Predicting The Durability Of Bitumen And Asphalt-based Pavements Using Multiphysics Modeling

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Abstract

Bitumen and asphalt durability is a critical concern in pavement engineering, particularly in the context of sustainability and carbon footprint reduction. Accurate prediction of the lifespan of these materials is essential for life cycle assessment (LCA) from cradle to grave. However, direct measurement of pavement lifespan through field or laboratory testing is challenging. This study proposes a simulation-based approach using COMSOL Multiphysics® to model the behavior of bitumen and asphalt under real-world conditions, incorporating relevant physical phenomena that influence material degradation.

The objective is to develop a predictive model for damage evolution and service life of pavements, using experimental data on bitumen and asphalt properties. The model integrates heat transfer and oxidation kinetics to simulate the thermal and chemical aging of bitumen, and couples these effects with a viscoelastic continuum damage (VECD) model to assess mechanical degradation over time. The simulation setup involves solving 1D heat transfer and oxidation equations along with a 2D Fourier finite element (FFE) [1] formulation for the solid mechanics problem featuring the viscoelastic continuum damage model. The latter approach allows resolving the 3D response under periodic traffic loads in a numerically efficient way. The viscoelastic continuum damage model is implemented as a dedicated physics interface tightly coupled to the underlying Solid Mechanics interface. Moreover, meteorological data from the ASHRAE database available from the Heat Transfer Module is used to drive the thermal boundary conditions in the heat transfer problem.

The resulting model enables comparative simulations of different bitumen formulations, linking laboratory performance metrics to field durability. This comprehensive approach captures the interplay of thermal, chemical, and mechanical processes affecting pavement longevity. The model serves as a valuable tool for decision-makers, facilitating the evaluation of material choices based on durability, environmental impact, and total cost of ownership.

In conclusion, this work demonstrates the potential of multiphysics modeling in COMSOL to support sustainable infrastructure design by enabling predictive damage analysis of pavement materials.

Reference

[1] M. Eslaminia, N. Guddati. Fourier-finite element analysis of pavements under moving vehicular loading. International Journal Of Pavement Engineering; Vol. 17, No. 7. pp. 602-614. 2015.

Figures used in the abstract

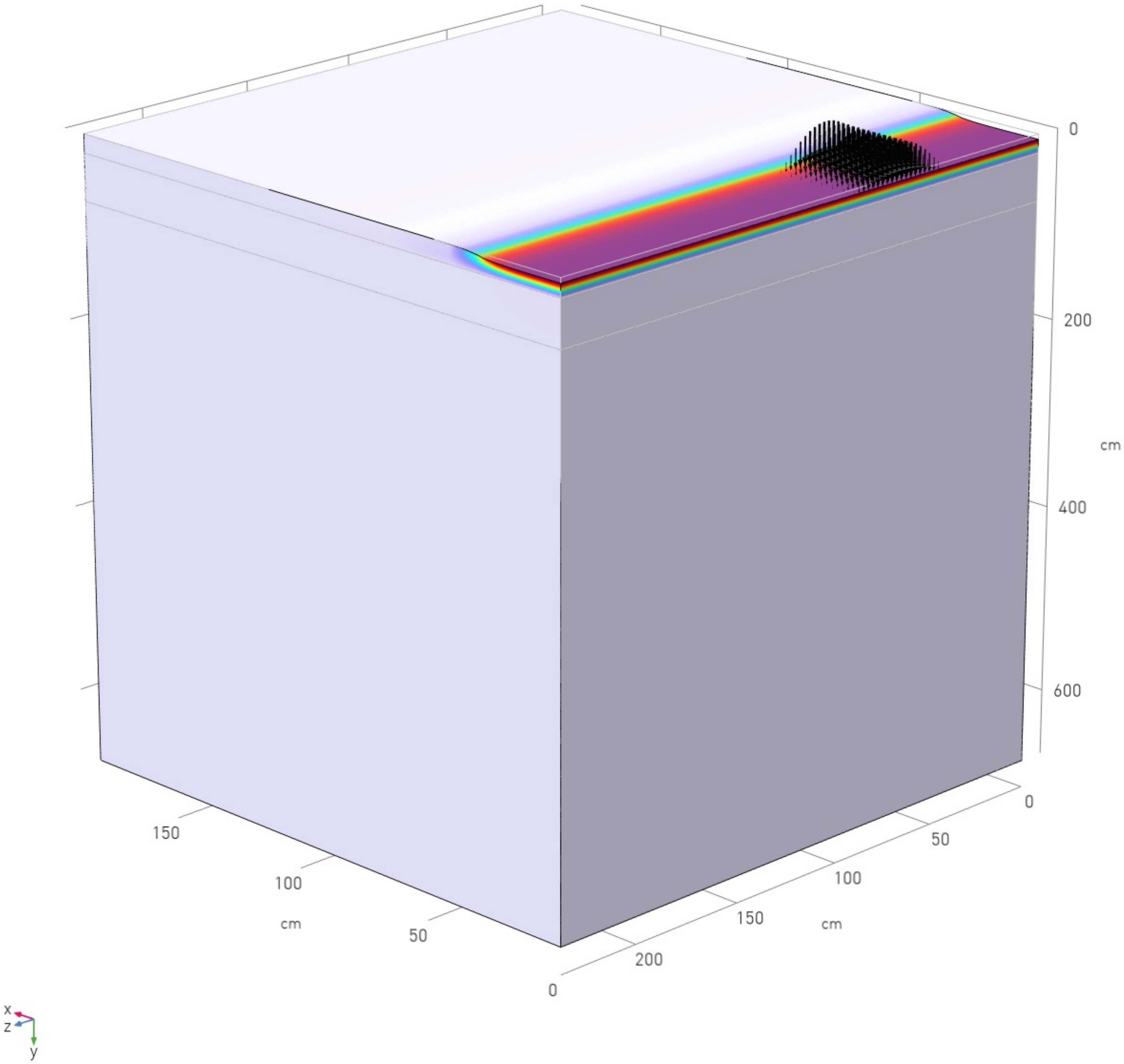

Figure 1 : Vertical displacement of aged asphalt-based pavement structure under traffic loads