Call for applications: PhD in computational mechanics

Title: Multi-scale mechanisms of thermo-mechanical frictional contact
Scientific advisers: V.A. Yastrebov, C.M. Ovalle Rodas, S. Forest
Period: Oct 1, 2020 - Sep 30, 2023 (36 months, Open-PhD funded by MINES ParisTech)
Laboratory: MINES ParisTech, PSL University, Centre des Matériaux, CNRS UMR 7633, Evry, France (35 km from Paris)
Keywords: contact mechanics, roughness, multiphysical coupling, multiscale, thermomechanics, friction, nonlinear materials, mortar method

Context

The frictional contact force observed in engineering systems represents a macroscopic quantity resulting from an interplay of many microscopic mechanisms. Understanding the origins of friction and the possibility of measuring and controlling it, requires studying these local mechanisms including the roughness of surfaces, the behavior of materials on a small scale as well as the presence of the third body and a lubricating fluid in the interface. Moreover, all these mechanisms should be approached within a thermo-mechanical context. Since the pioneering work of Bowden & Tabor, Holm and Archard, the concept of the real contact area, which is considerably smaller than the apparent contact area, allows to explain many interfacial phenomena. But despite considerable progress in the modeling of friction over the past 60 years, predicting friction between two materials with known surface properties remains a major challenge in engineering science. This difficulty stems from the complexity of the phenomena occurring in the interface (mechanical, thermal, chemical) and their interactions. In this thesis we will study the fundamental question of microscopic dry friction between rough metallic surfaces by taking into account the relevant behavior of the contacting materials as well as thermo-mechanical coupling. This innovative study is based on the unique combination of expertise of supervisors in crystal plasticity, contact and roughness modeling, thermo-mechanical experimental techniques, and advanced numerical methods of multi-physical coupling for contact problems.

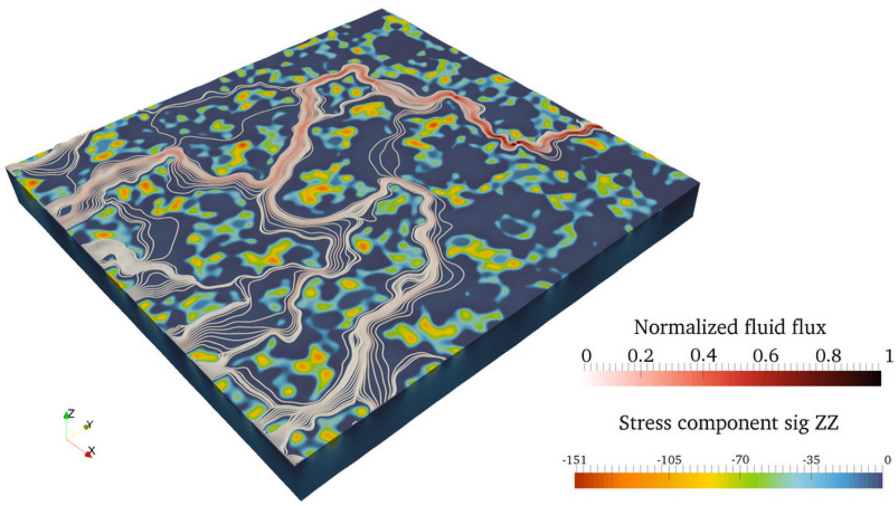

Figure 1: We show a nominally flat rough surface in contact with a rigid flat under changing normal load, colored spots highlight the true contact areas, there is also a fluid flowing through the contact interface, the color of streamlines corresponds to the flux intensity. It is an animation from the precursor PhD project of A. Shvarts on "Fluid-Solid coupling in contact interfaces between rough surfaces" supervised by V.A. Yastrebov *et al*, see in "References".

Objectives

The objective of this PhD project is ambitious: we will develop a thermo-micro-mechanical model of the contact interface in order to make a direct link between the macroscopic friction and (1) the properties of the contacting materials and (2) the characteristics of their surfaces. The microscopic model will include the following ingredients which will generalize contact studies for a broad class of crystalline materials: (1) controlled roughness of the surfaces brought into contact, (2) a model of general elasto-visco-plastic behavior relevant to the small scale of roughness, (3) heating source from friction and bulk dissipation, (4) heat diffusion and a strong thermo-mechanical coupling (thermal expansion and change in material parameters with temperature).

The implementation of this model will require a deep understanding of these three components and their coupling in the context of contact and dry friction. We therefore aim, by carrying out an elaborated statistical study, to propose a new macroscopic friction law which will be based on the measurable properties of materials and surfaces in contact. A phenomenological law for thermal conductivity of contact interfaces, important for numerous industrial applications, will be a part of "by-products" of this study. The theoretical study will be accompanied by finely tuned experiments.

Scientific approach and methods

In this study we will combine theoretical (35 %), numerical (35 %) and experimental (30 %) approaches which is the key strength of our research lab Centre des materiaux (Materials Research Centre). Given the complexity and quantity of the phenomena involved, the micro-mechanical model will be developed in our in-house parallel finite element software Z-set (www.zset-software.com) which already contains several key ingredients needed for the implementation of the project. The missing ingredient is the thermo-mechanical coupling for the generation of the frictional heat and heat exchange through the contact spots, through the interfacial fluid (convection) and radiation. A monolithic contact thermo-mechanical coupling will be implemented in the framework of this PhD project using the existing mortar-based finite element approach. The results will be compared with the weak coupling methodology available in the code. The multitude (because of the statistical properties of random surface roughness) of numerical simulations will be carried out on the lab's computer cluster using hybrid parallelism. The results of these microscopic simulations will be compared with the macroscopic friction models of the "rate and state" type which will also be implemented in the Z-set within the framework of the mortar method which will allow to tackle friction problems in a wide class of applications. The experimental part will include a study of heat generation in dry friction between rough surfaces printed in polymer (model material) with the use of high-speed infrared cameras. This study will validate the thermo-mechanical coupling and will help to reconstruct temperatures prevailing at contact spots.

Scientific and industrial outcome

In engineering and natural systems the thermo-mechanical coupling in frictional interfaces presents and important, challenging and not yet fully understood problem. In this project we will make a theoretical, numerical and experimental investigation on the heat generation and transfer in contact interfaces at the roughness scale for crystalline materials. The numerical simulations conducted with various material models and roughness parameters will enable to make a link between the thermal properties of the contact interfaces and the loading, its rate, material parameters and roughness. Such a link is still missing and presents a not fully resolved scientific question. In addition, this project will strongly enhance the capacities of our finite element software in treatment of strongly coupled thermo-mechanical frictional contacts. In addition, several constitutive models for interfacial conductivity will be implemented within the project and compared with micro-mechanical simulations.

References

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This project can be seen as a next step in understanding of coupling problems in contact interface at the small scale, which would follow a very successful PhD project of Andrei Shvarts (see the link to his dissertation above and some figures[1] in Anim. 1), which has received the CSMA PhD award (The French Association of Computational Structural Mechanics).

Supervisors

The project will be mainly carried out under the supervision of Dr. Vladislav Yastrebov (www.yastrebov.fr). The experimental part of the project will be supervised by Dr. Cristian Manuel Ovalle Rodas (LinkedIn). Professor Samuel Forest (matperso.mines-paristech.fr/People/samuel.forest/) will assist the team with his expertise in material modeling and homogenization approaches.

Candidate profile

We are looking for a candidate with a solid background (Master of Science or equivalent) in mechanics and/or computational mechanics and/or mechanical engineering and/or applied mathematics. Knowledge of the finite element analysis and adequate programming skills are mandatory, programming experience in C++ is a must[2], good knowledge of English is also required. The candidate should demonstrate a rigor, curiosity and autonomy.

Working conditions

The laboratory Centre des Materiaux is located in approximately 35 km to the South from Paris city center. The laboratory employs approximately 180 people including approximately 40 researchers, 40 technicians, 80 PhD students, $\approx$ 10 postdoctoral researchers and administrative staff. The focus of our research is materials processing and surface modification, the microstructural characterization and experimental study of the behaviour of materials as well as modelling and simulations of materials and structures. These studies are carried out in a close contractual collaboration with industrial partners such Safran, Airbus, Dassault, Turbomeca, PSA, Renault, CEA, EDF, Eurocryospace, Arcelor Mittal, Ascométal, Constellium, Areva, Onera, ENGIE, Hutchinson, TOTAL and many others. The PhD candidate will have a working contract for 3 years funded by MINES ParisTech and funding for few conferences/workshops/summer schools. She/he will be enrolled at the PSL University's Doctoral School and obtain after the defense a PhD diploma of PSL University with the notion of MINES ParisTech school.

Application

The interested candidates are invited to send their CV and a motivation letter to Vladislav Yastrebov vladislav.yastrebov@mines-paristech.fr, Cristian Ovalle Rodas cristian.ovalle_rodas@mines-paristech.fr, and Samuel Forest samuel.forest@mines-paristech.fr.

[1] To see the animation, you'll need to use Adobe Acrobat Reader.

[2] Most of the numerical developments of this project will be carried out in our in-house finite element software Z-set, which we have been developping for more than 35 years in close collaboration with The French Aerospace Lab ONERA. The code is written in C++.