Assessment of Fatigue Characteristics of Cold Recycling Mixes by Different Test Methods

J. Valentin, P. Mondschein, M. Macko
Department of Road Structures, Czech Technical University in Prague, Czech Republic

D. Stehlík
Department of Roads, Faculty of Civil Engineering, Brno University of Technology, Czech Republic

ABSTRACT: Fatigue testing of cold recycling mixes presents relatively complex and difficult issue. On the other hand fatigue characteristics feature besides the stiffness modulus one of the fundamental parameters for the multilayer pavement structure design according to the Czech technical specifications. During the last four years stiffness modules have been analyzed for various cold mixes with bituminous emulsion as well as with foamed bitumen. Ongoing research which has been done during last two years focused on the assessment of fatigue behaviour for similar batch of various cold recycling mixes with different combinations and contents of bituminous and hydraulic binders. Fatigue has been tested by repeated indirect tensile fatigue test at different temperatures and by four point beam by one temperature not in all aspects respecting the requirements given in the EN 12697-24 standard. The paper presents results reached for ITFT test, results of complex modulus measured by 4PB test and basic experience with fatigue testing of cold recycling mixes using 4PB test. In the paper recommendations for fatigue characteristics based on ITFT test method are outlined and recommended for use in the Czech pavement design method.

KEY WORDS: cold asphalt recycling, indirect tensile test, 4-point beam test, stiffness modulus, complex modulus.

1 INTRODUCTION

According to the findings from foreign sources, research of fatigue behaviour of cold recycling mixes has generally been conducted to a limited scope only. The reason behind this is primarily the unambiguousness resulting from heterogeneity of the type of mix which, according to the conclusions so far, causes relatively high variability of the results achieved. This fact has been confirmed by the findings obtained in the stiffness modulus testing (e.g. Valentin, 2009). In the recent years, experimental verification of fatigue characteristics was performed e.g. in Slovakia using trapezoidal test specimens (Schlosser 2007, Gillinger 2007). In contrast to that, Italy preferred the repeated indirect tensile fatigue test method (Santagata, 2009) which represents one of the methods assessed also within the framework of applied research at CTU in Prague.

Fatigue tests allow assessing the degree of susceptibility of the road surface structure to degrading; generally, from the experimental perspective it is possible to distinguish several test procedures according to the currently applicable European standard, EN 12697-24; the second and third methods are prioritised for asphalt mix testing at present:

- fatigue testing by repeated tensile stress on cylindrical specimens performed using a suitable asphalt tester,
- fatigue test of repeated stress with constant strain or permanent deformation carried out on trapezoid-shaped test specimens - two-point test,
- fatigue testing carried out applying the four-point beam method on a universal tester.

At present, all of the aforementioned three test methods can be applied and assessed in the Czech Republic; the most findings and measurement data are available for ITFT and 2P tests. In the past, design parameters for asphalt road surfaces have been specified based on the results of the testing.

2 FATIGUE BEHAVIOUR

The complex relation of stress to deformation of asphalt mixes, its dependence on the stress or strain value, load frequency and rise-time duration are the causes why fatigue life greatly depends on the method of fatigue testing. With respect to earlier experience with fatigue characteristic parameters determined experimentally by means of repeated tensile stress test under various temperatures, the test was finally chosen for cold recycling mixes as well. On the Nottingham Asphalt Tester device, fatigue testing is carried out applying the dynamic tensile stress test principle under repeated, constant load. With this method of fatigue testing, the test specimen is subject to a constant compressive force which causes tensile stress in the specimen; this has criticised by some expert’s conclusions and, therefore, the method is being replaced by the fatigue characteristics determination on four-point beam. With respect to the nature of cold recycling mixes which involves more difficulty in manufacturing the test specimens in the case of the four-point beam as they are more susceptible to destruction, the application of the method has been demonstrated as problem-laden. Nonetheless, experimental and practical comparisons have shown already in the past that, in the case of asphalt mixes, even the fatigue test with repeated indirect tensile test sorted the materials in the same way as the remaining, often more complex methods of fatigue testing.

The 4PB fatigue test involves specimens in the shape of beams to the dimensions of 50 x 50 x 400 mm which are subjected to a repeated bending in four points with free rotation and horizontal shift in all points of load as well as supports. The bending derives from the movement of the central load points in the vertical direction, perpendicularly to the longitudinal axis of the test specimen. The vertical position of both end points remains constant. The repeated displacement caused is symmetrical in both directions in relation to the zero position. At the same time, the sinus amplitude must be constant in time. The specimen is loaded with the selected stress with a frequency that may be chosen just like the strain to be reached during repeated cycles.

If the 4PB test is performed to determine the complex stiffness modulus first, the value of the force necessary to deform the specimen is then measured as a function of time; the same applies for the phase angle between the stress and strain signals. The stiffness modulus as such is then computed based on these variables.

The results of the fatigue test are the vertical deformation on the specimen up to its strain based on the number of load applications. As a standard, the values obtained are evaluated in the Wöhler diagram which shows the dependence of life (number of load applications) on the stress (horizontal strain). The dependence usually forms a straight line on a logarithmic scale; its slope is assumed to characterise the fatigue life of the asphalt mix quite well. The vertical axis of the diagram features the maximum value of the load in question, on a logarithmic scale, and the horizontal axis features the number of load cycles necessary for material failure (cracking). According to the practice common in the Czech Republic, in the case of indirect tensile fatigue testing the test must be performed with at least four stress levels to generate a Wöhler diagram. With respect to the nature of cold recycling mixes, it is recommended to perform the test with four different stress levels at least as well according to the experience so far. The diagram can also be shown as the dependence of the horizontal strain (ε) and the number of load cycles. The Wöhler diagram allows the subsequent determination and calculation of fatigue characteristics a, B and ε_6.

3 EXPERIMENTAL MIXES – DESIGN AND SPECIMEN PREPARATION

The results presented in this article are loosely connected to more than three years' of experimental research in the field of stiffness modulus of cold recycling mixes. Some results for selected mixes of this type have been presented e.g. in the paper (Valentin a Mondschein, 2009). Measurement of fatigue characteristics applying the repeated indirect tensile test on cylindrical specimens as well as basic fatigue behaviour research applying the 4PB method were conducted in relation to the stiffness modulus measurements. The tests were carried out using a universal asphalt tester under the temperatures of 27°C or 15°C. Moreover, it was necessary to identify the suitable stress frequencies for the 4-point beam test; so far, this constitutes rather a problem issue.

During the experiments, three laboratory sets of cold recycling mixes using bituminous emulsion and cement (23 mixes in total) and one set of foamed asphalt mix compositions (4 mixes in total) were prepared. The cold recycling mix sets with bituminous emulsion and cement were labelled REC_P, REC_V and REC_F. They differed from one another as to the content of individual elements. More detailed information on the composition of the mixes is available in the paper (Valentin and Mondschein, 2009), which also summarises the results of the stiffness modules obtained. The basic characteristics are given for the materials used, including a summary of the origin and some other related data. The basic characteristics of individual mixes are shown in tables 1 and 2. In the case of foamed asphalt mixes, the composition is also specified in the aforementioned article; table 3 summarises physical characteristics of the mixes.

Table 1: Cold recycling mix basic characteristics, binder – bituminous emulsion and cement.

Mix			**REC_P1**	**REC_P2**	**REC_P3**	**REC_P4**	**REC_P5**	**REC_P6**
RAP : additional aggregates ratio			100:0	80:20	70:30	100:0	80:20	70:30
Bitumen content	:	%-wt.	6.31	5.63	7.52	6.15	5.09	5.85
Voids content	:	%-vol.	16.3	13.9	11.1	17.4	17.3	14.0
Used RAP material			sorted RAP 0/11			sorted RAP 0/22		

Table 2: Cold recycling mix basic characteristics, binder – bituminous emulsion and cement.

Mix			**REC_V1**	**REC_V2**	**REC_V3**	**REC_V4**	**REC_V5**	**REC_V6**
RAP : additional aggregates : waste filler ratio			90:10:0	80:20:0	70:20:10	90:0:10	80:0:20	80:0:20
Bitumen content	:	%-wt.	5.90	6.33	6.33	6.18	5.89	5.64
Voids content	:	%-vol.	19.4	16.2	12.7	14.5	9.2	13.3
Used RAP material			sorted RAP 0/11					

Table 3: Foamed asphalt mix basic characteristics, binder – foamed bitumen and cement.

Mix			FC3	FF	FCF1	FCF2
RAP : waste filler ratio			100:0	80:20	80:20	90:10
Bitumen content	:	%-wt.	7,60	8,77	9,10	8,67
Cement content	:	%-wt.	3.0	-	2.0	2.0
Voids content	:	%-vol.	16,3	13,8	8,8	11,7
Used RAP material			sorted RAP 0/11			

Table 4a: Cold recycling mix basic characteristics, binder – bituminous emulsion and cement or waste filler.

Mix			REC_F1	REC_F2	REC_F3	REC_F4		
						I	II	III
RAP : waste filler ratio			100:0	100:0	90:10	100:0		
Cement content	:	%-wt.	-	-	-	-	-	3.0
Bituminous emulsion content	:	%-wt.	3.5	4.0	3.5	2.5	2.5	2.5
Waste filler (as binder)	:	%-wt	-	-	-	3.0	3.0	-
Voids content	:	%-vol.	9.6	9.1	8.5	6.5	6.3	6.2
Used RAP			sorted RAP 0/11					

Table 4b: Cold recycling mix basic characteristics, binder – bituminous emulsion and cement or waste filler.

Mix			REC_F5		REC_F6		REC_F7
			I	II	I	II	
RAP : waste filler ratio			100:0				
Cement content	:	%-wt.	-	3.0	-	2.0	2.0
Bituminous emulsion content	:	%-wt.	3.5	3.5	2.5	2.5	3.5
Waste filler (as binder)	:	%-wt	3.0	-	2.0	-	-

Test specimens for fatigue testing by repeated indirect tensile stress were made by means of an impact compactor applying 2x50 blows. To obtain test specimens for the 4-point test, plates of the dimensions of 400x300x50 mm were prepared using a segment pneumatic compactor according to CSN EN 12697-33 with subsequent cutting of the specimens to the dimensions as required.

4 EXPERIMENT AND RESULTS

The following part of the paper presents some results of the fatigue testing performed. Unfortunately, we failed to obtain a complete set of results for fatigue testing by the 4PB test method. The primary reason is the obvious effect of RAP heterogeneity which has prevented sufficient test reproducibility so far, and stimulated the fundamental consideration of suitability of the particular way of testing for certain mix types, particularly in cases where bituminous and hydraulic binders have been combined. Due to the aforementioned reason, at least the results of stiffness modulus determination by the 4-point beam test are presented.

4.1 Indirect tensile fatigue test (ITFT)

As has already been mentioned in the preceding chapter of the article, in contrast to the requirements of the applicable standard, EN 12697-24, fatigue characteristics were determined under temperatures of 27°C and 15°C. The reason behind the adjustment of thermal conditions of the test was the limited options of the asphalt testing device (from the point of view of maximum stress achievable) and the stiffness modulus values obtained for individual mixes under the aforementioned temperatures at the same time, particularly in the case of repeated tensile stress testing. Moreover, according to the previous experimental measurements, it may be assumed for traditional hot mix asphalts that the effect of a temperatures change, particularly if the test temperature of 15°C instead of 10°C is chosen, is negligible for cold recycling mixes.

Under the ITFT, at least 3 to 4 load levels were selected and tested in the stress range of 70-350 kPa for each of the mixes. For some mixes, the total height of the test specimen had to be reduced by cutting the specimen to approx. 40 mm, particularly to reach higher load levels due to the technical possibilities of the asphalt testing device at the CTU in Prague. A minimum of three specimens were tested for each stress level; the usual quantity tested was five specimens. The specimens were stressed by impulses of 120 ms. If the test specimen had not failed after 10.000 load pulses, the test was interrupted; the value was listed as the threshold load cycle number for the load and test specimen in question. All of the measurements obtained for a specific mix were subsequently used to generate Wöhler curves and derive fatigue characteristics with the application both according to the previously applied national standard ČSN 73 6160 and according to the currently applicable standard EN 12697-24. The results are summarised in the following tables.

Table 5: Fatigue characteristics of cold recycling mixes with bituminous emulsion and cement, test temperature 27°C.

Mix	**Fatigue characteristics calculated according to previous CSN 73 6160**			**Fatigue characteristics calculated according to EN 12697-24**		
	a	**B**	**ε_6 (x10^6)**	**a**	**B**	**ε_6 (x10^6)**
REC_P1	3.338	7.067	0.0651	3.334	6.978	0.0640
REC_P2	3.362	5.992	0.0433	3.031	3.574	0.0195
REC_P3	3.187	5.403	0.0504	2.718	3.097	0.0224
REC_P4	3.665	10.132	0.0553	3.596	6.712	0.0324
REC_P5	3.693	8.313	0.0385	3.623	6.906	0.0322
REC_P6	3.723	15.552	0.0779	3.721	15.556	0.0781
OKH I	**1.806**	**3.448**	**0.0329**	**1.969**	**3.308**	**0.0302**

From the point of view of the fatigue test results as summarised in tables 4-6 and in the selected examples of Wöhler diagrams, the values of fatigue characteristics were compared to the mix which has previously been tested experimentally and labelled, according to the technical standards previously applied OKH I - which corresponds to today's AC mix for sub-base layers (Novotný and Luxemburk, 2005). The mix was chosen with respect to its closeness to the cold recycling asphalt mixes tested. In this context, the values for the OKH-type of mix can also be compared to the requirements of TP 170 which determines the minimum value required as 5.0 for B-parameter fatigue characteristic and the minimum value required as 0.115 for the strain ε_6 (x10^6) under test temperature of 10°C. When interpreting the results, it applies that a mix with higher parameters of B-parameter, ε_6 and lower values of the a-parameter are of better quality. In this context, it should be pointed out that B-parameter may not be confused with the angular coefficient of the tangent to the Wöhler curve as B-parameter stands for the reciprocal value of such angular coefficient. As is obvious from the values summarised in table 5, it is impossible to make an unambiguous conclusion on fatigue behaviour of cold recycling mixes because the comparison of three related mixes which differ in the proportion of fine aggregate additions did not achieve an increase of B-parameter together with an increase of ε_6 in any of the cases. As concerns a-parameter, it is obvious that almost no change is obtained for mixes with identical RAP, with the exception of the REC_P3 mix. A more significant difference can be observed in the case of the calculation of fatigue characteristics according to EN 12697-24. It is obvious for mixes assessed both according to the original and according to the currently applicable technical standard that if B-parameter decreases, the remaining two parameters usually decrease as well. With respect to the trend observed when comparing individual mixes according to B-parameter or ε_6 it is possible to assume a positive effect of the partial substitution of reclaimed material by fine aggregate. From the point of the characteristics given, the results suggest a trend which has also been observed in the stiffness modules values. However, the trend for the strain value, $\varepsilon_{6,}$ is not unambiguous. Upon comparison of REC_P4 mix with REC_P6 mix, the situation is rather positive from the perspective of interpretation. The value of the strain calculated or of ε_6 increases with the increasing B-parameter; again, this confirms the belief that a partial substitution of reclaimed material with fine aggregate results in fatigue characteristic improvement. It is also confirmed that the benefit might be more significant in mixes with coarser RAP. However, further measurements are necessary to confirm the above.

The correlation coefficients for regression curves from which parameters a, B are derived are rather high; therefore, the selected curves may be considered suitably chosen from the statistical perspective. If cold recycling mixes are compared to the OKH I mix the asphalt mix is of better quality according to a-parameter while the cold recycling mixes reach more favourable results when the remaining parameters are assessed.

Similar findings were obtained in the case of mixes in the REC_V set which were tested at 15°C. Measurements were reproduced on new test specimens for some mixes in the set (REC_V4a – REC_V6a) in order to verify reproducibility of measurement for various cold recycling mixes of identical composition. Again, a certain illogical aspect in some results has been demonstrated. In the case of REC_V1 – REC_V3 mixes where the reclaimed material was partially substituted by fine aggregate, fatigue parameters a, B increase with the quantity of fine aggregate added. In contrast to that, a contrasting trend is observed for parameter ε_6. In the case of REC_V4 – REC_V6 mixes, a different situation can be noticed. The values of a remain almost unchanged; there is a significant increase in B depending on the degree of partial substitution of reclaimed material by waste filler and the quantities of cement used. The same trend is obvious also in the characteristic ε_6. To a limited degree, mixes in the REC_V set can be compared to the basic REC_P1 mix (without substitution by fine aggregate or waste filler) despite the fact that the mix was only tested for fatigue under the temperature of 27°C.

Table 6: Fatigue characteristics of cold recycling mixes, binder – bituminous emulsion and cement, testing temperature 15°C.

Mix	**Fatigue characteristics calculated according to previous CSN 73 6160**			**Fatigue characteristics calculated according to EN 12697-24**		
	a	**B**	**ε_6 (x10^6)**	**a**	**B**	**ε_6 (x10^6)**
REC_V1	3.470	12.642	0.1137	3.228	4.929	0.0359
REC_V2	3.628	13.812	0.0866	3.560	9.862	0.0679
REC_V3	4.128	31.153	0.0478	4.387	-17.302	0.0911
REC_V4	3.923	5.777	0.0106	3.916	5.565	0.0101
REC_V5	4.002	37.175	0.0686	3.987	31.095	0.0660
REC_V6	3.854	14.577	0.0542	3.854	14.060	0.0525
REC_V4a	4.110	14.815	0,0305	4.089	11.033	0.0234
REC_V5a	3.987	24.753	0.0589	3.899	17.013	0.0560
REC_V6a	3.858	14.881	0.0549	3.818	14.303	0.0579

In our opinion, the aforementioned general ambiguity of the results is greatly affected by the heterogeneity of the reclaimed asphalt pavement material; this problem has practically no solution for this type of mixes, particularly if the technology of recycling in situ is applied. The results of mix REC_P6 are affected by the fact that the test was only performed under the insufficient quantity of two stress values due to the limited number of test specimens (partly destroyed before testing). Although this means that the correlation coefficient of the regression (fatigue) line in the Wöhler diagram equals one, in comparison to REC_P4 and REC_P5 mixes the results significantly differs from the expected trend. The correlation coefficients for regression curves based on which parameters a, B have been derived are quite high with the exception of mixes REC_P2, REC_P3 and REC_V1; therefore, the curves can be considered well chosen from the perspective of statistics. In the case of mix REC_P6, this is only true to a certain degree due to the aforementioned reason. In the remaining cases, the lower value of some mixes within the range of 0.55 to 0.65 is primarily determined by the quantity of specimens tested under the individual stress levels where a lower number of repeated measurements performed usually give a higher variability. Therefore, it can be expected that if five and more test specimens are tested for each stress level as chosen, the results will be more exact; this is rather significant for this type of mixes. It appears desirable to perform measurements under at least five different stress levels.

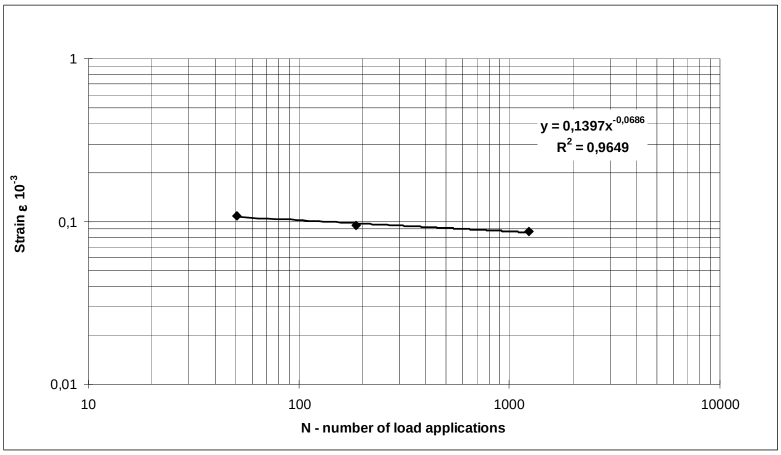

Figure 1: Wöhler diagram, REC_V6 mix @ 15°C

Table 7: Fatigue characteristics of cold recycling mixes, binder – foamed bitumen and cement, testing temperature 15°C.

Mix	**Fatigue characteristics calculated according to previous CSN 73 6160**			**Fatigue characteristics calculated according to EN 12697-24**		
	a	**B**	**ε_6 (x10^3)**	**a**	**B**	**ε_6 (x10^3)**
FC	3.212	4.602	0.0305	3.124	3.810	0.0200
FF	3.231	5.777	0.0538	3.185	5.063	0.0426
FCF1	3.683	8.475	0.0414	3.571	6.480	0.0255
FCF2	3.668	13.889	0.0794	3.435	6.810	0.0484

The last set of mixes for which fatigue characteristics were experimentally determined by ITFT consists of optimised foamed asphalt mixes. The results of fatigue testing performed for foamed asphalt mixes are summarised in table 7. Even this kind of cold recycling mix demonstrates that parameter B increases together with parameter a and strain ε_6 depending on improved mix composition in all cases. Upon a closer comparison of individual parameters, the effect of heterogeneity of the input material is obvious again; this results in certain, less logical trends amongst individual mixes. However, the effect of a partial substitution of reclaimed material with waste filler is very obvious. In this context, if mixes with different bituminous binder (foamed bitumen and bituminous emulsion) are compared from this perspective, the better effect of the bituminous emulsion is likely from the point of view of parameter B as well as strain ε_6. When comparing the optimised foamed asphalt mixes to the basic REC_P1 mix, improved fatigue behaviour is demonstrated particularly in the case of FCF1 and FCF2 mixes.

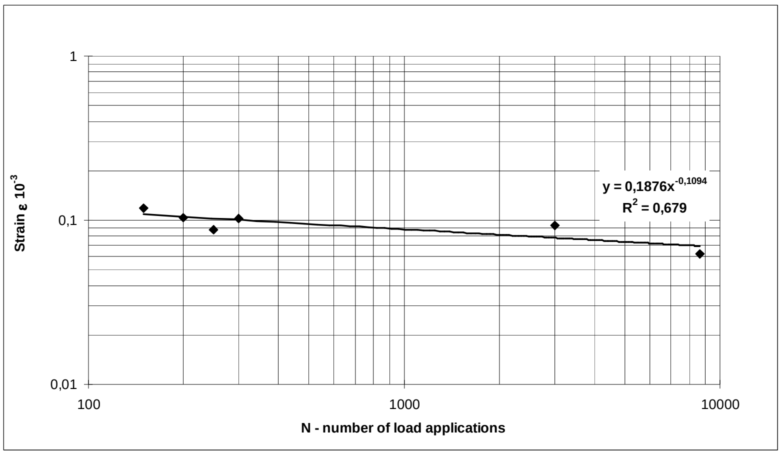

Figure 2: Wöhler diagram, FCF1 mix @ 15°C

4.2 Stiffness Modulus Determination by Means of 4PB Testing

The measurement was carried out in the perpendicular direction to the compaction of the beam specimens. The stress frequency, strain and temperature were selected similar to ČSN EN 12697-26 values for asphalt mixes. The reason for this choice was both the closeness of cold recycling mixes and the need for future comparability of fatigue characteristics of cold recycling mixes to the traditional asphalt mix. Generally, no standard requirements are currently available for fatigue testing parameters of cold recycling mixes; at the same time, the aforementioned standard does not explicitly address the issues of this sort of mix.
The test recorded the force F_0, deflection z_0, phase angle φ as well as the temperature and frequencies selected for the test. The complex stiffness modulus of the test specimen was determined as the modulus corresponding with the relevant load between the 45^{th} and 100^{th} repetition of the load. The stiffness modulus was finally determined as the average of values obtained for at least two test specimens. In the case of the measurements performed, an effort was made to use four test specimens on average; however, some specimens were destroyed as soon as test beams were made and then during the subsequent storing.

The measurements were carried out only under the temperature of 15°C. When the test specimen measurements commenced the displacement at the start of loading was selected to be 100 microstrain; however, due to the destruction of several test specimens the displacement was gradually reduced to the value of 50 microstrain. Measurements were made on each specimen with three different frequencies – 10 Hz, 20 Hz and 30 Hz; the measurements were then captured in the resulting curve of measurement frequency relation to the stiffness modulus determined. In contrast to standard methods applied to asphalt mixes when observing the stiffness modulus (NCHRP, 2002 or Clyne et al., 2003), measurements were not performed for the entire temperature range and frequencies <10 Hz.

The average values measured are given in the following tables 8-10. As is obvious from the results obtained, higher proportions of waste filler in the cold recycling mix (REC_V5a and REC_V6a) bring about a minimum the stiffness modulus modification depending on the stress frequency. In comparison to the stiffness modulus results obtained from the repeated indirect tensile stress test (Valentin, 2009); the values of the modulus are 25-40 % lower when the 4PB test is applied. In the case of results shown in tables 9 and 10, the trend of stiffness modulus value decrease with the decreasing stress frequency is obvious. The values of certain mixes where the hydraulic binder (cement) was replaced by waste filler are interesting. In those cases, the test method demonstrates that the waste filler have a more advantageous effect than cement; under standard circumstances and according to the results presented in (Valentin, 2009) this is not the expected trend. It will be necessary to reproduce the measurements; if the data measured is confirmed, this might open the debate on suitability of applying this method of stiffness modulus determination for cold recycling mixes, particularly if bituminous and hydraulic binders are combined therein.

Table 8: Complex stiffness modulus of cold recycling mixes, T=15°C.

Frequency	**Mix**		
	REC_V4a (MPa)	**REC_V5a** (MPa)	**REC_V6a** (MPa)
30 Hz	4,470	4,080	3,590
20 Hz	4,520	4,190	3,690
10 Hz	4,260	4,130	3,540

Table 9: Complex stiffness modulus of cold recycling mixes, T=15°C (comparison of waste filler and cement impact).

Frequency	**Mix**					
	REC_F1 (MPa)	**REC_F2 (MPa)**	**REC_F3 (MPa)**	**REC_F4 (MPa)**		
				I	II	III
30 Hz	2,370	3,510	940	2,050	2,290	1,070
20 Hz	2,160	2,720	670	1,770	1,970	540
10 Hz	1,800	2,230	550	1,500	1,720	380

Table 10: Complex stiffness modulus of cold recycling mixes, T=15°C (comparison of waste filler and cement impact).

Frequency	**Mix**				
	REC_F5 (MPa)		**REC_F6 (MPa)**		**REC_F7 (MPa)**
	I	**II**	**I**	**II**	
30 Hz	1,920	1,680	2,140	720	2,310
20 Hz	1,730	1,280	1,810	400	1,770
10 Hz	1,480	970	1,560	-	1,460

4.3 Four-point-beam fatigue test

The results of fatigue characteristic determination applying the 4-point beam test will not be presented in this paper due to the fact that no consistent sets of data demonstrating sufficient degree of experiment reproducibility have been obtained from the measurements carried out so far on mixes identical to those in the case of complex stiffness modulus measurements. As ensues from the findings so far, with a fine-tuning of input parameter settings the 4-PB test is applicable to cold recycling mixes with bituminous binder only. In this case, the mix has similar viscous-elastic behaviour to the traditional asphalt mixes and the course of stress and strain has the usual sinusoid shape. Mixes combining bituminous and hydraulic binders have demonstrated a number of anomalies during the measurements of the load cycle number dependence on the deformation and measurement reproducibility so far. These mixes also demonstrate an increased level of rigid material characteristics which will probably result in this type of fatigue test being unsuitable.

5 CONCLUSIONS

Based on the results of the fatigue testing by ITFT it is possible to specify preliminary values of fatigue parameters used by the pavement design methodology in Czech Republic. If the design parameters for cold recycling mixes should be added to the technical conditions of TP170 it can be recommended, based on the results obtained and verified so far, that the strain ε_6 (x10^6) threshold (minimum) value of 0.050 – 0.060 be applied to mixes with bituminous emulsion and the value of 0.030 – 0.040 to mixes with foamed bitumen for the design temperature of 15°C. In the case of fatigue parameter B, the value of 8 should be required for mixes with bitumen emulsion and 4 for foamed bitumen mixes. Both parameters can be further improved similarly to the values of stiffness modules by substituting partly RAP by waste filler.

However, the significant fact is that the scope of measurements so far does not allow any binding determination of proposed threshold values. Performed measurements repeatedly refer to the problem of cold recycling mix heterogeneity. In case of preliminary assessed 4PB test method the likely unsuitability of this method for some types of cold recycling mixes appeared. On the other hand concurrently performed stiffness modulus measurements by 4PB test procedure indicated the need for execution of comparison measuring of this method and more frequent non-destructive indirect tensile stress test. In the connection with the realization of respective comparative tests it will be however necessary to take into consideration the labour input during the preparation of testing specimens for modulus assessment as well as fatigue testing.

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