PhD position

Context and objectives

Numerical modeling of thin products forming under complex loads

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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 volumic 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.

Expected works

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.

Profile - Skills

Programming in C ++ and Fortran - Finite Element Method - Anisotropic constitutive laws - Mechanics of materials - HPC.

Place

This PhD thesis will take place at Cemef, Mines ParisTech laboratory in Sophia Antipolis. Cemef offers an internationally renowned scientific environment that will allow the candidate to collaborate with leading academic partners.

Team

The PhD student will work in the CMP (Computational Mechanics & Physics) department and more specifically in the research group CSM (Computational Solids Mechanics). The candidate must hold a Engineer degree (or equivalent) or a MSc in engineering, physics or applied mathematics and must be wishing to apply his knowledge in mechanical modeling and numerical methods to study metallic materials.

Sujet de Thèse

Contexte et objectifs de la thèse

Modélisation numérique pour l'étude des produits minces sous chargements complexes

La mise en forme de produits minces occupe aujourd'hui une grande place dans l'industrie. Ce type de produit est utilisé pour fabriquer une grande variété des pièces dans les secteurs les plus actifs de l'industrie aéronautique, automobile, énergétique ou du bâtiment. Quelque soit le secteur visé, les objectifs de réductions des coûts et du poids sont prépondérants et conduisent à une diminution systématique des épaisseurs. On constate ainsi que la mise en forme de ces produits, à chaque fois plus minces, pose des difficultés liées à l'apparition de zones d'endommagement. La maîtrise de ces procédés de mise en forme passe par une meilleure compréhension du comportement plastique du matériau (fortement anisotrope) et de l'endommagement qui en découle. La simulation numérique devient ainsi un outil incontournable.

Le logiciel Forge, dédié à la modélisation des matériaux soumis à de grandes déformations plastiques, est un logiciel leader dans le domaine de la mise en forme des produits massifs, et ce notamment grâce à un remailleur automatique performant. Les fonctionnalités actuellement présentes dans Forge limitent cependant son utilisation pour la modélisation des produits minces. En effet, la représentation de produits minces à l'aide d'éléments volumiques tétraédriques nécessite le développement de méthodes numériques adaptées pour une bonne maîtrise du temps de calcul et une gestion efficace du contact. De plus, de telles applications nécessitent d'intégrer des lois de comportement avancées (écrouissages cinématiques, critères anisotropes, modèles d'endommagement dédiés ...) pour modéliser avec précision l'apparition potentielle de zones de striction ou de rupture ou pour prédire correctement les retours élastiques.

Cette thèse vise à améliorer les capacités de Forge à modéliser la mise en forme des produits minces et ce pour des trajets de chargement non proportionnels complexes.

Travaux attendus

Une des raisons pour lesquelles les simulations numériques ne sont pas capables de prédire ces zones d'endommagement est liée à la complexité des trajets de chargement imposés à ces pièces. Cette complexité demande une très bonne représentation de la réponse plastique du matériau dont l'anisotropie doit être prise en compte de manière précise.

Le but principal de cette thèse est d'améliorer les capacités de Forge à modéliser des produits minces. Le premier levier sera l'utilisation des lois de comportement mieux adaptées à l'anisotropie des matériaux et ce pour des trajets de chargement non proportionnels complexes.

Ces lois de comportement anisotropes seront implémentées dans une bibliothèque externe qui sera couplée à un solveur mécanique dans Forge. Ce type d'approche donne une plus grande flexibilité pour l'implémentation de nouvelles lois de comportement et permet de séparer la structure des données éléments finis des aspects purement liés aux lois de comportement. Le candidat devra donc avoir un goût prononcé pour le **développement numérique dans cadre du calcul parallèle en C++ et Fortran**.

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Ce couplage nécessite le développement d'une formulation éléments finis adaptée ; le candidat développera une maîtrise avancée des méthodes éléments finis.

Avec les nouvelles lois de comportement anisotrope intégrées dans Forge, le projet s'orientera vers l'amélioration des techniques de modélisation de la mise en forme de produits minces. Pour ce faire, **l'application des techniques d'adaptation de maillage anisotrope sera utilisée pour minimiser le temps de calcul requis.** L'impact de l'adaptation de maillage anisotrope et des méthodes pour la gestion du contact dans le cadre de la formulation éléments finis développée sera également étudié.

Les développements réalisés dans cette thèse donneront lieu à des publications dans des revues internationales reconnues ainsi qu'à des participations à des conférences internationales dans le domaine de la mécanique numérique. Des collaborations avec l'Université de Rosario (Argentine) et l'Université Catholique de Santiago (Chili) sont prévues.

Profil – Compétences recherchées

Programmation en C++ et Fortran – Méthode des éléments finis – Lois de comportement anisotropes – Mécanique des matériaux – Calcul intensif.

Lieu

Cette thèse aura lieu au laboratoire Cemef de Mines ParisTech à Sophia Antipolis. Le Cemef propose un environnement scientifique de renommée internationale qui permettra au candidat de collaborer avec des partenaires académiques de premier plan.

Equipe et type de projet

L'étudiant en thèse travaillera au sein du Pôle CMP (Computational Mechanics & Physics) et plus spécifiquement dans le groupe de recherche CSM (Computational Solids Mechanics). Cette thèse s'adresse à un étudiant avec un diplôme d'école d'ingénieur (ou équivalent) ou Master M2R désireux d'appliquer ses connaissances en modélisation mécanique et méthodes numériques appliqués aux matériaux métalliques.

Phd position 2018 – 2021
Cifre TRANSVALOR
Research Laboratory: CEMEF (Mines ParisTech)

3DFRAC

Damage to fracture transition and 3D numerical modeling of fracture within a large deformation context

Context & Objectives

Transvalor is a software engineering company developing products dedicated to material forming processes applications. The main product FORGE® is a finite element software that enables to model material behavior under large plastic strain and complex loading conditions representative of forming processes. FORGE® is a leading software in this field used in more than 350 companies worlwide from various sectors of the mechanical industry including automotive, aerospace and energy industry.
In most forming processes, it is essential to predict and avoid the initiation of defects during material forming. Such predictions require appropriate material behavior law and ductile damage models, already available in FORGE® [1-3]. However, in some cases, the **modeling of failure** is essential and an accurate and robust numerical technique is necessary to predict correct failure surfaces (blanking and fine blanking processes, machining …). Although the context of this project is centered on numerical modeling of industrial manufacturing processes, the underlying physical phenomena and numerical developments are also relevant in other fields (e.g. biomechanics, geoscience, physics, among many others).

Nowadays, the modeling of fracture in the finite element (FE) software Forge® is based on the so-called “kill-element” technique. This technique consists in deleting elements from the mesh once a user-defined damage variable reaches a threshold. The kill-element technique is both easy to use and robust, but it also has major limitations. Its main limitation relies on its inherent mesh dependency. In addition, this approach gives raise to volume loss and the prediction of an accurate fracture surface is impossible (See Fig. 1). It is therefore necessary to improve the way fracture is modeled in a 3D environment and within the context of metal forming applications. To reach this goal, TRANSVALOR is hiring a Cifre PhD student and wishes to collaborate with CEMEF for its scientific supervision.

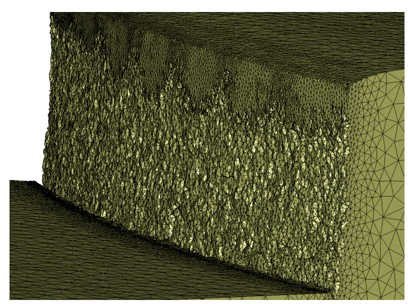

Figure 1 Rough fracture surface obtained during blanking simulation using the kill-element

CEMEF (Center for Material Forming Processes) MinesParisTech has a strong expertise in the numerical modeling of material forming processes (in particular in FORGE®) and a long experience in the study and the modeling of ductile damage [1-3] and fracture with advanced use of automatic remeshing techniques [4, 7-10].

The aim of this PhD project is the modeling of 3D ductile fracture in the FE software Forge®. This requires the development of new numerical techniques to model surface discontinuities and automatic crack propagation in a robust environment.

Work program

In order to address the objectives mentioned above, the expected scientific program is the following:

- **Improved kill-element technique:** This first axis will consist in improving the actual kill element technique by using mesh adaption techniques in order to control the mesh refinement perpendicular to the failure plane. Such technique will allow limiting the volume loss during kill-element and will induce smoother fracture surfaces [4]. Finally, additional mesh smoothing techniques could be applied in order to improve surfaces smoothness.
- **Damage to fracture transition and crack initiation:** Many studies were conducted in the past to predict ductile fracture in Forge [1-3]. Ductile damage models of failure criteria define a damage variable that grows and give raise to failure initiation once a threshold is reached. This damage analysis is based on continuous mechanics and the transition to discontinuous fracture will be addressed here. In particular, the insertion of a discontinuity, representing the crack surfaces, will be handled in a full 3D parallel environment based on continuous damage fields [5, 6].
- **3D Crack propagation:** Once initiated, 3D crack propagation will raise two main challenges that should be addressed: (i) prediction of crack path based on damage fields and (ii) development of advanced remeshing techniques to propagate cracks in the 3D mesh [6-8]. The idea would be to define fracture surfaces by Level-Set functions and to enhance a recently developed body-fitted mesh adaptation technique [9,10] to handle 3D crack propagation in a robust way.

The PhD student will benefit from lectures in materials science, non-linear solid mechanics, damage and fracture. These competences will provide opportunities to develop future activities in various R&D sectors in energy, transport and metallurgical industries.

Skills & abilities requested

Degree: Engineering degree or MSc in Computational Mechanics **with excellent academic records**.
Skills: Computational Mechanics and applied mathematics with a strong knowledge of the finite element method and programming (C++, Fortran) skills. Non-linear solid mechanics and in particular knowledge in damage and fracture mechanics would be appreciated. Proficiency in English, ability to work within a multi-disciplinary team.

Location

The 3-year PhD will take place at CEMEF, an internationally recognized research laboratory of MINES ParisTech located in Sophia Antipolis, on the French Riviera. The PhD student will also spend several days at TRANSVALOR also located in Sophia Antipolis, which offers a dynamic research environment, exhaustive training opportunities and a strong link with the industry. At CEMEF, she/he will join the Computational Solid Mechanics (CSM) team under the supervision of Pierre-Olivier Bouchard and Daniel Pino Munoz. Annual gross salary: around 27k€.

Application

The application file should be sent to scientific supervisors below and must include 1 CV, A motivation letter, academic records as well as 1 or 2 recommendation letters.

Pierre-Olivier BOUCHARD	**e-mail** : pierre-olivier.bouchard@mines-paristech.fr
Daniel PINO MUNOZ	**e-mail :** daniel.pino_munoz@mines-paristech.fr
Etienne PERCHAT	**e-mail :** etienne.perchat@transvalor.com
Jose ALVES	**e-mail :** jose.alves@transvalor.com

References

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