

# Effects of mesostructure on the in-plane properties of tufted carbon fabric composite

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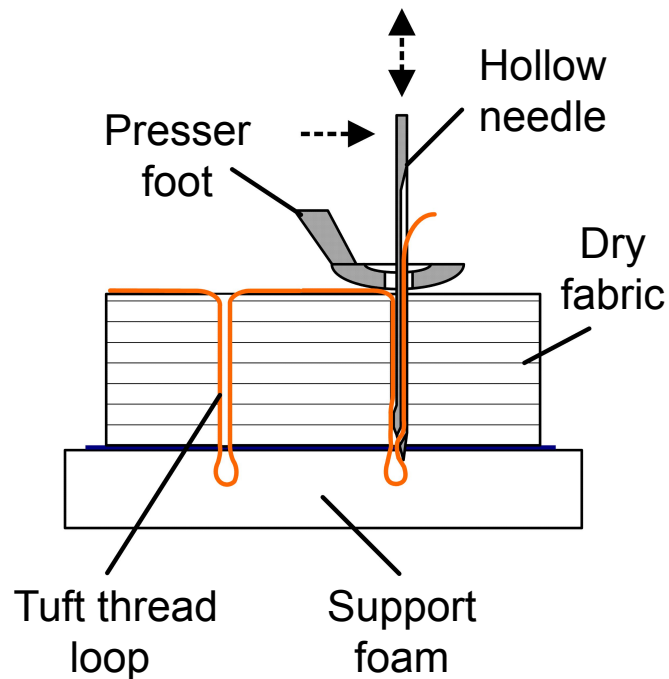
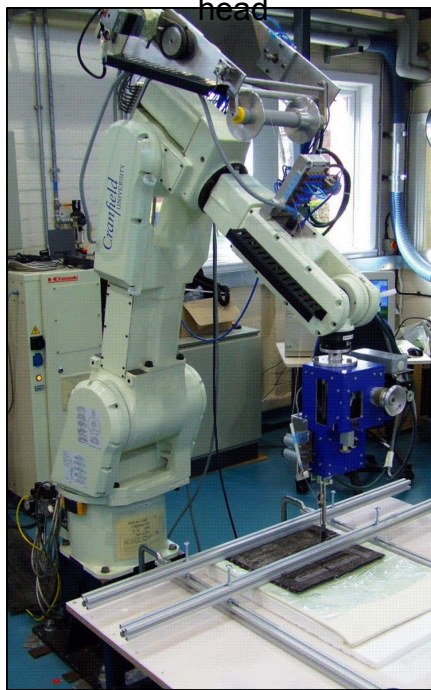
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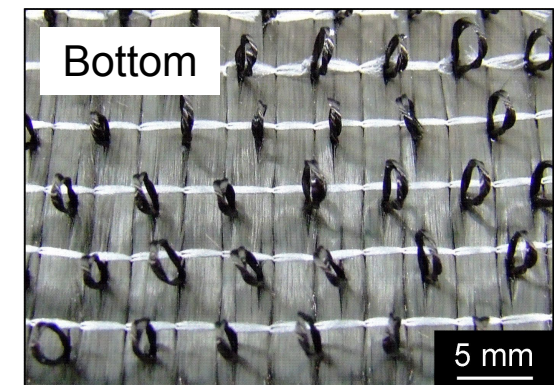
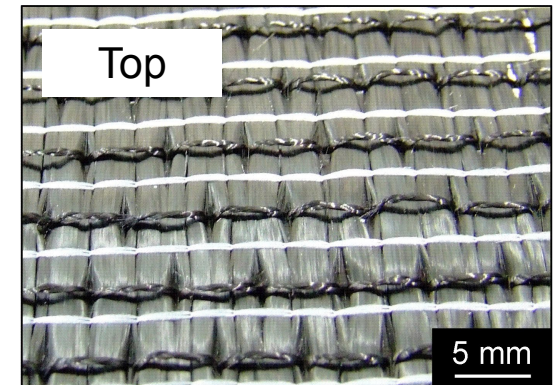
# Tufting process

- Modified one-sided stitching process
- Automated insertion of carbon, glass or aramid thread
- For dry composite preforms

Automated KSL KL150 tufting

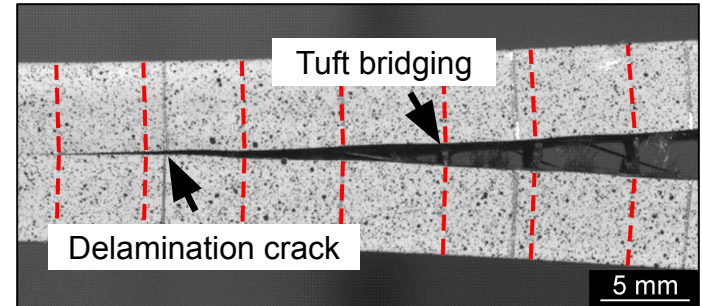


0.5% carbon tufted NCF



Main purpose: Through-the-thickness reinforcement technique

+ 460%/+60% mode I/II delamination toughness  
for only 0.5% areal tuft density (Cranfield)



DCB of 0.5% carbon tufted  
NCF

Drawback: Potential reduction of in-plane properties

**Stitching**: - considerable database

Stiffness: -15% to +10%      Tensile strength: **-25% to +25%**

**Tufting**: - to date only 3 experimental studies (KU Leuven, Cranfield)

Tensile strengths: **-14% to +10%**

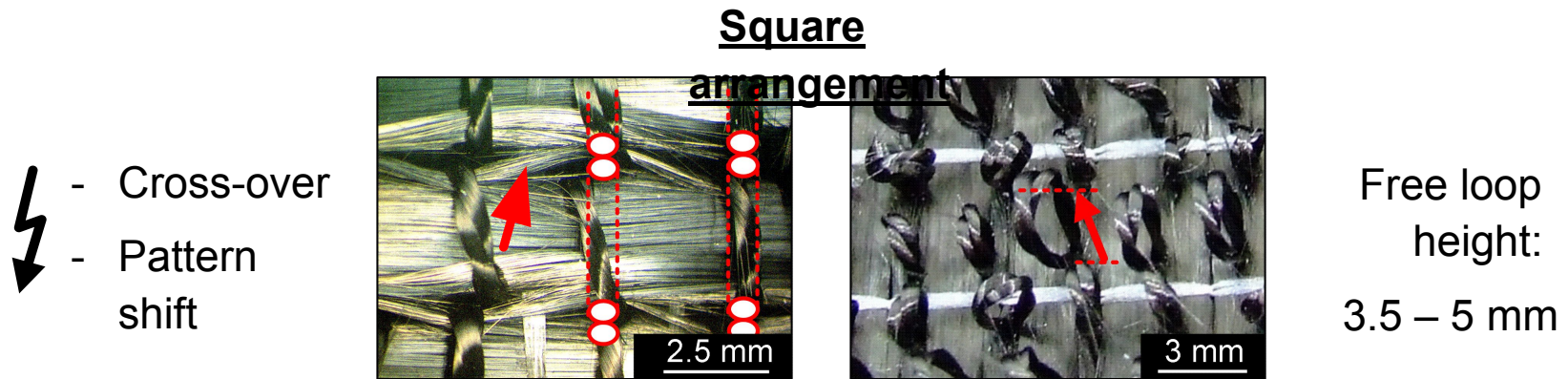
no agreement ⚡



**Need for detailed testing database on  
wider range of tufted materials**

- Carbon **Preforms**: Uni-weave -  $[0^\circ]_7$ ,  $[0^\circ]_{10}$   
balanced NCF -  $[(0^\circ/90^\circ)_s]_2$

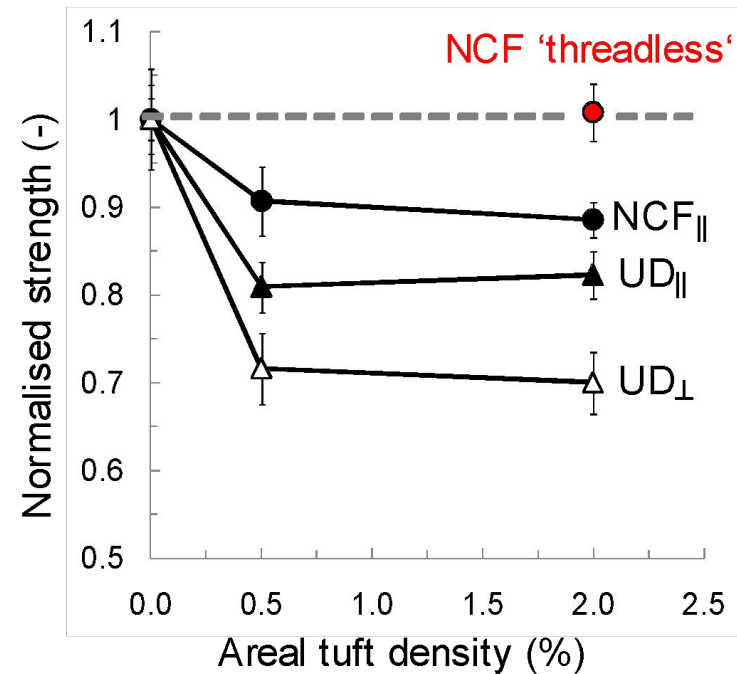
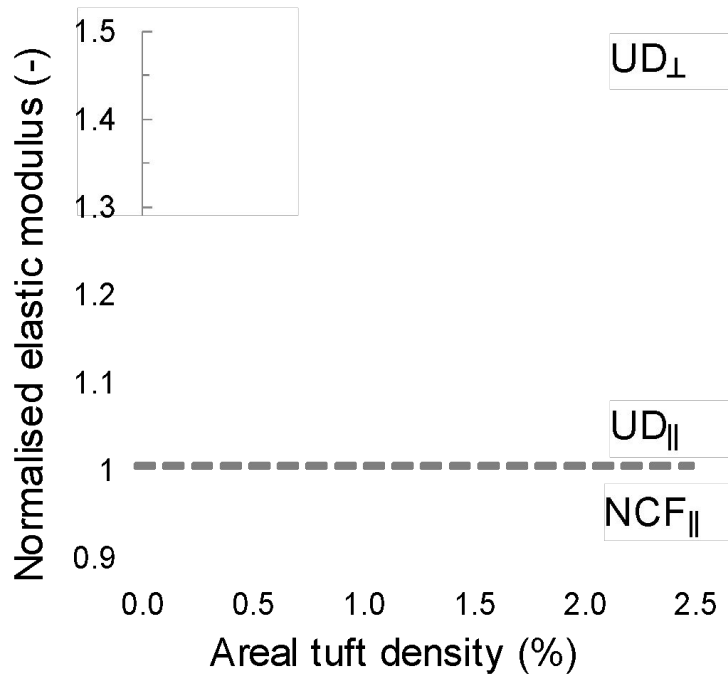
- **Tufted** with 2k HTA carbon thread in at  $s_x = s_y = 5.6 \text{ mm (0.5\%)} / 2.8 \text{ mm (2\%)}$



- **RTM** injection of epoxy resin (ACG MVR 444) for **dimensional control**

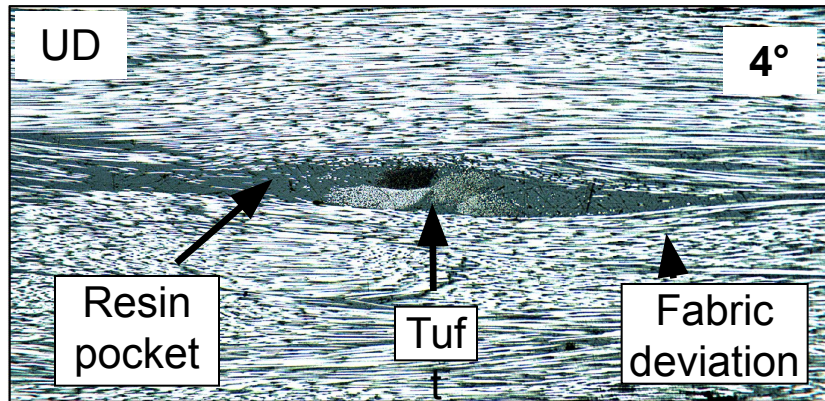
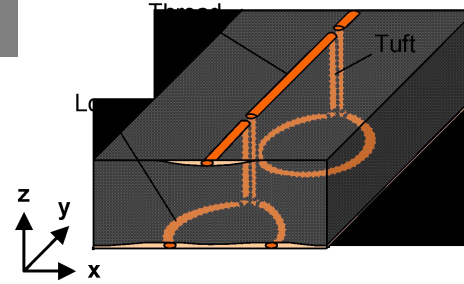


## Tensile tests (BS EN ISO 527-4:1997):

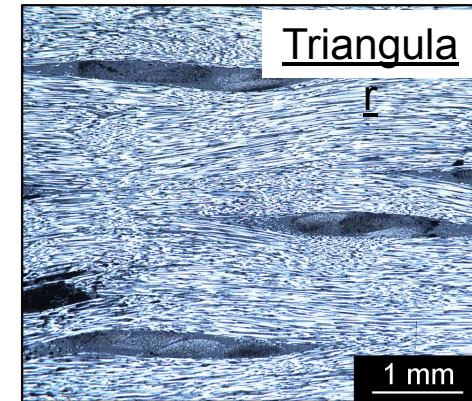


Property changes depend on fabric and tuft morphology

## In-plane disturbance (x-y):

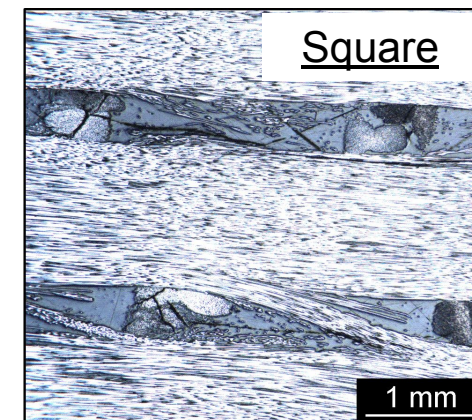
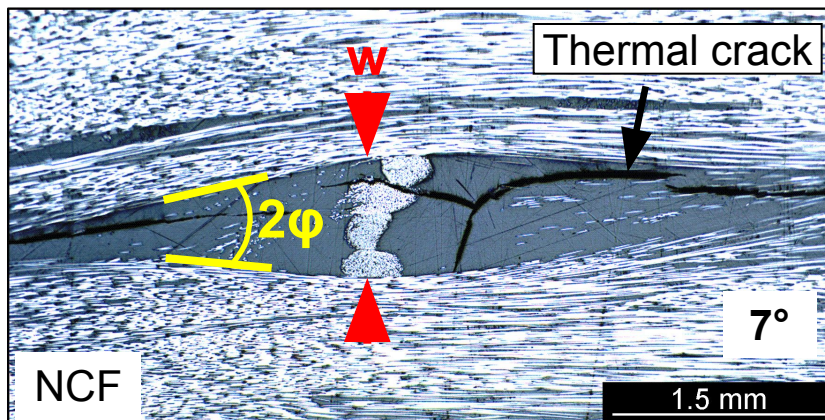


0.5%



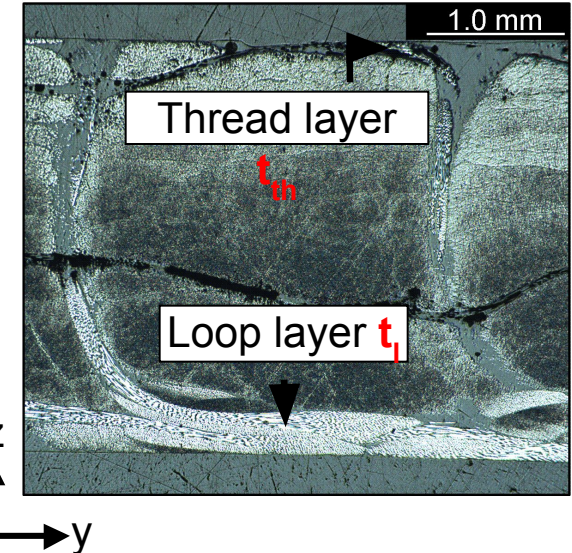
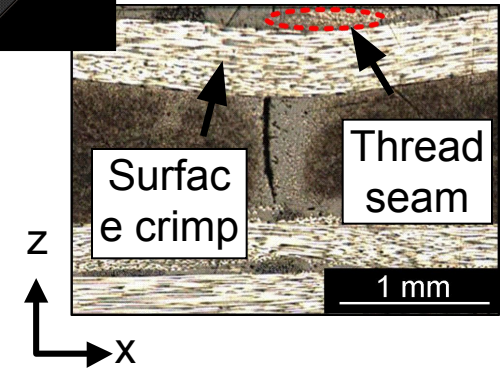
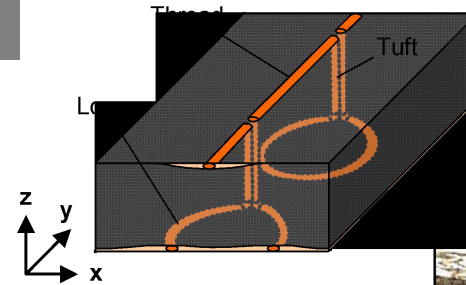
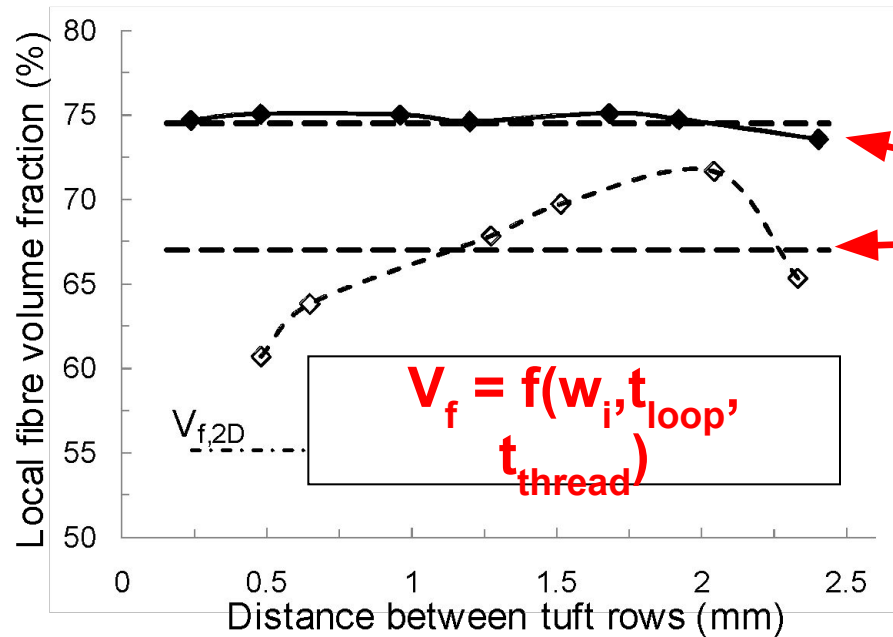
$w \downarrow, \phi \uparrow$   
UD: 6°  
NCF: 10°

2.0%



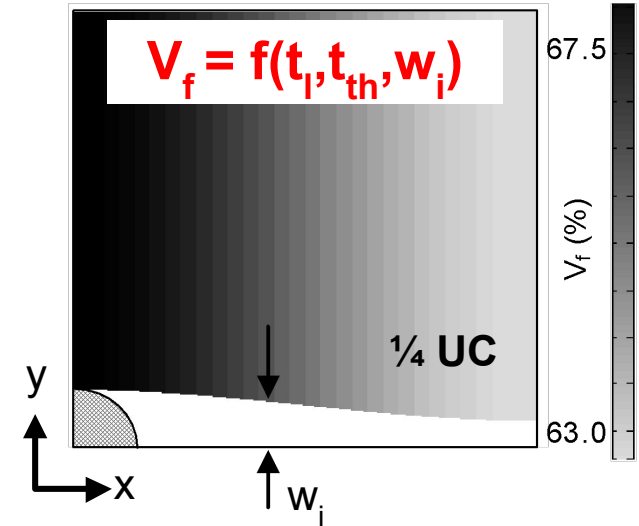
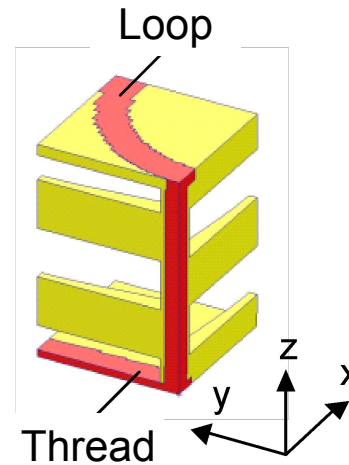
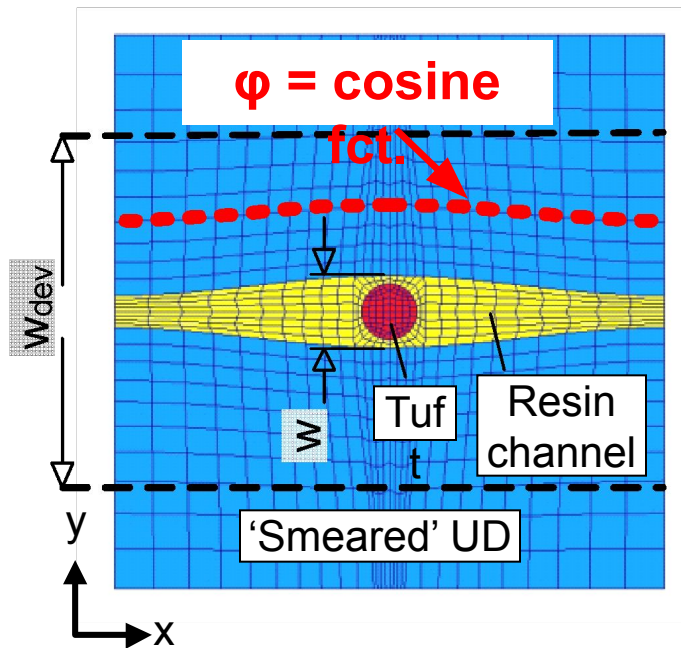
$w, \phi \downarrow$   
UD: 3°  
NCF: 4°

## Out-of-plane disturbance (x-z/y-z):



- Surface seam causes local fabric crimp
- Resin rich layers and pockets affect global and local  $V_f$





**Parametric 3D Unit Cell model (Marc):** UD, NCF, square and triangular arrangement  
Isotropic, linear elastic material + 'Rule of mixtures'

(Chamis)  
**Failure and degradation:**

Ply: Puck (FF + 3 modes of IFF)

Resin: Maximum strength

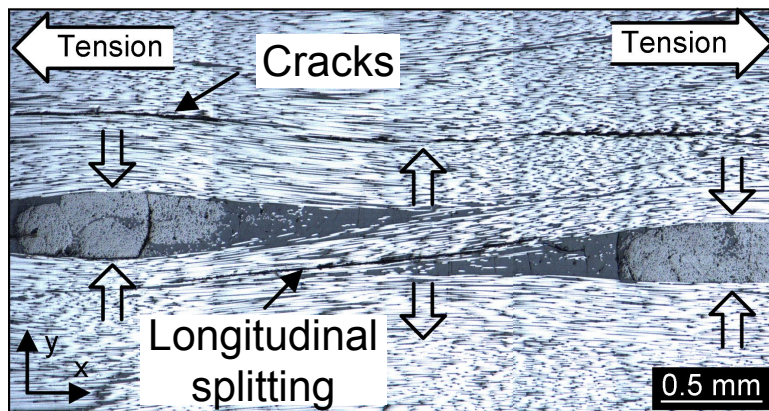
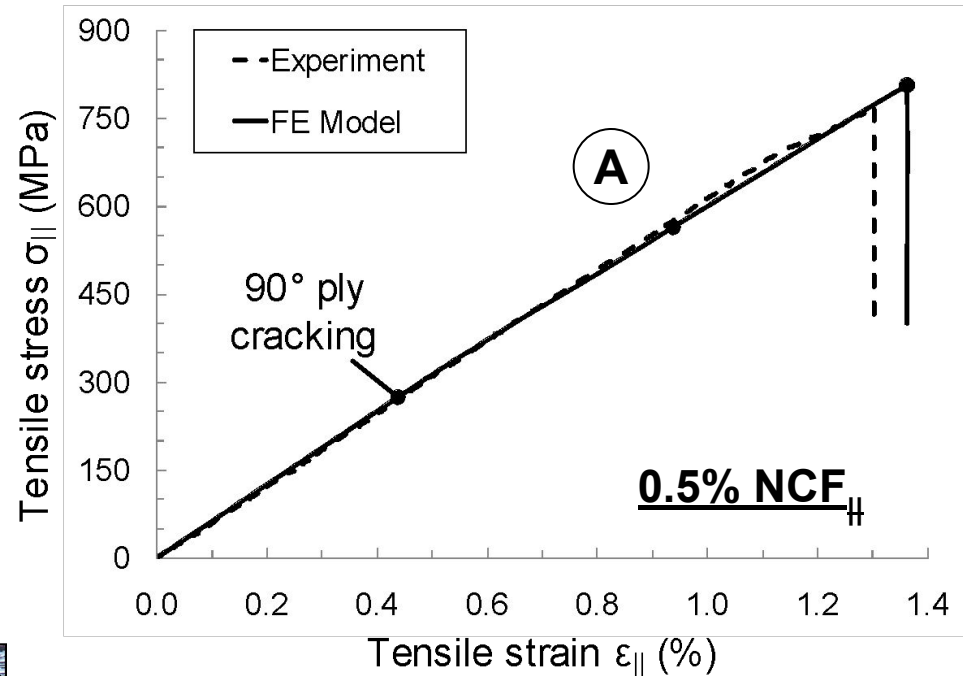
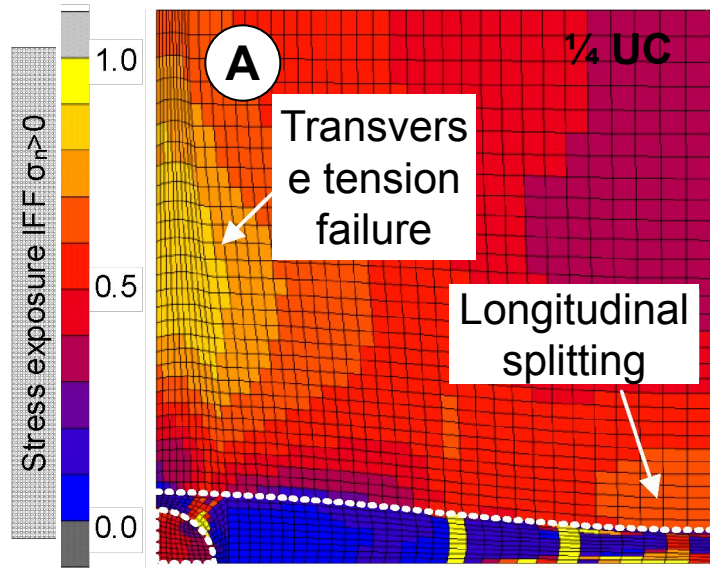
$$\begin{bmatrix} E_n \\ G_{nt} \end{bmatrix}_{\text{deg}} = \begin{bmatrix} 0.03^* / 1.0 \cdot E_n \\ 0.67 \cdot G_{nt} \end{bmatrix}_0$$

$$E_{\text{deg}} = 0.1 \cdot E_0$$

$$^* \sigma_n > 0$$

Knops, Comp.  
Sci. Tech.  
2006

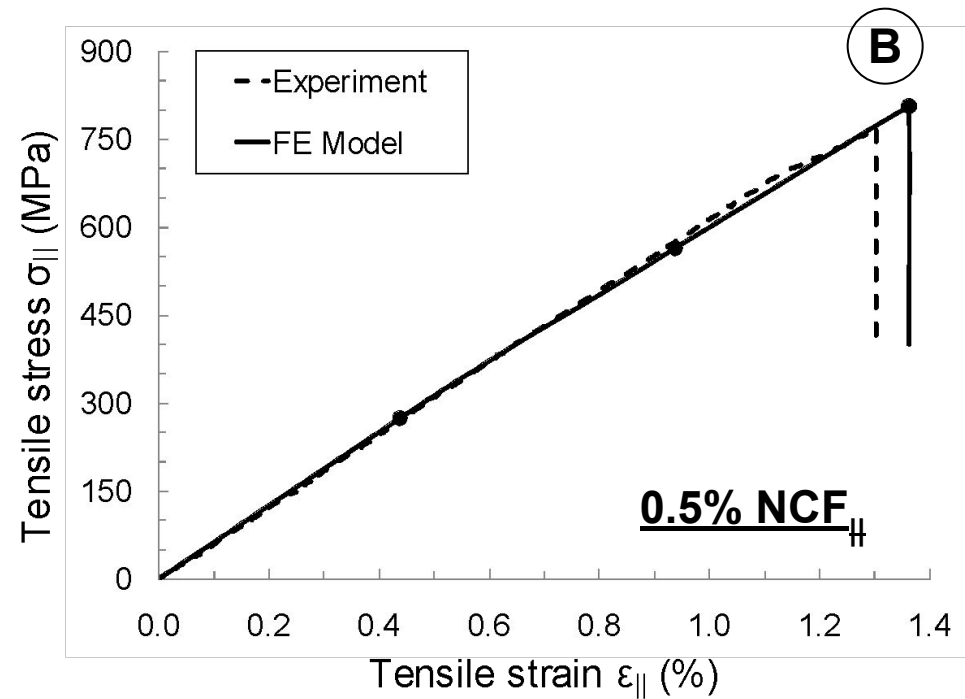
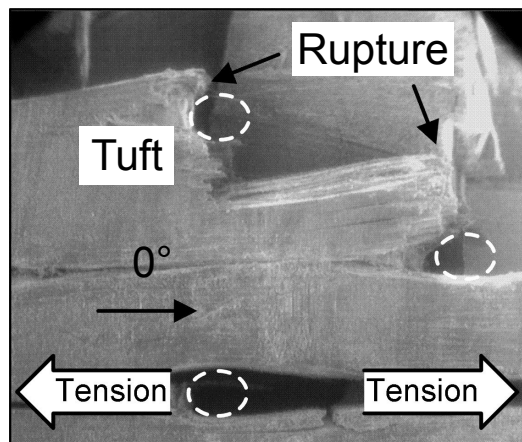
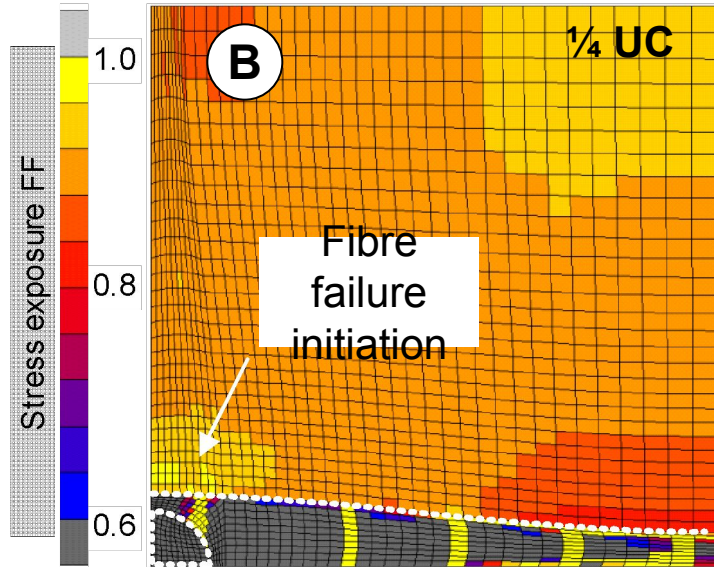
0° Ply



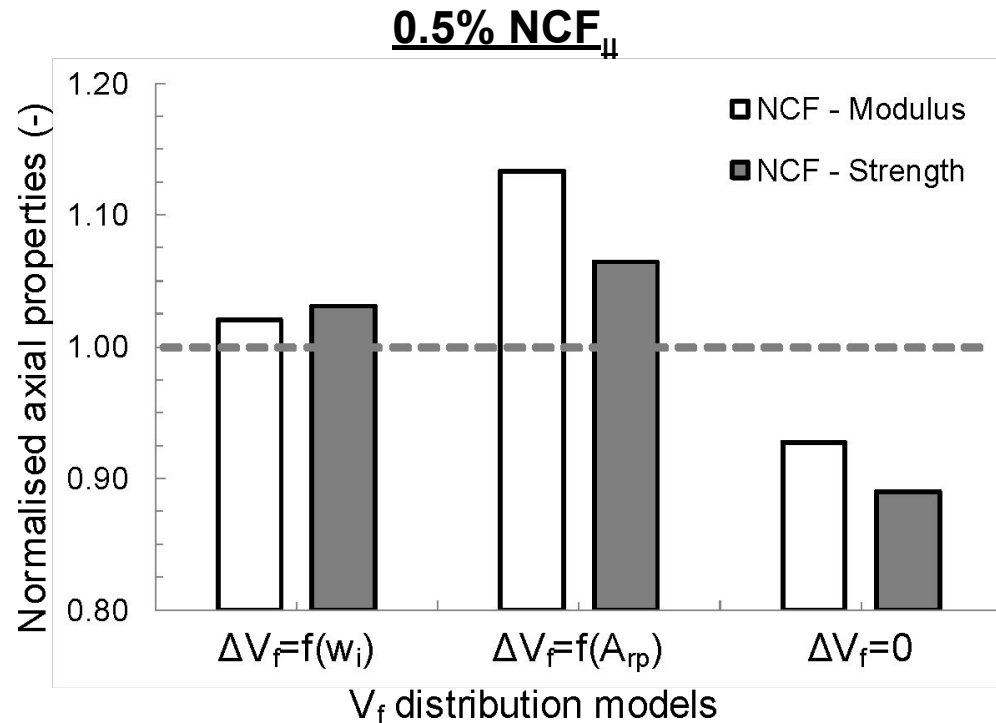
- Accurate modulus and strength, also for 2% density (error < 2/4%)
- Fabric straightening leads to transverse tension failure in fabric and longitudinal splitting of resin pocket



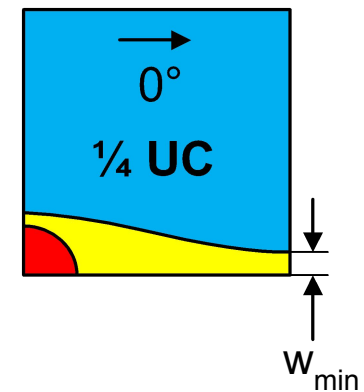
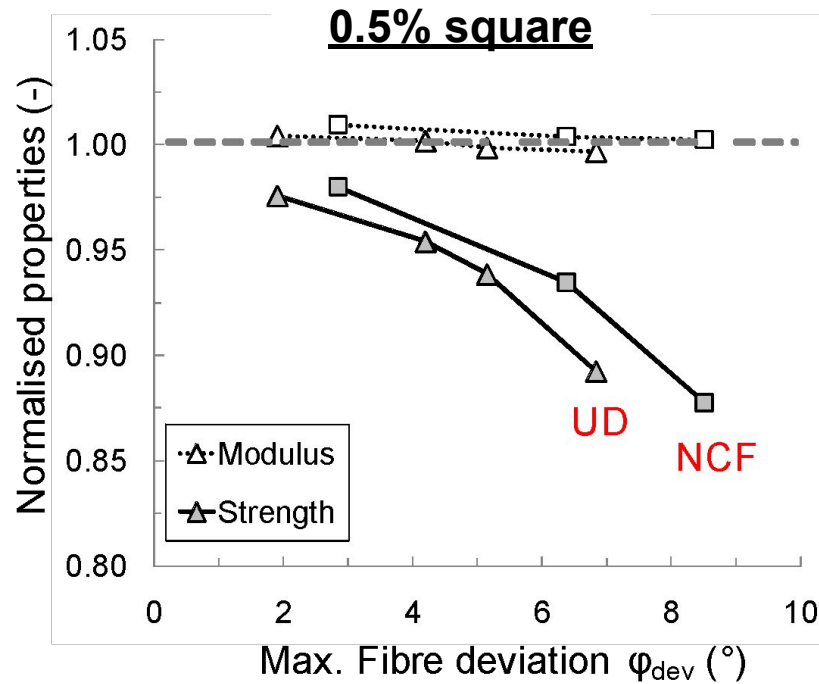
0° Ply



- Ultimate fabric fibre failure in close vicinity of tuft

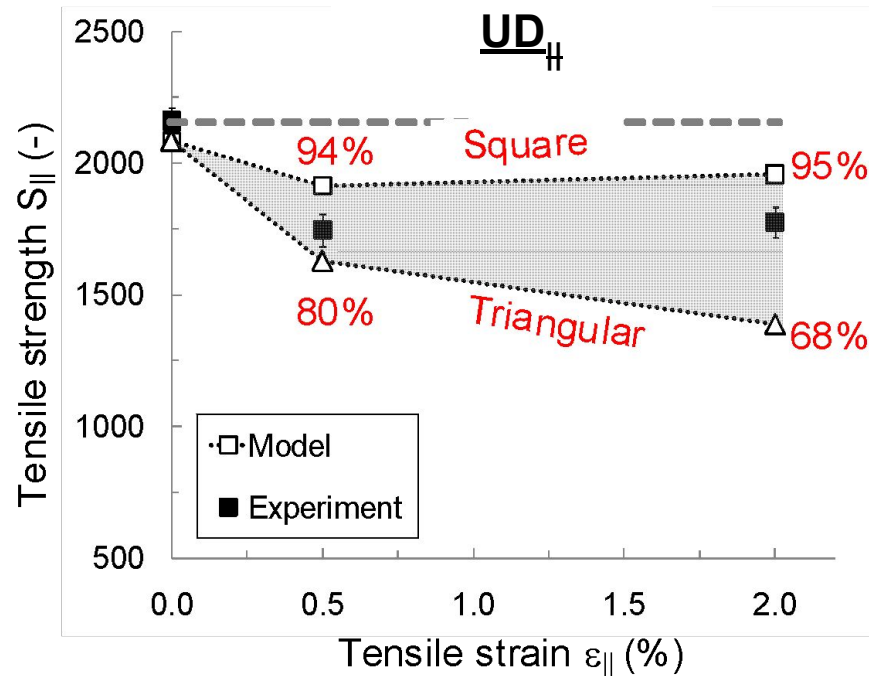


- Local fabric fibre distribution affects both stiffness and strength prediction
- **Gradient  $V_f$  model** agrees best with true morphology and tension results



- **Fabric fibre deviation** critical on tensile strength, effect on modulus negligible
- UD strength more sensitive to fabric deviation





- **Upper and lower strength bounds** defined by square and triangular pattern
- Triangular pattern causes most critical strength reduction

- Tuft introduces structural complexity into Z-reinforced composite
- Critical meso-structural tuft defects: resin rich pockets, fibre deviation, matrix cracking and local fibre compaction
- Tufting has no effect on longitudinal tensile stiffness of UD and biaxial NCF composite, but surface loops increase matrix dominated transverse stiffness
- Reduction in longitudinal tensile strength most prominent for UD (<-19%)
- Fibre undulation most critical contributing factor, fibre breakage limited effect on tensile strength
- High quality experimental morphology data allows accurate tensile stiffness and strength prediction of tufted composites