PhD Thesis Offer

Titre : Modelling of the dynamical performance of a protective structure ceramic-adhesive-composite: analysis of the adhesive layer functionality

Supervision :

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- Icube / ISL : Pr Nadia BALOUHLI / Dr Yaël DEMARTY

1) Context

The present PhD Thesis offer takes place in an upstream project dealing with the performance improvement of armors composed by the assembly of a cover ceramic layer and a backing composite layer (Fig. 1). The main function of the cover ceramic layer is to slow down the projectile advance by dissipating the energy through fragmentation process [Rahbek 2017, Shokrieh 2008, Colar 2013, Colar 2015]. The main function of the composite backing layer is to retain the ceramic fragments (non-perforation criteria) and to restrict the sinking of the armor (sinking criteria). An adhesive layer is used to join both layers. This adhesive layer is explicitly not functionalized to participate in the armor performance. ***One of the main objectives of this PhD Thesis is to understand and model the function of this adhesive layer in view of performance improvements of armors*.**

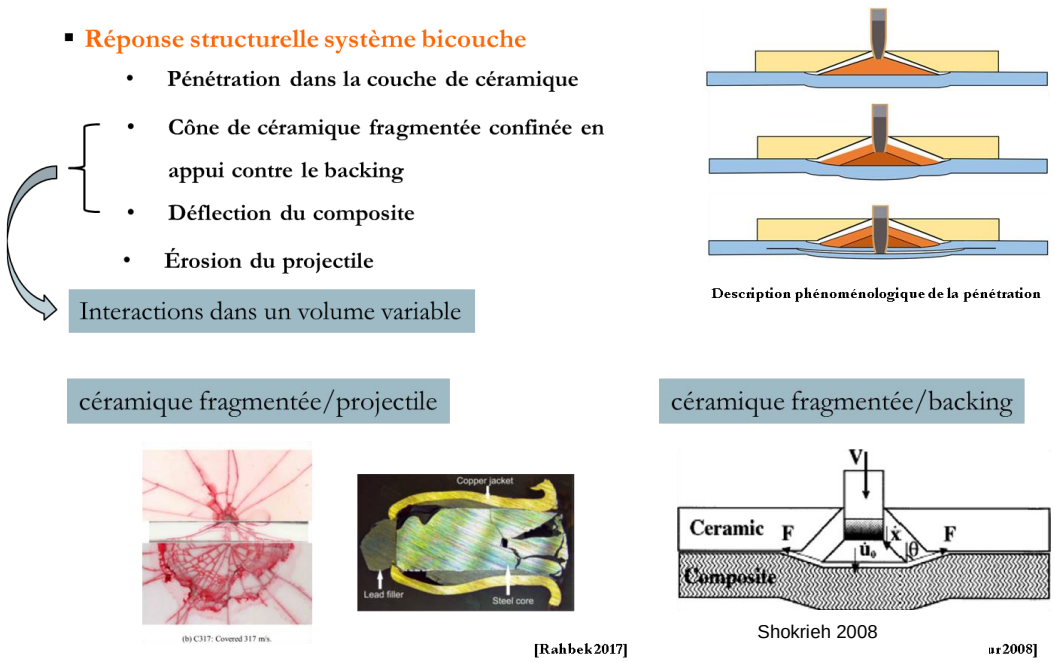

***Figure 1**: Principle scheme for the ballistic protection through the joining of a cover ceramic layer and a composite backing layer.*

If it is fundamental to understand the fracture modes by fragmentation of the cover layer under impact as well as the fracture modes of the backing layer, it is necessary to consider for the influence of the adhesive layer on these fracture modes. Indeed, the fracture strength of the adhesive layer provide to the system a sufficient bending stiffness to restrict the backing layer deflection and to prevent from its perforation by ceramic fragments. The adhesive layer is likely contributing in the fragmentation improvement of the cover ceramic layer. In the frame of this PhD Thesis, the classical approach coupling experimental tests and numerical tests will be taken. ***This PhD thesis aims at then to taking benefit from previous projects founded by the Agence Innovation Defense (AID)*** [Essongue 2022] Camalet 2020, Duplan 2020, Francart 2017] ***as well as the dedicated projects of current involved laboratories on the behavior modelling of bonded joints*** [Lopez-Puente 2005, Lélias 2018, Jaillon 2019a 2019b, Planas 2024].

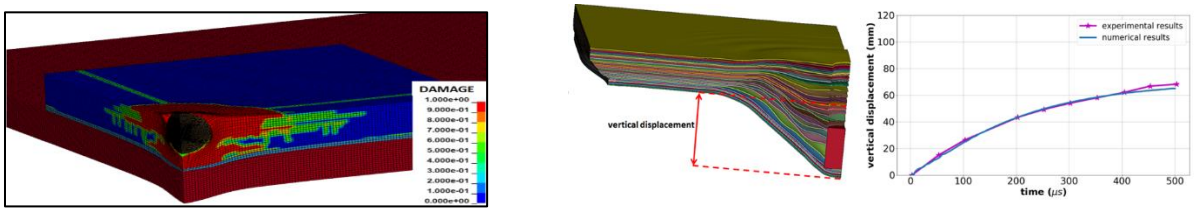

Figure 2 : Numerical model unde rapid dynamic of the perforation of three-layer protection.

In addition, in the frame the development of these armors, new materials for the 3-layer to be joined will be considered to meet at best the protection criteria (non-perforation criteria, sinking criteria, reusability, multi-impact protection, recycling and environment requirement). In this line, two industrial partners of ISAE-SUPAERO, Arkema for adhesives and Saint Gobain for backing and cover layers, will be involved ***as a way forward for this PhD Thesis.***

This PhD Thesis can then be regarded as the next step of previous works done on the topic by ISAE-SUPAERO in collaboration with ISL and ICUBE since 2017. The focus is on the influence of the adhesive material properties (including strength) on the fragmentation of the cover ceramic layer and on the deflection and associated damaging of the backing composite layer. This PhD Thesis takes place in scientific themes dealing with the modelling of material and bonded composite structures behavior at high rates.

2) Work program

Golab objectif :
Qualification of the mechanical strength of three-layer ballistic protection system by functionalizing of the adhesive layer and assessment of its role in the ceramic layer fragmentation and in the composite layer performation.

- ***Literature***
  - Damage and fracture mechanics of composite and ceramic, such as used in the current system
  - Use of behavior model developed previously:
    - Model for the ceramic fragmentation [Denoual 2000, Holmquist 2008, Camalet 2020, Duplan 2020, Forquin 2019]
    - Damage and fracture model for composire [Camalet 2020, Ilyas 2010, Cheng 2015, Lachaud 2020, Espinosa 2013]
  - Anlaysis of numerical models to characterize the current weak points and lacks in terms of parameters to be identirfied
  - Model behavior under high rate of bonded interfaces: cohesive zone model
  - Method for identification of model behavior under high rate of bonded interfaces

- ***Experimental test***

- *Method for identification of model behavior under high rate of bonded interfaces*
  A first step will focus on the choice of the adhesive layer as function of its ability to adhere and on the role of adherence on the strength of the three-layer system.
  The selected adhesive systems will then be characterized in static and in dynamic under bulk and confined configuration. The test campaigns will make use of available equipment in the labs, while dedicated protocols for certain solicitation under high rate need to be developed.
- *Behavior model for selected adhesives*
  A behavior model will be developed in the basis of experimental test results and numerical models and methods available in the labs. Its robustness will be assessed based on an experimental test campaign at various scales and on well-known materials.
- Additional test campaign of the mechanical behavior of ceramic and composite materials.
  - At the scale of materials, some of previously identified parameters exhibit some limits. New additional tests could be developed to improve the robustness (inter and intra laminar fracture energy, viscoplasticity at the laminate scale, elevated porosity in new ceramic)
  - At the scale of the three-layer protective system, various tests need to be defined:
    - Hyper rate canon tests at ICA (800 m/s)
    - Balistic test at ISL

➢ ***Numerical modelling***

- The numerical development of the three-layer system as well of each components have already been the topic of several works within the particpatin labs. This modelling basis will be used for this PhD Thesis [Camalet 2020, Essongue 2022, Lachaud 2020, Planas 2024, Schwartz 2023]. The first models allowing for the understanding of the adhesive layer functionalization will use existing developments as well as the sizing of experimental tests.
- Implementation of behavior model at high rate in cohesive zone models [Planas 2024]
- Each experimental test for each scale (including hyper rate and ballistic impact tests) will be comparted to numerical test (FE, SPH, discrete/continuous model…)
- Use of macro-element modelling (ME) for the bonded interface. This method has been created and developed at ICA since 2003 and allows for the mode enrichment (high fidelity at low cost) [Paroissien 2000, Schwartz 2023, Orsatelli 2024]. This method is fast and robust and will be compared to the CZM method for the mechanical behavior prediction.
- Adaptation on existing behavior model (ABAQUS explicit, « User Materials » [Lachaud 2020] to the new composite and ceramic materials.

In the frame of this project, a Post-Doc student will work in support of the PhD Thesis from the second year.

The candidate need to have knowledge in composite materials and structures, nonlinear analysis, numerical method for rapid dynamic and prone to perform coupling experimental/numerical analyses.

Key words : Fragmentation, damage, fracture, ceramic, composite, bonding, rapid dynamic, choc, impact, numerical method, Hopkinson bars bench, hyper rate canon

3) Administration

We are looking for candidates who solid knowledge in solid mechanics, material sciences, numerical simulations and mechanical characterization. Candidates must be able (i) to design new experimental test benchs within the participating labs while enduirng the cordinations of various technical teams, (ii) to perform numerical simulation and analyze the results, and (ii) to present the results and write papers.

Candidates must have (i) the taste for experimental and numerical works, (ii) human and management qualities allwing for soft intergartion within the team works and (ii) writing and oral skills in English.

Starting date : From October / November 2024
Duration : 3 ans
Salary : 2100 € net per month mois (salary increase planned in 2026 in agreement with loi de programmation de la recherche) + possible teaching contratc at ISAE SUPAERO (100 € to 200 € in plus per month)
Contacts : CV and application letter to be sent to:
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Finally remote meeting could be organized to discuss on topics, as function of candidates wish and dedicated question on the work environment.

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