Engineer intern in the **PIMM** laboratory at **ENSAM Paris**

Internship title: Thermo-oxidative aging of thermoset matrix and composites for high temperature durability

Research fields: physical-chemical and mechanical techniques, thermo-oxidation, epoxy, fibre reinforced composites

The present internship will focus on **experimental characterisation in order to favour the comparison with on-going numerical models** based on Finite Elements (FE). **The work could be pursued in a PhD thesis**.

Context: This internship is part of the ANR (Agence Nationale de Recherche) projet H^{3}YES (Hybrid approacH for High durabilitY of polymer matrix compositES of next low-emission aircraft). The ANR project aims to develop a novel hybrid methodology for characterization and simulation of Fibre-Reinforced Polymer Matrix Composites (FRPMCs) subjected to thermo-mechanical aging. These materials are ideal for structural applications due to their superior specific properties and environmental resistance. They are then perfect candidates for future generation of low-emission aircraft in order to address the ADEME outlines to cut France's greenhouse gas emissions by 55% by 2030 and achieve carbon neutrality by 2050. Thermoset (TS) FRPMCs provide a balance of thermal stability and mechanical strength, making them preferable for aeronautical applications that endure high temperatures above 100°C (*i.e.*, resist the effects of thermo-oxidation and thermal strains). Basalt-fibre Reinforced Polymer Matrix Composites (B-FRPMCs) are being studied as high-temperature alternatives to carbon FRPMCs due to their better compatibility with existing matrices. However, understanding their **thermo-chemical and mechanical behaviour** remains critical.

The appearance of a thin and finite thickness of oxidized layer (TOL) on the material surface can induce local embrittlement and the development of stress gradients which can be the cause of their cracking and consequently, premature fail [1], as previously identified for another(s) thermosetting matrix (Fig. 1a) and reinforced composites (Fig. 1b). From this background, PIMM drives a research program including the study of kinetics of **thermo-oxidative aging and mechanical degradation** for TS matrix and its FRPMCs for the better understanding of its possible damage scenarios.

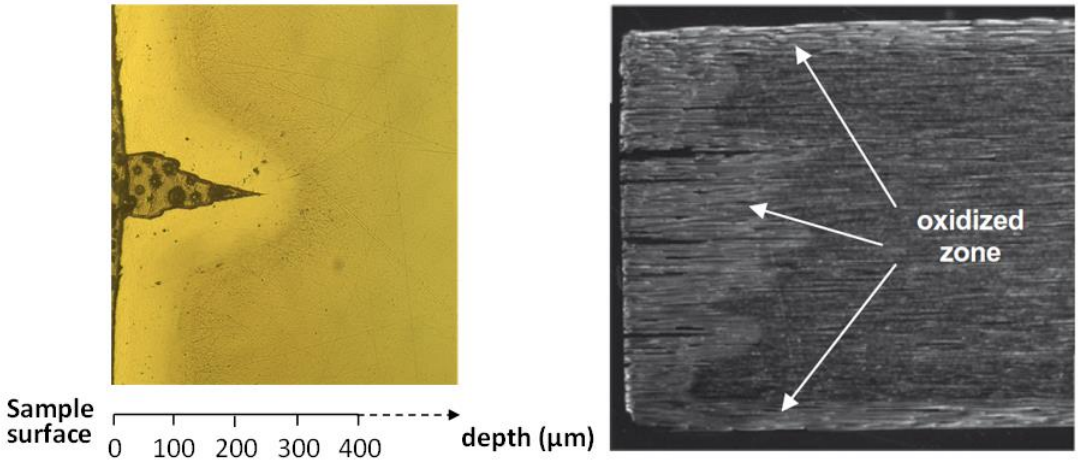

Figure 1. Cracking after exposure in the air of a) thermoset Tactix123+Tactix742/DDS after 200 h at 200°C and b) UD carbon fibre and PMR-15 composite after 906 h at 288°C

Objective & planning: The project aims to **experimentally characterise the thermo-oxidation gradients and its mechanical consequences of TS matrix and its composite based on laboratory technics**. This involves several tasks:

(1) Matrix films and thick samples will be manufactured in the laboratory using moulding techniques. UD films and thick samples will be manufactured through Vacuum-Assisted Resin Infusion. The study of **oxygen reaction kinetics in matrix films and unidirectional films** to establish linking different oxidation conditions in air (i.e., time, temperature) to thermo-chemical (*e.g.*, T_g, mass loss, density increase, free shrinkage) and thermo-mechanical (*e.g.*, E, ε_R, σ_R) properties. Standard **physical-chemical and mechanical characterisation techniques** (DSC, Archimedes' principle, tensile tests with video-extensometer, …) will be used.

(2) The study of the **diffusion and reaction coupling in thick matrix and thick UD samples after aging**. The goal is to faithfully describe the oxidation gradients on the though-thickness direction to evaluate the TOL and the gradients of properties of interest (*i.e.*, T_g and Young's modulus) using physical-chemical characterisation techniques (e.g., DSC, DMA). The TOL will be measured by sample preparation and microscopic techniques (e.g., indentation, optical micrography).

(3) Previous data will allow to **feed a home-made code in Abaqus which describe oxidation gradients for thick samples**. The candidate will allow to consider the new matrix aging kinetics and to validate the oxidation gradients for both matrix and composite samples by calculating the corresponding values of the TOL [2,3]. The numerical assessment of the effect of thermo-oxidation on stress/strain fields will be studied by coupling the previous model with mechanical relationships in the FE model by UMAT subroutines [4].

Références bibliographiques :

[1] X. Colin, A. Mavel, C. Marais, J. Verdu. Interaction between cracking and oxidation in organic matrix composites, J. Compos. Mater. Vol. 39 n° 15, pp. 1371–1389, 2005.

[2] J.P. Marquez Costa et al. Finite element modelling of the oxidation gradients of epoxy-diamine matrices below and above their glass transition temperature. Polym. Degrad. Stab., 234:111194, 2025.

[3] J.P. Marquez Costa et al. Modelling of the thermo-oxidation gradients in organic matrix composites. In Proceedings of the 24th JNCs, Gif-sur-Yvette, 2025.

[4] K. Pochiraju, G. Tandon. Evolution of stress and deformations in high-temperature polymer matrix composites during thermo-oxidative aging. Mech Time-Depend Mater. Vol. n° 12, pp. 45–68, 2008.

Candidate profile: The candidate could come from 3rd year in Engineering program and/or 2nd year in Master 2 in material science, mechanics, physics-chemist and/or composite materials. The candidate comes from a background in physics-chemist, mechanics and/or materials engineering and must show a taste for experimental testing. Knowledge in the field of polymers and composite materials as well as numerical tools will be very appreciated.

Duration: 5 to 6 months

Place: PIMM laboratory (*Procédés et Ingénierie en Mécanique et Matériaux*), Paris (75013), France

Contact: Send CV, cover letter and your previous academic grades to:

Juan Pablo MARQUEZ COSTA – Associate Professor at ENSAM – juan-pablo.marquez_costa@ensam.eu

Xavier COLIN – Professor at ENSAM – xavier.colin @ensam.eu