Computation tool development for self-healing asphalt mixture modelling

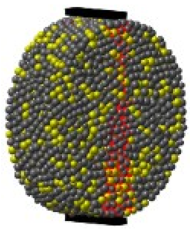
Summary

Asphalt mixture is the most widely used road surfacing material worldwide. This composite has its constitutive behaviour governed by the interactions of the composing materials. Usually, asphalt mixtures are composed of coarse and fine aggregates, bitumen, and air voids. The combination of fine aggregates and bitumen is the so-called asphalt mastic, which is considered the real binder of asphalt mixtures. While aggregates provide structural stability to the mixture, mastic binds the aggregates together. Over the years, flexible pavements are subjected to ageing, traffic load conditions, ambient moisture and temperature changes that might affect their structural integrity. As a consequence, these conditions lead to cracking initiation and propagation along the pavement, water penetration and adhesion reduction between aggregates and binder. Asphalt mastic is a natural self-healing material. However, this property is highly dependent on temperature and traffic load, and over the years the effectiveness of this characteristic is reduced by ageing. In other words, if sufficient time to recover and temperature are provided to the pavement, the binder is able to drain to the micro-cracks. One technique to increase this property in asphalt mastics regards the addition of encapsulated healing agents, *e.g.* sunflower oil, during the mixing process. The capsules release their oil content in the presence of compressive forces generated by the action of stresses acting in the asphalt mixture layer, which dissolves the binder and reduces its viscosity and brittleness. Ultimately, the binder flows into the neighbouring micro-cracks, extending the service life of pavements. In order to investigate the micromechanical behaviour of asphalt mixtures with the presence of encapsulated sunflower oil, this work aims to develop a three-dimensional (3D) numerical model based on the discrete element model (DEM) to simulate damage and the healing mechanism proposed by this technique at different loading and temperature conditions. The DEM model is based on the alternate application of the Law of motion and the Force-displacement law applied to the particles and the contacts of virtual samples, respectively. The method is capable of predicting large displacements, the internal interaction of the elements and the possibility of assigning appropriate microscopic properties to the different components within the asphalt mixtures. The 3D model adopts the Laguerre-Voronoi diagrams of the grain structure of asphalt mixtures to generate polygonal-shaped particles with respect to a defined particle size distribution, taking into consideration radius distribution, porosity, density of particles and dimensions of the virtual specimen.

For the purpose of representing the viscoelastic interaction among the particles, a generalized Kelvin contact model (GK) is developed in two approaches. In the first, a force-displacement incremental formulation method based on the Hereditary Integral formulation is adopted, where the increment in force is resultant from a change in displacement. In the second method, a direct integration of the constitutive equations, using a centred difference scheme, is developed. In general, the contact model is represented by an elastic portion, a viscoelastic portion and a viscoplastic portion and assumes that the total displacement results from the sum of the displacement of the individual components, while the contact force among the elements is equal to one another. Moreover, to simulate the fracture evolution in asphalt mixture structures, a bilinear model and a brittle model in association with the GK model are implemented in order to represent the pre-peak and softening regions in simulations with the presence of damage. With the developed contact models, it is expected to fully comprehend and simulate the 3D microstructure of the asphalt mixture with the presence of healing agents.

Keywords

Asphalt mixtures, asphalt mastic, sunflower oil, healing agent, DEM, viscoelasticity, GK model.



Asphalt mastic with encapsulated healing agents submitted to an IDT test.

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