INTERLABORATORY EXPERIMENT OF ASPHALT CONCRETE USING INDIRECT TENSILE FATIGUE TEST

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ABSTRACT

The principal purpose of this study was to evaluate repeatability and reproducibility of the Indirect Tensile Fatigue Test (ITFT) to quantify the fatigue resistance of asphalt concrete mixes according to EN 12697-24, annex E. A further purpose was to assess the performance of participant laboratories that apply this standard in routine use. A roadbase mix and high modulus asphalt concrete were chosen, representing the expected variation in the field. A total of eight laboratories around Europe participated in the study. Statistical protocols, including the International Standard ISO 5725-2, were utilized to describe the precision of the test. It was concluded that the ITFT is statistically rational and accurate, and is therefore recommended for use as a routine test standard to assess fatigue properties of asphalt mixtures.

Keywords: Indirect tension, Fatigue cracking, Asphalt mixture, Interlaboratory

INTRODUCTION

Determinations of the fatigue life and stiffness modulus of asphalt concrete are two of the most important characteristics associated with the design and evaluation of flexible pavements. This paper is limited to study the fatigue properties of asphalt concrete materials using the Indirect Tensile Fatigue Test. Laboratory fatigue testing of asphalt mixtures has been used to evaluate pavement fatigue life. Research efforts have focused on the response of the mixes to conditions in the field by means of a variety of testing methods and pieces of equipment, which have provided valuable knowledge [1, 2]. Different laboratories, however, can give widely different results even when using identical fatigue test set-up [3], which can influence the predicted fatigue life of a pavement. There is therefore a certain need for an operational fatigue test with known accuracy and precision for evaluation of asphalt mixtures. The purpose of this study was to evaluate the repeatability and reproducibility of the Indirect Tensile Fatigue Test (ITFT) in determining the fatigue cracking resistance of asphalt concrete materials according to EN_12697-24_2004, Annex E. In recent decades, the Indirect Tensile Test has been used by many investigators to characterize asphalt mixtures [4-8] .

SCOPE

The ISO 5725-2 standard practice for conducting an interlaboratory test to determine the accuracy and precision values has been followed as far as possible in accordance with EN_12697-24_2004 for the resistance to fatigue of hot mix asphalt. Two different asphalt concrete mix types of different composition to represent the field variations were prepared. Test specimens of high modulus asphalt mixtures and low variation in composition EME 14 10/20 and a roadbase mix of asphalt gravel with relatively low stiffness and high variation in composition were manufactured at two laboratories. Each participant laboratory was supplied with at least 15 samples of each mixture. Fatigue tests were performed at 10°C. Summary data sheets for analysis of the measurements were sent to each laboratory along with the test samples.

INTERLABORATORY TESTING PROGRAMME

Two different asphalt concrete mixes of different composition were prepared. The mixes were chosen to represent the asphalt mixtures frequently used in roadbase layers in Europe with respect to stiffness modulus and inhomogeneity in air void variation that form an essential component of the precision of a test method. Several batches of 30 mm thick test specimens of high modulus asphalt EME 14 10/20 (25000 MPa, 10°C) were manufactured at the laboratory of SCREG Il de France Normandie. Specimens of 100 mm in diameter were compacted according to EN 12697-31using a gyratory compactor. Test specimens of asphalt gravel AG16 70/100 (7900 MPa, 10°C) of 100 mm in diameter and 50 mm thick were cored from 50 mm thick slabs manufactured at VTI according to EN 12697-30. The mixtures' grading curves are shown in Figure 1. Before sending at least 15 samples of each mix to the participant laboratories, thickness and void content were determined for each specimen. The average void contents of the AG16 and the EME14 mixtures were 2.8 % with a standard deviation of 0.43 % and 2.9 % with a standard deviation of 0.30 % respectively. It is obvious that AG16 mix shows almost 30 % more variation in air voids content. The standard deviation limits represent the actual field conditions based on best practice.

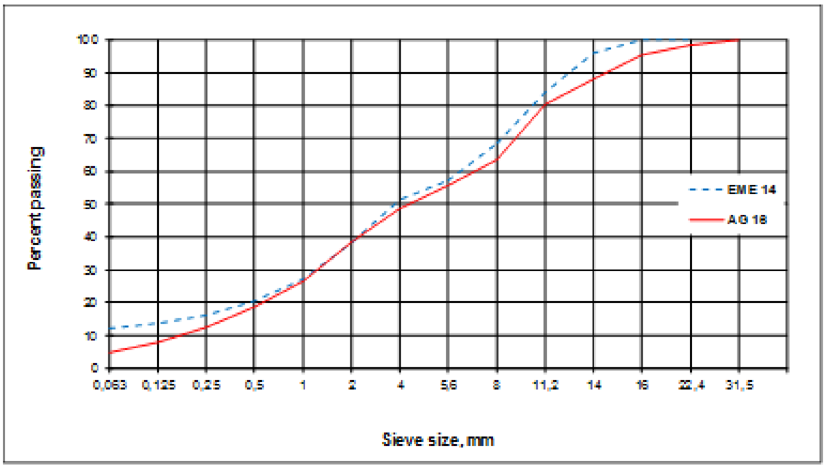

Figure 1: Grading curves of The AG16 and EME14 mixes

A total of 7 laboratories with different types of testing machines for ITFT participated in the test, see Table 1. Unfortunately, some laboratories are delayed. Nevertheless, measurements received to date are presented. It is worth mentioning that apparatus used in this work may have differences that could be crucial to the precision work. Strain gauges mounted on the specimen in the loading device at each participant laboratory are shown in Figures 2-4. It can be observed that in Skanska's device the deformation transducers are fixed to steel strips which are glued to opposite ends of the specimen (Figure 3). However, the deformation transducers at the other laboratories are fixed to steel strips glued on opposite sides over the specimen's thickness. See Figures 2 and 4. In addition, all participant laboratories except Skanska and NTEC used a flexible upper loading strip (Figure 5) for better contact between loading strip and specimen. These differences may be essential if the specimen has some irregularities in their dimensions. However, this is not expected in this study since all specimens have been laboratory-manufactured. Undesirable effects caused by differences between apparatus are not therefore expected. It is also noticeable from measurements that some laboratories were not able to test at large strain levels due to their limited maximum load capacity, especially when testing the high modulus mixtur. The fatigue test was performed according to EN_12697-24_2004, Annex E, with the following directives:

- The displacement transducers must be accurate to at least 1µm with a stroke of at least 2 mm.
- The deformation measurement beams must be glued: springs must not be used.
- The loading platen must measure 12.7 (+-0.1) mm for specimens with a diameter of 100 mm
- The tests must be continued until failure. The fatigue life of a tested series should cover a range between 10^3 and 10^6 applications depending on initial strain level.
- The initial strain is to be determined after stabilisation of the deformation signal (preconditioning to ensure good contact between the specimen and the loading platens. For convenience and consistency, the initial deformation is by definition the difference between the total maximum deformation after 100 cycles and the total minimum deformation after 60 cycles.
- During the test a constant load of at least 20 N must be maintained.

Table 1: Participant laboratories

Laboratory	Testing machine	Loading system	Strain gauge
SCREG Ile de France Normandie	COOPER NU14	pneumatic	LVDT
SCREG Sud Ouest	COOPER NU14	pneumatic	LVDT
SCREG Est	COOPER NU14	pneumatic	LVDT
VTI	MTS MTS-454	hydraulic	Extensometer
Skanska	IPC UTM-25	hydraulic	LVDT
NTEC	COOPER NU14	Pneumatic	LVDT
SCREG Ouest	COOPER NU14	pneumatic	LVDT

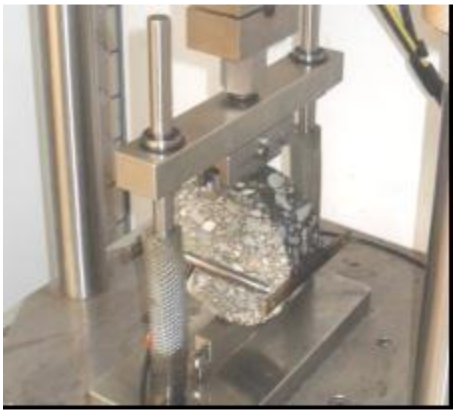

Figure 2: Cooper NU14 used by the SCREG laboratories.

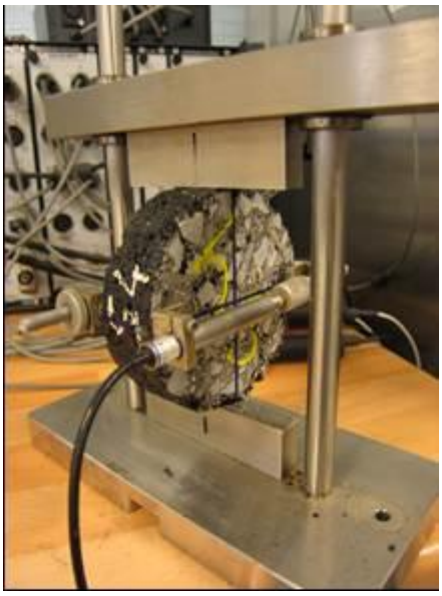

Figure 3: UTM used by the Skanska laboratory in Malmö

Figure 4: MTS 454 used by VTI

Figure 5: Flexible upper loading strip according to EN_12697-24_2004

INTERLABORATORY TESTING RESULTS

The measurements obtained (so far from 7 laboratories) were used to determine the precision statement of the test method. The number of samples tested by each laboratory varies between 8 and 15 due to damage prior to or during the test or a problem in performing the measurement. Roughly half of the specimens were tested by some participants. However, ISO Standard 5725 takes into account damaging only a few specimens. Conclusions should therefore be drawn with caution. In this study, however, no laboratory or measurement is discarded as an outlier in the statistical analysis. Also the level of the initial strain to be tested was not fixed. This was because the test is a constant-stress test and there is no control of the resultant initial strain. Strain (and not stress), as a variable, was used in the statistical analysis, since the strain is an essential parameter in pavement design. This case, where the strain variable is not fixed at some levels, is not ideal for statistical analysis as described by ISO Standard 5725 [9]. The determination of the between-laboratory variation has therefore been modified.

Relationships between initial strain and number of load applications until failure of the tested mixtures, AG16 and EME14, together with their regression relationships and coefficients are shown in Figures 6 and 7 and Table 2. It is obvious that not all laboratories have measurements covering the proposed range (up to 10^6 applications). The coefficients n and K are estimated through linear regression of logarithm of number of load applications (as a response variable) on logarithm of initial strain (as a predictor variable). The slopes (n) of the relationships are for the most part very close. The fatigue relationship between number of loads and the initial strain is

$$N_f = K \cdot \left(\frac{1}{\varepsilon}\right)^n \qquad (1)$$

Where

N_f = number of load applications
ε = initial strain in micro strain
K & n = regression constants

To determine the repeatability and reproducibility of the test variables at the laboratories, three levels of initial strain covering the ranges of the strain for each mix were chosen. The chosen strain levels are shown as dashed lines in Figures 6 and 7. The repeatability variance s_r^2 is estimated as the mean of the within-laboratory variances (*MSE*) and the reproducibility variance s_R^2 is determined as the sum of the between-laboratory variance s_L^2 and the repeatability variance s_r^2 , i.e. $s_R^2 = s_L^2 + s_r^2$ according to ISO Standard 5725-2.

$$MSE_i = \frac{1}{n_i - 2}\sum_{j=1}^{n_i}\left(y_{ij} - \dot{y}_{ij}\right)^2 \qquad \text{………………………………………………………………………………(2)}$$

$$s_r^2 = \frac{1}{p}\sum_{i=1}^{p} MSE_i \qquad \text{……………………………………………………………………………………………(3)}$$

Where

MSE_i = estimated within-laboratory variance (repeatability variance) at ith laboratory
p = number of laboratories
n = number of tests at i^{th} laboratory
y_{ij} = log number of load applications at x_j strain level at i^{th} laboratory
$\dot{y}_{ij}$ = fitted log number of load applications at x_j strain level at i^{th} laboratory

The determination of the between-laboratory variance s_L^2 is modified since the strain levels are not fixed at specific levels as described in ISO Standard 5725-2. Strain levels (observations) are scattered over the estimated fatigue relationship. The between-laboratory variance s_L^2 in this work is therefore defined by Equation 2 that is comparable to the formula reported in ISO 5725-2 (section 7.4.5.1) based on the assumption reported by Kutner et al [10] :

$$s_L^2 = \frac{1}{(p-1)}\left(\sum_{i=1}^{p} m_i^2 - p\bar{m}^2\right) - \frac{1}{p}\sum_{i}^{p} MSE_i\left(\frac{1}{n_i} + \frac{(x_0-\bar{x}_i)^2}{\sum_{k=1}^{n_i}(x_{ik}-\bar{x}_i)^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

Where

MSE_i = estimated within-laboratory variance (repeatability variance) at ith laboratory
p = number of laboratories
n_i = number of tests at i^{th} laboratory
x_0 = strain level at which repeatability and reproducibility are determined
$\bar{x}_i$= average strain level at i^{th} laboratory
m_i = fitted value of log number of load applications at x_0 strain level at i^{th} laboratory
$\bar{m}$= average fitted log number of load applications of laboratories at x_0 strain level

Tables 2 and 3 show the estimated regression coefficients according to fatigue relationship (Eq.1) and the within-laboratory variances (*MSE*). It must be emphasised that the basic assumption of ISO Standard 5725 is that repeatability will be approximately the same for all laboratories. The *MSE* value is a function of number of observations and the range of measurements (ISO Standard 5725-1) but the expected *MSE* value is influenced by the repeatability only. The observed *MSE* values indicate that repeatability variance may not be the same for each laboratory, see Tables 2 and 3. All values have nevertheless been accepted in this work. The repeatability standard deviation s_r, which is estimated as the square root of the arithmetic mean of the within-laboratory variances (*MSE*), is assumed to be the same for all strain levels, 0.238 and 0.196 for AG16 and EME14 mixes, respectively, estimated from the results of all participant laboratories, see Tables 4 and 5. A lower *MSE* can be obtained if the s_r value is estimated only based on those laboratories strictly following the interlaboratory test programme described above. This results in average s_r values of 0.226 and 0.171 for AG16 and EME14 mixes, respectively. It is also noticeable, as expected, that the s_r values are related to the standard deviation of the void contents of the mixtures reported previously, viz. 0.43 and 0.30 for AG16 and EME14 respectively. The higher the standard deviation of the void contents, the higher the repeatability standard deviation. This was why two different mixtures were chosen to cover actual field conditions. The reproducibility standard deviations of the test are the square root of the sum of the s_r^2 and the s_L^2 shown in Table 4 and 5. The AG16 mix shows lower values of the between-laboratory standard deviations compared to the EME14 mix. This is apparently related to fewer laboratories testing the AG16 mix, with almost 15 specimens tested by each. Two laboratories tested 9 specimens of the EME14 mix and one tested only 8; in all, eight laboratories reported their measurements. Clearly, each laboratory testing approximately 15 specimens would have been valuable to the study. Excluding laboratories not testing 15 specimens and using apparatus not strictly conforming to the EN standard for this test, it would result in significantly better reproducibility values (s_R=0.20), which is comparable to an earlier investigation [9]. Nevertheless, and bearing in mind the limitations of this study, the repeatability and reproducibility of the test are deemed to be adequate for routine use.

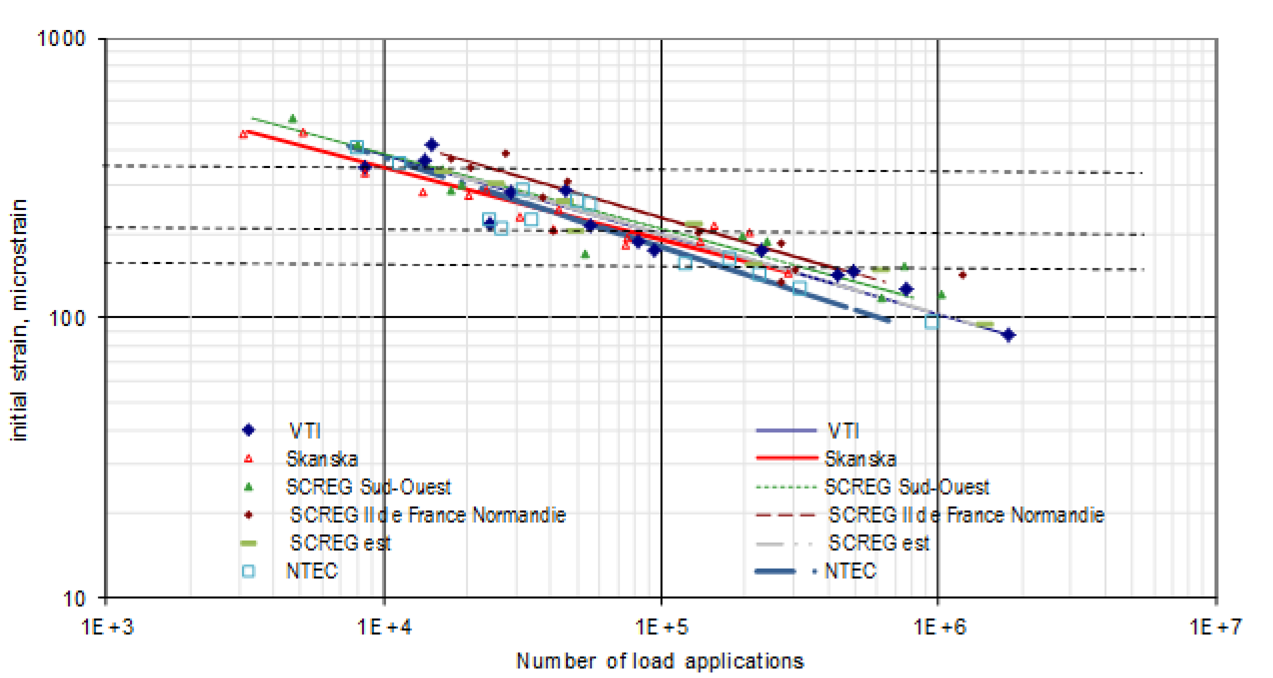

Figure 6: Fatigue relationships of asphalt mix AG16.

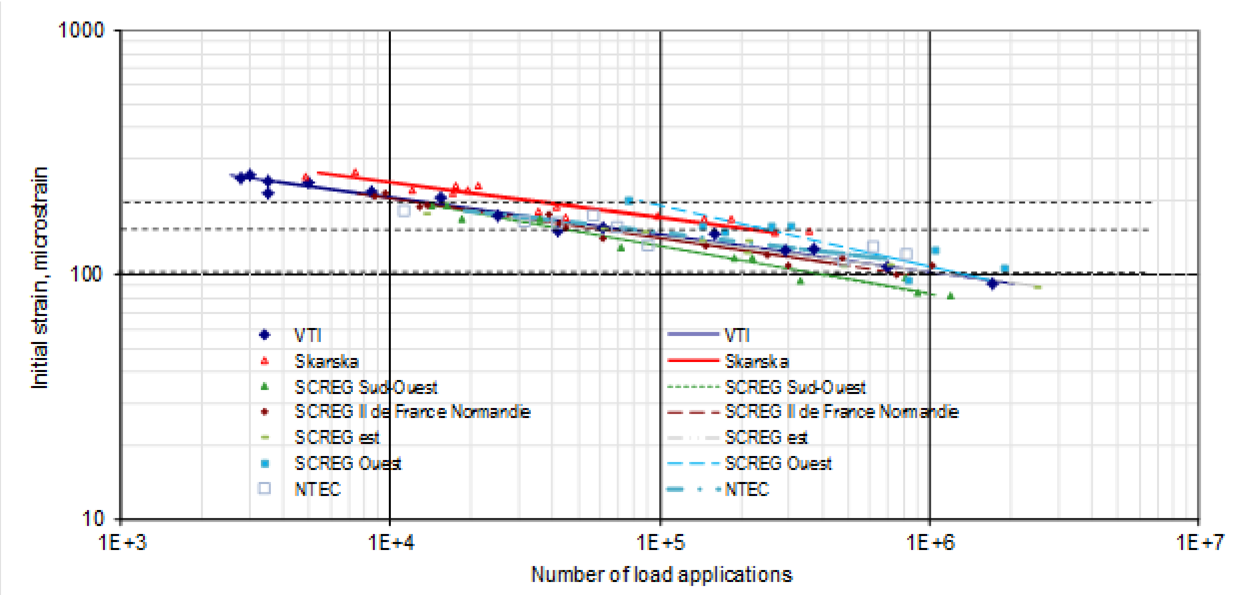

Figure 7: Fatigue relationships of asphalt mix EME14.

Table 2: Regression coefficients of fatigue relationship and within-laboratory variance of mix AG16

Laboratory	Number of specimens	n (slope)	K (intercept)	Coefficient of determination (R^2)	Within-laboratory variance (*MSE*)
SCREG Il de France Normandie	17	3.48	1.57E+13	0.91	0.063
SCREG Sud-Ouest	11	3.72	4.08E+13	0.90	0.083
SCREG Est	14	3.51	1.20E+13	0.85	0.057
VTI	14	3.50	1.14E+13	0.90	0.055
Skanska	15	3.86	6.41E+13	0.88	0.046
NTEC	15	3.13	1.15E+12	0.90	0.035

Table 3: Regression coefficients of fatigue relationship and within-laboratory variance of mix EME14

Laboratory	Number of specimens	n (slope)	K (intercept)	Coefficient of determination (R^2)	Within-laboratory variance (*MSE*)
SCREG Il de France Normandie	14	6.14	1.60E+18	0.95	0.027
SCREG Sud-Ouest	11	5.13	7.15E+15	0.96	0.021
SCREG Est	9	6.83	5.47E+19	0.95	0.023
VTI	15	6.56	1.54E+19	0.97	0.026
Skanska	15	6.89	2.41E+20	0.90	0.034
NTEC	9	7.85	1.14E+22	0.83	0.080
SCREG Ouest	8	4.03	1.60E+14	0.79	0.056

Table 4: Repeatability and reproducibility standard deviations at the three strain levels for mix AG16

Statistical parameter	Initial strain levels in microstrain		
	350	200	150
Repeatability standard deviation, s_r	0.238	0.238	0.238
Between-laboratory standard deviation, s_L	0.066	0.099	0.098
Reproducibility standard deviation, s_R	0.247	0.258	0.257

Table 5: Repeatability and reproducibility standard deviations at the three strain levels for mix EME14

Statistical parameter	Initial strain levels in microstrain		
	200	150	100
Repeatability standard deviation, s_r	0.196	0.196	0.196
Between-laboratory standard deviation, s_L	0.336	0.275	0.285
Reproducibility standard deviation, s_R	0.389	0.338	0.346

CONCLUSIONS

This interlaboratory experiment assessed the performance of a laboratory using EN 12697-24, Annex E, with respect to the participant laboratories. The repeatability standard deviations of the test, depending on mixture type, were 0.196 and 0.239, which refer to the logarithm of the number of load applications. The largest value of reproducibility standard deviation is 0.389, which is probably related to several laboratories testing only a limited number of specimens. This indicates reasonableness of the repeatability and reproducibility values compared to ISO standard 5725-1. Based on the statistical analysis of this experiment, it is concluded that the indirect tensile fatigue test for asphalt mixtures is efficient in characterising asphalt mixtures and deemed to be adequate in routine use.

It must be emphasised that this experiment is limited with regards to the number of participant laboratories, mixtures and number of specimens tested. In addition, some variety in testing apparatus has also been identified in this work. The precision statements must consequently be interpreted with caution. Further investigation would be valuable in order to verify the reported precision which might result in improvement of the test's accuracy.

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