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Région PAYS de la LOIRE

Characterization of the dynamic fracture toughness of composite materials by a microscopic approach

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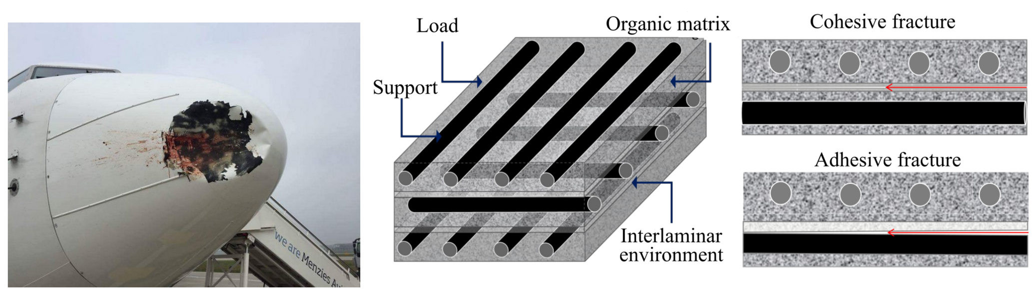
Context

Damages mechanisms on an impacted composite laminates



Bird-strike on plane and Delamination on composite laminates

- Issue of the delamination on a composite laminates under dynamic loading
- Study on the cohesive crack propagation
- Two main ways are used in the literature to characterize the inter-laminar strength under dynamic loading.

Microscopic approach

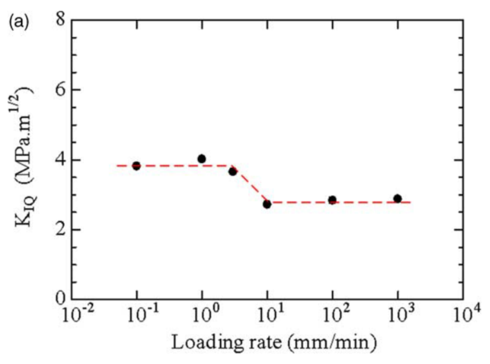
Determination of the stress intensity factor K_I

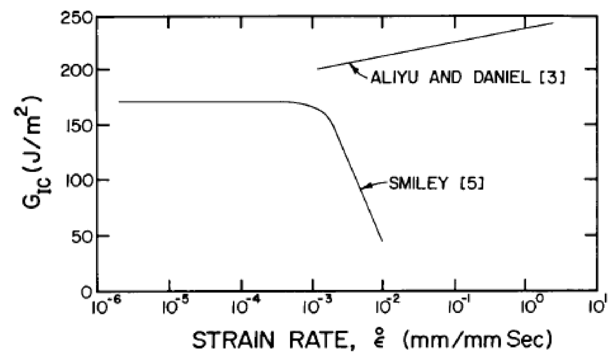
Influence of the Loading rate on K_{IC}

Macroscopic approach

Determination of the energy release rate G_I

Influence of the strain rate on G_{IC}





Different results on the fracture toughness in the literature (epoxy resin) [1](carbon/epoxy AS4/3501-6) [2]

In the literature there is no agreement of the dependence of the loading rate on the fracture toughness.

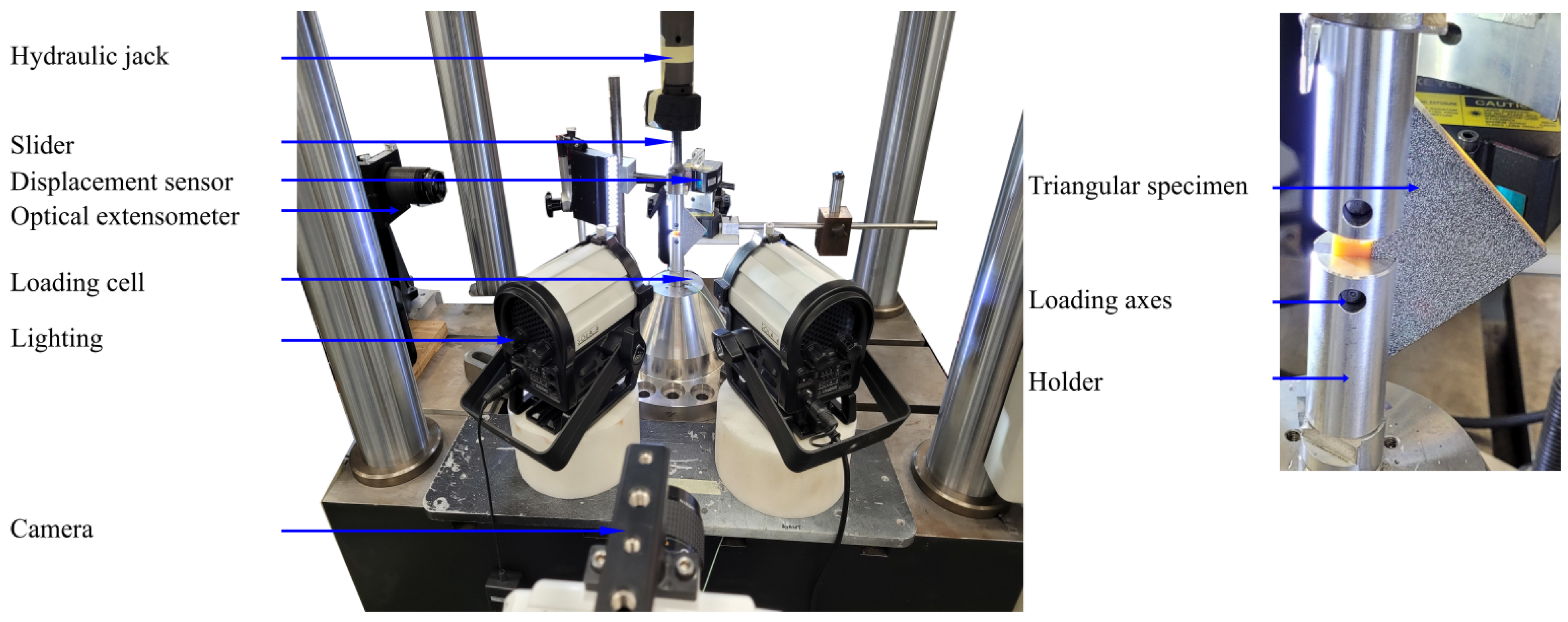
Objective of the study

From a microscopic approach with full field measurement, the goal is to characterize the loading rate dependency of the fracture toughness by taking into account the geometrical effect.

Experimental setup

An experimental setup has been developed to determine mode I fracture toughness on Hexply®M21 epoxy resin. A servo-hydraulic jack is used to performed tensile test with different loading rates between $10^{-4}\ m/s$ up to $1\ m/s$.

Considered specimens :
· Tapered Double Cantilever Beam (TDCB)
· Triangular specimen
· Different tests for each specimen has been performed to check repeatability



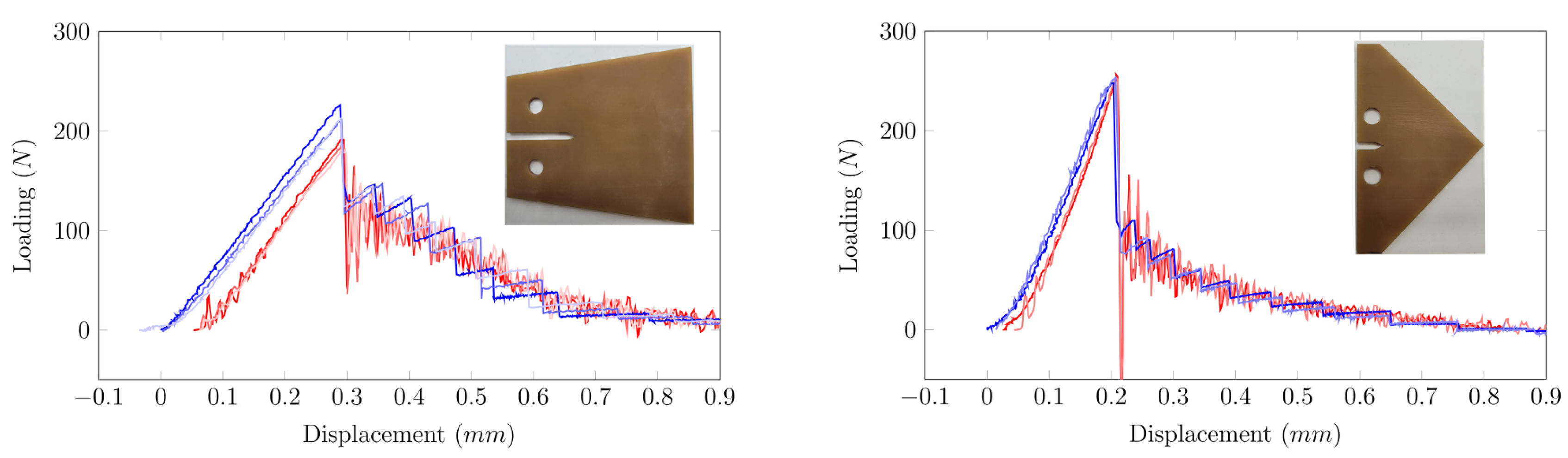
Experimental set-up on the left hand side and the triangular specimen on the right and side

Scalar measurements:
· Load → Piezoelectric load cell ± 60 kN
· Displacement → Optical extensometer
· All signals → 1 MHz data acquisition system

Field measurements:
· Digital Image Correlation (DIC) → High speed camera
· Temporal and spatial resolution → 1 kHz ; 1024 × 400 pixels²

Global Analysis

Influence of the loading rate on Load/Displacement curves



Load/Displacement curves ($10^{-4}\ m/s$ and $10^{-1}\ m/s$)

Rate dependency analysis for TDCB specimen:

- Low test dispersion
- The **maximum load decreases** with respect to the loading rate
- At the beginning of the crack propagation, **the load decreases** with respect to the loading rate
- The **stick-slip phenomenon** occurs at low loading rates

Rate dependency analysis for triangular specimen:

- Low test dispersion
- **No influence** of the loading rate
- The **stick-slip phenomenon** occurs at low loading rates

Microscopic approach methodology

Development of the Methodology:

The proposed method for determining the stress intensity factor K_I and the non-singular terms, $T-stress$ and $B-stress$ is based on digital image correlation and Williams series. The displacement fields u_w of the Williams series are defined by the following equation [3] :

$$u_w = \sum_{j=I,II} \sum_{n=n_m}^{n_M} a_j^n \phi_j^n(z) \quad (1)$$

a_j^n are real coefficients and ϕ_j^n are complex functions. n_m and n_M define the truncation of the Williams series. In mode I, the stress intensity factor K_I, the first non-singular term T or $T-stress$ and the second non-singular term B or $B-stress$ are defined by :

$$K_I = 2\mu\sqrt{2\pi}a_I^1 \quad (2)$$

$$T = 8\mu a_I^2 \quad (3)$$

$$B = 2\mu\sqrt{2\pi}a_I^3 \quad (4)$$

μ is the shear modulus of the considered material

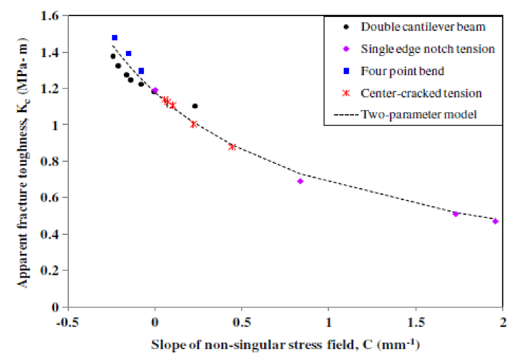


Figure 4 : Influence of B ($B = \frac{K_{Ic}C}{3}$) and the specimen on K_{Ic} [4]

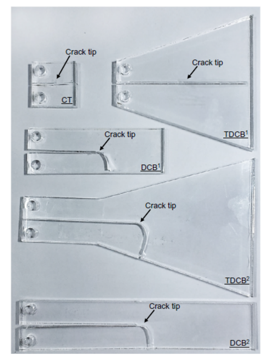
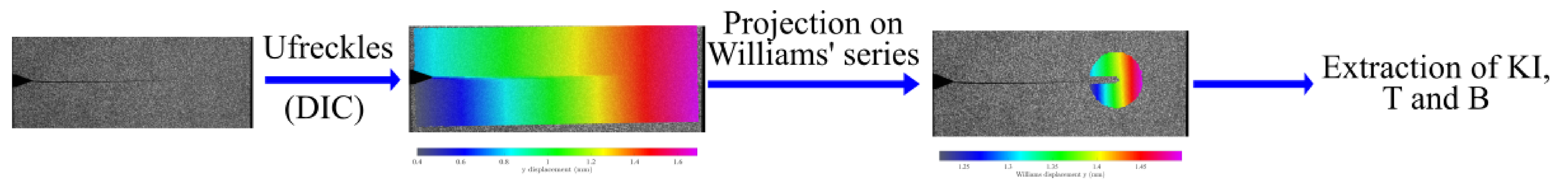


Figure 5 : Influence of the specimen geometry on the crack path [5]

Cotterell has explained that the T **stress controls the stability of the crack direction** whereas B **stress controls the stability of the crack propagation** [6].

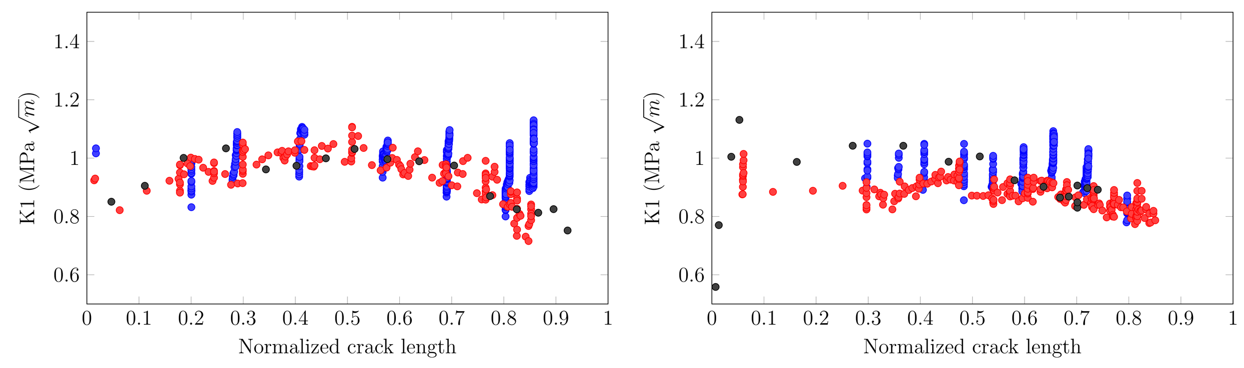


Methodology to extract Williams' series terms from image of the crack propagation

Analysis of Williams'series terms

In order to simplify the results, only one experiment for each specimen and each loading rate is considered.

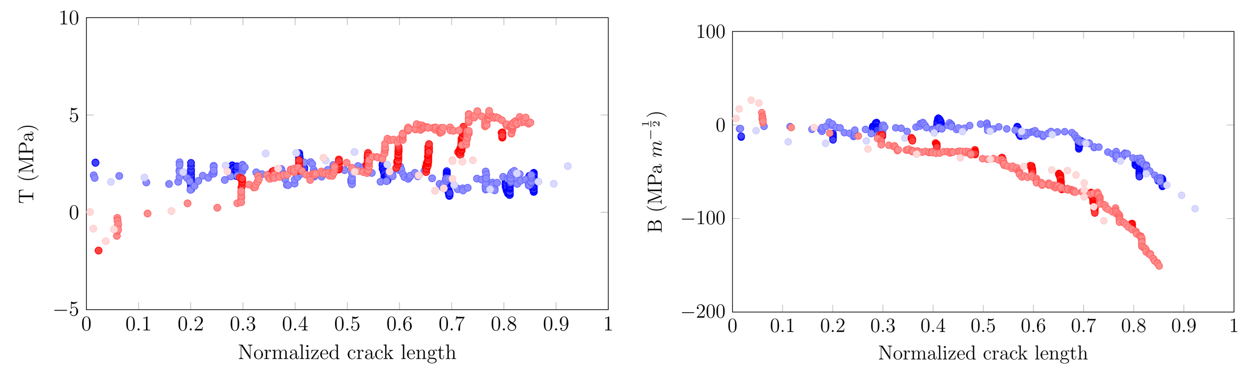
Influence of the loading rate and the specimen on K_I



Evolution of K_I with respect to the normalized crack length, on the left hand side for the TDCB samples, on the right hand side for the triangular samples ($10^{-4}\ m/s$, $10^{-1}\ m/s$ and $1\ m/s$)

- At low loading rate ($10^{-4}\ m/s$) the stick-slip phenomenon is observed
- It seems that K_I **decreases a little** with increasing of the loading rate for the considered loading rate ranges
- The decrease of K_I with the loading rate is more **important for the triangle specimen**

Influence of the specimen geometry on T and B



Evolution T and B with respect to the normalized crack length (TDCB samples, triangular samples)

- There is **no influence** of the loading rate on T **and** B
- For TDCB specimen T **is constant** along the crack path ($T \approx 2\ MPa$)
- For triangular specimen T **increases linearly** along the crack path ($T \approx 0\ MPa$ to $T \approx 5\ MPa$). At the end of crack propagation T reached a sufficiently high and positive value to produce crack bifurcation
- B is **constant** at the beginning of the crack propagation $B \approx -20\ MPam^{-\frac{1}{2}}$ before **dropping** at the end of the crack propagation. The decrease of B is more important for triangular specimen ($B \approx -150\ MPam^{-\frac{1}{2}}$) than TDCB specimen ($B \approx -80\ MPam^{-\frac{1}{2}}$)

Conclusions and future works

Conclusions :

- A microscopic approach using a full field measurements has been developed in dynamic loading.
  - Determination of the **fracture toughness and non singular terms**
  - Taking into account the **influence of the considered specimen**
- In theses considered loading rates, there is a **low decrease** of K_I with the increase of the loading rate

Future works :

- Improvement of the experimental set-up **to increase the loading rate**
- Development a **new experimental set-up** to compare the results with a **specific composite laminates**

References

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