Categories for stiffness and fatigue based on cyclic indirect tensile tests and their applicability in construction contracts

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ABSTRACT

The cyclic indirect tensile test (CIT-CY) was recently introduced as additional test procedure to European standardized asphalt test procedures. In Germany the pavement design can be based on material characteristics obtained on stiffness modulus and fatigue functions which are evaluated with CIT-CY. In order to adopt the rules provided by European construction products directive for these performance-based material properties, categories were introduced to the product standards which will allow the definition of requirements on these important characteristics.

Based on material properties obtained during various research and practical pavement construction projects, categories could be defined which allow the classification of these asphalt mixtures regarding properties which were applied in pavement design calculations.

In order to check the applicability of these categories in construction contracts, former research projects where evaluated regarding the effect of systematically varied asphalt properties on the resulting stiffness and fatigue properties. In addition to this, asphalt mixtures were sampled as loose asphalt mix after industrial production, cored from the completed pavements and also mixed in laboratory with using the constituent materials. Based on the found variability in the performance properties a concept for the contractual implementation of requirements for stiffness and fatigue is proposed.

Keywords: Asphalt, Contractual relationship, Design of pavement, Functional specifications, Performance based standards

1. INTRODUCTION

The European directive for construction materials demands for the application of a system of requirements for assuring the quality of any construction materials prior their use. For asphalt mixtures, these requirements are summarised in European standard EN 13108 series. In Germany, the European specifications were conveyed into the application document TL Asphalt [1]. The various asphalt mixtures are currently defined according to very precise specifications on the proportional composition, i.e. type of binder, binder content, aggregate grading as well as void content specification for a specimen after standardised compaction. This system resulted in low innovations in new asphalt mixture types but at the same time introduces a feasible low risk for non-durable pavement materials.

However, the introduction of new pavement design models based on the actual mechanical properties of the pavement materials led to the demand for evaluating the main durability-related characteristics of the pavement materials. For asphalt mixtures these are stiffness, resistance against fatigue, resistance against low-temperature cracking and resistance against rutting/permanent deformation. Especially the first two are the main input parameters needed for pavement design calculations. Both characteristics are measured by indirect tensile stress tests in which cyclic loading are applied. These test procedures had to be introduced into European standardisation process in order to allow the specification by using these properties in construction contracts.

In order to evaluate feasible categories, the practical range of properties experienced in applied construction projects as well as the test precision have to be considered. However for the application of these specifications in construction contracts also procedures for handling the control tests considering feasible tolerances shall be considered.

2. PAVEMENT DESIGN AND MATERIAL SPECIFICATION IN GERMANY

2.1 Empirical design principles

The status quo of pavement design, material selection and quality control is based on a system of shared responsibility of risk for client, contractor and asphalt mix producer. In common road construction practice, the contractor and the asphalt producer are usually two different legal companies. The client, most often a public road administration, would be responsible for the design of the pavement according to the design traffic. In Germany, a design catalogue [3] is used, in which feasible road structures can be drawn, for which a serviceability of a design life of 30 years can be expected. Based on the design traffic, the client would further prescribe asphalt mixture types which proved to be feasible for the given traffic loading condition in the past and is responsible for paving and compaction [4]. The asphalt mixtures are mixed by a material producer according to the mix design specification document [1] which corresponds to the European standard EN 13108. These requirements for material composition will then be part of the construction contract and the contractor and mix producer guarantees for the prescribed properties.

Usually warranty periods are four to five years, in which the asphalt road must prove suitable surface characteristics. Additionally, during paving works asphalt mix specimens are sampled for evaluating the relevant material properties as guaranteed in the contract between client and contractor. For these specimens, the aggregate grading, the binder content, binder viscosity and void characteristics of a impact-compacted specimen are checked. Additionally cores are taken from the finalised road for checking adequate compaction and interlayer bonding. If one or more properties of the actual delivered and paved asphalt are not in accordance with the contractual clauses, deductions of the payment may be defined [4].

In this contractual system, the client takes the risk for pavement design and material type selection. The asphalt mix producer takes the risks for inadequate mix composition and the contractor proves for compliance of the asphalt mix properties.

2.2 Mechanical-empirical design principles

Mechanical-empirical pavement design [2] was originally developed for the application in performance contracts (e. g. public private partnerships), in which the contractor takes responsibility for a pavement structure for a prolonged time period. This principle would encourage the application of construction materials with prolonged durability and would allow for innovative materials which are not in accordance with the current mix design principles [3, 4].

The design principle is based on actual material parameters, obtained in asphalt performance tests. Ideally, the temperature-dependent stiffness modulus and the fatigue resistance are evaluated by laboratory tests on the asphalt mix which are to be applied during road construction. Based on the actual sites temperature conditions (distribution of surface temperatures during the years) distinct stiffness parameters are calculated from the stiffness test results as well as base conditions. The predicted number of traffic loads during the design period is expressed as number of loading cycles with specific axle loads. For each combination of 13 stiffness distributions and 11 traffic loads, the distresses in the pavement are calculated by multi-layer elastic theory:

1. horizontal strain at the bottom of asphalt base layer for checking of fatigue cracking,
2. vertical stress on top of unbound base layer and subbase for checking the soil consolidation,
3. horizontal stress at the bottom of cemented bases for checking of fatigue cracking,
4. deviatoric stress in surface asphalt layer for checking rutting resistance.

By application of failure accumulation theory (Miner's law), the deterioration of each single loading cycle is summed up for checking of each of the four design criteria. For calibrating the laboratory-obtained material parameters (especially fatigue function) to real pavement conditions, shift and safety-factors are introduced. These safety factors so far are based on full-laboratory prepared asphalt mix properties.

By modification of layer thickness or choice of pavement material, the pavement structure can be optimised that the failure sum reaches a value of "1" at the end of the design service life. The same calculation can be applied in order to evaluate the theoretical service lifetime for various pavement structures. More details on the mechanistic-empiric design method can be found elsewhere [5-8].

By these means, a contractor can optimise a pavement structure for a set of specific road material properties and takes responsibility and risk for the model validity. The costs of this risk can be counterweighted with benefits by long-term contract runtime and innovative construction procedures.

2.3 Application of mechanistic empirical pavement design in conventional contracts

Since introduction, the mechanistic design principle proved a success and will in future also be applied in conventional road construction contracts. However in order to introduce the procedure in which the actual asphalt mix properties are closely linked to the result of a pavement design, the contractual frame has to be adjusted. The first contractual drafts were based on the demand, that the pavement will fulfil the pavement design requirements (i.e. all design criteria reach a service lifetime of 30 years). The contractor would choose suitable pavement materials and do the pavement design calculations. After construction, samples would be cored from the pavements and the relevant stiffness and fatigue characteristics would be evaluated and again the theoretical service lifetime would be calculated. The calculation result would be used for checking the contractual requirement. The contract models contained a fee deduction formula based on the calculated service lifetime in analogy with the common practice according to chapter 2.1 in case of using the conventional parameters. .

However, as analysed in several studies [7-8], so-far tolerated deviations in the asphalt mix properties (i. e. binder content, aggregate grading, degree of compaction) will significantly affect the stiffness and fatigue properties of the asphalt mix and therefore also result in highly-changing service lifetime as calculated from the mechanistic-empiric design procedure. For example, in [7], a reached degree of compaction of 97 % rather than 100 % would result in a reduction of theoretical service lifetime of 60 %, because of the strong effect of void content on the fatigue properties. According to commonly applied contractual procedures, a fee deduction of 3 % would result from this shortfall in compaction [4]. However, when the model contract would be applied and the deduction would be calculated on basis of the service lifetime calculation, the deduction would be 58 % of the fee. This example indicates that the total construction risk is significantly shifted from the client to the contractor. Reason for this is that the contractor would also be responsible for pavement design and material selection. Clearly another contractual model is required in order to keep risks of pavement design, material selection and construction evenly distributed between client and contractor.

Therefore, an experimental test campaign was initiated by the Federal Ministry of Transport and Infrastructure [10] for obtaining a data basis which would allow the draft of procedures, requirements and tolerances to be applied in contracts for pavements design according to a mechanistic empirical design guide. Additionally a basis for the draft of requirements according to European Construction Products Directive is needed. Therefore, the results of the experimental campaign were used for drafting additional categories for asphalt product standards EN 13108.

3. METHODOLOGY

3.1 Experimental design

In several research projects the effect of systematically varied asphalt properties (type of binder, grading, binder content, ageing, compaction degree) on the stiffness and fatigue characteristics were analysed in laboratory studies. The changing mechanical properties proved to have a significant effect on the theoretical service lifetime of an asphalt pavement as calculated according to mechanistic-empirical pavement design [7,9]. For drafting contractual procedures these results needed to be verified for real construction conditions in order to check if the found discrepancies can also be observed in reality. Therefore, 21 asphalt pavement works were selected, for which the asphalt mixtures were sampled in three stages during construction:

- 1st stage "type test": mixture prepared from the constituent materials in laboratory – specimens compacted in laboratory
- 2nd stage: "Mixture sample": plant-produced asphalt mixture was sampled on the construction site, specimens were compacted in laboratory
- 3rd stage: "Core sample": Cores were drilled from the pavement and represent real paving and compaction conditions.

3.2 Cyclic Indirect Tensile Test on cylindrical specimen (CIT-CY)

For the analytical design of new asphalt pavements and rehabilitation according to the German mechanical-empirical design procedure [2], the CIT-CY is used to determine the relevant characteristics for stiffness and fatigue of asphalt mixes. The cyclic test procedure was introduced 2015 into the European Standards EN 1267-24 and EN 12697-26. The deformation measurement system includes two LVDTs which are placed centrically on the cross-sectional area of the specimen. The measurements obtained during the tests are applied vertical force F and horizontal displacement u. From these the horizontal tensile stress, horizontal strain and stiffness are computed.

For the determination of the stiffness, multistage tests are conducted at four temperatures (-10 °C to 20 °C) and varied loading frequencies. The stiffness modulus is calculated from vertical force and horizontal deformation measurements as the average value of three tested specimens. By time-temperature superposition principle, the stiffness master curve is determined. This allows the interpolation of the asphalt stiffness for any temperature condition as needed for the mechanistic-empirical pavement design procedure for the reference frequency of 10 Hz (Figure 1).

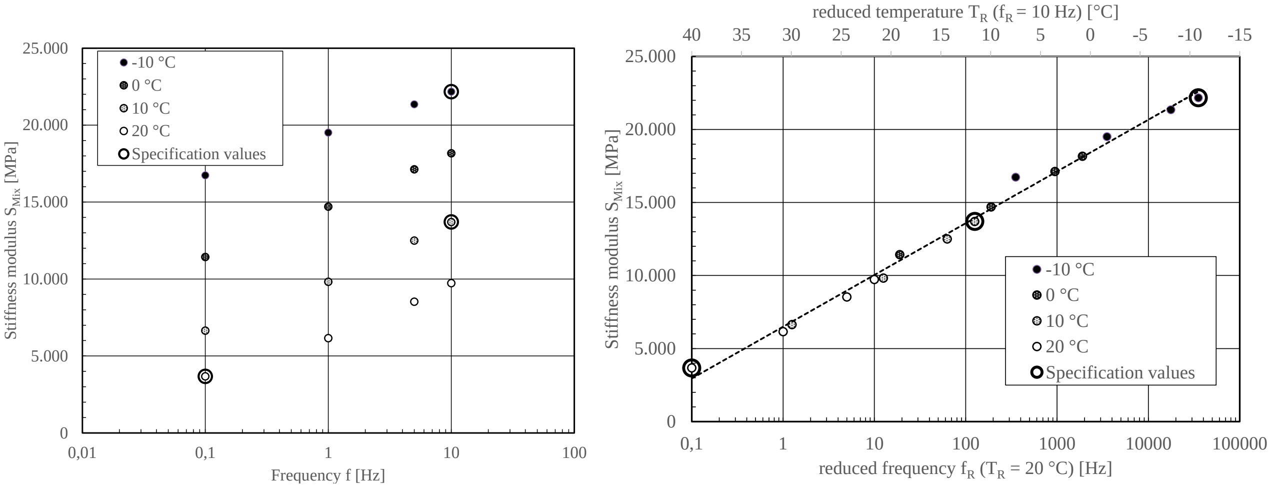


Figure 1: Exemplary illustration of test results of stiffness tests (left) and evaluation of stiffness master curve for stiffness interpolation

To determine the fatigue function CIT-CY are conducted at a temperature of 20 °C and frequency of 10 Hz. For evaluating the fatigue function, allowing the calculation of fatigue life (number of load cycles until failure) from the strain level, three loading forces are applied on three specimen each. The number of load cycles until fatigue is the number of load cycles at the time of macro crack formation N_{Macro} within the specimen. Once the macro crack has developed, complete failure of the specimen follows after a relatively small number of load cycles.

For evaluating the fatigue function as needed in pavement design procedure, the load cycle number at failure (N_{Macro}) is plotted versus the strain measured at the beginning of the loading for each fatigue tests. For a series of nine fatigue tests with varied stress and strain states a fatigue function as shown in Figure 2 can be developed. From this dataset also the logarithmic standard deviation s_{log} can be computed [11] as expression of the precision of the single fatigue function evaluation.

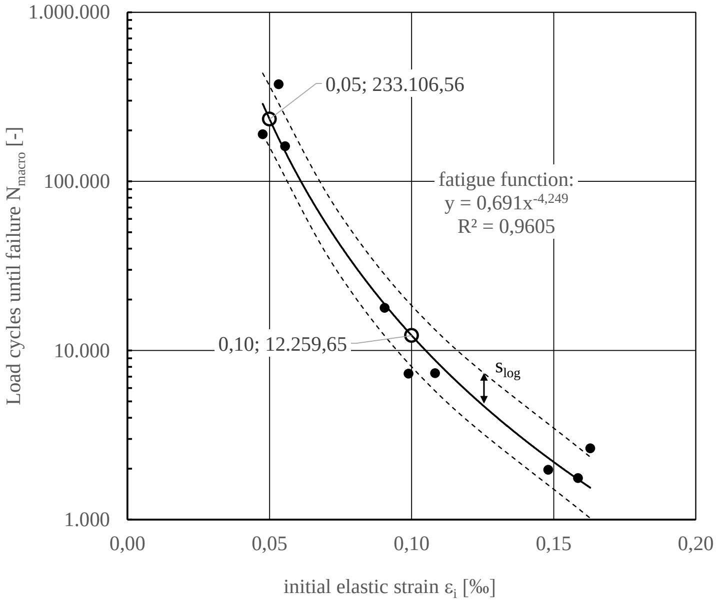


Figure 2. Exemplary illustration of results of fatigue tests as a fatigue function

3.3 Test parameters for mechanistic-empirical pavement design and type test requirements

As input parameters for the mechanistic-empirical pavement design [2], the results of stiffness and fatigue parameters are needed in form of functional parameters for calculating stiffness values for various temperatures as well as the fatigue life versus the strain level occurring in field loading. However, the type test documents, which are harmonised within Europe (EN 13108) only contain single material parameters which are for choice for asphalt specification. Therefore, additional test parameters were defined and proposed for introduction in new version of EN 13108-series.
In order to be able to describe the stiffness modulus in the temperature conditions, relevant for the use in pavement design applications, additional test conditions were added in EN 13108-20:

- CIT-CY, T = -10 °C, f = 10 Hz,
- CIT-CY, T = 10 °C, f = 10 Hz and
- CIT-CY, T = 20 °C, f = 0,1 Hz.

These specification values are plotted as circles in Figure 1. With these test conditions, which are part of the temperature-frequency-combinations actually tested in a multi-stage stiffness test, the stiffness conditions relevant for the actual pavement temperature conditions needed in pavement design are covered.
The asphalt pavement is designed for avoiding fatigue damage of the asphalt base layer during design pavement service life. For the pavement design calculation, the fatigue function according to Figure 2 is required which is a two-parameter function. However, fatigue characteristics as defined in type test requirements are only described by one parameter (ε_6). Especially the slope of the fatigue function representing the dependency of the fatigue life to the level of loading is not considered. Therefore, two new fatigue parameters were defined, which would allow the estimation of a fatigue function. The new parameters are the load cycle numbers until failure for two relevant strain values.

- CIT-CY, N_{macro}(0,1 ‰)
- CIT-CY, N_{macro}(0,05 ‰).

For illustration, these specification values are added in Figure 2.

4. RESULTS

4.1 Identification of specification categories and material classes

The stiffness parameters of the asphalt surface, binder and base course samples from the 21 test sections in the stage “type test” are plotted in Figure 3. As can be observed, the stiffness values within each of the three relevant temperature/frequency conditions can vary significantly from one mix to the other. The horizontal lines represent the categories which are available for specifying stiffness requirements according to EN 13108-series. Note, that the range of stiffness values measured lead to the requirement to add additional categories for better classify the stiffness especially for the high-stiffness ranges, as measured at low-temperature condition as well as for low-stiffness ranges. Therefore, four additional minimal stiffness categories need to be added to EN 13108: $S_{min,1.000}$, $S_{min,25.000}$, $S_{min,30.000}$, and $S_{min,35.000}$.

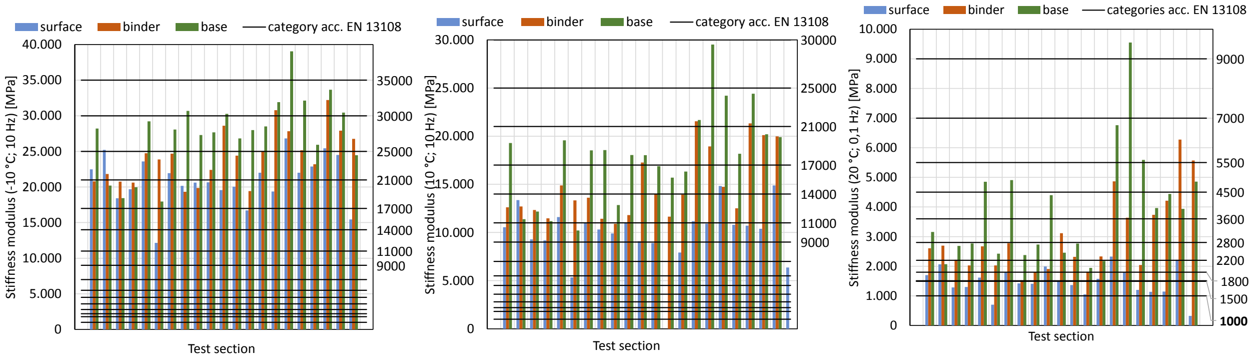


Figure 3: stiffness parameters of analyzed asphalt samples

The fatigue test parameters identified on asphalt samples of 21 test sections are given in Table 1. For each test section, the asphalt base and binder layer mix was sampled, each in the stages “type test”, “mixture sample” and “core sample”. For each asphalt sample, in total nine specimens were tested at varied load levels and the resulting pairs of initial strain and associated load cycle number until failure are plotted, compare Figure 2. For these nine test results, a fatigue function is fitted which is used for calculating the tow fatigue parameters N_{macro}(0,05 ‰) and N_{macro}(0,1 ‰). As can be observed from the logarithmic standard deviation s_{log}, similar accuracy of fatigue function can be found for the asphalt base course mixtures as well as asphalt binder course mixtures. Further, the sampling stage does not significantly affect the accuracy. For evaluating suitable fatigue classes which directly can be applied in pavement design as well as for fatigue resistance categories in type tests, the probability distributions of fatigue parameters N_{macro}(0,05 ‰) and N_{macro}(0,1 ‰) were evaluated. As plotted in Figure 4, the distribution of the fatigue parameters can be described as normal distributions. This allows the evaluation of quantile values, which can be applied for drafting categories.

As a result, seven categories were defined which represent the range of fatigue characteristics evaluated for the 21 test sections. For each category, two minimum load cycle numbers are defined. The minimum required load cycle number for a stain of ε = 0,1 ‰ is used for entitling the category. The second minimum load cycle number related to the strain ε = 0,05 ‰ is used as a second requirement for the category.

Table 1: Fatigue test parameters evaluated on asphalt base and asphalt binder samples in stages type test, plant mix and core sample

	Stage:	Type test			Mixture sample			Core sample		
	Sample	N(0,1 ‰)	N(0,05 ‰)	s_{log}	N(0,1 ‰)	N(0,05 ‰)	s_{log}	N(0,1 ‰)	N(0,05 ‰)	s_{log}
Asphalt concrete for base layers	a	1.958	11.965	0,083	4.474	35.279	0,166	2.984	16.568	0,073
	b	3.806	29.487	0,076	7.055	127.560	0,112	6.069	85.413	0,054
	c	2.166	16.689	0,088	3.177	32.393	0,131	4.074	26.406	0,064
	d	6.591	146.124	0,122	8.424	237.894	0,159	5.939	52.123	0,053
	e	4.059	22.571	0,141	4.324	54.209	0,048	5.229	77.918	0,058
	f	3.327	22.801	0,143	5.416	75.658	0,086	8.184	134.157	0,136
	g	3.018	20.109	0,164	2.936	32.304	0,075	3.809	37.295	0,107
	h	5.451	76.915	0,148	4.738	89.247	0,134	3.824	50.249	0,068
	i	5.506	128.900	0,117	5.164	134.030	0,105	2.583	20.321	0,077
	j	2.954	50.999	0,139	5.772	166.657	0,123	4.332	49.361	0,118
	k	5.831	110.214	0,127	10.547	230.586	0,161	3.074	29.000	0,121
	l	3.532	43.328	0,147	4.356	39.528	0,134	4.627	47.373	0,109
	m	7.046	156.843	0,101	6.841	106.751	0,089	5.709	66.490	0,057
	n	5.265	138.850	0,236	5.085	98.670	0,129	4.319	76.991	0,166
	o	8.330	106.259	0,096	6.592	129.018	0,143	4.115	58.137	0,071
	p	6.713	126.457	0,085	3.989	54.920	0,139	6.298	108.803	0,091
	q	9.709	65.343	0,217	7.943	122.455	0,126	7.617	64.724	0,184
	r	6.482	103.111	0,130	10.312	201.558	0,114	6.322	113.818	0,147
	s	6.669	91.816	0,068	4.229	54.156	0,118	7.692	113.379	0,055
	t	4.600	38.353	0,102	3.594	34.618	0,026	3.433	33.043	0,109
	u	9.453	192.285	0,119	5.046	125.347	0,174	7.531	121.547	0,139
	Mean s_{log}			**0,13**			**0,12**			**0,10**
Asphalt mix for binder layers	A	9.911	84.989	0,166	12.336	133.489	0,141	7.662	44.693	0,170
	B	13.086	180.095	0,095	12.269	233.349	0,181	16.691	135.318	0,111
	C	8.896	116.301	0,129	20.048	321.523	0,122	18.650	276.343	0,107
	D	9.288	137.651	0,076	10.819	132.226	0,114	21.140	270.246	0,133
	E	19.114	156.639	0,104	13.049	147.473	0,170	19.005	209.548	0,096
	F	26.962	289.784	0,173	10.835	108.821	0,061	17.945	163.477	0,102
	G	18.087	226.357	0,183	16.446	247.570	0,105	14.117	187.692	0,100
	H	13.305	138.195	0,099	15.723	194.697	0,112	15.761	227.070	0,076
	I	13.782	152.793	0,097	11.721	146.611	0,129	13.154	158.950	0,113
	J	10.313	128.426	0,105	13.192	250.138	0,138	11.904	130.685	0,085
	K	6.239	62.538	0,060	6.832	41.159	0,096	6.207	44.749	0,116
	L	13.527	178.799	0,103	20.811	245.133	0,122	8.333	76.760	0,075
	M	13.277	159.520	0,074	13.242	146.884	0,172	7.202	73.876	0,164
	N	9.852	114.034	0,120	7.652	130.525	0,135	12.104	103.378	0,090
	O	4.899	51.503	0,082	5.649	49.265	0,101	4.045	24.244	0,136
	P	8.755	103.382	0,097	13.947	168.032	0,157	7.615	84.875	0,161
	Q	12.742	206.963	0,137	14.052	182.691	0,119	19.495	175.815	0,111
	R	18.981	195.417	0,136	29.108	502.982	0,079	22.408	244.950	0,110
	S	24.252	423.340	0,096	14.702	198.729	0,054	14.351	141.170	0,115
	T	20.528	415.728	0,157	8.820	86.074	0,121	7.455	60.082	0,097
	U	8.358	108.843	0,105	7.230	68.026	0,155	4.790	51.568	0,106
	Mean s_{log}			**0,11**			**0,12**			**0,11**

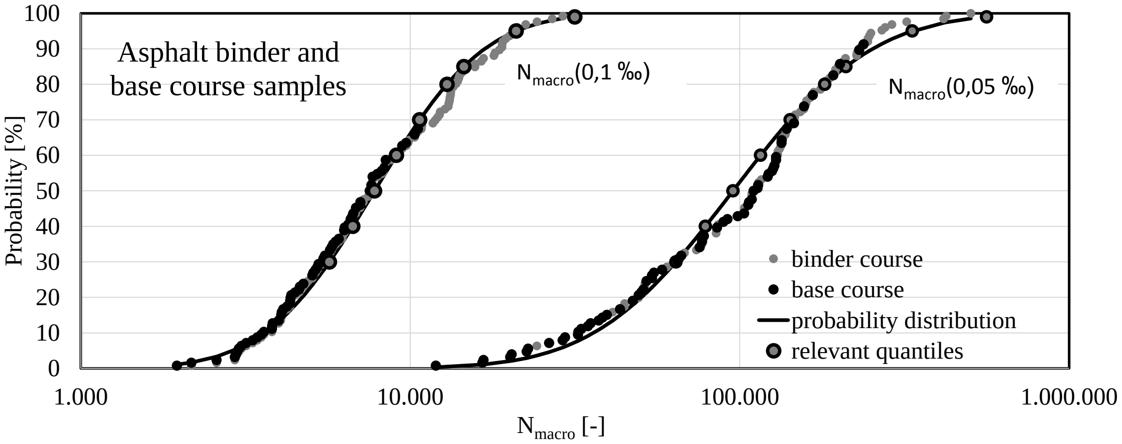


Figure 4: Probability distribution of fatigue parameters

Table 2: Categories for fatigue resistance based on CIT-CY

Quantile	Minimum load cycle number $N_{macro}(0,1 ‰)$	Minimum load cycle number $N_{macro}(0,05 ‰)$	category name $N_{Macro,min}$	*fatigue function: $N_{macro} = C_1 \cdot \varepsilon^{C2}$*	
				parameter C_1 of fatigue function	*parameter C_2 of fatigue function*
30 %	5.686	64.059	$N_{Macro,min,5700}$	1,824	-3,494
50 %	7.795	95.504	$N_{Macro,min,7800}$	1,892	-3,615
70 %	10.686	142.387	$N_{Macro,min,10700}$	1,963	-3,736
85 %	14.541	210.292	$N_{Macro,min,14500}$	2,034	-3,854
95 %	20.967	334.240	$N_{Macro,min,21000}$	2,123	-3,995
99 %	31.593	561.661	$N_{Macro,min,31600}$	2,226	-4,152
	No requirement	No requirement	$N_{Macro,min,NR}$	-	-

4.2 Discrepancies between the mechanical properties of designed and actual produced asphalt mixtures

During mix design of asphalt mixtures according to EN 13108 all tests are conducted on asphalt mixtures prepared and specimens compacted in laboratory. However, by plant mix production and site compaction diverting performance properties can result also for the same asphalt mixture composition as for the laboratory-prepared mixture. This effect has to be considered if asphalt mixture or cores are sampled on site and compared with actual mix design parameters for control tests. Therefore each of the 21 asphalt samples were evaluated in the stages type test and additionally also in production stage “mix sample” and “core”. As can already be observed in Table 1 and plotted in Figure 5, considerable differences in fatigue resistance between laboratory mix, plant mix and core sample can occur. These differences are not systematic. However, when samples from plant mixtures and/or cores are compared with samples from the mix design – laboratory - stage, there is a considerable risk, that the control test sample will show less advantageous test results.

The value of risk is synthesized in Table 3. For the three stiffness categories as well as the fatigue resistance the proportions of acceptable samples (same category in stages “plant mix” or “core specimen” compared to “type test”) as well as non-acceptable samples in two steps are identified. For example, of the 21 surface asphalt mixtures evaluated in the stage “plant mix”, 85,7 % reach the same or better stiffness category (for the test conditions -10 °C and 10 Hz) as in the stage “type test, whereas 14,3 % of the samples are classified in one category lower compared to the sample “type test”.

For the stage “core specimen” less samples are acceptable than for stage “plant mix”. This can be explained by the additional different compaction (site vs. laboratory) between stage “core specimen” and “type test”. For single properties (minimum stiffness at 20 °C and 0,1 Hz) only 28,6 % of the surface and binder course samples reach in the stage “core specimen” acceptable categories.

The binder course samples identify higher risk for non-acceptable categories compared to surface and base course samples.

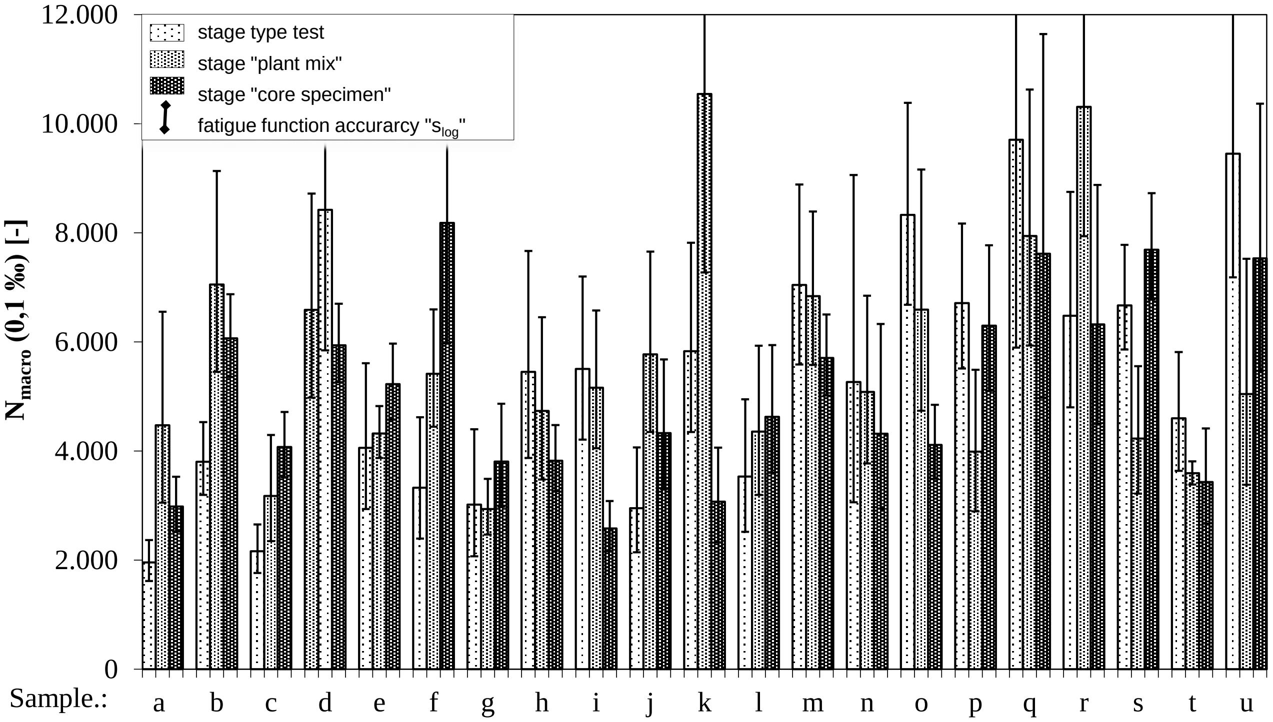


Figure 5: fatigue parameter N_{macro}(0,1 ‰) evaluated for the 21 asphalt samples in the stages "type test", "plant mix" and "core sample" as well as indication of fatigue function accuracy (s_{log})

Table 3: Proportions of samples for the stages "plant mix" and "core specimen" which are classified in the same or better or into worse categories compared to stage "type test"

Property	deviation in category from sample "type test"	Proportion [%]					
		surface course		binder course		base course	
		Plant mix	core sample	Plant mix	core sample	Plant mix	core sample
stiffness S_{mix} (-10°C; 10 Hz)	**same category or better**	**85,7**	**38,1**	**61,9**	**61,9**	**61,9**	**52,4**
	1 category lower	14,3	47,6	33,3	19,0	33,3	47,6
	2 or more cat. lower	0,0	14,3	4,8	19,0	4,8	0,0
stiffness S_{mix} (10°C; 10 Hz)	**same category or better**	**81,0**	**38,1**	**71,4**	**52,4**	**71,4**	**61,9**
	1 category lower	19,0	28,6	28,6	28,6	28,6	33,3
	2 or more cat. lower	0,0	33,3	0,0	19,0	0,0	4,8
stiffness S_{mix} (20°C; 20 Hz)	**same category or better**	**76,2**	**28,6**	**66,7**	**28,6**	**71,4**	**57,1**
	1 category lower	23,8	47,6	23,8	19,0	19,0	14,3
	2 or more cat. lower	0,0	23,8	9,5	52,4	9,5	28,6
fatigue resistance	**same category or better**	not evaluated		**76,2**	**52,4**	**81,0**	**81,0**
	1 category lower			14,3	23,8	14,3	14,3
	2 or more cat. lower			9,5	23,8	4,8	4,8

Based on the test results and derived stiffness and fatigue categories, a procedure is drafted for a pavement design and contractual management by use of these approaches.

5. PROCEDURE FOR PAVEMENT DESIGN AND CHOICE OF MATERIALS

5.1 Pavement design and choice on minimum mixture requirements

Based on a wide data basis categories for stiffness and fatigue resistance could be defined, which allow the pavement design as well as the application in type testing. As for standard construction contacts, the client would be responsible for pavement design. For applying mechanistic-empiric pavement design guide, the client would calculate pavement design based on different material parameters. He can choose suitable minimum stiffness values for the relevant

temperature/frequency conditions as well as a fatigue class for the pavement design. An example for this choice of material parameters is given in Table 4. Here, also the stiffness master curve and the fatigue function resulting from the chosen material parameters are given. The pavement design could be done by the client without any additional information regarding actual material parameters required. As the design materials are defined by minimum stiffness and minimum fatigue life, the result of the pavement design represents the bottom line of performance. Higher stiffness of asphalt mixtures as well as higher fatigue lives will result in higher calculated service lifetime.
The client would then tender the pavement construction with the given minimum required material categories which also were applied in pavement design.

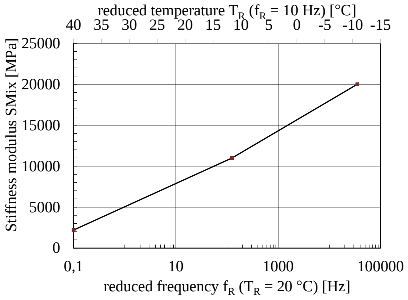
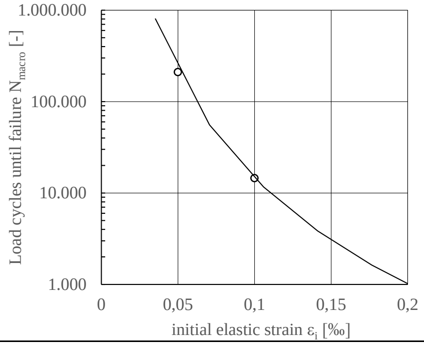
5.2 Mixture choice based on risk assessment

A contractor and the associated asphalt mixture producer then would choose a suitable asphalt mixture which meets the tendered material requirements. As the tender contains minimum requirements for stiffness and fatigue resistance, again the expected pavement performance will be as calculated during pavement design or better. Therefore, no additional pavement design calculation is required which will accelerate the tender process.

However, during industrial mix production and paving discrepancies may occur, which will have negative effects on stiffness and fatigue performance. As indicated in Table 3 the risk of non-complying material properties after plant mixing and/or paving can be relevant. In order to reduce the risk of non-complying stiffness or fatigue parameters in control samples taken during (stage “plant mix”) or after (stage “core specimen”) paving, the contractor may choose an asphalt mix of one or two categories better compared to the tendered specification.

The client would get an asphalt material which fully fulfils the specifications required for ensuring the pavement design assumptions. In order to check if the material properties are met during construction, control test samples could be taken. Because of the higher discrepancies between core specimens to type test properties compared to the plant mixed sample, these control shall be made on plant-produced asphalt samples.

Table 4: Example for a pavement design based on asphalt stiffness and fatigue categories

Minimum Stiffness	temperature/frequency	-10 °C, 10 Hz	10 °C, 10 Hz	20 °C, 0,1 Hz	
	Minimum stiffness [MPa]	20.000	11.000	2.200	
	stiffness category	$S_{min\ 20.000}$	$S_{min\ 11.000}$	$S_{min\ 2.200}$	
Fatigue resistance	strain level	0,1 ‰	0,05 ‰		
	minimum N_{macro}	14.541	210.292		
	fatigue category	$N_{macro,min\ 14.500}$			

6. CONCLUSIONS

Based on asphalt mixtures for surface, binder and base courses sampled on 21 asphalt pavements during mix design “type test”, mix production “plant mix” and after compaction “core specimen”, relevant categories for stiffness and fatigue resistance based on cyclic indirect tensile stress tests (CIT-CY) could be developed. The introduction of these specifications will allow the application of conventional construction contracts for pavements which were design according to German mechanistic-empirical design guide. The contribution drafts a procedure which allows the application of fundamental specifications with the same division of responsibility and risks between the client (pavement design and material class selection) and the contractor (material production and pavement construction):

1. Client conducts pavement design based on minimum stiffness category values and fatigue parameters. As a result the pavement design in terms of pavement layers (type of materials and layer thicknesses) can be tendered. The material properties are defined by minimum stiffness categories and minimum fatigue resistance category.
2. The contractor and associated asphalt mix producer will select suitable asphalt mixtures according to the tendered specifications. Because of non-negligible risks of divergences it is recommended, that materials of better classes shall be selected.
3. The construction contract contains references to the minimum stiffness and fatigue requirements as required minimum classes for stiffness and fatigue resistance.
4. During or after paving the client would sample asphalt mix at the construction site in order to check the requirements. These checks shall be done on mix samples because of smaller divergences to the type test materials due to the same laboratory compaction effects on specimen properties.

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