PhD Research Proposal – INSA Strasbourg / ICube-GCE

Multiscale Numerical Simulation of Tire - Pavement Contact for the Study of Degradation in Low-Carbon Road Infrastructures

Abstract

In the context of transport infrastructure decarbonization and increasing constraints on road network maintenance, this project aims to develop a three-dimensional modeling framework to assess the durability of wearing courses made from low environmental impact materials, incorporating high proportions of reclaimed asphalt pavement (RAP).

The proposed approach is based on a multiscale numerical modeling strategy coupling Contact Dynamics and the Finite Element Method (FEM), in order to realistically represent the effect of rolling loads on the mechanical behavior and damage evolution of bituminous materials. Simulations, performed using the LMGC90 computational code and incorporating a nonlinear viscoelastic contact law calibrated from experimental data, will enable the analysis of rutting and raveling mechanisms at both the micro- and macroscopic scales.

Building on multiscale experimental data obtained within the ANR Binary project, this work ultimately aims to provide predictive models of wear and degradation, contributing to the eco-design and optimization of sustainable, low-carbon road structures.

Candidate Profile

This project requires expertise in numerical simulation (DEM and/or FEM), continuum mechanics, constitutive laws for construction materials, and structural modeling. Basic knowledge of the Python programming language would be an asset. Applicants must hold a Master's degree in numerical mechanics or civil engineering.

Supervision

Juan Carlos Quezada (Associate Professor – HDR, ICube/GC-E)

Location

ICube/GC-E – INSA Strasbourg

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Application

To apply, please visit: https://amethis3.unistra.fr/amethis-client/prd/consulter/offre/770

(Application deadline: May 19, 2026)

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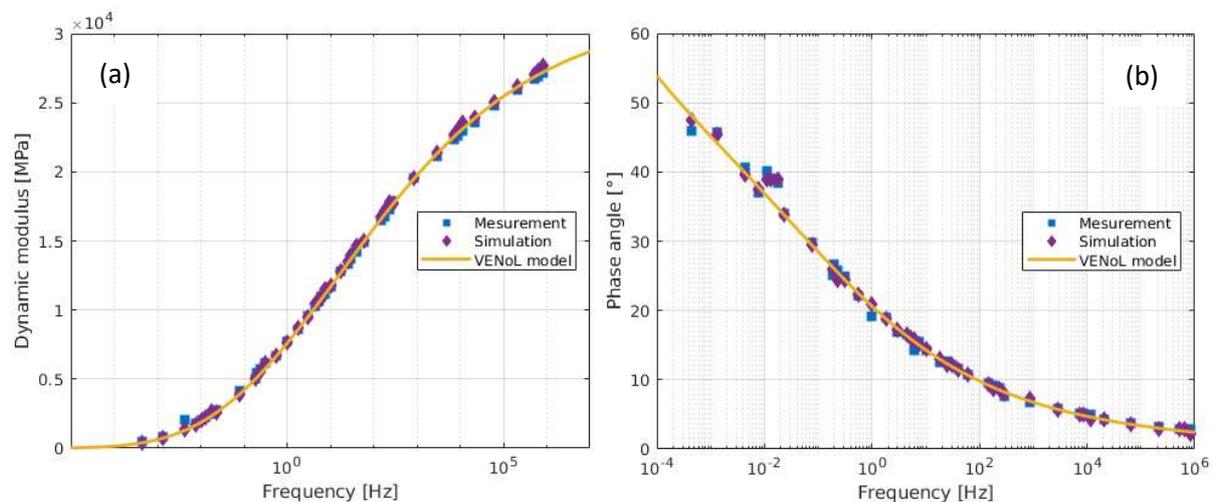Tél. +33 (0)3 88 14 47 00 - Fax + 33 (0)3 88 24 14 90
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Multiscale Numerical Simulation of Tire–Pavement Contact for the Study of the Degradation of Decarbonized Road Infrastructure

In a context marked by the aging of road networks and a reduction in the resources allocated to their maintenance, the decarbonization of transport infrastructure has emerged as a major challenge. In this perspective, the use of recycled materials in cold-mix formulations, such as emulsion-based asphalt (Projet National IDEE, 2024–2028) or alternative binders of plant origin constitutes a promising direction for the future of road construction (Synthesis for FNTP, Carbone 4, OFCE, NEO, 2021). These solutions contribute significantly to reducing the carbon footprint associated with the construction and maintenance of transport infrastructure.

It therefore becomes necessary to develop increasingly efficient, durable, and environmentally sustainable construction solutions. At present, for surface courses, the uppermost layers of pavements-regulatory requirements exist concerning friction, texture, and evenness. However, no standards or design methodologies currently enable a precise characterization of the mechanical properties ensuring the durability of these layers, despite their direct exposure to traffic loads. Recent research has thus focused on modeling and understanding the relationships between rolling loads, considered as dynamic solicitations, and the degradation mechanisms observed within road infrastructures.

Within this framework, the present project aims to develop a three-dimensional modeling approach to assess the effect of rolling loads on the service life of surface courses in transport infrastructure constructed from low environmental impact materials, incorporating high proportions of reclaimed asphalt pavement (RAP), as part of an eco-design optimization strategy.

Numerical simulations will be carried out using the Contact Dynamics (CD) method applied to rigid particles. This method relies on a discrete approach for simulating the dynamics of irregular granular media [1]. The LMGC90 software will be used for the numerical simulations; it enables the modeling of assemblies of rigid or deformable particles with various shapes through different algorithms [2]. In order to represent the behavior of bituminous materials, a nonlinear viscoelastic contact law has been implemented in this code. The developed contact model combines the original formulation of the CD method for rigid particles, ensuring the non-interpenetration condition, with a viscoelastic model acting at distant contacts. For the viscoelastic component of the contact law, the VENoL model [3] will be employed, as it is capable of reproducing the viscoelastic behavior of bituminous materials. Ongoing work conducted at the ICube laboratory of INSA Strasbourg demonstrates that this viscoelastic contact law successfully captures the rheological properties of bituminous materials, such as the evolution of the complex modulus and phase angle as functions of frequency and temperature [3–6] (see Fig. 1).

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Figure 1: Master curves of the complex modulus derived from experimental tests and numerical simulations for a two-point bending complex modulus test configuration (2PB), for different particle shapes (T_ref = 15 °C), and comparison with the VENoL model: (a) Magnitude of the complex modulus; (b) Phase angle [4].

In order to analyze the behavior of recycled materials in cold-mix formulations, the parameters of the viscoelastic contact laws will be calibrated based on the master curve of these materials. Subsequently, relying on the Time–Temperature Superposition Principle (TTSP), the parameters of the contact law may be extrapolated. These calibrated parameters will then be incorporated into a multiscale FEM/DEM modeling framework implemented using the LMGC90 code [7, 8].

Within this approach, the surface course will be simulated using the Contact Dynamics (CD) method with a viscoelastic contact model, while the base and subbase layers will be modeled using the Finite Element Method (FEM). Traffic loading will be represented by a force field reproducing the tire footprint applied on the surface of the pavement layer (see Fig. 2). An enhanced representation of tire–pavement contact is envisaged through coupling between a continuum approach (FEM), used for the tire, and the Contact Dynamics method for the surface layer, or alternatively through a fully discrete approach involving discretization of the tire within the contact zone.

The measurement of inter-particle forces generated between aggregates will enable the identification of stress distributions at the macroscopic scale within pavement layers. At the micromechanical scale, this approach will allow the identification of critical zones where rutting and surface cracking are most likely to initiate and develop. These insights will support the development of predictive models for wear and damage of surface layers, as functions of rutting and particle detachment processes.

To achieve these objectives, the study will initially rely on experimental investigations carried out במסגרת the ANR Binary project (2020–2025), conducted in partnership with INSA Strasbourg and Gustave Eiffel University (UGE) in Nantes. These experiments focus on virgin bituminous materials and have been performed in the laboratory at multiple scales, ranging from microscopic-scale tests (Rulob) to laboratory structural tests, such as the WTT (Wheel Tracking Test) and the T2R (Triboroute braking/acceleration test) (Triboroute, 2010; CEN TC227, 2014).
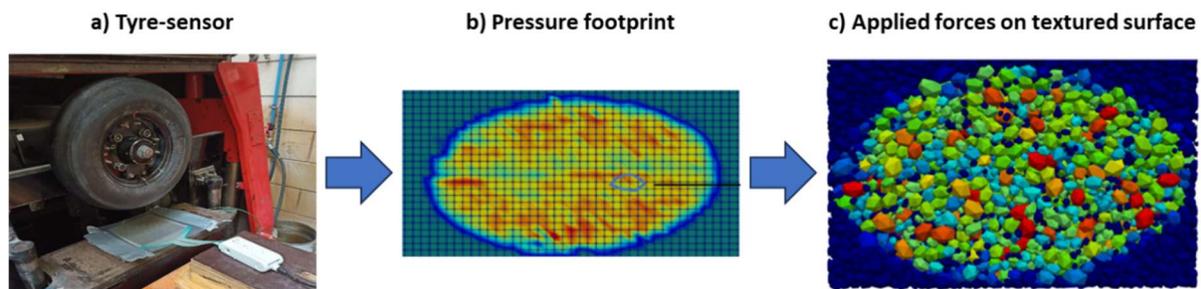
Figure 2: Schematic representation of the tire–sensor–CD coupling chain with application of contact forces on a textured surface. (a) Measurement of tire–sensor pressure. (b) Construction of the force matrix from pressure footprint data. (c) Application of vertical forces at the surface of particles in the Contact Dynamics simulation [6].

References

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