Simulation of damage induced acoustic emission in laminates

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COMPTEST, Girona, 01-06-2023

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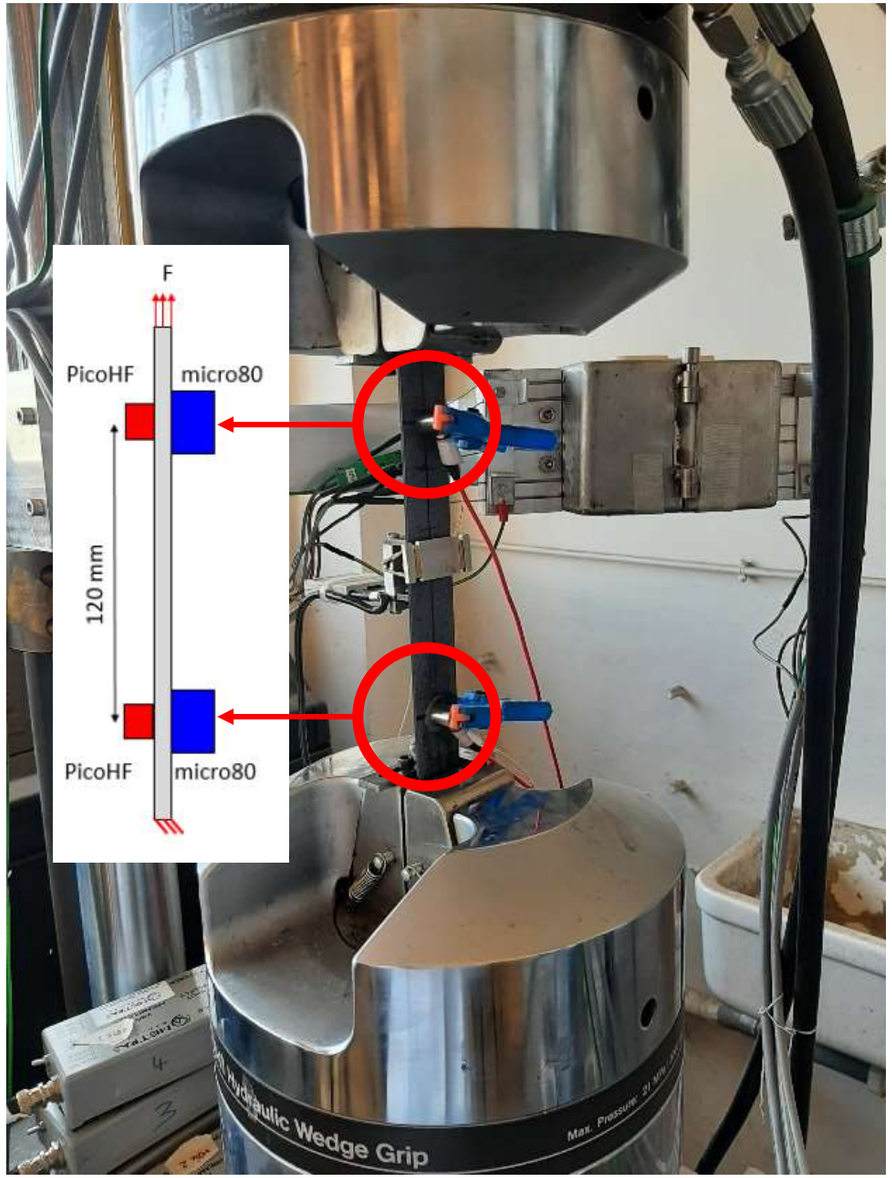
Acoustic emission testing



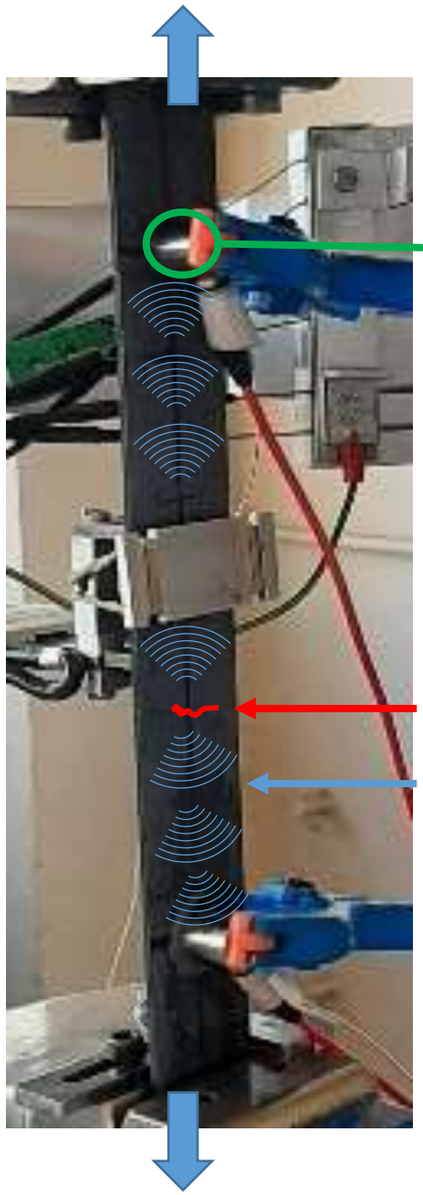
Material

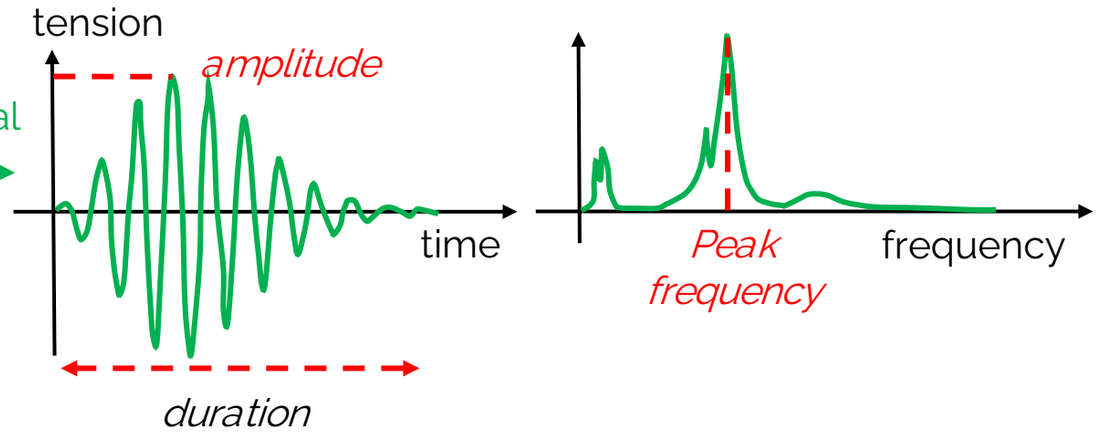
- $[0_n/90_n/0_n]$ laminates
- 0.3 mm thick Hexply® 8552 plies
- Epoxy resin/AS4 carbon fiber (60% v_f)

Instrumentation

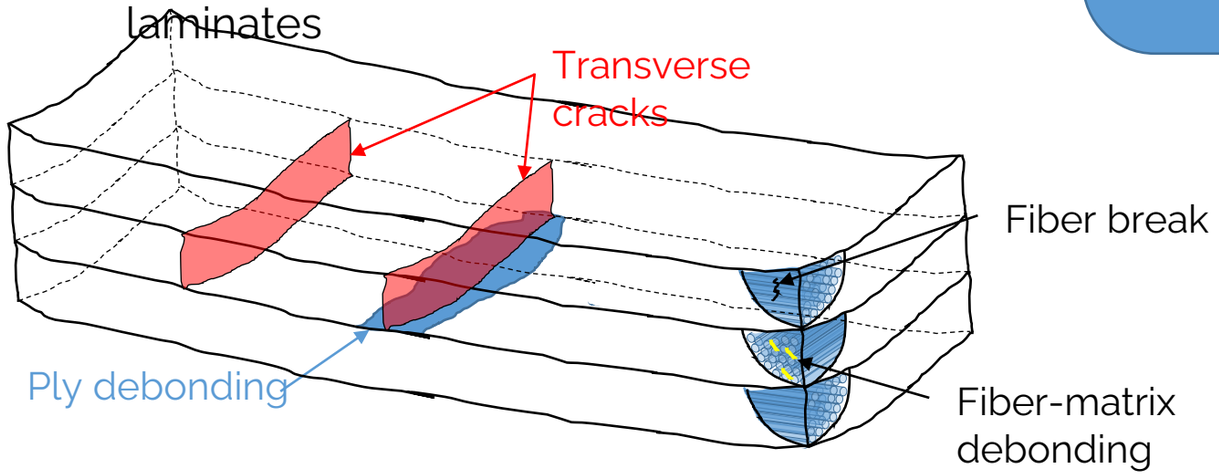
- 2 micro80 sensors (Mistras Group, Princeton, NJ, USA)
- 2 picoHF sensors (Mistras Group, Princeton, NJ, USA).

Acoustic emission (AE)



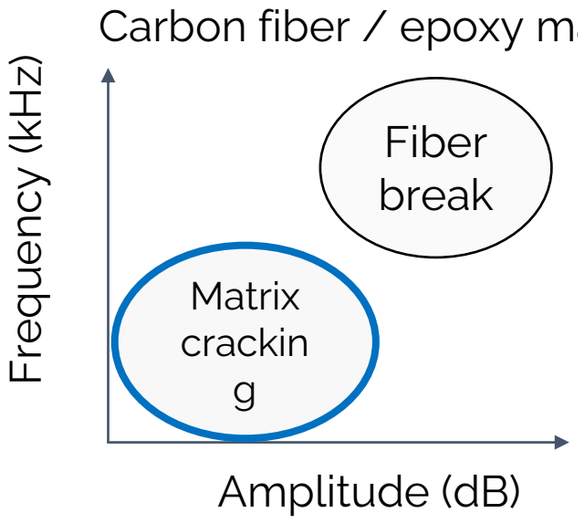


❑ Several damage mechanisms in laminates



Can we establish a link between one damage mechanism and the corresponding AE signal ?

AE – damage mechanisms classification



- Acoustic signal **classification approaches**

Anastassopoulos *et al.*, *Non Des. Test.*, **1996**

- Limits:

⇒ Lot of experiments needed

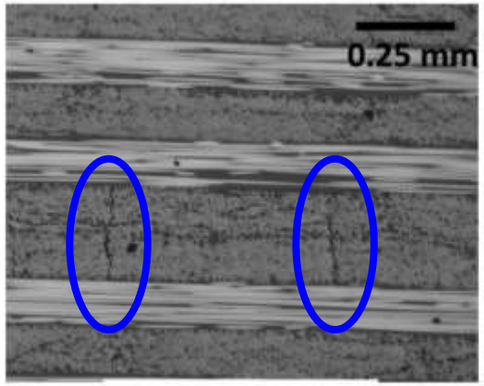
Morizet *et al.*, *Mech. Sys. Sig. Proc.*, **2016**

⇒ **Material/equipment dependence**

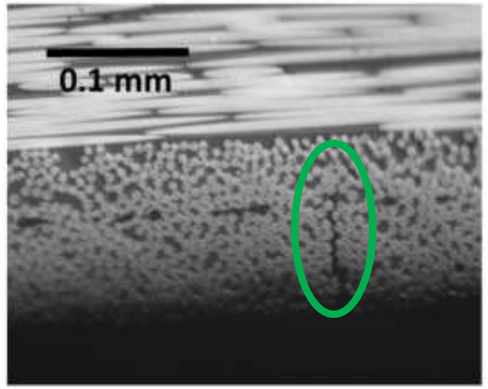
Godin *et al.*, *App. Sci.*, **2018**

⇒ Validation of quantitative links between damage mechanisms and signals?

Baker *et al.*, *CST*, **2015**



(c) Panel 3 double 90° Interior Cracks



(d) Panel 4 Surface 90° Crack

Baker *et al.*, *CST*, **2015**

PF … Peak Frequency
FC … Frequency centroid

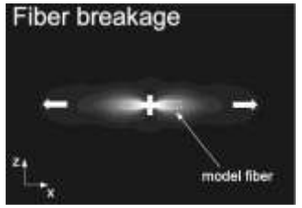
(1) Surface 90 ply cracking
➔ low PF and low FC

(2) Inner 90 ply cracking
➔ higher frequency content

➔ Numerical simulation to gain confidence in experimental approaches

Acoustic Emission simulation

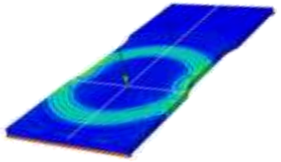
Media + source



Sause et al., *JNDE.*, **2010**

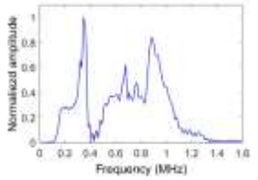
Zelenyak et al., *Ultrasonics*, **2018**

Wave propagation Acoustic signals

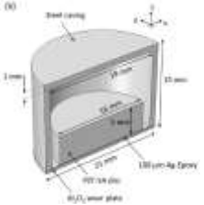


Le Gall *et al.*, *App. Sci.*, **2019**

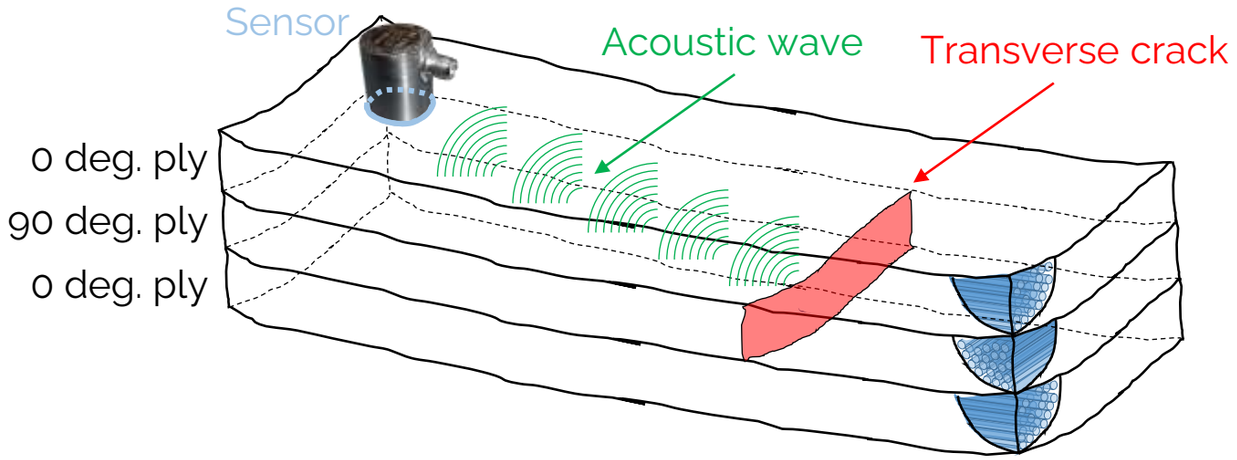
Sensor + acquisition chain



Le Gall *et al.*, *App. Sci.*, **2019**

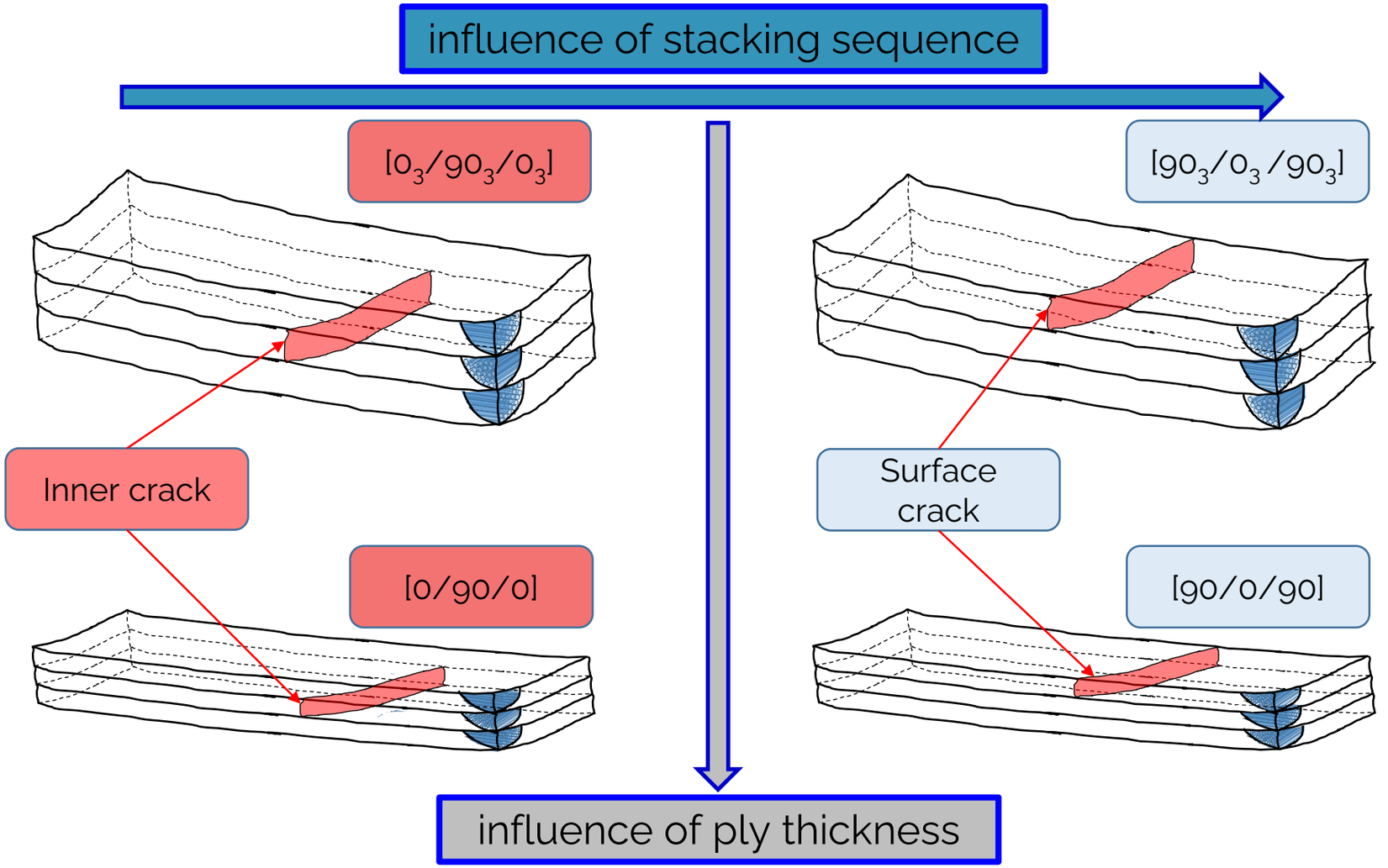


Sause et al., *S&A.*, **2018**



Objective

- Identify the acoustic signature of transverse crack in $[0_n/90_n/0_n]$ or $[90_n/0_n/90_n]$ (n=1 or 3)

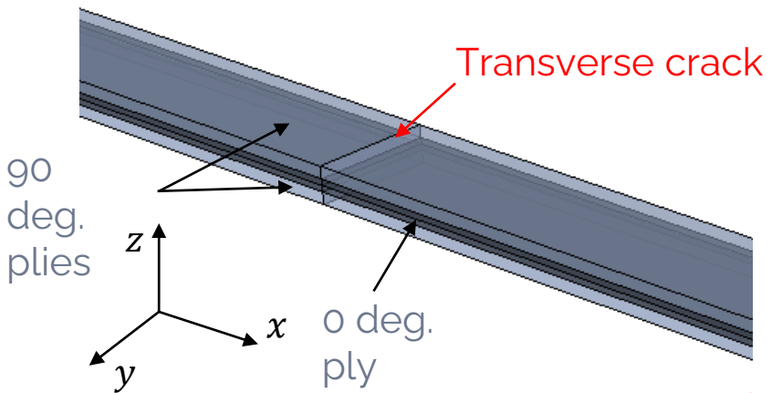


Media and source simulation

Media + source

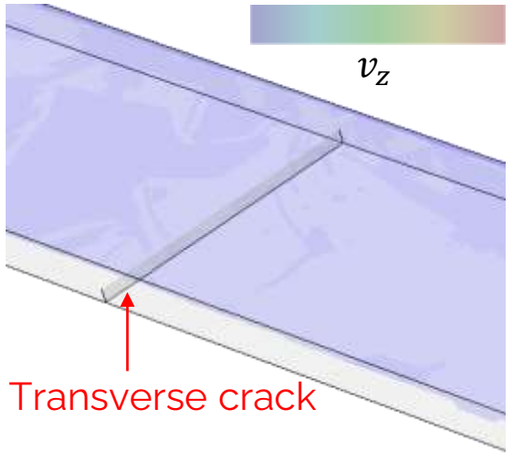
- $[0_n/90_n/0_n]$ or $[90_n/0_n/90_n]$ n=1 or 3
- Transverse crack initiation
- Coupled criterion to determine the transverse crack initiation loading

Leguillon, *EJMAS*, **2002**



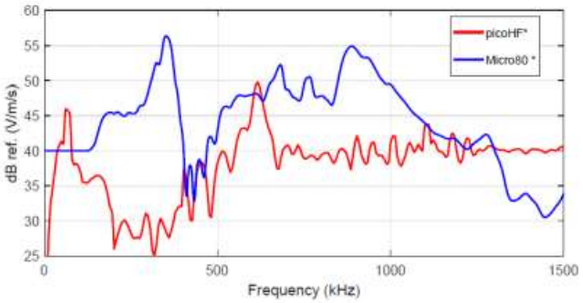
Wave propagation Acoustic signals

- Static loading step
- Node release to open the crack
- Implicit dynamic wave propagation step



Sensor + acquisition chain

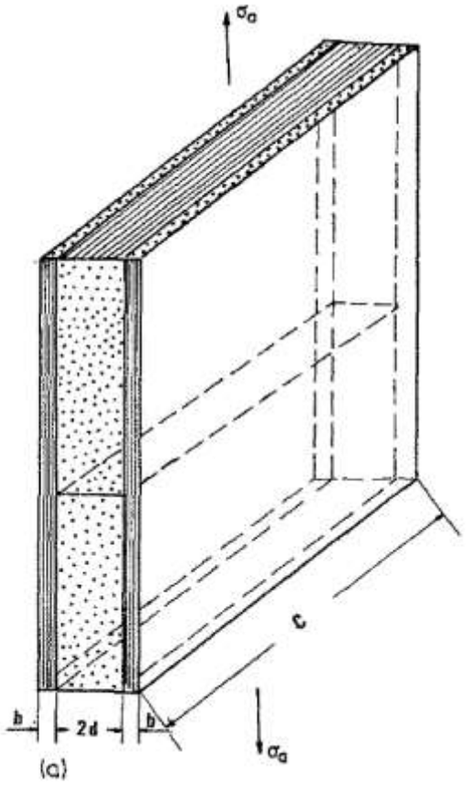
- Perfect point sensor
- Sensor influence through frequency response curve + sensitivity function

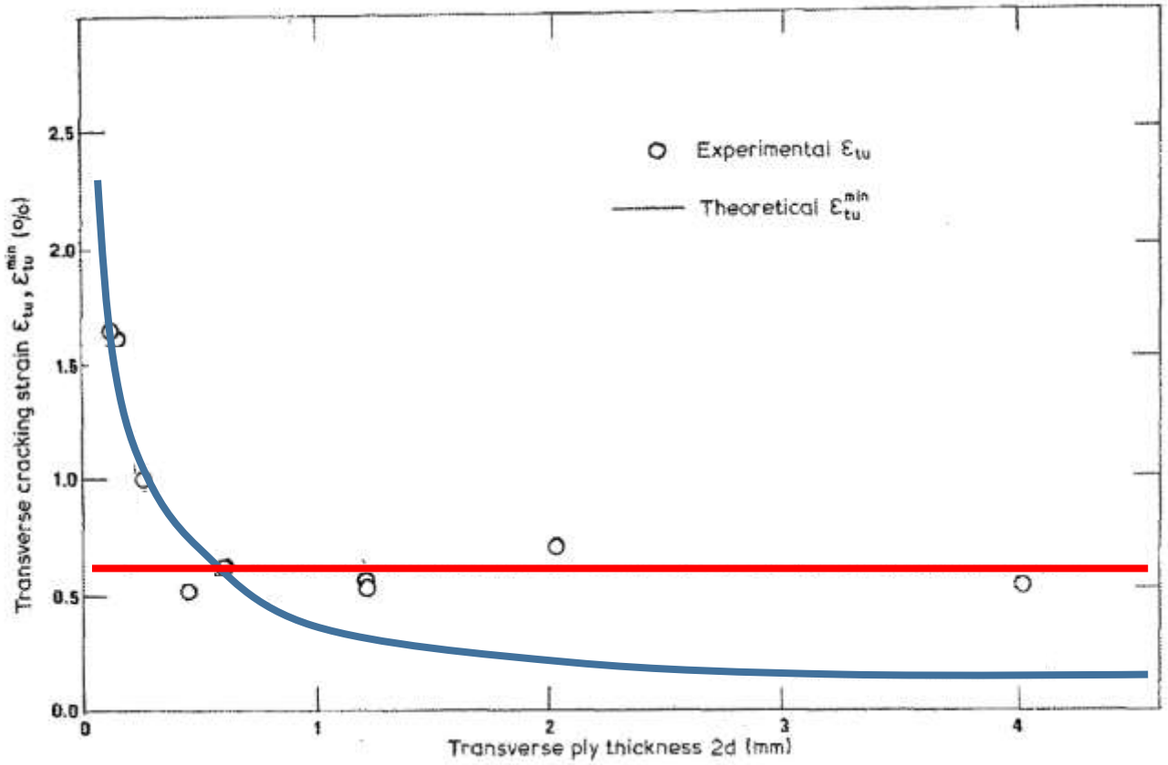


Influence of the ply thickness (theory)

- Energy criterion (Finite Fracture Mechanics) ➔ Does not work for thick plies Hashin, *JMPS*, **1996**
  Nairn, *IJF*, **2000**
- Idea: add a stress criterion to assess crack nucleation *Leguillon*, *EJMAS*, **2002**

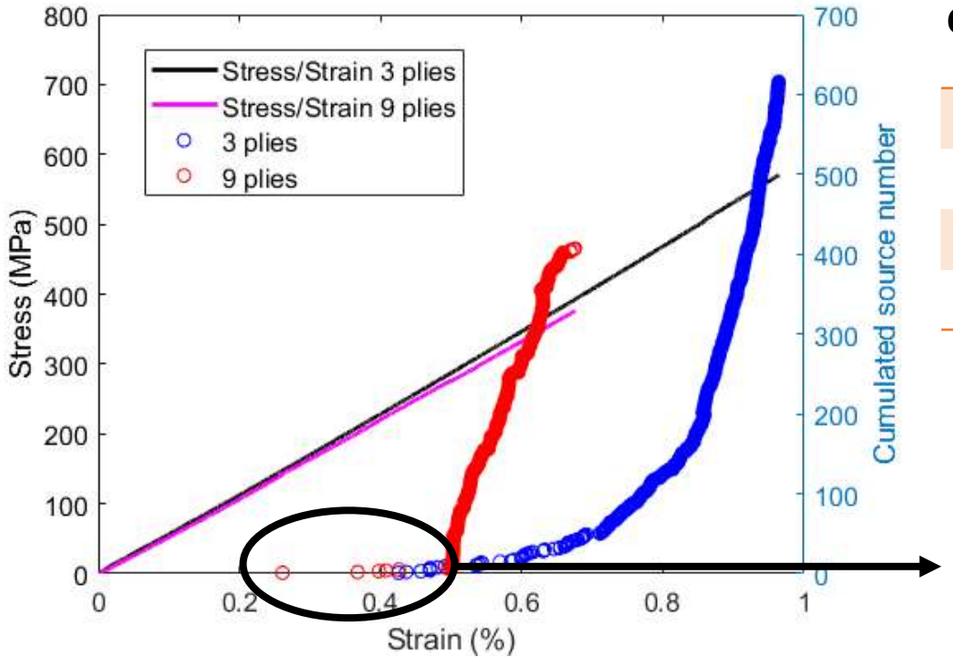
Parvizi, *JMS*, **1978**





Influence of the ply thickness (experiments)

- Energy criterion (Finite Fracture Mechanics) ➔ Does not work for thick plies — Hashin, *JMPS*, **1996**; Nairn, *IJF*, **2000**
- Idea: add a stress criterion to assess crack nucleation — *Leguillon*, *EJMAS*, **2002**

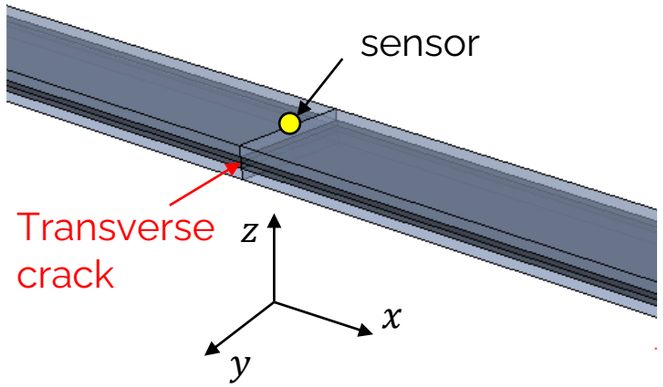


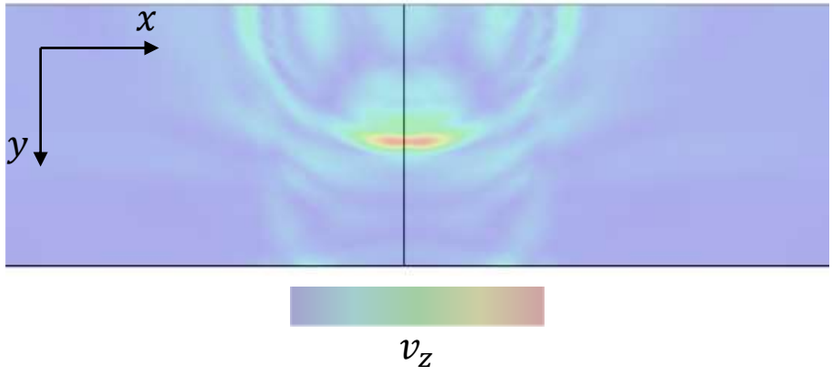
Configuration	Total thickness	Strain at first transverse crack
[0/90/0]	0.9 mm	0.007
$[0_3/90_3/0_3]$	2.7 mm	0.0025
[90/0/90]	0.9 mm	0.004
$[90_3/0_3/90_3]$	2.7 mm	0.0025

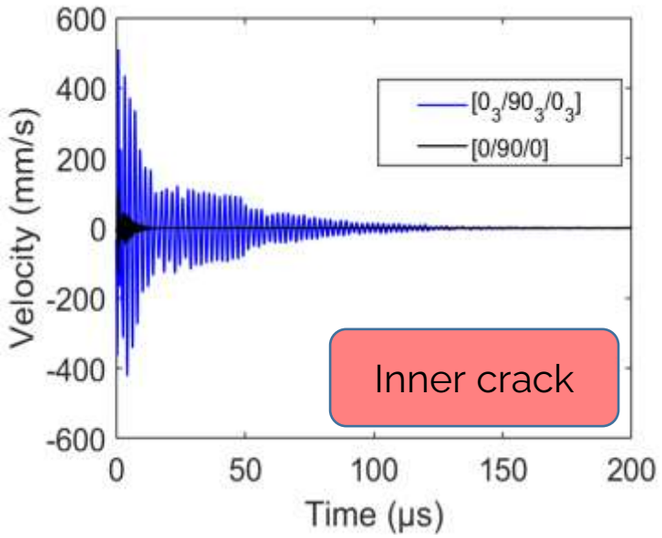
- Higher loading at first acoustic event for thinner ply

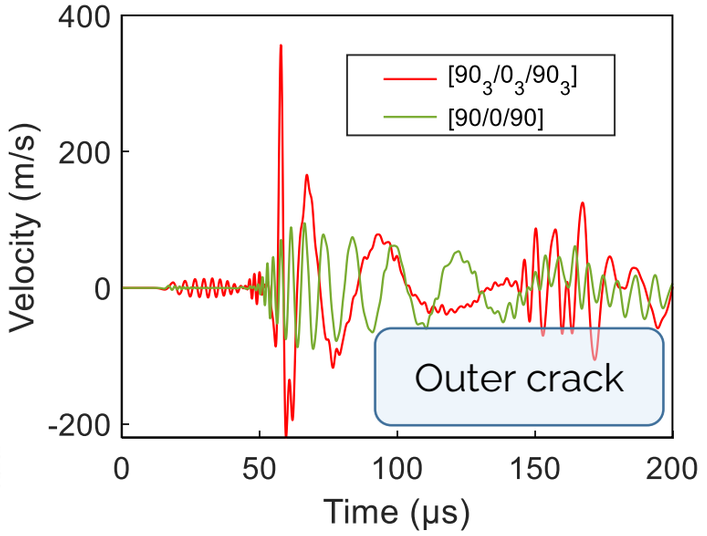
Influence of the ply thickness (simulation)

❑ Perfect sensor located at crack epicenter





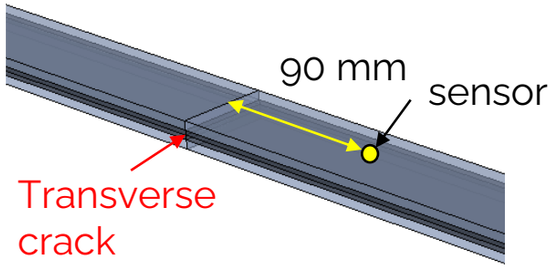




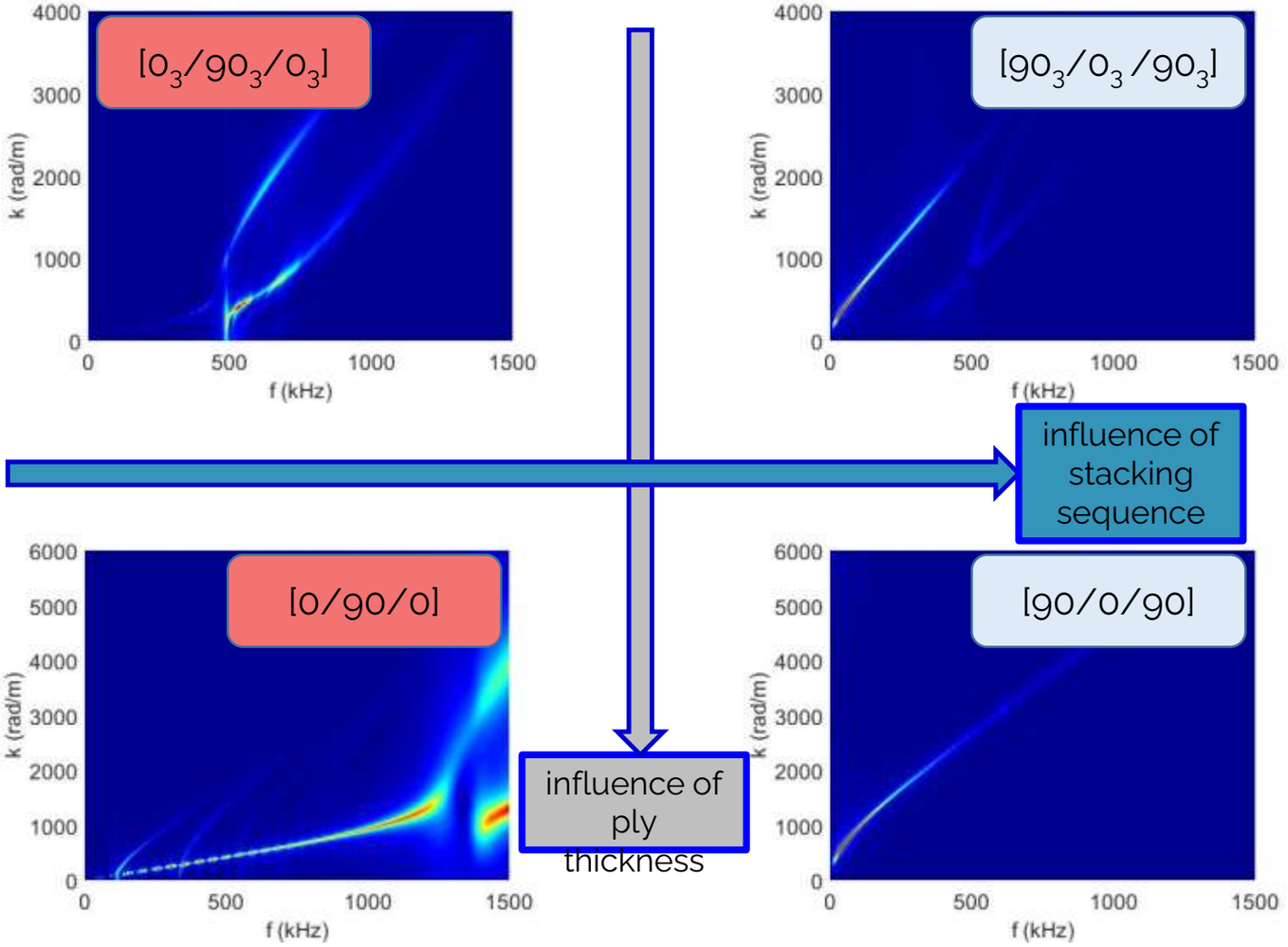
❑ Signals qualitatively quite different (closer) for inner (surface) crack

✓ Larger cracked area ➔ higher amplitude

Ply thickness/Stacking sequence



❑ 2D FFT ➔ excited modes



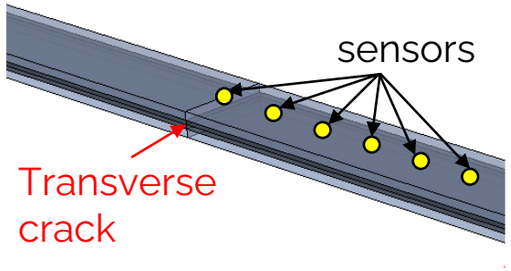
❑ High frequency, symmetric modes for inner cracks, frequency content depending on the ply thickness

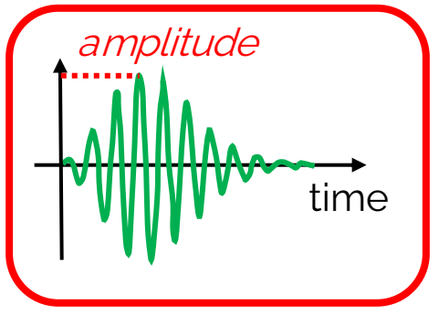
❑ Low-frequency, antisymmetric modes for outer cracks, similar frequency content

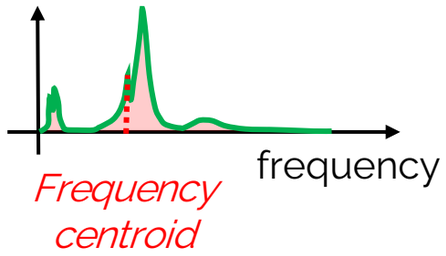
❑ Symmetric mode also excited for outer crack depending on the thickness

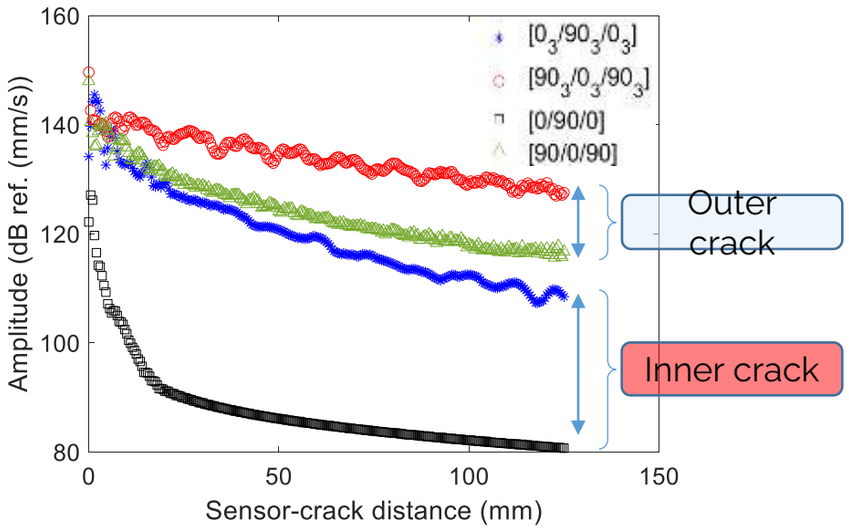
Influence of the source-sensor distance

- Perfect sensor located at several distances from the source









- Amplitude decrease with wave propagation (damping)

influence of stacking sequence

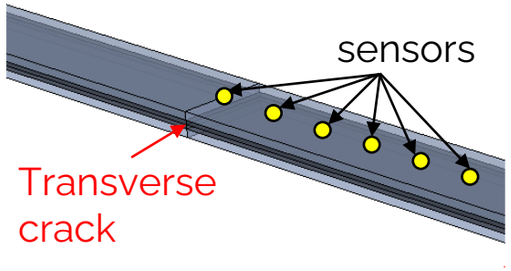
- Higher amplitude for outer cracks

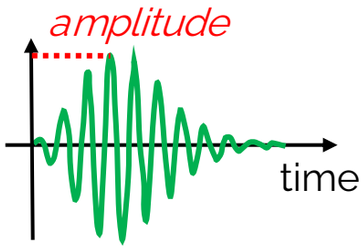
influence of ply thickness

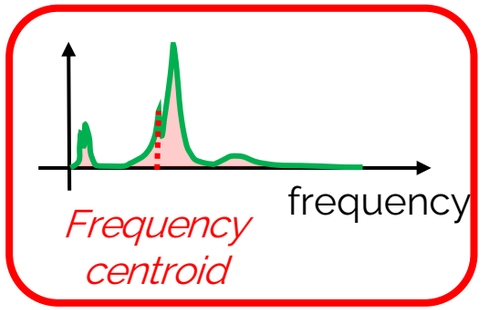
- Thickness ➔ Amplitude difference whatever the distance

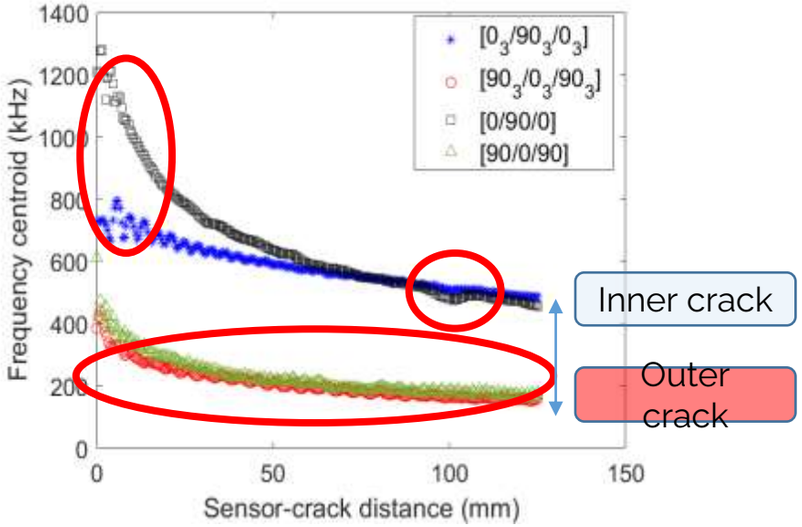
Influence of the source-sensor distance

- Perfect sensor located at several distances from the source









- Frequency decrease with wave propagation (damping)

influence of stacking sequence

- Frequency content difference between outer and inner cracks

influence of ply thickness

- Outer crack ➔ Same frequency content whatever the thickness
- Inner crack ➔ frequency content different close to the source, similar far from it

Summary/conclusions

- **No univocal link** between transverse cracking and the acquired AE signal
- Transverse cracking AE signals strongly depend on the **stacking sequence/ crack position** within the thickness
- Outer ply thickness has a limited influence on transverse cracking EA signals
- **Inner ply thickness** has a strong influence on signals only if the sensor is close to the source
- Inner and outer ply cracking could be considered **as two different damage mechanisms** in classification approaches

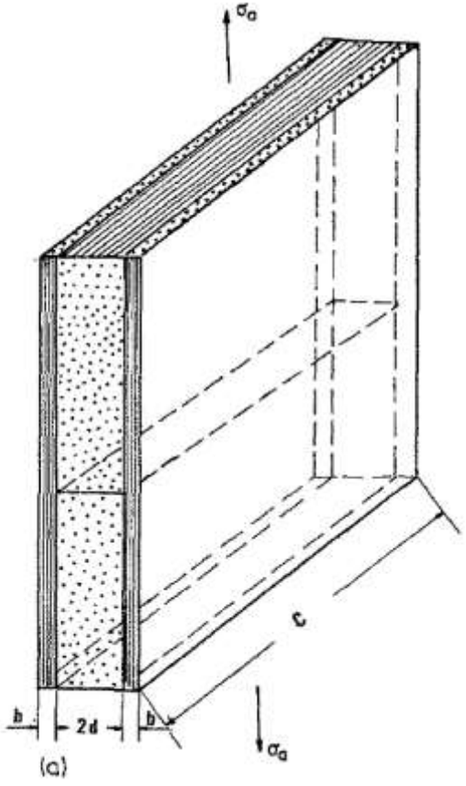
Any Questions?

Influence of the ply thickness

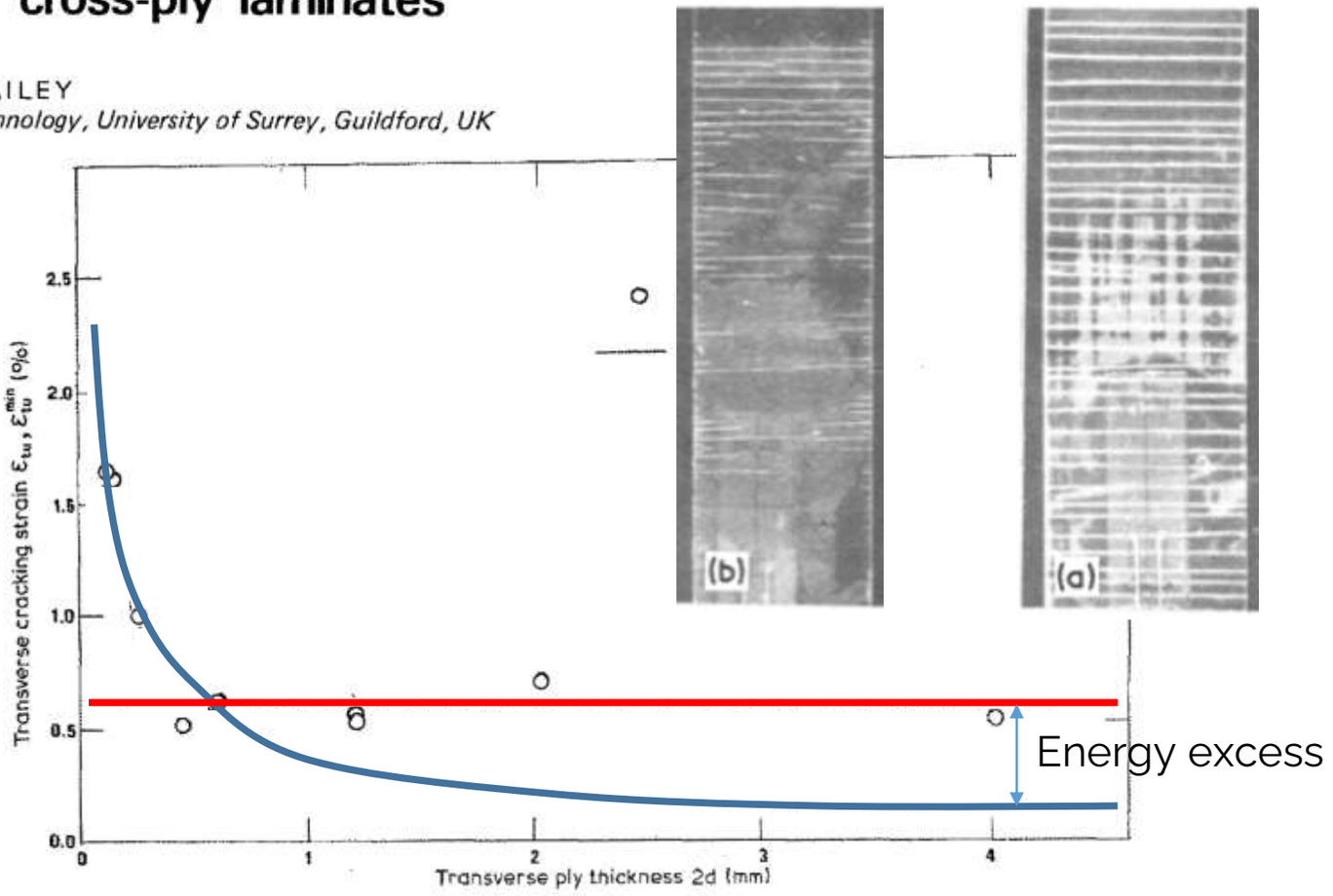
JOURNAL OF MATERIALS SCIENCE 13 (1978) 195–201

Constrained cracking in glass fibre-reinforced epoxy cross-ply laminates

A. PARVIZI, K. W. GARRETT*, J. E. BAILEY
Department of Metallurgy and Materials Technology, University of Surrey, Guildford, UK



- Large plies: energy excess => multiple cracks



Influence of the ply thickness

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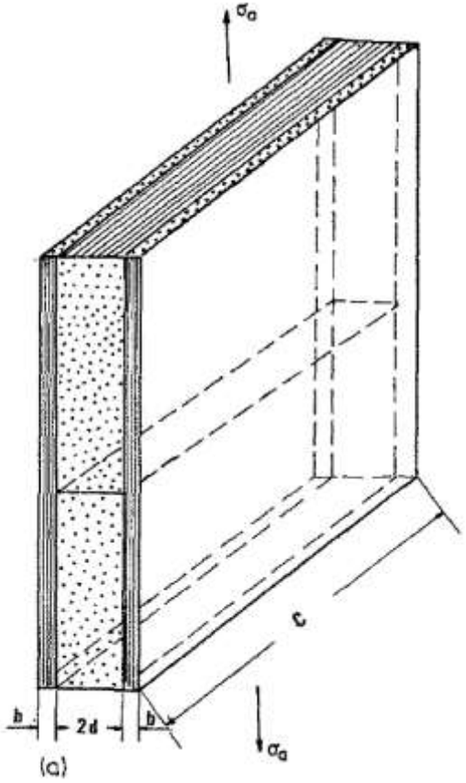
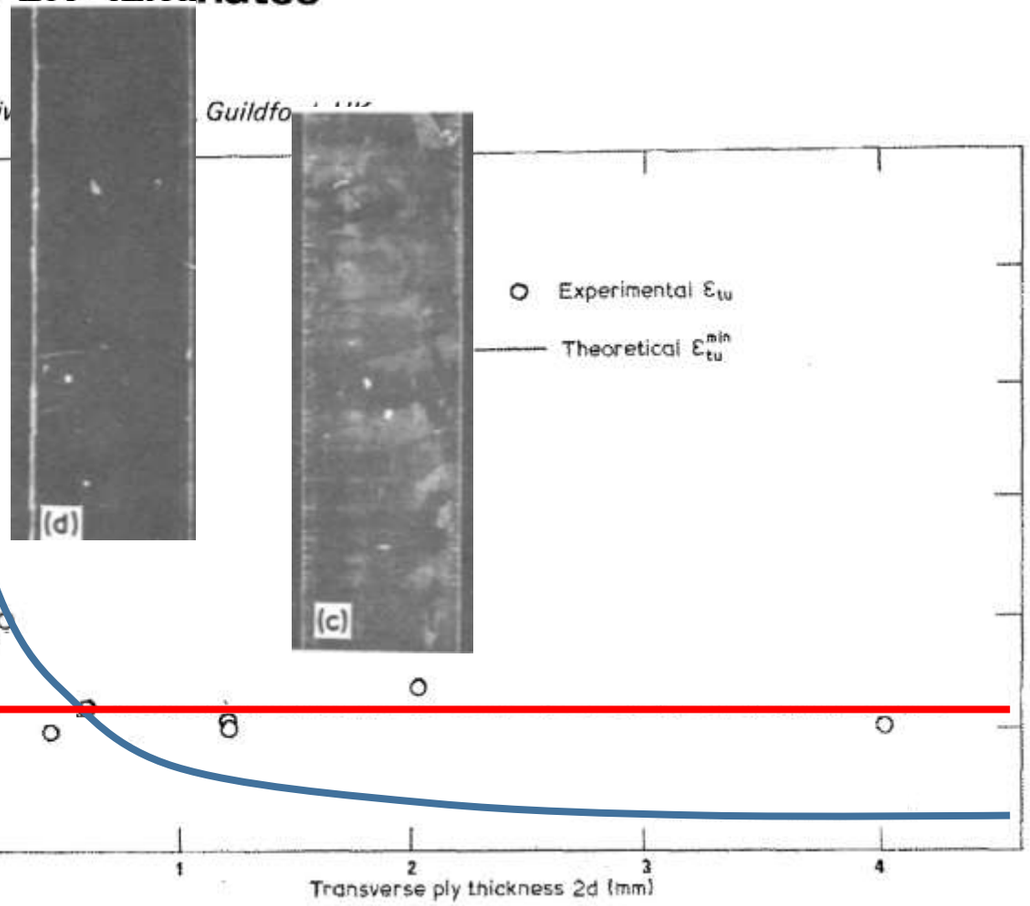
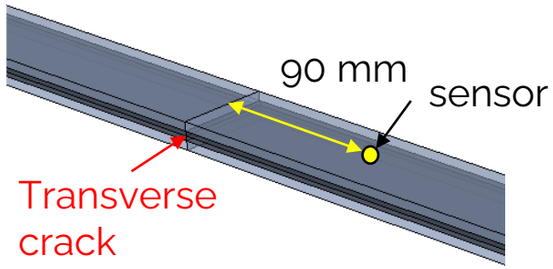


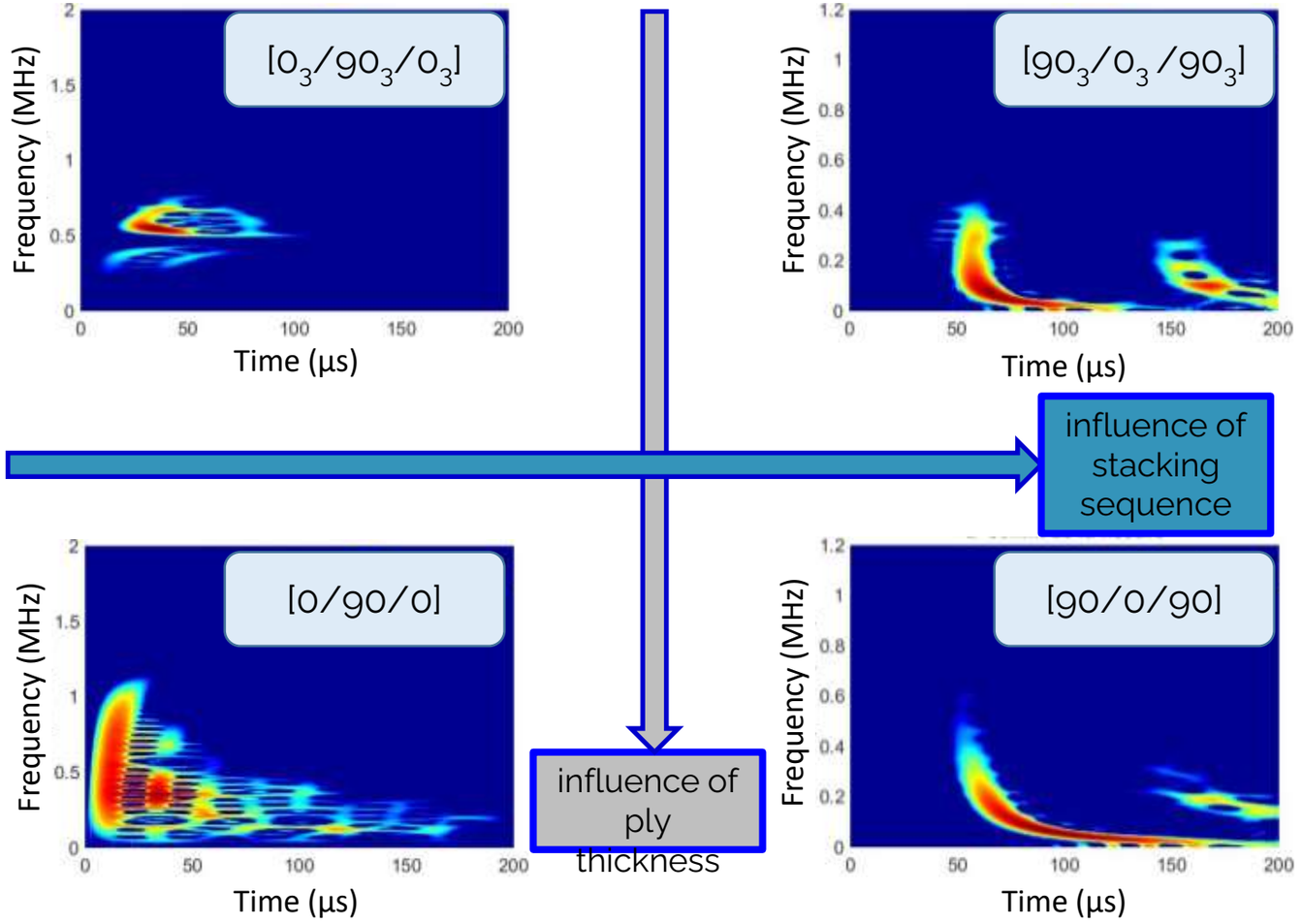


- Thin plies: All the energy is consumed in crack initiation

Ply thickness/Stacking sequence



- Time-frequency analysis



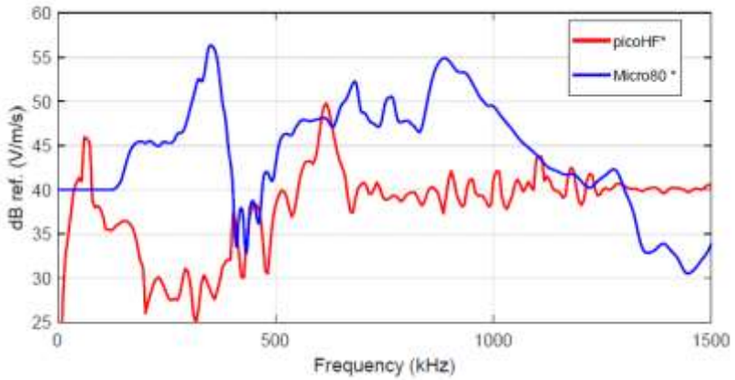
- Inner cracks: Higher frequency content for thinner plies
- Frequency content decrease with propagation time
- Relatively similar frequency content for outer cracks whatever the ply thickness

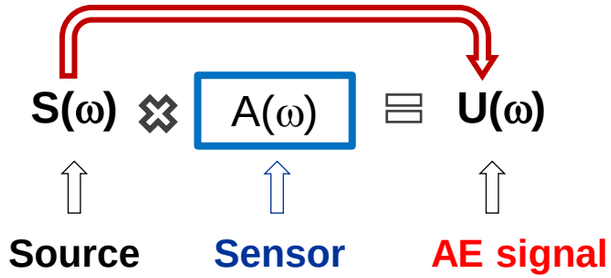
Preliminary comparison with experiments

Media + source

Wave propagation Acoustic signals

Sensor + acquisition chain





Quantitative comparison between simulation and experiments not trivial

- ❑ Relation between out-of-plane velocity and the sensor tension
- ❑ Consider all acquisition chain elements
- ❑ Modeling uncertainty (source/homogeneous ply assumption, etc)
- ❑ Experimentally, isolated damage mechanism?

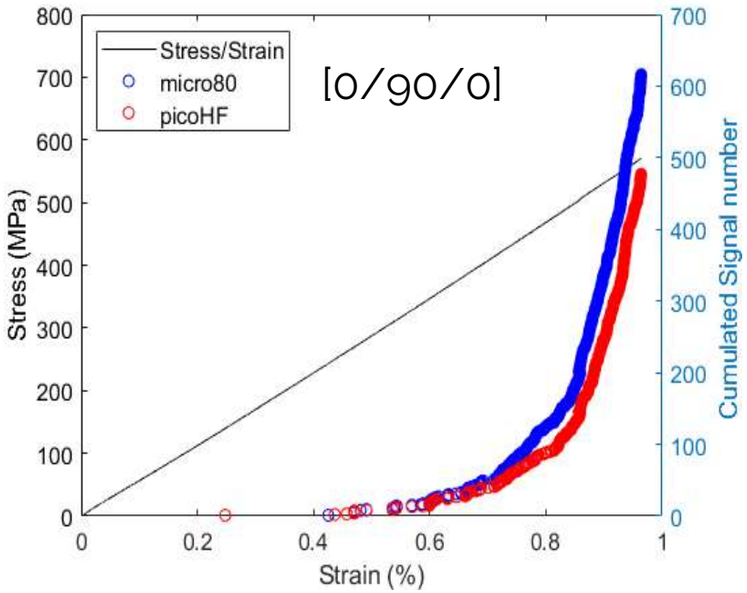
Preliminary comparison with experiments

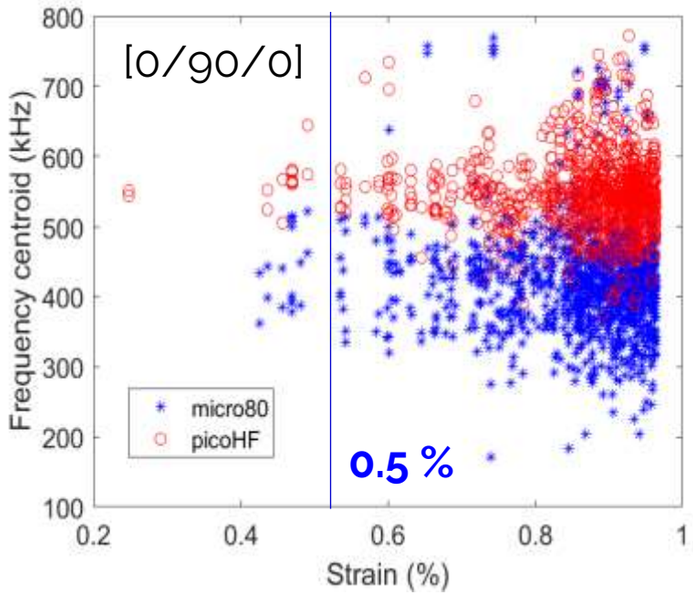
Media + source

Wave propagation Acoustic signals

Sensor + acquisition chain

Transverse matrix cracking

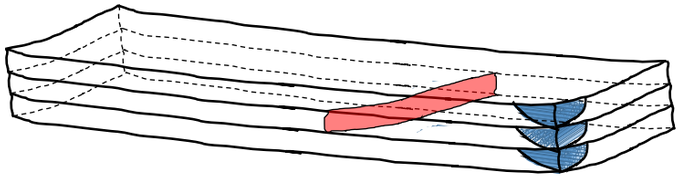




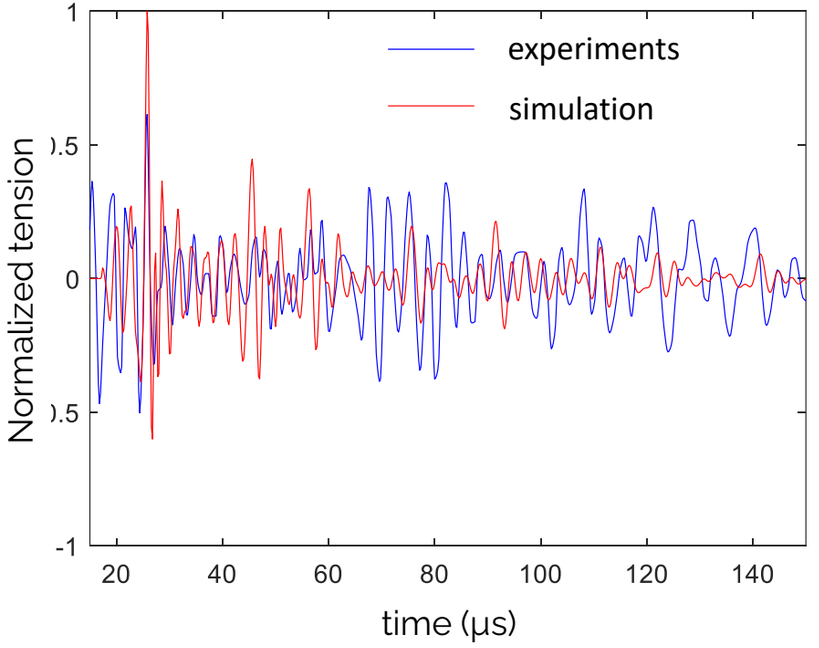
Preliminary comparison with experiments

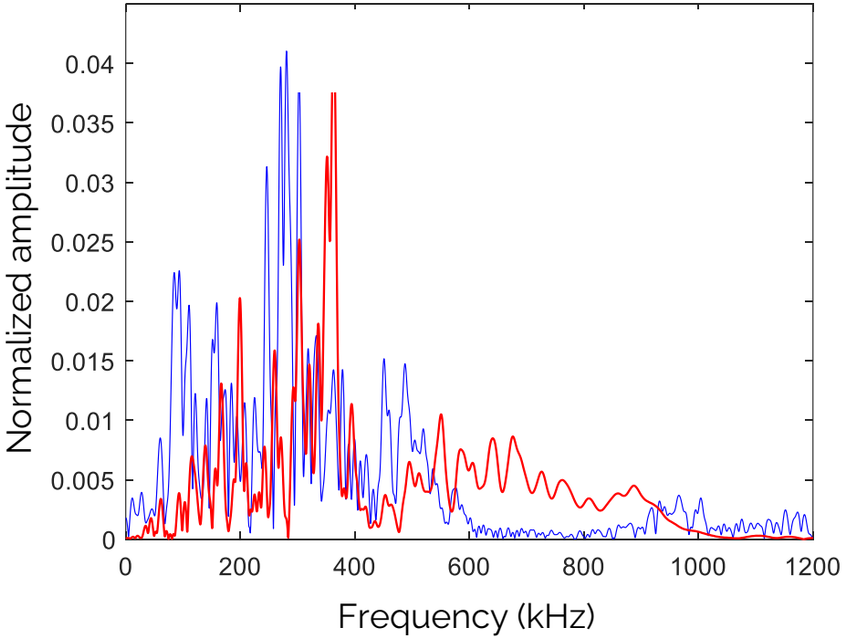
Inner crack

[0/90/0]



- Micro80 sensor
- Isolated damage mechanisms experimentally?
- Uncertainties from numerical modeling: e.g. source,acquisition chain





Example of modeling uncertainty: the AE source

- Similar qualitative trend
- Quantitative differences