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Validation of a synthetic model of hot mix asphalt

Johannes Neumann[1]*, Jaan-Willem Simon[1] and Stefanie Reese[1]

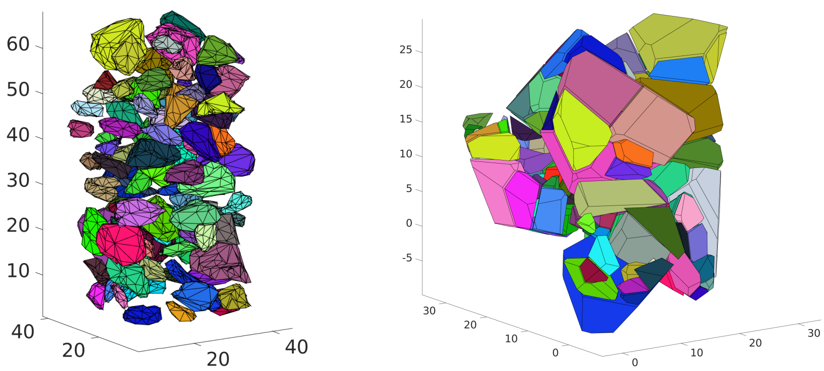
Micro Abstract
We have recently extended a method to obtain 3D synthetic models of hot mix asphalt by capturing the particle size distribution. The model is applied in the context of first-order strain driven homogenisation. The morphological accuracy of the model is compared to XRCT data by means of several common shape measures. Furthermore, the usefulness of the homogenised mechanical properties is assessed by comparing to master-curve data of the mixture scale.

[1]Institute of Applied Mechanics, RWTH Aachen University, Aachen, Germany
***Corresponding author**: jneumann@ifam.rwth-aachen.de

Introduction

A versatile framework for synthetic 3D mesoscale models of hot mix asphalt has recently been proposed [7]. There, different particle size distributions can be matched by a nested Voronoi tessellation algorithm. The mortar phase of a German standard hot mix asphalt is modelled in the linear viscoelastic regime. Effective macroscale properties are derived using first order numerical homogenisation.

Synthetic microstructural modelling of asphalt concrete offers an attractive alternative to image based modelling since its flexibility allows to change geometric properties and run parametric studies without the need to repeatedly prepare and digitise real samples. Some researchers concluded that image based approaches do not deliver more insight into the mechanics of asphalt concrete than synthetic methods do [6]. However, the accuracy of the particle shapes is critical [9].



(a) (b)

Figure 1. Real real mineral aggregate obtained by CT-scanning (a), and synthetic particles from nested Voronoi tessellation (b).

Here, CT-scanned real particle data is compared to data from nested Voronoi tessellation, see Figure 1. Furthermore, the effective properties for a loading frequency of 1 Hz are compared to data available in the literature.

1 Geometric modelling

Being a meso-model, it is necessary to set a size threshold between explicitly modelled geometric entities and smaller particles smeared out in a so called mortar phase. Further uncertainties stem from the volumetric composition of the mortar which severely influences the effective response. A reasonable size-threshold for geometric modelling in Europe is a sieve size of 2 mm. Thus, all particles > 2 mm are modelled explicitly and smaller particles are assumed to form a homogeneous mortar phase together with bitumen, voids, and fibres (mixture dependent), cf. Figure 2.

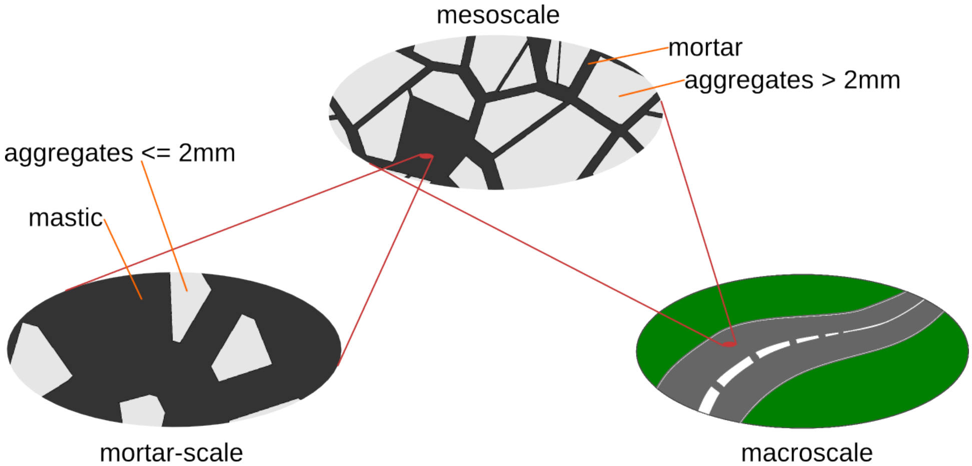


Figure 2. Scale separation used in the present work. Taken from [7].

A 3D Voronoi tessellation is employed to deliver synthetic shapes. Unfortunately, an unmodified VT is rather monodisperse and does not follow any typical asphalt PSD. Therefore, the VT has been nested in order to increse the size spectrum. However, it is yet unknown whether VP are a good approximation of real mineral aggregate used in road construction. In order to assess the suitability of VP, first, real particles are analysed using a CT scan.

1.1 Analysis of CT-scanned real particle data

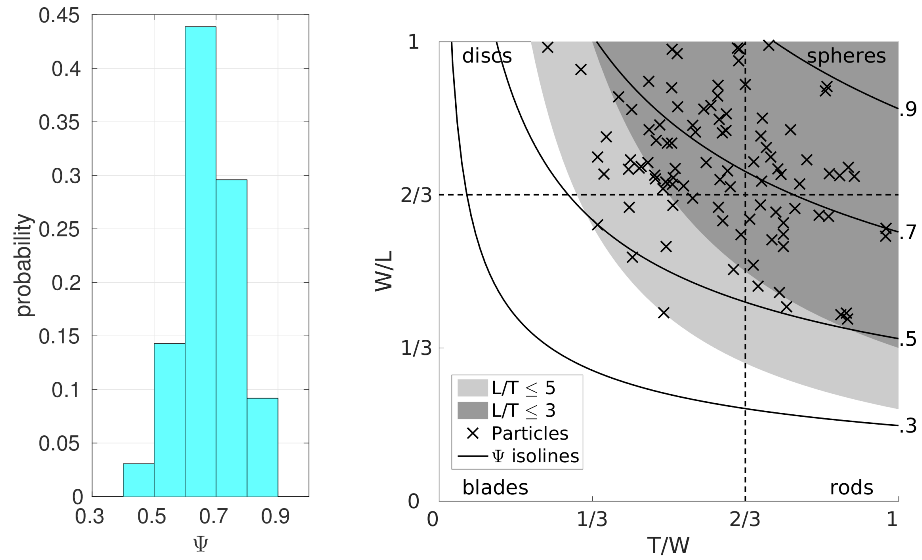
98 particles could be segmented from a CT scan of a mixture with a nominal maximum aggregate size of 13 mm and imported to `Matlab` in `VRML` format. The inertia tensor of each particle is computed using a tetrahedral mesh of the particle domain. After performing principal component analysis (eigenvalue decomposition) of the inertia tensor, the linear dimensions L, W, T are sampled in the directions of the principal axes. The linear dimensions are used as shape descriptors on their own in road engineering [1–3], but they also form a basis for more sophisticated shape measures like the intercept sphericity [5]

$$\Psi = \sqrt[3]{\frac{WT}{L^2}} \,. \tag{1}$$

A histogram of Ψ is depicted in Figure 3(a). The mean sphericity is found to be $\bar{\Psi} = 0.6782$. Zingg's shape classification diagram [10] is used to categorise the occurring particle shapes by means of dimensional ratios, see Figure 3(b). There, it can be seen, that all shape classes are present in the current sample. Hence, synthetic geometries must exhibit a similar shape diversity.

1.2 Analysis of synthetic particle data

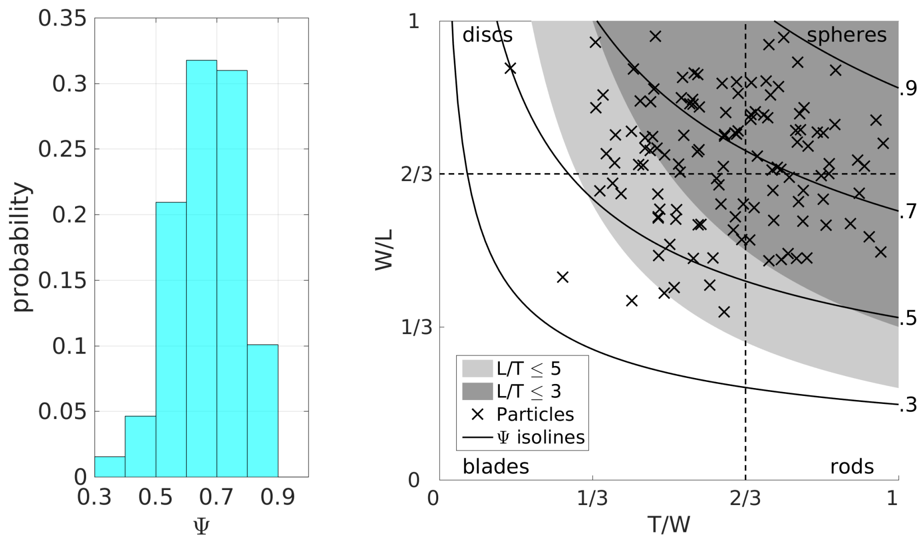
Using the nested VT algorithm, 129 VP are created for the same standard and analysed. Here, the mean sphericity is calculated as $\bar{\Psi} = 0.6658$, which is pretty close to the value reported for



(a) Histogram of Ψ. (b) Zingg's shape classification diagram.

Figure 3. Histogram of Ψ (a), and Zingg's diagram (b) of 98 CT-scanned aggregates.

the real data. Again, the histogram of Ψ and Zingg's diagram are given in Figure 4. It can be seen, that the synthetic shapes are a little more extreme than the real ones, but are generally similar. Furthermore, all shape classes are present in both data sets to a similar extent.



(a) Histogram of Ψ. (b) Zingg's shape classification diagram.

Figure 4. Histogram of Ψ (a), and Zingg's diagram (b) of 129 synthetic polyhedra created through nesting the Voronoi tessellation.

2 Validation of effective properties

Periodic unit cells are generated from the nested VT and first order strain driven numerical homogenisation is performed. Mesh convergence has been confirmed and required domain size for representativeness has been assessed. The mineral aggregate phase is assumed to be linear elastic and the bituminous mortar phase is modelled in a linear viscoelastic fashion. Experimental mortar data has been obtained from dynamic shear rheometry. However, the bitumen content is probably overestimated in the mortar mixture since the amount of adsorbed binder has not been taken into account, cf. [8]. Furthermore, the void content is unknown. In order to assess the validity of the predicted effective properties, our results are compared to other researcher's data, namely that of Karki, Kim et al. [4]. Although their mortar (or fine aggregate matrix) represents a different mixture, effective properties should roughly coincide, see Figure 5.

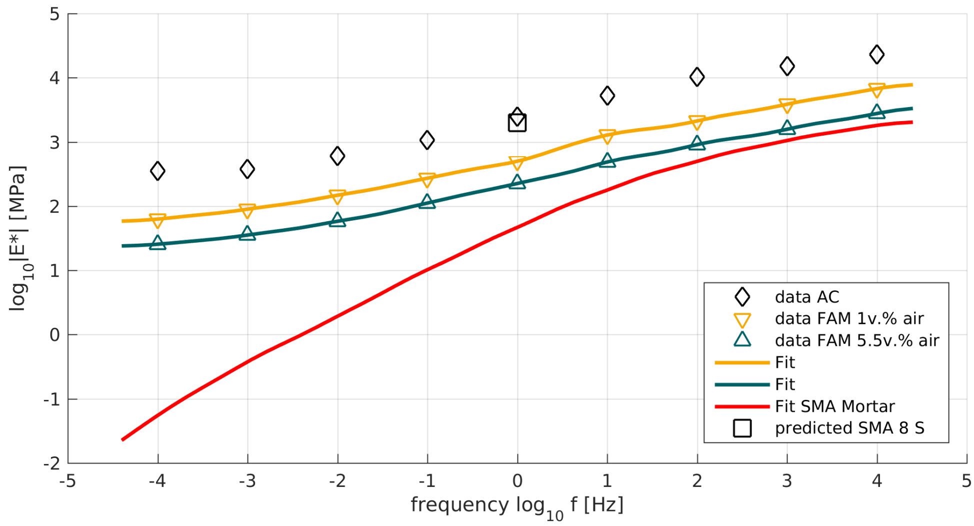


Figure 5. Comparison of our mortar data and the macroscale prediction for 1 Hz to the FAM and AC data of Karki, Kim et al. Data reproduced with permission.

Although our mortar is significantly softer than the one used by Karki, Kim et al., our prediction of macroscale modulus is only slightly below the experimental AC data. It is assumed, that this surprising finding is a result of the different aggregate moduli, E_A, used in the respective studies. We used $E_A = 80\,\text{GPa}$, whereas Karki, Kim et al. used $E_A = 68.4\,\text{GPa}$.

Conclusions

Regarding particle shape, it is concluded that nested Voronoi tessellations offer a suitable alternative to image based modelling. The shape diversity is similar and a similar sphericity is found. Further research should deal with the non-convexity of real mineral aggregate.

In general the agreement in effective macroscale properties looks promising. However, further simulations are needed to validate the results. It is hypothesised that deviations stem mostly from different material data of the involved phases.

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