The Effect of Water and Frost on Fatigue Life of Asphalt Concrete

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ABSTRACT: The paper presents testing of fatigue life of asphalt concrete which was subjected to action of water and frost. Simulation of water and frost action was based on the original AASHTO T283 method and its modification. The original method was modified in such a way that instead of a single freeze-thaw cycle 50 and 150 cycles were applied. Fatigue life was measured in the Indirect Tensile Fatigue Test in the NAT apparatus. The asphalt concrete specimens were prepared in laboratory. Some specimens contained liquid adhesive agent, namely fatty amine and others did not. The detrimental effect of water and frost was clearly identified. The testing procedure, the results and the practical conclusions are presented.

1. INTRODUCTION

In the present times fatigue life of asphalt mixtures is the primary criterion used in the design of road pavements. It is a parameter useful at the mixture design stage and promotes awareness of the effect of poor fatigue life on the overall durability of mixture. By allowing for the effect of water and frost on the fatigue life of asphalt mixtures more specific pavement design methods can be obtained.

Fatigue testing was carried out on asphalt concrete specimens subjected to the action of water and frost simulated in laboratory in different ways to obtain different levels of exposure and on the reference specimens. Fatigue testing was carried out according to the Indirect Tensile Fatigue Test (ITFT) method in the Nottingham Asphalt Tester (NAT). The action of water and frost was simulated with the original and modified AASHTO T283 method. In the modified method 50 and 150 freeze-thaw cycles were used respectively instead of a single freeze-thaw cycle.

The objective of testing was to define the detrimental effect of water and frost on the fatigue life of asphalt concrete which was reported before by Poczapskij and Goncharenko (1973), Lottman (1982), Gilmore et al. (1984), Kim et al. (1984), Lottman et al. (1988), Moutier et al. (1988), and the results of fatigue tests were used for separate analyses related to structural design of pavements by Jaskula (2004).

2. MATERIALS

Asphalt concrete mixtures designed for base course, designated further as AC25P, produced with and without the addition of fatty amine as adhesive agent were tested. Asphalt concrete 0/25 mm was made of 35/50 bitumen, 5/8 and 8/11 granite chippings, 2/8 and 12/25 crushed gravel, 0/2 natural (quartzite) sand, 0/2 crushed sand and limestone filler. The content of bitumen was 4.0% by weight. Fatty amine was added at a rate of 0.3% of the weight of bitumen. The mixtures were subjected to short-term ageing according to the SHRP test procedures (Harrigan et al. 1994); a loose, uncompacted mixture was conditioned for 4 hours in a draft oven at 135°C.

Different conditioning methods were used to simulate the action of water and frost at the laboratory, as presented in Table 1. Two methods of compaction (Marshall and rolling) were used due to some organizational reasons. The average voids content was similar for both compaction methods, and equal in average 5.4% for all prepared samples.

Table 1. Preparation and conditioning of specimens and testing methods

No.	Compaction method	Conditioning methods according to AASHTO T283 and their modifications				Test methods
1.	Roller compacted and cut out	Non-conditioned		With 1 freeze-thaw cycle		Indirect Stiffness Modulus and Indirect Fatigue Test for 7 levels of applied stress
2.	Marshall compaction	Non-conditioned	With 1 freeze-thaw cycle	With 50 freeze-thaw cycles	With 150 freeze-thaw cycles	Indirect Stiffness Modulus and Indirect Fatigue Test for one level of applied stress

The test material compacted by rolling comprised 36 cylindrical specimens of 102 mm in diameter and 50 mm in height which were cut out from 750x870 mm slabs compacted with roller. The test material compacted with the Marshall method comprised 30 cylindrical specimens of 102 mm in diameter and 50-60 mm in height.

To determine the Indirect Tensile Stiffness Modulus (ITSM) at least 3 samples were tested in a uniform series. To determine fatigue life of each mixture for the roller compaction method 7-9 samples were tested and for the Marshall compaction method 3 samples were tested.

3. TESTING

3.1. Indirect Tensile Stiffness Modulus

The following two general methods were used to simulate the action of water and frost: (a) AASHTO T283 method with 1 freeze-thaw cycle with the SHRP short-term oven aging included, as describe by Jaskula and Judycki (2008), (b) modified AASHTO T283 method with 50 and 150 freeze-thaw cycles instead of the single cycle applied in the original procedure. The one freeze-thaw cycle consisted of 4 hours of freezing at -18°C and 2 hours of thawing in water at +20°C. After all prescribed freeze-thaw cycles (1, 50 and 150) the specimens were placed in a water bath at +60°C for 24 hours. The specimens were not wrapped in a foil. After the water bath the specimens were dried up with a cloth and kept for 4 hours at a testing temperature.

The ITSM tests were carried out at +20°C and +25°C on both conditioned and non-conditioned specimens. The measures of resistance to the action of water and frost were the values of Indirect Tensile Stiffness Modulus Ratios (ITSMR) obtained by dividing the value of modulus for conditioned specimens by the value for non-conditioned specimens.

3.2. Fatigue life of asphalt concrete mixtures

The mixtures were subjected to the stress-controlled Indirect Tension Fatigue Test (ITFT) in NAT apparatus presented earlier by Said (1989), Read et al. (1997) andJudycki et al. (2002). In this test horizontal tensile stresses are generated along the vertical diameter of the specimen. Repeated loading results in failure of the specimen which cracks along the vertical diameter and sometimes a specimen is completely split. In the ITFT the limit of fatigue life is defined arbitrarily either as the point of critical vertical deformation or complete failure of the specimen (NAT Manual 1994). In this research it was assumed that the limit of the fatigue life was the complete failure.

The used Indirect Tensile Fatigue Test (ITFT) is rather simple and practical but it should be remembered that the premature failure in ITFT can be affected not only by horizontal tensile stresses but also by accumulation of permanent deformations especially at high temperatures, where nonlinear and viscoelastic material behavior is more pronounced. It is a certain disadvantage of this testing method.

The parameters monitored during the ITFT were: vertical deformation Δp measured with LVDT sensors and the amplitude of the horizontal stress in the specimens which was kept constant (σ=const) until failure of the specimen took place. In this research, the relevant literature was studied, which included Said (1989), NAT Manual (1994), Read et al. (1997), Judycki et al. (2002), and on this basis the test conditions were established. The tests were carried out at the following test parameters: temperature of +25°C, load rise time of 0.124 s, cycle duration of 1.5 s, 40-50 mm specimen height and 102 mm specimen diameter, amplitude of the horizontal stress values in the range from 220 kPa to 520 kPa in 60 kPa increments.

The ITFT fatigue curves $\sigma=f(N_f)$ and the number of cycles until crack initiation represented by the peak of $f(N_f)=N_f/\Delta p$ curve were determined with the method based on the dispersed energy concept described by Read et al. (1997) which assumes that stiffness is inversely proportional to the vertical deformation Δp, as described in details by Jaskula (2004).

4. TEST RESULTS

4.1. Results of testing of asphalt concrete compacted by rolling

Table 2 presents the values of the Indirect Tensile Stiffness Modulus Ratios (ITSMR). The Indirect Tensile Fatigue Test (ITFT) results are presented in Fig 1.

Table 2. Indirect Tensile Stiffness Modulus Ratios (ITSMR) for AC25P asphalt concrete according to AASHTO T283 with 1 cycle of freeze-thaw, compaction by rolling, (mean values of minimum 8 specimens).

ITSMR (%)			
AC25P with adhesive agent		AC25P without adhesive agent	
20°C	25°C	20°C	25°C
83.7	81.9	86.8	92.6

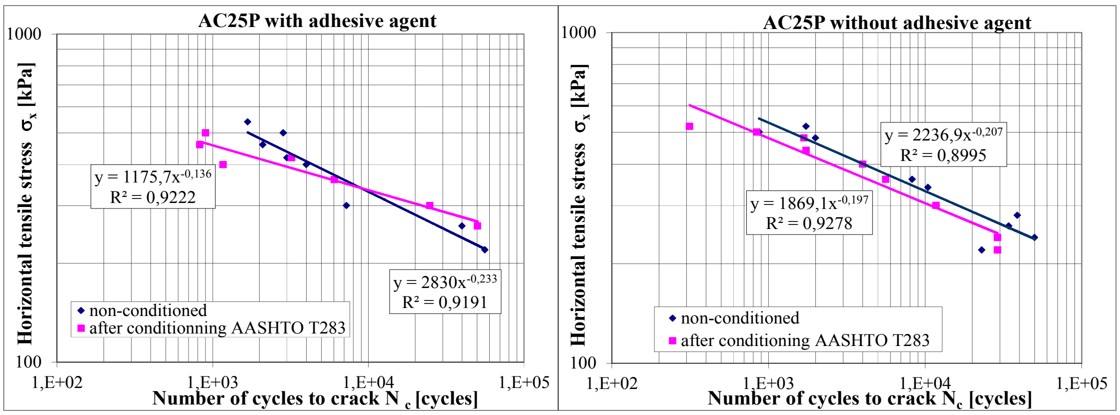

FIG 1. Fatigue curves of asphalt concrete conditioned according to AASHTO T283 with 1 freeze-thaw cycle and non-conditioned, compaction by rolling.

4.2. Results of testing of asphalt concrete compacted by Marshall method

Table 3 presents average values of the Indirect Tensile Stiffness Modulus Ratios of AC25P asphalt concrete in relation to the number of the freeze-thaw cycles. The specimens were compacted according to the Marshall method.

Table 3. Indirect Tensile Stiffness Modulus Ratios (ITSMR), compaction by Marshall method, (mean values of 3 specimens).

Number of freeze-thaw cycles	ITSMR (%)			
	AC25P with adhesive agent		AC25P without adhesive agent	
	20°C	25°C	20°C	25°C
1	90.7	78.7	94.6	77.9
50	54.9	35.5	32.4	17.4
150	34.4	32.9	16.0	18.0

Figure 2 presents a comparison of the results obtained in the ITFT fatigue testing on specimens made of AC25P asphalt concrete with and without adhesive agent, non-conditioned and conditioned in different ways. Results presented in this figure were obtained as mean values from 3 specimens tested at one level of horizontal tensile stress in the fatigue test (ITFT).

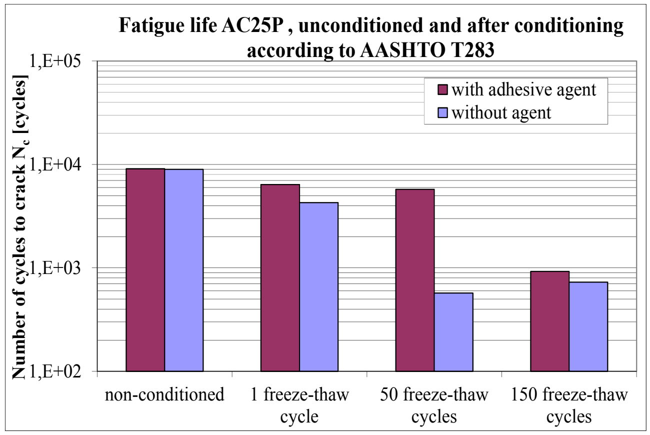

FIG 2. Comparison of the average fatigue life values of the AC25P asphalt concrete, compaction by Marshall method.

5. ANALYSIS OF TEST RESULTS

5.1. Concept of water and frost Fatigue Life Ratio

The fatigue life of asphalt mixtures exposed to the action of water and frost was determined by comparing the results of Indirect Tensile Fatigue Tests (ITFT) carried out on specimens subjected to the action of water and frost simulated in laboratory and non-conditioned. For the purpose of determining the changes in fatigue life between the specimens subjected to the action of water and frost and the non-conditioned specimens the concept of water and frost Fatigue Life Ratio ($FLR_{w,f}$) was introduced by Lottman (1982) and Lottman et al. (1988). This ratio was calculated as follows:

$$FLR_{w,f} = N_{f,c} / N_{f,nc} * 100\% \qquad (1)$$

where:

$FLR_{w,f}$ – water and frost Fatigue Life Ratio in percent,

$N_{f,nc}$ – average fatigue life (number of cycles to initiation of cracking) for the non-conditioned specimens, $N_{f,c}$ – average fatigue life (number of cycles to initiation of cracking) for the conditioned specimens.

For asphalt concrete specimens compacted by rolling which were subjected to the full scope of fatigue testing, i.e. at different 7 levels of horizontal stresses the fatigue curves were used to compare the fatigue life of conditioned and non-conditioned specimens. The number of cycles to failure N_f was taken from the curves stress vs. fatigue life $\sigma_x=f(N_f)$ at the three levels of stress σ_x (10%, 25% and 90% out of the maximum stress applied in the test). As the next step the $FLR_{w,f}$ were calculated for each stress level and results were averaged.

Where the scope of fatigue testing of the asphalt concrete specimens, compacted with the Marshall method, was limited to only one pre-defined level of stress σ_x, the variation in fatigue life after the action of water and frost was determined simply by calculating the ratios from formula (1).

If the value of the water and frost Fatigue Life Ratio $FLR_{w,f}=N_{f,c}/N_{f,nc}$ is lower than 100% it means that the action of water and frost does have a negative effect on the fatigue life of the tested material.

5.2. The effect of the action of water and frost simulated in laboratory according to AASHTO T283 on the fatigue life of asphalt concrete

As it can be seen on Fig. 1 (left) the action of water and frost simulated according to AASHTO T283 (single freeze-thaw cycle) has a limited effect on the fatigue life of asphalt concrete mixture produced with adhesive agent. The fatigue curves intersect which can be attributed to only moderately detrimental effect of the exposure to the action of water and frost simulated in laboratory according to AASHTO T283 on asphalt concrete mixture produced with the addition of adhesive agent. It was found in the statistical evaluation that the fatigue curves are not significantly different at the levels of confidence P = 90, 95 and 98%, and as such, they may be replaced with a single curve with determination coefficient R^2=0.85.

The negative effect of the exposure to the action of water and frost simulated according to AASHTO T283 (with 1 freeze-thaw cycle) is clearly visible for the asphalt concrete mixtures without adhesive agent, as shown in Fig. 1 (right). The fatigue curves are parallel and the curve representing AC25P after conditioning according to AASHTO T283 runs clearly below the curve representing AC25P without conditioning. The value of Fatigue Life Ratio $FLR_{w,f}$ is 62.1% as it was calculated from the data presented in the Fig. 1 (left). This means that the action of water and frost on the asphalt concrete without adhesive agent reduced its fatigue life by 37.9% and this value is of primary importance when evaluating the pavement condition in service. Determination of the value of $FLR_{w,f}$ for AC25P with adhesive agent was difficult due to intersecting of fatigue curves in Fig. 1.

Results of Indirect Tensile Stiffness Modulus Ratios (ITSMR) presented in Table 2 are contrary both to results of fatigue testing and to expectations. The values of the ITSMR at temperatures +20^{o}C and +25^{o}C for the mix without adhesive agent are greater than for the mix with adhesive agent. This issue will be discussed in the next chapter in this paper.

5.3. The effect of 1, 50 and 150 cycles of freeze-thaw on the fatigue life of asphalt concrete

The Fatigue Life Ratios determined for asphalt concrete mixtures with and without adhesive agent, as presented in Fig. 2 and Table 4, show a strong dependence on the method used to simulate the action of water and frost. The Fatigue Life Ratios of asphalt concrete with adhesive agent ranged from 70.3% for specimens conditioned according to AASHTO T283 with 1 cycle of freeze-thaw, through 63.2% after 50 freeze-thaw cycles and up to 10.1% after 150 cycles. A note must be made that after 150 freeze-thaw cycles partial cracking was noted before the fatigue testing. This is an indication of how severe is the effect of 150 cycles of repeated freezing and thawing on the tested asphalt concrete, with 5.4% voids.

Table 4. Comparison of water and frost Fatigue Life Ratio $FLR_{w,f}$ of AC25P asphalt concrete, compaction by Marshall method, (mean values of 3 specimens).

Number of freeze-thaw cycles	$FLR_{w,f}$ (%) at +25^{o}C	
	AC25P with adhesive agent	AC25P without adhesive agent
1	70.3	47.7
50	63.2	6.4
150	10.1	8.1

The Fatigue Life Ratios of AC25P without adhesive agent ranged from 47.7% when tested on specimens conditioned according to AASHTO T283 with 1 cycle and reached 6.4% after 50 and 8.1% for 150 freeze-thaw cycles. After 150 freeze-thaw cycles the specimens showed some cracking damage, caused by expansion during cyclic freezing of water.

The data given in Tables 3 and 4 and in Fig. 3 clearly show that fatigue life is a better indication of the water and frost effect on materials than the ITSMR .

Addition of adhesive agent had a noticeable, positive effect on the fatigue life of asphalt concrete exposed to the action of water and frost. Significantly different values of fatigue life ratio $FLR_{w,f}$ at +25^{o}C were obtained for AC25P after 1 freeze-thaw cycle with and without adhesive agent under repeated loading, namely 70.3% and 47.7% respectively. On the other hand, the ITSMR values for the Marshall compacted mixes measured at +25^{o}C, after single freeze-thaw cycle were 78.7% and 77.9% respectively. At +20^{o}C these values were 90.7% and 94.6% (see Table 3). These values of the ITSMR are very similar and, contrary to the fatigue life, show lack of evident performance improvement affected by the adhesive agent. For the mixes compacted by rolling the results of the ITSMR were even more confusing (see Table 2), mixes without adhesive agent showed greater values of ITSMR than mixes containing the agent. This raises doubts as to the practical significance of the Indirect Tensile Stiffness Modulus Ratio.

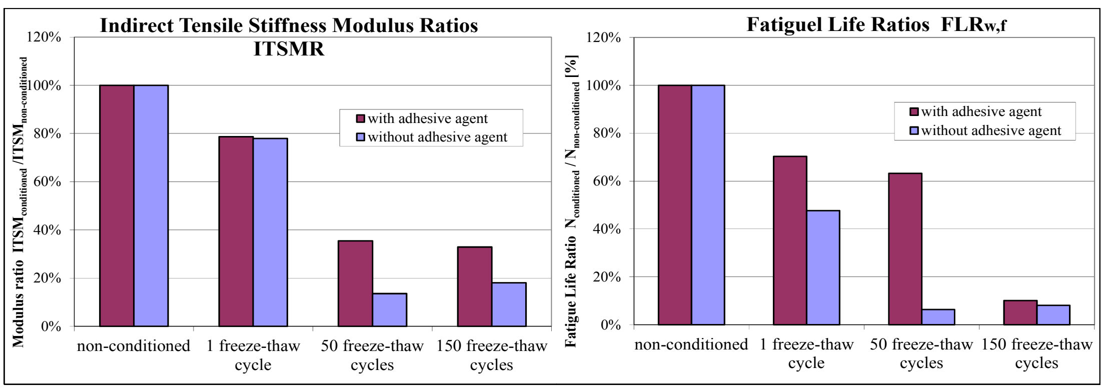

FIG 3. Comparison of $FLR_{w,f}$ and ITSMR at +25^{o}C after exposure to the action of water and frost simulated in various ways, compaction by Marshall method.

6. CONCLUSIONS

On the basis of the tests results it can be concluded that:

- Fatigue life after simulated action of water and frost, especially freeze-thaw cycles, measured under repeated loading provides a better indication of difference between the tested materials than the values of Indirect Tensile Stiffness Modulus (ITSM). A definite decrease of fatigue life was observed after AASHTO T283 conditioning with 1 cycle of freeze-thaw, while the decrease of the ITSM was much less in the same conditions.
- After the AASHTO T283 conditioning with 50 freeze-thaw cycles great decrease of fatigue life of asphalt concrete occurred. The Fatigue Life Ratio after 50 cycles was in a range of 6% for mixes without adhesive agent and 63% for mixes with adhesive agent. The advantageous influence of adhesive agent was very clearly visible.
- After 150 freeze-thaw cycles cracking of some specimens was noted before fatigue testing. It can be concluded that such high number of cycles in laboratory testing is not appropriate for open-graded mixtures. In any future research the number of cycles

should be reduced, for example, to 50. Even 50 cycles are not practical due to long testing time required and new methods of simulation of freeze-thaw are needed.

-The effect of adhesive agent was not clearly visible in the testing of the Indirect Tensile Stiffness Modulus after conditioning according to AASHTO T283 with the single freeze-thaw cycle. The results were confounded and indicated in some cases no effect of adhesive agents or even better resistance to water and frost of mixes without adhesive agents. On the contrary, the fatigue test on the same mixes indicated the evident advantageous effect of the adhesive agent after the single freeze-thaw cycle and much greater advantageous effect after 50 cycles. This raises doubts as to the practical significance of the Indirect Tensile Stiffness Modulus Ratio.

- Base course made of open graded asphalt concrete is particularly sensitive to the detrimental effect of water and frost due a high content of voids and easy penetration of water coming from the road surface, subbase or shoulders. The decrease of fatigue life of asphalt concrete base course material after the action of water and frost could be critical to the service life of the entire pavement.

- The observed decreases of fatigue life of the asphalt concrete for the base course should be used in computational analyses of pavement structures to determine the long–term performance.

7. REFERENCES

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