DETERMINING THE REMAINING PAVEMENT LIFE – FIELD RESULTS

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ABSTRACT

Aim of the research is to develop an empirical-analytical procedure to determine the remaining life of flexible pavements using both experimental and analytical information.

The later is derived from mechanistic analysis of various flexible pavements considering different traffic loads, climatic influences, material characteristics and other relevant parameters. Experimental information is obtained from special laboratory tests (stiffness and fatigue tests on the asphalt base layer). These tests were carried out on cores taken from different highway sections all over Germany. The analysis was done using pavement design software called PaDesTo that is based on the multi-layer theory. For the remaining life analysis the highway was split into sections with similar pavement characteristics.

In this paper, some experimental evidence is provided that indicates that the approach used by the authors can realistically predict the remaining life of pavements.

1 INTRODUCTION

The evaluation of pavement condition is getting increasingly important. This is mainly due to recently introduced contract types such as functional contracts and private public partnerships. In contrast to traditional contracts, the contractor has to maintain the road for a defined retention period. Especially at the end of the contract when the pavement is handed over to the principal, a pavement evaluation must be undertaken to check whether the contractor fulfils the requirements.

When evaluating the condition of pavements in Germany and many other countries around the world, condition assessment guides (CEG) are to be used that mainly focus on the assessment of pavement surface characteristics such as evenness, skid resistance, patches, ruts and surface cracks, while almost no attention is given to the mechanical integrity of the pavement layers and material. To help mitigate this problem, a condition assessment procedure is discussed in this paper that can consider mechanical factors, as for instance the fatigue state of asphalt materials, bottom up cracks in pavement layers etc. Based on such an assessment, the remaining pavement life before a pavement rehab will be required can be estimated more realistically. Additional factors such as predicted traffic loads, expected changes in climatic conditions and material parameters are also considered in the paper when estimating the remaining pavement life.

2 RESEARCH PROJECT AND PROCEDURE

This paper reports on a research project carried out at the Institute of Pavement Engineering at Dresden University of Technology, which was aimed at investigating the effect of the mix properties on the fatigue performance of asphalt pavements. An analytical pavement design method developed at Dresden University of Technology was used to predict the reaming life of asphalt pavements. Based on this method, a computer program called PaDesTo (Pavement Design Tool) was developed by Kiehne (4). Using this software, it is possible to determine the number of load cycles until the pavement fails. The damage criterion used was the fatigue failure of the asphalt base layer.

The remaining pavement life can be calculated using the traffic volume prognosis and laboratory test results of the asphalt mixes as input values for the design software. However, the input values for the software such as material parameters, climatic conditions and traffic load should be determined as accurately as possible. In particular, the material parameter should be determined using the results of laboratory tests.

Different cyclic load tests have been established in Germany and in other countries to investigate the fatigue behaviour of asphalt mixes. Within this project Indirect Tensile Tests (ITT) on Asphalt base Course (AC) mix samples were carried out in order to determine the stiffness and fatigue properties of the asphalt mixes. These tests were carried out on cores taken from different highway sections across Germany.

All pavements investigated showed a similar pavement structure (see Table 1).

Table 1: Pavement structure of the highway sections (1)

Highway section	**ASC [mm]**	**AIC [mm]**	**uAC [mm]**	**lAC [mm]**	**Sub Base**
A	40	80	80	100	FPL
B	40	80	100	120	FPL
C	40	80	-	140	FPL
D	40	90	-	140	FPL
E	40	80	-	120	FPL
F	40	90	120	100	FPL

ASC - asphalt surface course,
AIC - asphalt intermediate course,
uAC - upper section of the asphalt base course,
lAC - lower section of the asphalt base course,
FPL - granular frost protection layer

The results of the multi-stage and fatigue tests in combination with the analytical results using the design software indicated that it is possible to determine the remaining life of asphalt pavements.

3 LABORATORY TESTS

Figure 1 and 2 present the core excavation from a highway section.

Figure 1: Core excavation from a highway section

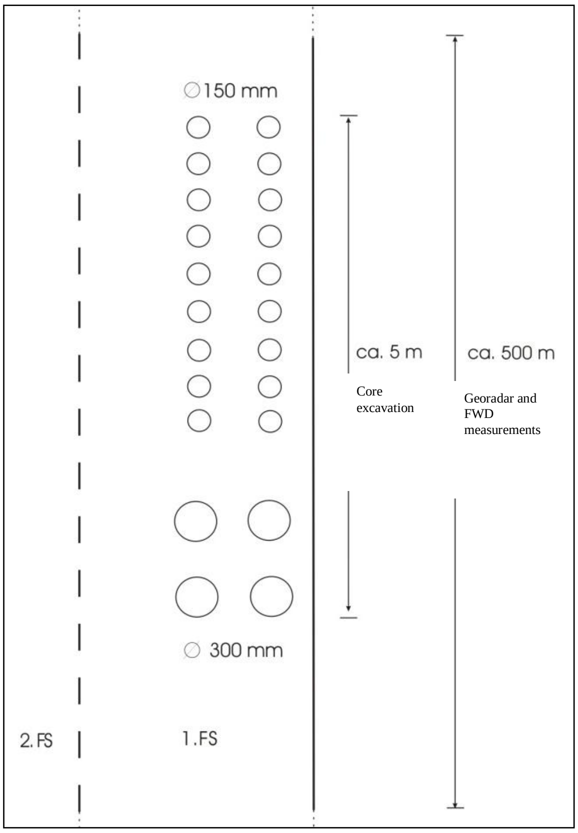

Figure 2: Core excavation locations

Within this research, 6 selected highway sections with different equivalent 10-t-axle load cycles applied were investigated (see Table 2). The anticipated design life of the pavements was 30 years. Cores were taken from the pavement exactly in and in the middle of the traffic path (Figure 1 and 2). The reason for that was to figure out if the asphalt in the traffic pathpath is fatiguing an accelerated rate compared to the asphalt in middle the traffic path.

Table 2: Equivalent 10-t-axle load cycles applied on the highway sections (1)

Highway section	**Load cycles applied [equivalent 10-t-axle load cycles]**
A	11 Million
B	19 Million
C	15 Million
D	14 Million
E	15.8 Million
F	11 Million

In a first step, the complex stiffness modulus was determined by means of the results of the ITTs carried out as a multi-stage test at three different temperatures. Further, the fatigue curves for the AC mixes were determined using the results of ITTs. Finally, temperature induced stresses were determined in a separate test.

Based on these results, the maximum allowable number of 10-t standard axle loads could be estimated using the pavement design software PaDesTo.

In order to guarantee the comparability of the test sections investigated, specific criteria were required for the highway section pavement structures. The following criteria were established:

- Pavement structure according to the empirical German design guideline RStO 86/89 (HMA on a granular base layer),
- all pavements were 10 to 16 years in use,
- high traffic volume; more than 10,000,000 equivalent 10-t axle load cycles,
- high amount of heavy traffic (>3.5 t axle load) (> 15 % (1).

The performance of an asphalt pavement is significantly affected by its resistance to permanent deformation (rutting) and its fatigue performance (crack formation and propagation). The deformation and strength characteristics of an asphalt mixture can be described with the aid of the following three mechanical properties:

- stiffness (elastic modulus),
- permanent deformation behavior,
- fatigue behaviour.

These parameters have an essential meaning for the analytical design of asphalt pavements. The results of ITT (stiffness and fatigue curve) allow studying the crack formation (crack development) in asphalt pavements and used as input values for the analytical design process.

3.1 Determination of the Stiffness Modulus

From each highway section, 18 cores were excavated. In order to determine the stiffness modulus values for the Asphalt Surface Course (ASC) mix, Asphalt Intermediate Course (AIC) mix and AC mix, the specimen were subjected to a force controlled harmonic sinusoidal loading at 10 Hz without rest periods at three different loading conditions and temperatures. The lower stress level was 0.035 N/mm^2.

The asphalt cores and samples that were taken from the centre of the traffic path are denoted by asphalt mix_I and the asphalt mix samples that were taken beside the centre of the traffic pathpath are referred as asphalt mix_B (e.g. AC_I und AC_B).

The tests for the determination of the stiffness modulus (multi-stage-tests) show that for all temperatures investigated the stiffness modulus of the ASC mix in the centre of the traffic path is on average 10 % higher than for the material taken out beside the centre of the traffic path (Figure 3). Further, the test results show that the stiffness modulus determined for the lower section of AC is on average 6 % lower for the material in the centre of the traffic path than beside it.

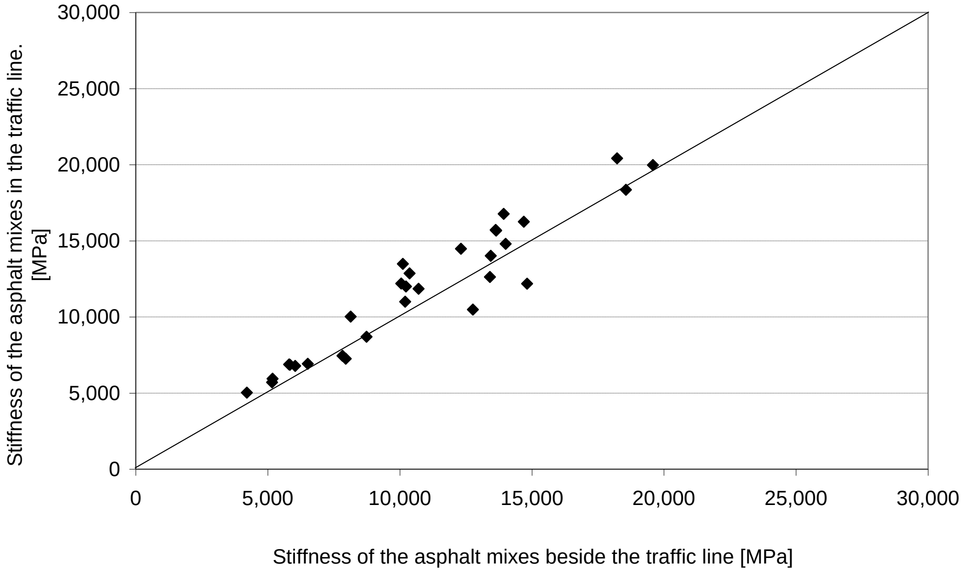

Figure 3: IEI-Modulus values for the ASC in and beside the centre of the traffic path (1)

Furthermore, it was found that the stiffness modulus values of the lower AC in the centre of the traffic path were about 4 to 8 % smaller compared to the stiffness modulus values of the lower AC beside the centre of the traffic path (Figure 4).

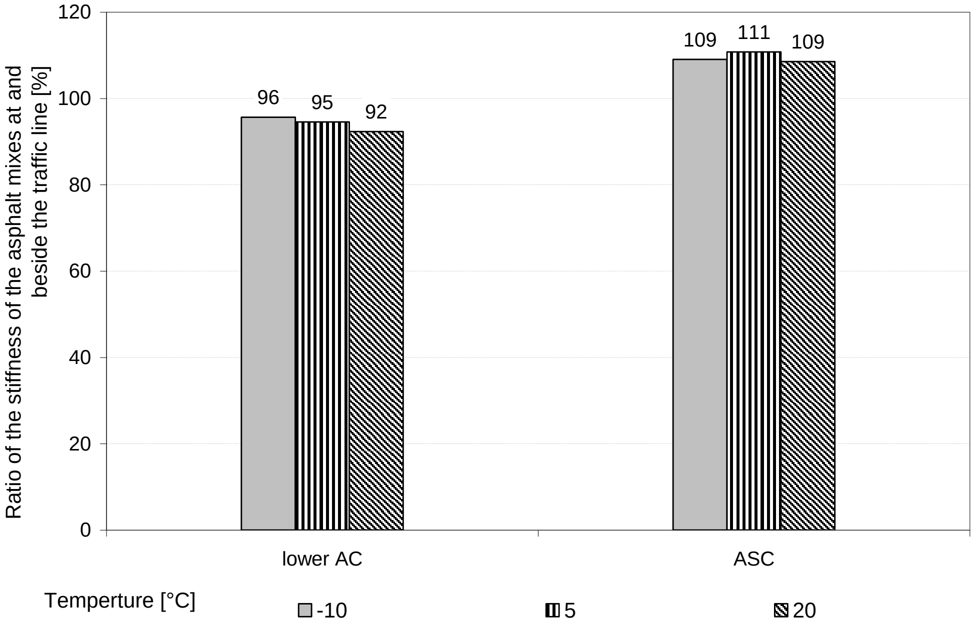

Figure 4: IEI-Modulus values (stiffness) for the ASC and lower AC in and beside the centre of the traffic path (1)

The reason for the differences could be that fatigue damage is developing at the bottom of the AC and that the stiffness is decreasing due to micro-cracking. Because of the damage at the bottom of the AC layer the tensile strain is increasing (decrease in stiffness). This will lead to a reduction in the effective stiffness of the complete asphalt layer (3). It is shown in (3) that the bottom up fatigue clearly exists. The accelerated pavement tests conducted at LINTRACK preludes that the moment at which the asphalt stiffness had reduced about 50% of its initial value coincided with the moment at which approximately 20 % of the centre of the traffic path showed cracking. It can be concluded that a different fatigue state of the pavement can be detected by a comparison of the stiffness values at different number of axle load applications applied – in this case by comparing the stiffness values from the cores taken beside and in the centre of the traffic path).

Based on the results of the fatigue tests, the stiffness of the lower AC mixes in the centre of the traffic path and beside was determined. Partially, there are appreciable differences of the material properties in the centre of the traffic path and beside which range about ±10 %. However, these differences can be assumed to have no significant effect on the fatigue characteristics of the material. The variations seem to be caused by inequalities during the pavement construction process. For example, the layer thickness and the degree of compaction can vary and therefore the fatigue process (formation of cracks) due to traffic loading is interfered by these effects. In consequence, the fatigue curves can be subject to shift or rotation which is not categorically due to traffic loading. However, a significant difference of the stiffness values of the lower AC mix in the centre of the traffic path and beside could be observed for highway section E only (Figure 5).

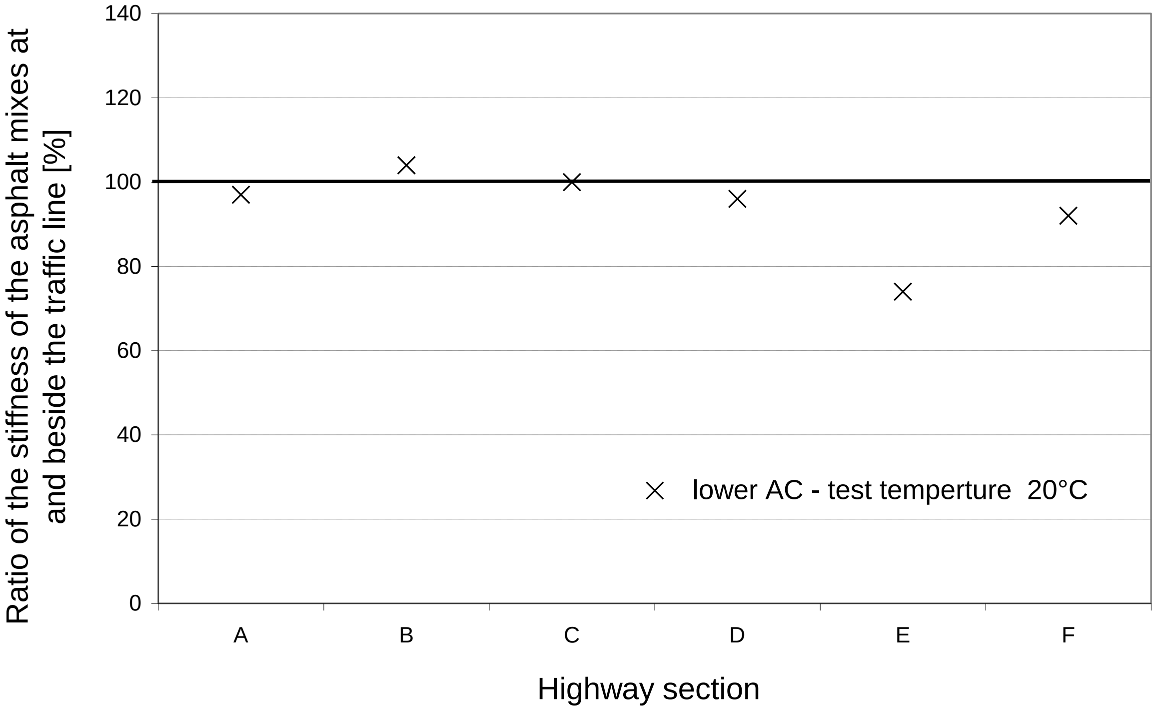

Figure 5: Stiffness ratios for AC mix in and beside the centre of the traffic path (1)

Taking into account the results of the stiffness tests, the following conclusions could be drawn:

- significant difference in the fatigue resistance for the lower AC mix in the centre of the traffic path and beside for highway section E,

- no significant difference in the fatigue resistance for all other highway sections due to little variation of the stiffness modulus.

3.2 Determination of the Fatigue Curves

Using the ITT results, the fatigue relations for the AC mixes were determined. Single fatigue tests at three different upper load levels at a temperature of 20°C and a frequency of 10 Hz were performed. The number of load cycles until macro-cracking were detected to determine the fatigue relationships. For all AC mixes investigated the strain and stress dependant fatigue relations were formed.

When interpreting the results of the fatigue tests it has to be considered that a direct comparison of the fatigue curves of the AC mixes in the centre of the traffic path and beside (same pavement structure) can only be made if the stiffness modulus of the asphalt mixes is on the same level. If the stiffness modulus of the asphalt mixes is varying, different elastic strain levels for the same load develop within the pavement structure.

Different stiffness values can be considered accurately when interpreting the fatigue behavior on the basis of strain dependent fatigue relations by means of a analytical design software. As a results of the calculations, the pavement life (in terms of number of load cycles until asphalt fatigue) can be determined. The laboratory test results (in terms of the stiffness and fatigue curves) form beside other parameters the input values for the calculation process. If such software is not available, the stress dependent fatigue curves have to be used simplified to get comparative predictions of the fatigue resistance of the AC in the centre of the traffic path and beside.

In general, the assumptions based on the results of the stiffness tests could be confirmed by the fatigue test results. A significant difference of the fatigue behavior of the AC mixes in the centre of the traffic path and beside could be observed for highway section E only.

Highway section A, B, C, D and F

The ITT results for the AC mixes from the highway sections A, B, C, D and F show that there is no significant difference between the stiffness and the fatigue relations for the mixes in the centre of the traffic path and beside. The minor differences of the fatigue relations are caused most likely by different construction conditions.

Highway section E

Since highway section E revealed a significant difference (25%) in stiffness modulus, a comparison of the stress dependent fatigue curves was conducted. Figure 6 shows that for the highway section E the AC mix in the centre of the traffic path has a lower fatigue resistance than the AC mix beside.

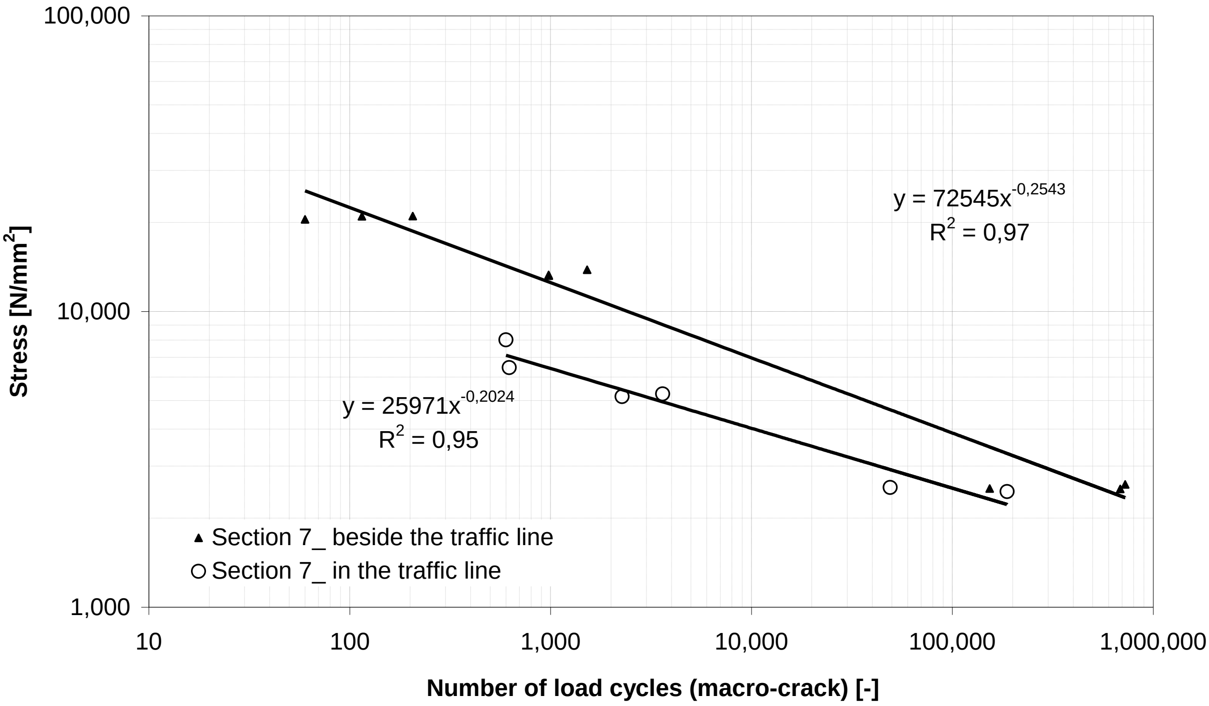

Figure 6: Fatigue relations for the AC in (AC_I) and beside (AC_B) the centre of the traffic path, highway section E

Further, it could be stated that the correlation coefficients of the fatigue relations of the AC mixes beside the traffic path are lower than for the mixes in the centre of the traffic path. This could indicate a change of the material characteristics respectively to fatigue of the asphalt material.

3.3 Temperature induced Stresses

Cooling down tests were conducted at a cooling rate of 10 K/h according to the procedure proposed in (1) to determine the tensile stresses that are occurring at low temperatures because of prevented thermal expansion.

The results of the cooling down tests state that depending on the mix properties of the AC mixes different stress levels occur at different temperatures. The lowest stress level was observed for the AC_I of the highway section E for the cores taken from the centre of the traffic path (AC_B). Furthermore, the difference of the temperature induced stresses between the samples taken in the centre of the traffic path and beside was investigated. The highest difference could be observed for mixes at highway section E. For all materials from the other other highway sections, the differences of the temperature induced stresses are mainly on the same level. Although, in most cases a lower temperature induced stress could be observed for the mix in the centre of the traffic path than for the material beside (Figure 7).

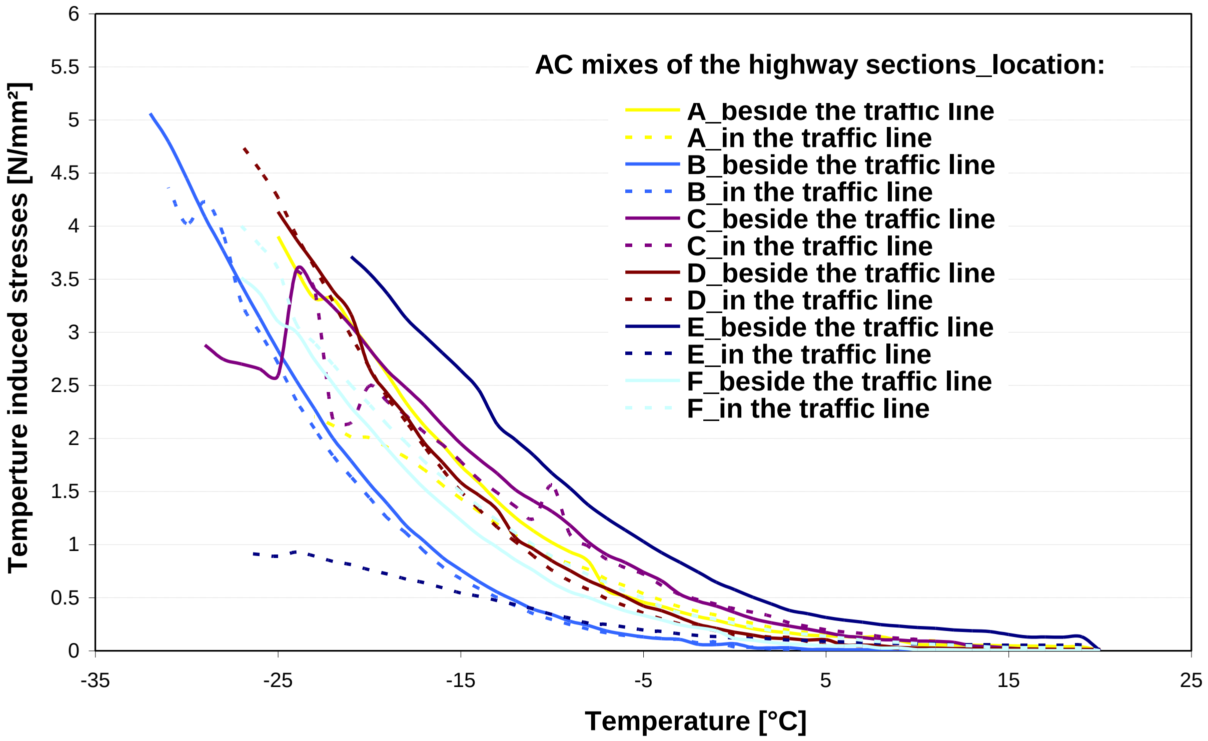

Figure 7: Temperature induced stresses for the AC in the (AC_I) and beside (AC_B) the centre of the traffic path

A high decrease in temperature induced stresses can be interpreted as an indication of asphalt fatigue. The results show, that the fatigue process can also be indicated by the performance of the temperature induced stresses. Very low temperature induced stresses and a very rapid decrease respectively indicate a poor fatigue resistance of the asphalt mix. However, to evaluate the temperature induced stresses, knowledge about the performance of the fresh mix has to be considered.

4 CALCULATION OF THE PAVEMENT LIFE

Finally, a consistency check was conducted in terms of the estimation of the tensile stress at the bottom of the AC layer. Based on the results of the consistency check, the fatigue life of the pavement was calculated. The fatigue life is defined by the occurrence of the macro-crack at the bottom of the asphalt base layer. The laboratory test results in terms of the stiffness values and the fatigue curves were used as input values for the calculation process.

4.1 Input values for the Calculation

In order to be able to design a pavement structure, knowledge on the material properties is essential. The laboratory test results formed important input values for the design process using the pavement design software PaDesTo. This design software is based on multilayered elastic analysis. Figure 8 presents the stiffness modulus function versus the temperature for the AC mix in the centre of the traffic path, highway section E (red path). The second function (green and blue path) presented in the diagram, shows the stiffness modulus function for a new that means “not-fatigued” asphalt mix. This function was determined using the procedure according Francken and Verstraeten (7). It can be seen that the stiffness of the aged and fatigued asphalt respectively is much lower at low temperatures compared to the “un-fatigued” asphalt mix due to the fatigue of the asphalt mix.

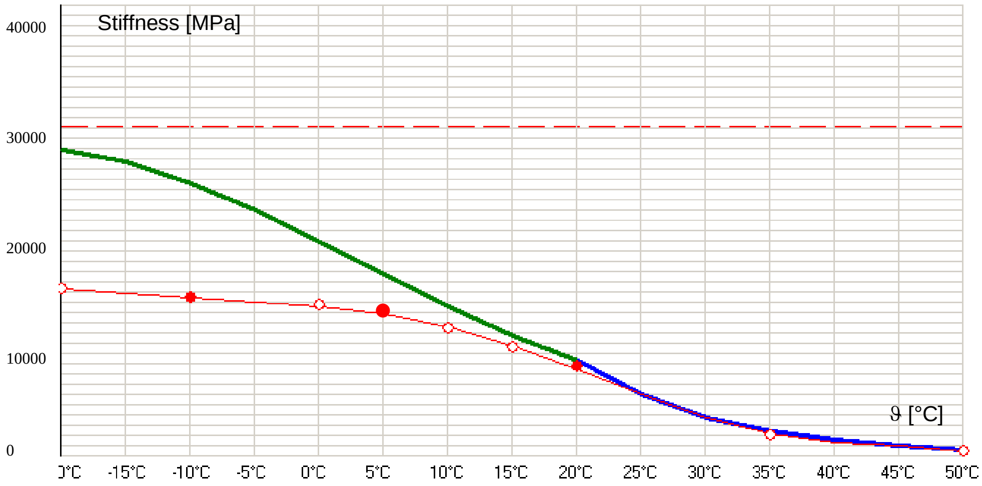

Figure 8: Stiffness modulus function versus temperature for the AC in the centre of the traffic path, highway section E

Table 2 presents the traffic load applied of the pavement highway sections in term of 10-t equivalent standard axles (ESALs). The ESALs were determined using the 4th power law. As an example, for the highway section E, the 10-t equivalent standard axles applied are about 15.8 Million. For the calculation process an annual increase of the heavy traffic of 3 % was estimated for all highway sections.

Table 1 shows the pavement structure of the sections. The unbound granular layer was modeled with a stiffness of 150 MPa. Based on the road category and the geographical position of the pavements the thickness of the frost protection layer was calculated according to RStO 01.

4.2 Analysis of the Calculation Results

Using the software PaDesTo the fatigue status of the highway sections and pavements respectively was determined. The fatigue status expresses the “consumption” of the pavement service life for the traffic volume expected. It can be emanated that a fatigue status of 100 % is equal to the end of pavement service life.

Because of the significant difference in the fatigue of the AC mixes, for highway section E the remaining life was determined separately for the pavement in the centre of the traffic path and beside. Figure 9 illustrates that for section E the difference of the remaining pavement life is 6 years under the same traffic loading.

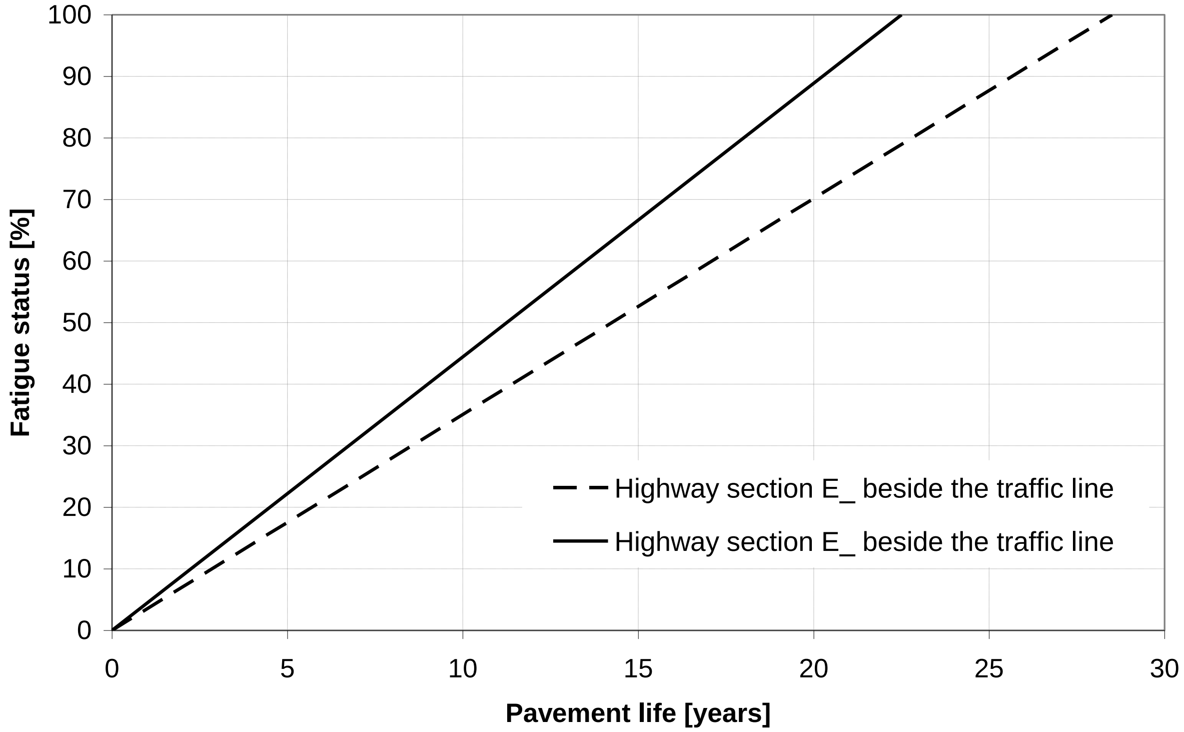

Figure 9: Fatigue status of highway section E depending on the pavement life in and beside the centre of the traffic path

For all other highway sections the stiffness and the fatigue relations were averaged for the pavement in the centre of the traffic path and beside. The results show that for the highway sections B, C, D und E the shortest remaining pavement life can be expected and for the sections A and F the longest life (Table 3).

Table 3: Expected pavement life of the highway sections (**1**)

Highway section	**Pavement life expected [Years]**
A	29
B	22
C	22
D	20
E	22.5
F	83

The pavement life of 83 years for the section F seems not to be realistic. A much shorter service life can be expected here.

The investigation preludes that the remaining life of flexible pavements can only be estimated on the basis of detailed observations together with analytical pavement design calculations. A comparative approach only based on fatigue relations is not possible.

5 SUMMARY AND CONCLUTIONS

The results of the multi-stage and fatigue tests in correspondence with the software PaDesTo showed that it is possible to determine the remaining life of asphalt pavements.

Within a research project conducted at Technische Universitaet Dresden, the number of load cycles until fatigue cracking was calculated to determine the remaining pavement life. The first step of the investigation was to select suitable pavement sections where cores were excavated. In the laboratory, ITTs were conducted on these cores. Subsequently, the ITT results were used to determine the stiffness and the fatigue curves as well as the temperature induced stresses for the asphalt mixes. Based on the laboratory results, calculations were undertaken to determine the remaining pavement life in terms of fatigue cracking. In particular it was found that a significant decrease of the stiffness (>20%) is related to significant fatigue damage.

It should be kept in mind that the estimation of the remaining pavement life was only based on the comparison of the fatigue performance. However, other factors like the rutting performance need to be included as well.

Furthermore, the state of fatigue was assumed to be linear, although an exponential behavior could also be assumed. More accurate predictions concerning the behaviour of the fatigue status can only be made by further testing. Therefore, it is anticipated that specimens will be taken out of the highway sections in about 3 to 4 years. By conducting fatigue tests in the same order as in this project, predictions of the fatigue damage process could be made. Thereby, detailed knowledge could be gained about the fatigue damage process and the crack propagation of the asphalt pavements investigated. Prerequisite for such an investigation is that there are no maintenance measures being applied on these pavements during the next years.

ACKNOWLEDGEMENTS

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