TITLE	**Numerical modeling of thin products forming under complex loads**
Project acronym	
Global objective of work	**The main purpose of this thesis is to improve the capabilities of Forge to model thin products. The first challenge to rise will be related to the development of constitutive laws adapted to reproduce the anisotropy of materials under complex non-proportional loading paths.**
Context	Thin products forming into complex shapes is getting more and more important in the industry. This type of product is used to manufacture a wide variety of parts in the most active sectors of the aerospace, automotive, energy or building industry. Whatever the sector targeted, the objectives of cost and weight reductions are preponderant and lead to a systematic decrease in thickness. We note that the shaping of these products, each time thinner, rises difficulties related to damage and failure issues. A better control of these forming processes involves a better understanding of the plastic behavior of the material (highly anisotropic) and the related damage process. Numerical simulations become an essential tool. The Forge software, dedicated to the modeling of materials subjected to large plastic deformations, is a leading software in the field of bulk forming, thanks in particular to an efficient automatic remesher. The features currently present in Forge, however, limit its use for modeling thin products. Indeed, the representation of thin products using tetrahedral bulk elements requires the development of numerical methods adapted to improve the computational time and the contact detection/resolution techniques. In addition, such applications require the integration of advanced constitutive laws (kinematic hardening, plastic anisotropy, dedicated damage models, etc.) to accurately reproduce the potential initiation of zones of necking, rupture or to correctly predict springback. **This thesis aims to improve Forge's ability to model the forming of thin products under complex non-proportional loading paths.**
Detailed presentation with figure(s)	One of the reasons why numerical simulations are not able to predict these areas of damage is related to the complexity of loading paths imposed on the material. This complexity requires a very good representation of the plastic response of the material whose anisotropy must be taken into account precisely. The main purpose of this thesis is to improve the capabilities of Forge to model thin products. The first challenge to rise will be related to the development of constitutive laws adapted to reproduce the anisotropy of materials under complex non-proportional loading paths. These anisotropic behavior laws will be implemented in an external library that will be coupled to a mechanical solver in Forge. This type of approach improves the flexibility in order to develop new constitutive laws and it also allows to separate the finite element data structure from the rheological behavior of the material. The candidate will have to be

	particularly interested in numerical **development within a parallel computing framework in C ++ and Fortran.** This coupling requires the development of a suitable finite element formulation; the candidate will develop advanced skills related to finite element methods. With the new constitutive laws of anisotropic behavior integrated in Forge, the project will move towards the improvement of the modeling techniques of thin products forming. To this end, **the application of anisotropic mesh adaption techniques will be used to minimize the required computational time.** The impact of anisotropic mesh adaption and contact techniques as part of the developed finite element formulation will also be studied. The developments in this thesis will result in publications in recognized international journals as well as participation in international conferences in the field of computational mechanics. Collaborations with the University of Rosario (Argentina) and the Catholic University of Santiago (Chile) are planned.
Tools	*C++ and Fortran Programming – Forge*
Key-words	*Anisotropy – Mesh adaption – C++ and Fortran programming – Finite elements method*
Project type/ cooperation	PhD funded by CEMEF (Mines ParisTech)
Skills, abilities requested	Degree: MSc or MTech in Metallurgy, Materials Science, Non-linear Solid Mechanics, with excellent academic records. Skills: Computational mechanics, C++ and Fortran programming, non-linear mechanics of materials and metallurgy. The candidate should be particularly interested in programming and numerical modeling and knowledge of plastic material anisotropy would be appreciated. Ability to work with multi-disciplinary teams is also a must.
Location	The PhD will be done at CEMEF at Sophia Antipolis (South East of France).
CEMEF team(s)	Computational Solid Mechanics (CSM) at CEMEF.
Supervisor(s)	Daniel Pino Munoz (daniel.pino_munoz@mines-paristech.fr) Pierre-Olivier Bouchard (pierre-olivier.bouchard@mines-paristech.fr) Katia Mocellin (katia.mocellin@mines-paristech.fr) François Bay (francois.bay@mines-paristech.fr)