EVALUATION OF THE DEFORMATION RESISTANCE OF ASPHALT MIXES BY CYCLIC COMPRESSION TESTS

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ABSTRACT

When conceiving asphalts for highly loaded federal roads, high deformation resistance requirements at high service temperatures have to be fulfilled to reduce or avoid rutting for respect of sustainability. To predict the deformation properties of asphalt mixes, cyclic compression tests CCT (uniaxial and triaxial) were developed. For two test methods, uniaxial cyclic compression tests without confinement (UCCT)) as a special case of the triaxial cyclic compression test (TCCT) for rolled asphalts and with some confinement (UCCTC) for mastic asphalts, a well-founded evaluation basis exists in Germany, such that the deformation resistance can be optimized during asphalt type testing, for instance.

As far as asphalts are concerned, it is distinguished between rolled asphalts and mastic asphalts. Reliable testing of the deformation resistance of these asphalts requires appropriate methods accounting for the special properties of both asphalts. Cyclic compression Tests with and without confinement according to the German technical regulations for testing asphalts for road construction according to EN 12697-25 allow for the defined testing of the deformation properties of both types of asphalts. The evaluation basis of both methods was derived scientifically from the relationships between deformations determined in practice and measured in the laboratory. Over many years of practical application, reliability of this evaluation basis was enhanced. In addition, the test methods allow for a differentiation of variably composed mastic and rolled asphalts, which is an important prerequisite for the evaluation of deformation resistance in practice. The article presents the investigation and evaluation of asphalts using both test methods.

Keywords: Performance Testing, Permanent Deformation, Cyclic compression Tests, Evaluation

1 INTRODUCTION

It is a major task of the road pavement to take up the loads caused by traffic and in particular heavy traffic and to remove these loads into the underground. Due to the strongly plastic and viscoplastic behavior of the asphalt at high service temperatures, irreversible damage in the form of rutting may occur. Rutting adversely affects transport safety and may result in the necessity of maintenance work. Hence, the deformation resistance is a major quality feature of asphalts.

As far as asphalts are concerned, it is distinguished between rolled asphalts and the practically void-free mastic asphalts. Reliable testing of the deformation resistance of these asphalts requires appropriate methods accounting for the special properties of both asphalts. Cyclic compression tests (CCT) according to the German Technical Regulations for Testing Asphalts for Road Construction (TP A-StB), part 25 B1: Uniaxial cyclic compression test (UCCT) [2] and part 25 A1: Uniaxial cyclic compression test with some confinement (UCCTC) of mastic asphalt [3] allow for the defined testing of the deformation properties of both types of asphalt. The evaluation basis of both methods was derived scientifically from the relationship between deformations determined in practice and those measured at the laboratory. These data were verified over many years of practical application. In addition, the test methods allow for a differentiation of variably composed mastic and rolled asphalts, which is an important prerequisite for the practical implementation of these test methods in the evaluation of deformation resistance in practice.

2 UNIAXIAL CYCLIC COMPRESSION TEST (UCCT)

The test method to evaluate the deformation behavior of rolled asphalts under high traffic loads and temperatures is the uniaxial cyclic compression test described in Germany by the above-mentioned technical regulations. The test method corresponds to the European asphalt testing standard DIN EN 12697-25 B [4] as a special case of triaxial testing (TCCT) without lateral confinement. Over long years, it has proved to be a practically suitable, reliable, and rapid laboratory method to test the deformation behavior.

2.1 Principle

The uniaxial cyclic compression test without lateral confinement, hereinafter referred to as uniaxial cyclic compression test, has been developed and tested within the framework of several research projects [5, 6, 7]. The test determines the deformation behavior of asphalts at high temperatures of 50°C under dynamic loading to simulate axle load. A cylindrical asphalt specimen (diameter 100 mm, height 60 mm) is subjected to a sinusoidal pulsed-shaped cyclic compression load that is distributed homogeneously over the base area of the specimen under isothermal test conditions. The specimens may be orthogonal-coplanar wet-cut Marshall-type specimens or other specimens, such as drilling cores from slabs produced at the laboratory. During the test, irreversible deformations of the specimen in load direction are recorded and evaluated for every load cycle. Figure 1 shows the setup for the test.

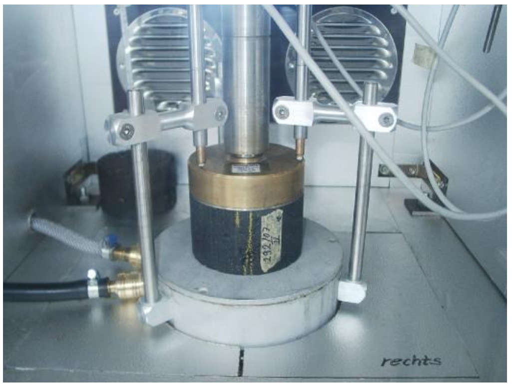

Figure 1: **Setup for uniaxial cyclic compression testing (UCCT)**

Testing is accomplished in an air bath with the test conditions and stress pattern shown in Figure 2.

Maximum stress σ_o:	0.35 MPa
Minimum stress σ_u:	0.025 MPa
Loading pulse duration:	0.2 s
Rest period:	1.5 s
Number of loading cycles:	10,000
Test temperature:	50°C

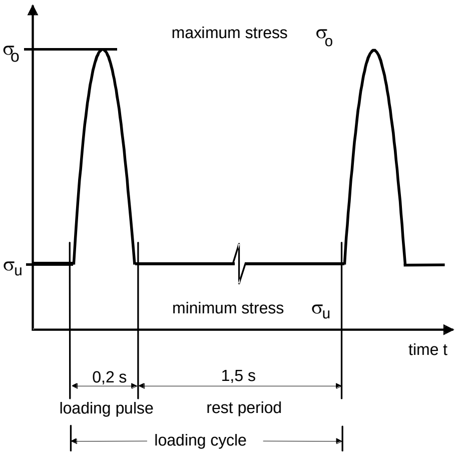

Figure 2: **Test conditions and stress pattern of the cyclic compression test [2]**

Evaluation is based on the remaining deformation or axial strain of the specimen recorded and stored as a function of the number of load cycles. The strain ε_n of the specimen is calculated according to the following equation for every measured load cycle:

$$\varepsilon_n = (h_0 - h_n)/h_0 \cdot 1000 \qquad \textbf{(1)}$$

where:

ε_n = axial strain of the specimen after n load cycles in ‰

h_0 = height of the specimen after pre-loading in mm

h_n = height of the specimen after n load cycles in mm

Figure 3 shows two typical pulse creep curves of rolled asphalt. The pulse creep curve can be split up into three phases in principle:

Phase 1: A strong initial deformation with a progressively decreasing deformation rate (consolidation).

Phase 2: A range of nearly constant deformation rate with an turning point (volume-constant shape variation).

Phase 3: Progressively increasing deformation (starting and advancing volume-dilatant destruction of the specimen structure). Asphalts of high deformation resistance usually lack phase 3 of the pulse creep curve until the defined end of the test.

To evaluate the deformation behavior, the pulse creep curve in phase 2 is of crucial importance. The most important parameter is the strain rate at the turning point ε_w^* [‰·10^{-4}/n]. If the inflection point is not reached during the test, the slope of the local tangent between the value pairs ($\varepsilon_{9,800}$,$_{9,800}$) and ($\varepsilon_{10,000}$,$_{10,000}$) in the quasi-linear range (phase 2) of the pulse creep curve is considered the strain rate (Figure 3).

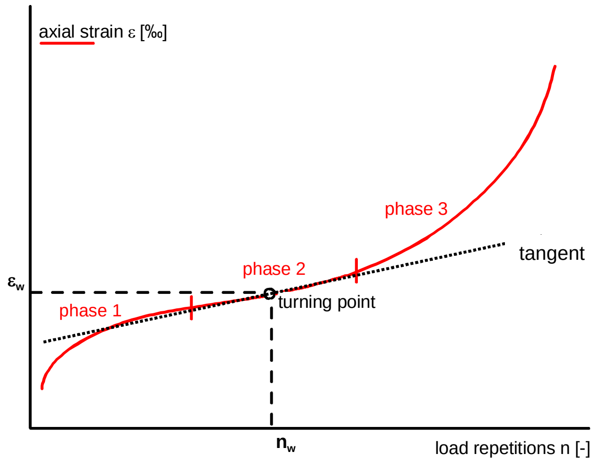

Figure 3: Typical impulse creep curve with tangent at the turning point

The parameter ε_w^* is determined from the strain rate curve that is derived from the pulse creep curve. The minimum of this curve represents the strain rate at the inflection point. The strain rate curve (Figure 3) is determined mathematically. For each value pair (ε_i, n_i) of the pulse creep curve, the local tangent is determined by the difference quotient of two value pairs located at the same distance before and after the initial values. For this purpose, the value pairs have to be chosen at a distance of 100 load pulses. The strain rate for the value pair (ε_i, n_i) is calculated as

$$\varepsilon_i^* = [\varepsilon_{(i+100)} - \varepsilon_{(i-100)}] / [n_{(i+100)} - n_{(i-100)}] \qquad \textbf{(2)}$$

where:

ε_i^* = strain rate of the specimen at the measurement point i in ‰·10^{-4}/n

ε_i = strain of the specimen at the measurement point i in mm

n = number of load cycles at the measurement point i.

The parameters at the inflection point (case 1) are calculated using the approximation approach

$$\varepsilon(n) = a + b \cdot n^k + c \cdot (e^{d \cdot n} - 1) \qquad \textbf{(3)}$$

for the mathematical description of the pulse creep curve. The coefficients a, b, c, d, and k can be determined iteratively by regression calculation. In this way, the strain rate ε_w^* at the inflection point is obtained.

Statistical investigation of the distribution of the strain rate ε* confirmed the assumption that this parameter might be distributed log-normally for grit mastic asphalts after transformation. For this reason, the values are logarithmized.

2.2 Evaluation Basis for the Prognosis of the Deformation Behavior

For the evaluation of the stone mastic asphalt SMA 11 S by the cyclic compression test, a basis for three traffic categories was developed by several research institutes [6, 7]. In this evaluation basis, strain rates are recommended for SMA 11 S under special loads due to heavy traffic, high service temperatures, and a certain duration of use. This evaluation basis was developed by comparing the strain rate of cyclic compression tests with the rutting depth of roads analyzed. These roads are roads of the classes SV and I designed as double-lane, four-track rural roads with cover layers made of stone mastic asphalt SMA 11 S.

This evaluation basis was further extended to cover two temperature categories based on complementary studies by Karlsruhe Institute of Technology (KIT) [1, 8]. Temperature loading can be considered by laboratory cyclic compression tests at variable test temperatures. According to these tests, the strain rates at increasing test temperature in the range analyzed (50 to 60°C) depend on the strain rate at 50°C. This finding was transferred to a diagram that defines requirements on the strain rate for variable traffic and temperature loads (Figure 4).

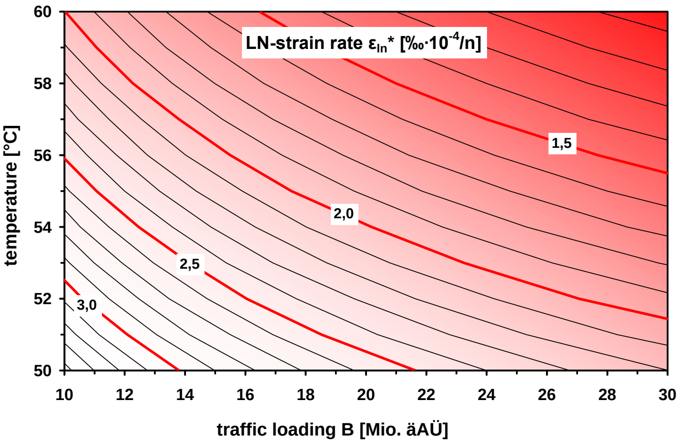

Figure 4: **Evaluation diagram for stone mastic asphalts to determine requirements on the strain rate under variable traffic and temperature loads [1, 8]**

Based on this diagram, strain rates of the cyclic compression test were defined for various, defined traffic loads and temperature sensitivities (see table 1).

Table 1: **Evaluation Table for stone mastic asphalts by cyclic compression tests under various traffic and temperature loads, maximum LN-strain rate at 50°C for various cases of load combinations [8]**

Maximum Value of the LN-Strain Rate ε_{ln}*** [‰·10^{-4}/n]***	**Temperature Load**	
Traffic Load	Category 2 normal high temperatures in situ	Category 1 very high temperatures in situ
Category 1 very high, class SV	Case 4: 2.2	Case 1: 1.1
Category 2 high, class SV	Case 5: 2.6	Case 2: 1.3
Category 3 normal, classes SV, I, II	Case 6: 3.0	Case 3: 1.7

2.3 Applications in Practice

Among others, the uniaxial cyclic compression test is applied successfully in the

- optimization of formulations of deformation-resistant rolled asphalts for road construction during initial testing, for instance,
- investigation of deformation damage on traffic areas in damage analysis,
- development of special pavements (container terminals, runways, etc.), and the
- prognosis of the deformation behavior of SMA for damage prevention [9].

Evaluation of the deformation properties of the stone mastic asphalt SAM 11 S shall be described below as a function of the binder concentration, type of binder, and type of filler or type of binder carrier. The first composition consists of a limestone filler, fine and coarse aggregates of Rhine moraine, fibers, and polymer-modified bitumen 25/55-55 A. Variation of the binder content during first testing resulted in three asphalt mixtures with the asphalt void contents given in Figure 5. The fictitious void contents in the aggregate mixture reach an optimum at a binder content of 7.0 M.-%.

Marshall-type specimens were subjected to cyclic compression tests for all three mixtures. Graphic representation of the strain rates versus the binder content for case 1 also shows an optimum (Figure 6).

Then, the composition of the asphalt mixtures was kept constant, while the binder was replaced by a polymer-modified binder 45/80-50 A. As expected, higher strain rates were obtained. The optimum deformation resistance in this case is reached at a smaller binder content (Figure 6). In a third case, the limestone filler and fibers were replaced by a zeobite filler. The impact of the filler on the deformation resistance was measured by the cyclic compression test. With the varied filler, the optimum binder content of the third variation corresponds to that of the second, but the strain rate is higher (3.1‰ • 10^{-4}/n), which indicates more unfavorable deformation properties.

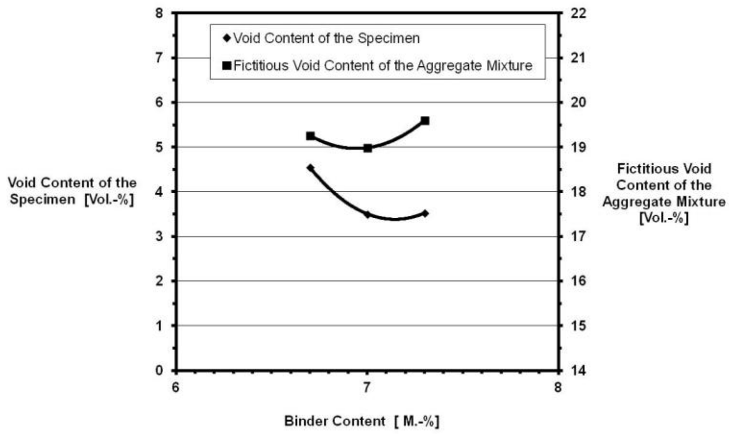

Figure 5: **Void content of the Marshall-type specimen and fictitious void content of the aggregate mixture as a function of the binder content in case 1**

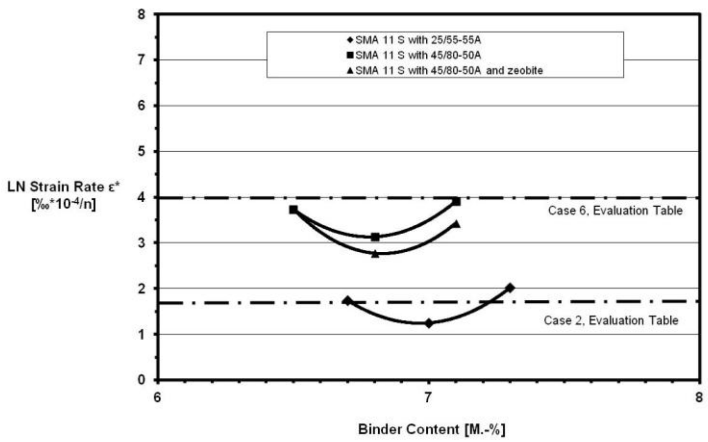

Figure 6: **Strain rates of three different types of asphalt as a function of the binder content**

The deformation properties of the stone mastic asphalts studied can be evaluated using the above evaluation scheme (table 1). The first variation with a strain rate of 1.3 ‰·10^{-4}/n can be used for traffic category 2, class SV, with a high traffic load in category 1 of temperature load, i.e. at very high temperatures in situ (case 2). Of course, this type is also suited for the remaining combinations of categories, that is for cases 3 to 6. Asphalt of variation 3 can be used in category 3 with normal traffic load, classes SV, I, and II in temperature category 2 (case 6). Use of variation 2 with a strain rate of 3.1 ‰$\cdot 10^{-4}$/n cannot be recommended for the construction categories.

In addition, the approach to studying, representing, and evaluating deformation properties of mastic asphalts in a cyclic compression test yields the following results:

- The optimum binder content of an asphalt composition as obtained from a cyclic compression test is in the same range as that obtained from the technical evaluations of the void contents of the compressed specimen.
- Variations of the composition as a function of the binder content yield relatively different levels of the deformation resistance, the absolute values of which can be evaluated.
- Stone mastic asphalts composed according to the technical regulations and used in practice also reveal large differences in the deformation behavior. It is therefore indispensable to test and evaluate this property using the method mentioned.
- The approach can be applied analogously to other types of asphalt, e.g. asphalt binders. Experienced testing institutes already possess evaluation bases.

3 UNIAXIAL CYCLIC COMPRESSION TEST WITH SOME CONFINEMENT (UCCTC)

The deformation behavior of mastic asphalts under high traffic loads and at high temperatures is tested by uniaxial cyclic compression test with some confinement described in the above technical regulations in Germany [3]. Over long years, it has turned out to be an applicable, reliable, and rapid laboratory method to test the deformation behavior of mastic asphalts.

The dynamic die penetration test is applied for initial tests and suitability tests of the mastic asphalts MA 11 S, MA 8 S, and MA 5 S.

3.1 Principle

In the UCCTC, a cylindrical mastic asphalt specimen (diameter 150 mm, height 60 mm) with plane-parallel base surfaces is subjected to a haversine, pulse-shaped cyclic compression load of a centrally positioned die with an area of 2500 mm2 (corresponds to a diameter of 56.42 mm that is smaller than the diameter of the specimen) under isothermal conditions at 50°C. The loads (minimum and maximum stress) and the load pattern are identical with those of a uniaxial cyclic compression test (see Figure 2).

Figure 8 shows the setup for the test.

Figure 8: Setup for the uniaxial cyclic compression test with some confinement for mastic asphalts (UCCTC)

During the test, the resulting axial permanent deformation or penetration depth is recorded as a function of the number of load cycles prior to every load cycle (Figure 8). The test is completed after 2,500 load cycles (first termination criterion). The penetration depth in mm measured at the end of the test is used for evaluating the deformation resistance.

In the UCCTC, the maximum penetration depth was limited to 5 mm (second termination criterion), as larger penetration depths cause impermissibly large deformations and the associated structural changes of the specimen, which may falsify the result.

The following diagram shows two typical curves of mastic asphalts with a good and bad deformation resistance (Figure 8).

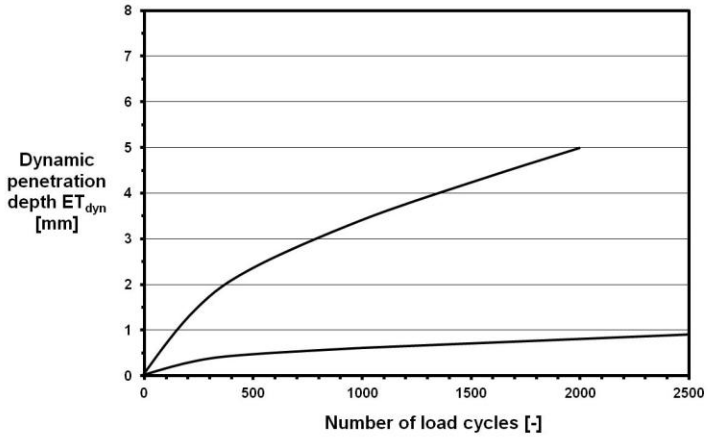

Figure 8: **Dynamic penetration depth as a function of the number of load cycles measured for mastic asphalts with a high (bottom curve) and low (top curve) deformation resistance [3]**

The penetration depth ET_{dyn} as a function of the number of load cycles n is described mathematically (with a high degree of determination) using the function $ET_{dyn} = b \cdot na$. The dynamic penetration depth is determined at n = 2,500 load cycles. In this way, it is also possible to evaluate tests that were completed prematurely due to the termination criterion of 5 mm.

3.2 Evaluation Basis

Within the framework of a research project [10], an evaluation basis was developed for the UCCTC. It is based on a comparison of the most important deformation parameters of dynamic penetration depth in the laboratory test and rutting depth of mastic asphalt pavements of various bridges of highly loaded road sections in various climate zones.

The following table lists recommended dynamic penetration depths taking into account the traffic load and climate/location.

Table 2: **Recommended values ET_{dyn} for mastic asphalts in UCCTC under various traffic and climate loads (updated excerpt from [10])**

Category	Load due to		ET_{dyn} [mm]
	Traffic	Climate/Location	
1	Slowly rolling and standing heavy traffic (congestion range, slope/gradient)	Extremely warm summer, long direct insolation, mild winter	≤ 1.5
2	Rolling traffic with a high fraction of heavy traffic	Warm summer with direct insolation, mild winter	≤ 2.5
3	Rolling traffic with a low fraction of heavy traffic	Moderate temperatures, short insolation, cold winter, elevated location	≤ 5.0

3.3 Applications in Practice

The Uniaxial cyclic compression test with some confinement is applied successfully for

- first tests and suitability tests for MA 11 S, MA 8 S, and MA 5 S,
- the optimization of formulations for deformation-resistant mastic asphalts in road construction,
- investigations of deformation damage on traffic areas (also of site specimens) of mastic asphalts,
- the development of special pavements of mastic asphalt (industrial areas, etc), and
- the investigation of the influence of additives on the mastic asphalt properties.

The dynamic penetration depth reacts to smallest variations of the composition of the mastic asphalt mixture already and allows for a differentiated evaluation of mastic asphalt as far as its resistance against remaining deformation is

Mastic asphalts with penetration depths of 1.0 mm to 2.5 mm in static tests and, hence, a high deformation resistance were found to have dynamic penetration depths of 0.5 mm to 6.0 mm. It is known from experience, however, that mastic asphalts with dynamic penetration depths of > 1.5 mm are not suited for traffic areas under very high loads corresponding to Table 2 (slowly rolling and standing traffic, e.g. congestion areas in front of traffic lights, extremely warm summer, direct insolation). Consequently, this test method can be applied for the further necessary differentiation of the deformation resistance of mastic asphalts with an apparently high deformation resistance under static conditions.

In addition,

- the test method is more precise and the repeatability is much better than that of a static test,
- the test conditions in the dynamic die penetration test are closer to practice in terms of temperature and dynamic loading, and
- the asphalt properties can be improved by the use of a polymer-modified bitumen.

4 SUMMARY

Two dynamic compression tests, the Uniaxial cyclic compression test with some confinement UCCTC and the uniaxial cyclic compression test UCCT, to evaluate the deformation resistance of mastic asphalts and rolled asphalts were described. It was found that both methods

- allow for the testing and evaluation of the deformation properties on an objective, validated basis,
- allow for a differentiation of the deformation resistance of specifically composed asphalts, and
- have been used successfully in practice for many years already.

Hence, both methods to evaluate the deformation behavior are suited for practical use. It is therefore recommended to include the uniaxial cyclic compression tests in the technical regulations for initial and control tests to obtain higher service life of roads with respect to sustainability.

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