Prediction of Fatigue Behaviour of Asphalt Mix from Tests on Asphalt Mastic

Michael Steineder, Valentin Donev, Lukas Eberhardsteiner, and Bernhard Hofko

Abstract With the introduction of the EN 13108-xx in 2008, it became possible to use performance-based test methods for the assessment of asphalt mixtures also in contracts. There are various test methods for addressing the performance characteristics of asphalt mixtures (i.e. low temperature cracking resistance, stiffness, resistance to fatigue and to permanent deformation). They are specified in the EN 12697-xx. However, these rather complex test methods require a large test effort compared to empirical tests; in the special case of fatigue tests, a substantial amount of material and time for specimen preparation is needed. Therefore, it is the main goal of an on-going research project to assess fatigue resistance on the mastic level by Dynamic Shear Rheometer (DSR), since mastic is the relevant binding component in asphalt mixtures. In this research, asphalt mixes with ten different types of bitumens and three different types of aggregates were produced and tested for fatigue on the four-point bending beam (4PB). The mastic components of each asphalt were mixed and tested for fatigue in the DSR. The results and analyses show a good correlation between the fatigue tests on both levels. With the shear stress level for 10^6 fatigue load cycles and the initial stiffness on mastic level, the strain level at 10^6 fatigue load cycles (ε_6) for the respective asphalt mix can be assessed with a very small deviation.

Keywords Asphalt Mix · Mastic · Fatigue · DSR · 4PB

1 Introduction

The primary causes for deterioration of asphalt pavement surface layers are thermal cracking, rutting and fatigue cracking. The European standard EN 12697-24 contain only performance-based fatigue test methods for asphalt mixtures, but not for mastic. The performance-based fatigue test with 4-point bending beam (4PB), which was used for this study, addresses the fatigue resistance at moderate temperatures. This test method demands high amounts of material and time for specimen preparation and

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testing. Therefore, it was the main goal of this study to assess fatigue resistance on the mastic level by Dynamic Shear Rheometer (DSR) to save time and material. Asphalt mixes can be split into two parts. One part are the mineral aggregates with a grain size bigger than 0.125 mm and the other part is the mastic containing the bitumen and the aggregates with a grain size lower than 0.125 mm. The performance of asphalt mastic depends on the properties of its components, such as the asphalt binder and mineral filler, as well as the interfacial interaction between these components [1].

In order to find a correlation between mastic and mix level, 14 different mastic samples were tested, with each sample containing different types of fillers and bitumen, and varied filler-bitumen ratios. Previous studies have already established that the fatigue resistance of mastic increases or decreases as a function of the filler-bitumen-content [2]. Although there are countless methods to determine the fatigue resistance of bitumen or mastic [3–5], this study focuses on a time sweep test with a hyperbolic specimen shape [6].

2 Materials

To ensure a broad range of results, a wide spectrum of different bitumen and aggregates was used for the tests. Therefore, ten different types of bitumen that are mainly used in Central and Western Europe were selected, with their respective key properties listed in Table 1. The aggregates used were also from the aforementioned countries. A summary of all 14 mixed mastics and asphalts can be found in Table 2.

Table 1 shows the 10 different bitumen used in this study combined with the penetration at 25 °C, softening point measured with ring and ball test method and performance grades for each bitumen.

Table 2 lists the asphalt mixes (asphalt concrete AC 11) with a binder content of 5.9 M% and mastics mixed with the 10 different bitumen. For the mixes with bitumen

Table 1 Properties of bitumen samples used in the study

Mixture	Bitumen grade	Penetration (1/10 mm)	R&B (°C)	PG-grade
Bitumen 1	50/70	64	51.3	64-22
Bitumen 2	50/70	64	48.8	70-22
Bitumen 3	50/70	67	47.9	64-16
Bitumen 4	50/70	56	49.7	64-22
Bitumen 5	PmB 25/55-55	46	58.0	76-22
Bitumen 6	PmB 25/55-55	43	79.8	82-16
Bitumen 7	PmB 25/55-55	39	60.7	76-16
Bitumen 8	PmB 25/55-55	40	58.5	76-22
Bitumen 9	70/100	85	47.3	58-22
Bitumen 10	PmB 45/80-65	58	87.0	82-22

Table 2 Mixed mastic/asphalt

Mixture	Bitumen grade	Aggregates	Bitumen	F/B-Ratio
Aspahlt A/Mastix A	50/70	Germany	Bitumen 1	1.327
Aspahlt B/Mastix B	PmB 25/55-55	Germany	Bitumen 5	1.327
Aspahlt C/Mastix C	50/70	Germany	Bitumen 2	1.327
Aspahlt D/Mastix D	PmB 25/55-55	Germany	Bitumen 6	1.327
Aspahlt E/Mastix E	50/70	Germany	Bitumen 3	1.327
Aspahlt F/Mastix F	PmB 25/55-55	Germany	Bitumen 7	1.327
Aspahlt G/Mastix G	50/70	Germany	Bitumen 4	1.327
Aspahlt H/Mastix H	PmB 25/55-55	Germany	Bitumen 8	1.327
Aspahlt I/Mastix I	70/100	Germany	Bitumen 9	1.327
Aspahlt J/Mastix J	PmB 45/80-65	Germany	Bitumen 10	1.327
Aspahlt K/Mastix K	70/100	Austria	Bitumen 9	1.216
Aspahlt L/Mastix L	PmB 45/80-65	Austria	Bitumen 10	1.216
Aspahlt M/Mastix M	70/100	Swiss	Bitumen 9	1.085
Aspahlt N/Mastix N	PmB 45/80-65	Swiss	Bitumen 10	1.085

50/70 and PmB 25/55-55, mineral aggregates from Germany were used. For those with bitumen 70/100 and PmB 45/80-65, all three aggregates from Germany, Austria and Switzerland were used. The mass-based filler-bitumen ratio for each mastic is also indicated in the table. This ratio was set to be the same in the asphalt mixtures and the mastic.

3 Test-Method

3.1 Asphalt Fatigue—4 Point Bending Beam (4PB)

The EN 12697-24 [7] defines the 4PB test as one of the standardized methods for characterizing the performance of asphalt mixtures under fatigue loading. The test places a prismatic beam on its longitudinal axis between four symmetrically placed clamps (two inner and two outer), and subjects the beam to a periodic, vertical loading from the two inner clamps, whilst the two outer clamps stay fixed. The loading is performed sinusoidally in strain-controlled mode. The dynamic modulus decreases as the beam becomes weaker due to the increasing damage with increasing the number of load cycles. The fatigue criterion is met when the dynamic modules reaches half of its initial value from the beginning of the test [6].

3.2 Mastic Fatigue with Hyperbolic Specimen Shape

In accordance with AASHTO M 320 [8], two different parallel-plate testing geometries are available for binder grading, the PP08 and the PP25, applied to lower and upper temperature testing ranges respectively. Due to the high temperature-dependent nature of bitumen, and the applicable torque limitation of the Dynamic shear rheometer (DSR), the PP08 is chosen for the DSR fatigue test. The standard specimen geometry of a PP08 is of a cylindric shape, with a diameter of 8 mm and height of 2 mm. However, tests through extensive previous research concluded that this geometry is not suitable for fatigue testing, as the specimens produced either pure adhesion failure at the interface bitumen/DSR or a combination of adhesion and cohesion failure. This problem can be addressed through a redesigned specimen geometry based on the original PP08. The new geometry requires the specimen height to be increased to 3mm, and a circular necking in the centre of the cylinder that decreases the diameter to 6 mm to establish a predetermined point of failure. Adverse stress concentration along the sample's edges is avoided with the inclusion of a 0.3 mm platform at both ends of the hyperboloid.

A shear stress distribution of this hyperboloid sample produced by Abaqus confirms the possibility for the redesigned geometry to obtain true cohesion failure within the mastic specimen. The creep stiffness of the matrix sample depends on the test temperature: the higher the applied temperature, the higher the creep stiffness. A certain minimum stiffness must be maintained at the test temperature to avoid creep deformation. Thus, a test temperature of +10 °C was chosen. Furthermore, a high number of load cycles is required to reach fatigue failure in fatigue performance testing. To ensure economic efficiency, a high frequency (30 Hz) loading mode is proposed in a limited timeframe. However, it should be noted that higher frequencies cause more friction heating to the mastic specimen due to a higher dissipated energy [6].

4 Results

The degree of correlation between the results of the fatigue tests at the mastic and at the asphalt mixture level is an indication of the influence of mastic properties as well as their predictive power with regard to the overall fatigue resistance of asphalt. This paper presents a multiple regression model, describing the strain amplitude ε_6 from the 4PB test (asphalt mixture) as a function of the shear stress τ_6 and the initial complex modulus $|G^*|_{start}$ from the DSR test (asphalt mastic), as shown in Fig. 1. Multiple linear regression is the most common multivariate statistical analysis model used for description of dependencies and prediction in the literature [9–11].

The derived model provides a very good fit to the experimental results, achieving a coefficient of determination of 0.92. Furthermore, the analysis shows that both predictor variables contribute significantly to the model at a significance level of α

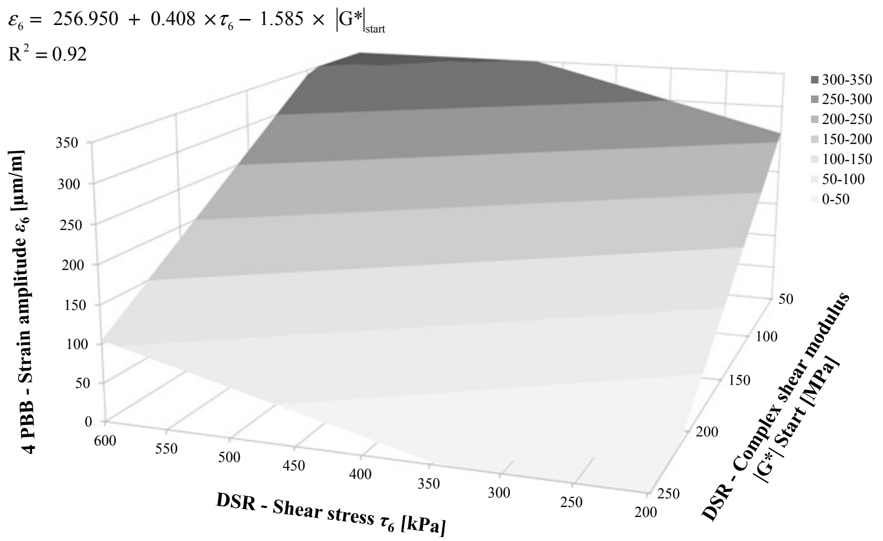

Fig. 1 Prediction of asphalt strain (ε_6) using multiple regression with experimentally determined mastic parameters (shear stress τ_6 and complex shear modulus) as independent variables

= 0.05. Multicollinearity problems are not to be expected, since τ_6 and $|G^*|_{start}$ are uncorrelated (correlation coefficient $\rho = 0.08$).

The regression coefficients for τ_6 and $|G^*|_{start}$ have a positive and a negative algebraic sign, respectively, which coincides with the theoretical expectations.

Thus, higher values of the shear stress (higher mastic fatigue resistance) and lower values of the complex modulus (less stiff mastic) yield higher values of the strain amplitude (higher asphalt-mixture fatigue resistance). The deviations of the individual asphalt mixtures from the model are shown in Fig. 2, using a predicted versus Observed plot. It can be seen that the model predictions are evenly distributed around the diagonal (mean error equals zero), with no particular mixture significantly deviating from the diagonal line.

5 Conclusion

This study proves the possibility to assess the fatigue resistance of asphalt mixture with simple time sweep tests performed on its mastic level with a DSR. This fatigue test only requires a DSR and a silicon mould to produce a hyperbolic specimen, with which a high repeatability and a minimum number of adopted test attempts can be achieved. Although this paper is limited to the correlation of fatigue resistance of asphalt and mastic mixes, the wider scope of this project aims to investigate the reasoning behind differences in the fatigue behaviour of mastic with different

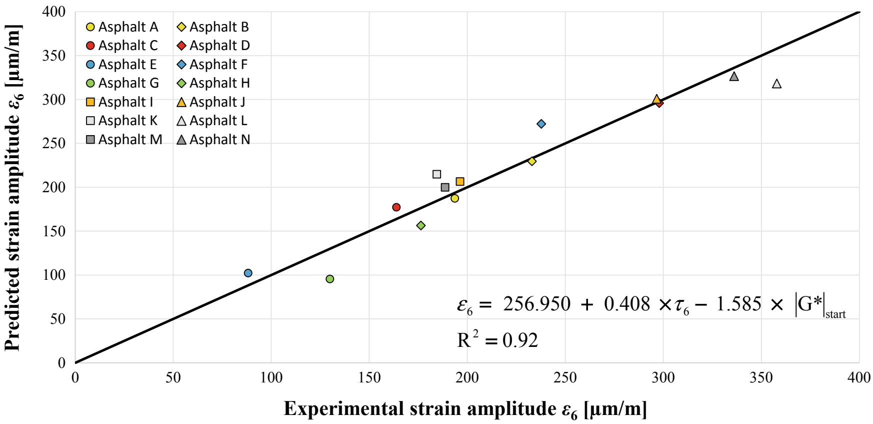

Fig. 2 Comparison of experimentally determined versus predicted asphalt strain amplitudes ε_6

bitumen-filler combinations; such as filler grain size and shape, or the impact of ageing and moisture.

References

1. Guo, M., Tan, Y.: Interaction between asphalt and mineral fillers and its correlation to mastics' viscoelasticity. Int. J. Pavement Eng. 10 (2019)
2. Mannan, U.A., Tarefder, R.A.: Evaluation of fatigue damage and healing of asphalt mastics for different filler contents. Can. J. Civ. Eng. **46**(6), 494–500 (2019)
3. Link, R.E., Shenoy, A.: Fatigue testing and evaluation of asphalt binders using the dynamic shear rheometer. J. Test. Eval. **30**, 303–312 (2002)
4. Micaelo, R., et al.: Fatigue resistance of asphalt binders: assessment of the analysis methods in strain-controlled tests. Constr. Build. Mater. **98**, 703–712 (2015)
5. Mukandila, E.: Principle of Dynamic Shear Rheometer Testing of Non-standard Samples for Cohesion and Adhesion of Bituminous Road Seal Materials (2015)
6. Hospodka, M., Hofko, B., Blab, R.: Introducing a new specimen shape to assess the fatigue performance of asphalt mastic by dynamic shear rheometer testing. Mater. Struct. **51**(2) (2018)
7. CEN: EN 12697-24: Bituminous mixtures—test methods for hot mix asphalt—Part 24: resistance to fatigue. Brussels (2012)
8. AASHTO: AASHTO M 320-10: Standard Specification for Performance-Graded Asphalt Binder. American Association of State and Highway Transportation Officials, Washington, D.C. (2010)
9. Hayter, A.J.: Probability and Statistics for Engineers and Scientists, 4th edn., 826 pp. Brooks/Cole, Cengage Learning, Boston, MA (2012)
10. Montgomery, D.C., Runger, G.C.: Applied Statistics and Probability for Engineers, 6th edn., vol. xvii, 811 pp. Wiley Inc., Hoboken, NJ (2014)
11. Ross, S.M.: Introduction to Probability and Statistics for Engineers and Scientists, 6th edn., vol. xv, 670 pp. Elsevier, AP, Amsterdam, Boston (2014)