Complementary information

Supervisors: Pr. C. Chazallon - https://www.researchgate.net/profile/Cyrille-Chazallon

Dr. G. Koval - https://www.researchgate.net/profile/Georg-Koval

Institution: INSA Strasbourg

Department: Civil Engineering and Topography

Laboratory and Research team: ICube – GC-E

E-mail: cyrille.chazallon@insa-strasbourg.fr

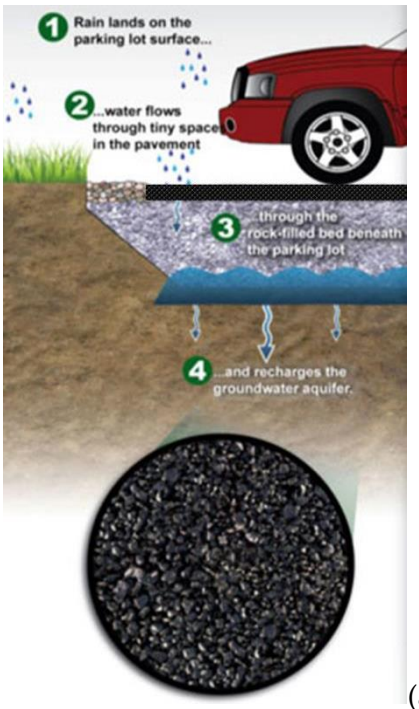
georg.koval@insa-strasbourg.fr

Detailed description of the research work proposed for a PhD

Title: Modelling water flow and sediment transport in porous asphalt by DEM/CFD coupling

1. Background

In recent years, cities worldwide have faced an escalating risk of pluvial flooding and its repercussions, primarily due to climate change-induced extreme precipitation events and urbanization. Flooding is a common natural disaster worldwide, foreseeing increased frequency due to climate change. Porous Asphalt (PA) pavements offer a promising solution, initially designed for motorways but now recognized for urban use. They efficiently manage stormwater runoff, mitigating flood risk while being cost-effective and eco-friendly (see Figure 1). However, the impact of water pressure and flow on PA pavement durability remains unclear, necessitating further research. Clogging, caused by void blockages and pollution accumulation, undermines drainage capacity, posing a significant challenge. Research efforts focus on understanding clogging mechanisms and developing resilient PA mixtures to reduce flood risk without compromising durability. Developing a robust model for permeability based on porosity and associated sediment mass balance facilitates the extrapolation of results beyond laboratory's experiments. This allows the analysis of asphalt concrete with different porosities, water flow velocities, and solid concentrations. The derivation of general and simplified equations related to measurable system quantities (porosity, permeability, granulometry, fluid flow, solid concentration, etc.) is a crucial tool for the design of PA pavements.



(a)

(b)

Figure 1 – (a) Scheme of a typical porous asphalt pavement and (b) a real example [1].

2. Objectives of this work

- Develop a numerical model to simulate water flow (computation fluid dynamics - CFD) through permeable pavements coupled to discrete element modelling (DEM) to describe the granular material structure and sediments.
- Incorporate factors influencing clogging, including sediment transport and pollutant accumulation and their effect on structure permeability.
- Investigate the impact of different pavement materials and designs on clogging susceptibility.
- Validate the model using experimental data from our tests..

3. Numerical approach

The impact of clogging on pavement permeability, will be held through Discrete Element Modeling (DEM) for granular material structure and sediments, and the simulation of water flow through PA pavements using Computational Fluid Dynamics (CFD). The solid and fluid equations will be coupled in order to define permeability of PA pavements.

The PA pavement will be described as a porous medium composed of solid particles bounded together by asphalt binder. Water charged with sediments flow through the connected pores of this medium. Two phases will be described: solid (asphalt concrete and sediments) and fluid (water). The solids will be modeled using the Discrete Element Method (DEM) [2, 3, 6], which can easily handle the motion of a very large number of particles. Cohesive interactions between asphalt concrete particles will be considered. Sediments interact through simple

elastoplastic (frictional) contacts [4]. Particle calculations will be performed using the open-source DEM code YADE or PFC from ITASCA.

The fluid, averaged over the pores, will be described using a Computational Fluid Dynamics (CFD) scheme. Equations of continuity and fluid motion (Navier-Stokes) define the fluid flow. Fluid calculations will be conducted using the open-source CFD software OpenFOAM.

A quantitative assessment of the evolution of the permeability depends on the characterization of the interactions between solid and fluid phases in more complex porous materials (see an example of a granular matrix composed by particles of different shapes in Figure 2). A comparison with experimental results from literature will allow the calibration of these parameters, a major element for the numerical description of the loss of permeability during clogging process.

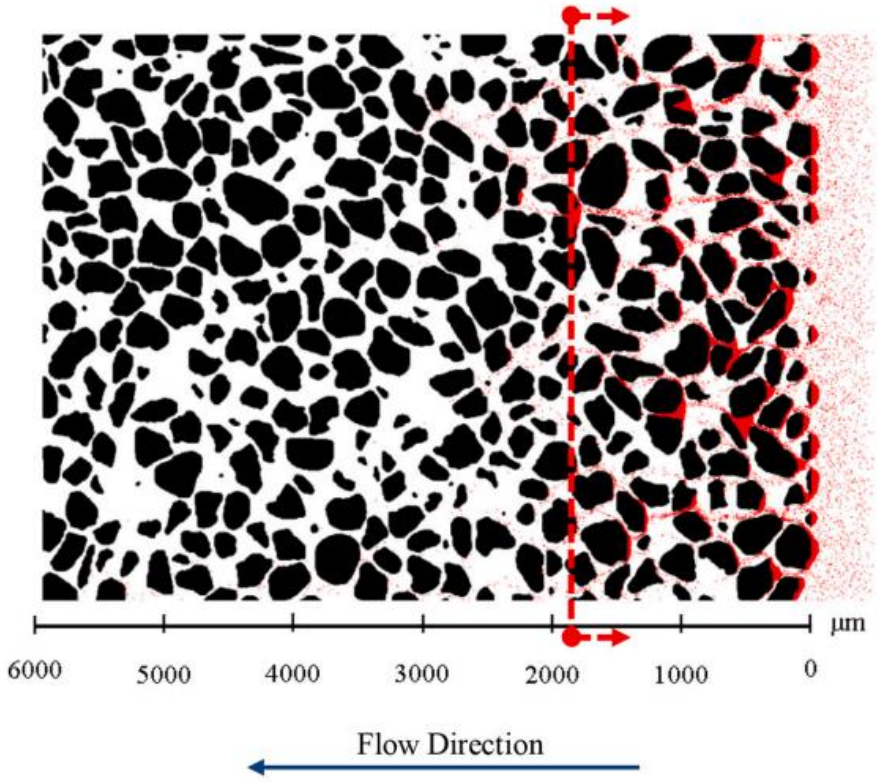


Figure 2 - Illustration of clogging is taking place in simulations from [5].

4. References

[1] Porous Asphalt Pavements, *Virginia Asphalt Association*. http://vaasphalt.org/pavement-guide/porous-asphalt-pavements/, consulted in 17th April 2024.

[2] P.A. Cundall and O.D.L. Strack (1979). A Discrete Numerical Model for Granular Assemblies. *Geotechnique*, 29, 47-65. DOI: 10.1680/geot.1979.29.1.47

[3] G. Koval, J.-N. Roux, A Corfdir and F. Chevoir (2009). Annular shear of cohesionless granular materials: From the inertial to quasistatic regime. *Physical Review E*, v. 79, p. 021306. DOI: 10.1103/PhysRevE.79.021306.

[4] K. Kamrin and G. Koval (2014). Effect of particle surface friction on nonlocal constitutive behavior of flowing granular media. *Computational Particle Mechanics, v.* 1, p.p. 169–176. DOI: 10.1007/s40571-014-0018-3.

[5] A. Elrahmani, R. I. Al-Raoush and T. Seers (2023), Clogging and permeability reduction dynamics in porous media: A numerical simulation study. *Powder Technology*. DOI:10.1016/j.powtec.2023.118736

[6] J. Hu, T. Ma, K. Ma, DEM-CFD simulation on clogging and degradation of air voids in double-layer porous asphalt pavement under rainfall, Journal of Hydrology Volume 595, April 2021, 126028

Keywords: pavements, asphalt concrete, permeability, DEM, CFD.

Scientific competences: During the PhD work the student will acquire deep experience in multiphysics simulations like multi-particle modeling and fluid dynamics. Computational competences will be developed (notably in Python). The proposed work will be also an opportunity to deal with high level pavement engineering.

Background required from the applicant: We are looking for applicants interested on the study of materials and structures. Computer skills and previous experiences in one (or more) of the mentioned fields are welcome, but not mandatory.

Curriculum vitae
Pr. Cyrille CHAZALLON
INSA de Strasbourg
ICUBE-UMR 7357, INSA de Strasbourg
Team Energy and Civil Engineering
24 Boulevard de la Victoire
67084 Strasbourg cedex
☎ Bureau: + 33 3 88 14 47 66
cyrille.chazallon@insa-strasbourg.fr
http://icube-gc.unistra.fr/index.php/Accueil

2010 - present : **Professor** INSA de Strasbourg

Associate editor of the International Journal of Road materials and Pavement Design, Ranking (2022) Civil and Structural Engineering : 48/350 / Q1

Leader of Energy and Civil Engineering team (https://icube.unistra.fr/en/)
Leader of Materials and Structures of Civil Engineering group with H. Nowamooz, G. Koval, S. Mouhoubi, J.C. Quezada
Current phd students : D. Liu, Z. Chen, O. Hammoud, L. Coulon

- *Current accepted international journal papers*

2025
Wang, C., Chazallon, C., Hornych, P., Mouhoubi, S., Jing, P., Effect of self-cementing properties on the resilient behaviour of recycled concrete aggregates used in base and subbase
Road Materials and Pavement Design, 2024, DOI: 10.1080/14680629.2024.2302804

2024
Chong Wang, Cyrille Chazallon, Sandrine Braymand, Pierre Hornych,
Thermogravimetric analysis (TGA) for characterization of self-cementation of recycled concrete aggregates in pavement, Thermochimica Acta, Volume 733, 2024, 179680,https://doi.org/10.1016/j.tca.2024.179680.

2023
A. Dansou, S. Mouhoubi, **C. Chazallon**, M. Bonnet
Modelling of the fatigue cracking resistance of grid reinforced asphalt concrete by coupling fast BEM and FEM, *Road Materials and Pavement Design*, Pages: 631-652 | DOI: 10.1080/14680629.2022.2029755 Taylor & Francis (IF : 3.792, SNIP : 1.789, SJR : 1.14)

C. Wang, C. Chazallon, P. Hornych , S. Braymand
Influence of self-cementing properties on the mechanical behaviour of recycled concrete aggregates under monotonic loading, *Construction and Building Materials*, Elsevier (IF : 6.141, SNIP : 2.483, SJR : 1.662), page 130259, Volume 367, n° 27, février 2023, *doi:https://doi.org/10.1016/j.conbuildmat.2022.130259*

H. Ge, J-C. Quezada-Guajardo, V. Le Houerou, **C. Chazallon**
Three-dimensional FEM-DEM coupling simulation for analysis of asphalt mixture responses under rolling tire loads, *Construction and Building Materials*, Elsevier (IF : 6.141, SNIP : 2.483, SJR : 1.662), page 130615, Volume 369, 2023, *doi:https://doi.org/10.1016/j.conbuildmat.2023.130615*

Ge, H., Quezada, J.C., Le Houerou, V., **Chazallon, C.**, Hornych, P.

A new tire-sensor-pavement coupling chain for investigating asphalt mixture responses under rolling tire loads, ***Road Materials and Pavement Design,*** 2023, 24(S1), pp. 245–262, DOI: 10.1080/14680629.2023.2180833

Wang, C., Chazallon, C., Hornych, P., Braymand, S.
Permanent and resilient deformation behaviour of recycled concrete aggregates from different sources, in pavement base and subbase, ***Road Materials and Pavement Design***, 2023, 24(9), pp. 2245–2262, DOI: 10.1080/14680629.2016.1259123

Wang, C., Chazallon, C., Jing, P., Hornych, P., Latour, B.,
Effect of self-cementing properties on the mechanical behaviour of recycled concrete aggregates in unbound pavement layers, ***Transportation Geotechnics***, 2023, 42, 101054, https://doi.org/10.1016/j.trgeo.2023.101054

L. Coulon, G. Koval, **C. Chazallon** & J.-N. Roux (2023): Analytical modelling of complex stiffness modulus tests in direct tension-compression on asphalt concrete and nonlinearity effect due to strain amplitude, Road Materials and Pavement Design, Volume 24, Issue 1, pages 216-246, DOI: 10.1080/14680629.2021.2014349

PUBLISHED PAPERS

	Total	**2018 to 2025**
International journal papers	**65**	**31**
National journal papers	**11**	**9**
International conference papers	**76**	**28**

International scientific activities

- **Leader of the european project Interreg-V :** ORRAP (2016-2020)
- **Partner of the following European projects :** TEM^3 (2010-2014) Interreg-IV, Direct-Mat (2007-2010) FP7th , COST 337 (2000-2003) and COST 351 (2004-2008)
- **High-end foreign expert, Shandong University** (Jinan), Chine, (2015 – 2021).

National scientific activities

- **Leader of the National Research Agency (NRA) projects :** SolDuGri (2014-2019), BINARY (2019-2024)
- **Partner of NRA :** MoveDVDC (2018-2022)
- **Partner of national project :** DVDC (2106-2022), ISSU (2024-2027)

Phd supervisors, Habilitation to conduct research (HCR), Reviewer (phd and HCR)

	Total	**2018 à 2025**
Phd. Supervised and defensed Currently 4 phd supervised	**19**	**8**
Reviewer : PhD. / HCR	**18 / 4**	**10 / 3**
Jury : PhD. / HCR	**4 / 2**	**1 / 0**

Georg KOVAL
Associate Professor

Phone. : (33) 03 88 14 47 84
E-mail : georg.koval@insa-strasbourg.fr
https://orcid.org/0000-0001-9939-7420
https://www.researchgate.net/profile/Georg_Koval

Institut National des Sciences Appliquées de Strasbourg

24, Boulevard de la Victoire
67084 Strasbourg – France

EDUCATION AND PROFESSIONAL EXPERIENCE

09/2009 – present **Associate professor** – National Institute of Applied Sciences (INSA) of Strasbourg, Department of Civil Engineering and Topography, France.

10/2008 – 08/2009 **Lecturer** – National Institute of Applied Sciences (INSA) of Strasbourg, Department of Civil Engineering and Topography, France.

01/2008 – 09/2008 **Post doctorate** – Title: *Fluidization of saturated granular materials: effects of fluid sources and seismic waves.* Institute of Earth Physics of Strasbourg (IPGS), France.

10/2004 – 01/2008 **PhD in Civil Engineering** – Discipline: Materials and Structures. Title: *Interface behavior of granular materials*. École des Ponts ParisTech (ENPC), France.

10/2003 – 06/2004 **Master** – Solid Mechanics, Materials, and Structures (MSMS). Option: Mechanics and Materials. École des Ponts ParisTech (ENPC), France.

03/2001 – 08/2003 **MSc in Structures** – Title: *Application of homogenization theory to viscoelastic composites*. Federal University of Rio Grande do Sul (UFRGS), Brazil.

03/1996 – 12/2000 **Civil Engineer** – Federal University of Rio Grande do Sul (UFRGS), Brazil.

SCIENTIFIC PRODUTION

- Papers in international journals: 20
- International communications: 8
- Citations (ResearchGate) : 972
- H-index (ResearchGate): 12

5 MAJOR PUBLICATIONS

K. Kamrin, G. Koval, Nonlocal constitutive relation for steady granular flow, *Physical Review Letters*, vol. 108, num. 17, 2012. DOI: 10.1103/PhysRevLett.108.178301 (469 citations)

G. Koval, J.-N. Roux, A. Corfdir, F. Chevoir, Annular shear of cohesionless granular materials: From the inertial to quasistatic regime, *Physical Review E*, vol. 79, num. 2, 2009. DOI: 10.1103/PhysRevE.79.021306 (157 citations)

K. Kamrin and G. Koval, Effect of particle surface friction on nonlocal constitutive behavior of flowing granular media, *Computational Particle Mechanics*, vol. 1, num. 2, 2014.
DOI: 10.1007/s40571-014-0018-3 (70 citations)

G. Koval, F. Chevoir, J.-N. Roux, J. Sulem, A. Corfdir, Interface roughness effect on slow cyclic annular shear of granular materials, *Granular Matter*, vol. 13, num. 5, 2011.
DOI: 10.1007/s10035-011-0267-2 (42 citations)

X. Gao, G. Koval, C. Chazallon, Energetical formulation of size effect law for quasi-brittle fracture, *Engineering Fracture Mechanics*, vol. 175, 2017.
DOI: 10.1016/j.engfracmech.2017.02.001 (29 citations)

RESEARCH PROJECTS

SOLDUGRI – For a sustainable solution for infrastructure reinforcement using fiberglass grids. ANR Project. 01/01/2015 – 31/12/2019. Project Leader: INSA de Strasbourg (C. Chazallon).

ORRAP – Optimal recycling of asphalt concrete aggregates in low-traffic roadways. European Project – Interreg-V Upper Rhine. 01/11/2016 – 31/10/2019. Project Leader: INSA de Strasbourg (C. Chazallon).

MOVEDVDC – Modeling of aging and damage for the assessment of pavement service life. ANR Project. 02/01/2018 – 31/12/2021. Project Leader: IFSTTAR (P. Hornych).

SCIENTIFIC SUPERVISION

Léo Coulon, Multiphysical modeling of damage and aging in asphalt pavements. Thesis defended on July 12, 2023. MSII Doctoral School, ICUBE Laboratory. Thesis Co-Directors: C. Chazallon and J.N. Roux.

Lei Ma, Modeling of damage and cracking in asphalt pavements. Thesis defended on December 06, 2022. MSII Doctoral School, ICUBE Laboratory. Thesis Co-Directors: C. Chazallon and Y. Descantes.

Guixian Liu, Discrete modeling of asphalt pavements reinforced with fiberglass grids. Thesis defended on May 23, 2019. MSI Doctoral School, ICUBE Laboratory. Thesis Co-Directors: C. Chazallon and A. Daouadji.

Xiaofeng Gao, Model for predicting the nominal strength of quasi-brittle materials: application to the modeling of damage and rupture of asphalt pavements under fatigue loading using the discrete element method. Thesis defended on March 06, 2017. MSII Doctoral School, ICUBE Laboratory. Thesis Co-Directors: C. Chazallon and Y. Descantes.

Ba Danh Le, Discrete modeling in mechanics of fracture of brittle materials. Thesis defended on June 07, 2013. MSII Doctoral School, ICUBE Laboratory. Thesis Supervisor: C. Chazallon.