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Composite Materials Group



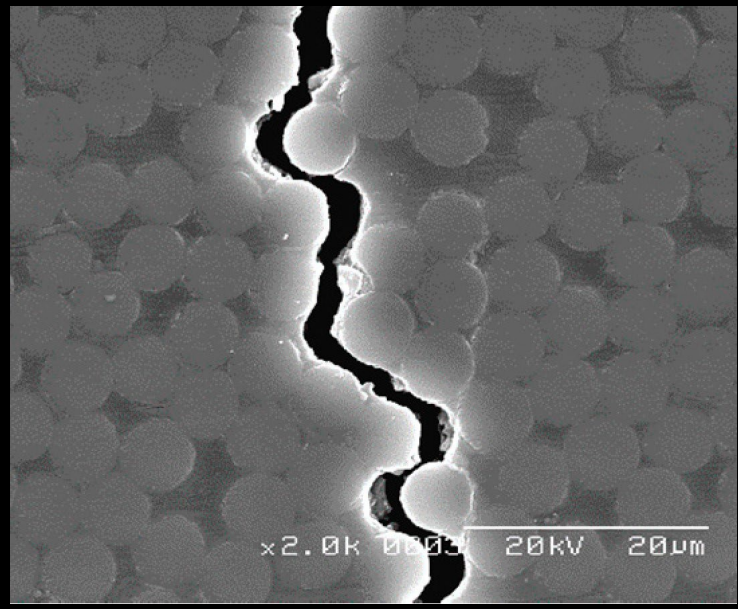

# High-speed monitoring of transverse cracking in fiber-reinforced composites

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# The problem!

- Details of initiation and propagation of transverse cracks are important
- However, not studied, or better to say, could not be studied, in real-time
- Why?




*Atsushi and Kawada, 2018*

# Issue I: speed of (brittle) crack

- Speed of crack propagation ~ speed of sound in the matter
- In epoxy ~ 2000 m/s (≈ 7000 km/h ≈ Mach 5.5)


F/A-18C Hornet in transonic flight
Mach 1.8

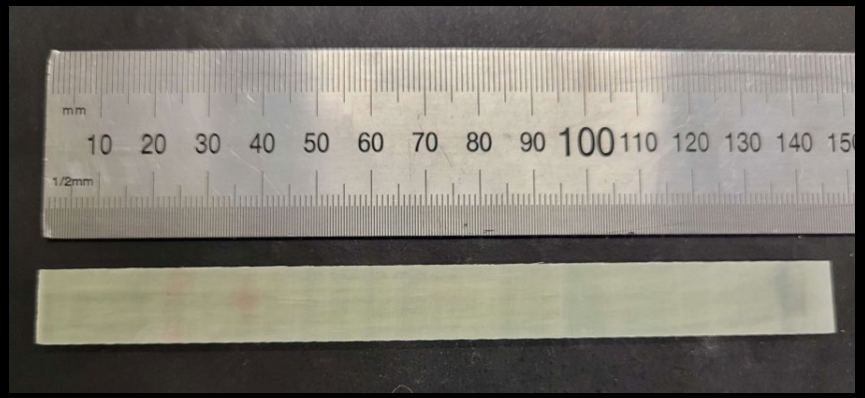
- Crack needs ~ 0.0001 ms to travel the thickness of a 200 µm thick ply
- Imaging rate of ~ 10 MHz is needed → 10,000,000 (!) frames per second
- Even then, we still need to exceed this number to have at least one image during crack growth
- But that's not the only problem ☺

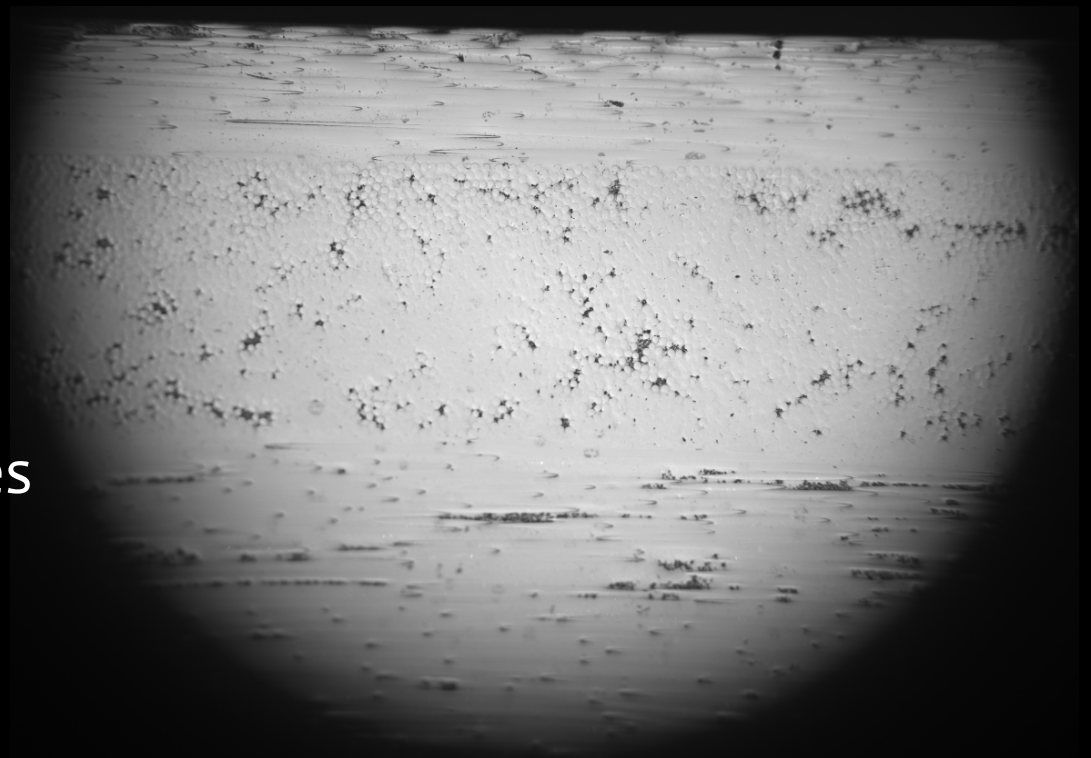
# Issue II: microscale imaging

- Interesting phenomena occur at the microscale
- So the high-speed imaging must be conducted at very high magnifications
- To resolve individual fibers, a minimum resolution of 2-6 µm/pixel is needed
- So 10 MHz imaging with 2-6 µm resolution
- One may say “Good luck with that”, but we gave it a try ☺

# Material

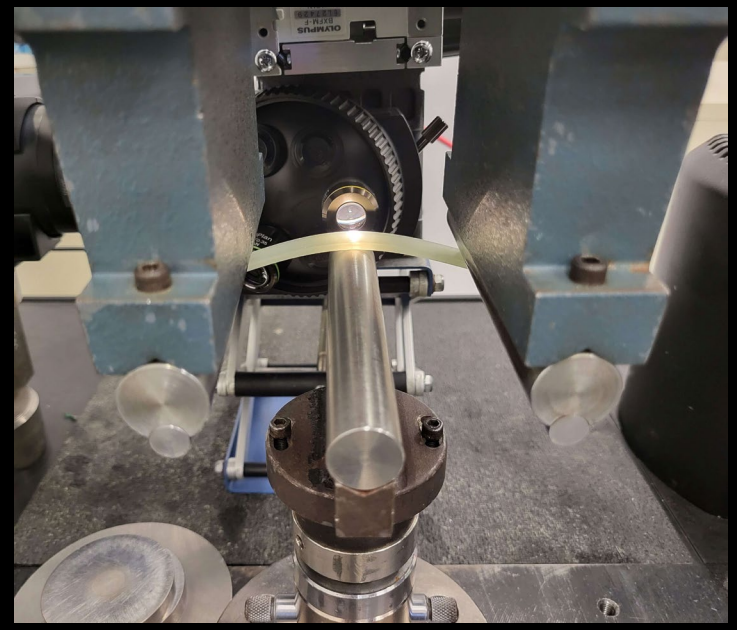
- Glass fibers and epoxy matrix
- Drum winding and autoclaving
- $[0/90/0/0/0]_s$ and $[0/90/90/0/0]_s$
- Ply thickness within [0.28, 0.35] mm
- 3-point bending specimens with polished edges



# Test set-up

- 3-point bending (inverted rollers)
- Loading rate: 1 mm/min
- High-speed camera: Photron FASTCAM MINI AX
- Mounted on an OLYMPUS microscope
- Looking at the edge of the specimen during loading



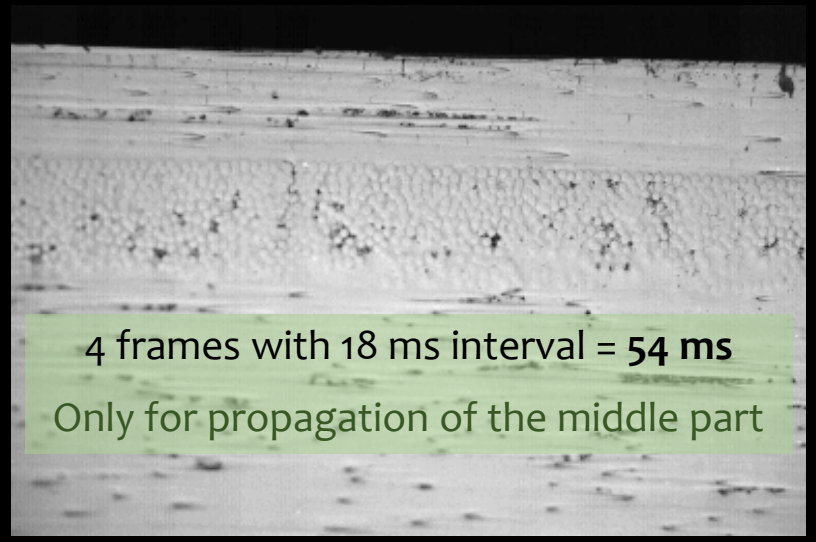


# Imaging settings

- Rate 25 kHz ≈ 0.04 ms (400 times less than the required rate!)
- Storage 1.16 s (29k frames)
- Magnification 20×
- Resolution 384 × 256 pixels ( ~ 5 µm/pixel)
- Window size 1.8 × 1.2 $mm^2$

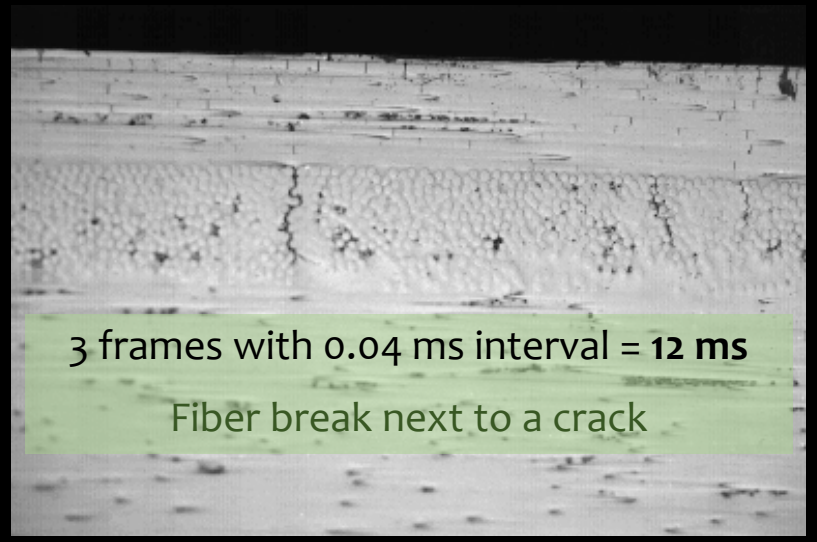
# Results

# Single 90° ply – Specimen 1



4 frames with 18 ms interval = **54 ms**

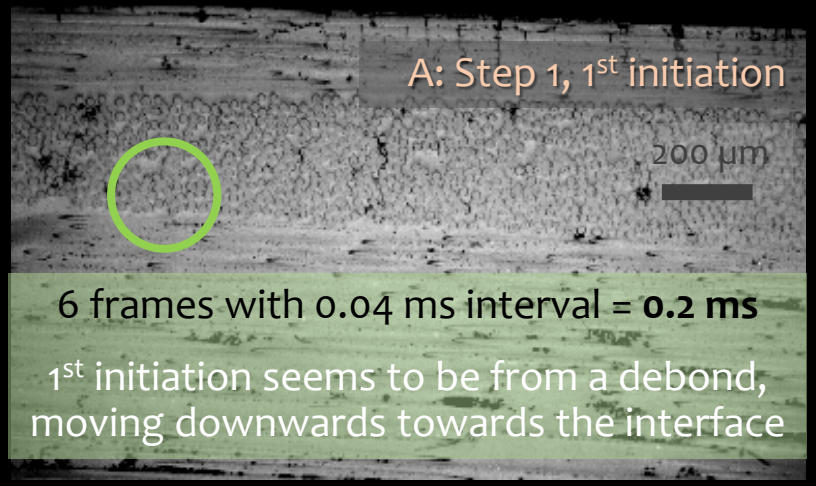
Only for propagation of the middle part

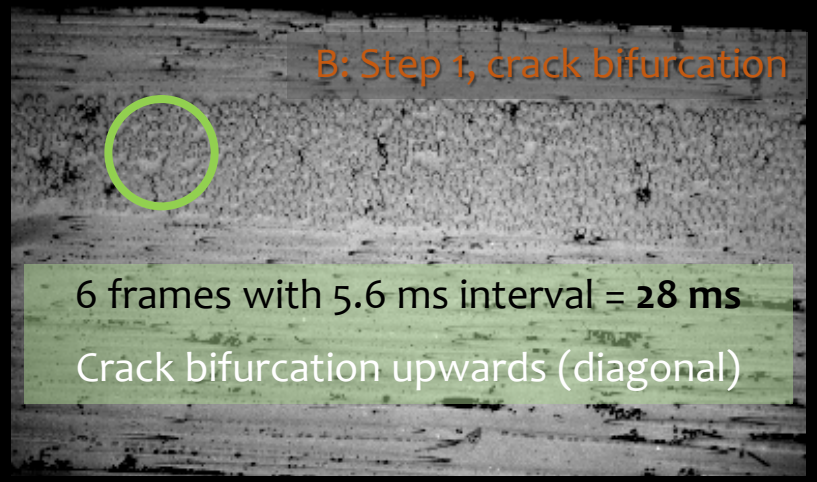


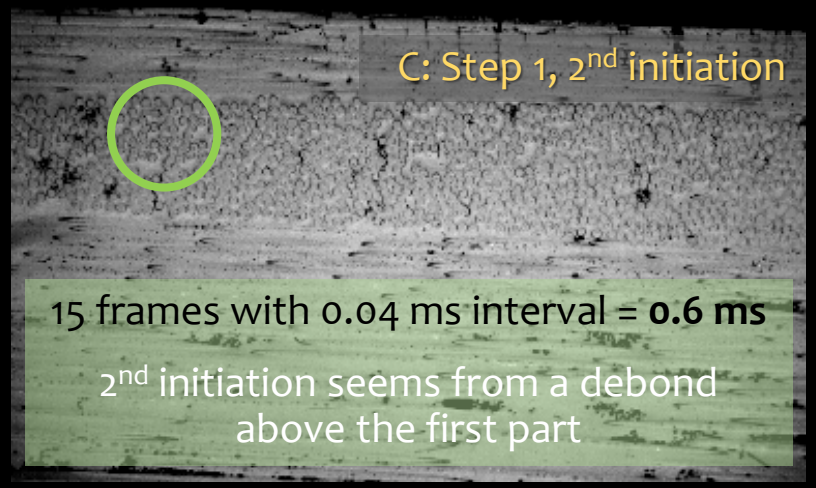
3 frames with 0.04 ms interval = **12 ms**

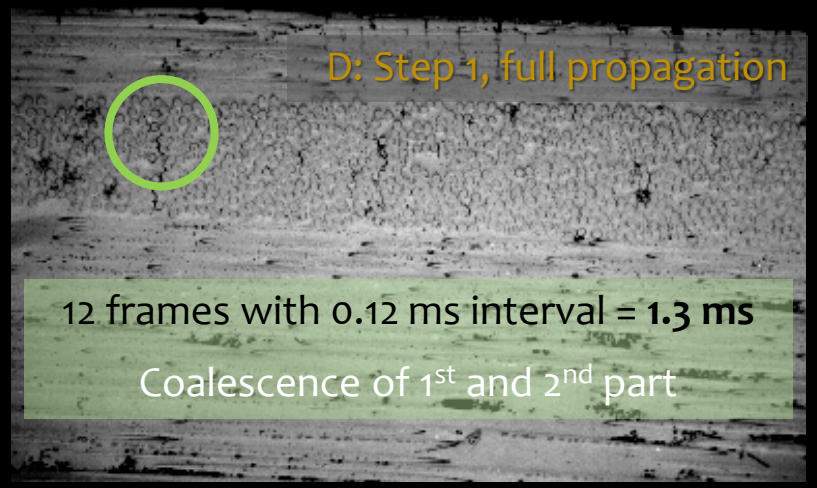
Fiber break next to a crack

# Single 90° ply – Specimen 2



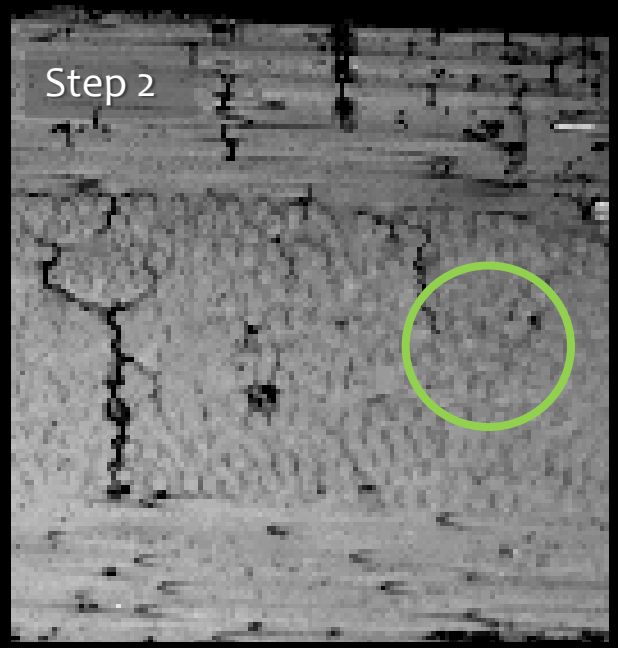





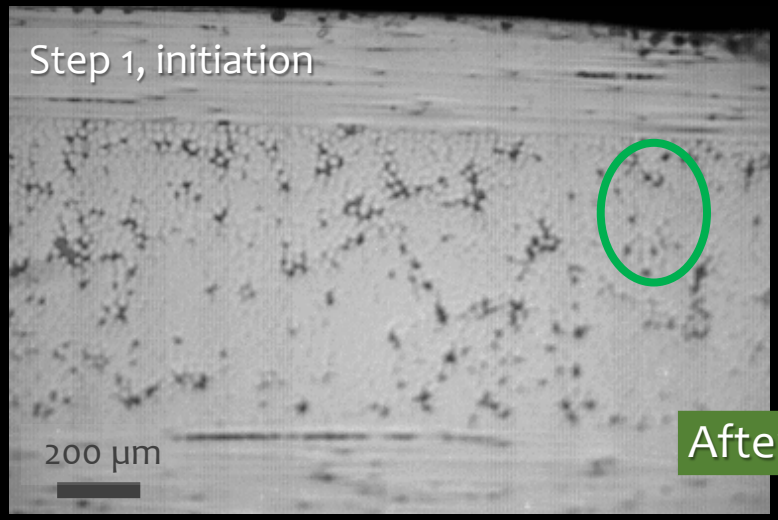

# Single 90° ply – Specimen 2



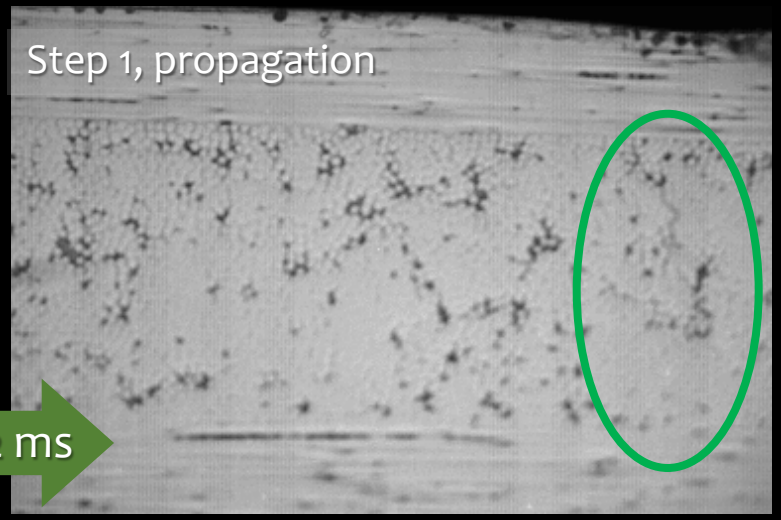

8 frames with 4 ms interval = 28 ms

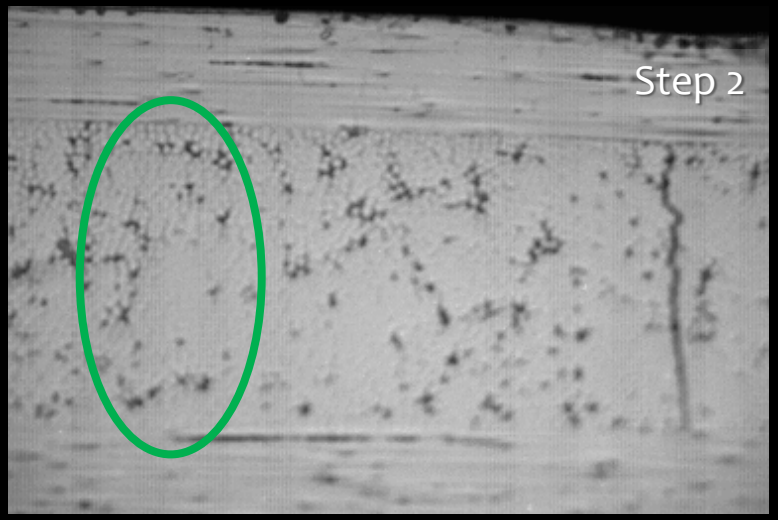
Initiation next to a half-crack

# Double 90° – Specimen 1




After 2 ms




5 frames with 0.04 ms interval = **0.16 ms**

Initiation far from ply interfaces

7 frames with 0.04 ms interval = **0.24 ms**

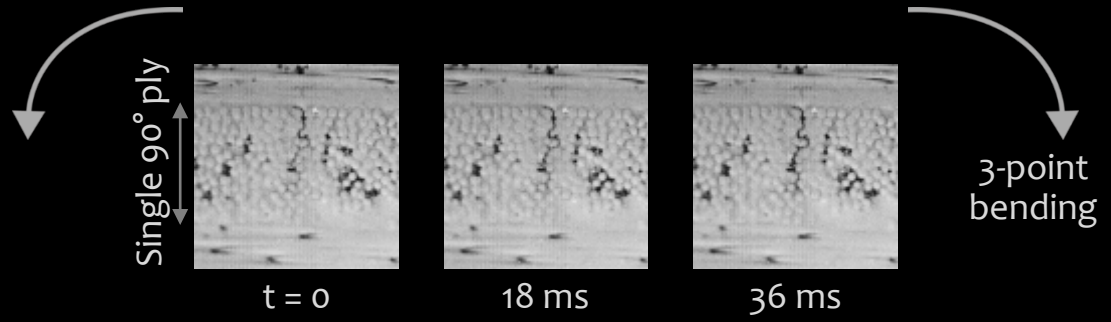
Sudden propagation through the thickness

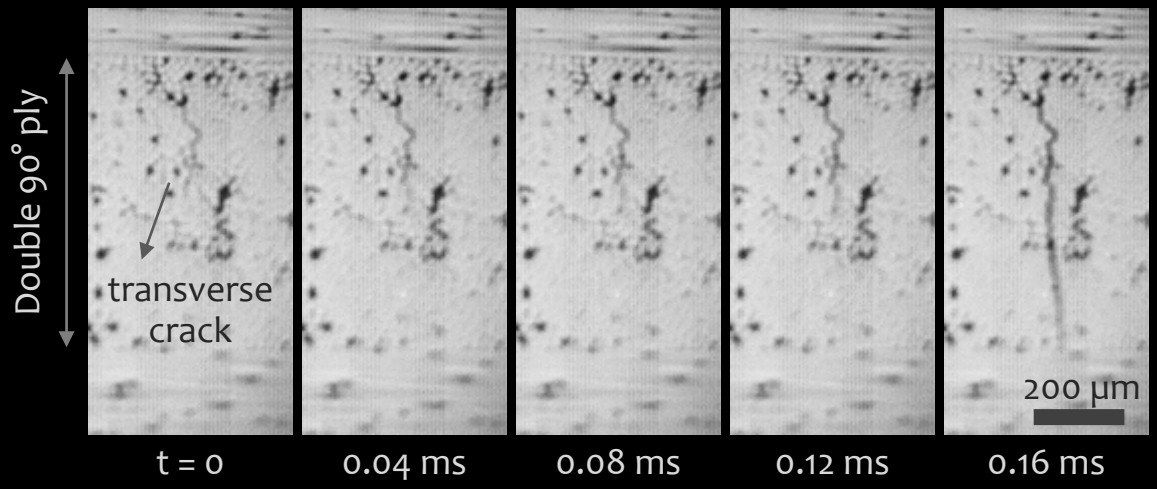
3 frames with 0.04 ms interval = **0.08 ms**

Very suddenly!

# Single vs. double 90°

- The comparison is pre-mature
- More cases need to be studied



# Void analysis ongoing …



*Note delaminations from crack tips at upper interface*

# To-be-answered Questions

- Position of transverse cracks relative to each other influences their speed?
- Their propagation rate depends on the initiation side (back or front)?
- Crack initiation yields a competition between defects and high-strain ply interfaces (in the case of bending)?
- Initiation side of cracks has more torturous path than their propagation?
- Interaction of transverse crack with other damage mechanisms (fiber breaks, delaminations, … )?

# Thanks for your attention!



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