SUJET DE THESE / PhD SUBJECT

**TITRE / TITLE:**
Scratch testing for measuring fracture – computational approach and scale effects

**ABSTRACT:** In stimulation processes for hydrocarbon production or geothermal energy production, the bottleneck that prevents the implementation of advanced fracture computational models is the availability of appropriate experiments and interpretation techniques for obtaining the material parameters needed. Fracture energy is the major quantity at stake and its estimation is in most cases inferred from empirical relationships (e.g. based on UCS), with very large error margins. Scratch testing has emerged over the last decade for measuring rock properties. The scratch test experiment consists in pushing a cutting tool at the surface of a material sample at a given penetration depth. The purpose of this PhD work is to develop a robust computational model with a thorough understanding of the physical processes that are at stake during scratching, and then to elucidate the various scale effects that may occur, i.e. the interaction between the parameters used for the experiment and the microstructure of the material.

**Mots clés (Keywords):** fracture, rocks, scratch testing, scale effects

CONDITIONS D’EXERCICE / WORKING CONDITIONS

Laboratory: Laboratoire des fluides complexes et leurs réservoirs (UMR 5150) in association with Dept. of Civil and Env. Engrg. Northwestern University, Evanston IL, USA


PhD Director: Gilles Pijaudier-Cabot
PhD co-Director: Gianluca Cusatis
In Collaboration with: Ange-Therese Akono

Lieu (Place): Université de Pau et des Pays de l’Adour, Anglet Campus - 2 years and Northwestern University (USA) – 2 years

Start: Sept. 2020  
**Duration:** 4 years – with 2 degrees from UPPA and Northwestern University

Employeur (employer): Université de Pau et des Pays de l’Adour (UPPA) and Northwestern University (USA)

Salaire mensuel brut (monthly salary before taxes): 1768 € (France) & PhD fellowship at Northwestern University

SAVOIR-FAIRE DU LABORATOIRE / HOST LABORATORY PROFILE

This PhD project is part of the work program of the international hub “Newpores”, co-sponsored by the laboratoire des fluides complexes et leurs réservoirs (UMR 5150) at E2S UPPA and Northwestern University (Center for sustainable engineering of infrastructures and geological materials.). Newpores is an international hub gathering over 15 scientists from France, Spain, Belgium and USA, dedicated to the mechanics and physics of porous materials.
Research project: in stimulation processes for hydrocarbon production or geothermal energy production, the bottleneck that prevents the implementation of advanced fracture computational models is the availability of appropriate experiments and interpretation techniques for obtaining the material parameters needed. Fracture energy is the major quantity at stake and its estimation is in most case inferred from empirical relationships (e.g. based on UCS), with very large error margins.

As opposed to concrete, ceramics and metal alloys where ad-hoc fracture specimens can be manufactured and tested, it is not always possible in rock mechanics because it is not easy – if impossible – to extract during well drilling larges pieces of rocks in which specimen geometries (such as rectangular notched beams) are machined. Core-based specimens ought to be used, insuring simple preparation of the samples. Obtaining cores from wells during the drilling process is expensive and their availability for fracture testing, which is a destructive process, might be restricted. In some instances, cutting debris are the sole rock pieces from which properties can be inferred. Direct fracture tests on such debris are hardly possible, and there is a lack of methodology and proper workflow for extrapolating data acquired at the debris scale (cm) and bellow (grain size – micron to mm) to that of rock masses resolved in geo-models.

Scratch testing has emerged over the last decade for measuring rock properties. The scratch test experiment consists in pushing a cutting tool at the surface of a material sample at a given penetration depth. It has been widely used in material sciences, for the strength characterization of ceramics, polymers, coatings, for wear and abrasion of metallic surfaces. While making a groove at the surface of the specimen, two distinct failure regimes are typically observed depending on the cutting depth: for shallow depths, failure occurs due to intense plastic shearing. It is related to the ductile response of the material. A brittle mode, characterized by the propagation of a tensile crack, can be observed above a threshold cutting depth. The interpretation of test data has been quite controversial because the transition between the ductile and brittle modes is smooth. Considering that one mode dominates over the other one is always debatable. In addition, friction and chipping were neglected. Chipping results into a series of transient cutting regimes and crack propagation is curved although it is assumed to remain straight in the analytical models.

Scratch testing can be performed at the mm-scale, but also at the sub-micron scale, opening the path to multiple scale experiments (from debris to core-based specimens), but at the same time addressing the question of size effect and up-scaling properties from the micron scale to the centimeter scale. Indeed, current studies show that the fracture energy (e.g. of shale) measured at the micro scale is significantly different from that measured at the mm scale. This might be due to the interaction between the grain assembly and the experimental process.

The purpose of this PhD work is to develop a robust computational model with a thorough understanding of the physical processes that are at stake during scratching, and then to elucidate the various scale effects that may occur, i.e. the interaction between the parameters used for the experiment (depth of cutting,...) and the microstructure of the material. For this purpose, a lattice-based model will be implemented. Progressive damage and fracture, friction between the cutting tool and rock, shear failure, and finally large displacements upon the full separation after fracture resulting into chips (rock fragments) will be implemented. Considering the fact that the microstructure may be inserted in the lattice description, scale effect will be addressed too.
Comparisons with experiments on various rocks for which the fracture energy is known will be performed.

*The project duration is 4 years with 2 years residency requirement at both places. The candidate is expected to earn a Ph.D. from both institutions at the end of the project.*

**COMPETENCES REQUISES / REQUIRED COMPETENCES**

The applicants should have a MSc-degree focused either on structural engineering or on rock mechanics. Inclination toward computational modeling and programming will be highly appreciated.

**CRITÈRES D’ÉVALUATION DE LA CANDIDATURE / CRITERIA USED TO SELECT CANDIDATE**

Criteria used in selection of the candidate:
- Candidate's motivation, scientific maturity and curiosity.
- Academic results
- English proficiency

Selection process steps (french part):
- Establishment of the selection committee.
- Evaluation of the applicants cv’s
- Interview with the selected candidates and ranking.

Selection process steps (USA part):
During the PhD at Northwestern University, students will be enrolled within the Mechanics, Materials and Structures (MMS) program. Northwestern’s policy is to accept students through a competitive selection process upon reception of an official application. For information on the application process, prospective students are encouraged to contact Ms. Melissa Koelling, Academic Coordinator (mkoelling@northwestern.edu)

**CONSTITUTION DU DOSSIER DE CANDIDATURE / REQUIRED DOSSIER,**

Send an e-mail to Prof. Gilles Pijaudier-Cabot with your candidature containing:
- CV (CV)
- Cover letter detailing candidate's motivations
- Copy of your diploma and academic records (marks and ranking)
- Letters of recommendation (if any)
- Contact details for 2 referees

**DATE LIMITE DE DEPOT DU DOSSIER (Deadline of application) : May 15th 2020**

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