Test Methods

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Experimental testing and assessment of stiffness modulus and fatigue of various cold recycling mixes

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Summary

Cold recycling in pavement rehabilitation and new construction records growing utilization and forms a part of sustainability strategies in road engineering. Usually reclaimed asphalt pavement (RAP) is used for mixes where bitumen emulsion or bitumen foam is used together with suitable hydraulic binders. Besides RAP there are possibilities of part substitution by secondary or waste materials from quarries.

From the technical point of view, these mixes have to be tested by traditional and more advanced testing methods explaining performance behavior of these mixes. The performance and related characteristics can be in best manner described and assessed by rheologic properties. During the experimental work the focus concentrated especially on measurement of stiffness modules at different temperatures (5°C, 15°C, 27°C) representing different pavement conditions during the year and fatigue tests for different stress conditions. Results and their comparison for different mixes are be presented and discussed in the paper.

KEYWORDS: cold asphalt recycling, bitumen emulsion, stiffness modulus, fatigue, Nottingham Asphalt Tester.

1. INTRODUCTION

In a number of contributions and specialist articles, it is possible to notice the attention paid by the road construction community to the implementation and further optimization of recycling technology. Primarily, cold technologies have experienced relatively great development in the Czech Republic and Slovakia since, besides the benefits of waste and recyclable material processing, other advantages are said to be the lower energy demands and protection against

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excessive greenhouse gas emissions. This trend, championed also by e.g. the EAPA (European Asphalt Pavement Association), is undoubtedly desirable since it activates a certain degree of road construction self-sufficiency as well as an ability to implement the principles of sustainable and ecologically acceptable construction. On the other hand, the trend has its pitfalls, which primarily include the still limited knowledge of the functional behavior of such mixes and the subsequent degree of uncertainty as to whether such cold mixes are utilized as efficiently as they could be in construction and whether the design and useful behavior of the entire road structure is optimized.

The key parameters in this context and the assumed contributors towards the utilization of such mixes in road structures can certainly be identified as stiffness (expressed by the relevant stiffness modulus) and fatigue characteristics, each of which should assist in predicting the durability of such structures. Due to the considerable heterogeneity of such mixes, even though the reclaimed material is sorted, it is impossible to ensure a homogenous quality when milling multiple surface layers, therefore determining the parameters is not the easiest of tasks. It is further complicated by the availability of several methods that can be utilized, particularly in the event of monitoring fatigue characteristics. This contribution is an attempt to depict the rheological behavior of cold mixes, into which emulsified asphalt and cement have been applied.

2. TEST MIX PREPARATION

The selection of mix composition and the method of preparing test samples, including their subsequent curing, have an undisputable effect on the results in the characteristics examined. This fact is even more significant in the case of rheological qualities where a certain characteristic is always examined in relation to another variable.

Two sets of lab-designed mixes have been selected for this contribution while, in the case of fatigue characteristics, comprehensive results could only be compiled for the first set. The test mix set was produced at the Geotechnical and Transport Construction Department at the Technical University in Košice. Out of the total number of 8 mixes, two mixes were selected for the experiments as described below. The mixes were characterized by differing proportions of reclaimed material and ground aggregate as well as by the quantity of emulsified asphalt and cement added. The composition of the mixes is specified in Table 1a, b, where the mixes are designated as AE1 and AE2.

The mixes were designed to conform with the Slovak technical standard STN 73 6121 in accordance with their expected use in the base layer. Cationic Emultech P bitumen emulsion and blast furnace Portland cement II/B-S 32.5 R were used in their production. The basic components involved were sorted reclaimed material 0-16 and grading 0-2 limestone. To increase the proportion of fine particles, rock (limestone) powder was added to one of the mixes. To determine the stiffness modulus and fatigue characteristics, test slabs were made using static pressure of 75 kN. Marshall specimens were prepared at the same time.

The other group of mixes, for which only stiffness modulus values have so far been determined, has been produced by the Road Construction Department laboratory at the Czech Technical University in Prague. Seven mixes were designed; recyclable material of grade 0-11 was used to produce mixes EC1-EC 5 while mixes EC8 and EC9 contained sorted recyclable material of grading 0-22. In the case of selected mixes, a proportion of fine aggregate 0-2 was designed, which is classified by the producer as a material difficult to utilize (melaphyre, Košťálov quarry). To produce laboratory mixes EC8 and EC9, similarly to the Košice mixes, cationic bitumen emulsion, Emultech P, was used; bitumen emulsion Vialit RE60 was applied to the remaining mixes. Blast furnace Portland cement 32.5 R was used as the hydraulic binder for all mixes. In the case of two mixes, a part of the cement component was replaced by residual filler from aggregate production, which represents another recycled material that is currently verified as a potential component for cold recycling mixes.

Table 1a: Cold recycling mix composition with reclaimed asphalt material (RAP) and bitumen emulsion.

Mix			EC1	EC2	EC3	EC4	EC5
Binder			bitumen emulsion + cement				
RAP : additional aggregate ratio			100:0	80:20	70:30	100:0	100:0
Bitumen emulsion content	:	%-b.m.	2.5	2.5	2.5	2.5	2.5
H2O content	:	%-b.m.	5.1	5.1	5.1	5.1	5.1
Cement kontent	:	%-b.m.	3.0	3.0	3.0	2.75	1.5
Residua filler	:	%-b.m.	-	-	-	0.75	1.5

Table 1b: Cold recycling mix composition with reclaimed asphalt material (RAP) and bitumen emulsion.

Mix			AE1	AE2	EC8	EC9
Binder			bitumen emulsion + cement			
RAP : additional aggregate ratio			75:25	60:40	100:0	100:0
Bitumen emulsion content	:	%-hm.	3.5	3.0	2.2	3.5
H2O content	:	%-hm.	n.a.	n.a.	3.4	2.5
Cement kontent	:	%-hm.	1.5	3.0	2.0	2.0
Residua filler	:	%-hm.	6.0	-	-	-

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Test samples of mixes produced at CTU in Prague were prepared using the Marshall test compaction, applying 2x50 blows despite the fact that, in accordance with the applicable Czech technical conditions (TP112, TP126 or TP162), the preferred treatment tends to use the static pressure method. As additional information, we can state that last year basic measurements were carried out on samples made on a Superpave Gyratory Compactor while the objective for the near future is to compare all methods.

Subsequently, test samples of both sets were cured for 28 days under laboratory conditions followed by stiffness modulus determination and fatigue testing. In the case of several mixes, the measurements were performed 9 months after the test samples were made; at this time a minimum increase of strength characteristics due to cement hydration and curing of the specimens can be expected.

3. DETERMINATION OF STIFFNESS MODULUS AND FATIGUE CHARACTERISTICS

2.1. General

The stiffness modulus was determined using the Nottingham Asphalt Tester (NAT) developed at the end of 1980's at Nottingham University (Cooper & Brown) with the objective of facilitating routine testing for rheological characteristics of asphalt mixes. This type of test device is primarily utilized in cases where standard methods such as the Marshall test have provided insufficient qualitative evidence and cannot deliver a qualified assessment of the relevant asphalt mix. As has been previously stated (e.g. [1]), the NAT allows monitoring of the following rheological characteristics of the material in a broad range of temperatures (-10 °C to +40 °C):

- stiffness modulus determined by means of repetitive transverse tension test,
- resistance against permanent deformation by means of repetitive axial load test,
- resistance against permanent deformation by means of dynamic asphalt mix curing test,
- resistance against permanent deformation by means of static asphalt mix curing test,
- resistance against repetitive load (fatigue) by means of a transverse tension test.

An advantage of the device is the possibility of using common test specimens as well as road samples, both of which are adapted to a 100 mm diameter. The tester consists of a testing frame, pneumatic unit (units with an hydraulic mechanism are an alternative option), control unit, temperature chamber and a PC with the evaluation software.

2.2. Stiffness Modulus

The asphalt mix stiffness modulus is an important deformation characteristic that, along with the Poisson number, is used in road structure design. The stiffness modulus is defined as the ratio of tension and relative deformation under a certain temperature that has a specific Poisson number value, and characterizes the material in its ability to resist the effects of load. The ability to transfer higher load effects increases with increasing stiffness modulus values.

Stiffness modulus values are determined based on the repetitive transverse tension test, which is usually carried out on Marshall specimens. Direct pressure load transferred in the vertical section plane of the sample results in transverse tension perpendicular to the load direction. During the test, LVDT sensors measure horizontal deformation. Stiffness modulus measurements are usually taken at temperatures of 15°C to 40°C. In the case of cold recycling mixes, temperatures of 5°C, 15°C and 27°C were selected. The load affecting the specimen cannot be influenced directly and, therefore, only the values of the assumed resulting horizontal deformation changes can reduce or increase the value of the load in action. The maximum required horizontal deformation is usually selected from the interval of 5-10 microns. The test yields the asphalt mix stiffness modulus calculated from the average of five measurements taken.

2.3. Fatigue

Fatigue tests are generally divided into several groups:

- performed on test specimens in the shape of a truncated wedge (trapezoid) under constant tension or with a permanent deformation,
- performed by means of the NAT device through a test of repetitive transverse tension loads on Marshall specimens,
- performed using the four-point beam method.

The NAT device allows the performance of the fatigue test using the dynamic transverse tension test when a repetitive constant tension is applied. This method of fatigue testing utilizes a permanent pressure force that affects the test specimen and generates tension, which is criticized by a number of experts; therefore, this method is being replaced in the harmonized European standard by the four-point beam method. However, it has been proven in practice that, even in the case of fatigue testing by transverse tension under repetitive tension, if the fatigue testing method is consistent for all samples, the results for tested materials end up in a sequence identical to that evidenced by, often, more difficult methods of fatigue testing.

Based on the fatigue test results the resistance of the mix tested against the effects of repetitive tension is formulated. The test simulates tension generated in the road structure layers by a dynamic load. The basic principle of the test is the generation of a repetitive movement of pressure load in the vertical section plane of the sample, which generates repetitive tension load in the transverse direction perpendicular to the direction of the load effect (Fig. 1).

This test measures the vertical deformation of the sample up to the breaking (cracking) point. Rupture is manifested by the occurrence of cracks in the vertical direction of the specimen section, which can lead to the breaking of the specimens made with brittle materials. The vertical deformation of the specimen is measured by LVDT sensors with a linear range of up to 10 mm.

The result of the fatigue test is the development of vertical deformation of the specimen until the breaking point, depending on the number of load cycles. The values obtained are evaluated in the Wöhler diagram, which depicts the dependence of the load effects upon life of the material. This dependency usually represents a straight line in a logarithmic scale and it is assumed that its incline is a good expression of the fatigue life of asphalt mixes. The vertical axis of the diagram covers the maximum value of the relevant load in the logarithmic scale while the horizontal axis covers the number of load cycles necessary to rupture the test specimen. To generate a Wöhler diagram, it is necessary to perform the test under at least three different tension levels.

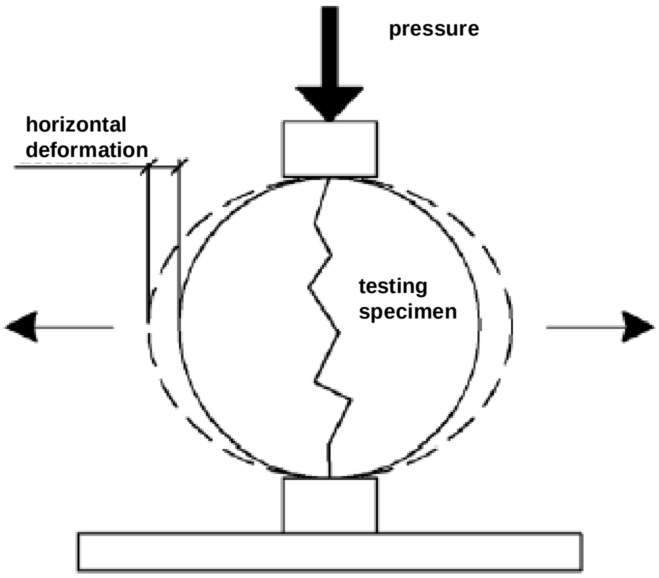

Figure 1: Description of the fatigue test method with repetitive transverse tension loads.

When using the NAT device, fatigue testing is usually carried out under temperatures of 15°C to 40°C which does not fully cover the admissible conditions

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as stipulated in the present EN, which requires fatigue characteristics assessment under lower temperatures as well. With respect to the fact that the testing procedure of determining fatigue characteristics for cold recycling mixes has not been used in the Czech Republic, this partial disagreement can be considered insignificant. Moreover, with better quality mixes the device, installed in the Civil Engineering Faculty of the CTU, only facilitated testing under lower temperatures with difficulties. The power source of the NAT device is weak and does not always allow proper deterioration of the asphalt mix at the required level of tension (or the resulting deformation). Due to these reasons, a comparative measurement has been taken in the past, which proved the relatively negligible effect of temperature in the Wöhler diagram evaluation (log ε versus log N). The conclusions were obtained by measurements performed with truncated wedge specimens in the sense of Czech technical standard ČSN 73 6160. The comparative measurement was performed for the ABS I mix. Five specimens were tested under 40°C, three specimens under 15°C.

The result of the fatigue test acquired by use of the NAT, which represents input for the determination of standard fatigue parameter values, is depicted in Fig. 2. The figure describes the logarithmic dependence between the vertical deformation level ε and the number of load repetitions until rupture, N.

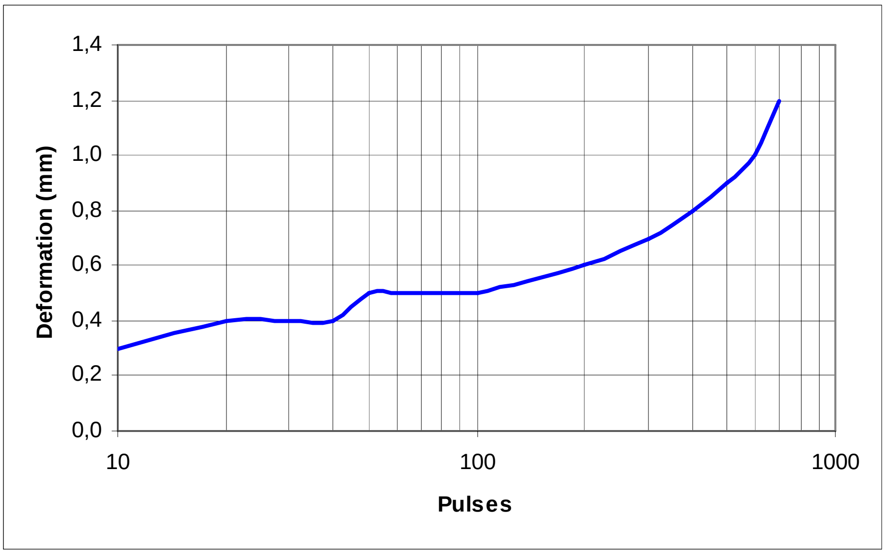

Figure 2: Result of fatigue test on NAT apparatus.

The evaluation determines the fatigue characteristics based on the Wöhler diagram and on the following equations in which N stands for the number of load cycles until rupture of the specimen and $\varepsilon_{0,j}$ represents the maximum amplitude of the relative deformation under test conditions (j) at the beginning of the measurement, while ε_6 is the average deformation size derived from the fatigue curve with 10^6 load cycles, expressed in 10^{-6} µm/m.

$$\log\varepsilon_{0j} = \log\alpha - 3 + \beta \log N \tag{1}$$

which corresponds with

$$\varepsilon 10^3 = \alpha N^{\beta} \tag{2}$$

The fatigue relation according to the applicable methodology is expressed as

$$\log\varepsilon = -a - B^{-1} \log N \tag{3}$$

and, therefore, the fatigue parameters of laboratory tests α and β are related to the design method fatigue parameters by relations, [5]:

$$\log\alpha + a = 3 \quad \text{and} \quad B = -1/\beta \tag{4}$$

which means that

$$\log\varepsilon_{0j} = \mathrm{a}_{\mathrm{j}} + B \cdot \log N \quad \text{or} \quad \varepsilon 10^{-3} = A \cdot N^{-B} \tag{5}$$

3. RESULTS, DISCUSSION AND SUMMARY

The results of stiffness modulus determination for temperatures of 5°C, 15°C and 27°C with the corresponding Poisson numbers (0.25; 0.33 and 0.39) are listed in the following figures, 3-5. The test was performed on at least three test specimens for each temperature. Mixes EC1, EC3 and EC4 were subject to non-destructive repetitive transverse tension load test after 28 days of curing and the results led to the following conclusions:

- the positive impact of the proportion of fine aggregate (which is obvious also in the case of the fatigue test, according to the partial results so far),
- the negative impact of substituting a part of the cement component with residual filler.

The first conclusion may be explained by the increased proportion of finer particles, despite the fact that sorted reclaimed material of 0-11 grade was used for those mixes. The other finding should not be to the detriment of using residual filler. On the contrary, mixes where a part of the reclaimed material is substituted by residual dust and the proportion of cement has remained constant should be the subject of further examination, along with the behavior of mixes in cases when the proportion of cement is slightly decreased and the proportion of residual filler exceeds at least 5%-by mass of the mix. The considerably broad range of stiffness modulus values (e.g. for 15°C it amounts to 1,800-6,000 MPa) is rather surprising.

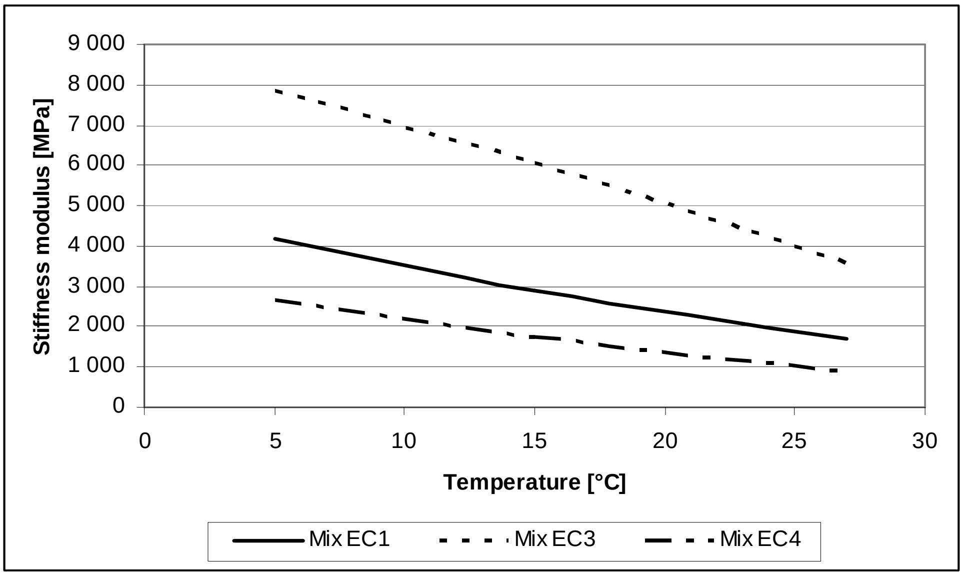

Figure 3: Stiffness modules of mixes EC1, EC3 and EC4 at 5°C, 15°C and 27°C.

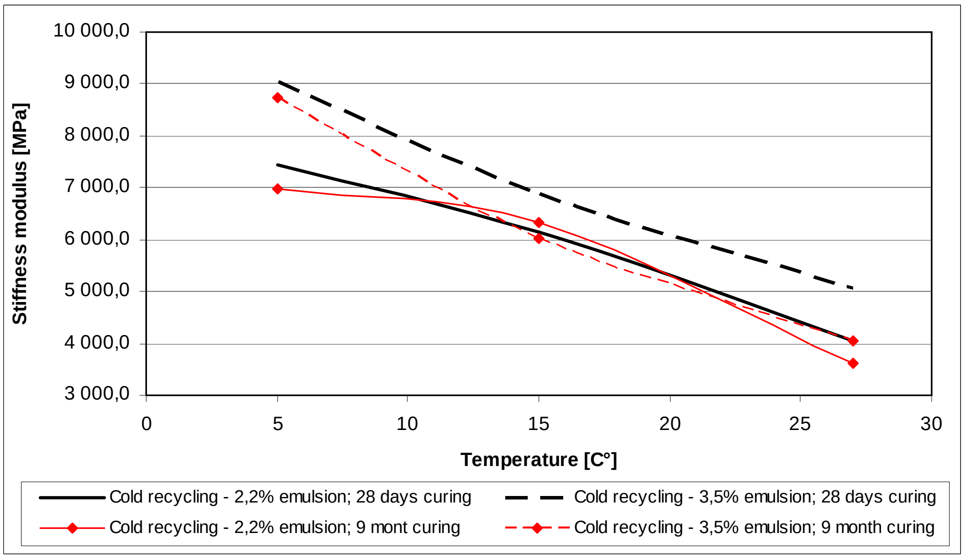

Figure 4: Stiffness modules of mixes EC8 and EC9 at 5°C, 15°C and 27°C.

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Two effects were examined in the determination of stiffness modules of mixes EC8 and EC9, as depicted in Fig. 4 – the effect of varying the bitumen emulsion proportion and the effect of varying the curing time. In the first case, the expected positive impact of the bitumen emulsion (with an unmodified proportion of cement) on the stiffness modulus value was proven; with regards the curing time the results are not absolutely unambiguous. In the case of the mix containing 3.5%-by mass of bitumen emulsion, the stiffness modulus value decreased on average by about 12%; the mix containing 2.2% of bitumen emulsion the values after 28 days and 9 months of curing are almost identical (in the case of 15°C the stiffness modulus value even slightly increased; however, this has not been reconfirmed by another test and may be caused by the heterogeneous nature of the material).

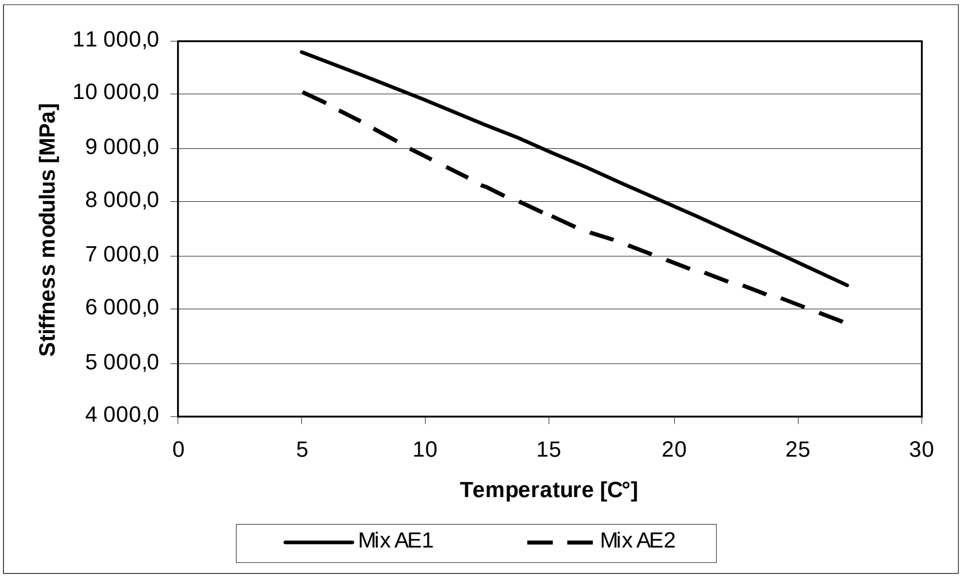

Figure 5: Stiffness modules of mixes AE1 and AE2 at 5°C, 15°C and 27°C.

With mixes AE1 and AE2, the stiffness modules were determined after 9 months of curing. In comparison to mixes EC1-EC5, these also confirm the assumingly positive impact of the added aggregate. The difference between values of mixes AE1 and AE2 is probably due to the higher proportion of bitumen emulsion in the first mix. At the same time it is possible to believe that in increasing the proportion of finely ground aggregate, this increase from a certain level starts having a negative effect, which might be another cause of the lower stiffness modulus values of mix AE2. Values for 27°C were used for the subsequent determination of fatigue characteristics.

In the evaluation of fatigue tests we assume that the material tested is homogenous and isotropic and that its deformation is governed by the linear visco-elastic –

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Boltzmann – material. The way asphalt mix samples rupture depends primarily on the temperature under which the fatigue testing is carried out and on the magnitude of the tension or deformation. Ruptures can be classified as brittle, which means the material is separated by a fracture; plastic, which means shearing along sliding areas and pliable, in which case the material divides along the edges of grains. Asphalt mixes undergo combinations of such ruptures. Under low temperatures, the brittle character prevails while at temperatures above 20°C the ruptures more closely resemble the pliable type. In the case of cold recycling mixes, based on the results listed below, it is possible to discover brittle rupture types with a distinct fracture. In the case of this type of mix, the effects of deformation due to the weight of the test specimen itself, which has a negative impact on maintaining the shape of the test specimens and is characteristic for certain asphalt mixes under test temperature of 40°C, were not examined.

The results of the fatigue test achieved are summarised in Table 2 and in figures 6 and 7, while the determination of fatigue characteristics as such was carried out according to the previous procedure applied in Czech technical standard ČSN 73 6160, which also corresponds with the figures and, is in accordance with the procedure as stipulated in EN 12697-24, where the horizontal axis covers the relative deformation and the vertical axis the number of load cycles. When comparing both approaches it is obvious that results according to EN yield slightly higher values.

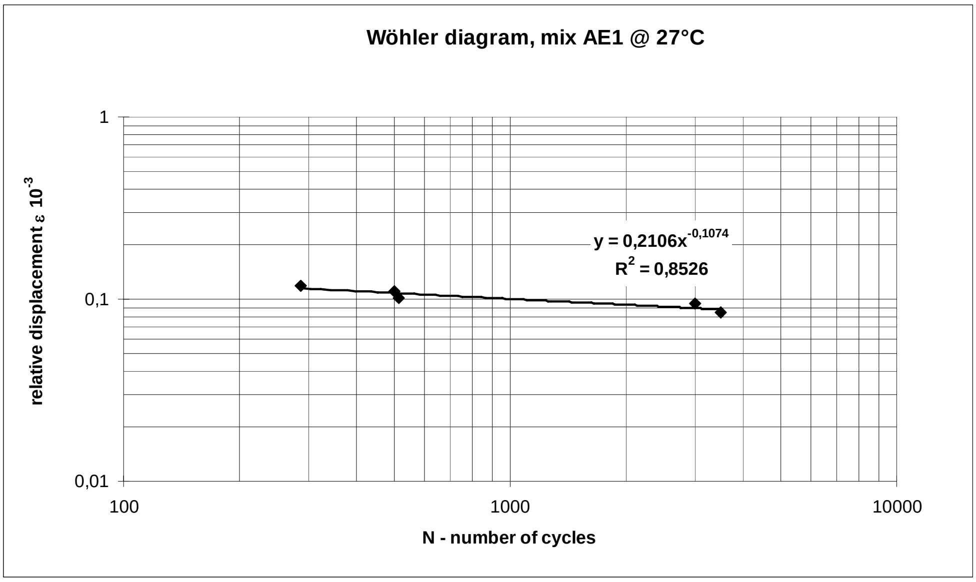

Figure 6: Result of fatigue test of mix AE1.

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The interpretation of the results of fatigue behavior of the cold recycling mixes tested is not absolutely unambiguous and reflects the problem of homogeneity of the reclaimed material used. From the perspective of parameter “a”, mix AE2 shows a better fatigue behavior; on the other hand, parameters “B” and “ε_6” prove a better fatigue behavior of mix AE1. This, moreover, is in line with the conclusions of the fatigue tests with the trapezoid samples, [3]. When comparing the mixes analyzed with a selected representative of bitumen coated aggregate mixes, the cold recycling mixes show mediocre fatigue behavior and, therefore, a shorter life.

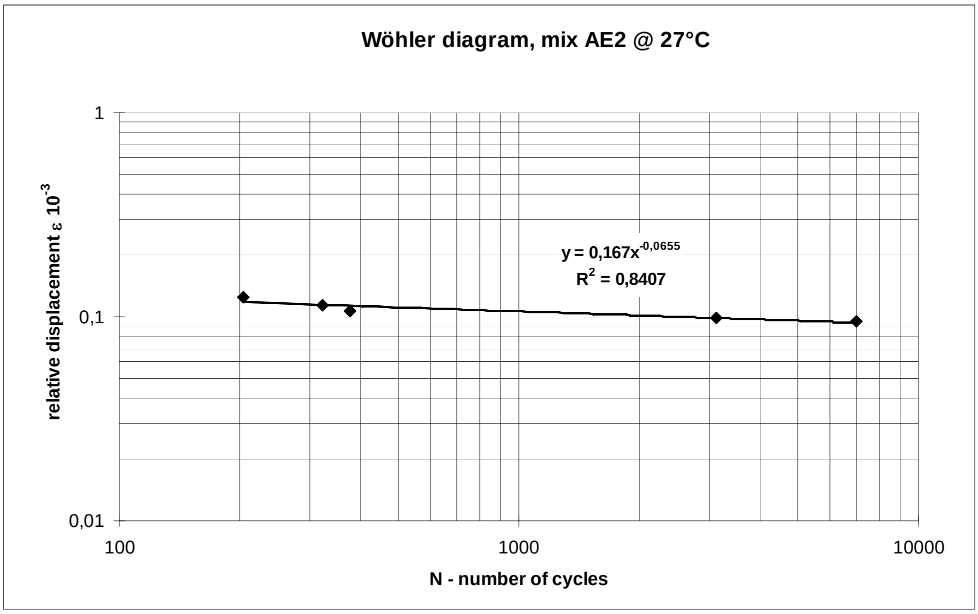

Figure 7: Result of fatigue test of mix AE2.

Table 3: Summarization of fatigue characteristics.

Mix	Fatigue characteristics according ČSN 73 6160 calculation			Fatigue characteristics according EN 12697-24 calculation		
	α	β	ε_6 (x10^3)	α	β	ε_6 (x10^3)
AE1	0.2106	-0.1074	0.04776	0.2346	-0.1259	0.04119
AE2	0.1763	-0.0655	0.07132	0.1810	-0.0779	0.06166
OKH I	1.8063	-0.2900	0.03287	1.9685	-0.3023	0.03022

From the point of view of the homogeneity of reclaimed material, which enters the cold recycling mixes as a significant factor, we consider the knowledge of its material composition including the quantity of binder and basic characteristics of such binder one of the key determining facts. In the effort of aiming to use reclaimed material to the optimum level, this fact should result in consistent sorting as well as in a need to mill the individual layers of the pavement structure separately to prevent heterogeneities of the milled material that might lead to negative effects on the resulting recycling mix characteristics that might be difficult to forecast.

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References

1. Tesař, Z., *Vliv nízkoteplotních pojiv na vybrané mechanicko-fyzikální a reologické vlastnosti asfaltových směsí*, Master theses, Faculty of Civil Engineering, CTU Prague, 2005. (in Czech)
2. Valentin, J., Mondschein, P., Pešková, Š., *Assessment of Stiffness Modulus of Cold Recycling Mixes as a Basis for their further Optimization*, ISAP 2008, Zürich. (not published yet)
3. Gillinger, J., Reologické vlastnosti za studena recyklovaných zmesí. *Acta Montanistica Slovaca, vol. 12(2007), No. 1, pp. 53-61.*, 2007. (in Slovak).
4. Valentin, J., Mondschein, P., *Porovnání vybraných vlastností směsí studené recyklace s asfaltovou emulzí a asfaltovou pěnou*, VIII. Vedecká konferenci s medzinárodnou účastku, Košice, 2007. (in Czech)
5. Ministry of Transport of Czech Republic, *TP170 – Designing of road pavements*, Prague, 2004.