



# Planar Delamination Behaviour of Composite Laminates under Out-of-plane Loading

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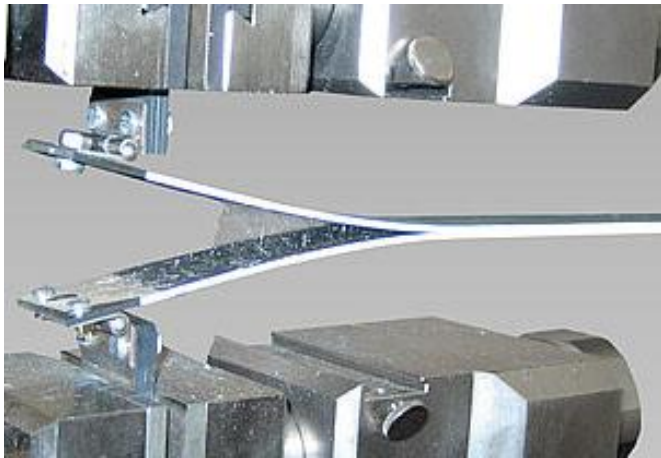
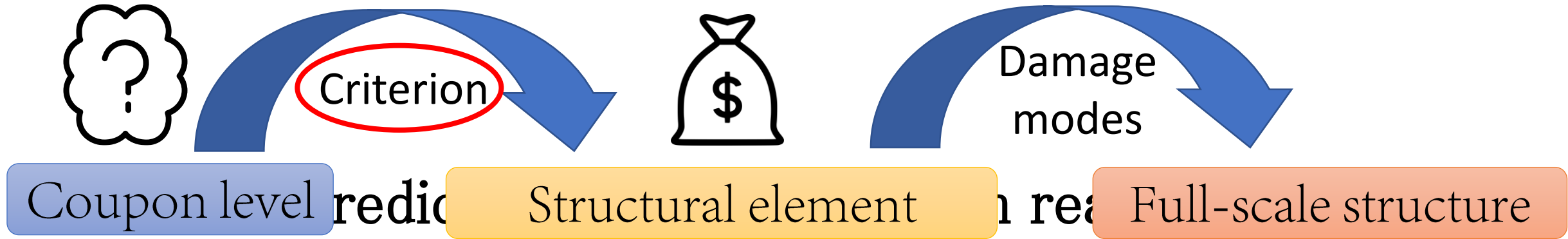
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Department of Aerospace Structures & Materials

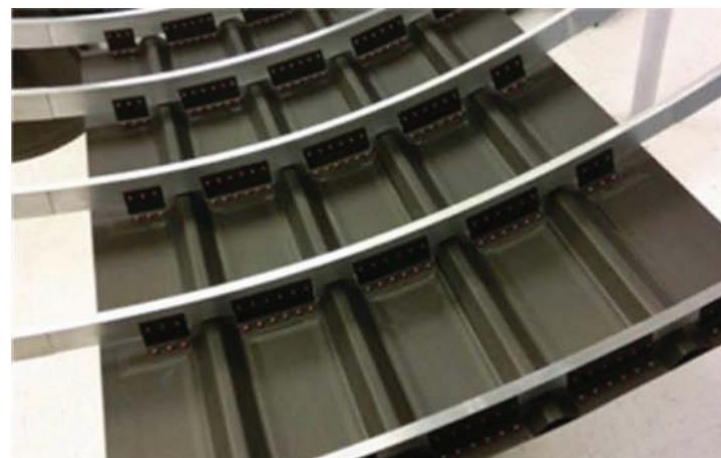
Faculty of Aerospace engineering



# Delamination initiation and propagation in CFRP composite laminates



• ZwickRoell testing equipment

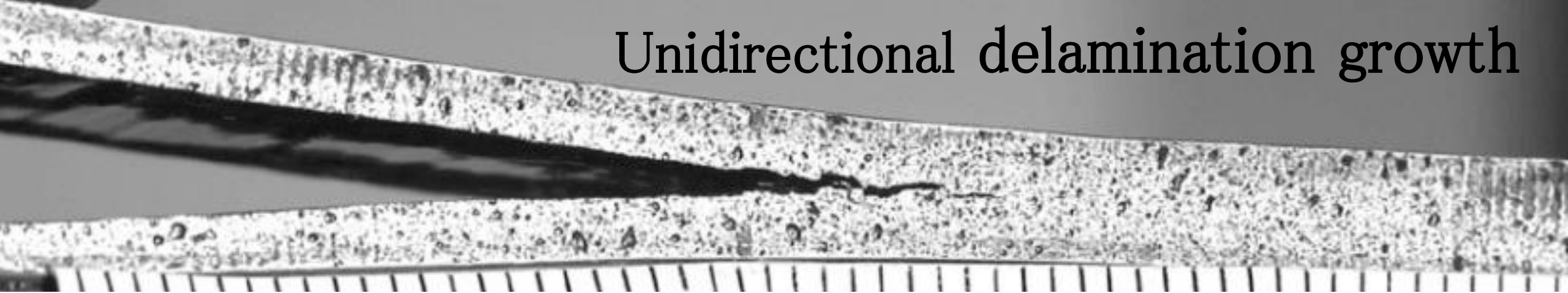


• Janugaon vijay kumar, IJJET, 2013

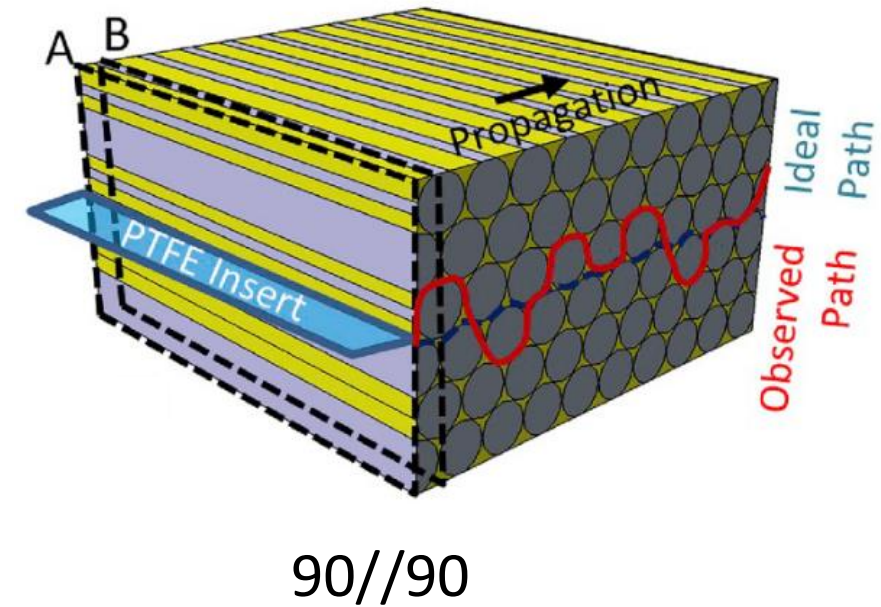
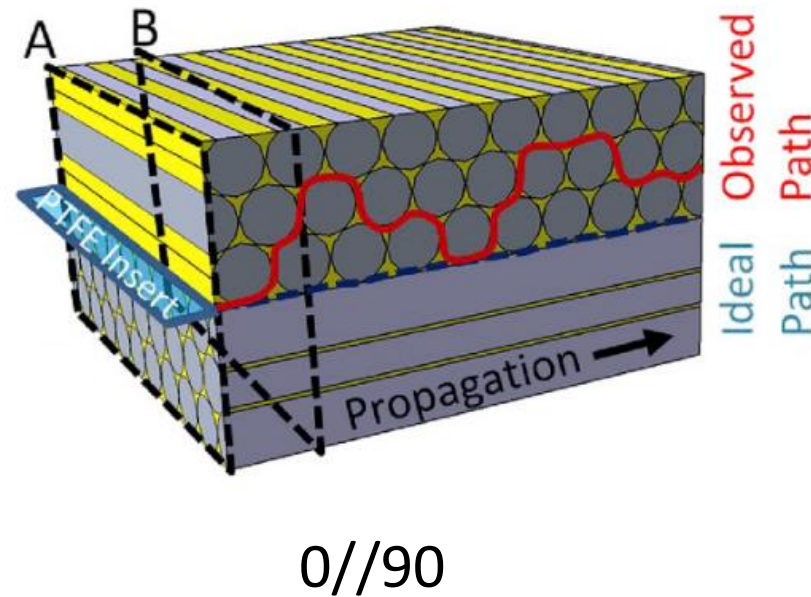
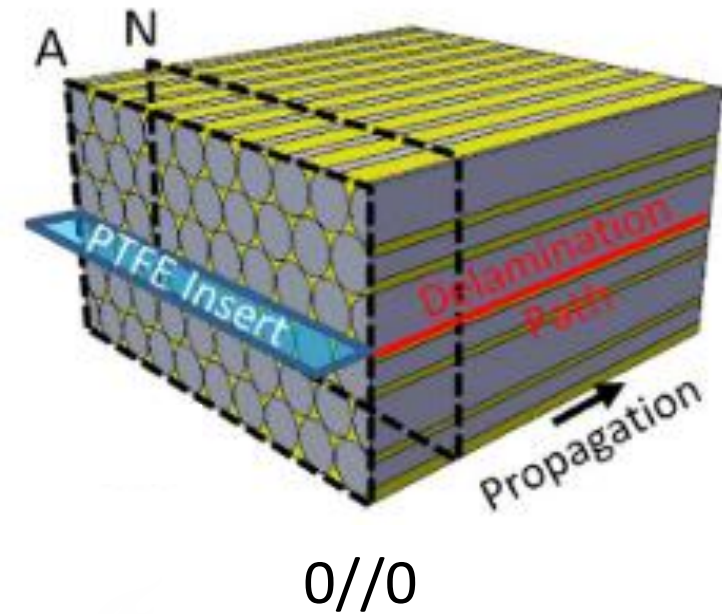


• Comac C919, Aviation Week, 2022

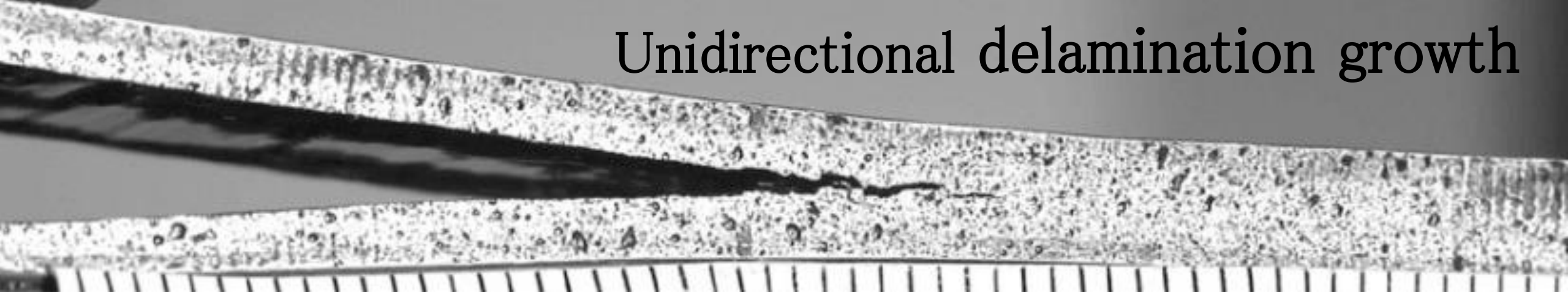
# Unidirectional delamination growth



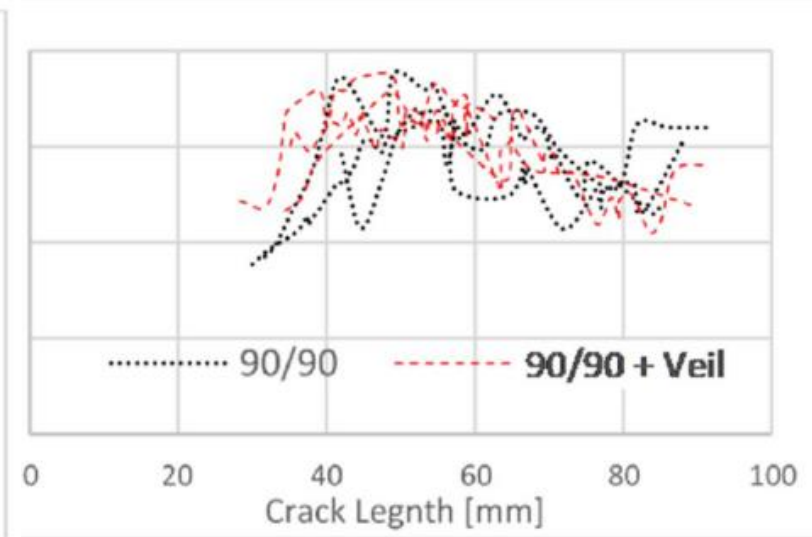
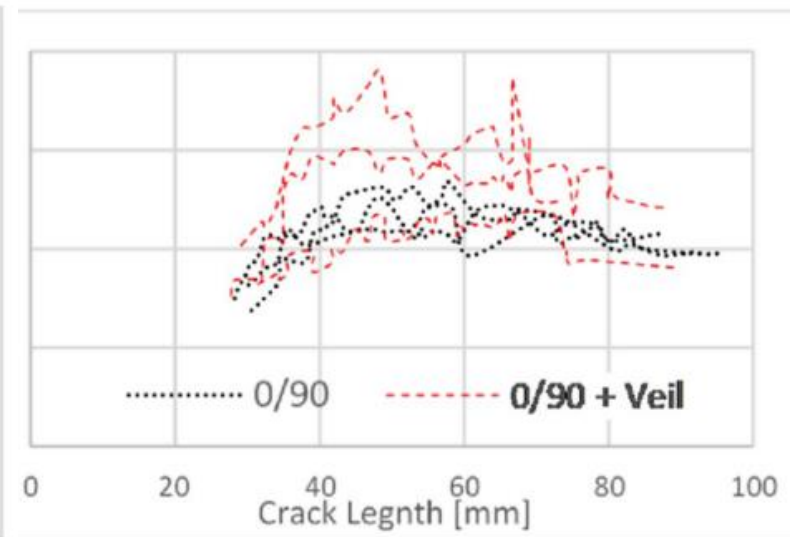
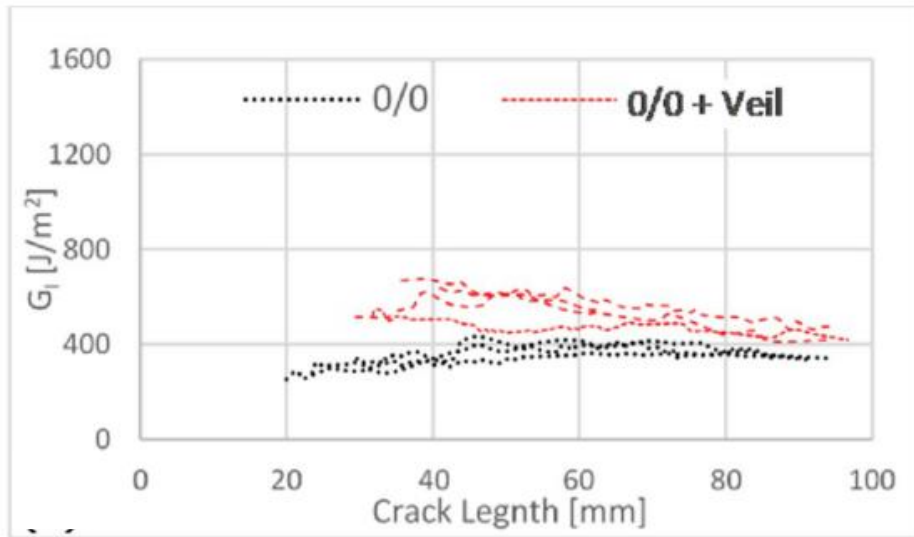
## Different interfaces



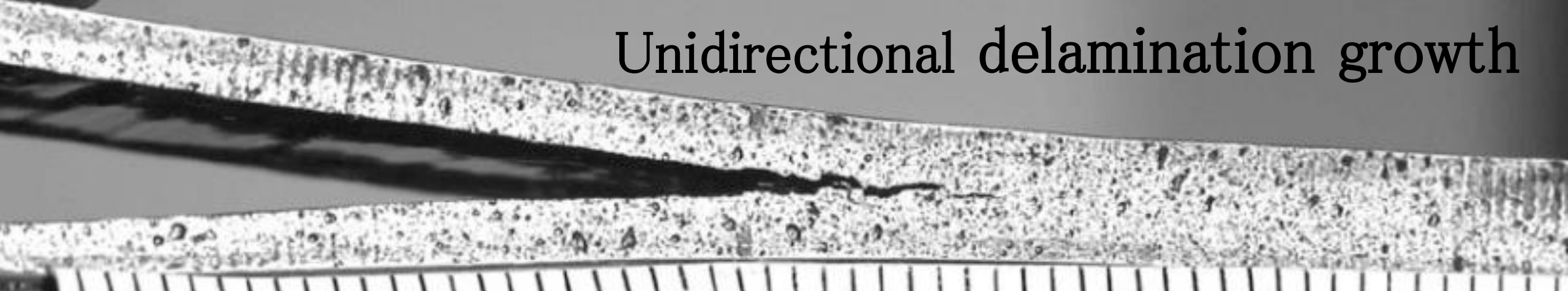
# Unidirectional delamination growth



## Different interfaces

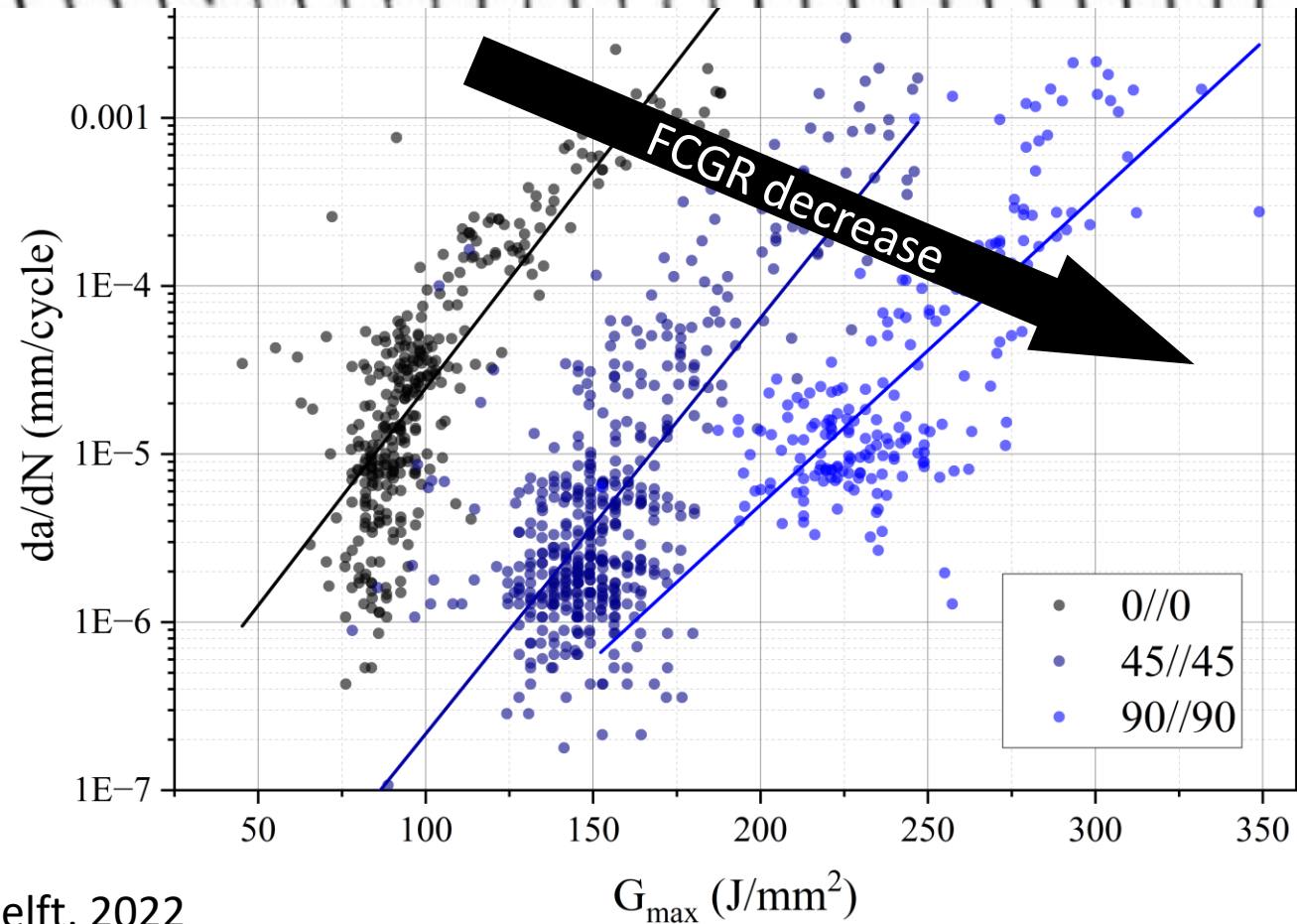


# Unidirectional delamination growth



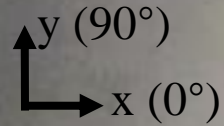
## Different interfaces

$$\frac{da}{dN} = C(f(\Delta G, G_C, G_{th} \dots))^n$$

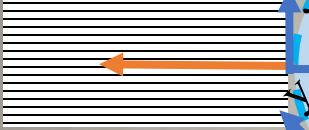


# Planar / Multidirectional delamination

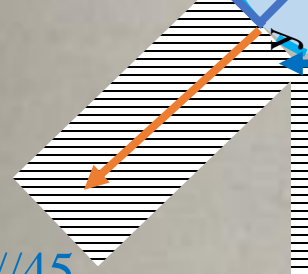
- Global 0//0 interface



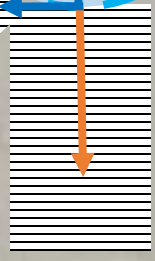
0//0



45//45



90//90



- Observation
- Measurement
- Characterization

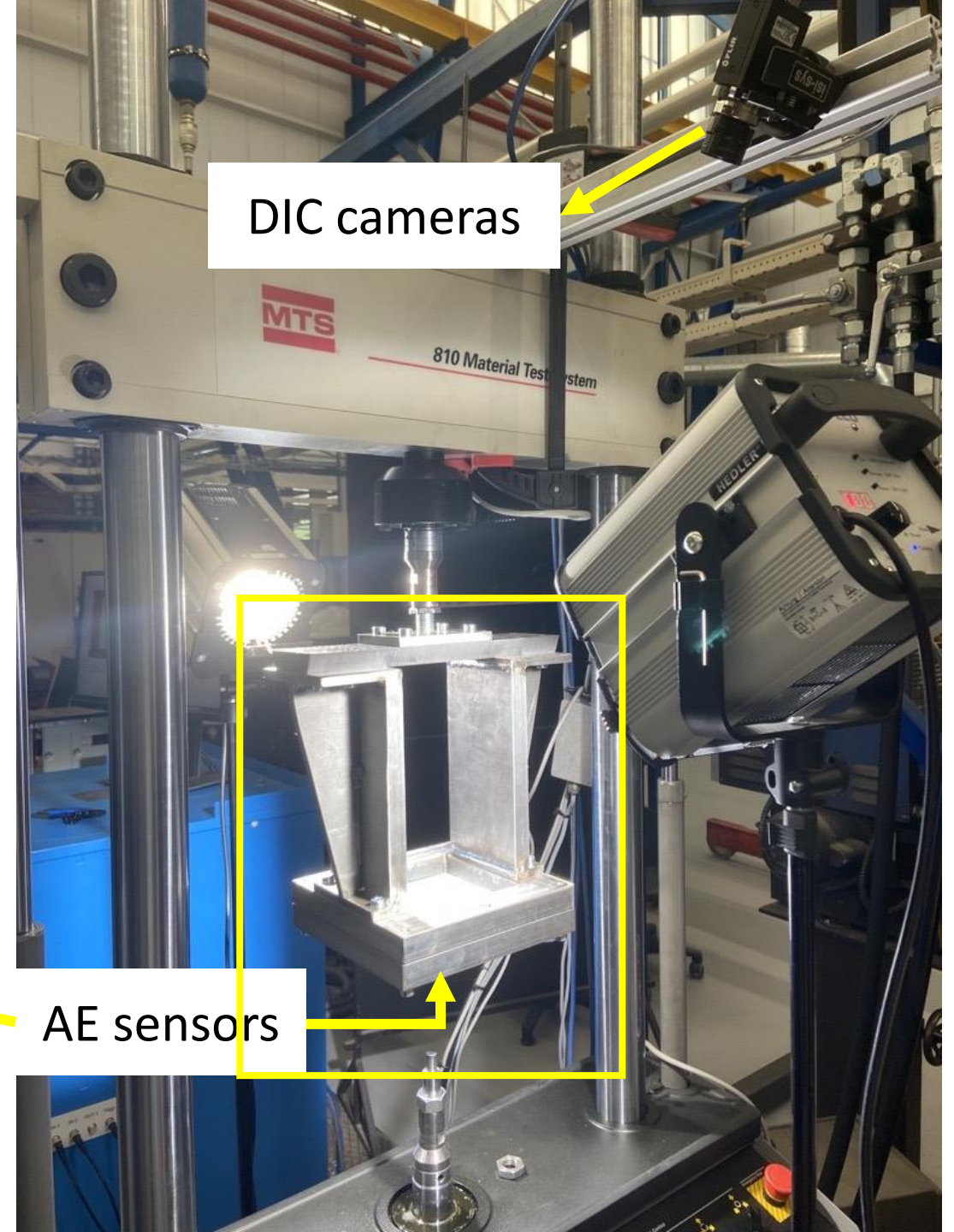
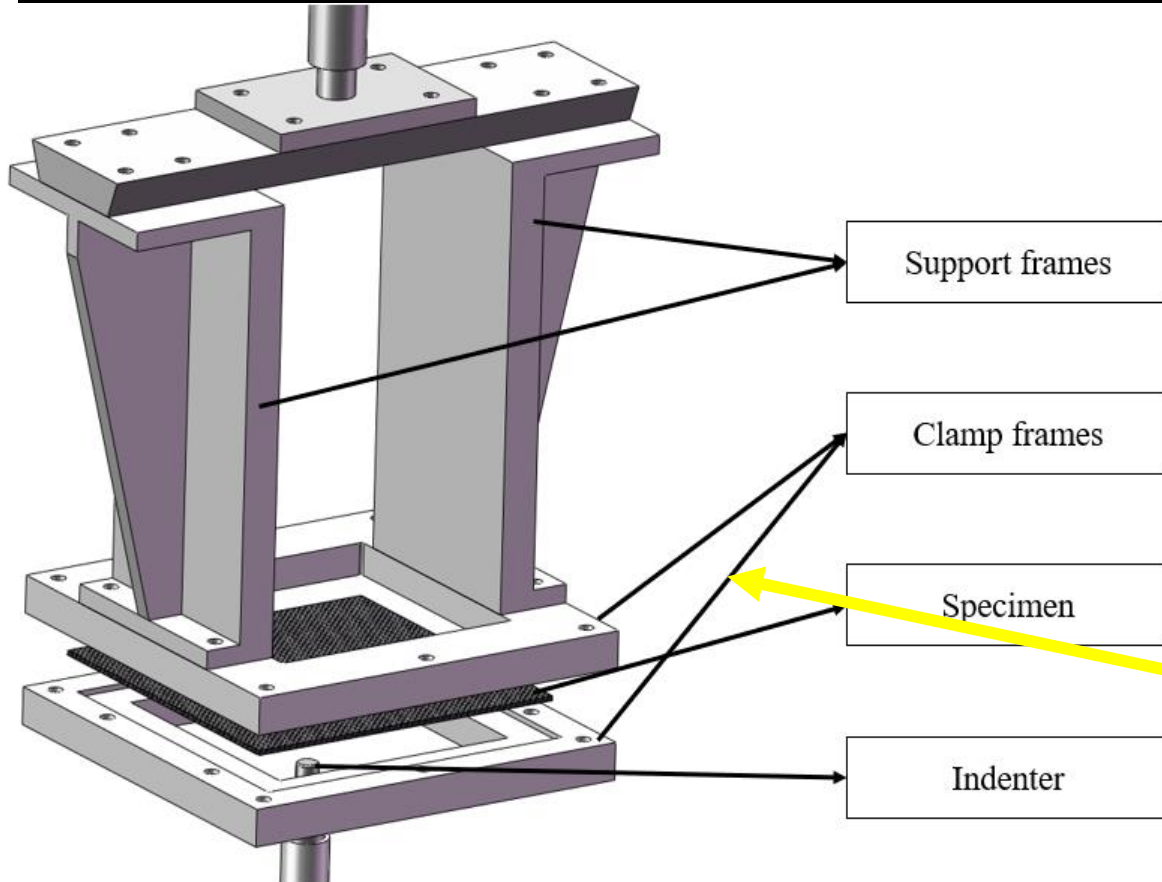
Circular delamination

CFRP panel

# New test methodology

## Semi-complex configuration

### Out-of-plane indentation

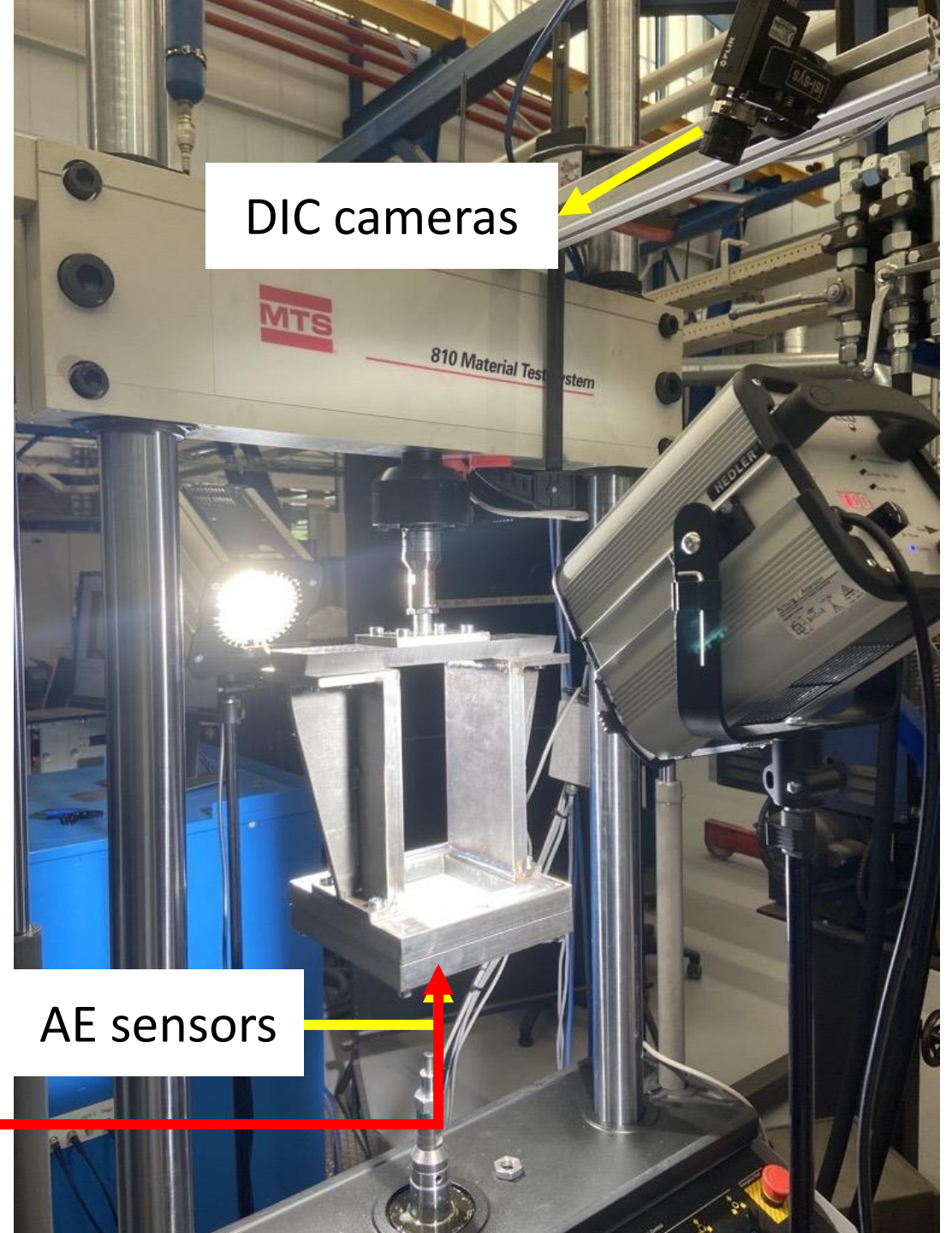


# New test methodology

## Semi-complex configuration

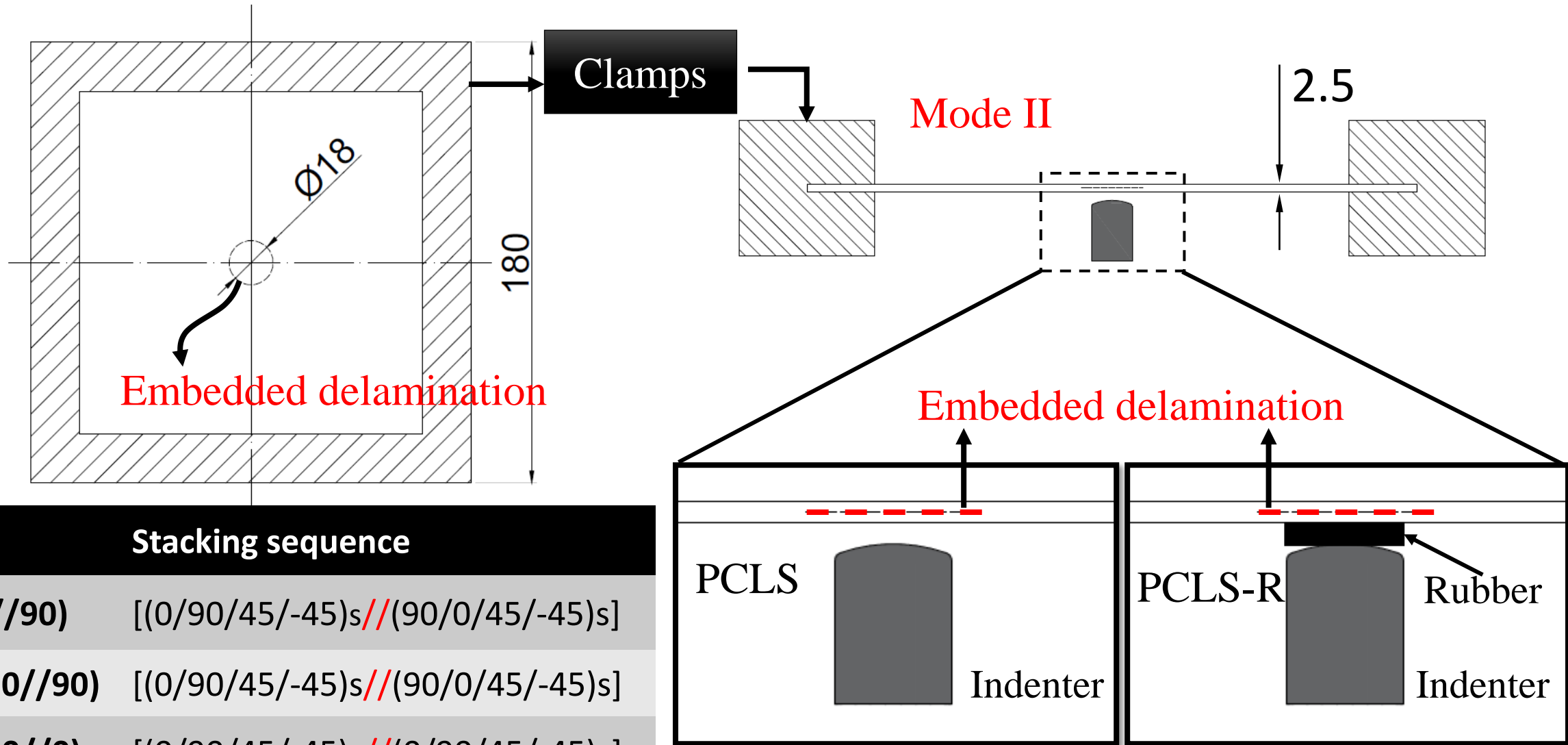
### Out-of-plane indentation

Pulse echo  
C-scan



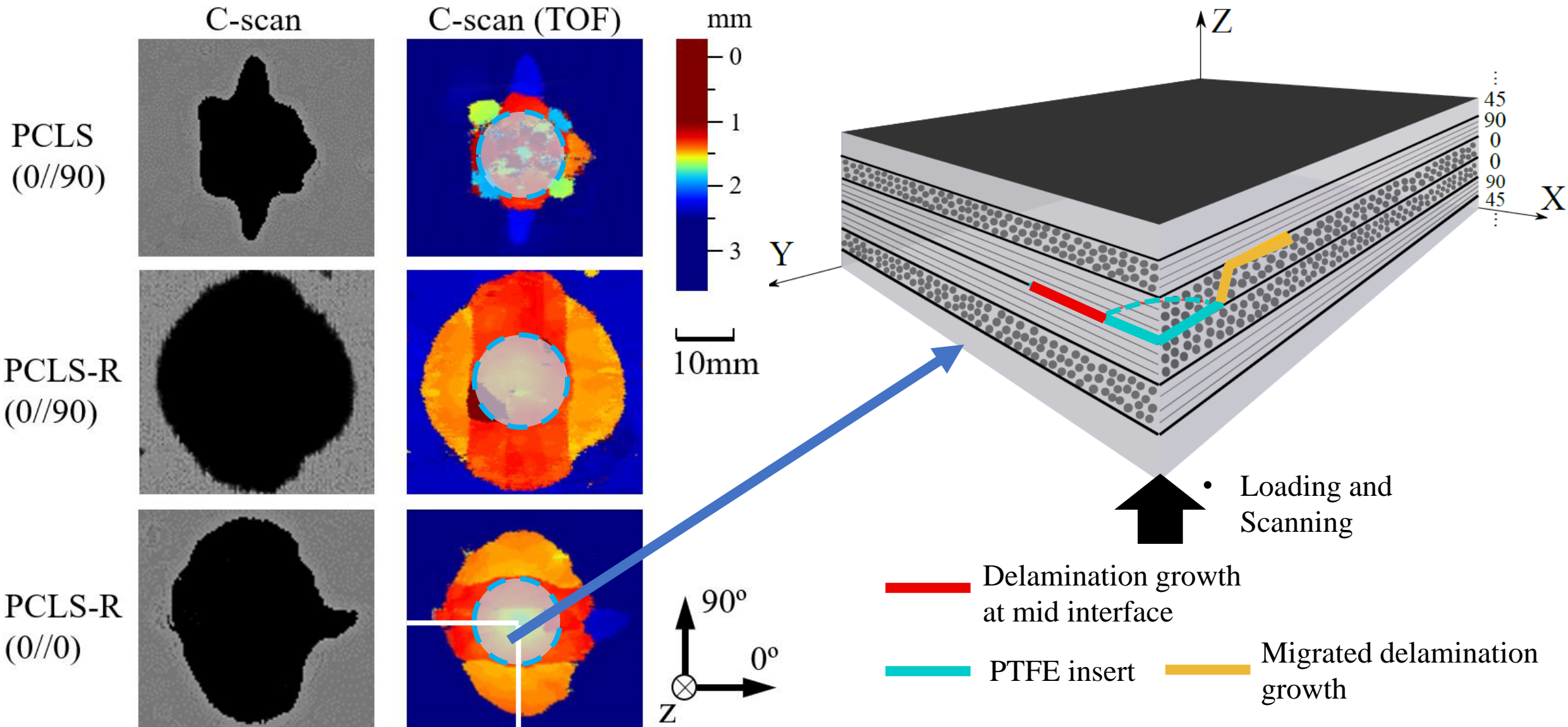


# Test configurations - Planar Central Loaded Split (PCLS)



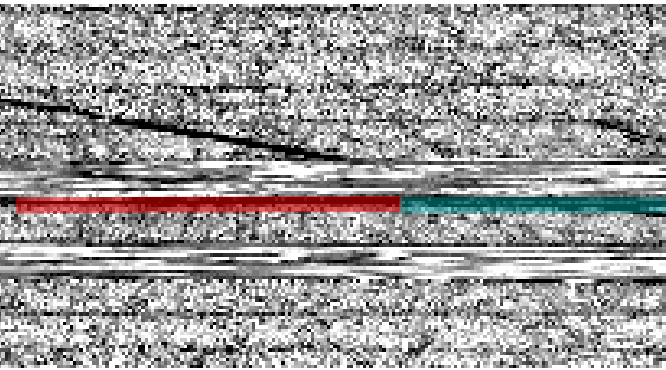
Label	Stacking sequence
PCLS(0//90)	$[(0/90/45/-45)_s // (90/0/45/-45)_s]$
PCLS-R(0//90)	$[(0/90/45/-45)_s // (90/0/45/-45)_s]$
PCLS-R(0//0)	$[(0/90/45/-45)_s // (0/90/45/-45)_s]$

# Planar delamination pattern - C-scan



# Planar delamination pattern - cross-section

Mid interface delamination



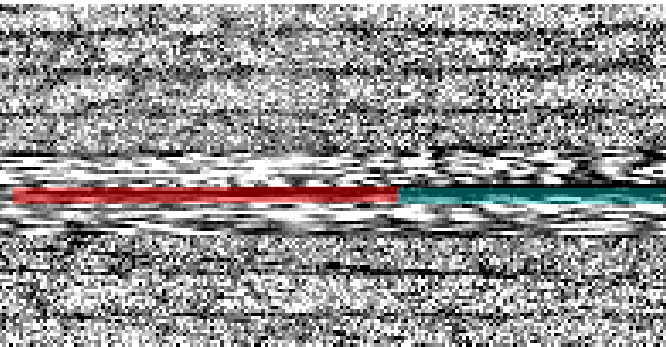
0//90



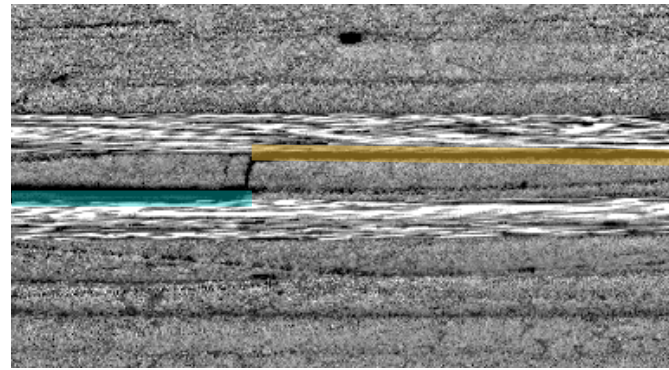
Crack propagation direction



0//0



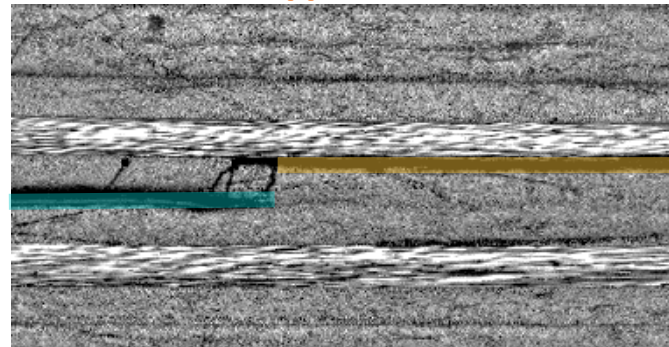
Migrated delamination growth



0//90

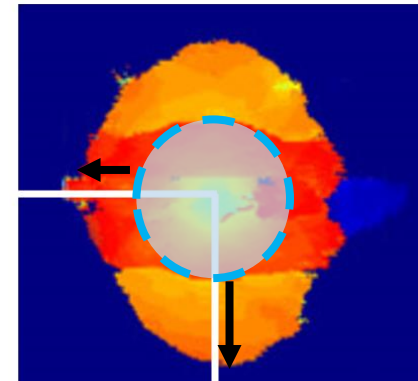
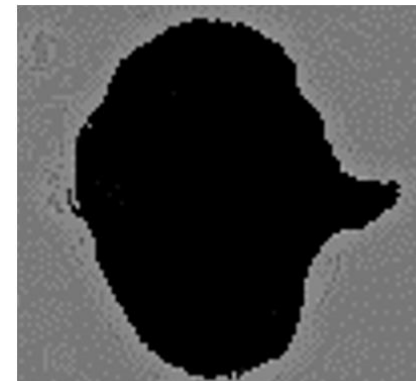
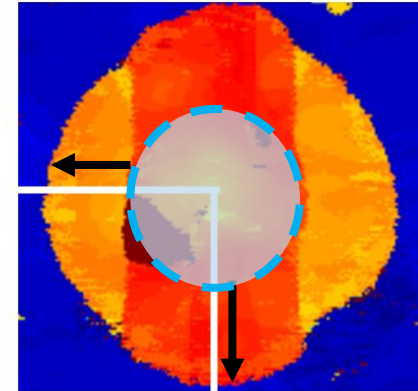
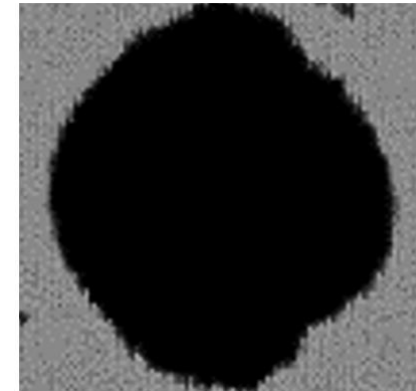


PCLS-R  
(0//90)

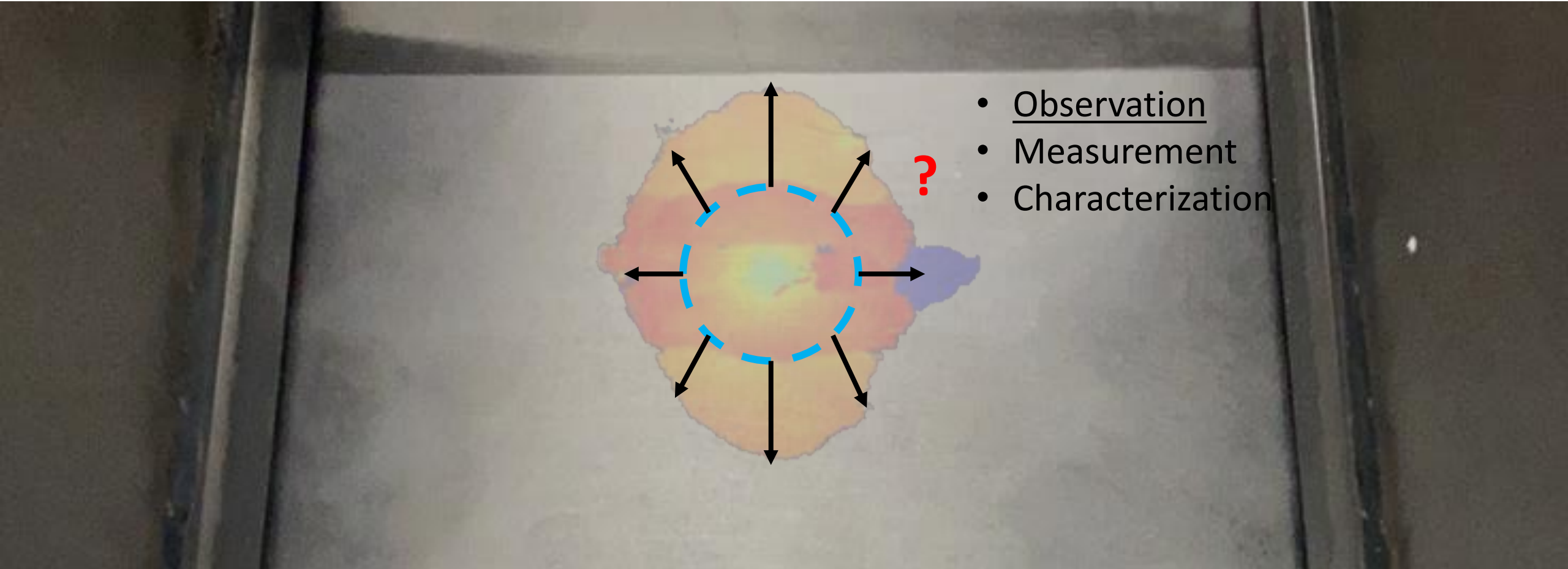


0//90

PCLS-R  
(0//0)



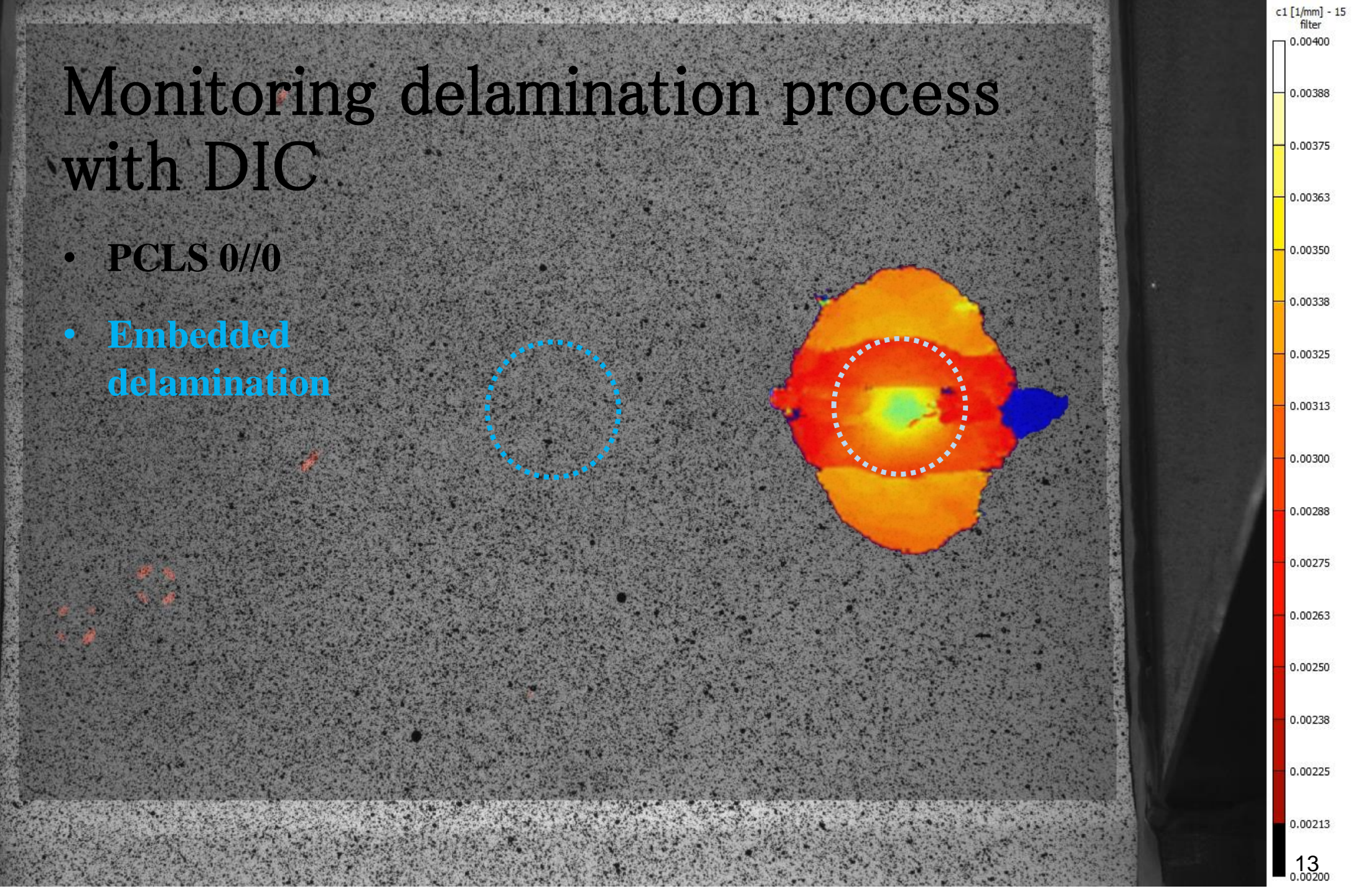
# Planar / Multidirectional delamination



**CFRP panel fixed in a frame**

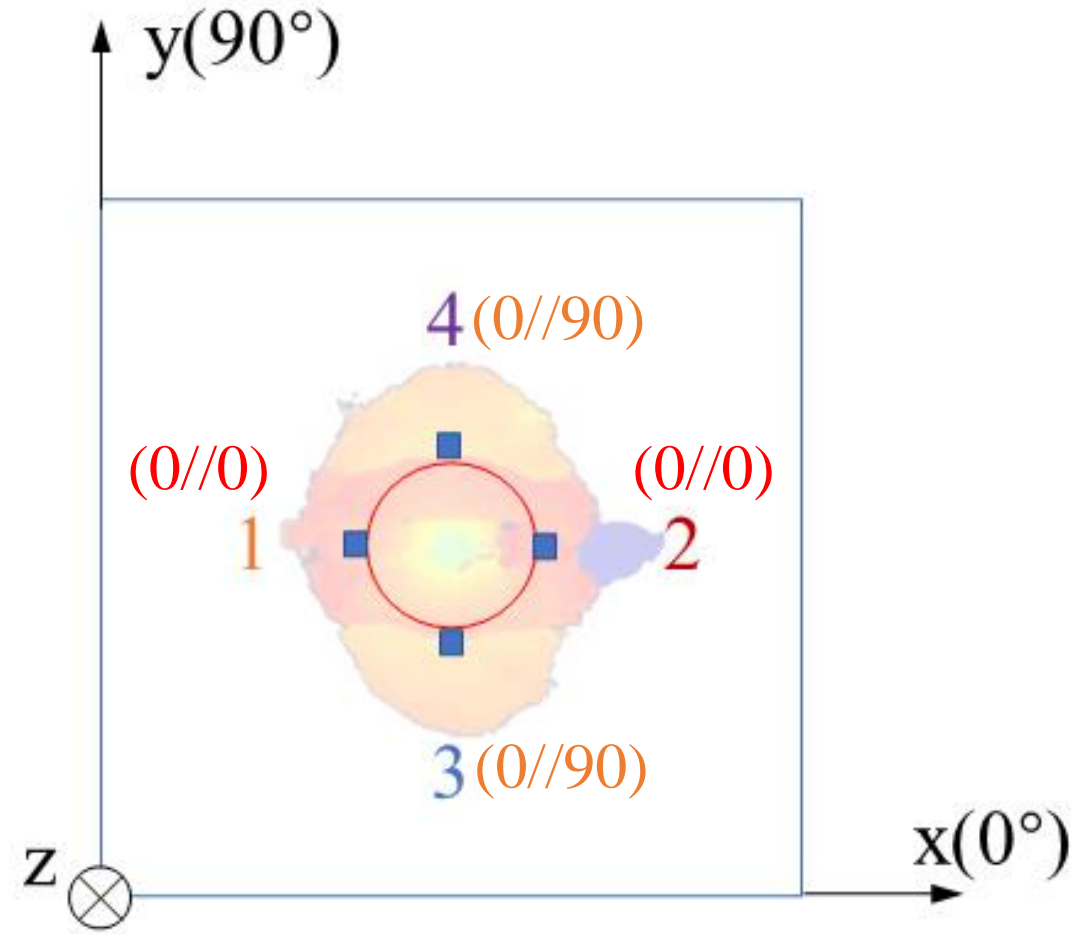
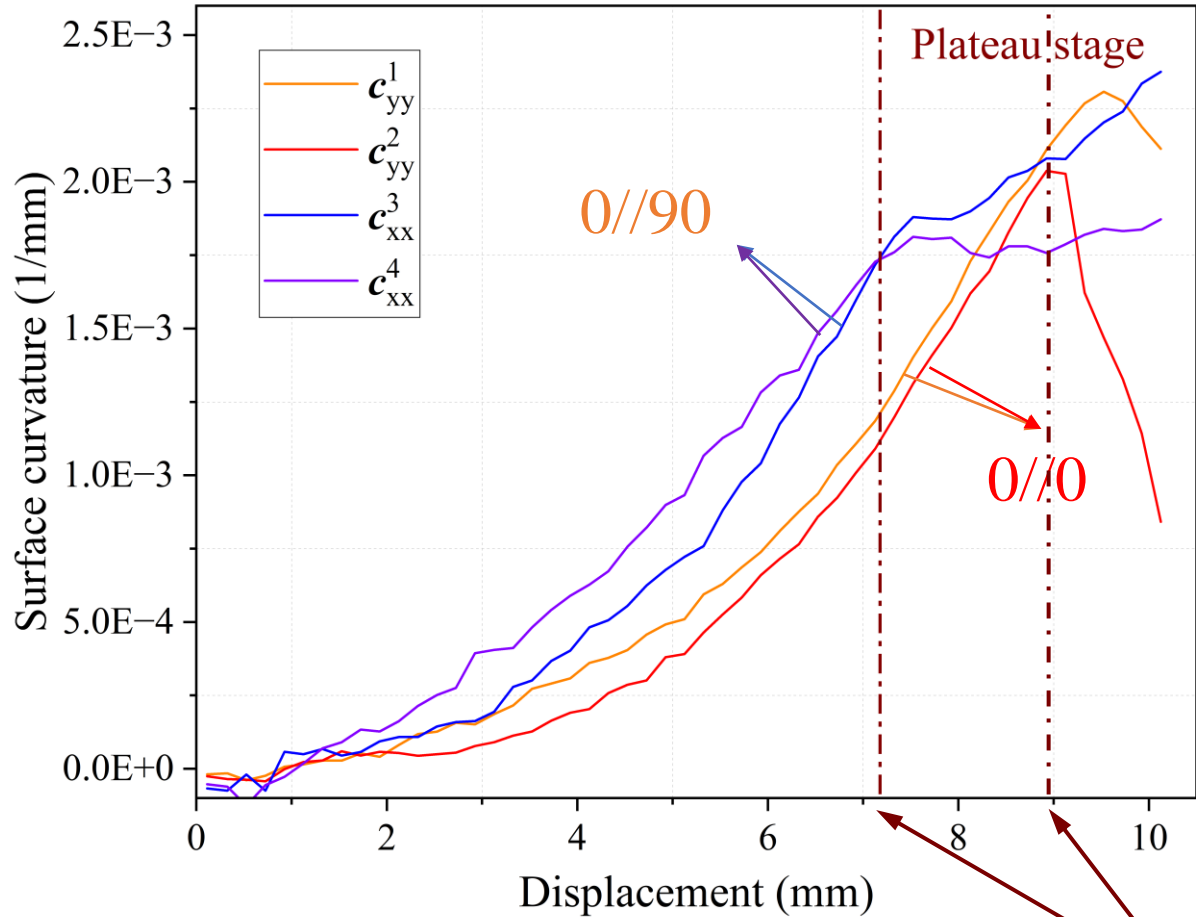
# Monitoring delamination process with DIC

- PCLS 0//0
- Embedded delamination



# Monitoring delamination process - DIC

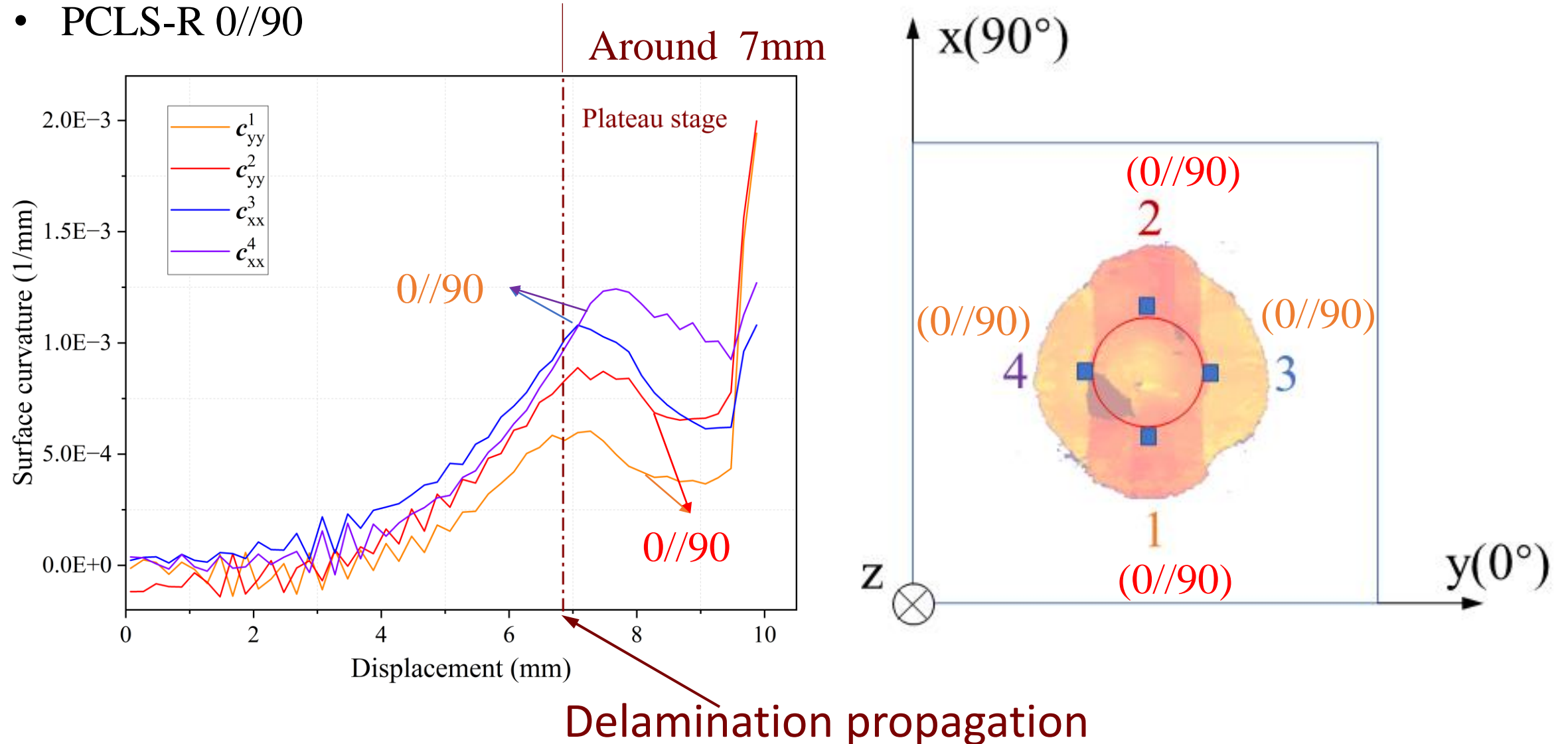
- PCLS-R 0//0



Delamination propagation

# Monitoring delamination process - DIC

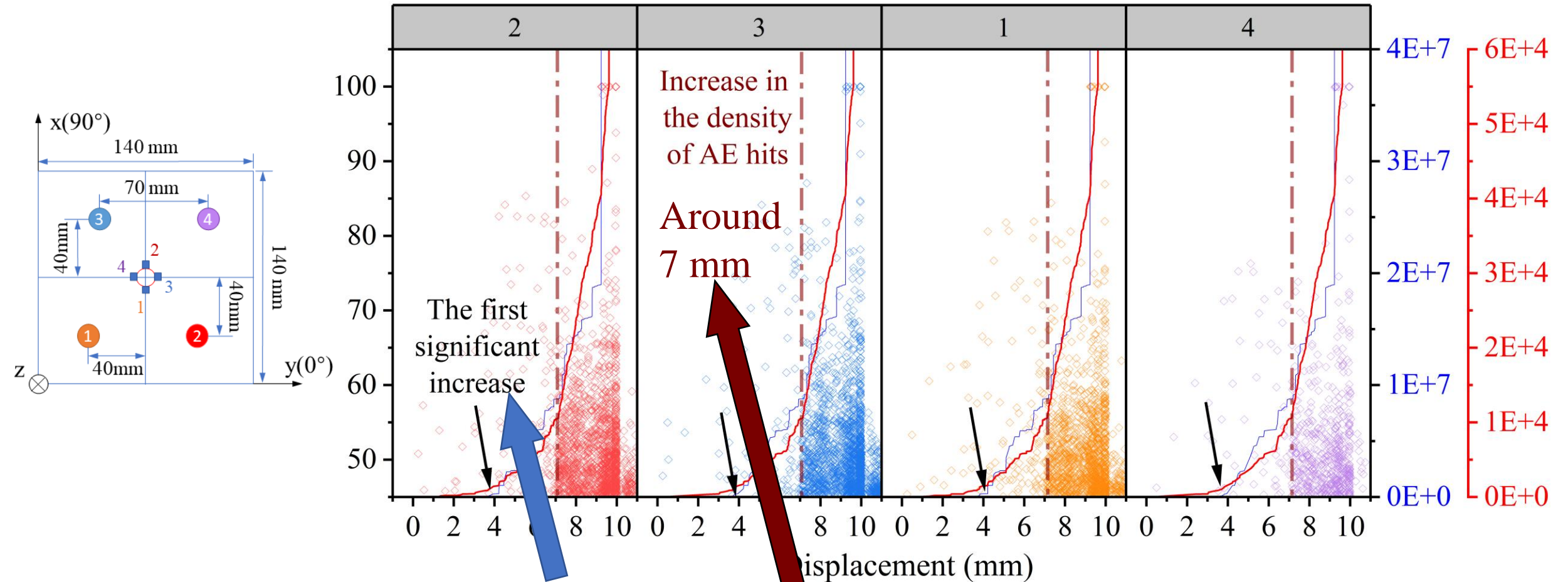
- PCLS-R 0//90



# Monitoring delamination process - AE

- PCLS 0//90

◆ AE amplitude (dB) — Accumulative AE energy (aJ) — Accumulative AE counts

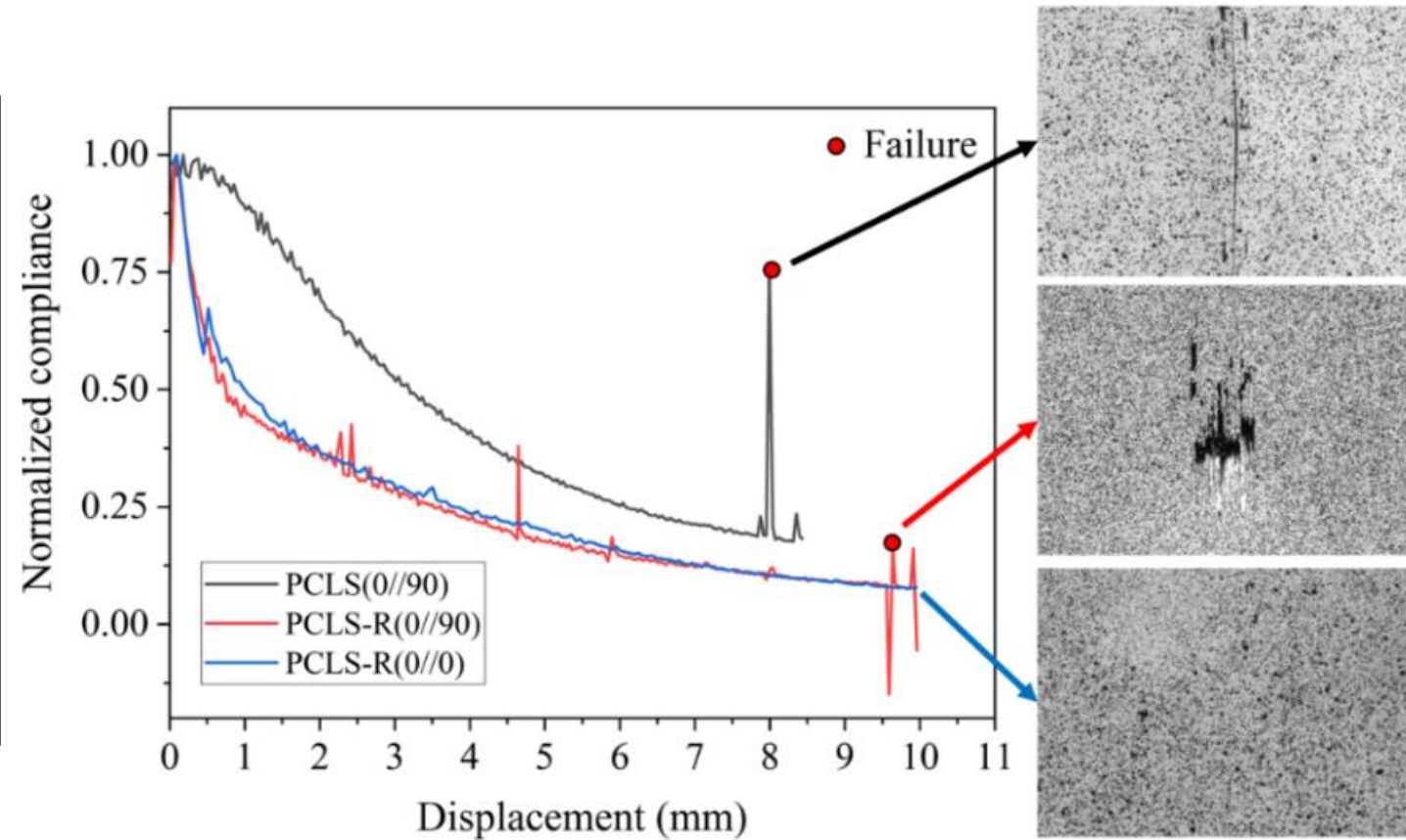
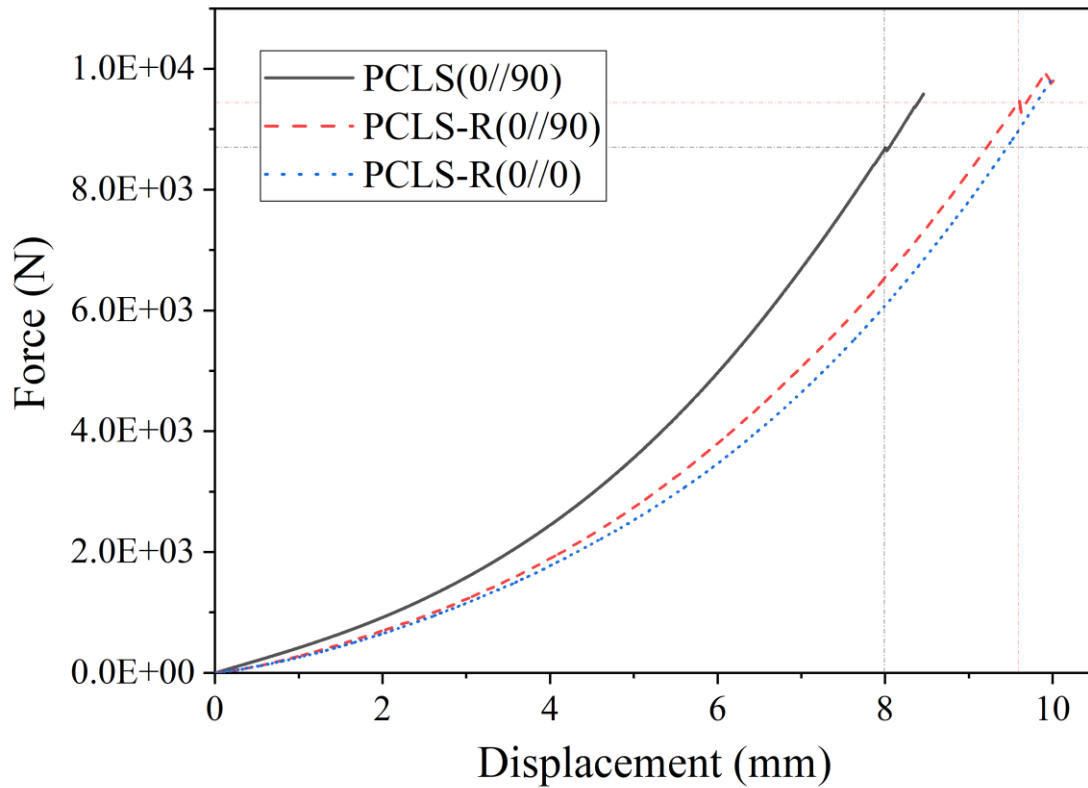


Estimations of delamination initiation and propagation

Further qualitative analysis of the damage modes is required

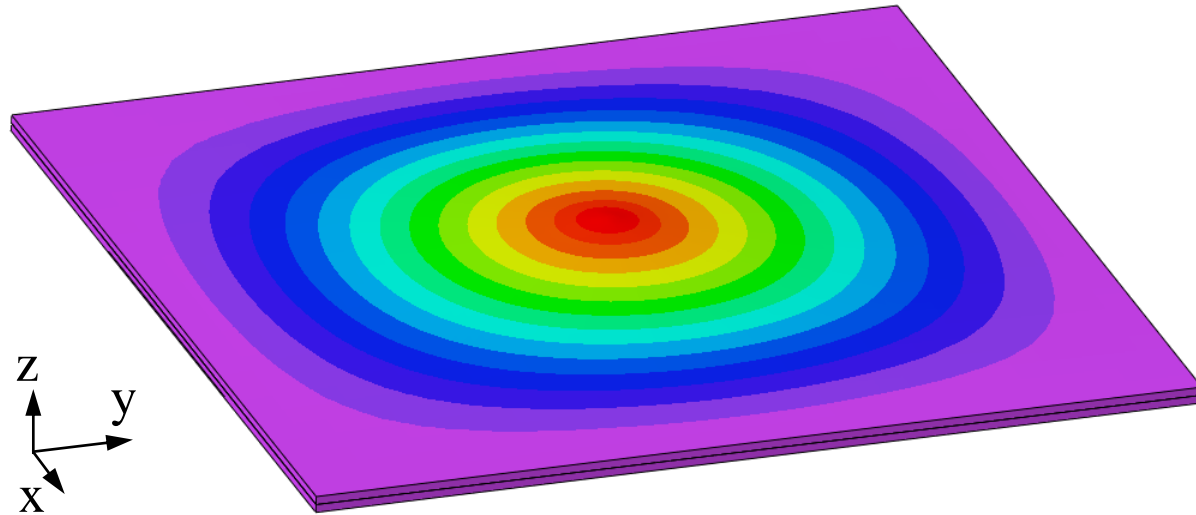


# Force-displacement behaviour & Compliance analysis

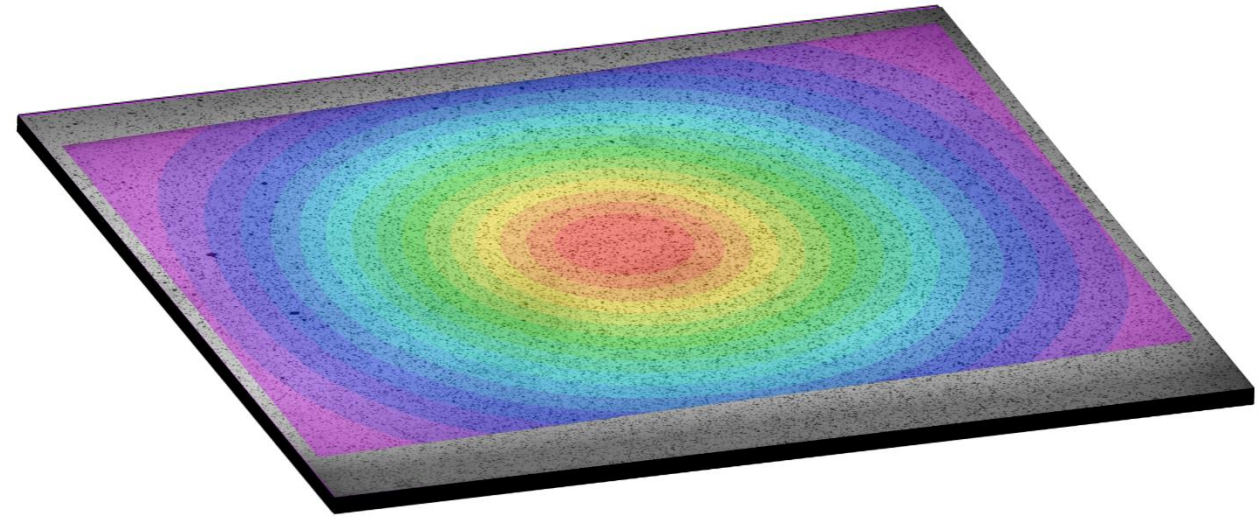


# Numerical simulation & its validation with DIC

- Numerical model



- DIC analysis



# Conclusions

# Conclusions

A new test methodology has been developed

Revealing planar delamination behaviour under quasi-static out-of-plane loading:

- Continuous stiffening behaviour
- Planar delamination pattern: delamination propagation and migration
- Monitoring delamination process by using DIC and AE

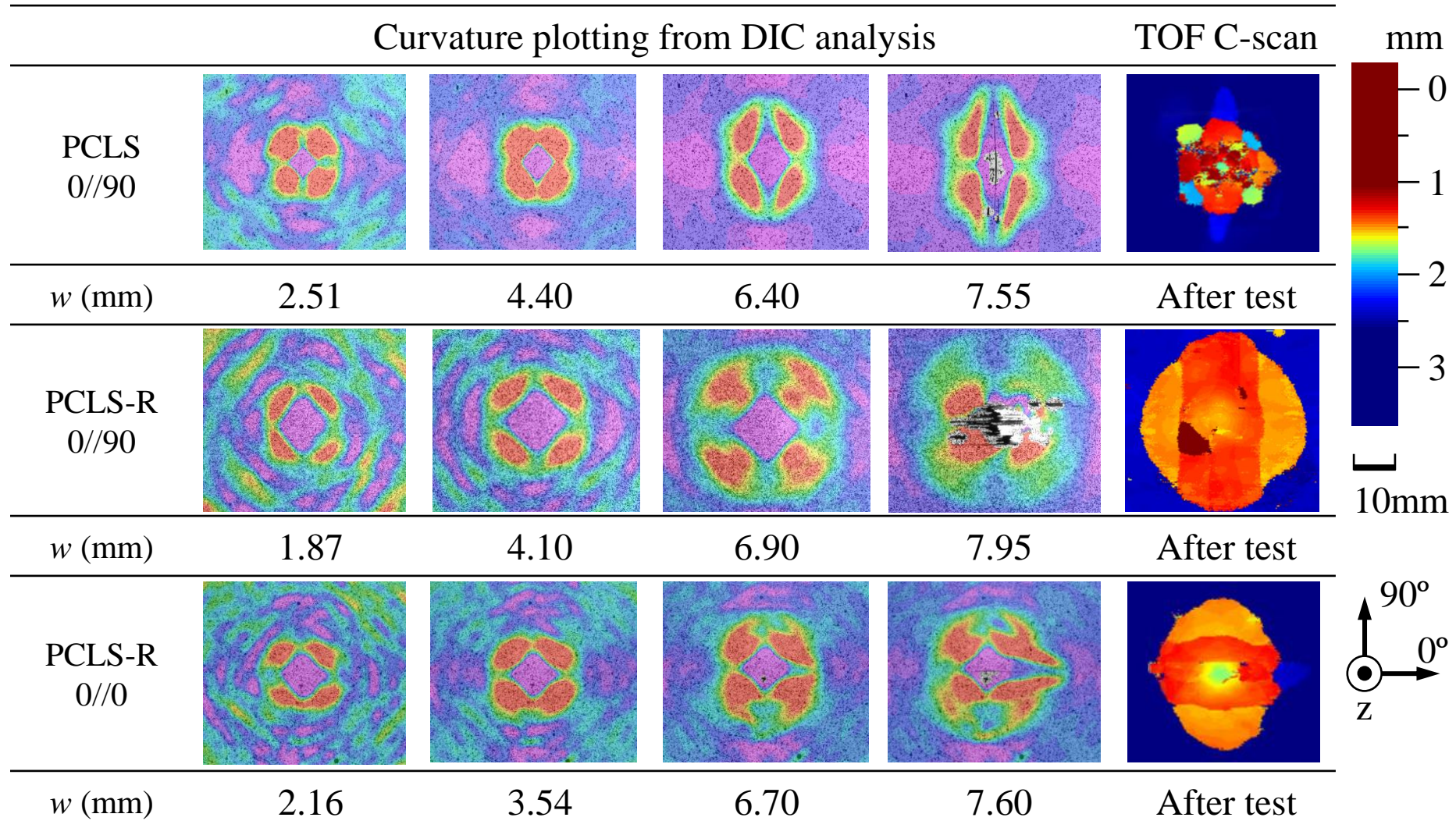
**? How can we characterize planar delamination**

Measurement of planar delamination growth

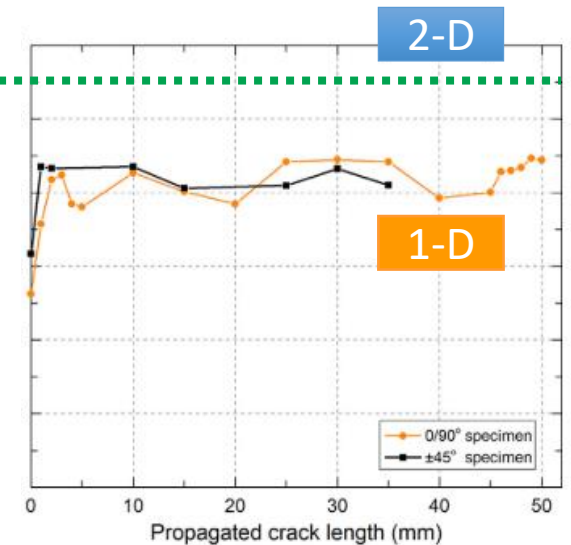
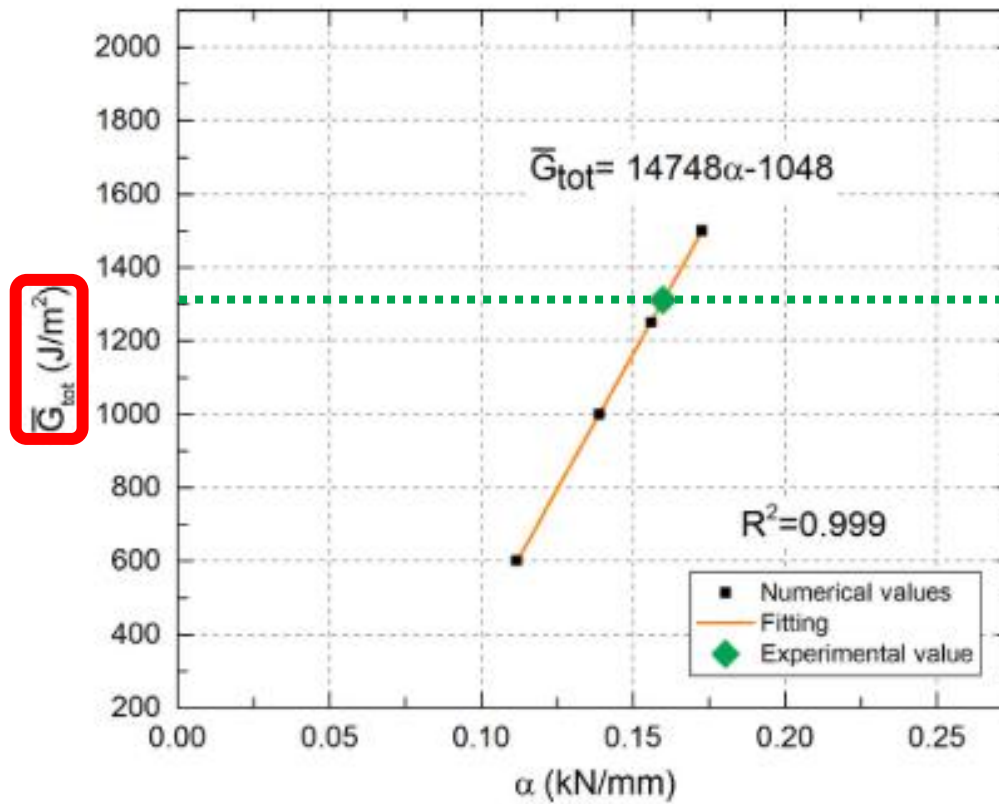
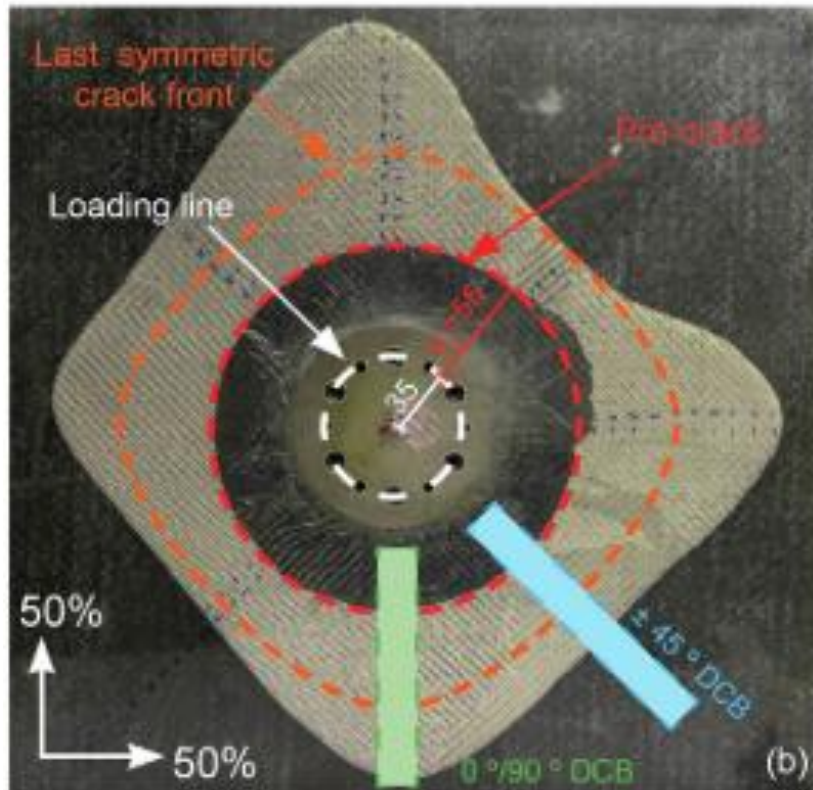
Criterion for planar delamination growth

$$\frac{d?}{dN} = C(f(\Delta G, G_C, G_{th} \dots))^n$$

# Monitoring delamination process - DIC



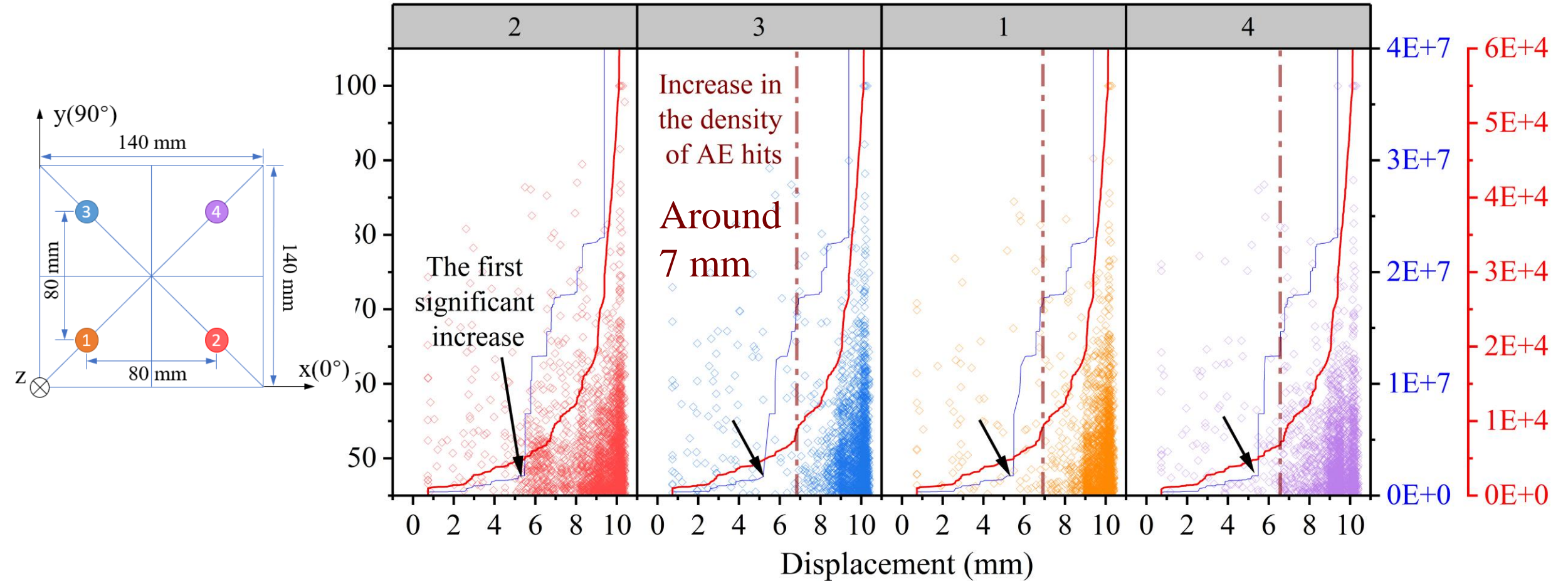
- Cameselle-Molares, 2019



# Monitoring delamination process - AE

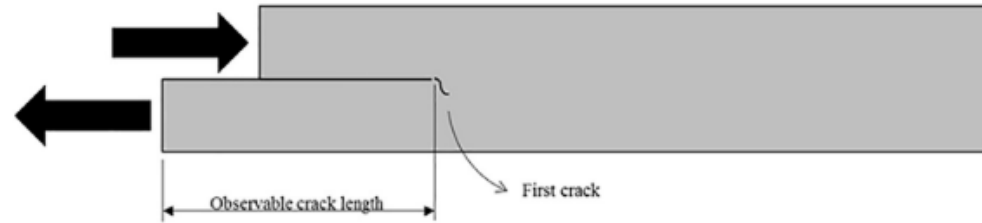
- PCLS 0//0

◆ AE amplitude (dB) — Accumulative AE energy (aJ) — Accumulative AE counts

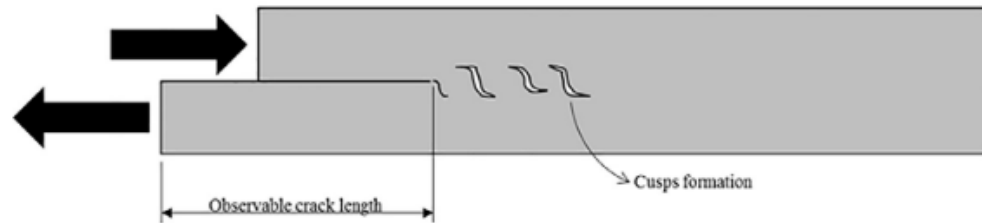
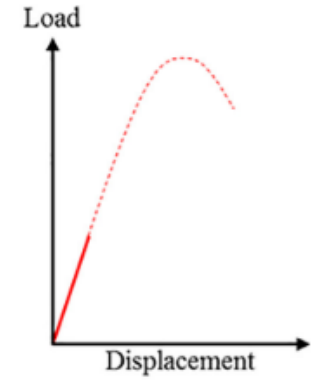


# Mode II dominant delamination

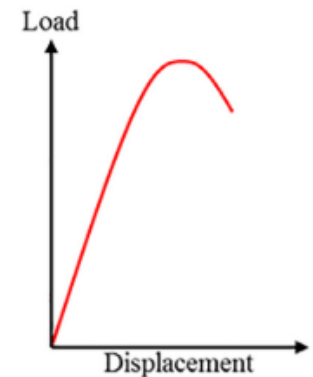
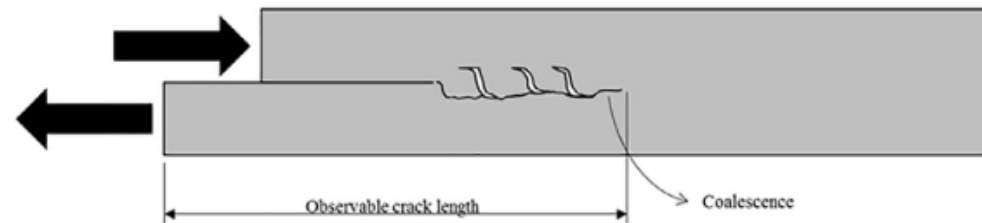
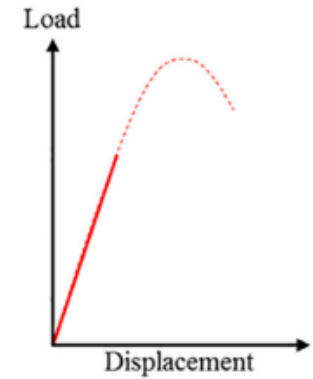
- Amaral et al, Engineering Fracture Mechanics, 2018



(a)



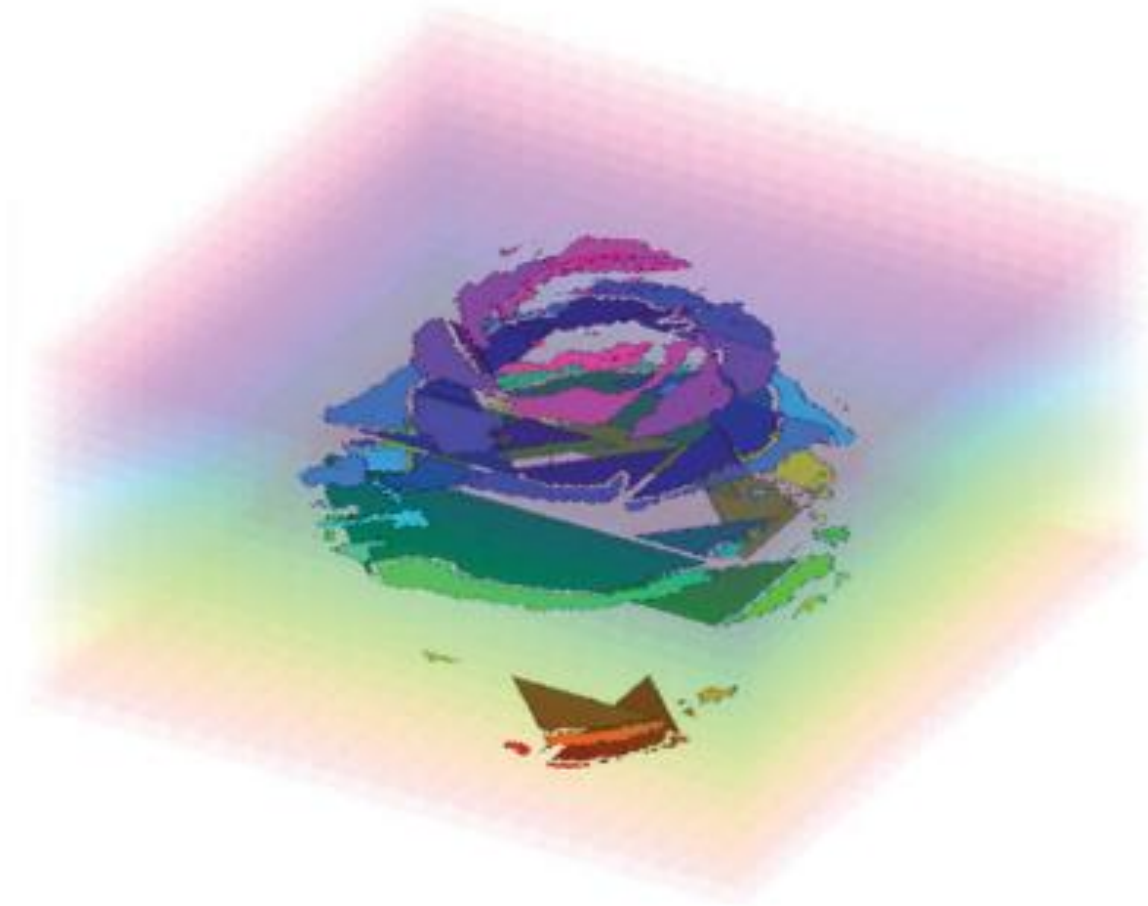
(b)



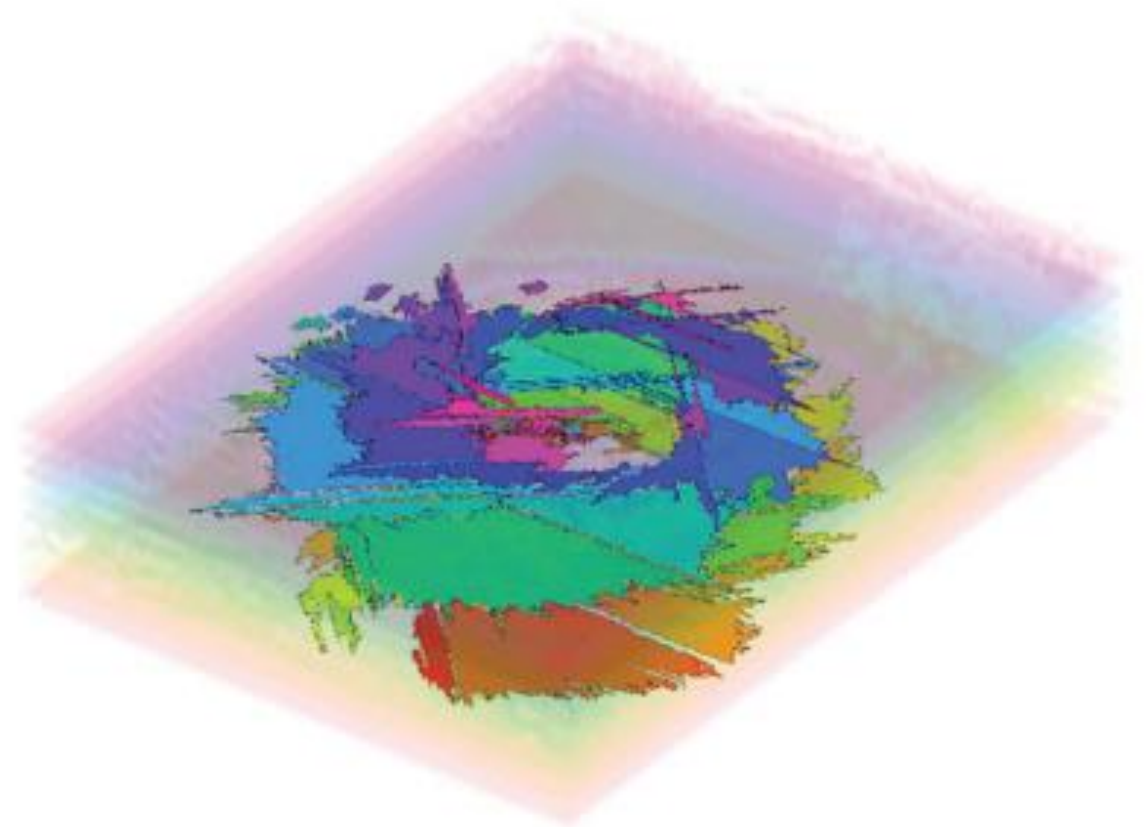


# Impact-induced delamination

- Ellison et al, Journal of Composite Materials, 2018



- UT extended segmentation



- CT segmentation