Evaluation of Asphalt Concrete Strength with Recording of Damage Accumulation

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ABSTRACT:

Paper shows part of series test results for fine-grained dense asphalt concrete, prepared with the use of oxidated bitumen to failure at cyclic creep. Load and relax duration for each cycle were equal to 10 s and 60 s respectively. Test temperature: 22 ^{0}C. It has been determined that creep strain under load and recovered strain at relax increase with the growth of cyclic number. The value of the recovered strain in the end of relax period decreases (from 52% to 20%) till half of the cyclic number to failure according to exponential dependence with the growth of cyclic number and further it remains constant till sample failure.

Using the curve of asphalt concrete long-term strength, constructed according to the test results of more than 110 samples to failure under creep scheme at the stresses from 0.05 MPa to 0.31 MPa, based on Bailey's criterion, the expression was obtained for determination of cyclic strength for the asphalt concrete.

Key words: asphalt concrete, cyclic creep, creep strain, recovered strain, cyclic strength.

1. INTRODUCTION

Asphalt concrete layers of highways during operational period are subject to complex combinations of mechanical impacts of vehicles' wheels and ambient temperature. As it is known, mechanical properties of asphalt concrete depend greatly on temperature and load characteristics, such as value, duration and rate of loading [1-3]. Therefore, it is very important the experimental determination of asphalt concrete characteristics, as well as modeling of its mechanical behavior in conditions close to the real ones.

Mechanical failure of asphalt concrete pavement occurs gradually under impact of frequently repeated vehicle's load; i.e. the damage, occurring with each passage of the vehicle's wheel, is accumulated.

There are several approaches to taking into account the damage accumulation in asphalt concrete pavements.

The viscoelastic continuum damage mechanics approach (VECD) is based on the extended elastic-viscoelastic correspondence principle, proposed by R.A. Schapery [4]. This approach, used for the first time by Little D.N. and Kim Y.R. [5-8], has been often applied by other researchers for characterization of asphalt concrete fatigue considering non-linear strain and healing [9, 10]. In the VECD-approach the physical strain and stiffness of the viscoelastic material (asphalt concrete) are substituted by their pseudo similarities, i.e. for pseudo strain and pseudo stiffness respectively, which vary from one loading cycle to another. Calculation of pseudo strain requires knowledge of dynamic modulus and phase angle, which can be measured experimentally by appropriate devices.

The tensile strain of asphalt concrete is analyzed experimentally in this paper using cyclic stress with relax period and based on the Bailey's summation principle of damage. The formula has been proposed for the determination of cyclic strength for asphalt concrete.

2. MATERIALS

In this paper bitumen of grade 100-130 has been used meeting the requirements of the Kazakhstan standard ST RK 1373-2013 [11].The bitumen grade on Superpave is PG 64-40 [12]. Bitumen has been produced by Pavlodar processing plant from crude oil of Western Siberia (Russia) by the direct oxidation method.

Hot dense asphalt concrete of type B meeting the requirements of the Kazakhstan standard ST RK 1225-2013 [13] was prepared using aggregate fractions of 5-10 mm (20 %), 10-15 mm (13 %), 15-20 mm (10 %) from Novo-Alekseevsk rock pit (Almaty region), sand of fraction 0-5 mm (50 %) from the plant "Asphaltconcrete-1" (Almaty city) and activated mineral powder (7%) from Kordai rock pit (Zhambyl region).

Bitumen content of grade 100-130 in the asphalt concrete is 4,8 % by weight of dry mineral material.

Samples of the hot asphalt concrete are prepared in form of a rectangular prism with length of 150 mm, width of 50 mm and height of 50 mm in two step procedures. The first step, the asphalt concrete samples were prepared in form of a square slab by means of the Cooper compactor (UK, model CRT-RC2S) according to the standard EN 12697-33 [14]. The second step, the samples were cut from the asphalt concrete slabs in form of a prism. Deviations in sizes of the samples didn't exceed 2 mm.

3. EXPERIMENT

Tests of hot asphalt concrete samples in a form of rectangular prism on cyclic creep were carried out according to the direct tensile scheme until a complete failure. The 0.305 MPa stress has been applied to the tested sample quickly and kept constant for 10 seconds. Then the stress was removed quickly, and the sample was free of stress for the following 60 seconds. The test temperature was equal to 22 °C. The tests were carried out in a special assembled installation, which allows applying a load to the asphalt concrete sample within 1 second. The sample strain was measured by means of two clock typed indicators while data was recorded in a video camera.

Figure 1 shows the graph of cyclic strain for asphalt concrete sample. This sample have resisted to 12 full "load-relax" cycles, and it was failed in the 13^{th} cycle. Failure time was equal to 848 seconds. The graphs, showing the increase of strain under stress and its recovery during relax period in cycles, are represented in Figures 2 and 3. It is clear how the increase of creep strain rate under stress as well as the rate of its recovery during relax period increase with the growth of cycle number.

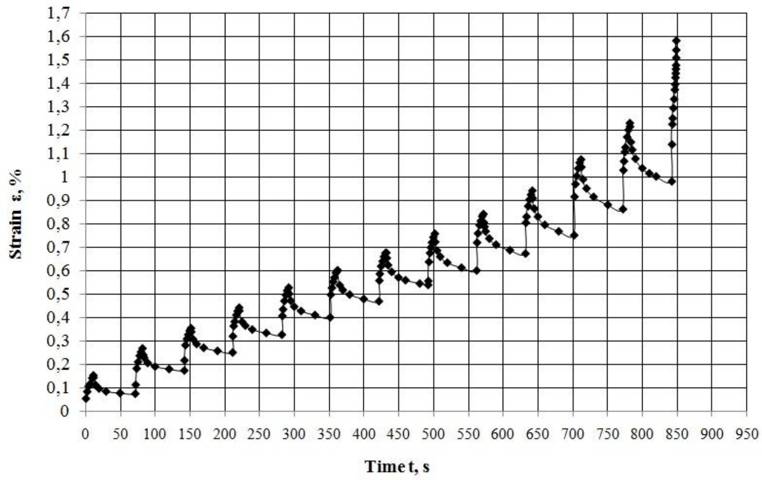

FIGURE 1. **Cyclic Strain of Asphalt Concrete**

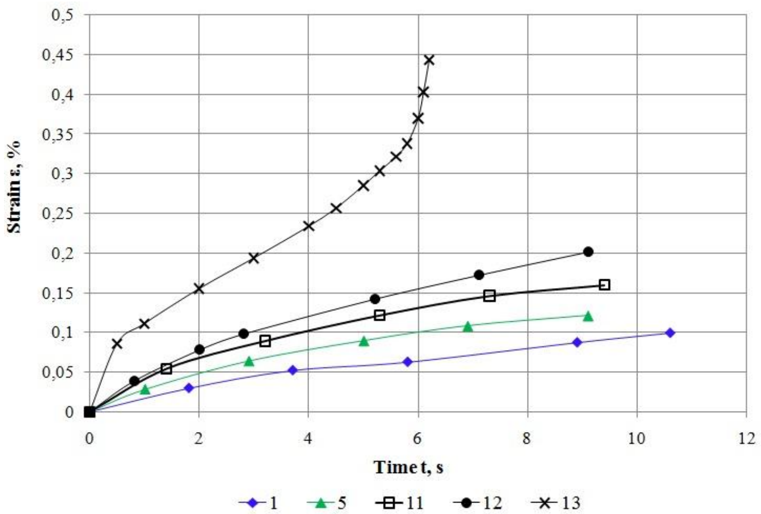

FIGURE 2. Deformation of Asphalt Concrete under Stress in Various Cycles

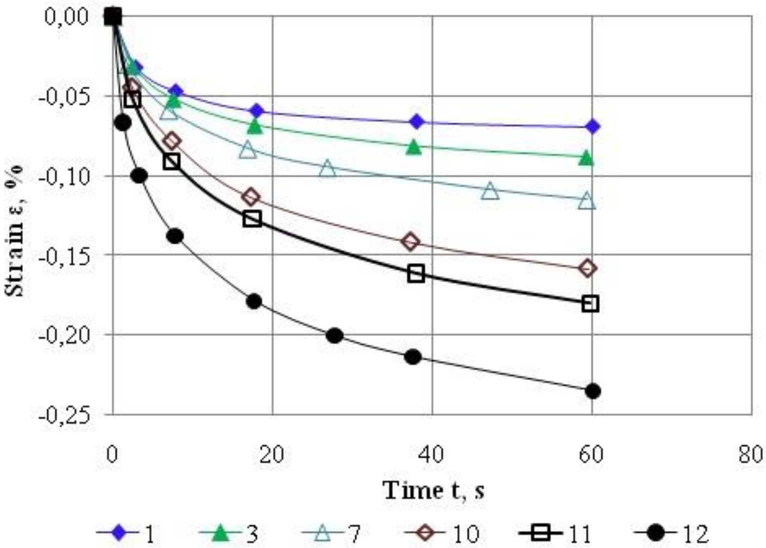

FIGURE 3. Recovery of Asphalt Concrete Strain after Removal of Stress in Various Cycles

It is clear that the maximum creep strain of each cycle occurs in the end of loading period, and maximum recovered strain occurs in the end of relax period. As it is seen from Figure 4, both these strains increase with the growth of cycle number, but the rate for the increase of the first one is considerably higher than for the second one.

It turned out that the value of the recovered strain in the end of relax period decreases (from 52 % to 20 %) till 7th cycle according to exponential dependence with the growth of cycle number and further it remain constant (equal to 20 %) till sample failure (Figure 5). It seems that the increased recoverability of strain in the initial cycles can be explained by the hardening of asphalt concrete.

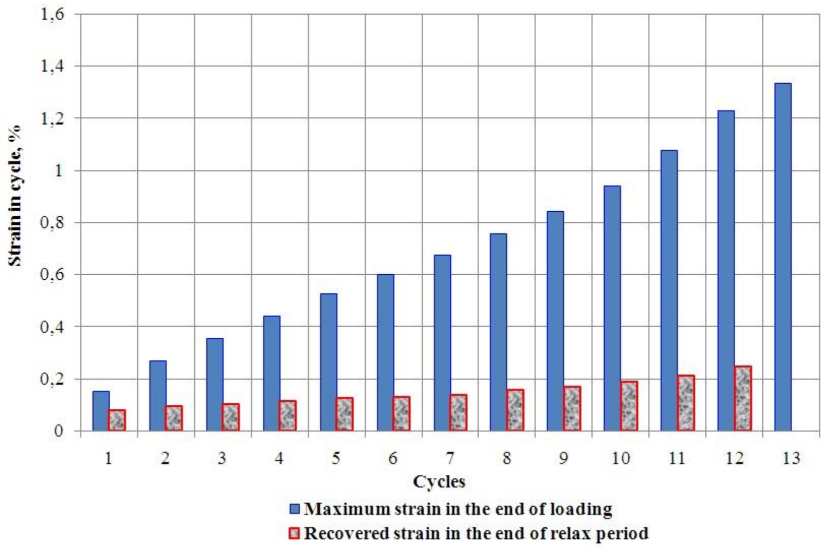

FIGURE 4. Bar Charts of Maximum Strain of Asphalt Concrete in the End of Loading and Recovered Strain in the End of Relax Period in Cycles

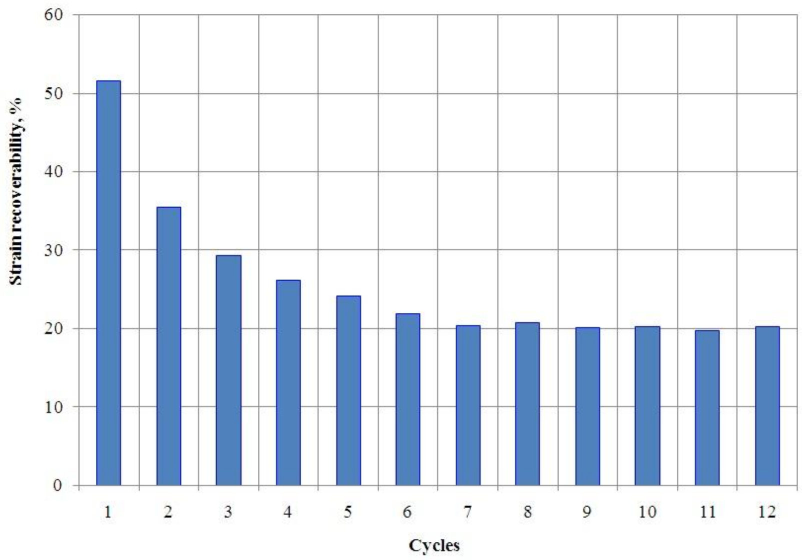

FIGURE 5. Recoverability of Asphalt Concrete Strains in Cycles

Total 10 samples were tested in the previously described conditions (loading duration 10 s, relax period duration 6 s) and the average number of cycles to failure of the samples was 9.

4. CYCLIC STRENGTH MODEL

4.1. Bailey's criterion

At present the so-called Bailey's criterion is well-known in science and engineering practice [15] which can be described in the following form:

$$\int_0^{t_p} \frac{dt}{\tau\left[\sigma(t)\right]} = 1, \qquad (1)$$

where t_p = failure time; $\sigma(t)$ = stress, varied in time; and $\tau[\sigma(t)]$ = dependence of material failure time on stress.

Bailey's criterion (1) considers load duration, i.e. the speed of the vehicle along the highway. Dependence $\tau[\sigma(t)]$ of Bailey's criterion represents by itself the analytical equation for the so-called curve of long-term strength.

4.2. Long-term strength

Long-term strength is the time, on the expiry of which the material is failed under the impact of the load, suddenly applied and kept constant [16, 18]. It is determined based on the test results for the material under the scheme of creep. Figure 6 shows the graph of long-term stress for fine-grained hot asphalt concrete at the temperature of 20-22 °C.

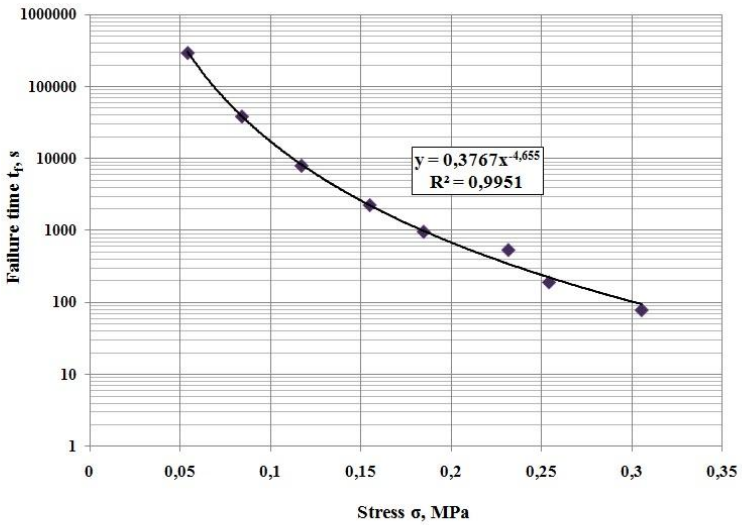

FIGURE 6. Curve of Long-Term Strength for Asphalt Concrete at The Temperature of 20-22°C

It is seen from Figure 6 that the curve of long-term strength of the considered asphalt concrete is approximated satisfactorily by an exponential function. Therefore, in accordance with [16, 17], the adopted approximating function is the following form:

$$t_p = \frac{1}{A(n+1)\sigma^n}, \qquad (2)$$

t_p - failure time, s;

σ - stress, MPa;
A - constant, having unit $MPa^{-n} \cdot s^{-1}$;
n - dimensionless exponent.

4.3. Cyclic loading

As known the pavement structures are subject to cyclic loadings with traffic. Each cycle consists in two periods. During the first period (t_0) the applied stress σ remains constant (loading period), and during the second one (P-t_0) the stress does not occur, i.e. $\sigma = 0$ (relax period). One full loading cycle has the duration P. In this work the duration of cycles P, loading period t_0 and relax period P-t_0 are adopted as constant.

4.4. Cyclic strength

Considering equation (2) Bailey's integral (1) may be written as:

$$A(n+1)\int_0^{t_p} \sigma^n(\tau)\, d\tau = 1. \qquad (3)$$

In case of cyclic loading:

$$t_* = N \cdot P, \qquad (4)$$

where t_* - failure time of material (asphalt concrete) during cyclic loading;
N - number of cycles "load-relax" till failure.

Transferring from t_p to t_*, and for the case when σ = const from expressions (3) and (4) we can find the number of cycles "load-relax" till failure:

$$N = \frac{1}{t_0\left[A(n+1)\sigma^n\right]}. \qquad (5)$$

Values of unknown parameters A and n of the formula (8) have been determined by regression equation in Figure 6 and approximation function (2):

n = 4,655; A = 0,4694 $MPa^{-n} \cdot c^{-1}$.

Number of cycles "load-relax" till failure of asphalt concrete sample, calculated under the formula (5), was equal to 9. As it was mentioned above, average number of cycles to failure of the tested ten samples was 9.

Thus, one can consider that the formula (5), derived on the basis of Bailey's summation principle of damage using the equation for the curve of long-term strength, which was obtained experimentally, determines satisfactorily the cyclic tensile strength of the asphalt concrete in the following conditions: load and relax durations are equal to 10 s and 60 s respectively and at temperature 22 ^{0}C.

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