ASPHALT CONCRETE MODELING BY THE MULTISCALE FINITE ELEMENT METHOD

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1. Introduction

Asphalt concrete (AC) is a composite material consisting of a stone aggregate with irregularly shaped, randomly distributed and oriented grains, a bituminous binding agent, air voids as well as further specific additives (the binder mixed with a mineral filler of a very small diameter is called a mastic). In this study, we focus on the AC typical version comprising only the first three constituents. From the road engineer point of view, behavior of this composite is analyzed at the macro resolution. However, all of the phenomena occurring at lower scales should be incorporated in the macro scale analysis. A cumbersome fact is that above mentioned constituents of this heterogeneous compound can be described with different material models. A stone aggregate is typically analyzed as the elastic body [5,10,14], whereas the asphalt binder is usually assumed to behave viscoelastically [5,8,10–12,15] or viscoelastoplastically [2,9]. In complex studies, accumulating fracture damage due to thermal effects [2, 5, 14] is also investigated. Modeling of the mastic-aggregate interface is another demanding aspect [5, 8, 10].

Beside the phenomenological approach, which is costly and time consuming, numerical modeling of asphalt concrete is a very active research field. The developed methods allow to capture the effective response of this material under applied loads. This approach is justified specially in the context of the whole asphalt roadway analysis.

In this study, we focus on the efficient numerical modeling of the AC heterogeneity. Both the aggregate and binder phases are modeled as purely elastic. For the sake of simplicity, air voids and mastic-aggregate interfaces are also ignored. Our main objective is to present the upscaling method for AC taking into account both the randomness and non periodicity of its micro structure (c.f. [13]).

2. Methodology

In order to analyze the asphalt mix at the macro resolution, we use the multiscale finite element method (MsFEM). Its idea is based on a concept of special shape functions accounting for the material heterogeneity [3, 4] and neither periodicity nor scale separation are requested. Further contribution to the MsFEM was to accommodate it for higher order approximation [1, 7]. The algorithm of the MsFEM consists of three main steps. First, a coarse mesh is generated to discretize the analyzed domain. Subsequently, auxiliary problems (see [1] for details) are solved within every coarse element to assess modified shape functions resulting from the heterogeneity. This step leads to the computation of the effective stiffness matrices by fast algebraic operations without integration. Finally, the coarse mesh (generated at the first step) with these matrices is used to solve the problem of our interest.

The crucial part of this study is also the generation of the random AC micro structure. We propose a new algorithm based on a structured grid instead of the Voronoi diagram that is commonly employed for this purpose (c.f. [12, 13, 15]).

3. Results

We compared the results of the MsFEM and the fine mesh (an extremely refined mesh covering the material heterogeneity) computations. Significant reduction of the degrees of freedom number was observed without severe modeling error introduction.

4. Discussion

The present study is a part of the ongoing research aimed at the effective AC modeling. We demonstrated the applicability of the MsFEM to this scientific problem. The improved homogenization method is very efficient in the case of non periodic domain without a distinctive scale separation. In another paper [6], we presented the application of the MsFEM to non periodic viscoelastic materials with trivial inclusion shapes. Consequently, our further research effort is to verify the algorithm of the random AC generation for purely elastic cases and apply the MsFEM to real-life domains with nonlinear material models.

Acknowledgments The authors acknowledge the financial support of the National Science Center (NCN) under the grant no. UMO-2017/25/B/ST8/02752.

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