JC² October 2022

Toward a reliable damage prediction tool for the design of linerless propellant tanks

Jean Vereecke[1], Christophe Bois[1], Jean-Christophe Wahl[1], Florian Lavelle[2], Erwann Le Goff[3]

1 : Institut de Mécanique et d'Ingénierie de Bordeaux, Université de Bordeaux, 351 Cours de la Libération 33405 Talence

2 : Centre National d'Etudes Spatiales, 52 rue Jacques Hillairet, 75012 Paris

3 : ArianeGroup, site d'Issac, rue du Général Niox, 33165 Saint-Médard-en-Jalles

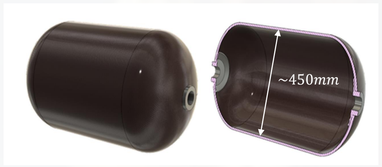
Context & objectives

Ariane 6 Next and future launchers :

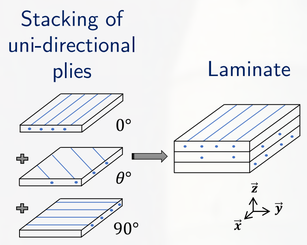
Reduce mass and cost of propellant tank using linerless composite structures

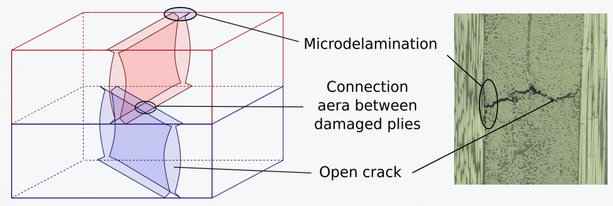
- Carbon-epoxy must store cryogenic liquid at approximately 5 bar
- Permeability must be ensured by the composite (technological lock)

1. Understand and predict damage evolution in composite laminates
2. Find the relationship between damage and permeability
3. Select the best stacking sequences that meet functional criteria



All-composite linerless (Type-V) tank demonstrator *[Thales Alenia Space]*

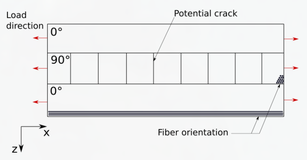


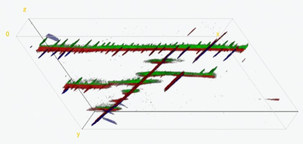


Damage scenario of laminated composite

Global methodology

Understanding and modelling the **accumulation of cracks** in an isolated ply [1]



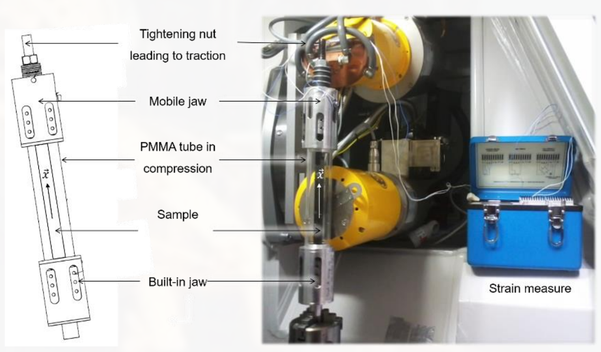


Studying the **interactions and the propagation** of cracks through the different layout

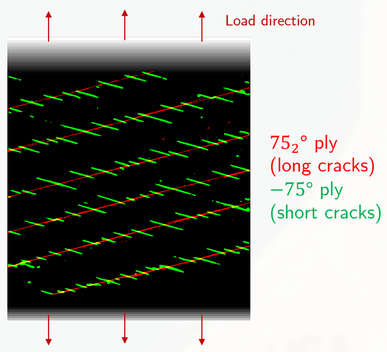
Relate damage rate in each ply to the effective **permeability**

Experimental observations

- Specimens are loaded in a tensile machine in order to generate damage
- At a certain temperature
- Then placed into a device to open crack and well see them



Experimental setup : loading outfit for X-ray observations [2]



Projection of the −75°/75_2° interface

Observations :

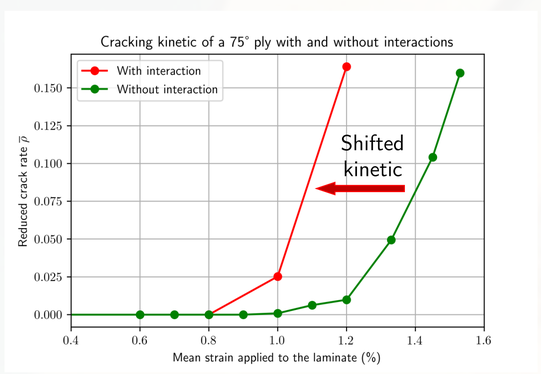
- Shorts cracks accumulate along the long ones
- Cracking threshold of adjacent ply is reduced locally

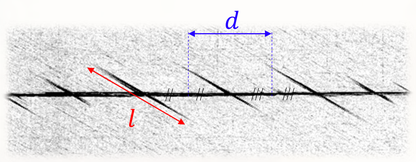
Quantitative measurements

The reduced crack rate provide the crack surface over the observed zone.

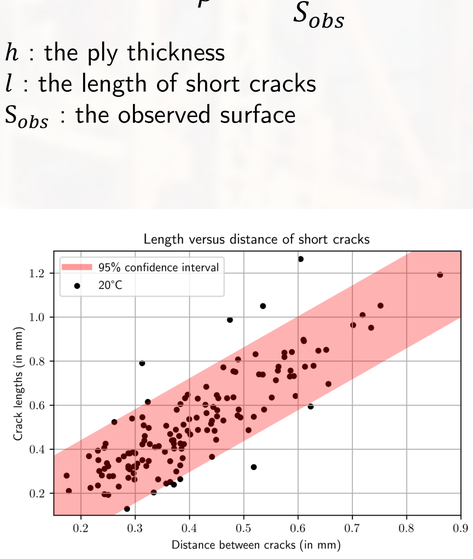
$$\bar{\rho} = \frac{h \sum_{N_{crack}} l}{S_{obs}}$$

h : the ply thickness
l : the length of short cracks
S_{obs} : the observed surface





Definition of length l and distance d



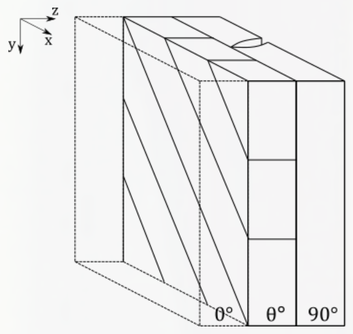
Linear relationship between **distance** and **length**. Long cracks are further from each other than short ones.

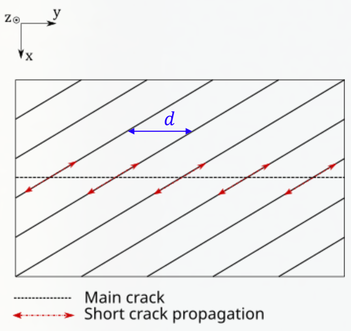
⇒ **It leads to a proportionality between the crack rates of interacting plies**

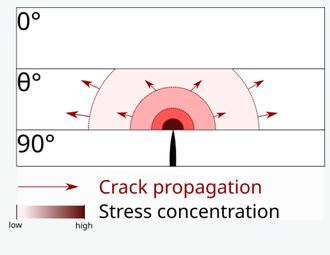
Numerical modelling

Objectives :

- Understand interactions behavior by using Finite Fracture Mechanics (FFM)
- Identify dominating parameters and quantify their influence



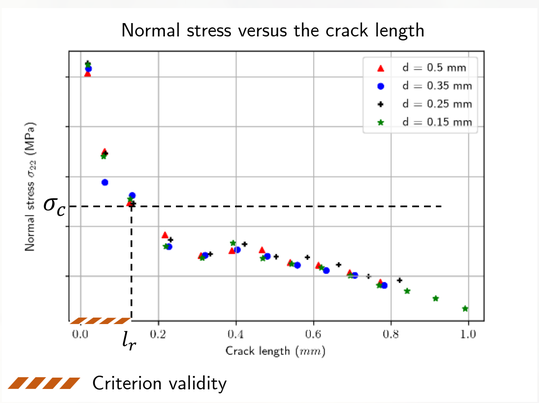




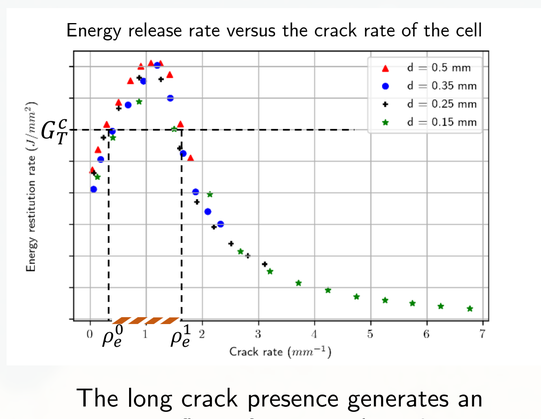
3D geometry of the RVE (Representative Volume Element)

A crack process divided into two steps...

- Initiation : the mean **stress** over the crack extension reaches the critical values $\boldsymbol{\sigma_c}$ [3, 4]
- Propagation : the **energy** available during the crack extension reaches the critical value $\boldsymbol{G_T^c}$ [3, 4]



The stress concentration at the edge of the long crack validates the criterion



The long crack presence generates an overflow of energy released

Multiple distances between short cracks have been tested :

- **Stress** concentration depends on the **distance** to the main crack
- **Energy** release rate depends on the **crack rate** of the cell

The mean crack length is calculated:

$$\Rightarrow A\rho_e^0 < l_r \quad and \quad l_c = min(l_r, A\rho_e^1)$$

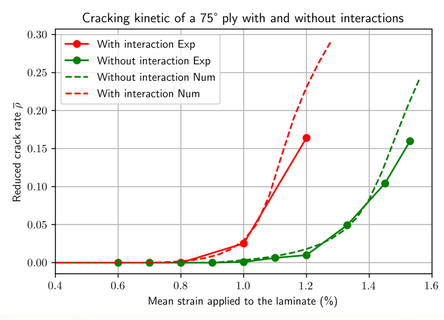
- l_c the crack length
- l_r crack length provided by the stress criterion
- ρ_e^0, ρ_e^1 crack rates provided by the energy criterion
- A cell area

Results & perspectives

Interactions behavior has been observed :

- Linear relationship between **length** and **distance** provides a constant ratio of the two crack rates
- This ratio depends on the **intersecting angle** between plies, on the **temperature**, on **ply thicknesses**, and on **crack threshold.**

Results from simulations explained such a phenomenon using **Finite Fracture Mechanics**. The implementation of phenomenological laws into a mesoscopic model led to acceptable predictions.



Comparison btw prediction and experimental results

References

[1] Jean Vereecke. Explicit modelling of matrix damage in a laminated composite comparison between linear fracture mechanic and cohesive zone model, ECCM20, 2022

[2] Tanguy Briand. Caractérisation et modélisation de la relation entre l'endommagement et la perméabilité dans un composite stratifié en condition cryogénique. *Thèse de doctorat*, Université Bordeaux, 2020.

[3] Dominique Leguillon. Strength or toughness? A criterion for crack onset at a notch. European - Journal of Mechanics - A/Solids, 21(1) :61-72, January 2002.

[4] Pietro Cornetti, Nicola Pugno, Alberto Carpinteri, David Taylor, Finite fracture mechanics: A coupled stress and energy failure criterion, Engineering Fracture Mechanics, Volume 73, Issue 14, 2006.

cnes CENTRE NATIONAL D'ÉTUDES SPATIALES

arianeGROUP

RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

I2M BORDEAUX