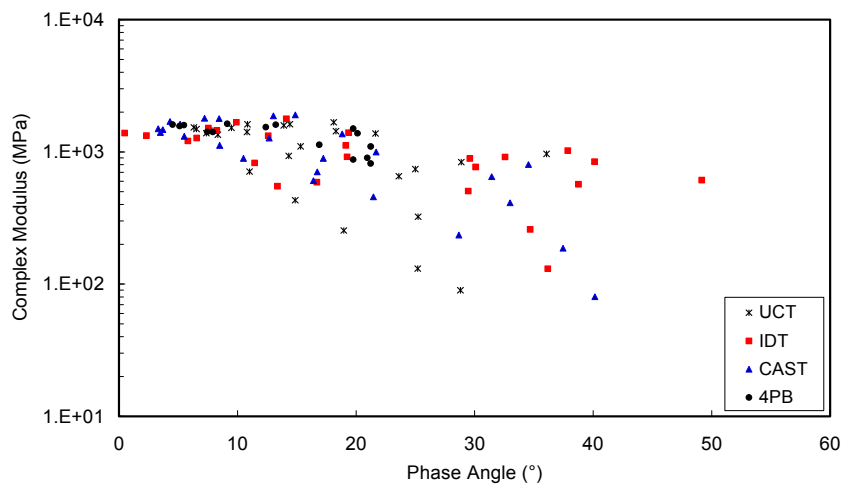
Tests	Sigmoidal parameters				WLF parameters	
	δ	α	β	γ	C1	C2
UCT	1.35	1.86	-2.82	0.68	43.1	240.4
IDT	-8.90	12.11	-4.30	0.33	50.0	239.5
CAST	-0.05	3.34	-2.73	0.51	35.2	241.5
4PB	0.09	34.29	2.37	0.02	47.8	270.3

4 CONCLUSIONS AND DISCUSSIONS

This study shows a successful implementation and calibration of 4PB in Switzerland. The Empa-made 4PB test set-ups and LabVIEW programs were worked well. The calibration of 4PB was conducted with an aluminum bar and showed reasonable results. Also, four different test methods were compared with sigmoidal mastercurves and black diagrams. More details and fatigue results can be seen in our presentation of 4PB workshop.



(a) Mastercurves predicted by sigmoidal functions



(b) Black diagrams

Figure 4. Comparisons of sigmoidal mastercurves and black diagrams

5 REFERENCES

- Junker, J.P. 1987. *Entwicklungen zur Bestimmung mechanischer Materialkennwerte an bituminösen Baustoffen, insbesondere an Asphalt*, EMPA-Bericht Nr. 215.
- EN 12697-26, 2004. Bituminous mixtures – test methods for hot mix asphalt – part 26: stiffness, *European Standard*, European Committee for Standardization (CEN), Brussels.
- EN 12697-24, 2004. Bituminous mixtures – test methods for hot mix asphalt – part 26: resistance to fatigue, *European Standard*, European Committee for Standardization (CEN), Brussels.
- Gubler, R., Partl, M.N., Canestrari, F., and Grilli, 2005. A. influence of water and temperature on mechanical properties of selected asphalt pavements. *Materials and Structures*: 38;523-532.
- Sokolov, K., Gubler, R., and Partl, M.N. 2005. Extended numerical modeling and application of the coaxial shear test for asphalt pavements. *Materials and Structures*: 38;515-522.
- Fonseca, O.A. and Witczak, M.W. 1996. A prediction methodology for the dynamic modulus of in place aged asphalt mixture. *Journal of the Association of Asphalt Paving Technologists*: 65;532-565.