Multiscale fracture modeling of bituminous mixtures – from fatigue behavior to ultimate strength properties of asphalt concrete

Upgrading of requirements concerning energy-efficiency and economy (service life) of intrastructural buildings, together with modern structural design, leads to continuously increasing performace requirements of commonly-used building materials, such as concrete and asphalt. As regards flexible pavements, insufficient knowledge about the thermal, mechanical, and time-dependent material behavior of asphalt lead to the development of a multiscale model for asphalt within the Christian Doppler Laboratory for "Performance-Based Optimization of Flexible Pavements" (installed in 2002) at Vienna University of Technology. The aim of this multiscale model is to relate the macroscopic behavior of asphalt to the material composition and the properties of the constituents at finer scales of observation. The transfer of mechanical properties from one scale to the next higher scale (upscaling) requires appropriate homogenization methods, depending on the material behavior which has to be transferred. On the one hand, upscaling of e.g. elastic and viscous properties of asphalt can be performed by means of averaging in the framework of continuum micromechanics using established analytical schemes. On the other hand, upscaling of damage information and strength properties, as presented in this thesis, is a topic of ongoing research. By introducing microcracks at a respective scale within the multiscale model, damage information can be transferred towards the macroscale, allowing the description of e.g. fatigue behavior. For upscaling of strength properties, on the other hand, numerical methods such as the finite element method or numerical limit analysis approaches have been employed recently.

The first part of this thesis is dedicated to upscaling of strength properties by means of limit analysis, concentrating on the identification of failure modes in composite materials and the transfer of strength behavior from one scale to the next higher scale. The discretized form of limit analyis is applied to 2D and 3D composite material systems. Different strength properties are assigned to the constituents, i.e., to the matrix, the particles, and the interfaces. By means of limit analysis, upper and lower bounds for the effective material strength are computed for different loading situations, giving access to different failure modes and effective failure surfaces of the composite material.

The second part of this thesis is dedicated to modeling of the viscoelastic and fatigue behavior of asphalt. A comprehensive experimental program, used for identification of viscoelastic parameters of a power-law type creep model, is employed. Based on the identified mastic behavior, upscaling is performed from the mastic scale to the macroscale, taking fatigue behavior of asphalt into account. Therefore, a new fatigue model for composite materials (in this thesis applied to asphalt) is proposed, which combines multiscale modeling (continuum micromechanics) with fracture mechanics. This model, requiring no empirical parameter, is validated by means of stress-controlled cyclic-uniaxial-tensile tests.

Finally it can be concluded, that, on the one hand, limit analysis is a suitable tool for upscaling strength behavior of composite materials characterized by a distinct failure mechanism and, on the other hand, the multiscale nature of the proposed fatigue model allows determination of the influence of the mix-design, the material behavior of each constituent, and the type of loading on the overall fatigue performance.