2006-2201: FEASIBILITY OF VIRTUAL LABORATORY FOR ASPHALT MIXTURES AND PAVEMENTS

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Feasibility of Virtual Laboratory for Asphalt Mixtures and Pavements

ABSTRACT

The objective of this study is to develop a Virtual Testing Laboratory for Asphalt Mixture (VTLAM) in senior undergraduate and graduate student education. The virtual lab is based upon computer simulation, and will be Internet supported. Therefore, in the future, students can access the lab 24-7 (24 hours a day, 7days a week) to conduct test without location limits.

In the computer program, the authors propose to simulate mixture properties using the advanced micro-fabric discrete element method. The program will employ the micro-fabric discrete element method, which has the ability to consider aggregate-aggregate contact by using the distinct/finite element method with the assistance of mixture internal microstructure. The asphalt concrete is a multiphase material which has different properties from the original components which are aggregate, mastic, and air voids. The physical properties and performance of asphalt mixture is governed by the properties of aggregate (shape, surface texture, gradation, skeletal structure -microstructure, modulus, etc.), properties of asphalt binder (grade, complex modulus, relaxation characteristics, cohesion, etc.), and asphalt-aggregate interactions (adhesion, absorption, physio-chemical interactions, etc.). The numerical analysis is based upon the microstructure components of the asphalt mixture. In addition, the aggregate, binder/mastic, and mixture properties will be provided by a database according to different aggregate types and binder grade. The authors will work with local research agencies to establish a comprehensive laboratory database.

The virtual lab will help senior and graduate students to evaluate asphalt mixture performance by calculating the material parameters. In the future, the virtual lab can be used to evaluate and predict asphalt mixture rutting, fatigue cracking, thermal cracking, and other distress. The final target is to help students and engineers in design of asphalt mixture and asphalt pavement when a fully developed virtual laboratory for Asphalt Mixture is established. It is expected that the expanded virtual lab can be used in pavement distress simulation and pavement design in the future. It is also expected that, after the completion of this lab, the education, especially distance learning will become very easy because the students can access the lab without time and location limit.

Backgrounds of Virtual Laboratory for Asphalt Mixtures and Pavements

Paving asphalt concrete is multiphase material which has different properties from the original components—aggregate, mastic, and air voids. The physical properties and performance of HMA is governed by the properties of aggregate (shape, surface texture, gradation, skeletal structure, modulus, etc.), properties of asphalt binder (grade, complex modulus, relaxation characteristics, cohesion, etc.), and asphalt-aggregate interactions (adhesion, absorption, physio-chemical interactions, etc.). The asphalt concrete pavement is a very complicate composite with a gradation of aggregate and a certain amount of asphalt after mechanical compaction. Figure 1 shows the aggregate for typical asphalt mixture, different sizes of coarse aggregate in mixture after image processing, and asphalt mixture construction.

a. Aggregate stockpile b. different aggregate size c. asphalt concrete construction

Figure 1. Asphalt Mixture and Construction

The development of micromechanical models started about a hundred years ago, beginning by Voigt (1889), Einstein (1911), and Reuss (1929). During this time, a number of research studies addressed micromechanical models with both non-interacting and interacting particles. In models with non-interacting particles, geometries were either specified or not specified. Some simple micromechanical models for describing various purposes for different composite materials include Hirsch's Model (Hirsch, 1962), Counto's Model (Counto, 1964), Paul's Model (Paul, 1960), the Arbitrary Phase Geometry Model (Hashin & Shtrikman, 1962), the Composite Spheres Model (Hashin, 1965), the generalized self-consistent scheme model (Kerner 1956, Christensen & Lo, 1986), the Mori-Tanaka model (Mori & Tanaka, 1973), and Christensen et al. model (2003). Recent studies have shown that existing micromechanical models, such as the composite spheres model and the arbitrary phase geometry model, do not adequately describe the complex microstructure of asphalt concrete (Buttlar & You, 2001). Existing micromechanical models are over- or under-predicting the stiffness of asphalt concrete. This is due primarily to the inability of the models to properly predict the contribution of aggregate interlock to the overall response of the mixture. Therefore, a new micromechanical modeling technique for asphalt concrete is needed to improve the understanding of the fundamental properties of asphalt concrete.

Some advanced micro-mechanical modelings are used to study granular materials or asphalt concrete. Kose et al. (2000) and Masad et al. (2002) report the strain distribution within asphalt binders in asphalt concrete using 2D finite element with the linear elastic properties of the binder and aggregate. Chang et al. (1999) also derived an expression for elastic moduli of an assembly of bonded granulates, based on the response of two particles connected by an elastic binder. Chang and Meegoda (1997) proposed a micromechanical model based upon the discrete element method (DEM) to simulate hot mix asphalt (HMA). Rothenburg et al. (1992) developed a micromechanical model for asphalt concrete to investigate pavement rutting. An innovative feature of this research considered inter-granular interactions in the presence of binder and aggregate-binder interaction.

In recent years, microstructure-based micromechanical models were proposed by Buttlar & You, 2001; You & Buttlar, 2002; You, 2003; You & Buttlar, 2004; You & Buttlar, 2005; You et. al., 2005, using discrete element (DE) model and finite element (FE) approaches. The proposed models are novel due to the consideration of the material's true microstructure – including the inclusion of the matrix of the material. In addition, the models allow large displacement between particles in the material, which is desired in engineering, military, and aerospace. The virtual test concept was developed in many areas such as virtual test of nuclear bomb, hospital, museum, and library. A computer simulation using micro mechanics computation is virtually conducted to measure the material properties, simulate an engineering phenomenon, or even a design of asphalt concrete mixture based upon the ingredient. Figure 2 illustrates the general procedure of the virtual laboratory for asphalt mixtures and pavements. In the illustration, asphalt mixture is tested using the virtual laboratory to predict the performance in pavement structure design.

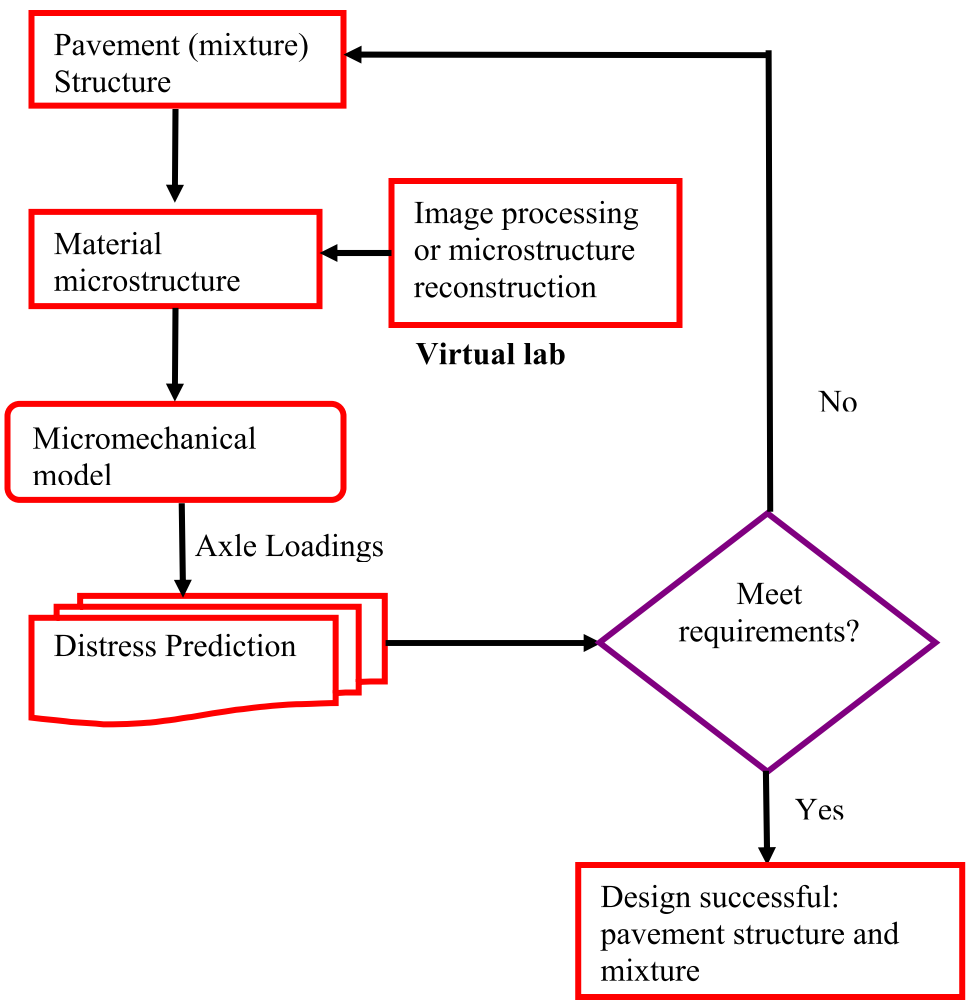
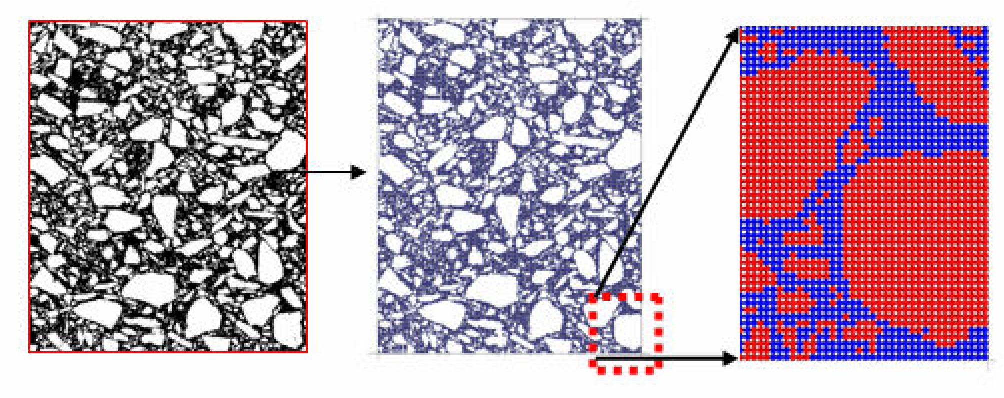


Figure 2. General procedure of the Virtual Laboratory for Asphalt Mixtures and Pavements

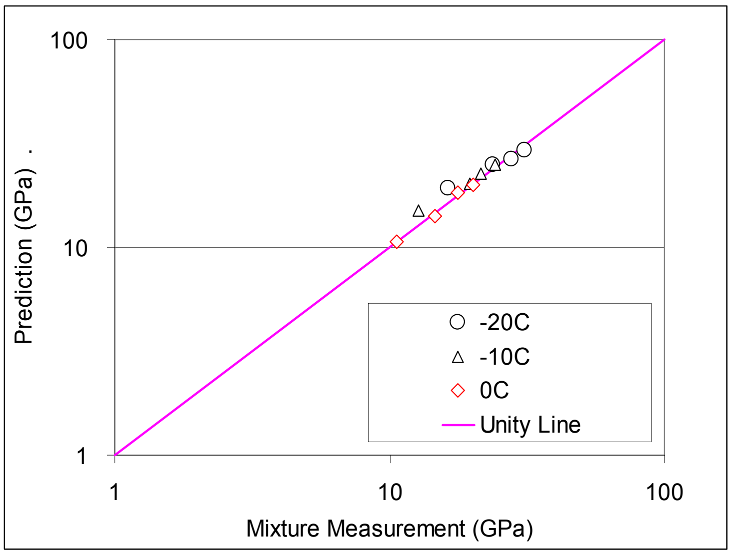
Virtual Laboratory for Asphalt Mixtures and Pavements

In this section, a brief discussion of some preliminary work in the Virtual Laboratory for Asphalt Mixtures and Pavements is provided.

The modeling portion of the work is based upon the microstructure-based micromechanical models proposed by Buttlar & You (2001) and You & Buttlar (2004, 2005, and 2006). The mixture is modeled with a gradation of aggregate and a certain amount of asphalt mastic using discrete elements as shown in Figure 3. In order to model asphalt concrete microstructural features and calculate mixture complex modulus E* across a range of temperatures and loading frequencies, a two-dimensional morphology of the asphalt concrete mixture was first captured with a high-resolution scanner, manipulated using image processing techniques and reconstructed into an assembly of discrete elements. Before imaging, the asphalt concrete were cooled to a low temperature and then sliced in half with a water-cooled masonry saw, producing a smooth surface. The two phases were modeled, aggregate and mastic, where the mastic was assumed to be a combination of asphalt and aggregate finer than 2.36 mm. The dividing line of 2.36 mm was chosen based upon the image processing and modeling capabilities present at the time of this study. It was decided to model the aggregates with size larger than 2.36 mm as aggregate particles and place aggregate materials finer than the 2.36 mm sieve into homogenized mastic. The aggregate particles are usually built with clusters of around 50 to 100 particles depending upon shape. A commercial package, Particle Flow Code in Two Dimensions (PFC2D) is a commercially available discrete element program used in this study to simulate mixture response (particle displacement) to conduct the simulation in this virtual lab environment. The example showing here is a cross-section of a 19-mm nominal maximum aggregate size limestone-dolomite mixture with 4.8% asphalt content. The coarse aggregate (retained on 2.36-mm sieve) volume concentration is 0.55. Figure 3(d) shows the comparison of the E* values obtained in the virtual lab test (DEM simulations) for the mixture with the experimental results. Clearly, a very good correspondence between predicted and simulated results was obtained using the clustered DEM approach. In this particular case, it should be noted that the favorable predictions were obtained without the need for model calibration. A paired t-test analysis indicated with 95% confidence that the E* values obtained from the simulations were statistically similar to the experimental results.



a) Microstructure b) DE Model c) Local DE



d) Complex Moduli Predictions (GPa)

Figure 3: DE Model of a piece concrete pavement surface

The future work will be extended to study the pavement performance based upon complicate modeling procedure. The users will be able to use the World Wide Web to conduct their tests. At this time, several graduate students already used this system to conduct different tests such as compression test of specimen, pavement layers response measurement, and fracture analysis.

Application of the Virtual Laboratory in Graduate Student Projects

The Authors have introduced the application of the virtual laboratory in graduate student projects at Texas A&M University –Kingsville and Michigan Technological University. In Texas, five graduate students completed their master degree research projects using the discrete and finite element modeling simulation and online tools:

- Microstructure modeling of asphalt mixture using finite elements

- Asphalt mastic modulus prediction using discrete and finite element modeling technique
- A simple asphalt pavement overlay model using discrete and finite element modeling technique
- Identification of particle location for a discrete element model (EE department).
- Development of online pavement information system based on WebGIS and Geodatabase for the South Texas Region

In addition, several student papers have been prepared for publication. A Ph.D. student in Michigan Tech is currently conducting further study to develop the virtual lab test procedure so that a friendly user interface and functional predictive tool can be possibly available.

The limitation of current practice is the complicate modeling procedure in the online prediction. The work done in the past is on a personal computer instead of online processing. However, it is feasible to expand the simulation through internet with some additional work. The authors are preparing research proposals for external funding to expand the research topic so that a real time online simulation tool can be developed. The authors are currently working with the researchers in University of Illinois at Urbana-Champaign on these tasks.

Summary and Conclusion

A preliminary study of Virtual Laboratory for Asphalt Mixtures and Pavements is briefly discussed to evaluate asphalt mixture performance. The virtual lab is based upon computer simulation. The authors propose to simulate mixture properties using the advanced micro-fabric discrete element method. The computer program will employ the micro-fabric discrete element method, which has the ability to consider aggregate-aggregate contact with the assistance of mixture internal microstructure. By using the virtual lab, substantial savings in time and money can be reduced in daily physical laboratory tests. In the future, the virtual lab can be used to evaluate and predict asphalt mixture rutting, fatigue cracking, thermal cracking, and other distress. The final target is to help students and engineers in design of asphalt mixture and asphalt pavement when a fully developed virtual laboratory for asphalt mixture is established. It is expected that the expanded virtual lab can be used in pavement distress simulation and pavement design in the future. It is also expected that, after the completion of this lab, the education, especially distance learning will become very easy because the students can access the lab 24-7 (24 hours a day, 7days a week) without location limits.

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