Characterisation of Ceramic Assemblies for Radioactive Waste Disposal: Mechanical behaviour

Internship duration and location: 6 months, starting from March 2027, at Institut de Recherche Dupuy de Lôme (ENSTA – Campus de Brest)

Context

Andra, the French national agency for radioactive waste management, is responsible for finding long-term disposal solutions for various categories of radioactive waste. For the most hazardous high-level, long-lived waste, the current approach involves vitrification and storage. The long-term solution, both in France and worldwide, is deep geological disposal at a depth of 500 meters, as planned in the “Cigéo” project (see QR code below).

Vitrified waste is placed in a stainless-steel container, which should then be inserted into a carbon steel disposal container designed to protect the waste for 500 years. However, under disposal conditions, low-carbon steel corrodes and releases hydrogen gas, the management of which is complex during both the operating period and after closure of the facility. Andra is therefore exploring alternative solutions to carbon steel, including the feasibility of manufacturing disposal containers from ceramics. To this end, Andra built a partnership with Galtenco Solutions, a company with expertise in the gel-casting process for manufacturing large ceramic components. A 1:6 mock-up container has hence been recently manufactured (Figure 1). Achieving a reliable, 500-year watertight sealing between the ceramic container body and lid requires: optimized surface design and structuring, an appropriate sealing material, and a heating system to melt this material. Understanding the adhesion mechanisms and, important here, evaluating mechanical performance are critical to optimizing the assembly.

The Institute of Research Dupuy de Lôme (IRDL), which will host this Master’s project, has recognized expertise in multi-material assemblies, adhesive bonding, and durability of engineered structures subjected to severe environmental and mechanical conditions. The laboratory develops combined experimental and numerical approaches dedicated to the characterization and prediction of the mechanical behaviour of bonded assemblies, from coupon-scale interfaces (Butt joint ISO 6922:1987, Thick Adherent Shear Test ISO 11003-2:2019) to representative industrial structures. Previous works [1-2] carried out at IRDL notably addressed the failure prediction of tubular bonded structures using coupled stress-energy criteria and experimental validation on representative assemblies (Figure 2). Building on these recognised competencies, the project will focus on the mechanical characterization and durability assessment of ceramic interfaces, including ceramic–polymer and ceramic–enamel systems, for long-term radioactive waste management applications.



Figure 1: a 1:6 HLW mock-up container

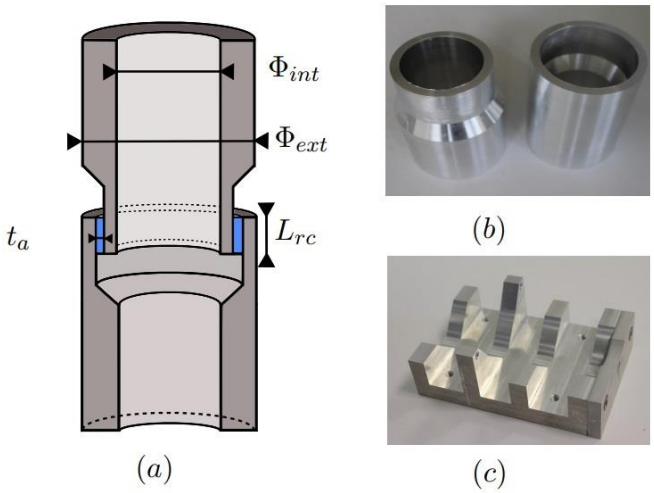


Figure 2: (a,b) Tubular bonded samples and substrates, c bonding device.

Project Tasks

- Mechanical characterization of ceramic-polymer/enamel interfaces at coupon scale through shear and adhesion testing, including analysis of interfacial damage and failure mechanisms.
- Experimental investigations on representative industrial structures and technological demonstrators of bonded assemblies [3], based on recent developments in ceramic container systems for radioactive waste disposal.
- Scientific exchange, validation to correlate local interface behaviour with structural-scale response, and synthesis of the experimental methodologies and results in collaboration with academic and industrial partners involved in radioactive waste management technologies.

A strong and sustained exchange with Andra and Galtenco will take place throughout the project, opening the possibility of a follow-up through a PhD thesis.

Required skills

- Solid background in **solid mechanics** and **mechanics of materials**
- Knowledge of **mechanical testing methods** and experimental characterization
- Understanding of **fracture mechanics**, damage mechanisms, and interface behaviour
- Familiarity with **bonded joints**, adhesive bonding, or multi-material assemblies
- Experience in **experimental data analysis** and signal processing

References

[1] Arnaud, N., Créac'hcadec, R., & Cognard, J. Y. (2015). Identification of the Elastic–Plastic Behavior of Adhesively Bonded Structures Under Multi-Axial Loadings: Comparison of a Modified Arcan Test and a Tension/Compression–Torsion Test. The Journal of Adhesion, 2014.

[2] Le Pavic J, Bonnemains T, Lolive E, Stamoulis G, Da Silva D, Thévenet D, Failure load prediction of a tubular bonded structures using a coupled criterion, Theoretical and Applied Fracture Mechanics, 2020.

[3] Debelle A, Besnard C, Miot S, Perret E, Couillaud S, Ganster P, et al. Ceramics as alternative solutions for the geological disposal of high-level radioactive waste: Andra's R&D program. Int J Appl Ceram Technol, 2024.

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