On the investigation of free edge effects in composites using full field measurements

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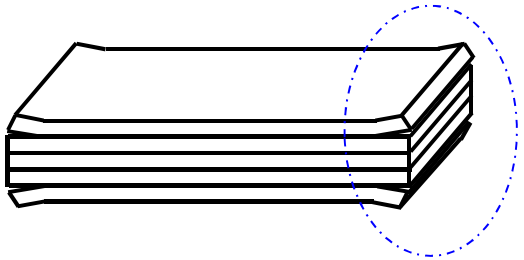
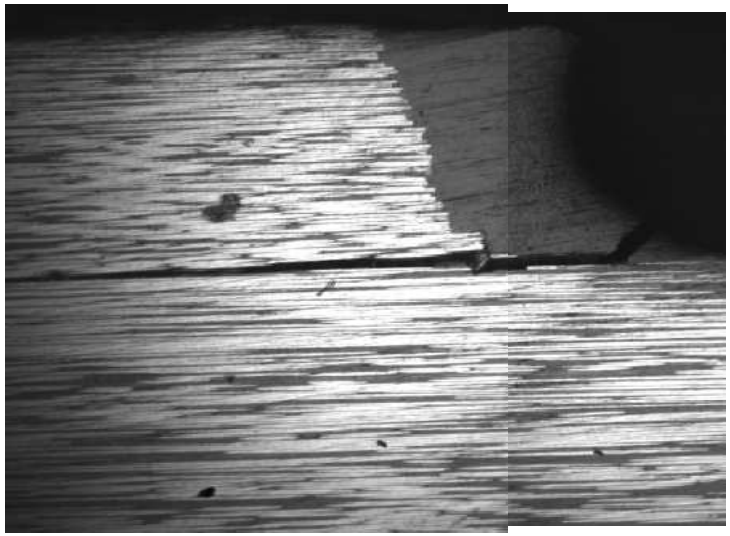
ONERA
THE FRENCH AEROSPACE LAB

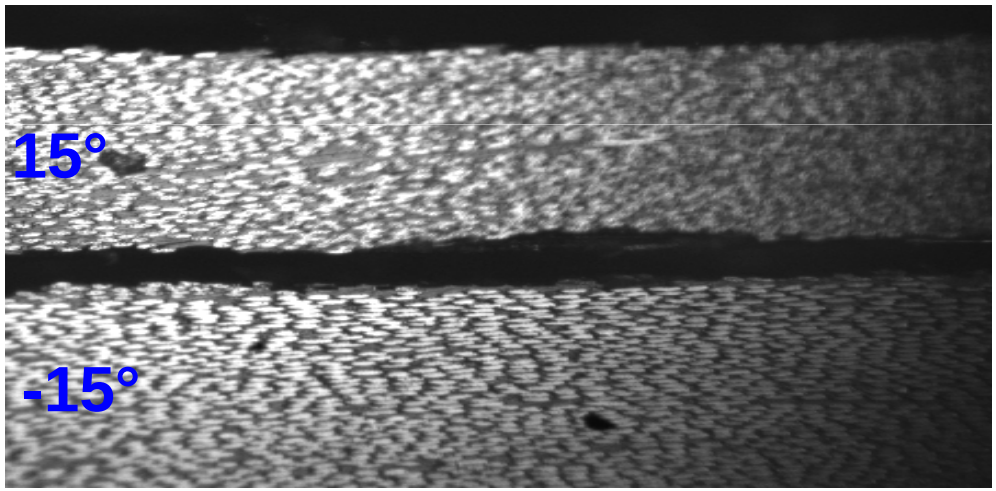
Context : delamination

- Extensive use of composite materials
- design of composite structures globally well mastered
- Free edge and junctions : delamination problems





Ply drops

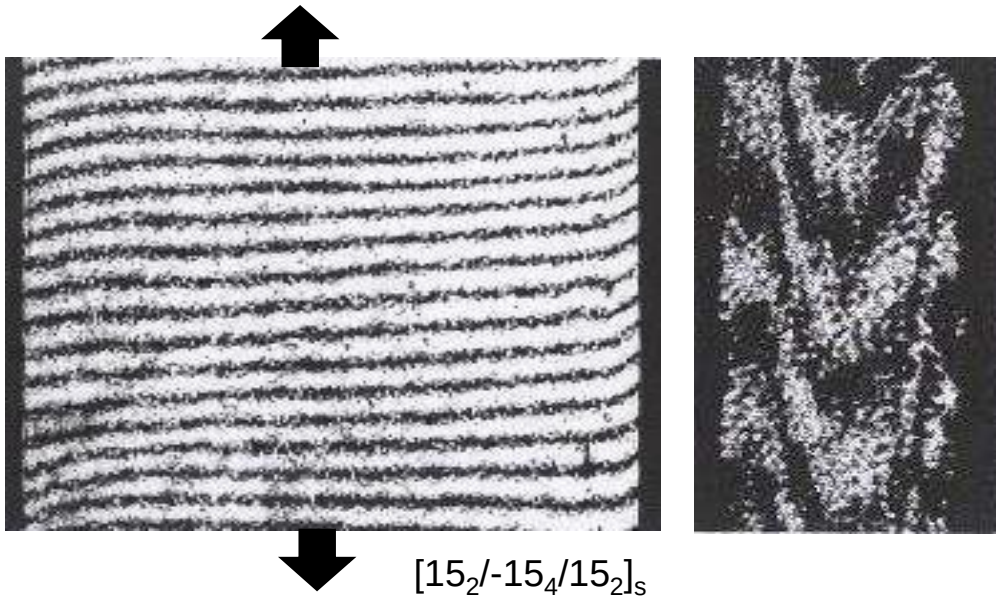


15°/ -15°interface

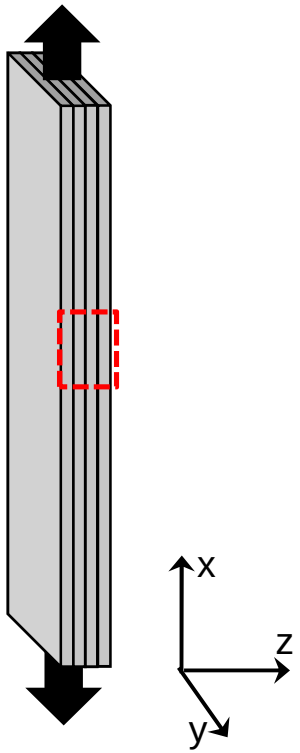
Context: free edge effects

- Free edge and interlaminar interfaces
- Discontinuity of inter-ply mechanical properties
- Stress concentration

[Czarnek, Post, Herakovich,1983]



$[15_2/-15_4/15_2]_s$



Highest free edge effects at 15°/-15° interfaces

Objectives

- Experimentally study free edge effects at mesoscopic scale
- Investigate the behaviour and the micro-mechanisms in the vicinity of interlaminar interfaces
- Highlight the influence on free edge effects of microstructure heterogeneities and geometrical singularity

Summary

Experimental Procedure

- Studied materials
- DIC Technique
- Experimental set up

Free edge effects and damage micro-mechanisms

- Macroscopic behaviour
- DIC measurements at mesoscopic scale
- Microscopic observations

Influence of structural and microstructural heterogeneities

- Microstructure heterogeneities (quasi-UD laminates)
- Geometrical singularity (laminates with ply drops)

Conclusions

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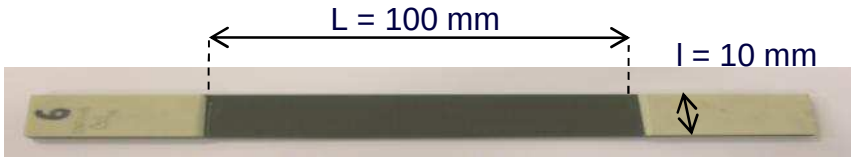
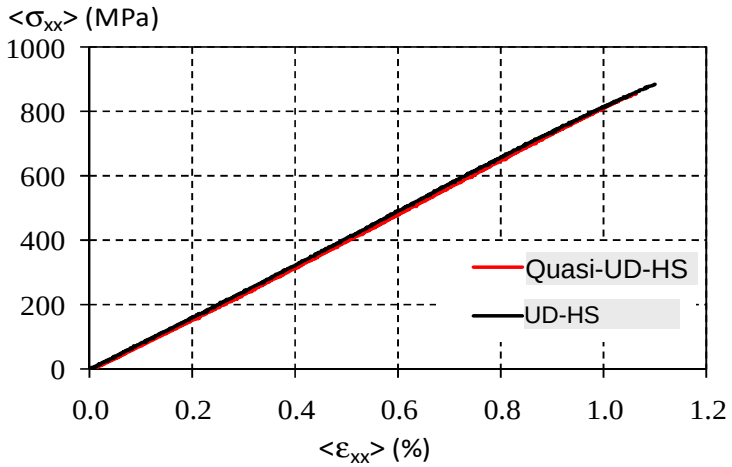
Effect of material microstructure

Plane samples : $[(15/-15)_2]_s$



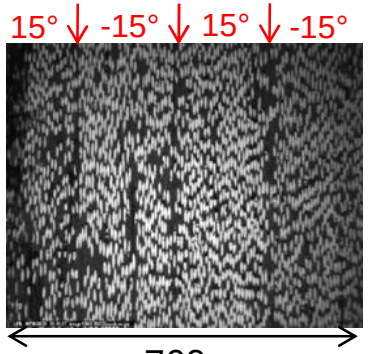
Denomination	UD-HS	Quasi UD-HS
Supplier (Hexcel) Reference	CTS / 920	G947 / M18
Mean ply thickness (mm)	0.205	0.180

Macroscopic behaviour

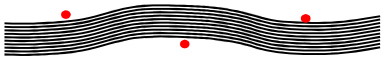


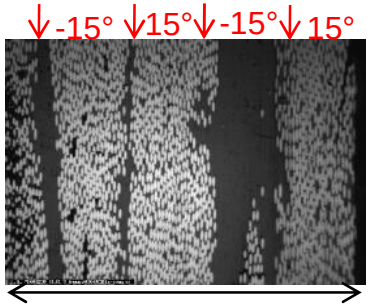
Microstructure observations

UD-HS



Quasi-UD-HS

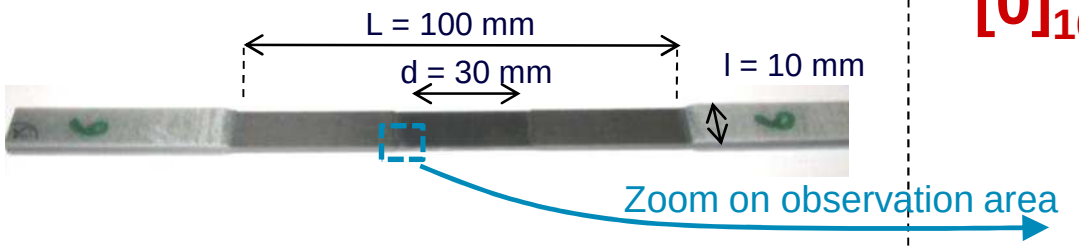




Experimental procedure

Effect of structure

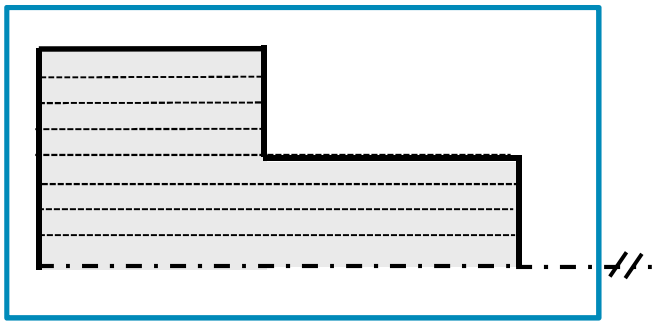
Samples with ply drops



Supplier Reference	**M55J / M18**
Denomination	**UD-HM**
Structure	UD
Stacking sequences	$[(15_2/\text{-}15_2)_2]_s$ and $[0]_{16}$
Fibre type	HM
Mean ply thikness (mm)	0.100

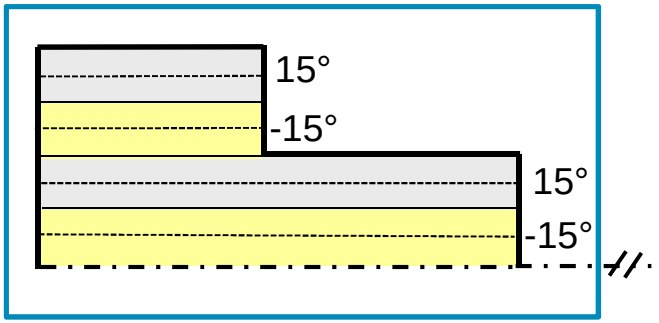
Geometrical singularity

$[0]_{16}$



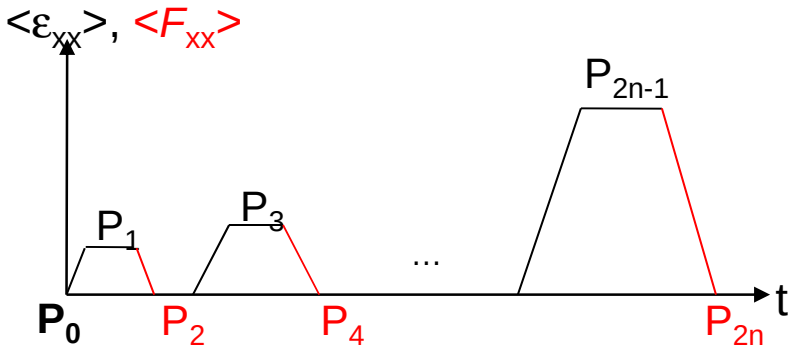
Material and geometrical singularity

$[(15_2/\text{-}15_2)_2]_s$



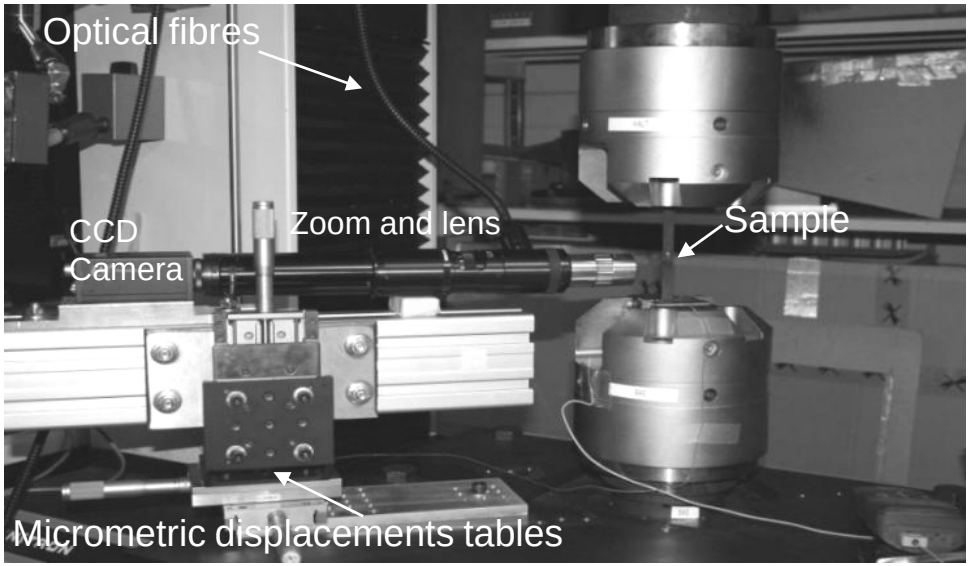
Experimental procedure

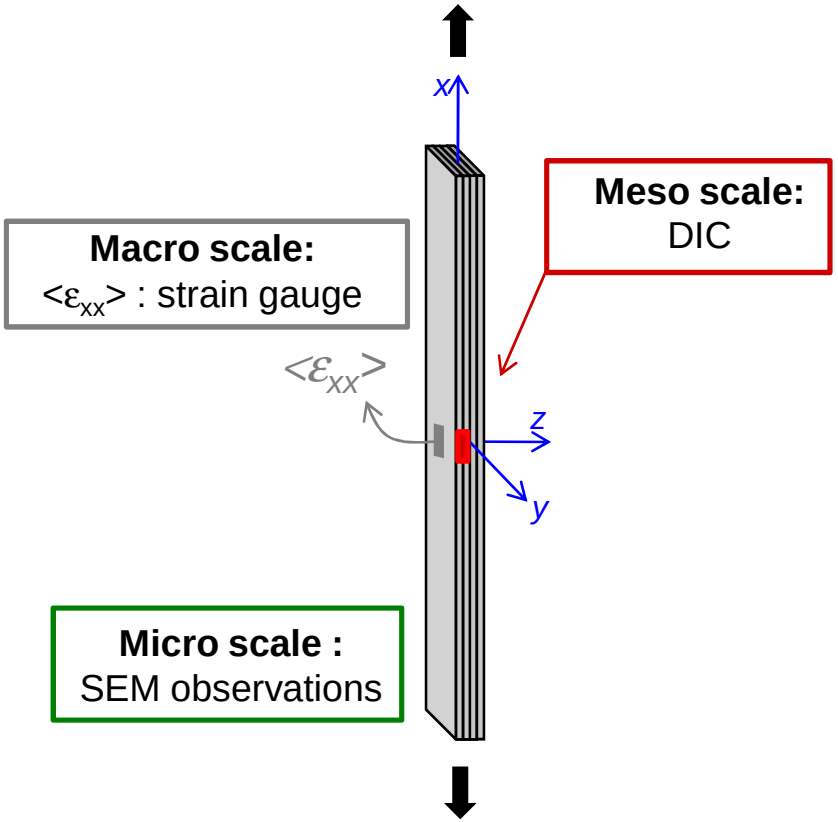
Uniaxial tensile tests with loading and unloading steps



P_{2n-1} Loaded state under $\langle\varepsilon_{xx}\rangle$

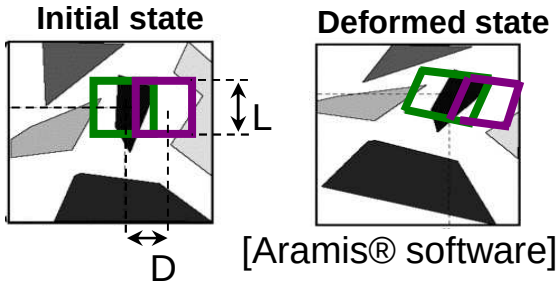
P_{2n} Unloaded state with $\langle F_{xx}\rangle = 0N$





Experimental procedure

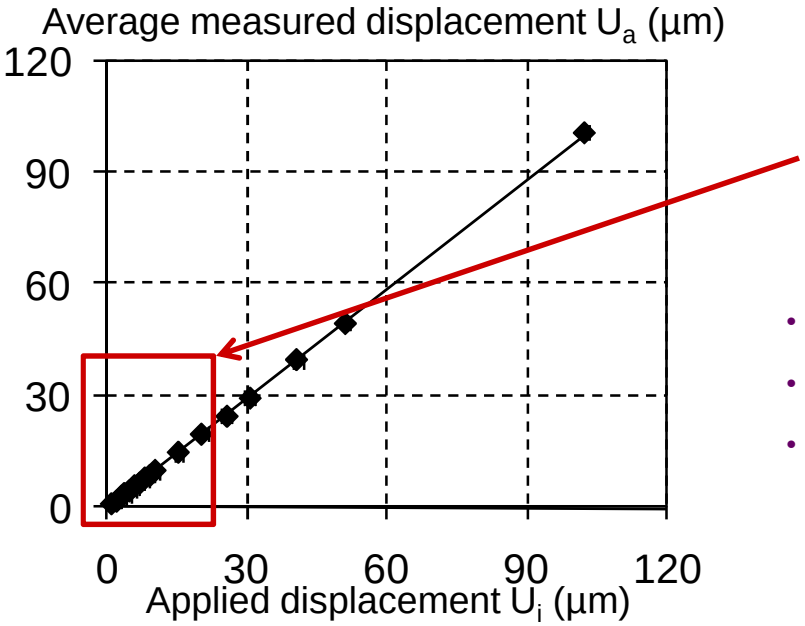
DIC Technique and cameras characteristics



[Aramis® software]

Resolution (pixels)	1024 x 1368	2048 x 2736
Dynamique (bits)	10	12
(L,D) pixels	(30,20)	(60,40)

Measurements uncertainties



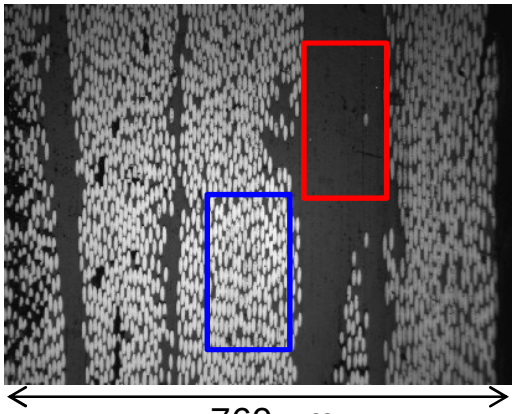
Expected displacements < 20µm (camera recentred on initial observation area)

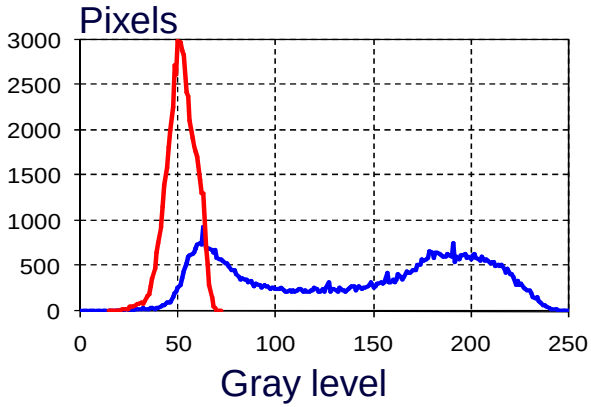
- Standard deviation calculation for U_i = 20 µm
- Displacements uncertainties < 0.02 µm
- Strain uncertainties < 0.1%

Experimental procedure

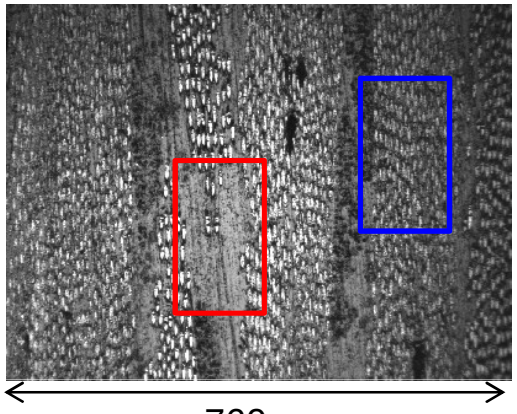
DIC technique principle : gray level distribution

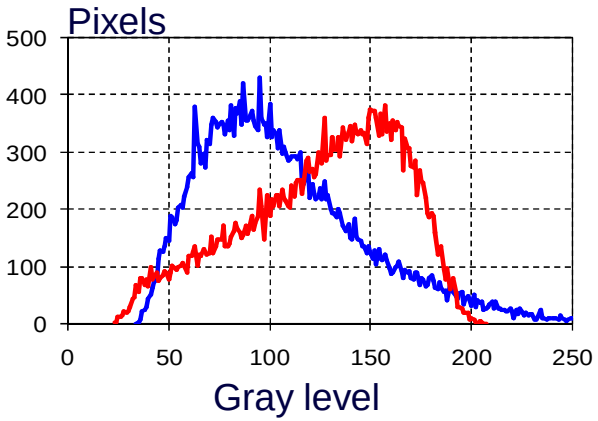
Mirror polishing





« coarse » polishing





Direct use of microstructure to DIC measurements

Summary

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Free edge effects and damage micro-mechanisms

- Macroscopic behaviour
- DIC measurements at mesoscopic scale
- Microscopic observations

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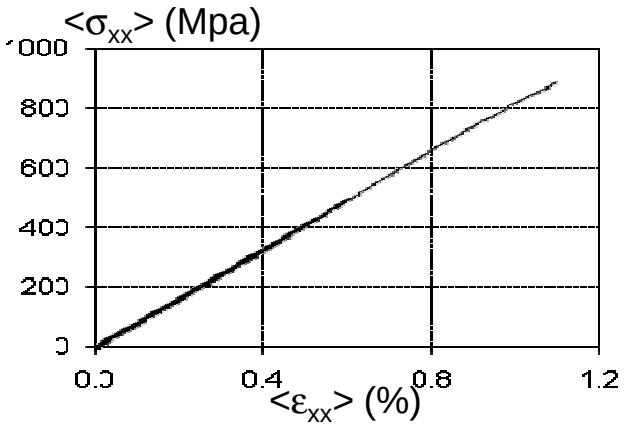
- Microstructure heterogeneities (quasi-UD laminates)
- Geometrical singularity (laminates with ply drops)

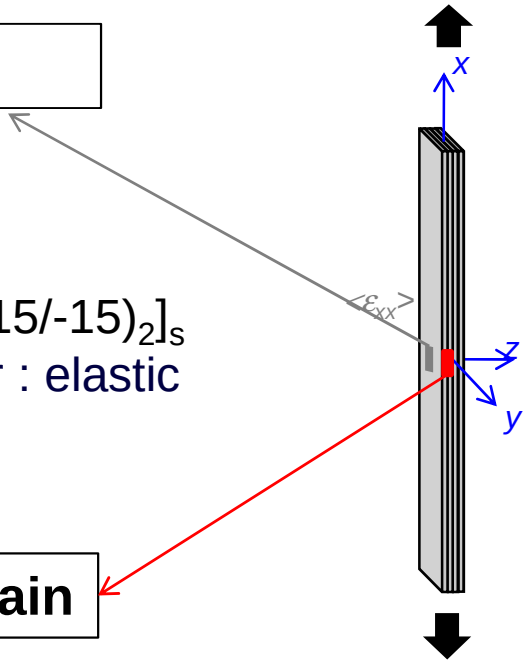
Conclusions

Free edge effect and damage micro-mechanisms

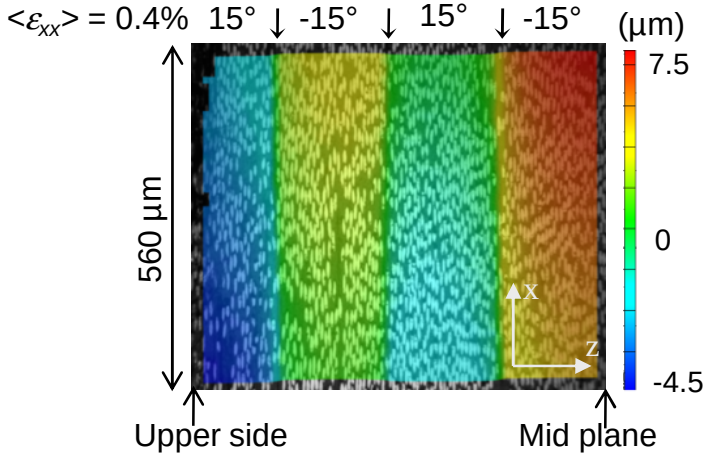
Macroscopic behaviour

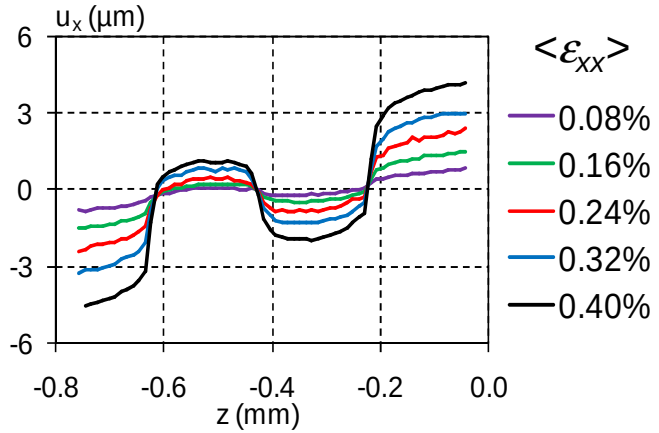


- Material : UD-HS
- Stacking sequence : $[(15/-15)_2]_s$
- Macroscopic behaviour : elastic linear until failure



DIC results at mesoscopic scale under tensile strain

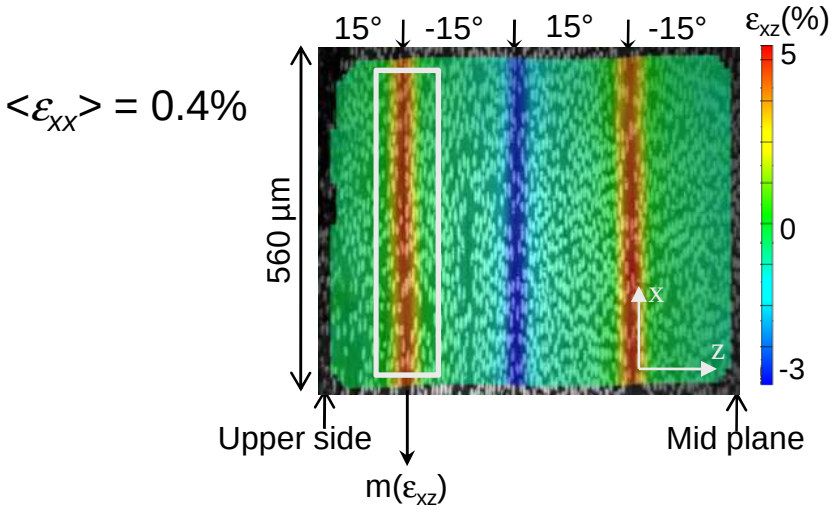


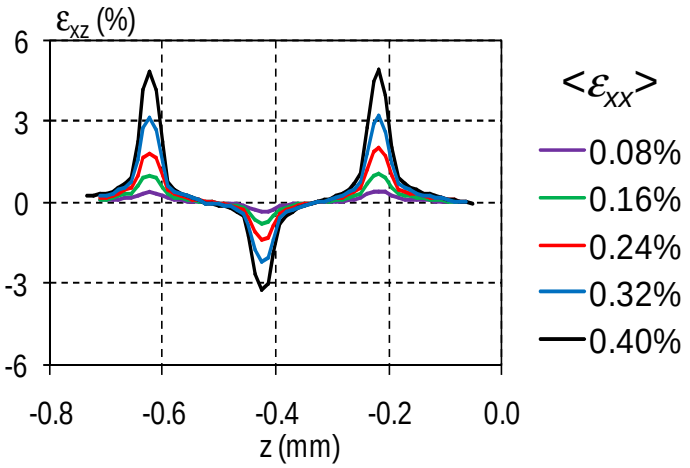


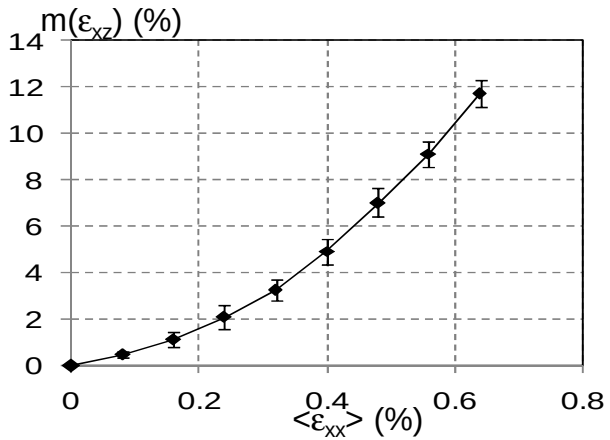
Camera Resolution (px)	1024 x 1368
Pixel size(µm)	0.55
(L,D) (px)	(30,20)

Free edge effect and damage micro-mechanisms

DIC results at mesoscopic scale under tensile strain





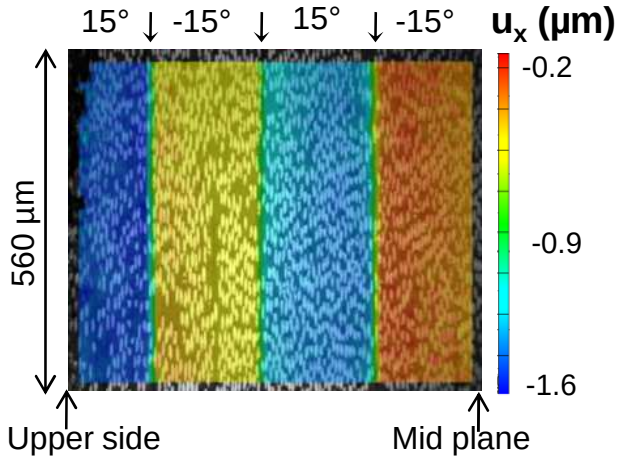


- High u_x displacements gradients and ε_{xz} shear strain concentrations
- Non linear variation of ε_{xz} as a function of $\langle\varepsilon_{xx}\rangle$

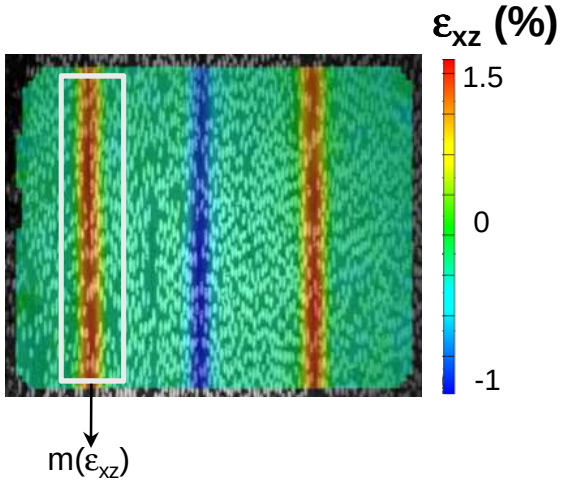
→ and after sample unloading?

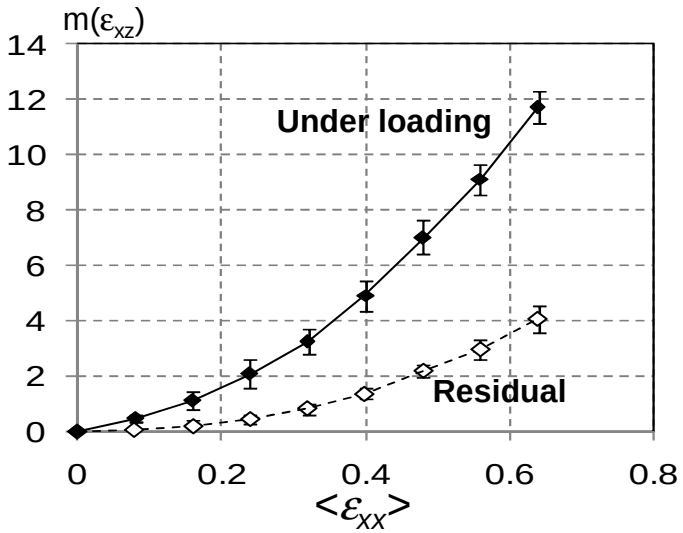
Free edge effect and damage micro-mechanisms

DIC results at mesoscopic scale after sample unloading



$<\varepsilon_{xx}> = 0.4\%$



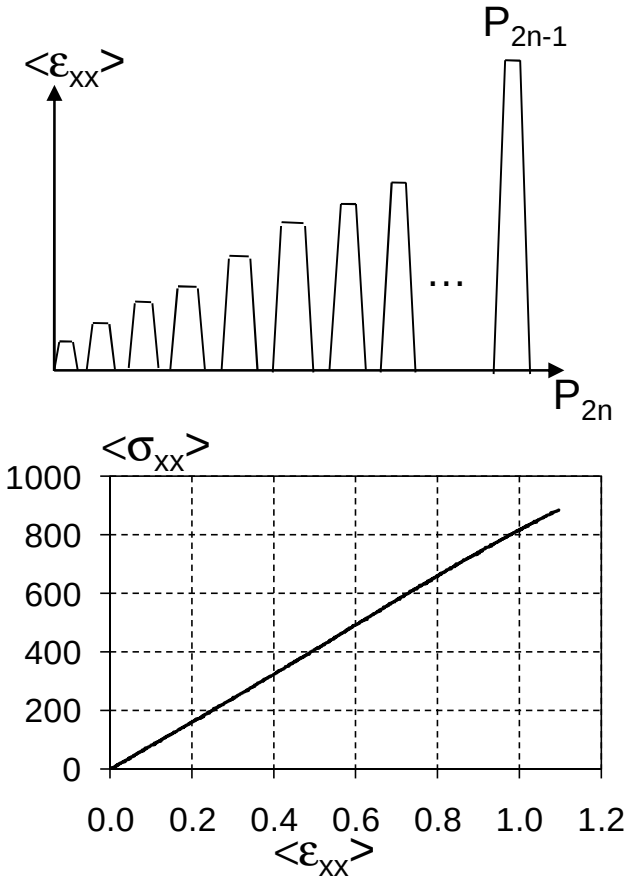


- Residual shear strain at interlaminar interfaces
- Damage nature?

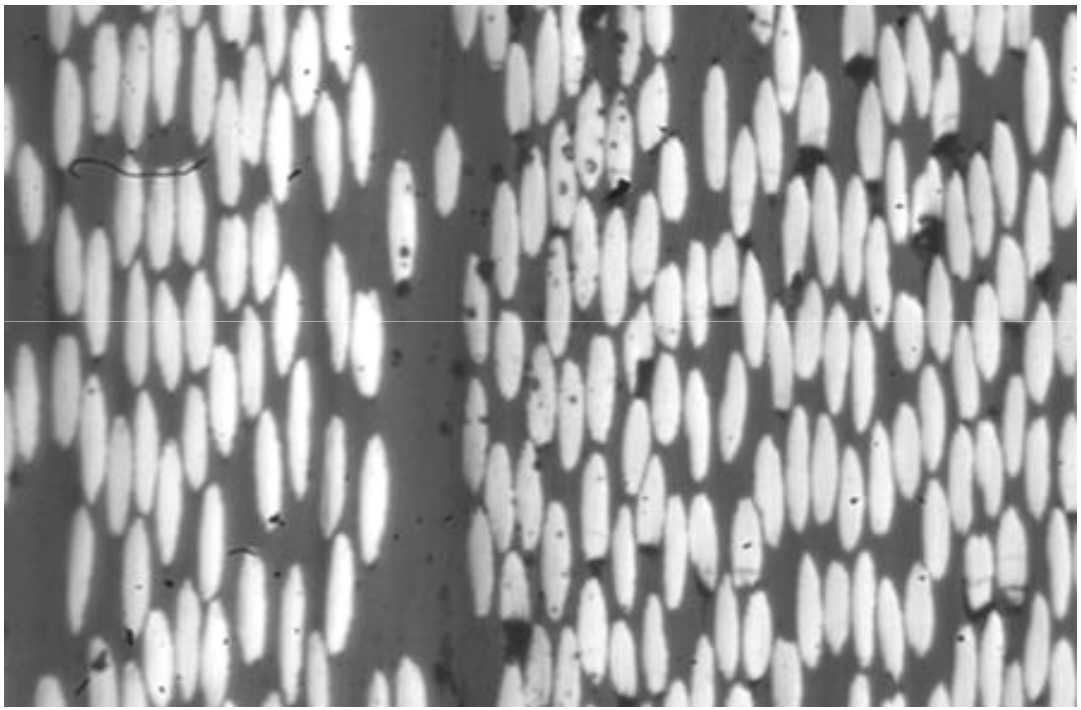
→Microscopic observations

Free edge effect and damage micro-mechanisms

Observations at microscopic scale during tensile tests



Initial state

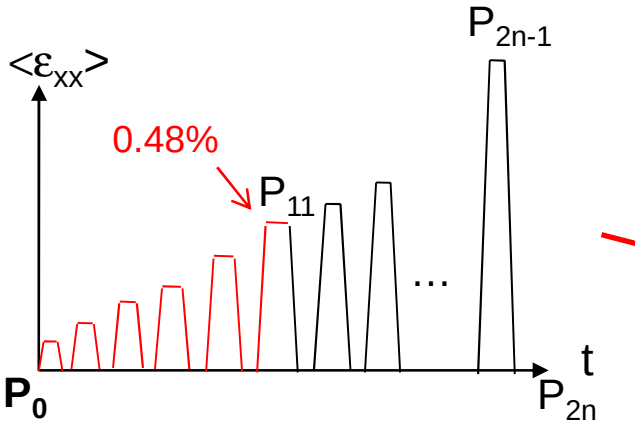


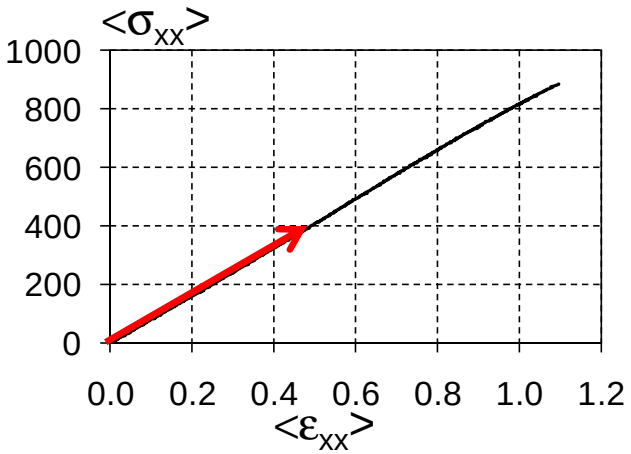
+15° -15°

Interlaminar interface

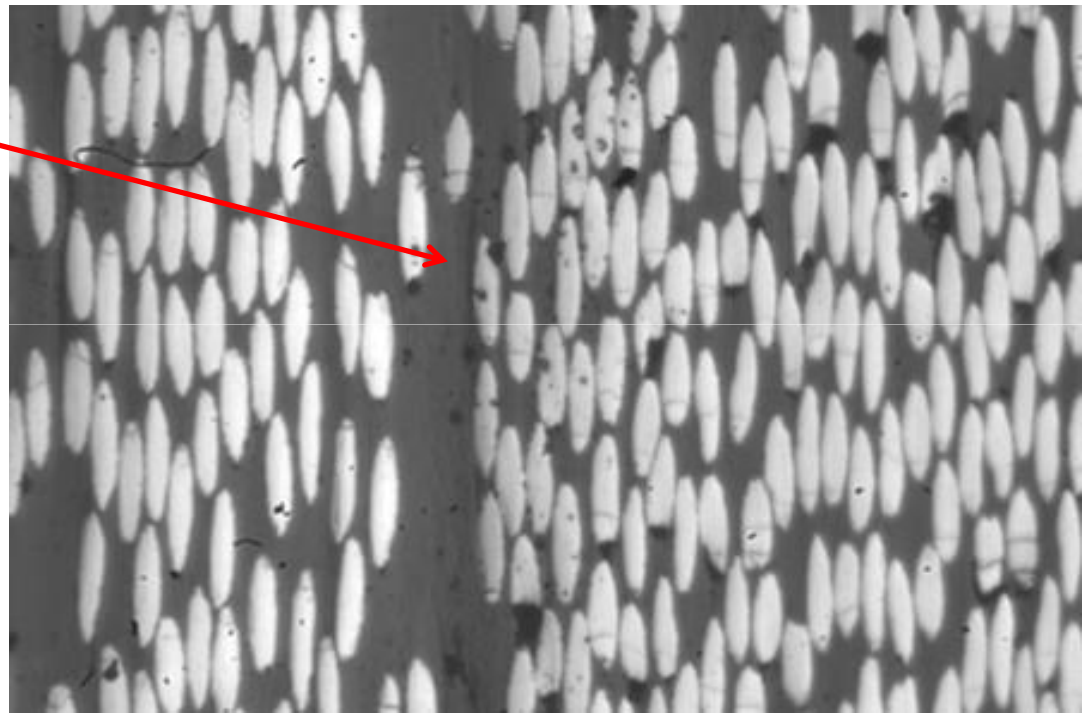
Free edge effect and damage micro-mechanisms

Observations at microscopic scale during tensile tests





Loaded at $\langle\varepsilon_{xx}\rangle = 0.48\%$



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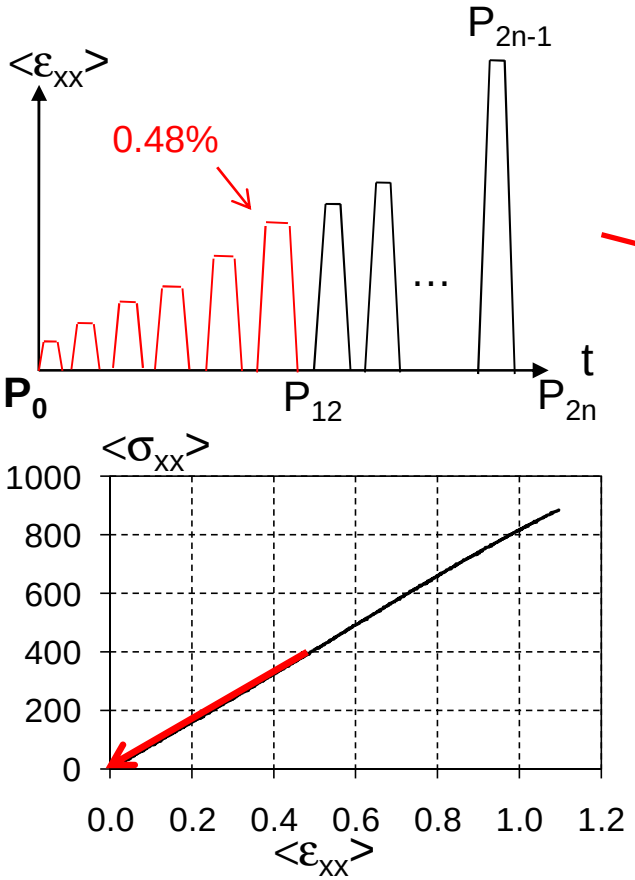
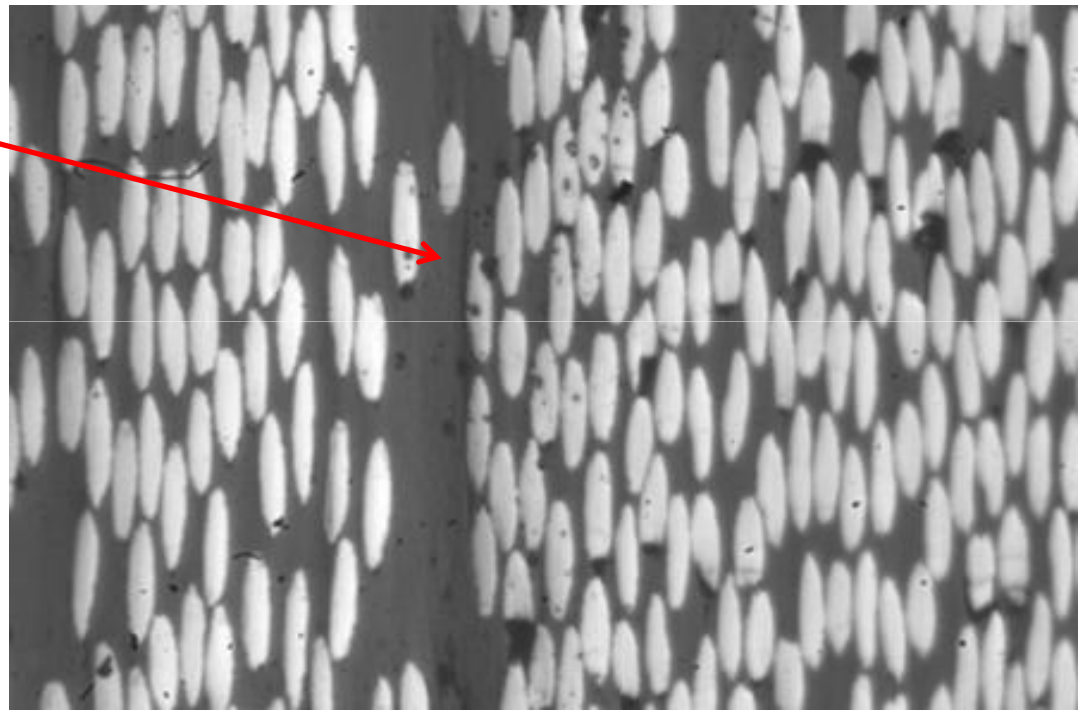


Unloaded after $<\varepsilon_{xx}> = 0.48\%$

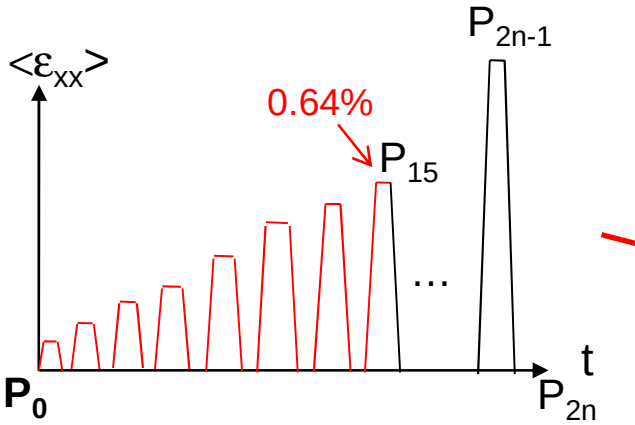


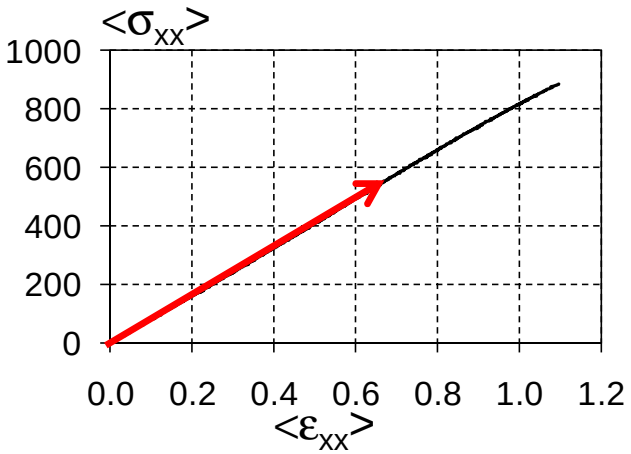
+15° -15°

Interlaminar interface

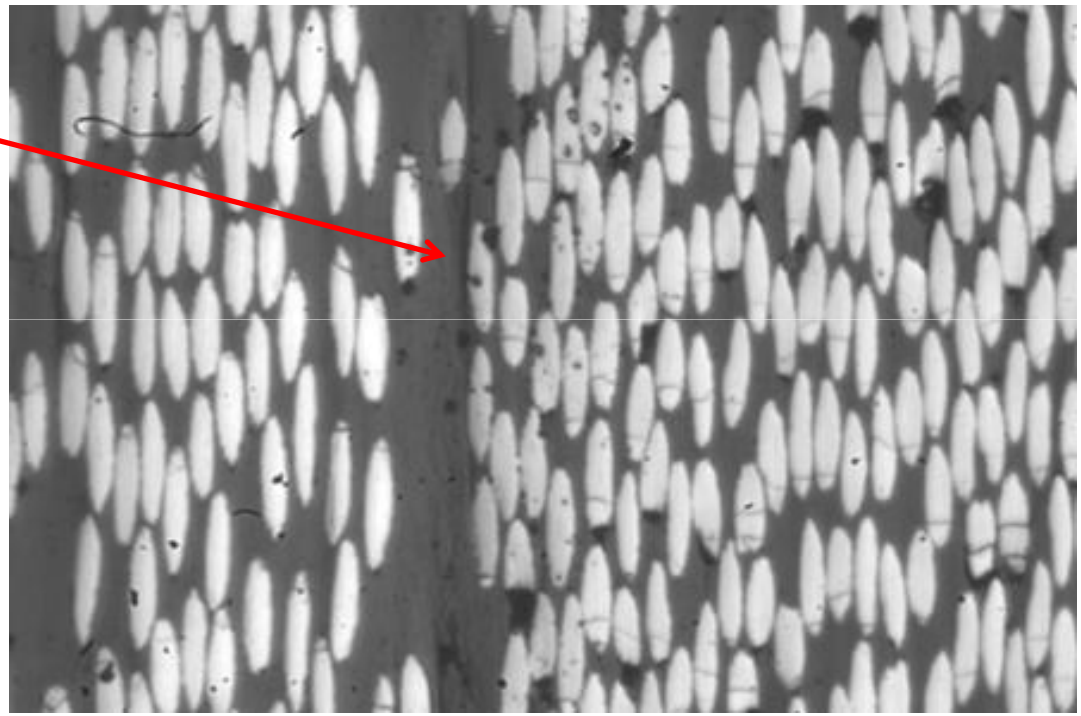
Free edge effect and damage micro-mechanisms

Observations at microscopic scale during tensile tests





Loaded at $\langle\varepsilon_{xx}\rangle = 0.64\%$

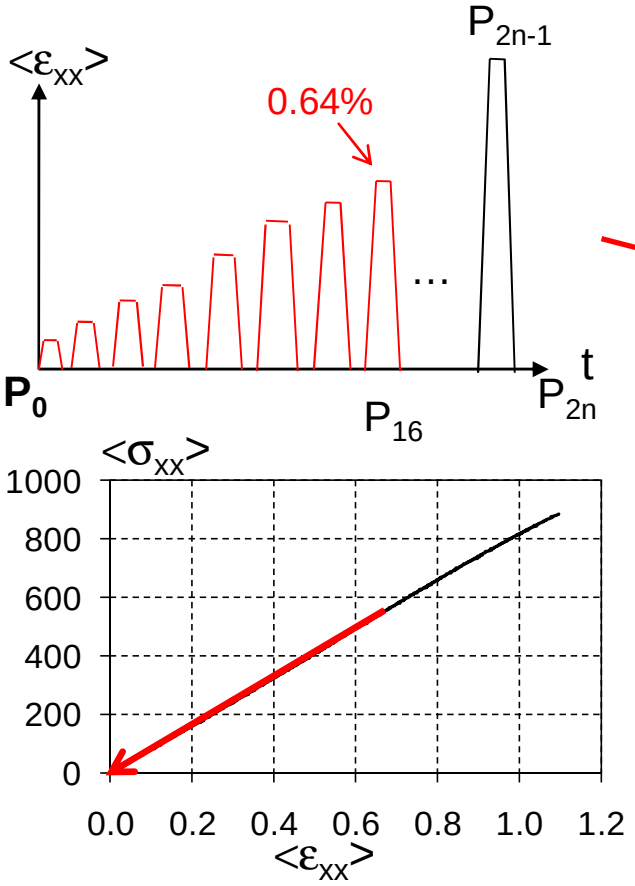


+15° -15°

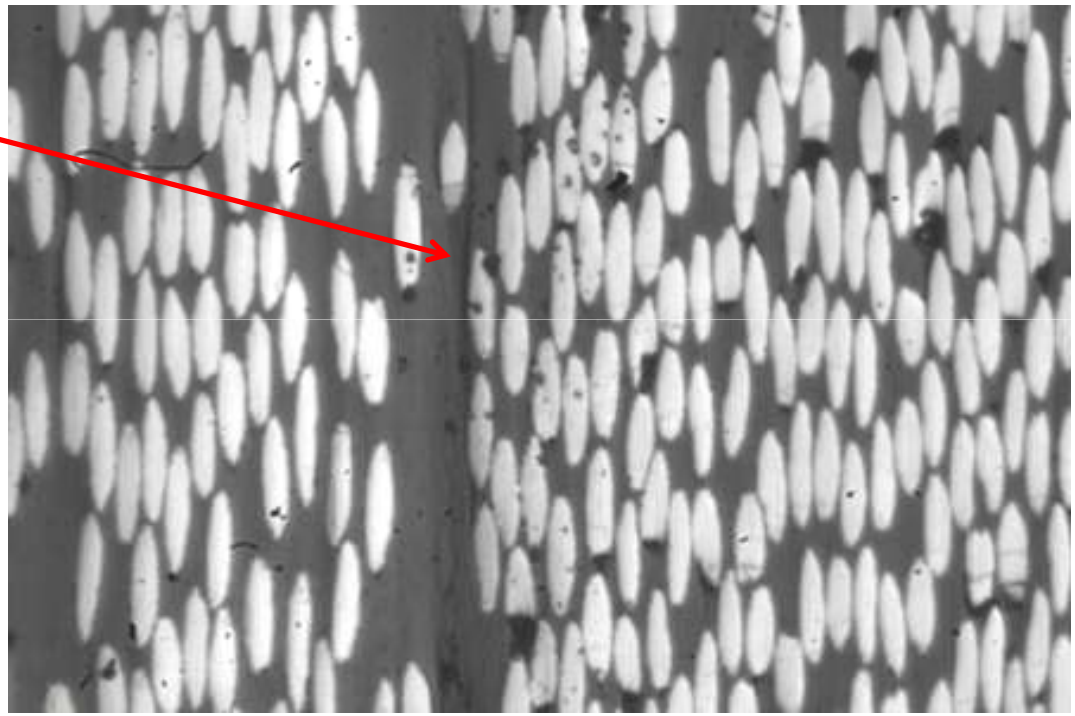
Interlaminar interface

Free edge effect and damage micro-mechanisms

Observations at microscopic scale during tensile tests



Unloaded after $\langle\varepsilon_{xx}\rangle = 0.64\%$

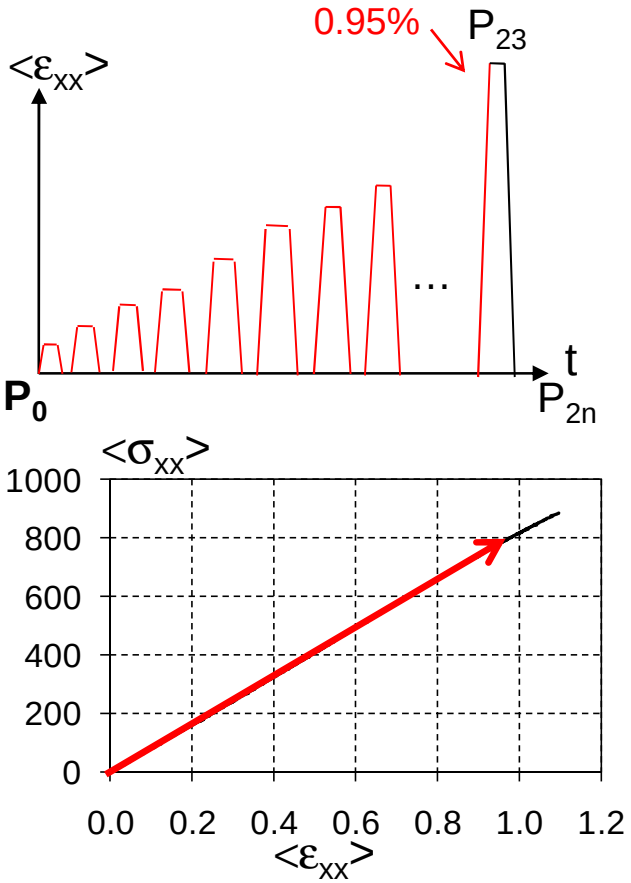


+15° -15°

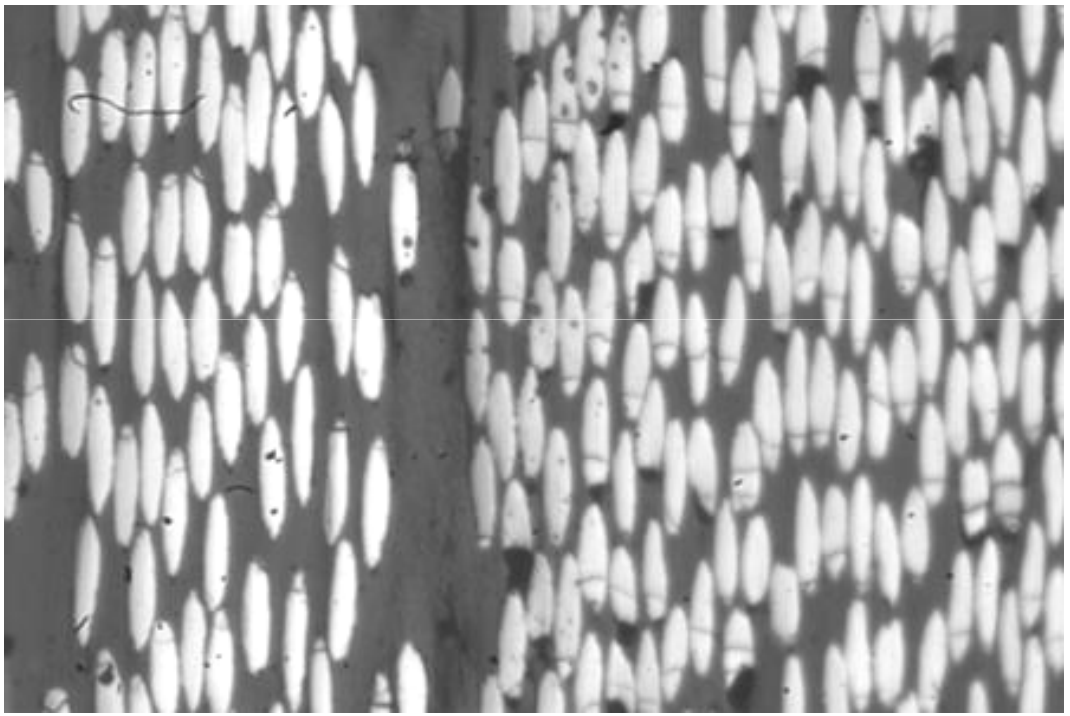
Interlaminar interface

Free edge effect and damage micro-mechanisms

Observations at microscopic scale during tensile tests



Loaded at<ε_{xx}> = 0.95%

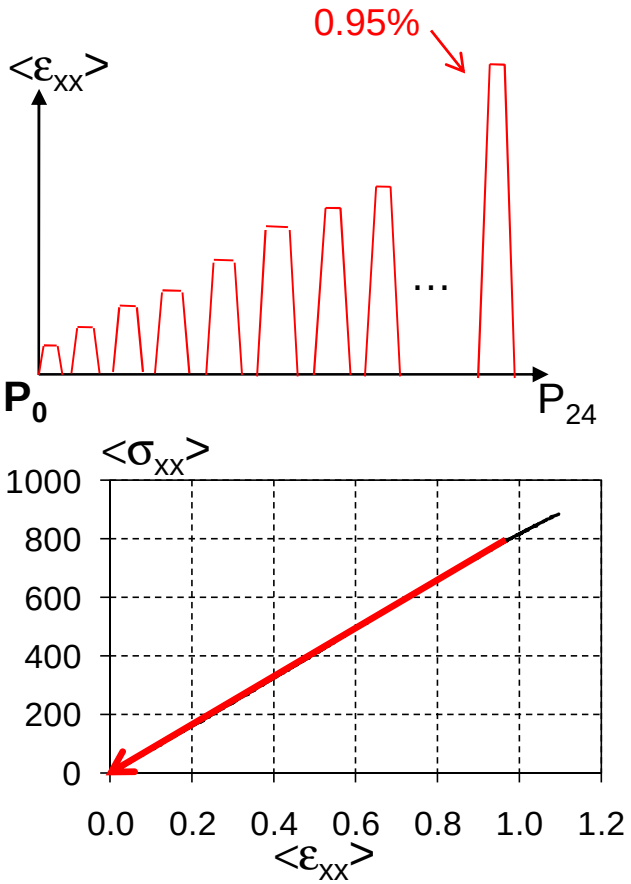


+15° -15°

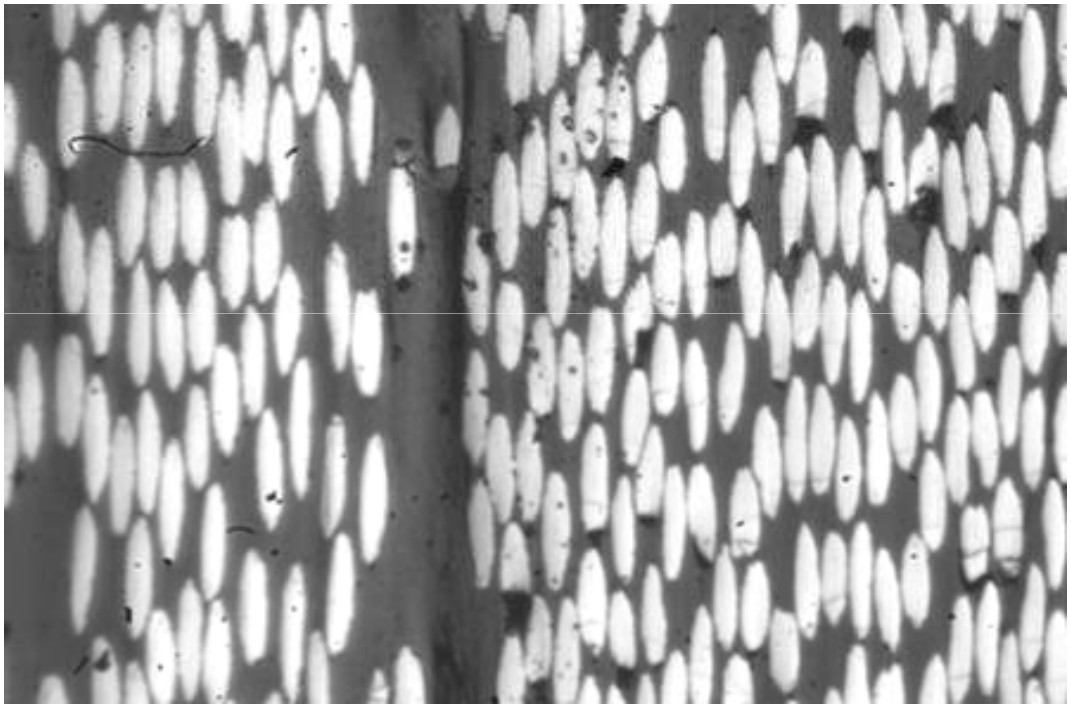
Interlaminar interface

Free edge effect and damage micro-mechanisms

Observations at microscopic scale during tensile tests



Unloaded after $\langle\varepsilon_{xx}\rangle = 0.95\%$

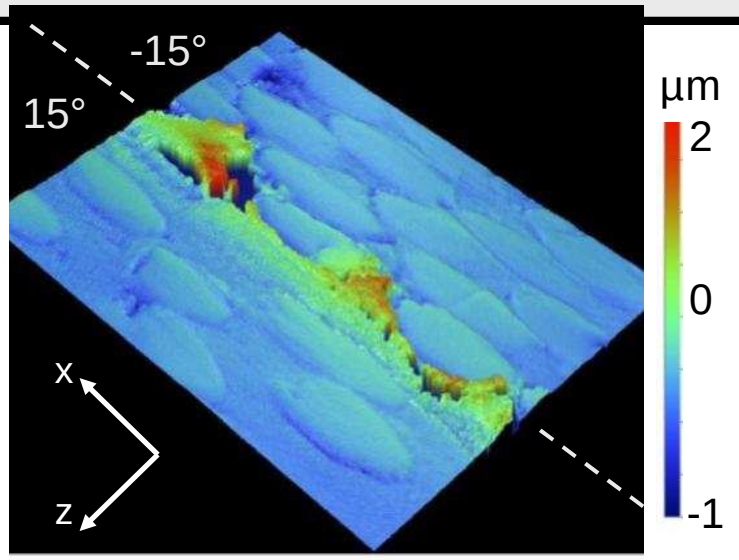


+15° -15°

Interlaminar interface

Free edge effect and damage micro-mechanisms

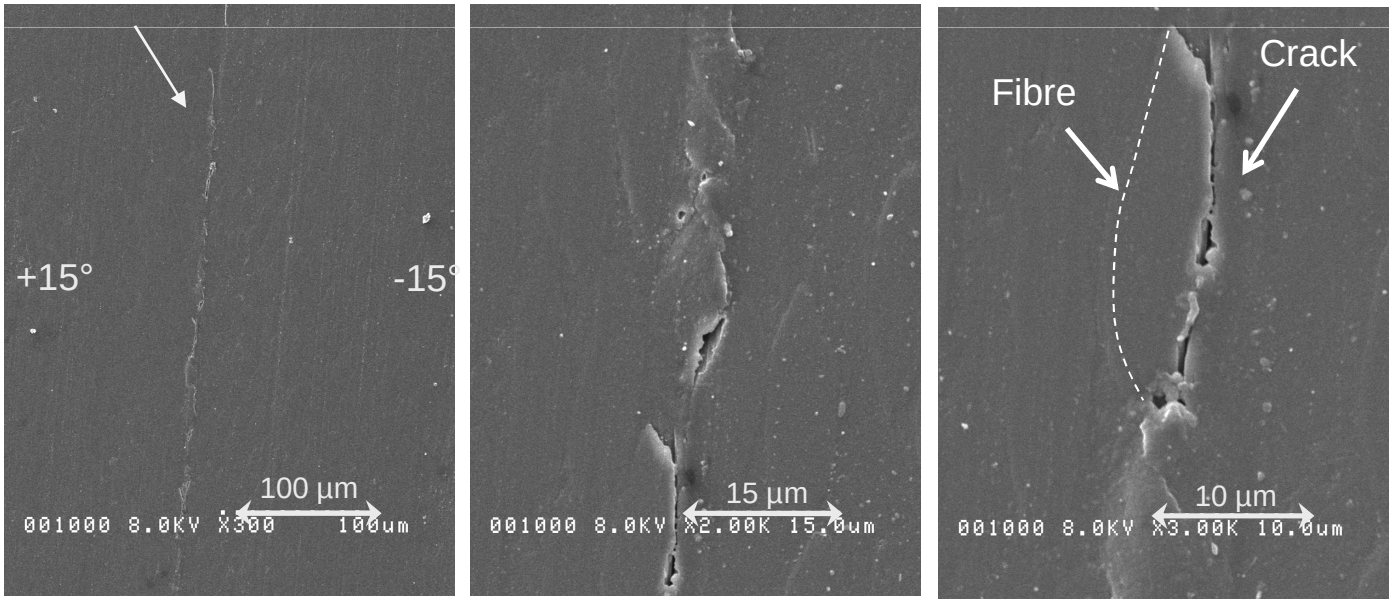
Observations at microscopic after $<\varepsilon_{xx}> = 0.95\%$



Interferometric profilometry observations

SEM observations

Interlaminar interface



Cracks located at fibre/matrix interfaces

Summary

Experimental Procedure

- Studied materials
- DIC Technique
- Experimental set up

Free edge effects and damage micro-mechanisms

- Macroscopic behaviour
- DIC measurements at mesoscopic scale
- Microscopic observations

Influence of structural and microstructural heterogeneities

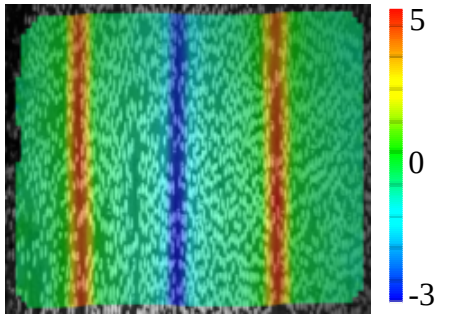
- Microstructure heterogeneities (quasi-UD laminates)
- Geometrical singularity (laminates with ply drops)

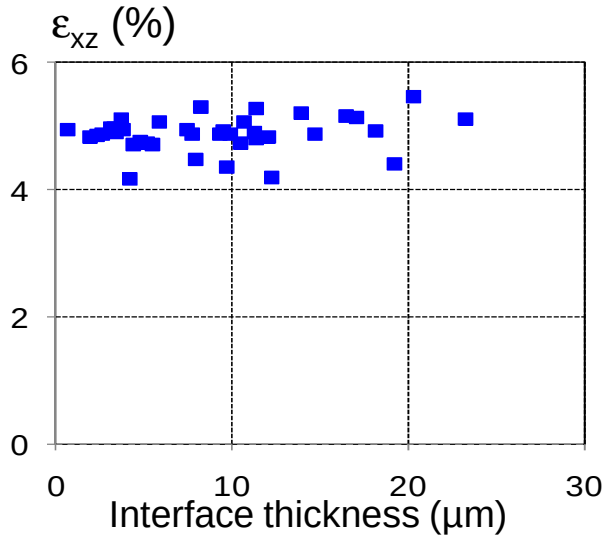
Conclusions

Influence of structure and microstructure

Influence of microstructure heterogeneities

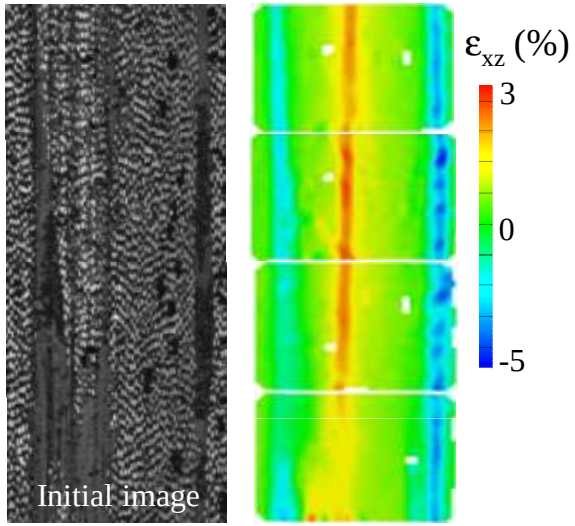
UD-HS

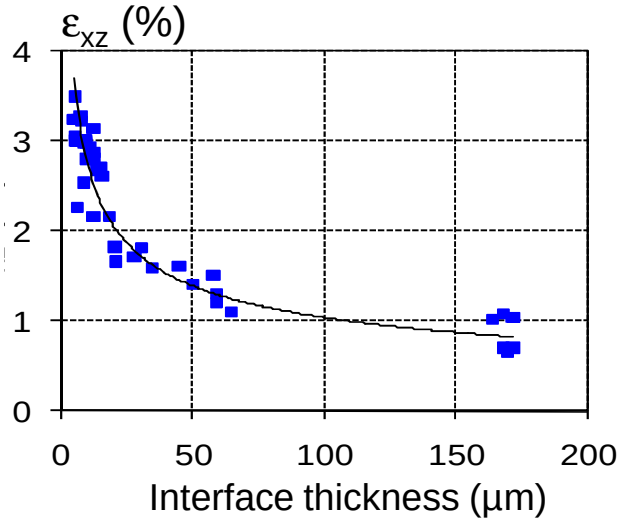




$\langle \varepsilon_{xx} \rangle = 0.4\%$

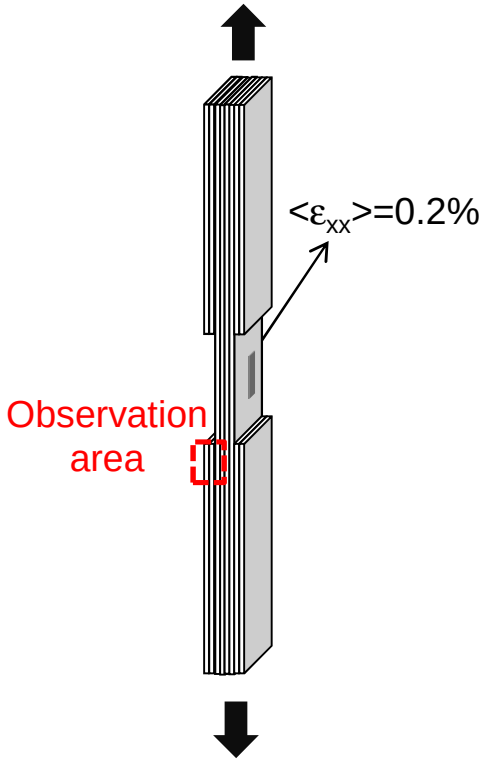
Quasi-UD-HS





Influence of structure and microstructure

Influence of a geometrical singularity (ply drops)



Material

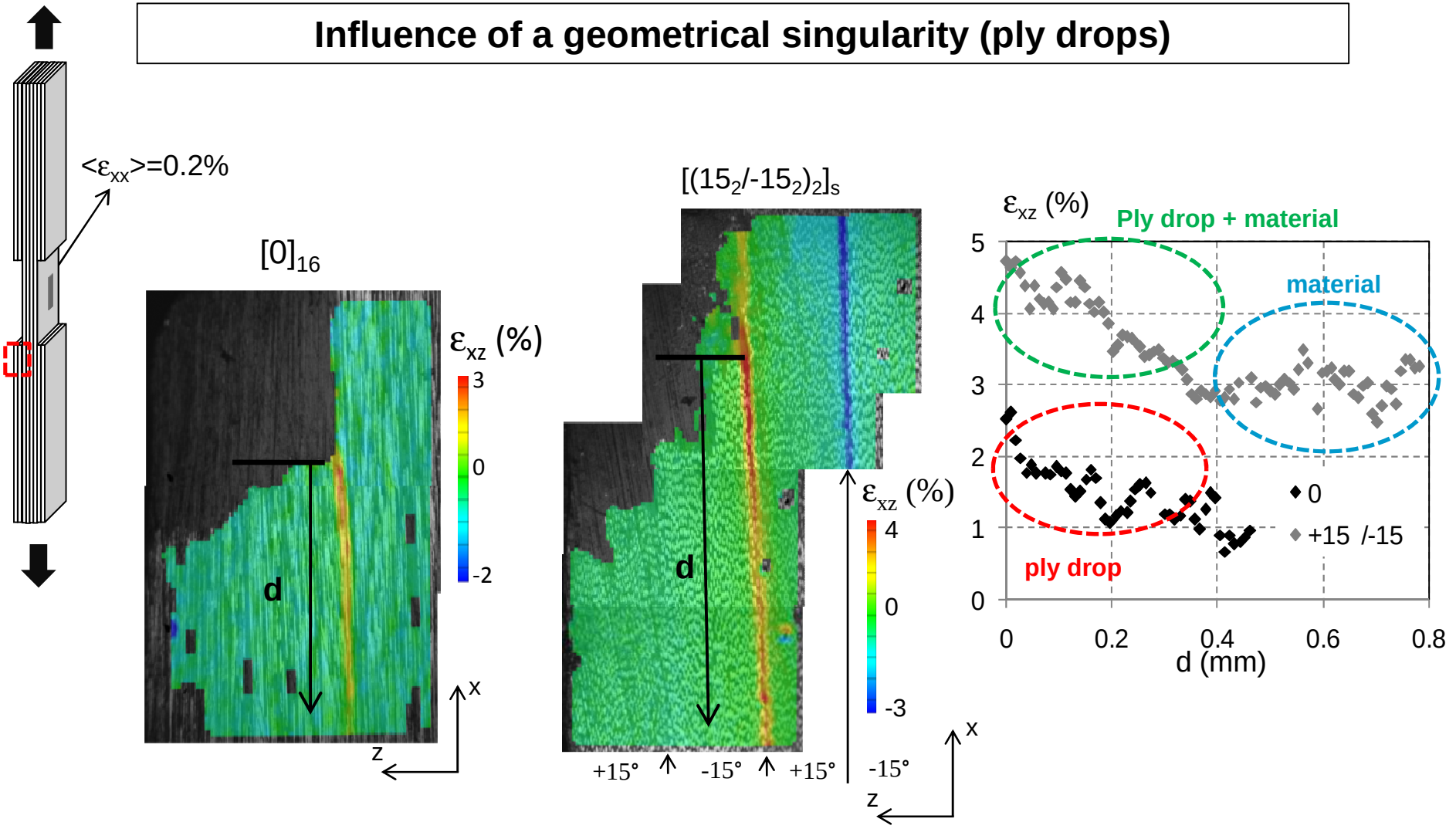
Material	UD-HM
Stacking sequences	$[(15_2/-15_2)_2]_s$ and $[0]_{16}$
Mean ply thikness (mm)	0.100

Optical parameters

Caméra Resolution (px)	2048 x 2736
Pixel size(µm)	0.21
(L,D) (px)	(60,40)

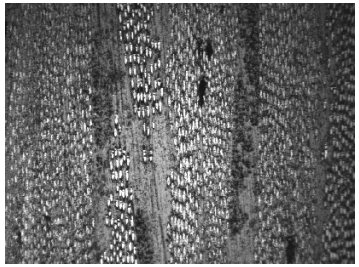
Influence of structure and microstructure

Influence of a geometrical singularity (ply drops)



Conclusions

Experimental free edge study

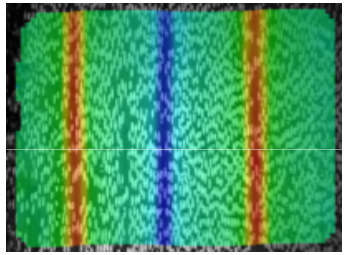


Experimental procedure

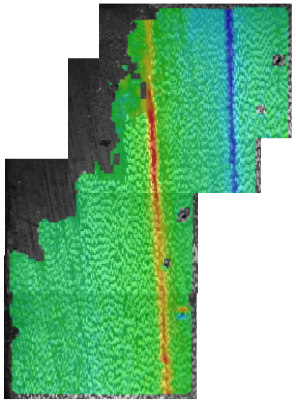
- DIC measurements at mesoscopic scale

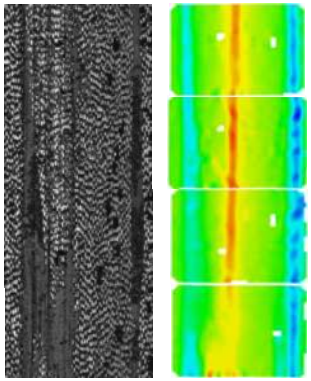
Free edge effect and damage micro-mechanisms

- Shear strain concentration
- Residual displacements gradients at mesoscopic scale
- Damage at microscopic scale



Structural and microstructural influence on edge effects





On the investigation of free edge effects in composites using full field measurements

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