LABORATOIRE D'AUTOMATIQUE DE MECANIQUE ET D'INFORMATIQUE INDUSTRIELLES ET HUMAINES
LAMIH UMR CNRS 8201

INSTITUT CARNOT ARTS

PhD Position offer

Subject:	Adaptive coupled discrete/continuous approach for the forming of materials
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Research unit:	LAMIH – UMR CNRS 8201 (https://www.uphf.fr/LAMIH/en/)
Department:	Mechanical Engineering
Financial support:	Hauts-de-France region, MG Valdunes, Université Polytechnique Hauts de France
Start date:	October 2020
To apply:	CV, motivation letter, recommendation letters (in a single .pdf or .zip file), to be sent to cedric.hubert@uphf.fr

PhD thesis objectives

While the metal forming community have fair hindsight of the phenomena linked to bulk material forming, such as plasticity or thermal effects, one of the key points of a process performance is friction. It is a complex phenomenon which remains not well mastered, and may lead to micro-cracks in the formed parts (Figure 1a), fatigue fracture of the forming tools and of the manufactured parts in service, or local, microstructure transformations that could dramatically change the expected behaviour of the tools and the formed parts. Studying such local phenomena on reduced regions may lead to make assumptions on how these local regions are affected by the global loadings on the part or process, which may change with the forming or service scheme (Figure 1b).

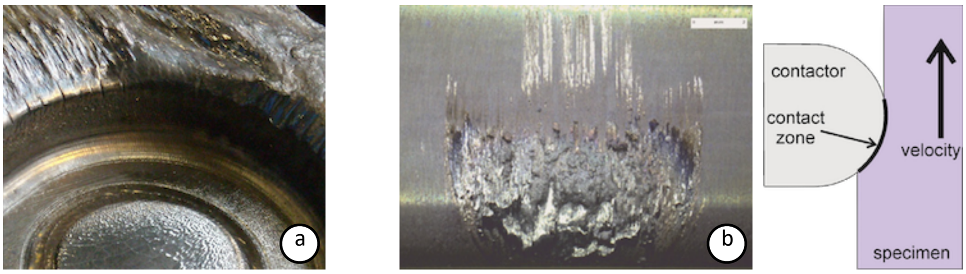

Figure 1: Illustration of (a) micro-cracks on a cold forming tool and (b) simplified experimental simulation [1]

Simulations of metal forming operations are usually based on the Finite Element Method (FEM), even when the objective is to model defects occurence in the formed part (such as wear or cracks), or when simulating particular forming operations such as blanking/punching or shearing. With the standard FEM, wear is often modelled by changing the nodal positions of the worn elements, and cracks are modelled using an element deletion technique. Both approaches lead to material loss, and thus, the classical Continuum Mechanics assumption the FEM relies on does not apply anymore. Other methods close to the FEM were developed to address this issue, such as Continuum Damage Mechanics [2], the eXtended Finite Element Method [3], or the Cohesive Zone Model [4]. These methods suffer from multiple difficulties, such as taking into account multi-fracturation, crack deviations and closure. Moreover, some processes may lead to third body generation (often by friction), which is supposed to interact with the surfaces that generated it, and which affects the interface (thermo-)mechanical behaviour.

In opposition to the FEM, the Discrete Element Method (DEM) is widely used to model divided media such as raw powders or granular materials. Particular classes of the DEM, named Lattice Element Method [5] or Bonded Particle Element Method [6], allow to model continuous media via the introduction of interaction laws between the particles, which local parameters enables to simulate the material apparent behaviour. It has been successfully applied to the fracture of rocks or concretes. Apart from the calibration phase for the interaction laws, partially solved by a recent study [7], the DEM currently fails to model plasticity: DEM relies on the Discrete Mechanics framework.

In order to take advantages of both the FEM and the DEM, some authors developed coupling methods, mainly based on Arlequin techniques [8]. These approaches allow to model a Region Of Interest using discrete elements, so that they can exhibit fracture, and other regions of the model, far from this ROI but whose behaviour must be accounted for, with the FEM. Both regions are coupled by means of an overlap region in which the residual energy is minimised to ensure the mechanical fields continuity. This is already an interesting advance but such methods suffer from front wave reflections at the FEM/DEM interface and require fine adjustment of the parameters that drive the coupling scheme [9]. Moreover, the simulation cost remains high since the time step of the (mainly explicit) simulations is governed by the DEM region, which needs fine "meshes" to give relevant mechanical results.

The aim of this PhD thesis is to develop an original numerical strategy in order to study local phenomena due to friction while keeping a global view of the modelled process. This will be achieved using two numerical methods: the Finite Element Method (FEM) and the Discrete Element Method (DEM). The start of the simulation will be based on the already widely used FEM, while the DEM will be dynamically, late activated, *i.e.* when the load state in a given region of the FEM mesh is close to the onset of fracture. This means the material is about to turn in the field of fracture mechanics since a small additional amount of strain leads to fracture, which is what the DEM was designed for. This approach will allow to keep reasonable simulation times up to the onset of a crack, and to obtain accurate results in the cracked regions without braking the fundamentals of both methods.

According to the literature, most of the implementations of FEM-DEM couplings remain at the research level, mainly because of the artefacts generated by the coupling region, or because of the limitations assigned to the DEM, namely its inability to account for large strains, which is a phenomenon inherent to metal plasticity. One of the most advanced implementation was proposed by C. A. Labra *et al.* [10]. It models a medium with both the FEM and the DEM at the same time, the discrete elements being activated only when the critical value of a given failure criterion is reached in the FEM mesh. However, keeping two "meshes" across a full simulation is costly, apart from the fact that the DEM domain must be generated with care and is also a time consuming step. Moreover, it does not accounts for large strains. The proposed approach (Figure 2) involves a lazy remeshing of the critical regions, which will allow to keep reasonable simulation times for most of the simulation. Moreover, reaching such deformations levels in a simulation involving both the FEM and the DEM will enable application of this method to metal forming, or other applications involving large strains, instead of only small strains applications.

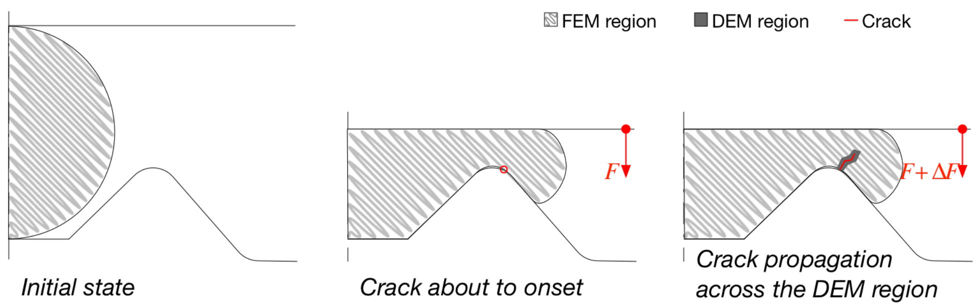

Figure 2: Illustration of the strategy proposed in the PhD thesis.

Methodology to reach the scientific objectives

Investigations on the most appropriate coupling technique between FEM and DEM have been carried out by the supervisors. First results obtained using the Lagrange multipliers coupling technique are promising, while it is also cost-effective.

The work to be carried out by the PhD student will be as follows:

- Literature survey on coupling techniques:
    - To evaluate the front wave reflections at the coupling interface
    - To evaluate/validate the degrees of freedom concerned by the coupling
- Definition of the strategy to replace the FEM region by a DEM one:
    - relevant FEM region size
    - elastic interaction parameters between discrete elements
    - field data transfer from the FEM to the DEM region
- Physical experiments to validate the model, for example using the 200 tons press available at SWIT'Lab joint laboratory (between the Université Polytechnique Hauts-de-France, University of Lille, Centrale Lille, CNRS and MG Valdunes)

Desired skills and knowledge of the PhD student

Use of commercial finite element softwares (*e.g.* Abaqus, Ansys, LS-Dyna), general knowledge on material behaviour and Finite Element Method, programming languages (Matlab, C++).

Knowledge on Lagrange multipliers / coupling techniques would be a plus.

References

[1] Dubois A. *et al.,* (2018), Surf. Coat. Tech., doi.org/10.1016/j.surfcoat.2018.03.055
[2] Hubert C. *et al.,* (2012), J. Mater. Process. Technol., doi.org/10.1016/j.jmatprotec.2011.12.011
[3] Xue *et. al.*, (2019), Comp. Mater. Sci., doi.org/10.1016/j.commatsci.2012.12.008
[4] Debras C. *et. al.*, (2019), Int. J. Mech. Sci., doi.org/10.1016/j.ijmecsci.2019.105038
[5] Schlangen E. *et. al.*, (1996), Int. J. Eng. Sci., doi.org/10.1016/0020-7225(96)00019-5
[6] André D. *et. al.,* (2012), Comput. Method. Appl. M., doi.org/10.1016/j.cma.2011.12.002
[7] André D. *et. al.,* (2019), Comput. Method. Appl. M., doi.org/10.1016/j.cma.2019.03.013
[8] Jebahi M. *et al.,* (2013), Comput. Method. Appl. M., doi.org/10.1016/j.cma.2012.11.021
[9] Leclerc W. *et al.*, (2019), Int. J. Solids Struct., doi.org/10.1016/j.ijsolstr.2018.10.030
[10] Labra C. A. *et. al.,* (2012), Monograph CIMNE (2012). M132
[11] André D. *et. al.,* (2015), ISTE Limited, doi.org/10.1002/9781119116356

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