PURPOSE

Opening a new route in solid mechanics: Printed protective structures

PhD position in ERC Starting Grant

PURPOSE

Dynamic fragmentation of metals is typically addressed within a statistical framework in which material and geometric flaws limit the energy absorption capacity of protective structures. This project is devised to challenge this idea and establish a new framework which incorporates a deterministic component within the fragmentation mechanisms. In order to check the correctness of this new theory, we will develop a comprehensive experimental, analytical and numerical methodology to address 4 canonical fragmentation problems which respond to distinct geometric and loading conditions which make them easily identifiable from a mechanical standpoint. For each canonical problem, we will investigate traditionally-manufactured and 3D-printed specimens made of 4 different engineering metals frequently used in aerospace and civilian-security applications. The goal is to elucidate whether at sufficiently high strain rates there may be a transition in the fragmentation mechanisms from defects–controlled to inertia–controlled. If the new statistical-deterministic framework is proven to be valid, defects may not play the major role in the fragmentation at high strain rates. This would bring down the entry barriers that the 3D-printing technology has found in energy absorption applications, thus reducing production transportation and repairing, energetic and economic costs of protective structures without impairing their energy absorption capacity.

PhD Research

Multiple localization and fracture in printed metallic thin-walled cylinders subjected to dynamic expansion

Host

University Carlos III of Madrid

Supervisor

Professor José A. Rodríguez-Martínez

Synopsis

The dynamic expansion of thin-walled cylinders is an experimental arrangement recently used by various researchers to study the fragmentation of metallic materials. The symmetry of the problem minimizes the waves disturbances along the hoop direction of the sample. Similarly to the ring expansion problem, the specimen is subjected to uniaxial tension before localization. However, the fragmentation is now caused by the formation of multiple pairs of (intersected) necking bands aligned with the two directions of zero stretch rate. The different localization and fragmentation patterns in the ring expansion problem and the cylinder expansion problem are due to the different stress states that develop in the necked sections during the post-critical deformation regime. The goal is to bring to light the relationship between the necking and fragmentation patterns, and (1) inertia effects, (2) stress multiaxiality effects and (3) mechanical behaviour of the material. Special attention will be paid to elucidate the role played by material porosity, surface roughness and anisotropy, since these are

specific characteristics of additively manufactured specimens. The PhD research will include experimental and analytical work.

Research outputs

- **Cylinder expansion experiments** with four different printed metals (and their traditionally-manufactured counterparts) to assess the mechanisms which control the localization and fragmentation behaviors of additively manufactured materials.
- **Development of 3D perturbation analyses** to investigate the joint effect that inertia, strain rate, porosity and anisotropy have on the onset and development of necking instabilities in cylinders subjected to dynamic loading.

The final goal is to elucidate whether the porosity and surface defects of printed metals determine their strength, ductility and energy absorption capacity under impact loading.

Multidisciplinary / international research approach

The experimental part of the research will be conducted in a **prestigious lab in the United States**, where the ESR will have to spend 6-8 months. There, the ESR will become familiar with various experimental techniques and she/he will gain specific experience and know-how in the dynamic radial expansion of cylinders. Moreover, the ESR will develop at the **University Carlos III of Madrid** —where she/he will conduct the rest of the PhD research— the 3D linear perturbation model to assess the interplay between inertia, strain rate, loading path and anisotropy in the formation of necks in metallic cylinders subjected to dynamic loading. The analysis and interpretation of the results, and the comparison between experiments and linear stability analysis, will also be conducted at the UC3M. The ESR will be exposed to an international environment in which she/he will have the opportunity to meet and collaborate with prestigious scientists within the framework of Solid Mechanics.

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 the course**: From PhD to Scientific Leadership to be organized by Yellow Research in Madrid.
- **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/).
- **Organization of a scientific conference:** the ESR will participate in the organization of a prestigious Euromech Colloquium that will be held in Madrid from 21 to 24 May 2019 (http://605.euromech.org/).

Benefits

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

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Key publications

Fressengeas, C., Molinari, A. Inertia and thermal effects on the localization of plastic flow. *Acta Metallurgica*. 1985; 33, 387–396.

Fressengeas, C., Molinari, A. Fragmentation of rapidly stretching sheets. *European Journal of Mechanics A/Solids*. 1994; 13, 251-268.

Dudzinski, D., Molinari, A. Perturbation analysis of thermoviscoplastic instabilities in biaxial loading. *International Journal of Solids and Structures*. 1991; 27, 601–628.

Mercier S., Molinari A. 2003 Predictions of bifurcations and instabilities during dynamic extensions. *International Journal of Solids and Structures*. 2003; 40: 1995–2016.

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 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
Degree	Master degree or equivalent
Degree field	Physics

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 PURPOSE.

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 PURPOSE. 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 December 2018

The PhD starts in March 2019