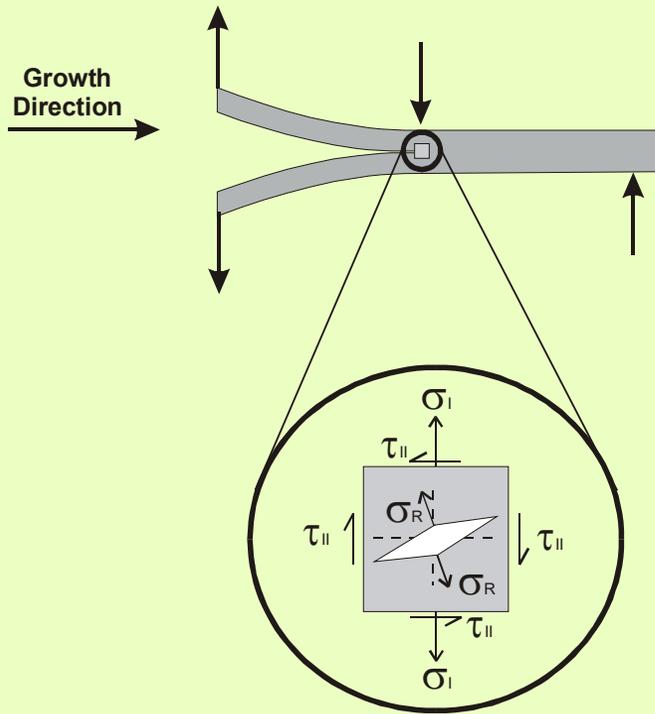
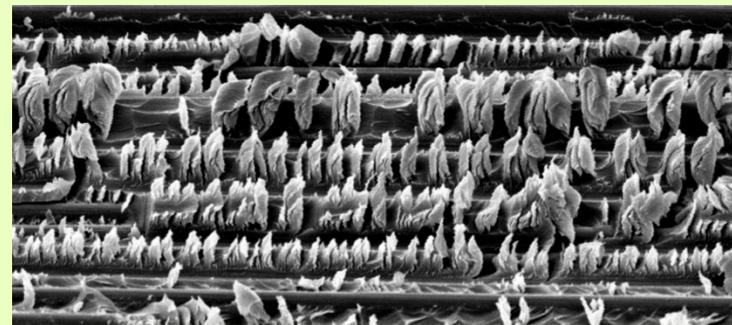
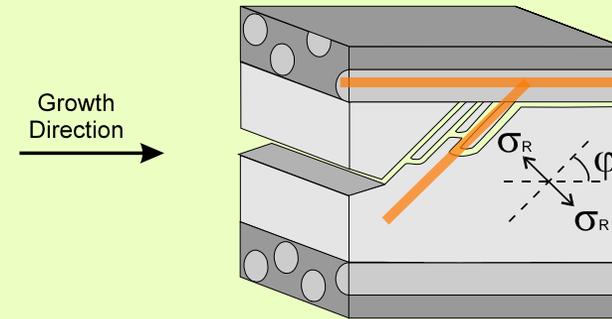


Fractographic insights into mixed-mode I/II/III and the associated delamination migration

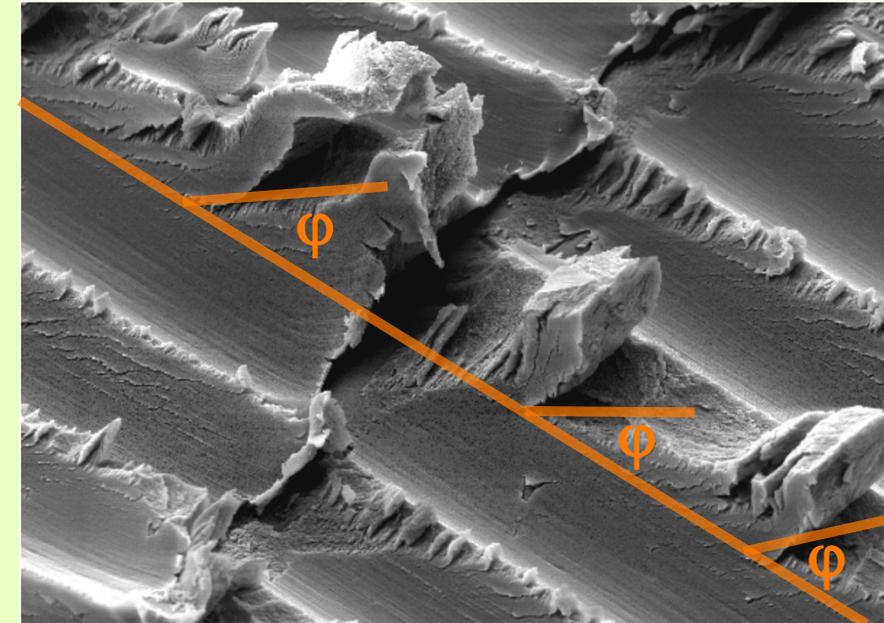
Prof Emile S. Greenhalgh (e.greenhalgh@imperial.ac.uk), Dr Carla Canturri, Prof Silvestre T. Pinho



Stress state at delamination tip[†]



Inclined cracks lead to shear cusps – characteristic of mode II & mode I/II delamination



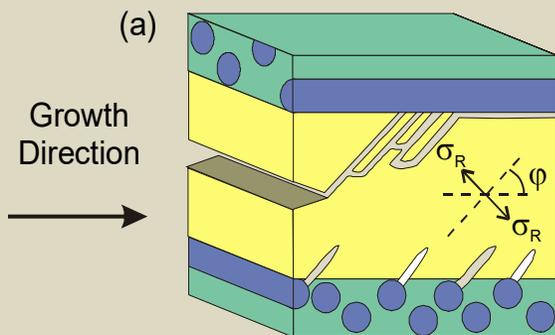
Shear cusp imprint angle (ϕ) is the plane orthogonal to σ_R – i.e. the mode (I/II) mixity.

[†]Greenhalgh, *Failure analysis and fractography of polymer composites*, Elsevier, 2009.

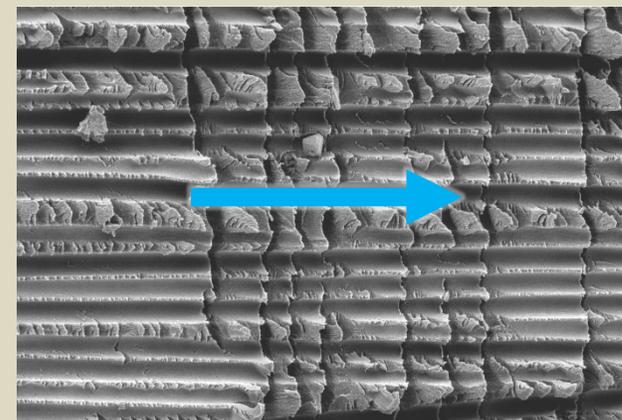
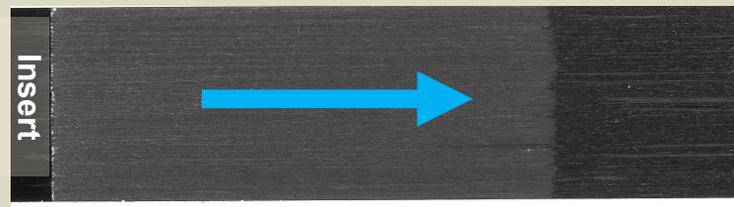
Fractographic insights into mixed-mode I/II/III and the associated delamination migration

Directionality and Migration

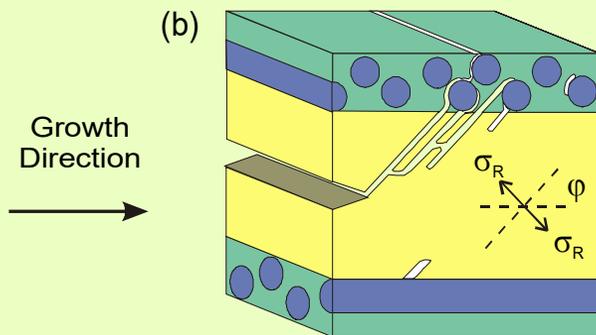
Fundamental rule – delaminations preferably grow in the fibre direction†.



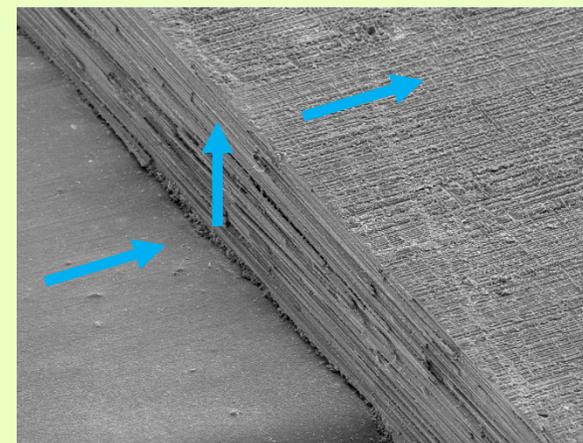
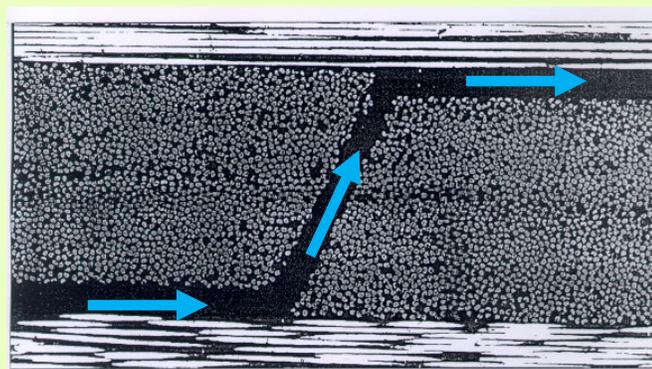
Zero uppermost - $0^\circ/\theta^\circ$ ply interface (no migration)



If drive delamination to grow at an angle to the fibre direction – migrate to new ply interface‡



Zero lowermost - $\theta^\circ/0^\circ$ ply interface (migration)

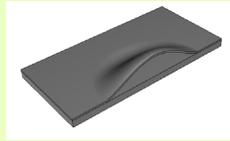
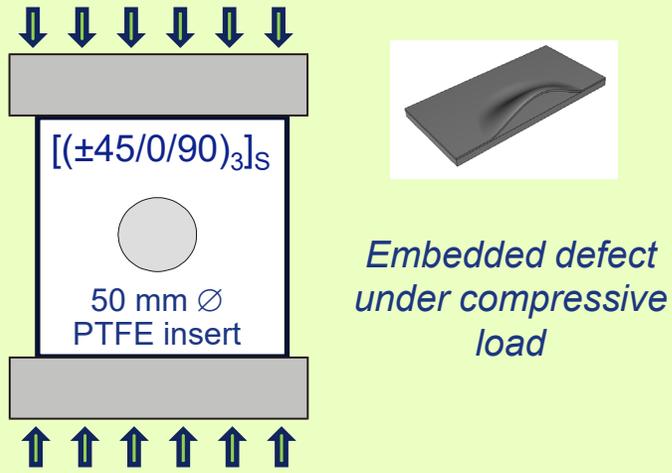


†Singh & Greenhalgh, *Plastics, Rubber and Composites*, 1998;27:220–6.

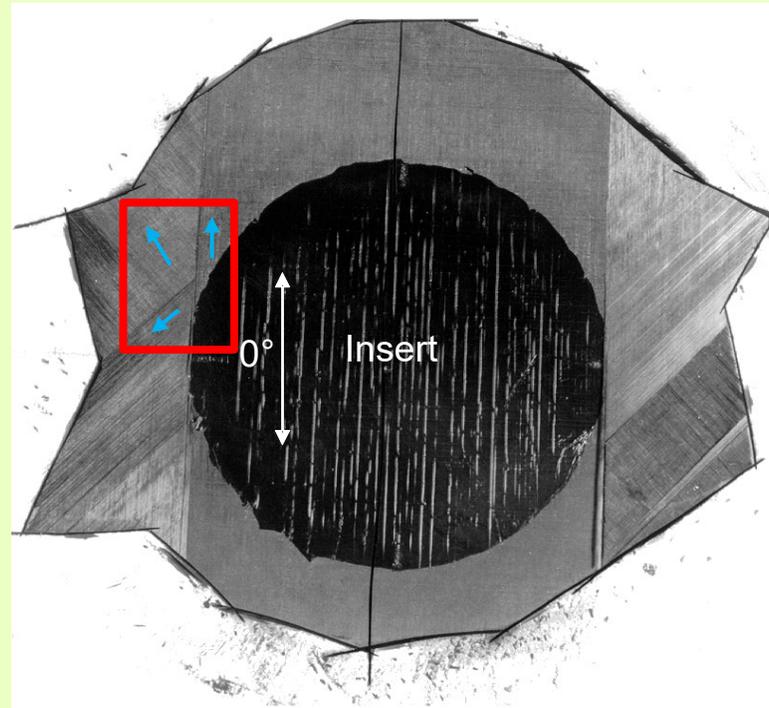
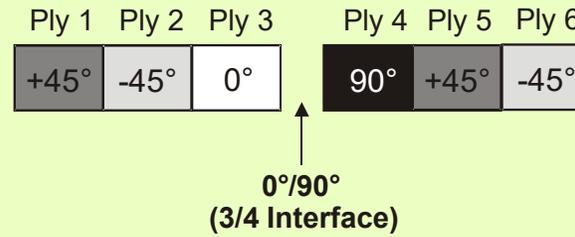
‡Greenhalgh, Rogers & Robinson, *CSTE*, 2009: 69(14): 2345-2351.

Fractographic insights into mixed-mode I/II/III and the associated delamination migration

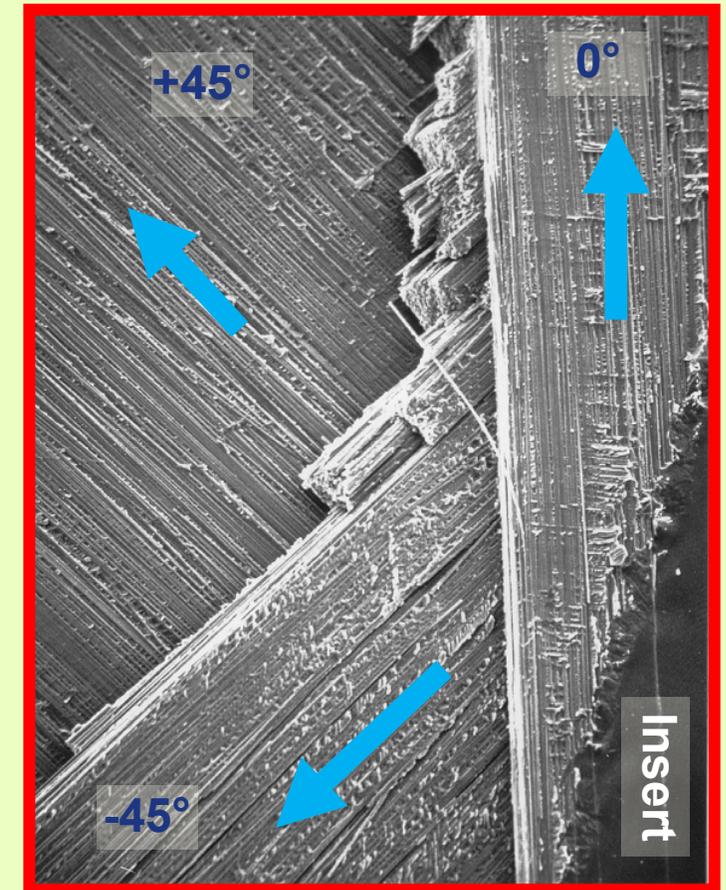
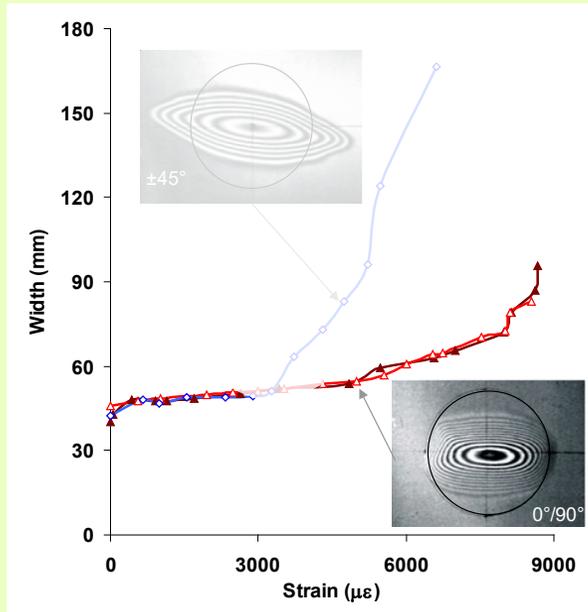
Implications of Migration – Embedded Delamination†



Embedded defect under compressive load



Exposed delamination growth from 50 mm \varnothing defect



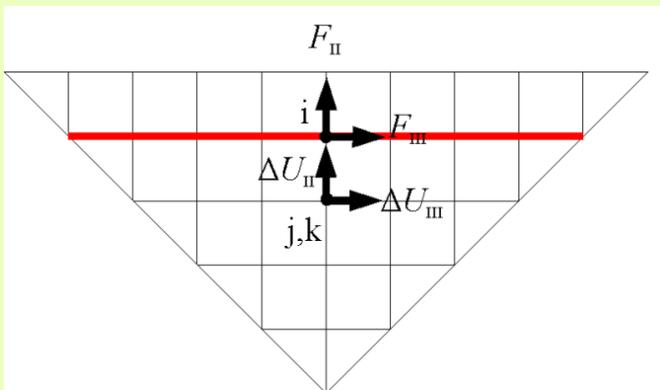
Detail of boxed area (x500)

†Greenhalgh, Rogers & Robinson, *CSTE*, 2009: **69(14)**: 2345-2351.

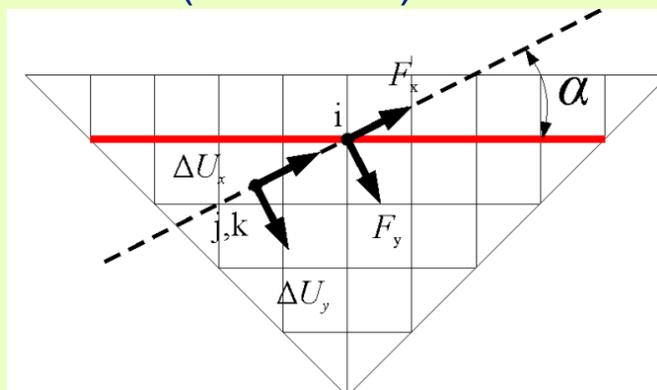
Fractographic insights into mixed-mode I/II/III and the associated delamination migration

Define (local) mode II and mode III with respect to fibre direction.

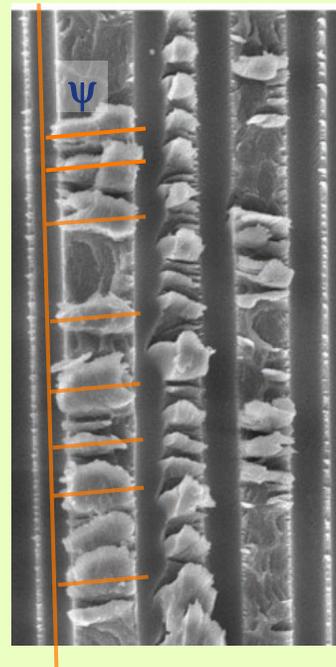
Global conditions



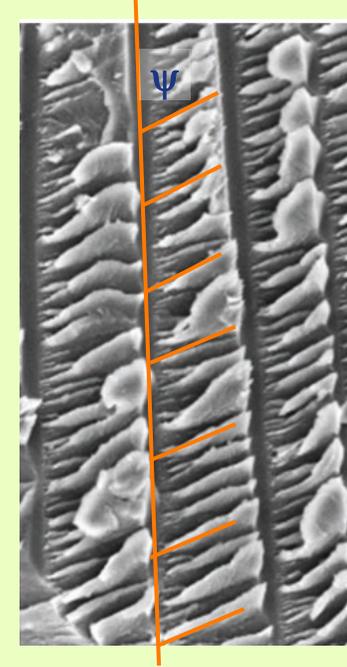
Local (w.r.t. fibre) conditions



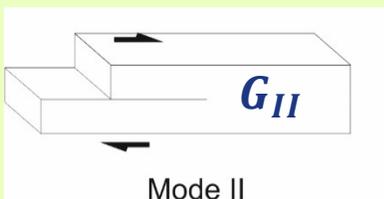
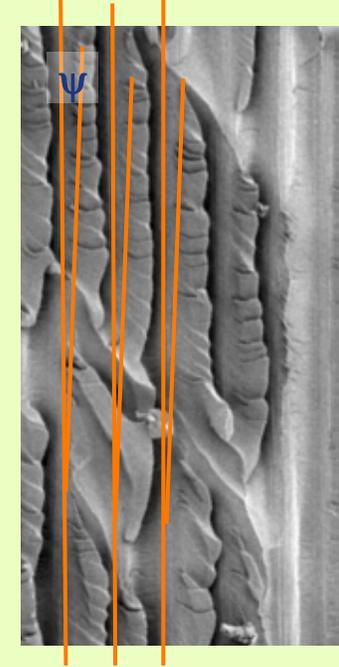
$G_{III} \ll G_{II}$



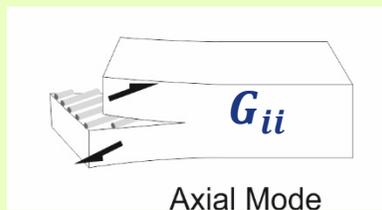
$G_{III} \sim G_{II}$



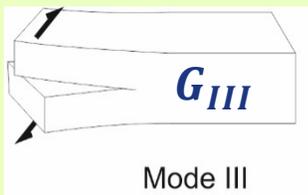
$G_{III} \gg G_{II}$



Mode II



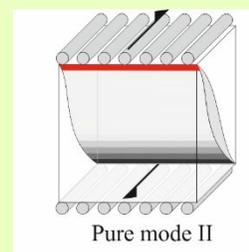
Axial Mode



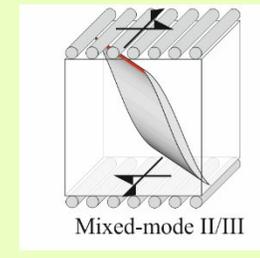
Mode III



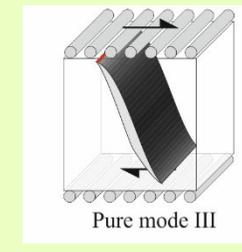
Transverse Mode



$\Psi \sim 90^\circ$



$\Psi \sim 70^\circ - 20^\circ$



$\Psi \sim 0^\circ$

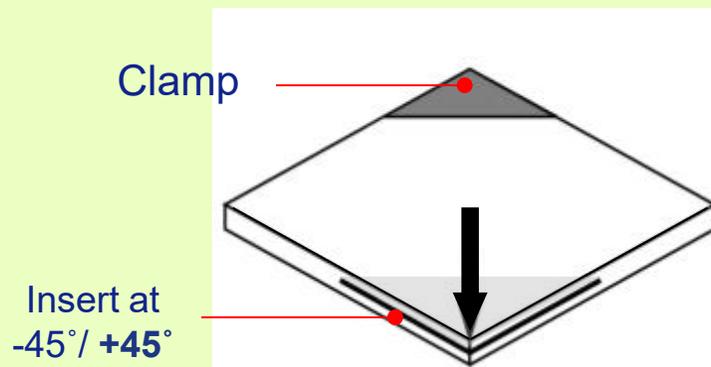
Translate global mode II & III into local axial (mode ii) and transverse (mode iii) shears w.r.t fibre direction (α)[‡]

Cusp rotation w.r.t fibres (ψ) gives measure of G_{III}/G_{II}

Fractographic insights into mixed-mode I/II/III and the associated delamination migration

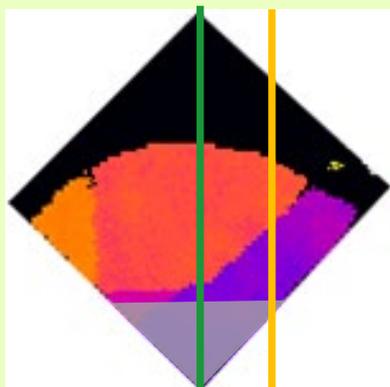
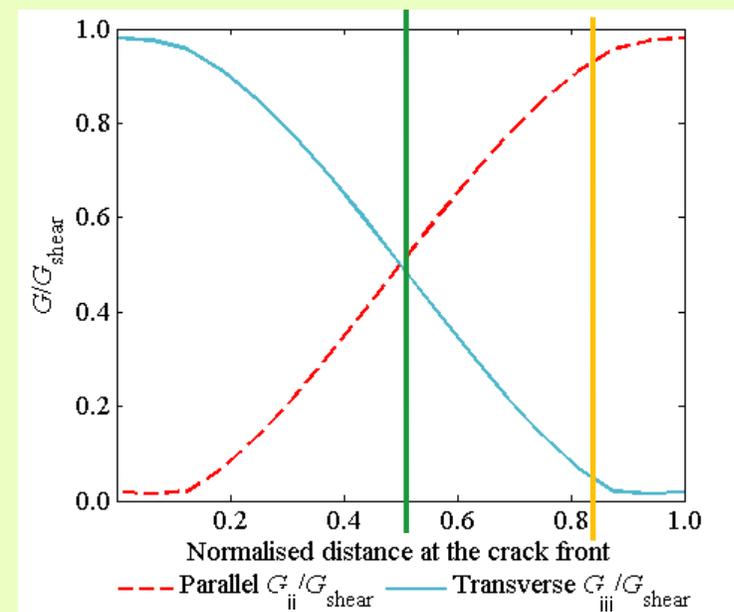
What growth direction angle, with respect to the fibres, promotes migration?

WTELS[†] - local mode-mixity (ii/iii) varies across insert width.



Migration site at insert edge defines local mode-mixity (G_{iii}/G_{ii}) condition for migration to manifest.

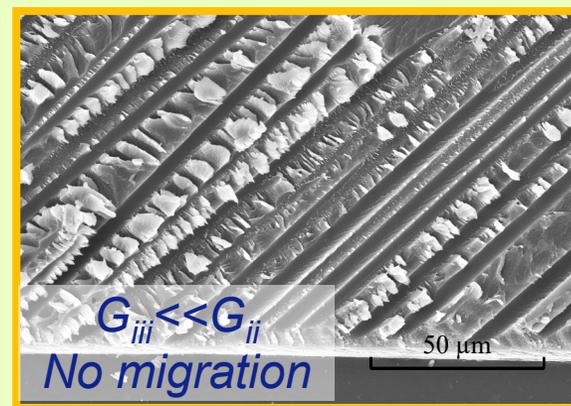
$$G_{shear} = G_{ii} + G_{iii}$$



Ultrasonic Scan



Exposed surface



Critical G_{iii}/G_{ii} for migration ~ 0.26