Discrete Element Modelling of Asphalt Mixture

With the increasing demands for heavy loads, large traffic volume and new tendering schemes, pavement design is now moving towards more mechanistic based design methodologies with the purpose of producing long lasting and high performance pavements. By implementing the cutting-edge technology, discrete element method (DEM), the PhD project regarding the study of mechanical behaviour of asphalt mixture was recently conducted at DTU. Those further insights into the material mechanical behaviour at meso-scale obtained from DEM simulation play an important role in understanding the link between performance and composition characteristics of asphalt mixture.

Approaches for studying asphalt mixture

Asphalt mixture is a complex multiphase material, which is commonly used for pavement structures. The mechanical performance of asphalt mixture is largely dependent on the material properties of its individual components and the way they interact with each other at microscale. Due to its viscoelastic properties, asphalt mixture exhibits time and temperature dependence, which could be characterized by dynamic testing, as shown in Figure 1. Table 1 summarizes different approaches for studying multi-phase materials like asphalt mixture. Compared to experimental testing and empirical methods, which are the traditional way of studying asphalt mixture, advanced numerical modelling provides the possibility of better insight of the material characterization and realistic prediction of cause-and-effect relationships, especially when it is combined with the laboratory test calibration.

Through his PhD project at Technical University of Denmark (DTU), the author studied the viscoelastic behaviour of asphalt mixture by means of discrete element modelling, with the purpose of finding optimization guidance for mix design to reduce pavement rolling resistance. The developed model was calibrated and verified based on laboratory dynamic test data of asphalt mixture. In addition, part of the lab test data was obtained from University of California Pavement Research Center – Davis & Berkeley during a three-month exchange visit there.

Discrete Element Modelling

Asphalt mixture is a typical discontinuous multi-phase material, which mainly comprises mastic, aggregates and air voids.
to the top loading plate, and the response stress $\sigma$ will lag the strain for a linearly viscoelastic material like asphalt mixture, as demonstrated in Figure 2.

2. Next, the geometric model of asphalt mixture was created based on the volumetric properties from the mix design, including the aggregate gradation and the volume ratio between mastic and aggregates. Figure 3 illustrates the developed DEM model, where different components within asphalt mixture were distinguished, including the aggregate, mastic and air void. Within the aggregates, different aggregate fractions could also be grouped and manipulated. The contact between different components could be captured by applying different constitutive models, which were calibrated based on the laboratory test data of the asphalt mixture.

3. Thereafter, the same dynamic test was conducted on the developed numerical model as the tests conducted in the laboratory to the asphalt mixture samples, and eventually the numerical model was verified by comparing the simulation results with those obtained from the laboratory test.

### Better insight

The developed model is able to capture the viscoelastic properties of asphalt mixtures at real traffic loading frequencies. It is possible to access the internal mechanical response of the material at macro-scale inside the flexible pavement structure, and hence the internal stress distribution and relative velocities could be easily monitored and analysed. Based on the developed model, the effect of aggregate gradation, aggregate shape and air void content on the viscoelastic behaviour of asphalt mixture was studied, which provide a better insight into the internal mechanical properties of asphalt mixture. Furthermore, a feasible way to study the correlation between the amounts of dissipated energy and the rolling resistance of asphalt mixtures could be obtained through the developed DEM model. It was found that usage of relative smaller stones is helpful for reducing rolling resistance without sacrificing the overall performance of asphalt mixture.

### Reference:


Table 1: Summary of approaches for studying asphalt mixture.

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<thead>
<tr>
<th>Approach</th>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>Experimental test (Laboratory)</td>
<td>Straightforward; reasonable accuracy</td>
<td>Cost and time consuming; Unable to isolate effect of different components</td>
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<tr>
<td>Empirical method (Laboratory/field)</td>
<td>Convenient to implement</td>
<td>Dependence on similar materials and climate conditions</td>
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<tr>
<td>Numerical modelling</td>
<td>Able to isolate effect of different components</td>
<td>Require skilled man-power; Difficult to calibrate</td>
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Huan Feng’s PhD project was financially supported by the COOEE project and DTU. The COOEE Project focuses on establishing a scientific background for novel pavement types and asset management solutions that minimize the rolling resistance for cars and trucks, and eventually attains the goal of reducing CO$_2$ emission from the transportation sector.