Bristol Composites Institute

Hygro-thermal Effects on the Translaminar Fracture Toughness of Composite Laminates

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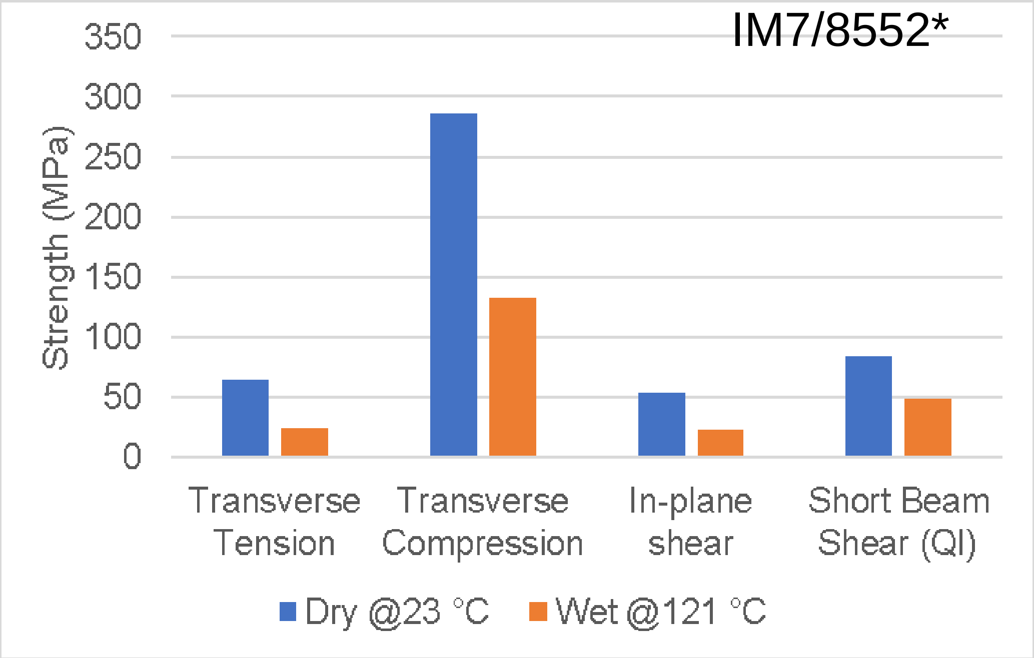
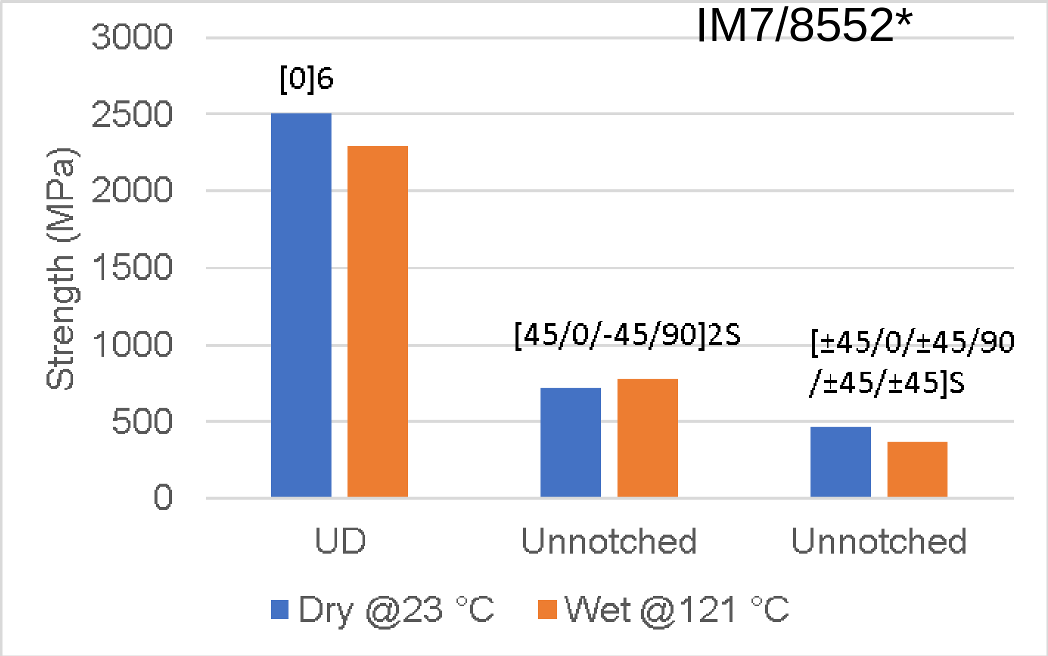
Motivation

- In-service temperature and moisture alter the mechanical behaviour of composites
- Matrix materials have more susceptibility to temperature & moisture than reinforcing fibres

Matrix dominated strengths



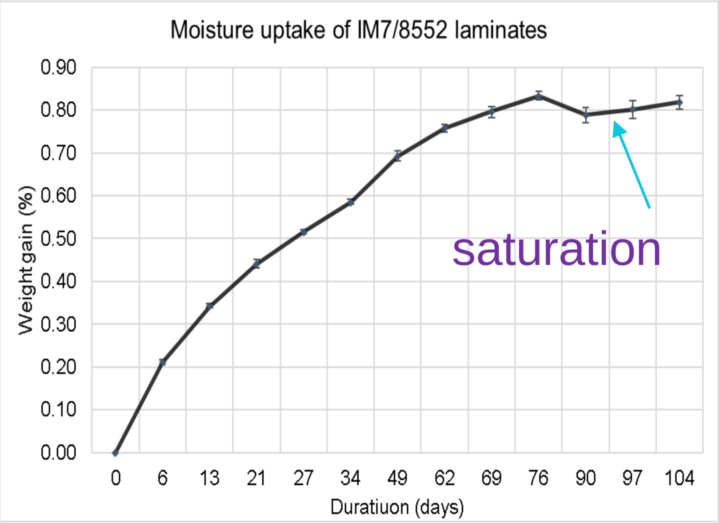
Longitudinal tensile strengths



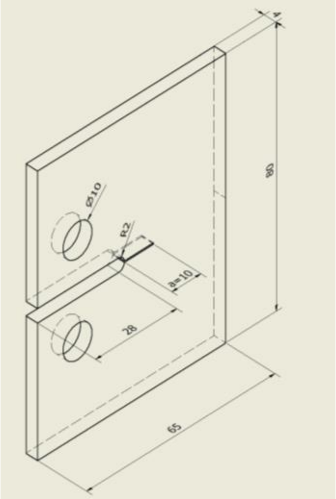
*Marlett K., Hexcel 8552 IM7 Unidirectional Prepreg 190 gsm & 35%RC Qualification Material Property Data Report, NCAMP, Wichita State University, 2011.

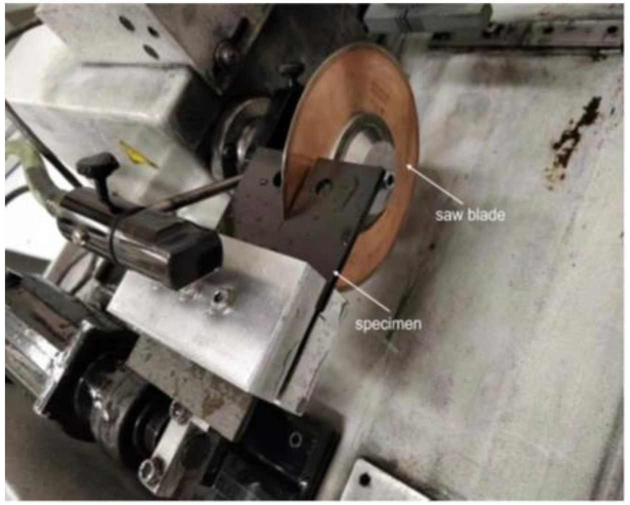
Longitudinal tensile failure of composite laminates

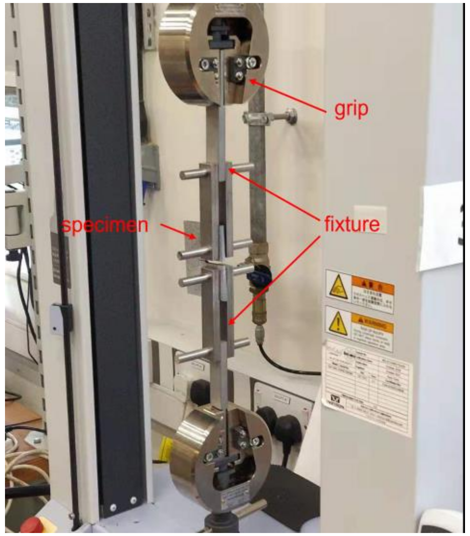
- Translaminar fracture toughness is associated with the longitudinal tensile failure of laminates
- Involves tensile failure of fibres
- Controls the damage initiation and propagation in the case of longitudinal loading of laminates
- Translaminar fracture toughness of dry and wet IM7/8552 laminates were investigated using compact tension tests
- Special tools were used for laminate cutting and drilling
- Shimadzu 10 kN machine

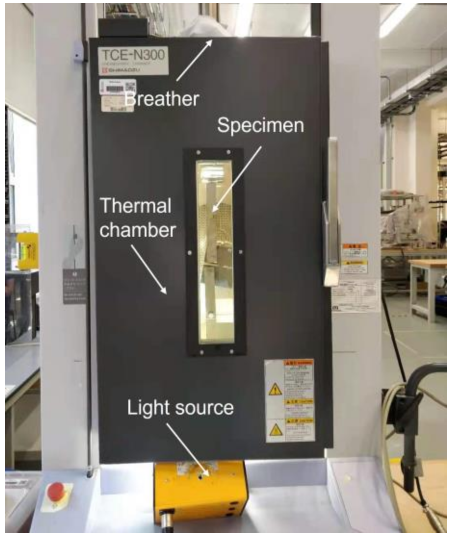


“wet” specimens conditioned at 70 °C and 85% relative humidity





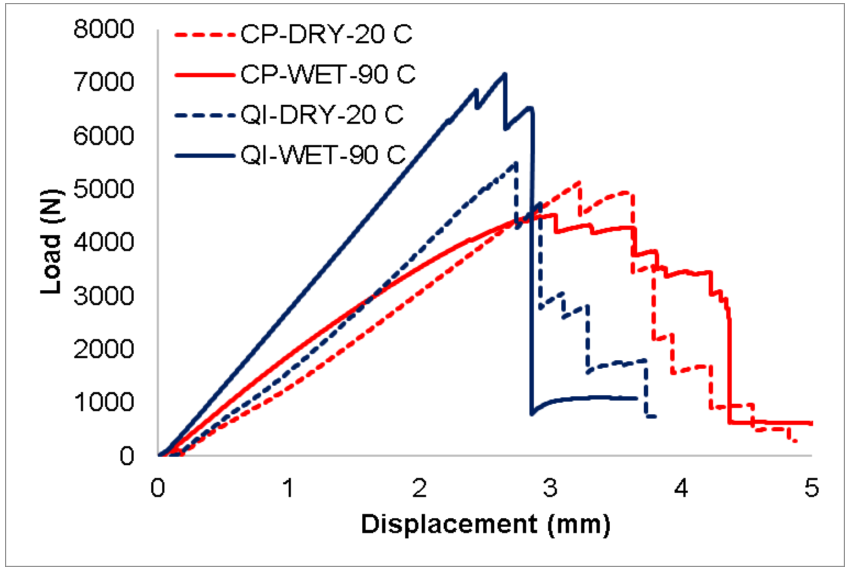




Longitudinal tensile failure of composite laminates

Lay-up	Dry specimens (as manufactured)			Wet specimens (fully saturated)		
	23° C	40° C	90° C	23° C	40° C	90° C
Cross-ply (CP) $[90/0]_{8s}$	3	3	3	3	3	3
Quasi-isotropic (QI) $[90/45/0/-45]_{4s}$	3	3	3	3	3	3

Load-displacement curves of selected tests



Data Reduction – Compliance calibration method

- Initiation fracture energy of 0° plies are calculated from the total energy of cross-ply laminates by using*

$$G_{0Cini}(a) = \frac{-P^2}{2t^0}\frac{\alpha(\beta+\alpha a)^{-\left(1+\frac{1}{\chi}\right)}}{\chi}$$

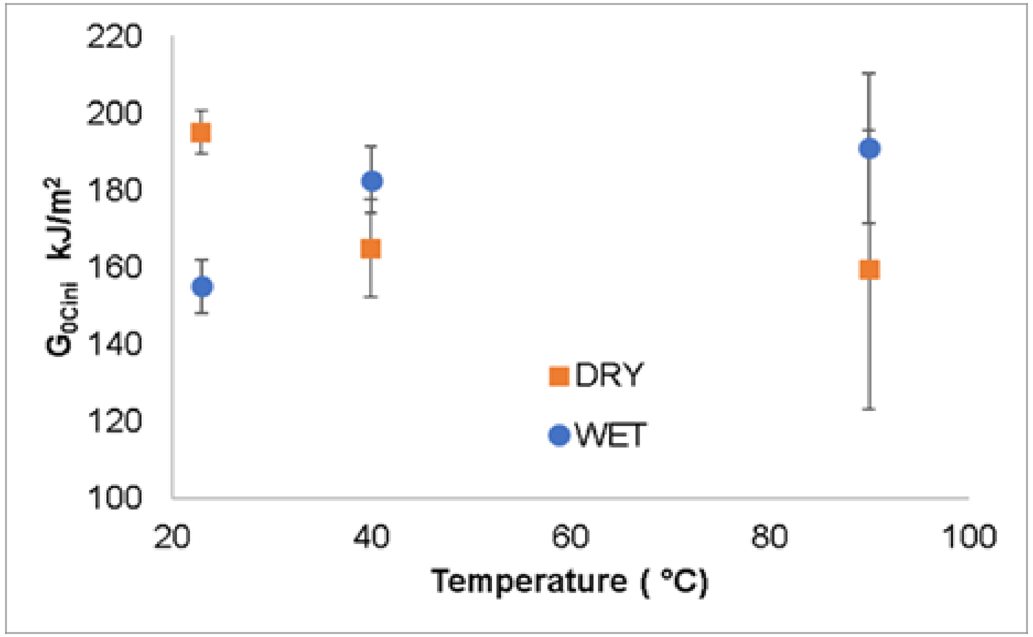
- Initiation fracture energy of QI laminates are calculated by using

$$G_{Cini}(a) = \frac{-P^2}{2t}\frac{\alpha(\beta+\alpha a)^{-(1+1/\chi)}}{\chi}$$

*Davila, C.G., A procedure for superposing linear cohesive laws to represent multiple damage mechanisms in the fracture of composite, Int J Fracture, 2009

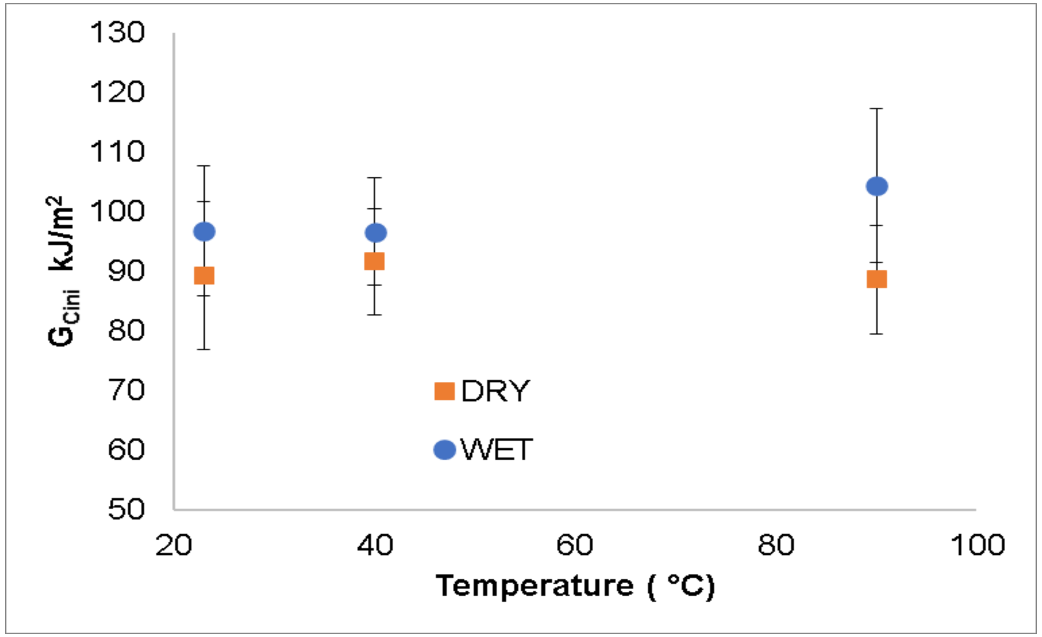
Translaminar fracture toughness of composite laminates

Initiation energy of 0° plies from CP laminates



- Initiation energy of dry specimens decreases with the temperature
- Initiation energy of wet specimens increases with the temperature
- Hot-wet specimens exhibits similar/higher fracture energy than room temperature dry specimens yet different failure mechanism

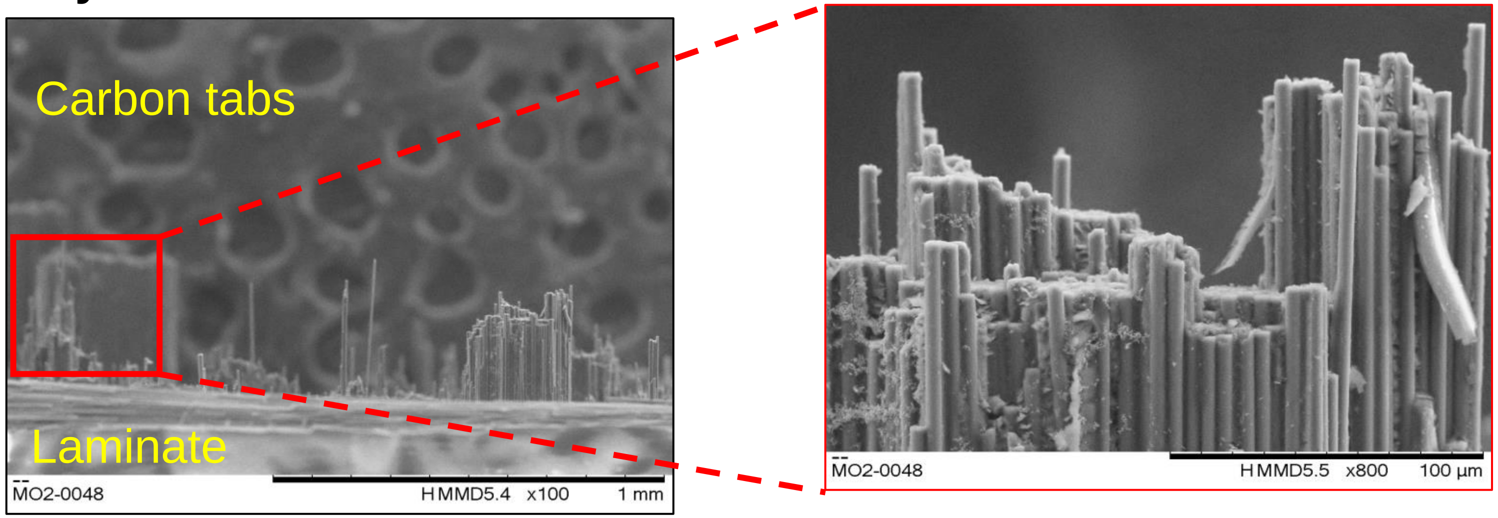
Fracture toughness of the QI laminates



- Initiation energy of wet laminates are higher than dry laminates irrespective of the temperature
- Wet QI specimens tested at 90 °C is 17% higher than dry specimens tested at 23 °C

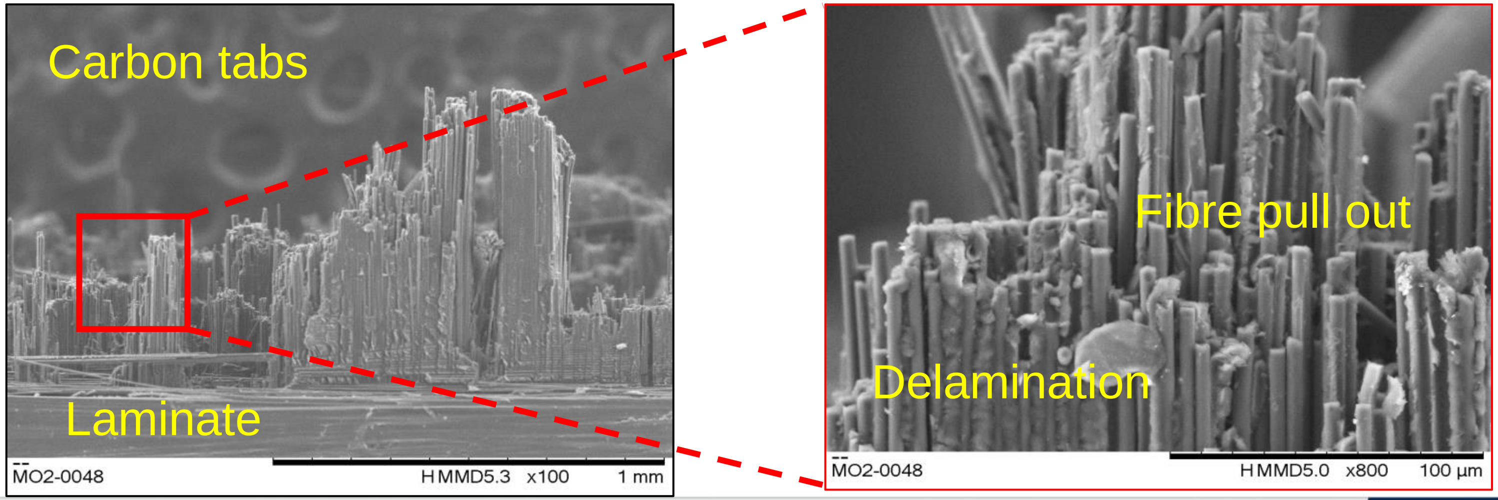
Fractographic analysis of cross-ply specimen tested at 23 °C

Dry



- Insignificant delamination of 0° plies from 90° plies
- Minimal debonding of fibre from matrix
- 0° fibre breakage along the crack path means clean fracture of fibre bundle

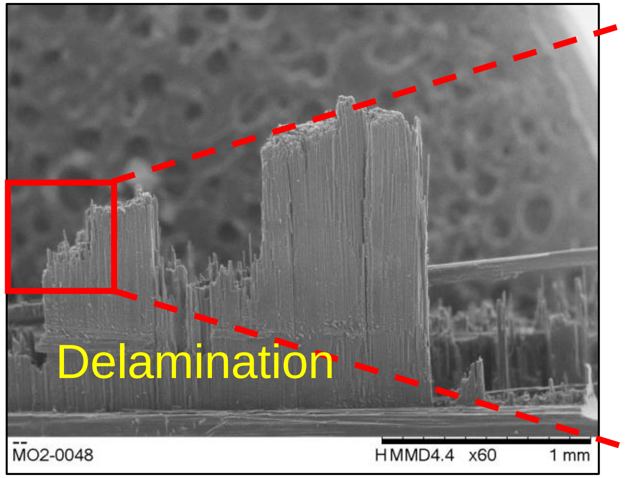
Wet (fully saturated)

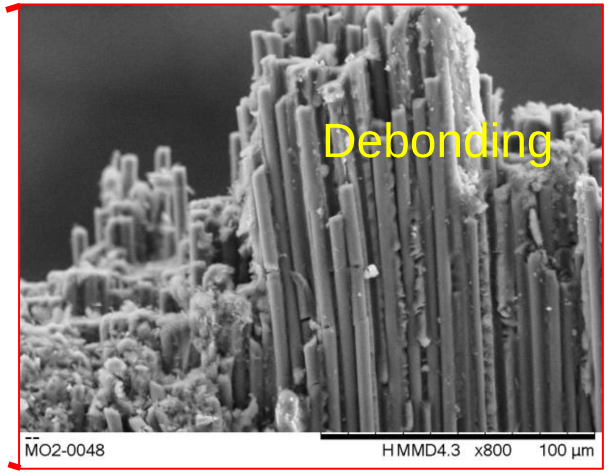


- Higher delamination than dry coupons due to matrix degradation
- Short fibre pull out noticed
- More debonding due to weak fibre matrix interface
- Friction between the fibre matrix interface decreases which leads to lower energy dissipation than dry specimens

Fractographic analysis of cross-ply specimen tested at 40 °C

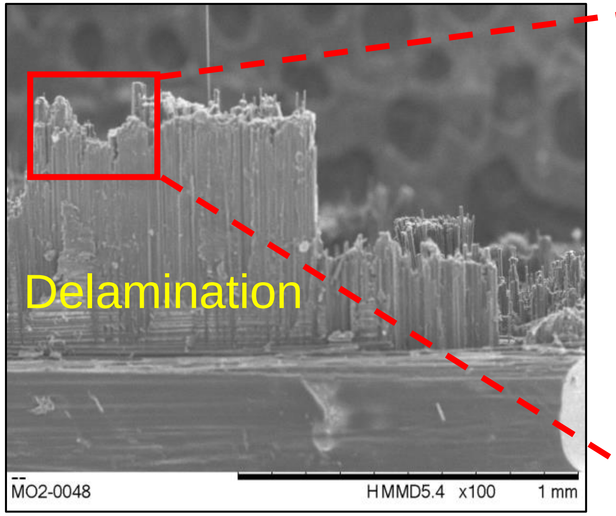
Dry

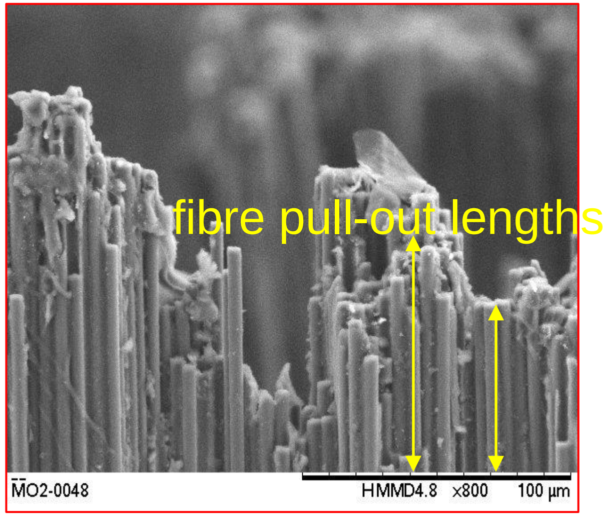




- Higher delamination than RT coupons
- More debonding due to weak fibre matrix interface
- Less stress transfer leads to lower energy dissipation than RT dry coupons

Wet (fully saturated)

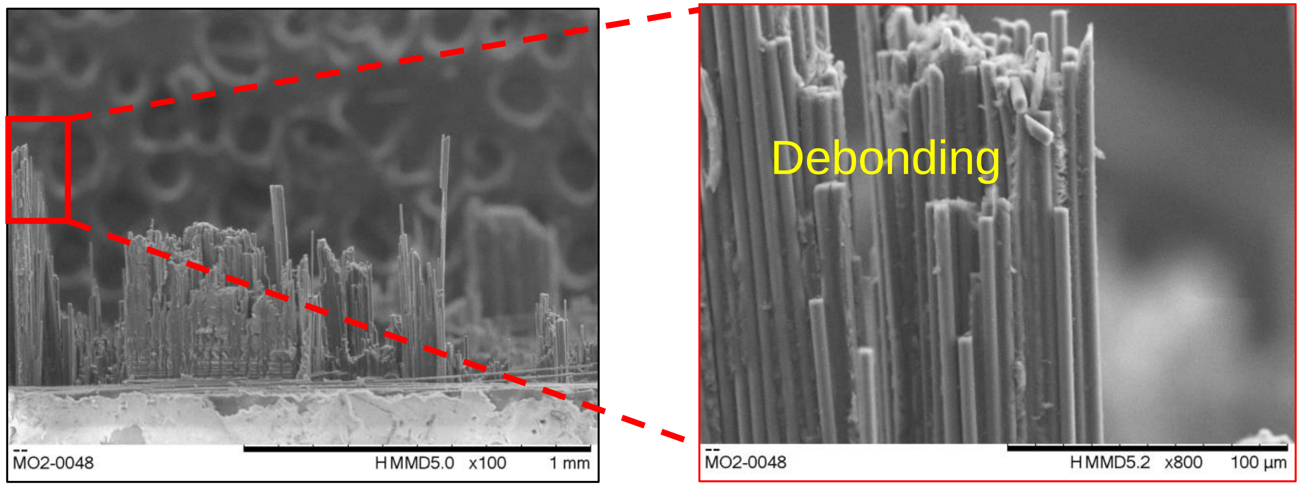




- Similar delamination with dry (40 °C) coupons
- Less debonding and higher stress transfer due to stress relaxation than 40 C dry coupons
- Leads to higher energy dissipation
- Longer fibre pull-out length than RT wet coupons

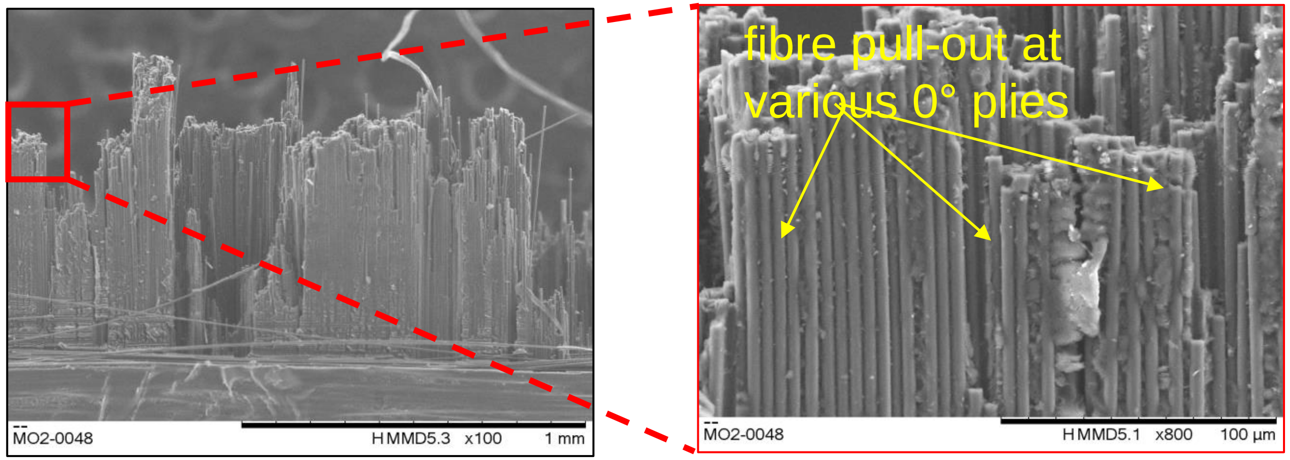
Fractographic analysis of cross-ply specimen tested at 90 °C

Dry



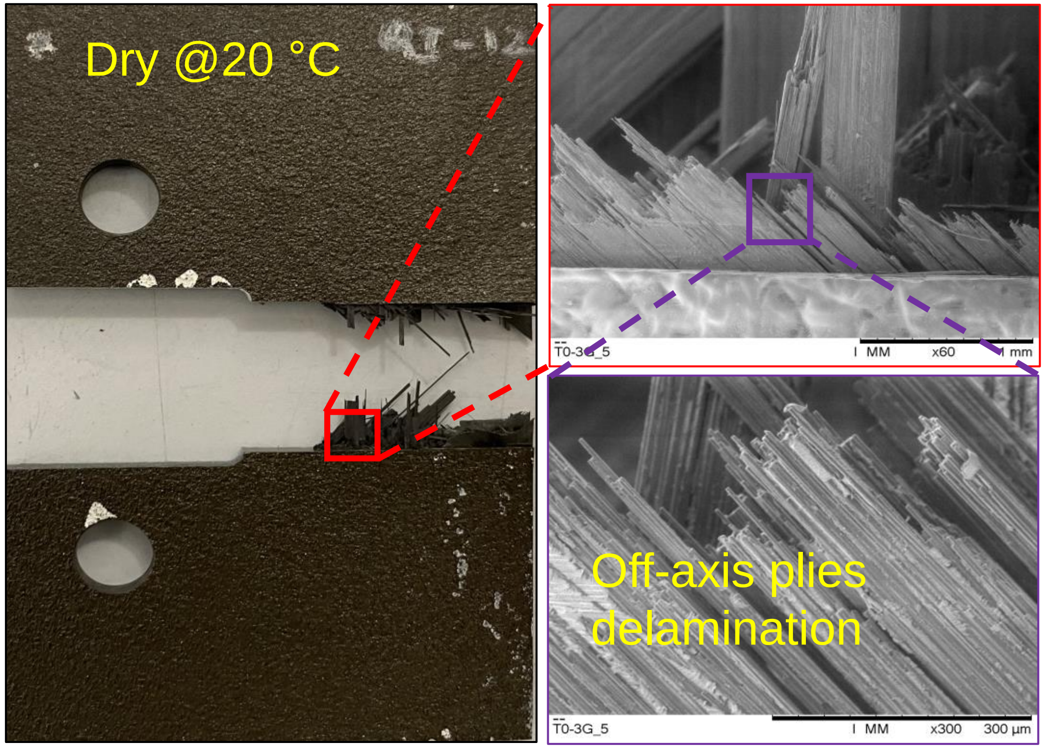
- Higher delamination than RT coupons but less delamination that 40 °C coupons
- More debonding due to weak fibre matrix interface
- Less stress transfer leads to lower energy dissipation than other dry coupons

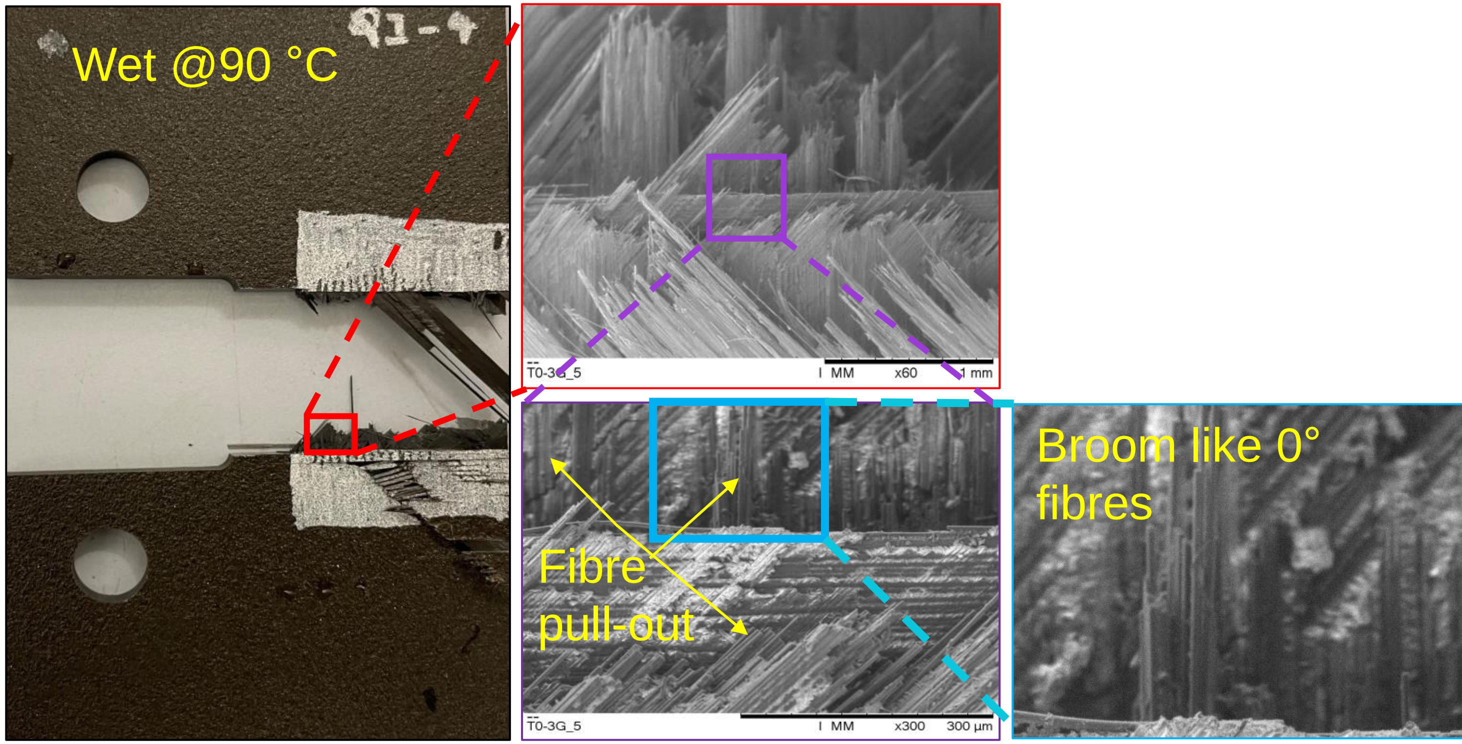
Wet (fully saturated)



- Dispersed delamination than 40 °C coupons/could be accounted as bundle pull-out
- Less debonding and higher stress transfer due to stress relaxation and leads to higher energy dissipation
- Mostly pull-out of fibre bundles/cluster of fibres than individual fibres
- Higher stress transfer and dissipated energy than other coupons

Fractographic analysis of QI specimen





- 0° fibre breakage normal to pre-crack direction
- Off-axis plies delamination after 0° fibre breakage

- 0° fibre pull-out creates broom like structures
- Less off-axis plies delamination than room temperature dry specimens
- High fracture energy dissipation

Summary

- The matrix dominated properties of composite laminates deteriorate at hot-wet environments
- The longitudinal properties of the UD laminates decreases at hot-wet conditions
- However, progressive failure of multi-directional laminates offers improved fracture properties at hot-wet conditions
- The total fracture energy dissipation is attributed to different progressive failure events such as matrix failure, fibre breakage, delaminations, fibre pull-out and fibre/matrix debonding.
- Wisely chosen lay-up configurations offer improved longitudinal strength, stiffness, and toughness properties at extreme temperature and moisture conditions
- For example, the initiation fracture toughness of the elevated temperature (90 °C) wet QI specimens is ~17% higher than the room temperature (23 °C) dry specimens

Thank you

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