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Determination And Evaluation Of Structural Remaining Substance Of Asphalt Roads - Asphalt Analysis

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Abstract

Especially in Germany in the future road construction will be shaped less by the new construction but rather through the maintenance and renewal. Because the existing road substance is used up in growing ever stronger and quicker measure. With reference to the steadily rising traffic load and for a qualified maintenance planning the knowledge of the real structural condition of an asphalt pavement gets more and more important. The present paper presents an approach that forecasts the remaining service life of an asphalt pavement on the basis of asphalt parameters determined by laboratory tests. Therefore asphalt samples were taken from existing asphalt pavements which are already bearing many years of traffic load and their specific asphalt properties such as stiffness and fatigue resistance were determined by tests. The asphalt material properties of an asphalt road for several cross-sections (all required cores about a length of 10m) and several sections (required cores with a distance between 100m and 150m to each other) are determined and evaluated. Likewise, the volumetric properties of the asphalts and the material properties from the individual components in the asphalt mix are considered in the analysis and evaluation. With these results of the asphalt studies in the laboratory together with a forecasting method based on the analytical design of asphalt pavements the possibility exists to give statements to the expected remaining service life of asphalt pavements.

Keywords: Remaining Substance; asphalt pavement; asphalt properties (stiffness, fatigue); analytical design

1. Introduction

In Germany, road construction in the future will be less characterised by the building of new roads than by the maintenance and resurfacing of existing ones. The enormous increase in road traffic will wear out the existing road substance in an ever stronger and quicker manner. With this in mind, a Pavement Management System has been developed in re-cent years on the basis of an objective, network-wide evaluation of the currently existing state of roads. In this process, however, the structural material characteristics (with regard to the effort involved in their maintenance) have not been taken into account.

Insufficient work (or even work not) carried out in the area of (substance) maintenance inevitably lead to an erosion of the substance, which diminishes the utility value of the road paving. As a result of the demands made of roads, which have exceeded all expectations, such damage is caused to the roads, which results in a significant reduction in their service life. Heavy freight traffic is a significant participant in this development. Both the mass of the vehicles and their axle loads undergo constant increase – and this in association with a simultaneous upsurge in daily frequencies.

2. Approach

2.1. General aspects

Building on the fundamental results of FE 04.199/2004/ARB "Comparative evaluation of the residual substance of asphalt roadways following many years of use by road traffic" (Ressel, Lipke et al. 2008) concerning the determination and evaluation of the remaining substance of asphalt roadways, material samples were again taken on the same test road tracks (tt), so as to be able to provide as precisely as possible an estimate of the useful life remaining of an asphalt road that has been subject to traffic for a considerable period of time, based on asphalt characteristics determined by technical trials.

2.2. Selection of the test road tracks

In order to create an assessment background, efforts were undertaken to investigate various types of asphalt road structures (according to construction classes). For this purpose, data-bases were drawn on, which contain construction data for road paving from the whole of Germany. This data includes the existing layer thicknesses, statements on the method of execution (material) of the foundation and details of the year the road structure was laid down. For a comparative assessment, a wide range of selection criteria should be fulfilled by all the test road tracks taken into account, which were defined as follows:

- subject to many years of traffic load,
- asphalt package on base course without binder,
- asphalt surface in conformity with the "Directives for the Standardisation of Road Sur-face Structures of Traffic Infrastructures" (RStO) 86/89,
- high traffic loads with a high proportion of heavy weight vehicles.

Mean daily traffic densities (DTV), together with the corresponding heavy-load vehicle volumes, measured at permanent automatic counting systems were made use of to precisely determine the traffic load. This enabled the actual mean daily vehicle volumes to be calculated for each of the years of use.

2.3. Drilling core extraction

In 2006, drilling cores extractions were undertaken at the four relevant test road tracks within the framework of FE 04.199/2004/ARB. In 2011 at the same places, drilling core samples were again taken from the tyre track on the right side of the main traffic lane in order to determine whether changes in the asphalt characteristics had taken place in the meantime.

Fig. 1. Drilling core extraction on the test road tracks.

Figure 1 depicts, firstly, the still sealed drilling holes of the drilling core samples taken in 2006 and, secondly, directly following, those drilling holes of the drilling core samples from the tyre track on the right hand side of the main traffic lane by Federal Highway Research Institute employees in 2011.

2.4. Representation of the test road track

The asphalt package was laid on a layer containing no binders on all the test road tracks. With many of the drill cores, it was observed that the layer bonding between the asphalt binder course and the asphalt base course was no longer present. Also noticeable was the fact that there was usually no uniform distribution of voids on the underside of the asphalt binder course. Table 1, shown below, provides an overview of the layer structures and layer thicknesses detected on the individual test road tracks analysed.

Tabel 1: test tracks (tt) layer structures and layer thicknesses.

test track (tt)	wearing course (AC D) [cm]	binder course (AC B) [cm]	upper base course (uAC T) [cm]	lower base course (lAC T) [cm]	frost protection layer [cm]
I	4	8	8	10	35
II	4	8	10	12	41
III	4	8	-	14	59
IV	4	8	-	12	51

3. Material testing

3.1. General aspects

The material-specific characteristics, such as stiffness, fatigue behaviour and deformation behaviour are of key importance for an analytical evaluation of asphalt surfaces based on material testing. Hitherto, the optimisation of the asphalt composition has mostly ensued in relation to its resistance to plastic deformations. As a consequence of this, the resistance to crack formation was scarcely taken into account.

The advent of the indirect tensile test now allows the fatigue behaviour of asphalt to be tested in the laboratory. A large number of investigations have been conducted in various research institutions to describe the fatigue behaviour of asphalt (durability) by means of the indirect tensile test. The indirect tensile test represents a relatively simple, cost-effective and quick testing method to record the stiffness and fatigue behaviour of asphalt. The key advantages of the indirect tensile test lie in the fact that a large area in the specimen possesses a constant tensile stress.

In order to determine the tensile stresses, which may occur at low temperatures as a result of a blocked thermal expansion, cooling tests were performed in accordance with the national technical testing specifications. This technical test to examine the material involves the simulation of the stress occurring in asphalts as a result of negative temperature changes arising from weather conditions. The asphalt materials to be tested are examined using a defined cooling rate. The length of the sample tested is kept constant during the cooling process. Cooling-related tensile stresses (cryogenic tensile stresses) are induced in the sample as a result of the blocked thermal shrinkage. When the cryogenic tensile stresses reach the tensile strength of the sample, then cracks appear. The cryogenic tensile stresses (as a function of the temperature), the breaking temperature as well as the breaking tension are recorded in the findings observed in the cooling test.

3.2. Determining the stiffness modulus-temperature function

3.2.1. Test parameters

The experimental determination of the modulus of elasticity ensues on the samples for all materials. If the asphalt base course has been laid as a double layer, then this is divided into an upper and lower "layer". For the indirect tensile tests to determine the stiffness moduli, the test samples were subjected to a stress load frequency of 10 Hz at four different temperatures and three different stress levels. The test temperatures selected as test temperatures for these investigations were -10°C, 0°C, 10°C and 20°C, respectively.

To determine the stiffness modulus-temperature function, the samples were subjected to stress by means of a continuous, force-regulated, harmonic sinus threshold load. To ensure the positional stability of the sample, a constant lower-limit tension (under-tension - the lower limit value of the sinus threshold load) of 0.035 N/mm² was selected for all individual tests. The determination of the upper-limit tension ensued in accordance with the initial elastic elongation principle. The stress levels for the indirect tensile tests were selected so that the initial elastic elongations lie in an interval range from 0.05 ‰ to 0.10 ‰.

3.2.2. Results

For the evaluation of the indirect tensile tests or the calculation of the stiffness moduli, the Poisson's ratios were selected in accordance with the testing temperatures as μ = 0.298 (at 20°C), μ = 0.239 (at 10°C), μ = 0.198 (at 0°C) and μ = 0.174 (at -10°C).

The modulus of elasticity was calculated using the following equation:

$$E = \frac{\Delta F \cdot (0.274 + \mu)}{h \cdot u} \quad (1)$$

and the lateral strain according to the following equation:

$$\varepsilon_x = \frac{\sigma_x \cdot (1 + 3\mu)}{E} \quad (2)$$

where in Equations (1) and (2):

E	is the modulus of elasticity
ΔF	is the force difference between the overload and underload applied
μ	is the Poisson's ratio
h	is the height of the sample
u	is the lateral elastic deformation
ε_x	is the lateral elastic strain in the middle of the sample
σ_x	is the tensions in the centre of the sample.

As a matter of principle, it may be stated that based not only on the principles of indirect tensile testing but also on the estimation procedure developed by FRANCKEN and VERSTRAETEN (Francken, Verstraeten 1974), higher levels of stiffness were determined for all types of asphalt examined, the longer they were used as road surfaces subjected to the effects of the weather and traffic conditions. Figure 2 depicts all the stiffness modulus-temperature functions determined for the material making up the lower asphalt base course. Each sequence occurs for almost all the asphalt mixtures examined.

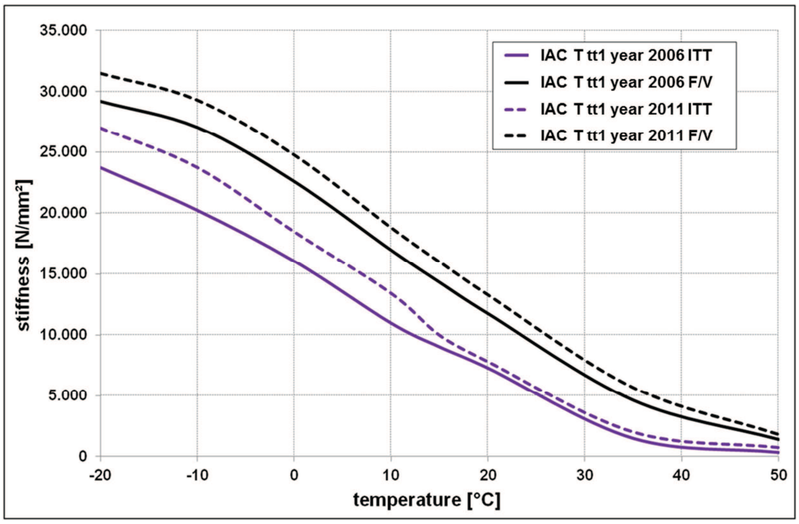

Fig. 2. stiffness modulus-temperature functions – Comparison of 2006 to 2011

3.3. Determination of the fatigue behavior

3.3.1. Test parameters

Several individual tests with three different overloads (stress amplitudes) were carried out to determine the fatigue function. The load frequency was set to 10 Hz. The tests to determine the fatigue behaviour took place at a test temperature of 20°C. Since the strain-dependent fatigue functions for asphalt mixtures are essentially temperature-independent (as demonstrated by investigations undertaken by READ (Read 1996), it was not therefore necessary to perform the planned fatigue tests at a variety of different test temperatures. The determination of the upper-limit tension for the fatigue tests was carried out based on the results of the calculation of the stiffness modulus-temperature functions. To ensure a positional stability of the sample, a lower-limit tension of 0.035 N/mm^2 was selected, this representing the lower limit of the sinus threshold strain. In addition, when performing the fatigue investigations care was taken that the three selected stress levels lie in a range of initial elastic elongations of approx. 0.3‰, 0.15‰ and 0.05‰.

3.3.2. Results

The number of load cycles N_{macro} is defined as the cycles-to-failure value. When this value is reached in the course of the fatigue testing, the beginning of the occurrence of macrocracks can be observed in the sample. The continuation of the test is characterised by the rapid propagation of cracks, which then results in the failure of the sample. Based on the concept of dissipated energy, a method for the determination of the load-cycle number N_{macro} was developed by HOPMAN (Hopman 1996). For this purpose, the so-called "energy ratio" ER is defined from the load-cycle number and the modulus of elasticity l |E(N)| calculated for N. Based on the progression of the function ER(N), it is possible to calculate the cycles-to-failure value (N_{macro}) for the macrocrack criterion at the maximum value of the function ER(N).

$$ER(N) = E(N) \cdot N \qquad (3)$$

where:

ER(N)	is the energy ratio
|E(N)|	is the modulus of elasticity calculated for the load change observed
N	is the associated load-cycle number.

The calculation of the material-specific fatigue function ensued on the basis of the load-cycle numbers determined using the indirect tensile test until the samples exhibit macrocracks. Macrocracks occur when the tensile strength is locally exceeded. The load-cycle numbers were determined for all the asphalt base course mixtures examined (strain-dependent fatigue functions) up to the appearance of macrocracks as a function of the initial horizontal elastic elongation.

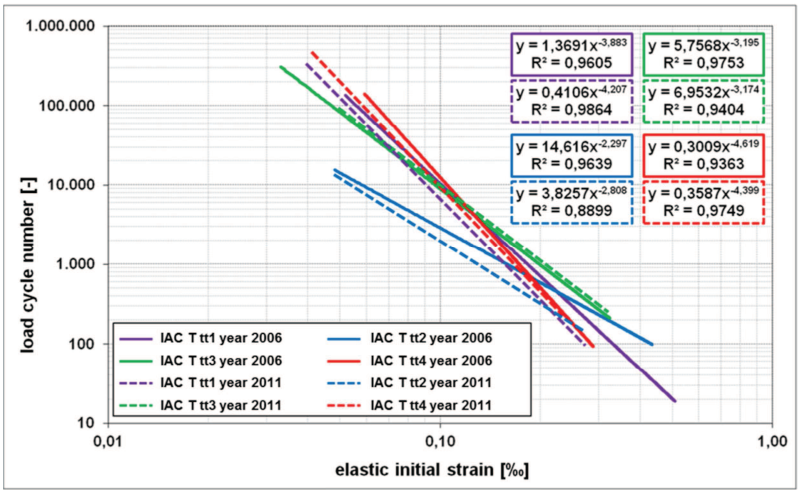

Fig. 3. Fatigue functions – Comparison of 2006 to 2011

In Figure 3, the fatigue functions determined in the tests can be seen for the lower asphalt base course materials of the four test road tracks. As was to be expected, the fatigue functions of the various types of asphalt, from which samples were taken at a later date, should lie below those on the same section of the road, which are the basis for the material investigations undertaken in 2006 of the drilling core extraction. For the test road tracks I, II and IV, it can be reported that a further material fatigue has occurred, which means that only short remaining service lives are to be expected. A different behaviour was observed on test road track III. Based on the fact that the two fatigue functions obtained (from 2006 and 2011) are practically identical, no further material fatigue appears to have taken place during the "additional" utilisation period.

3.4. Determining the low-temperature behavior

3.4.1. Test parameters

Adapter plates were attached to the front surface of the asphalt prisms by means of an epoxy-based, two-component adhesive. This system was then installed into the testing device. During the cooling process, the position of the two adapter plates was recorded by two displacement-transducer pairs attached to two temperature-indifferent measurement bases. From a starting temperature of +20 °C, the asphalt samples were cooled at a constant cooling rate of 10 K/h. The sample length measured before the start of the test was kept constant during the cooling process. The thermogenic tensile stresses occurring in the sample as a result of the deliberate impediment of the thermal shrinkage were recorded as a function of the temperature and time, while the maximum thermally induced tensile stresses as well as the breaking temperature were recorded when the sample failed (exhibited cracks).

3.4.2. Results

The results of the cooling tests indicate that a change in this property of the asphalt has occurred. This is detectable on the basis of the profile of the cryogenic tensions. Materials comprising the asphalt base course, which do not suffer from stresses resulting from the weather and traffic over a long period of use, exhibit significantly lower cryogenic tensions at the same (test) temperatures. As a result of the temperature change (under the assumption that the cooling rate actually takes place in reality), greater strains occur in the lower asphalt base course investigated.

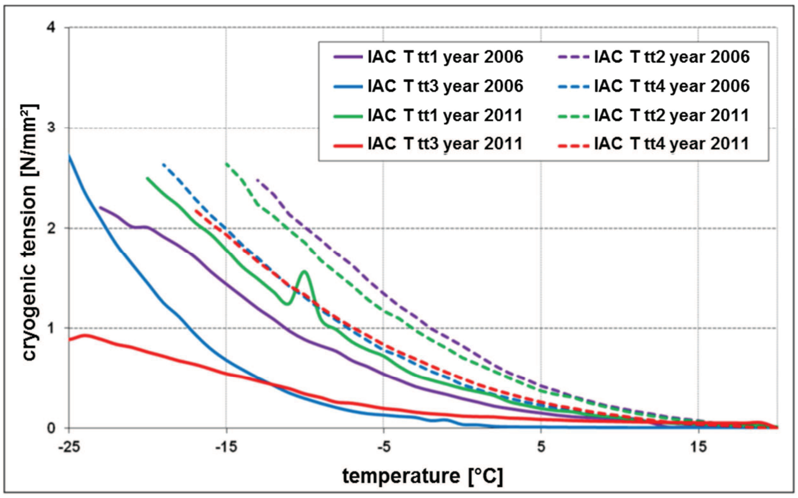

Fig. 4. Cryogenic tensile stresses – Comparison of 2006 to 2011

Figure 4 depicts the results of the cooling test, i.e. the cryogenic tensions arising in the sample due to the cooling process. The solid lines characterise the results of the tests performed on the asphalt materials taken from the road paving in 2006, while the dotted line represents those results from the same asphalts that were subjected to the stresses of climate and traffic for approx. another five years. It can clearly be seen that under the conditions of the same temperature of the asphalt cooling test, higher levels of tension were induced in those asphalts in road paving that were subjected to stresses for a longer period – i.e. the relaxation ability of asphalt in use was further reduced. For considerations of the service life, this also means a higher degree of stress/strain as a result of changes in temperature.

4. Considerations of service life

4.1. General aspects

The first consideration required is to clarify the definition of the downtime point. The downtime point is determined by the occurrence of a macrocrack on the underside of the asphalt base course, as this denotes structural damage in the road paving. Pavement design in Germany takes into account the formation of cracks from underneath – i.e. the material properties of the lower asphalt base course are key design-relevant influence parameters. For the analytical evaluation of the test road tracks, the Software Pavement Design Tool (PaDesTo) was used, with which the fatigue status and thus the downtime point can be calculated based on the input design values determined, the existing layer thicknesses of the asphalt package as well as the traffic load borne/specified.

Input parameters affecting the calculation of the downtime point of the individual test road tracks are, on the one hand, the stiffness modulus-temperature functions determined of the asphalt surface layers investigated, and on the other hand, the fatigue functions of the lower asphalt base course established. Furthermore, other road-related parameters, such as the number of lanes, the longitudinal inclination, the behaviour of the material at low temperatures (cryogenic tensions), the existing layer structure and the geographical location, are also taken into account for the calculation of the downtime points.

4.2. Input values for service-life considerations

The calculation is performed taking the existing layering sequence into account. Based on the given layer structure, the tensions at crucial points within the road paving are calculated. All asphalt surfaces of the test road tracks investigated are based on a frost protection layer according to the statements made by the relevant public bodies.

Based on the geographical location (frost impact zone) of the individual test road tracks within the road network, the resulting thicknesses for the frost-proof surface are determined (asphalt package on frost protection layer). Additional factors for greater or lesser thicknesses, such as prevalent water conditions and the design of the peripheral areas, were kept constant in determining the minimum thicknesses of the frost-proof road surface. The actually existing conditions of the individual test road tracks were taken into account when determining the greater or lesser thicknesses for the criterion of the position of the gradient. The existing layer structure of the individual test road tracks has already been depicted.

The traffic loads prior to the drilling core extraction in 2011 for all the test road tracks investigated have already been depicted in Section 4. From the time of the drilling core extraction, a mean annual increase in heavy weight vehicles of 3 % was assumed up to the end of the period of use striven for. This approach for determining the design-relevant tension ("B-number") was carried out for on test road tracks. Table 2 depicts the traffic loads (since construction of the roads) determined for the calculation of the downtime points of the test road tracks investigated.

At the current time, however, it cannot be clearly stated what traffic increases had been assumed (or what traffic scenarios included) for the individual test road tracks in the design then used. For the forecast of the traffic load to be expected (from the date of the drilling core extraction), a characteristic axle load distribution has been selected for federal motorways "BAB long-distance traffic", which is divided into eleven axle load categories.

Tabel 2: Traffic loads of the test road tracks.

test track (tt)	year of road construction	Drilling cores extraction	heavy weight vehi-cles proportion [%]	Traffic load „B“ [10-t-axle Mio.]
I	1995	summer 2011	20,9	75,7
II	1987	summer 2011	18,3	53,7
III	1991	spring 2011	21,0	53,5
IV	1990	autumn 2011	29,6	48,1

The critical input values for the analytical evaluation (or determination) of the downtime points are the asphalt characteristics determined in the tests, such as the fatigue behaviours of the lower asphalt base course, the stiffness (as a function of the temperature) of the various asphalt layers as well as the low-temperature behaviour. For this purpose, the cryogenic tensions of the asphalt base course materials determined for the calculation of the downtimes were set at 50%. The results are included in the relevant sections.

When calculating the downtime points, the minimum deformation values required (in accordance with the "Directives for the Standardisation of Road Surface Structures of Traffic Infra-structures" (RStO) 01, Table 1) were taken into consideration for the frost protection layers. A deformation modulus E_{V2} with 45 N/mm² was selected for the subsoil/foundation. The frost-sensitivity class for the pending soils of the test road tracks investigated was selected as “very sensitive to frost”.

When calculating the downtime points, there exists an increasing need to take account of the temperature profiles in all the asphalt layers – due first and foremost to the effects of climate change on road surfaces structures incurred using the asphalt construction method. At the present time, it is assumed that thirteen surface temperatures should be taken into account for asphalt paving in Germany, for each of which the temperature profile in the asphalt pack-age is mathematically determined. Equally, the frequency of occurrence of these surface temperatures within a year was taken account of in the analytical design.

4.3. Results and comparative considerations

The permissible axle transitions of the individual structural layers are determined from the fatigue function and compared to the existing or forecast axle transitions. The number of axle transitions are divided into axle load classes. For each axle load class, the stress calculations are performed separately for the prevalent surface temperatures in each case and the resulting temperature profiles within the asphalt layers. All the definitive combinations of temperature and load, the individual results of which are summarised for the evaluation based on the hypothesis by MINER (Miner 1945), are taken into account in the calculation of the downtime points and thus in the analytical design.

At the present time, it is assumed that an asphalt road surface should last for a minimum of 30 years without sustaining damage. However, since it is not always precisely known how long a road surface will actually remain free of damage in the sense of the national set of regulations for traffic areas, this service life striven for is set at 100%, thus enabling the downtimes calculated to be provided in terms of percentages. When, say, a value of 85% is obtained for the calculation of the downtime point of a given road construction, then this means that this road paving has remained free from damage 15% longer in relation to the service life striven for, taking all the required parameters into consideration. This would there-fore correspond to a service life of more than 30 years. In the first place, the fatigue status of an asphalt construction is determined, and this expresses the "wear/consumption" on the service life for the traffic load to be expected.

The results of the comparative studies of the remaining (or total) service life are depicted in Table 3.

Table 3: Remaining (or total) service lives (in years) – Comparison of 2006 to 2011

test track (tt)	hitherto service life	expected remain-ning life „2006“	expected total service life „2006“	expected remain-ning life „2011“	expected total service life „2011“
I	11 / 16	14	25	5	21
II	19 / 24	5	24	1	25
III	15 / 20	5,5	20,5	5	25
IV	16 / 21	6	22	1,5	22,5

Test road track I was subjected to traffic for approx. 11 years up to the first drilling core ex-traction in 2006. Based on the results of the material investigations, an expected remaining 14 years of service life was determined. This resulted in a total service life forecast of 25 years. Based on the results of the material investigations of the drilling core extraction carried out in 2011 (previous period of use 16 years) on the other hand, an expected remaining service life of five years was obtained. On summing these figures, a total service life of 21 years is now forecast. It follows from this that – due to the extra five years of use (with the associated weather conditions and the traffic load) the asphalt material is suffering more strongly from fatigue than was forecast in 2006.

Following both the drilling core extractions and the subsequent material analyses, an expected remaining service life of approx. five years was forecast for test road track III. The significantly higher stiffness of both the asphalt wearing course and asphalt binder course materials, which were determined from the samples taken from the drill cores in 2011, also provides a contribution to this forecast result of the remaining service life. For test road tracks II and IV, it proved possible to confirm the forecasts of the total service lives made in 2006 with the findings of the second forecast made in 2011, where the material properties of the asphalt samples then taken served as the underlying data.

Test road tracks II and III exhibit the same total service lives forecast and approximately the same traffic load, although significantly different thicknesses of asphalt package. For test road track III, however, the thickness of the asphalt base course was reduced by 80 mm compared to the asphalt base course of test road track II (Table 1). This means that the material used for the asphalt base course on test road track II is not as fatigue-resistant as that of test road track III.

5. SUMMARY

In the future, road construction in Germany will be less characterised by new road building than by the maintenance of this valuable infrastructure. This therefore requires targeted maintenance strategies. With this in mind, a Pavement Management System has been developed in recent years on the basis of an objective, network-wide evaluation of the currently existing state of roads. This enables weaknesses to be detected in good time and priority rankings to be drawn up for the necessary maintenance measures. In this regard, the surveying and evaluation of the states of the roads play a particularly important role. Nevertheless, only the surface picture recorded is drawn on or visually assessed for the determination of the substance condition characteristics. For this reason, it is necessary to determine the remaining substance of an asphalt road paving, which takes into account the factors load, age, climate and material properties and thus allows a holistic, structural evaluation of a road pavement.

In this work, the results of indirect tensile tests form the essential foundation for the determination and evaluation of the remaining structural substance of asphalt road paving. In this regard, investigations were carried out on test road tracks at two separate dates, the asphalt samples taken then being analysed in the laboratory. The stiffness modulus-temperature functions and – for the lower asphalt base course – the fatigue functions were determined for all the asphalt layers. On the basis of the results of the fatigue investigations obtained, it was possible to describe a large bandwidth, within which the fatigue functions of asphalt base course materials can lie. The results of determining the asphalt characteristics at low temperatures have also enabled the material change occurring to be exhibited based on the progress of the cryogenic tensions.

In conclusion, it can be emphasised that considerations of the remaining service life are possible in conformity with the Guidelines for Calculational Dimensioning of Concrete Surfaces in Road Surface Superstructures (RDO) for asphalt 09. The results of the asphalt investigations of the second period under review (2011) were able to confirm the first forecast made in the drilling core extraction in 2006. In this regard, however, it is imperative that the characteristic asphalt values be directly determined.

Furthermore, it has become clear that – based on the material properties determined – an estimation of the remaining substance of asphalt paving is only possible in conjunction with a calculation method, which also takes account of the factors age, climate and traffic load.

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