THEORE3M

The mechanics and physics of dynamic localization and fracture in heterogeneous ductile materials

PhD position in Research Grant funded by:
US Air Force – Air Force Research Laboratory
Air Force Office of Scientific Research

PURPOSE

The purpose of THEORE3M is to identify the mechanisms which control localization and fracture in ductile heterogeneous materials subjected to high strain rates. We will carry out the micro- and macro-mechanical characterization of different metal-matrix composites that will be modelled with different multiscale approaches. Multiscale constitutive models will be implemented in finite element codes to simulate various dynamic fracture experiments that will be specifically designed and performed in THEORE3M. Namely, we will carry out: (1) plate-impact experiments, (2) dynamic shear fracture tests and (3) ring expansion fragmentation experiments. This research effort will integrate the unique capabilities of the USAF through its Air Force Research Laboratory, Materials and Manufacturing Directorate (AFRL/RX), the Technion – Israel Institute of Technology, and the Universidad Carlos III of Madrid, to couple experimental and computational resources to address this critical need.

PhD Research

High-speed fragmentation and spall fracture: experiments and modelling

Host

University Carlos III of Madrid

Supervisors

Dr. José A. Rodríguez-Martínez
Dr. Juan C. Nieto-Fuentes

Synopsis

The dynamic behaviour of materials and structures is a pervasive problem in the Air Force. High dynamic loads are inherent in ballistic and munitions applications, novel and emerging engine and aircraft structures, and hypersonic re-entry and flight. Materials employed in these demanding environments are often heterogeneous in their microstructure and consequently in their macro-scale mechanical properties, with a clear incidence on localization and failure/fracture. In this research we are going to perform experiments and modelling to determine the mechanisms which control dynamic fracture of heterogeneous materials, with special emphasis on 2 canonical problems: **spall fracture in plate-impact tests** and **dynamic fragmentation of rings**. The **plate-impact tests** consist of launching a projectile (plate) at high speed by a gas gun against a target (plate) initially at rest. During impact, compression shock waves are generated in both plates (projectile and target). These waves reach the free surfaces of target and plate and they are reflected as rarefaction (tensile) waves. Very large tensile stresses are generated in the location where these tensile waves met –spall plane-, leading to the ductile (spall) fracture of the target due to the growth and coalescence of defects and voids (due to the high triaxiality and the large local plastic deformation), giving rise to the so-called spall fracture. In the

experiments, the impact velocities will vary in intervals of 50 m/s, from 250 m/s to 650 m/s. The **dynamic fragmentation tests** consist of a thin ring which is axially penetrated by a circular cross-section projectile with conical nose and trunk diameter greater that the inner radius of the ring. The projectile will be manufactured with tempered manganese steel to minimize its deformation during the test. The problem shows radial symmetry which minimizes the propagation of waves along the circumferential direction of the sample. The advance of the impactor leads to a progressive hoop stretching of the ring until localization occurs in the form of multiple necks, which eventually lead to the fragmentation of the sample. As in the spall experiments, the impact velocities will vary in intervals of 50 m/s, from 250 m/s to 650 m/s. We will simulate in ABAQUS Standard and Explicit both plate-impact tests and ring fragmentation experiments using homogenized micromechanical and phenomenological macroscopic constitutive approaches. We will develop user subroutines to implement into ABAQUS the constitutive models that will be calibrated with specific characterization experiments that will be performed at the Israel Institute of Technology.

Research outputs

- **Novel experimental techniques** to perform dynamic fragmentation and spall fracture experiments.
- **Development of multiscale finite element models** to obtain insights into the mechanisms which control dynamic fracture of heterogeneous materials.

The recruited researcher will have access to the unique facilities of the Impact Laboratory of the Department of Continuum Mechanics of the University Carlos III of Madrid, with all the equipment required to perform plate-impact tests and fragmentation experiments: gas guns to launch strikers at velocities as high as 800 m/s, two high speed cameras with filming rate up to 2.1 Mfps to record the tests, 1 photon doppler velocimetry system and 1 oscilloscope with a sampling rate of 20 Gs/s. In addition, the recruited researcher will have access to all the computational resources of the Nonlinear Solid Mechanics group, including licenses of ABAQUS, Matlab and Mathematica, and several workstations.

Multidisciplinary / international research approach

The recruited researcher will become familiar with various experimental techniques and modelling approaches, and she/he will gain specific experience and know-how in the dynamic fracture of engineering materials with aerospace and defense applications. Moreover, the research will be conducted in collaboration with the Air Force Research Laboratory, Materials and Manufacturing Directorate, and the Dynamic Fracture Laboratory of the Israel Institute of Technology, so that the recruited researcher will be exposed to an international environment, helping her/him to develop connections in prestigious research centers and universities.

Training activities

The successful candidate will have access to the PhD program of the **University Carlos III of Madrid** as well as to the training activities organized by the Nonlinear Solid Mechanics group. These activities include, among others:

- **Attendance to prestigious international conferences** on Solid Mechanics.
- **Attendance to technical courses** on materials science and continuum mechanics organized by different prestigious institutions, e.g. the International Center of Mechanical Sciences (http://www.cism.it/).

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Benefits

The successful candidate will be employed for 3 years within the framework of a prestigious research grant and receive a generous **financial package.**

Key publications

Czarnota, C., Jacques, N., Mercier, S., Molinari, A., 2008. Modelling of dynamic ductile fracture and application to the 150 simulation of plate impact tests on tantalum. Journal of the Mechanics and Physics of Solids 56, 1624-1650.

Czarnota, C., Mercier, S., Molinari, A., 2006. Modelling of nucleation and void growth in dynamic pressure loading, 152 application to spall test on tantalum. International Journal of Fracture 141, 177-194.

Lin, Z., Lingcang, 182 C., Yinglei, L., Jianxiang, P., Fuqian, J., Dongquan, C., 2004. Simplied model for prediction of 183 dynamic damage and fracture of ductile materials. International Journal of Solids and Structures 41, 7063-7074.

Roy, G., 2003. Vers une modelisation approfondie de l'endommagement ductile dynamique. Investigation experimentale 196 d'une nuance de tantale et developpements theoriques. Ph.D. thesis. University of Poitiers, France.

Hiroe, T., Fujiwara, K., Hata, H., Takahashi, H. Deformation and fragmentation behaviour of exploded metal cylinders and the effects of wall materials, configuration, explosive energy and initiated locations. *International Journal of Impact Engineering*. 2008; 35, 1578–1586.

Zhang, H., Ravi-Chandar, K. On the dynamics of necking and fragmentation - II. E effect of material properties geometrical constraints and absolute size. *International Journal of Fracture*. 2008; 150, 3-36.

Zhang, H., Ravi-Chandar, K. On the dynamics of localization and fragmentation-IV. Expansion of Al 6061-O tubes. *International Journal of Fracture*. 2010; 163, 41–65.

Zaera, R., Rodríguez-Martínez, J. A., Vadillo, G., Fernández-Sáez, J., Molinari, A. Collective behaviour and spacing of necks in ductile plates subjected to dynamic biaxial loading. *Journal of the Mechanics and Physics of Solids*. 2015; 85, 245–269.

Rodríguez-Martínez, J.A., Molinari A., Zaera R., Vadillo G., Fernández-Sáez, J. The critical neck spacing in ductile plates subjected to dynamic biaxial loading: On the interplay between loading path and inertia effects. International Journal of Solids and Structures. 2017; 108: 74–84.

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Profile

We are looking for highly motivated European and/or North-American early-stage researchers with the following profile:

- Hands-on mentality, good organizational and communication skills.
- Proactive attitude and ability to work both independently/autonomously and within a team.
- Good communication skills in English.
- Willingness to travel.

Required educational level

Degree Master degree or equivalent
Degree field Engineering: civil, mechanical, aerospace

Career stage

Early stage researcher or 0-4 years (Post graduate)

Professional and/or research experience

We will particularly consider those candidates with proven experience in technological and/or research activities. Publication/s in journals indexed in the Journal of Citation Reports will be especially welcomed.

Letter of motivation

The candidates must provide a letter of motivation where they clearly state why, under their point of view, they should be enrolled in THEORE3M.

References

At least one recommendation letter from the scientist/s who mentored the candidate during her/his master studies is required. The letter must clearly expose the profile of the candidate with emphasis in the qualities which make her/him suitable for being recruited in THEORE3M. Additional recommendation letters from any other professor/professional will be most welcomed.

Specific qualifications

Candidates should have a solid background in Continuum Mechanics, Experimental Mechanics, Dynamic Behavior of Materials, Mathematics and Programming.

Flexible working conditions

We are committed to provide flexible hours and home working conditions for researchers having family obligations. The following web-site contains relevant information **related to the EU equal opportunities policy** https://ec.europa.eu/info/aid-development-cooperation-fundamental-rights/your-rights-eu/know-your-rights/equality/non-discrimination_en. Moreover, the web-site http://www.partnerjob.com/ facilitates geographic mobility by providing help to find a job for an accompanying partner.

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Contact details

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The application period closes in July 2021

The PhD starts in September 2021