Numerical model of the fracture process of asphalt mixture using the semi-circular bending test

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Asphalt mixtures are made from mineral aggregate and binder. Compacted mixtures contains air voids. The amount of voids depends on the type of asphalt mix and varies from 1 to 25 % by means of volume. If the void content exceeds the range of 3% to 5% the asphalt mix can be classified as a porous medium. Asphalt pavements of highways are prone to deterioration under traffic load and environmental conditions. Cracking, fatigue cracking and low-temperature cracking are the major failure modes. Presently, the Polish and foreign regulations do not specify a direct criterion to classify a designed asphalt mix due to its cracking resistance. Fracture properties of asphalt pavement can be defined on the basis of fracture mechanics and strictly related to the laboratory test results. One of the most suitable and frequently used method is the bending test of semi-circular specimens (SCB).

Determination of fracture mechanics parameters of mineral-asphalt mix on the basis of bending test of the pre-cut semi-cylindrical specimens is a relatively simple task. The major concern is to unify parameters of the experiments: temperature, loading velocity and strain measurement mode. Figure 1 presents specimens and selected results of mineral-asphalt mix tests, conducted by the Road Construction Division at the Faculty of Civil and Environmental Engineering, Gdańsk University of Technology [1].The nine tested asphalt mixes were selected with respect to aggregate type and void content. Consequently, the fracture toughness K_{IC} was estimated, using the following equation

$$K_I = \sigma_0 Y_I \sqrt{\pi a} \tag{1}$$

where a is the cut depth, σ_0 test extreme stress, Y_I normalized stress intensity factor due to type I fracture.

Extreme bending stress in the specimen are computed using Eq. (2), where F is the maximum test force, r - specimen radius, B - specimen thickness:

$$\sigma_0 = F/2rB \tag{2}$$

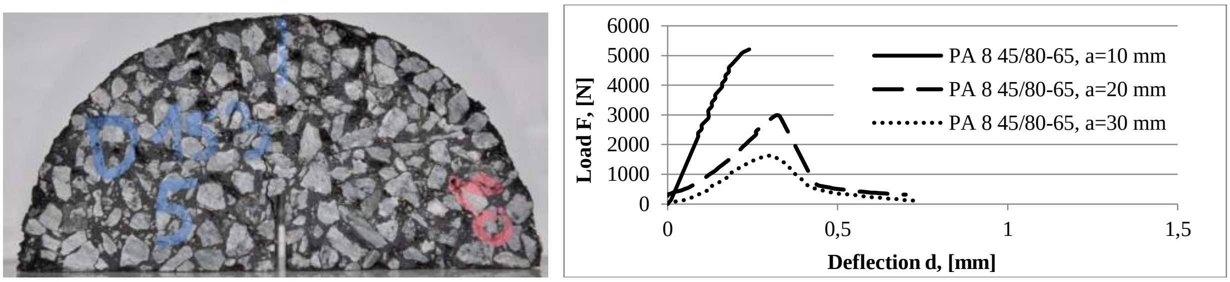
The normalized stress intensity factor is given by the following equation

$$Y_I = 4.782 - 1.219(a/r) + 0.063\exp(7.(\tag{3}$$

Next the J-integral is specified by Eq. (4), where U is the strain energy to failure of the specimen, B is the thickness of specimen, dU/da is the variation of strain energy with the variation of notch depth:

$$J_C = -\left(\frac{1}{B}\right)\frac{dU}{da} \tag{4}$$

The authors' investigations [1] made it possible to conclude that the fracture resistance assessment of asphalt mixes based on K_{IC} alone is insufficient. It is therefore recommended to direct the tests on the fracture energy J_C, using specimens of variable pre-cutting notch depth and applying a crack-mouth-opening displacement (CMOD) detector. Such a research has been already scheduled.



A B

Fig.1. A) The SCB specimen for the fracture resistance experiment B) bending load vs. deflection graph, different values of cutting depth considered [1].

The in-depth understanding of the specimen failure mechanism requires the constitutive relations defined. It is a considerable task, mostly due to material inhomogeneity. Attempts are made to this problem, using both available software and the author-made models. Material model calibration may be conducted on the basis of well performed experiments only.

The works presents an attempt to model the fracture of specimens, in more general terms, asphalt pavements by means of available engineering software. Computational analysis of a two-dimensional plane strain model was made, assuming homogeneous material of appropriately averaged material parameters based on reference values. The second stage of computations is made for a three-dimensional model. The next stage is to find out a precise description of a nonhomogeneous material, regarding bitumen, aggregate and voids. Calibration of the latter model is bound to bring about a high amount of work. A nonlinear fracture description should be applied.

The last stage of the work is to consider random variation of governing parameters and location of aggregate particles in specimens. Statistical dispersion of experimental data should be linked with the uncertainty of aggregate location and the values of material parameters.

References:

[1] Szydłowski C., Judycki J.: Laboratory investigation of asphalt mixtures fracture toughness using semi-circular beams (SCB). Highway engineering 10: 348-353, 2015, in Polish