Numerical simulation of asphalt mixtures fracture using continuum models

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Abstract

The paper analyses numerical models of fracture processes of semi-circular asphalt mixtures specimens subjected to three-point bending. Such a nonhomogeneous material can be modeled at different accuracy levels. The most straightforward is the continuum model. Here the computational parameters are averaged data of the components: asphalt, aggregate and the porous voids contributing the material. The advantage of such simplified constitutive models is their direct application on large pavement parts, they are not restricted to laboratory test pieces only. Parameter calibration of the asphalt mixtures constitutive models requires advanced, complex experimental test procedures. Considering random character of the analysed problem in the continuum model framework is a distinct challenging task.

Keywords: asphalt mixtures, fracture, SCB, laboratory tests, MES calculations, continuum model

1. Introduction

The limitation of damage processes of road pavements due to common traffic is crucial for their economic and safe design. Fracture parameters of the mineral-asphalt mixtures should be consecutively incorporated in the pavement design procedures [1, 2, 6].

The fracture analysis of asphalt mixtures test pieces is difficult to provide. No unified procedures exist to involve these processes. Various specimens are in use, the semi-circular are easy to prepare and the most widespread. The three-point bending tests (Fig.1) are conducted at various temperatures (the range –30°C to +30°C) and various loading rates (from 0.001 to 150 mm/min). The crack-initiating notch depth is a key parameter here. The results are naturally dispersed, due to various reasons, e.g. aggregate layout in the specimens. They should be considered in the fracture parameter selection to reflect material toughness.

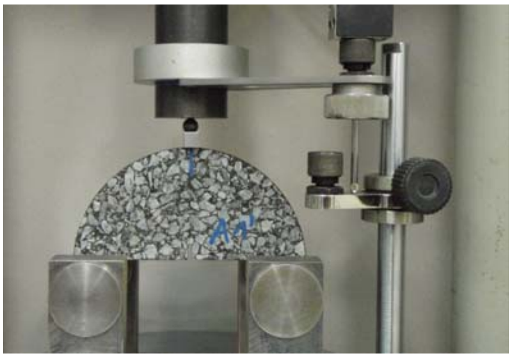

Figure 1: Semi-circular specimens

The laboratory tests should be supported by numerical computations. The accuracy level may be stated arbitrarily, e.g. the mesoscale models. Difficulties arise to apply these models in the analysis of existing road pavements. The continuum or multi-scale models seem to be the most effective. Parameter calibration for these models may involve a considerable effort, additional difficulties arise while material parameters are considered random.

2. Laboratory tests

The laboratory at the Road Construction Division at the Faculty of Civil and Environmental Engineering, Gdańsk University of Technology conducts experiments to estimate fracture parameters of a mineral-asphaltic mix [3]. The semi-circular test pieces subjected to three-point bending (Fig. 1) are in use. The original test methodology described by standard PN-EN 12697-44 was appropriately modified. Vertical deflections were measured in the experimental course. The displacement rate was 1 mm/min. Specimen and loading frame during the test were located in thermostatic chamber of the press to achieve a constant desired test temperature –20°C. The tests were performed with three notch depth: 10 mm, 20 mm, 30 mm, and on two types of asphalt mixtures due to wear stone (matrix asphalt SMA 8 and porous asphalt PA 8). The aggregate skeleton was designed according to Polish Technical Guidelines WT-2 2010 [8]. Fig. 2 presents test results for a selected mix.

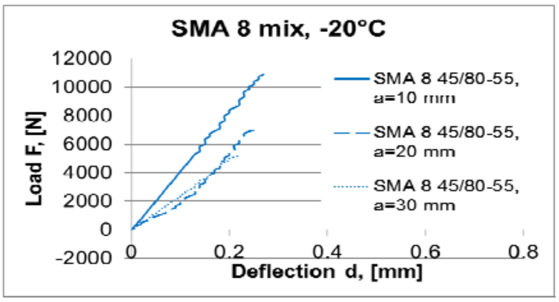

Figure 2: Laboratory tests results – mix SMA 8

The method described in the standard PN-EN 12697-44 is solely based on the assessment of fracture resistance K_{IC} of asphalt mixtures, based on the maximum force recorded in the specimen bending test [3]. Further classification of mixtures in terms of fracture properties incorporated the I-integral, to capture the critical strain energy release rate (Fig. 3).

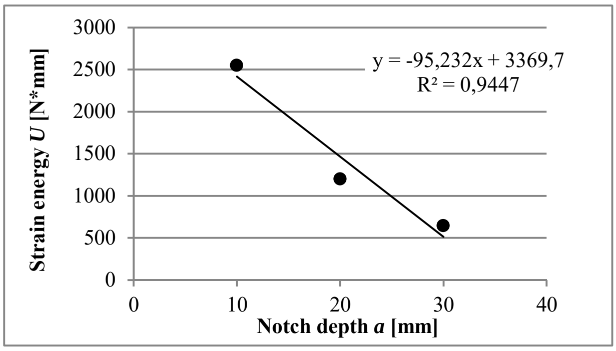

Figure 3: Energy vs. notch depths

3. Numerical models

Different models are analysed by means of a standard ABAQUS package. The smeared crack model and the cohesive joints and element model are the major two selections. The former model does not record the fracture course (Fig. 4), the latter allows to reflect the process precisely (Fig. 5). Both models are based on a proper constitutive material descriptions.

The modern computational software incorporates models relevantly reflecting asphalt-mix structure (Fig. 1) even in the three-dimensional test cases. In the latter case their application to road pavements is strongly limited.

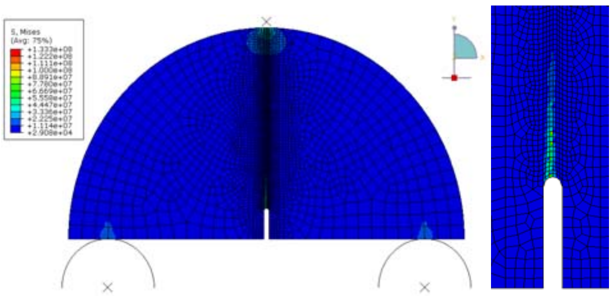

Figure 4: Smeared crack MES model

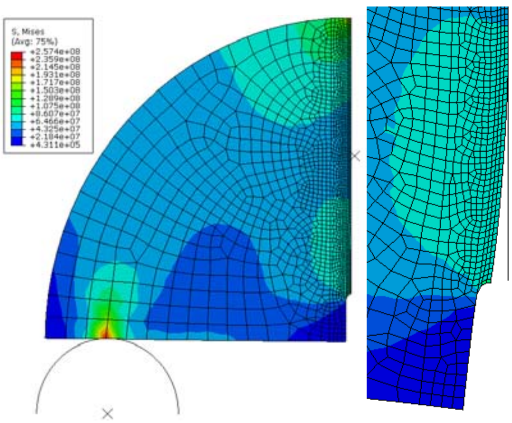

Figure 5: Cohesive element crack model

The analysis aims at the simple continuum model to reflect fracture phenomena. This limitation also comes from laboratory tests, directed to overall test-pieces instead of their components. The contact parameters are especially hard to define.

The elastic-brittle material model was initially assumed. It matches the real tests of the first analytical state, performed at –20°C. The laboratory results, mostly resembling the linear F-d response (Fig. 2), make the approach correct. In the homogeneous model case appropriate averaging was performed of ingredient material parameters, considering the ingredient proportion.

The calibration of the assumed model should be conducted on a representative volume element (RVE) [7]. The model incorporates the well-known solution of numerical analysis for both concrete [5] and mineral-asphalt mix [6]. Such a generalised model takes a random model of material parameters. The simplest direction is to apply random fields of an individually adjusted specimens.

The appropriate material softening model is another key issue, concerning both smeared crack and cohesive joint models. The material parameters were estimated on the basis of experiments and material homogenization attempts.

4. Conclusions

The character of both laboratory testing and numerical analysis is preliminary. In order to precisely assessment the fracture energy the tests are directed on the crack-mouth opening displacement (CMOD).

The models tend to a calibration, considering the notch dimensions, mixture content diversity and the specimen dimensions. An additional issue may concern the temperature impact on the damage process. It is required for the material models to calibrate parameters, by means of averaging the parameters of components.

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