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Review

Review on heterogeneous model reconstruction of stone-based composites in numerical simulation

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HIGHLIGHTS

- A thorough review was made on the heterogeneous model of stone-based composites.
- The models can overall fall into two categories: image based model and computer generated model.
- The advantages and limitations of the two types of models were summarized.
- Future research suggestions were presented based on the review results.

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ABSTRACT

Numerical simulation has been widely employed in investigating stone-based composite behaviors. Model reconstruction is a prerequisite step to conduct numerical simulations. The objective of this paper is to provide a comprehensive review on the development of heterogeneous model reconstruction of stone-based composites, in particular, Portland cement concrete and asphalt mixtures. The numerical models mainly refer to discrete element models and finite element models. According to the review results, there are two types of heterogeneous models for stone-based materials based on modeling methods, the image based model and computer generated model. The image based model is obtained through image processing on X-ray or optical images by identifying the different phases in the composite. The computer generated model is obtained by placing computer generated aggregate particles into asphalt or cement matrix. Some subcategories for both the image based and computer generated models were detailed as well. The pros and cons of the image based models and computer generated models were also stated and some suggestions were provided. In general, image based models can capture the detailed geometrical information of each phase, but it is costly and time consuming, and the model accuracy is highly dependent on the image processing techniques. Compared to image based model, the computer generated model is more cost effective and much easier to implement, but the main concern is the accuracy of the aggregate model shapes. Future research directions are also provided based on the authors' views.

Contents

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1. Introduction

Numerical simulation in microscopic scale has been widely employed in investigating stone-based composite behaviors, such as stress-strain relation, fracture behavior, particle deformation, and fatigue behavior. The stone-based composite mainly refer to those composed of aggregate particles and bind matrix, such as cement concrete and asphalt concrete. A prerequisite step of numerical simulation is the microstructural model reconstruction. In the early stages, stone-based composite are regarded as a homogeneous material for easy computation. With the development of model reconstruction techniques, heterogeneous model has been well developed during last two decades. The key concept of heterogeneous model is assign different properties for the aggregates and the binder matrix. Compared to homogeneous model, the heterogeneous model is more consistent with the actual condition so that the results of the numerical simulation shall be more reliable. The objective of this paper is to provide a comprehensive review on the development of heterogeneous model reconstruction of stone-based composites, in particular, Portland cement concrete and asphalt mixtures. Stone-based composites are common construction materials in civil engineering. Generally, stone-based composites refer to materials composed of stone particles and binder matrix (e.g. cement paste or asphalt binder). Numerical simulation is a method to quantitatively analyze the evolution of a physical system. In particular, numerical simulation for stone-based composites analyzes evolutions in particle interaction and deformation, stress distribution, crack initiation and propagation, etc. The widely used simulation methods for stone-based composites include the finite element (FE) method, discrete element (DE) method and computer fluid dynamics (CFD). They have been validated as robust approaches that can achieve required accuracies [1]. Numerical model reconstruction is a prerequisite step for any numerical simulation of stone-based materials. In early stages, homogeneous models were used for simplicity. With the development of simulation techniques, the limitations of homogeneous models have caused more concerns. Therefore, researchers have been seeking approaches to reconstruct heterogeneous models in accurate and easy means. Overall, the existing approaches fall into two categories: the image based model and computer generated model as seen. The computer generated models can be subcategorized into two classes: models with user defined aggregates and models with realistic aggregates. The illustration of the categories are shown in Fig. 1. The detailed overview of each subcategory are presented in the following sections.

2. Image based composite model

Image based models are obtained through image processing on X-ray or optical images. The essential concept of this type of model mainly includes three steps. First, physical samples of stone-based composites are prepared. Then, X-ray or optical scanning is employed to obtain cross sectional or surface images of the specimens of stone-based composites. Next, image processing is conducted to identify different phases from each other (e.g. aggregate particles and air voids). Finally, the geometric information of each phase in the composite is imported into specific numerical simulation tools to reconstruct a numerical model. Optical imaging can only obtain information on the specimen's surface, so it is only used to reconstruct 2D numerical models. On the contrary, X-ray imaging can obtain the internal information of samples, so it can be used for 3D model reconstruction.

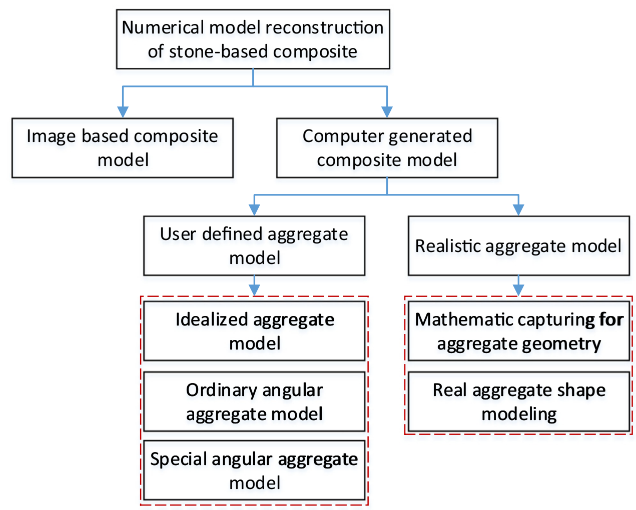

Fig. 1. Categories of numerical model reconstruction for stone-based composites.

2.1. Early stage application of X-ray/optical imaging to characterize stone-based composites

X-ray CT was initially utilized to visualize the internal structures and element distributions of soils and composites in civil engineering in the early 1990s [2–4]. Afterward, the technique was utilized to analyze the internal deformation field of asphalt concrete [5]. A noticeable achievement was made later to visualize the detailed information of aggregate-asphalt interfaces and the air void distribution in asphalt concrete based on two-dimensional (2D) X-ray CT images or optical images [6–10]. At this stage, while the three-dimensional (3D) images can be obtained to visualize the internal structure via the stacking of 2D X-ray CT images, the 3D model of stone-based composites were not available yet. Nevertheless, such achievement can be regarded as the pre-step of the reconstruction of numerical models for stone-based materials. The image processing technique has a curtail influence on internal structure analysis. Overall, image processing techniques include contrast enhancement, noise reduction, gray intensity thresholding, binarization, etc. Binarization based on grayscale intensity can isolate aggregate particles from asphalt and air voids or isolate air voids from solids. It is achieved by setting a threshold gray intensity to isolate different phases. The different colors in numerical images are stored with various grayscale intensities, which normally corresponds to numbers from 0 to 255. With the achievement of phase isolation, aggregate orientations and air void distributions of stone-based composite samples can be investigated, e.g. [7,9,11,12]. It was found that the air voids in asphalt concrete were