# *Material characterisation and calibration of a meso-mechanical damage model for braid reinforced composites*

***CompTest 2004 - Bristol***

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# Outline of presentation

I Braided composites – Manufacturing & Characteristics

II The meso-scale damage model – Presentation

III The meso-scale damage model – Adaptation to braids

IV Industrial example and limitation of current models

# I. Braided composites: characteristics and performance



## 1. Characteristics

A potential material for the *automotive industry* due to:

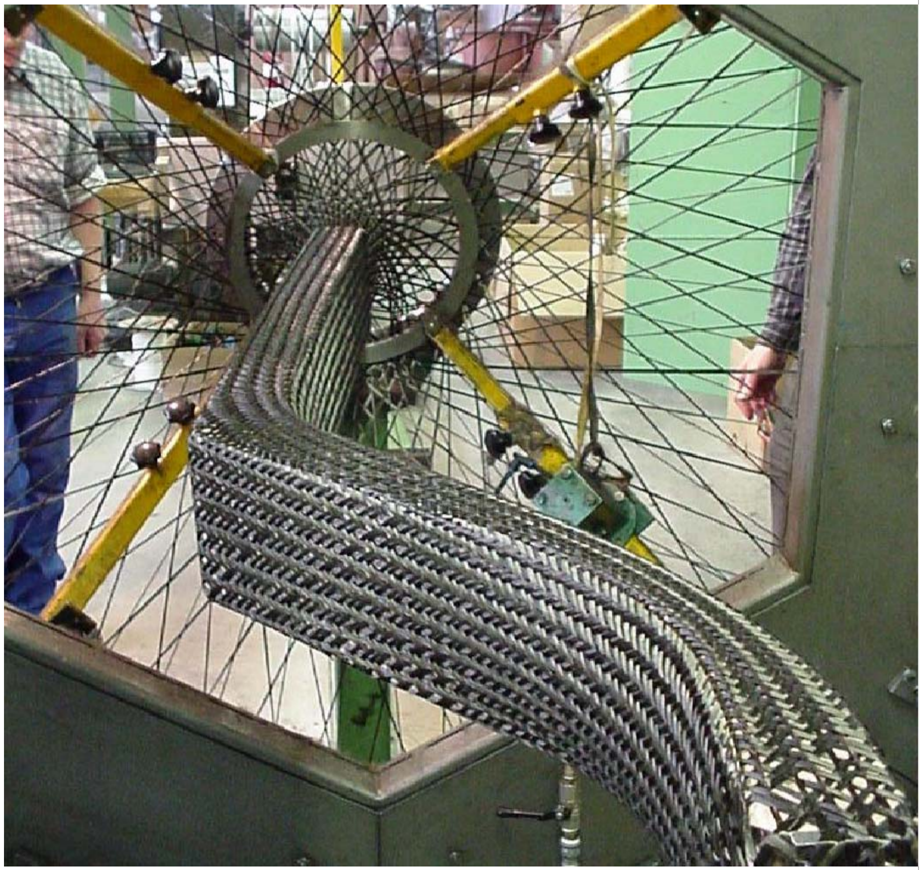
→ good specific stiffness

→ high strength-to-weight ratios

→ high impact resistance

→ high specific energy absorption for crash applications

→ braiding machines are adaptable for a wide range of shapes and fibre architectures and easily tailored for geometric and mechanical properties.



**Tubular braided preform** ***(courtesy of Eurocarbon)***

# I. Braided composites: characteristics and performance

## 1. Characteristics

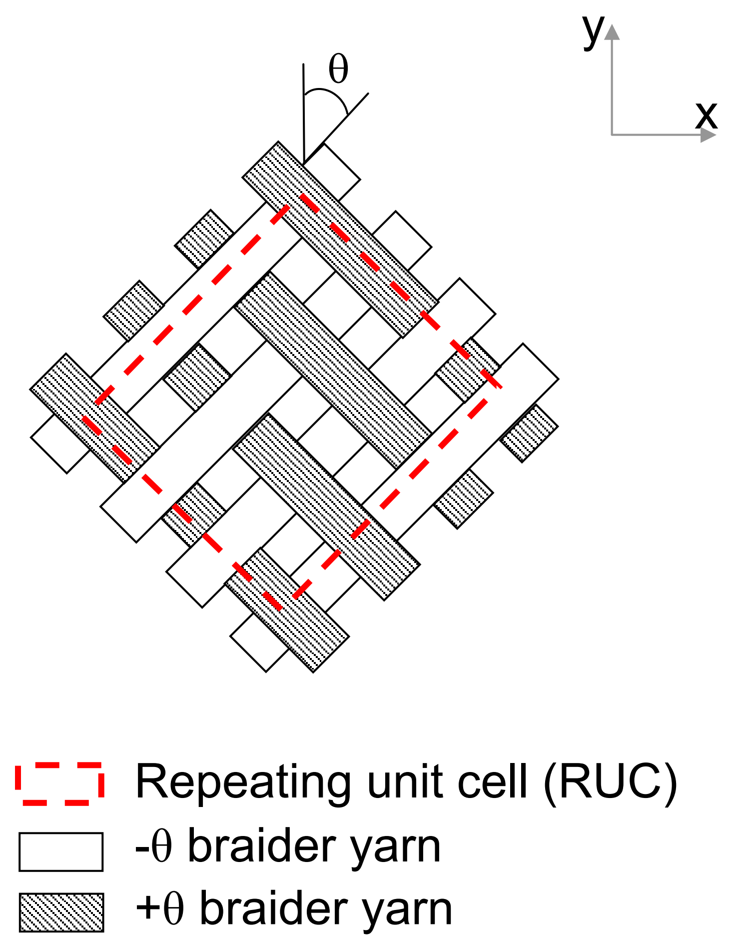
The braid architecture allows tailoring of mechanical properties by the use of:

→ braid angles

→ Percentage of tows in different directions (triaxial braids)

→ quantity of fibres in tows

→ number of braider yarns between cross-over points

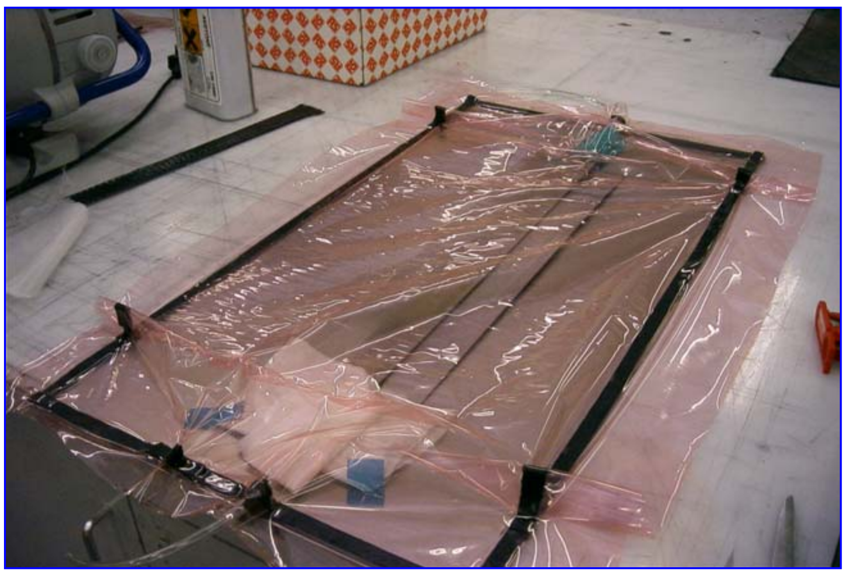


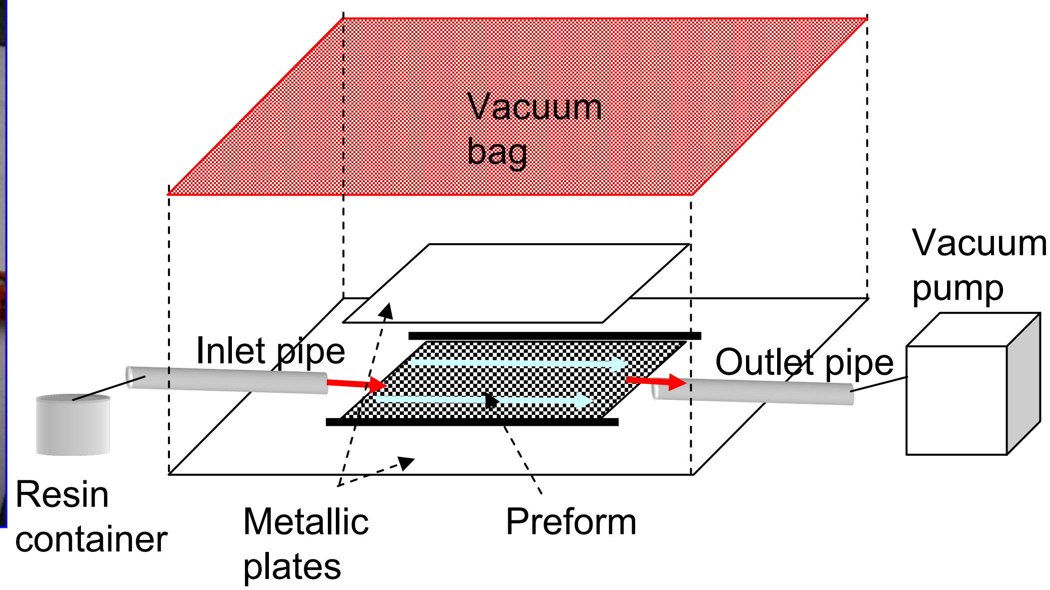

**Repeating unit cell for a 2x2 braid**

## 2. Manufacturing

Various manufacturing processes available:

→ RTM, RIFT, resin infusion, vacuum resin infusion, …





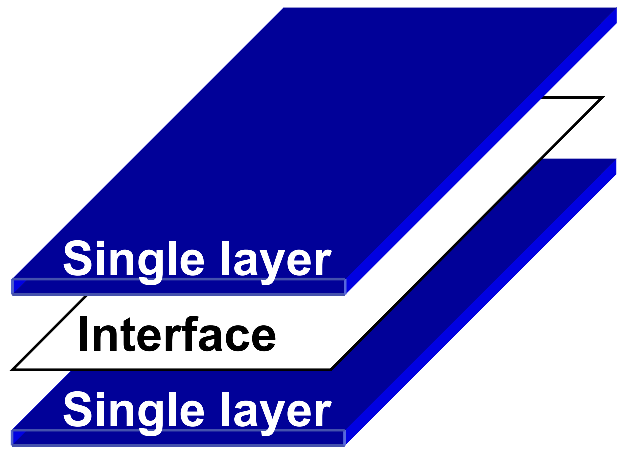

**Vacuum resin infusion**

# II. The meso-scale damage model: presentation



## 1. Description

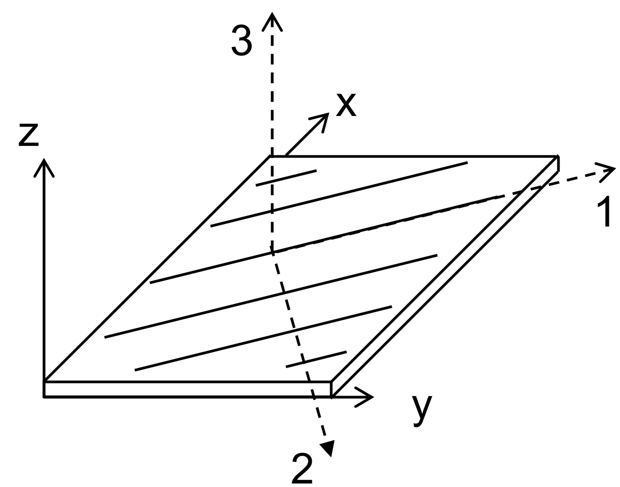
- Laminate scale defined by 2 meso-constituents
- Use of damage mechanics for predicting meso-constituents degradation
- Damage indicators ($d_{11}$,$d_{22}$, $d_{12}$) are linked to variation in moduli




- Damage mechanisms taken into account are:

  **a. Fibre breakage b. Matrix microcracking**

  **c. Fibre/matrix debonding d. Delamination (low)**




- Damaged strain energy density in a single layer:

$$E_D = \frac{1}{2(1-d_{11})}\left[\frac{\sigma_{11}^2}{E_1^0} - \left(\frac{\nu_{12}^0}{E_1^0} + \frac{\nu_{21}^0}{E_2^0}\right)\sigma_{11}\sigma_{22} - \left(\frac{\nu_{31}^0}{E_3^0} + \frac{\nu_{13}^0}{E_1^0}\right)\sigma_{11}\sigma_{33} - \left(\frac{\nu_{32}^0}{E_3^0} + \frac{\nu_{23}^0}{E_2^0}\right)\sigma_{22}\sigma_{33}\right]$$

$$+\frac{1}{2}\left[\frac{\langle\sigma_{22}\rangle_+^2}{E_2^0(1-d_{22})} + \frac{\langle\sigma_{22}\rangle_-^2}{E_2^0} + \frac{\sigma_{33}^2}{E_3^0} + \frac{\sigma_{12}^2}{G_{12}^0(1-d_{12})} + \frac{\sigma_{13}^2}{G_{13}^0} + \frac{\sigma_{23}^2}{G_{23}^0}\right]$$

Damage governed by in-plane stress

# II. The meso-scale damage model: presentation

- From damaged strain energy : -

$$Y_{22} = \frac{\partial\langle\langle E_D\rangle\rangle}{\partial d_{22}} = \frac{1}{(1-d_{22})^2}\left\langle\left\langle \frac{\langle\sigma_{22}\rangle_+^2}{E_2^0}\right\rangle\right\rangle \qquad Y_{12} = \frac{\partial\langle\langle E_D\rangle\rangle}{\partial d_{12}} = \frac{1}{(1-d_{12})^2}\left\langle\left\langle \frac{\sigma_{12}^2}{G_{12}^0}\right\rangle\right\rangle$$

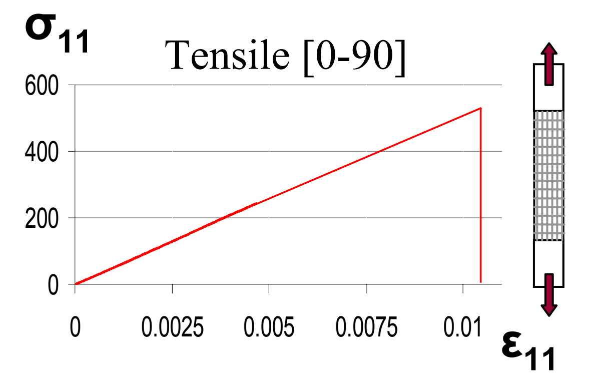
- Assume uniform damage state through each meso-constituent thickness

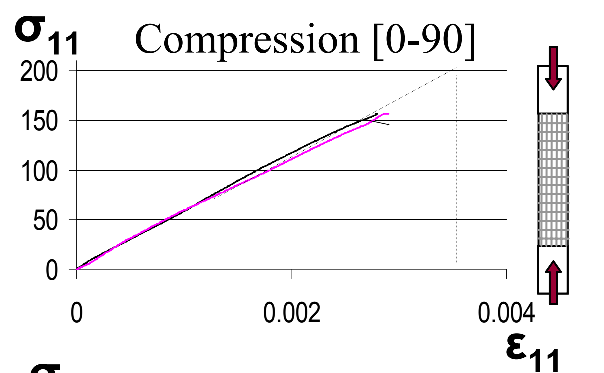
- Damage and Plasticity coupling expressed through elastic domain function

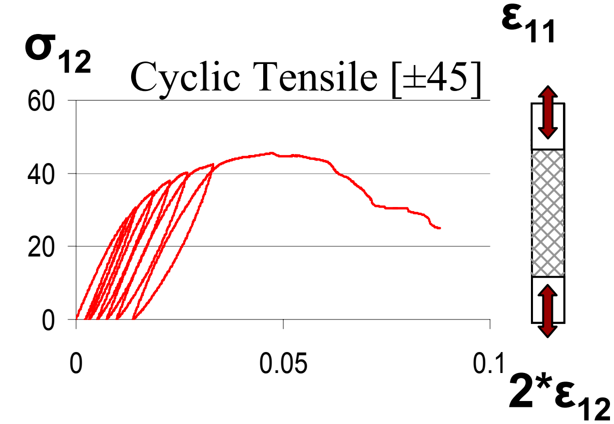
$$f = \sqrt{\tilde{\sigma}_{12}^2 + a\tilde{\sigma}_{22}^2} - R(p) - R_0$$

Function of the accumulated plastic strain p

- Model calibration through testing program on different laminate types



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# III. The meso-scale damage model: Adaptation to braids



## 1. Experiment

→ Focus: Cyclic tensile loading on [±45] braided laminate

- High degree of inhomogeneity resulting from non-uniform strain distribution within a given unit cell
- Width dimension > 3 x RUC length
- Coupon dimensions: 150x65 mm

→ Manufacturing of flat coupons

- Use of vacuum resin infusion for flat braided panels
- **LY3505** (epoxy resin)/**XB3403**(hardener) system
- Good price/performance ratio

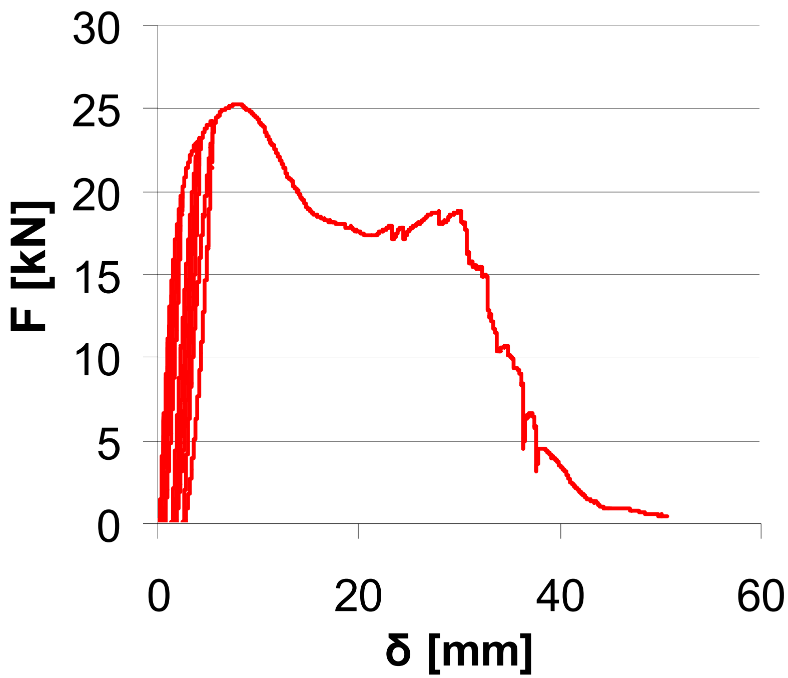
# III. The meso-scale damage model: Adaptation to braids



## 1. Experiment

→ Test observations

- High degree of fibre rotation: "scissoring effect"
- Necking (up to 23% width reduction at complete failure)

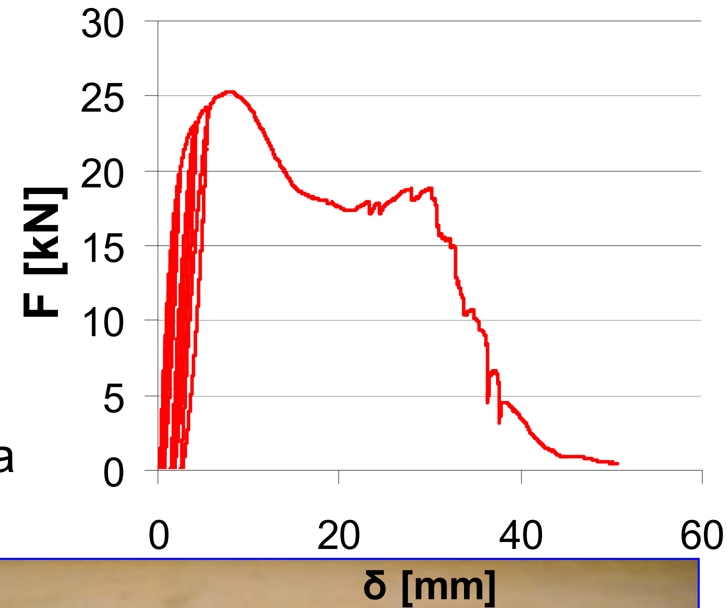


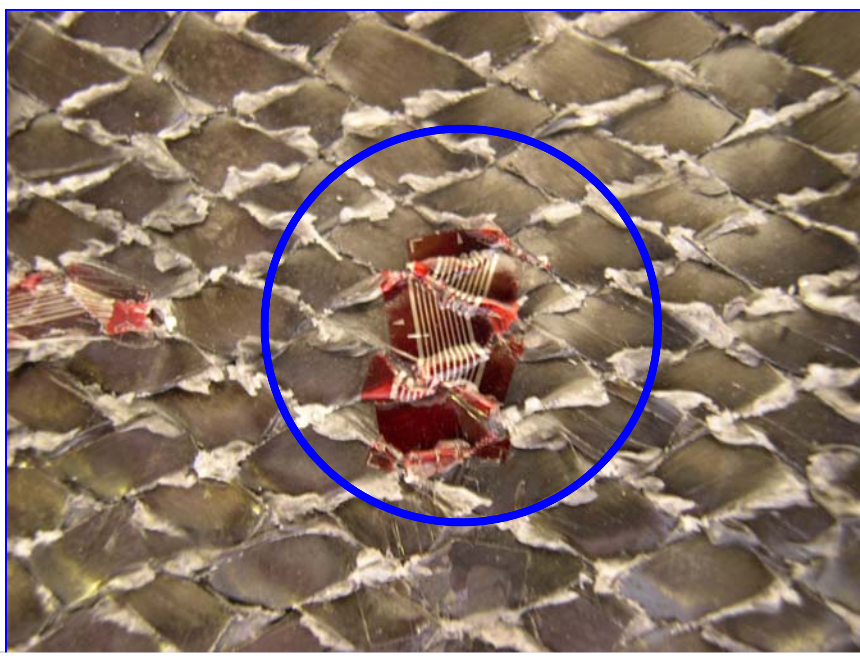

# III. The meso-scale damage model: Adaptation to braids

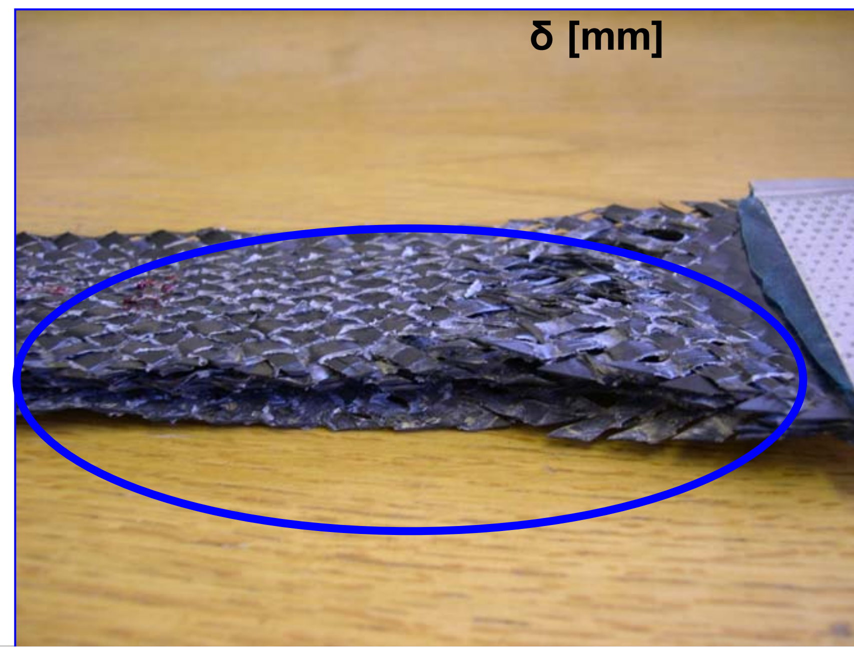
## 1. Experiment

→ Test observations

- High delamination after first peak load
- Strain measurement problem after peak load due to strain gauge failure
- difficulty to measure strains in post-peak load area





# III. The meso-scale damage model: Adaptation to braids



## 1. Experiment

→ Measures taken

- Focus on pre-peak load
  - Necking and delamination
    - measure of width reduction with $\varepsilon_{22}$
    - assume constant thickness ⟶ Delamination negligible

↓

- Use of pseudo true stress for calibration test

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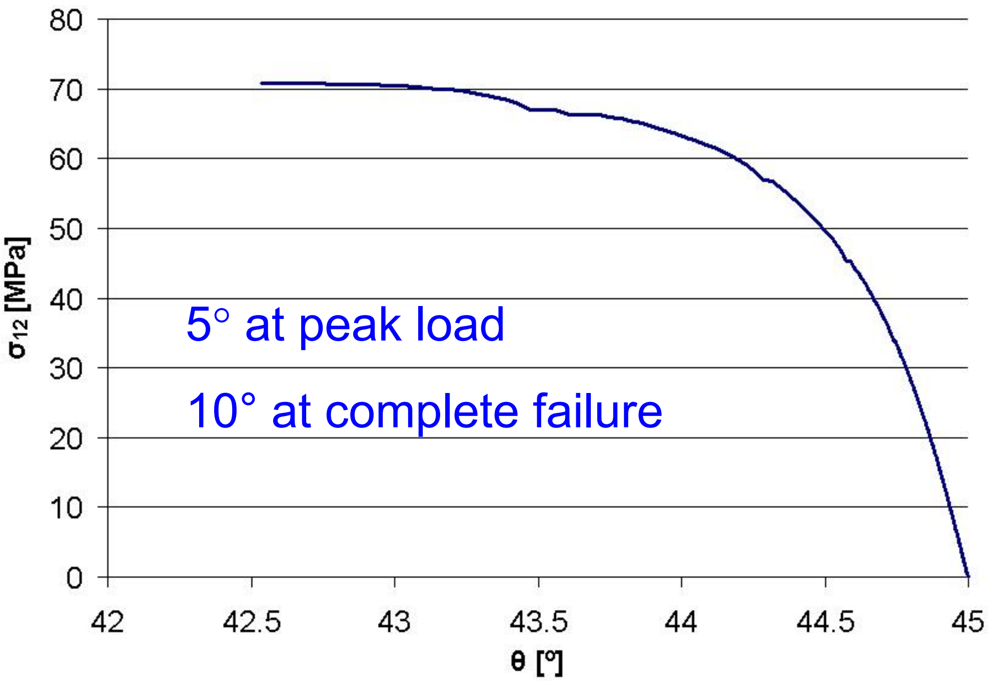
# III. The meso-scale damage model: Adaptation to braids

## 2. Fibre rotation

→ Angle determination

- For inextensible fibre, fibre rotation is expressed with: $$\Delta\theta = ArcTan\frac{1+\varepsilon_y}{1+\varepsilon_x}$$
- **Results in a Non linearity of damage evolution**
- **No delamination taken into account**

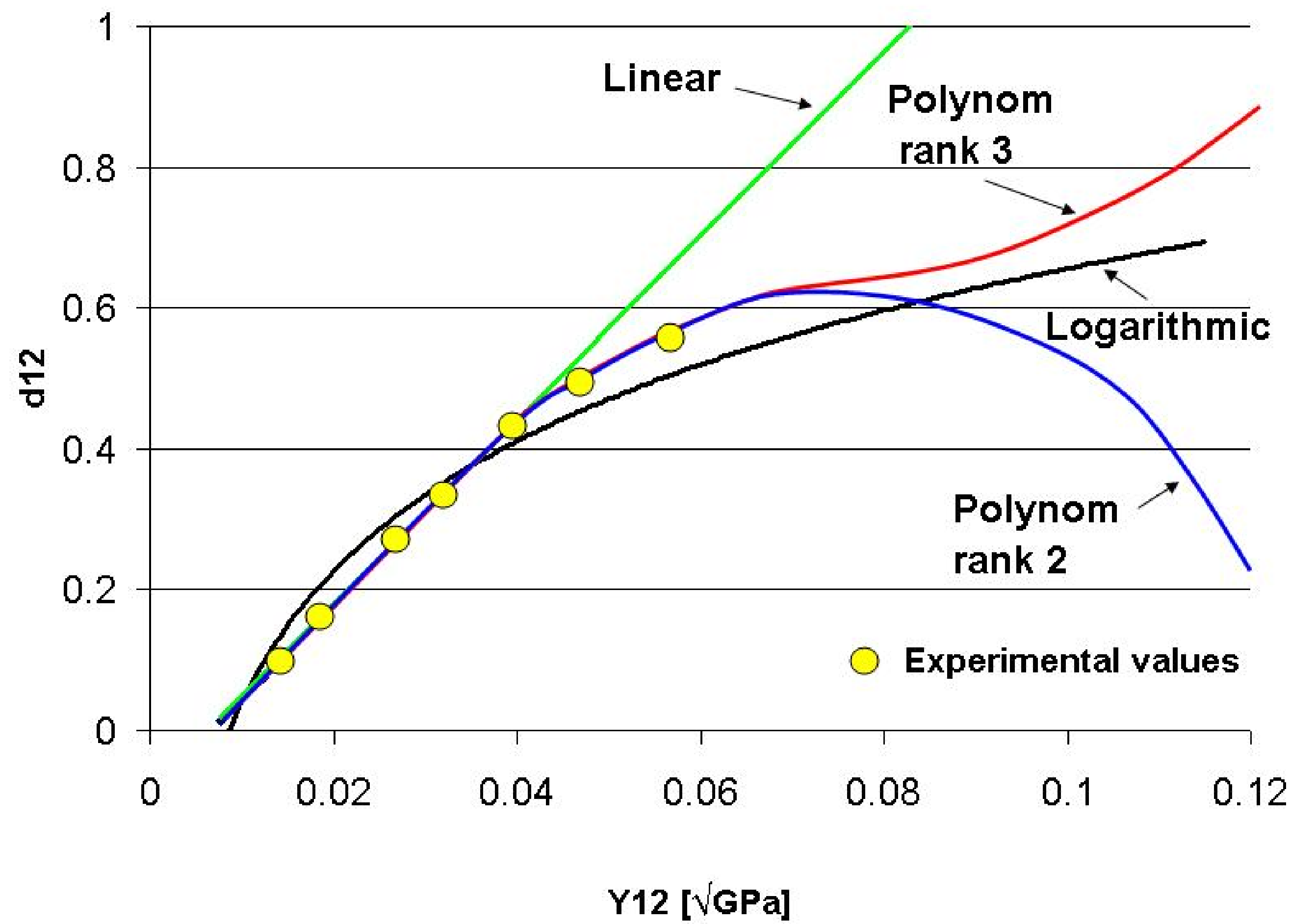



# III. The meso-scale damage model: Adaptation to braids



→ Effect on damage evolution

• Non-linearity of the damage law ⟶ Log. & poly. approximations

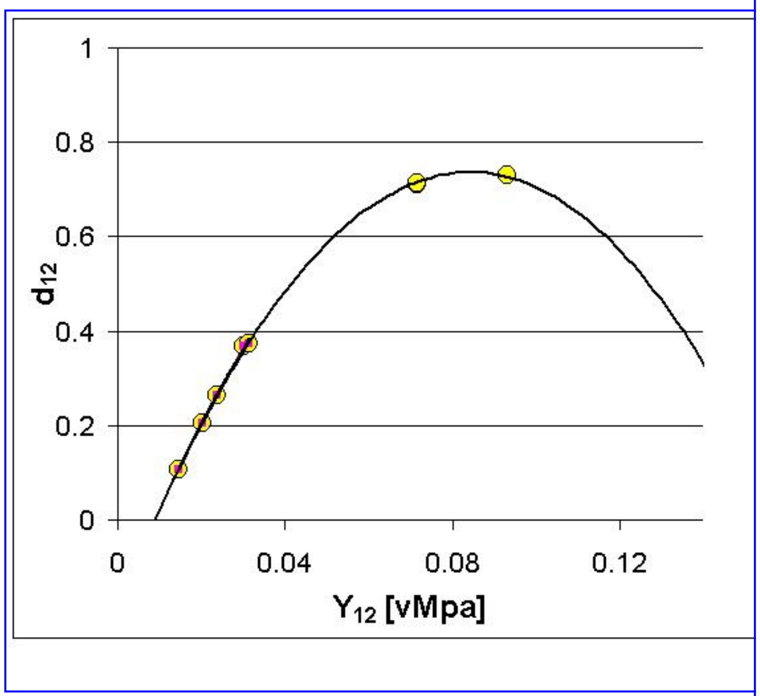


# III. The meso-scale damage model: Adaptation to braids

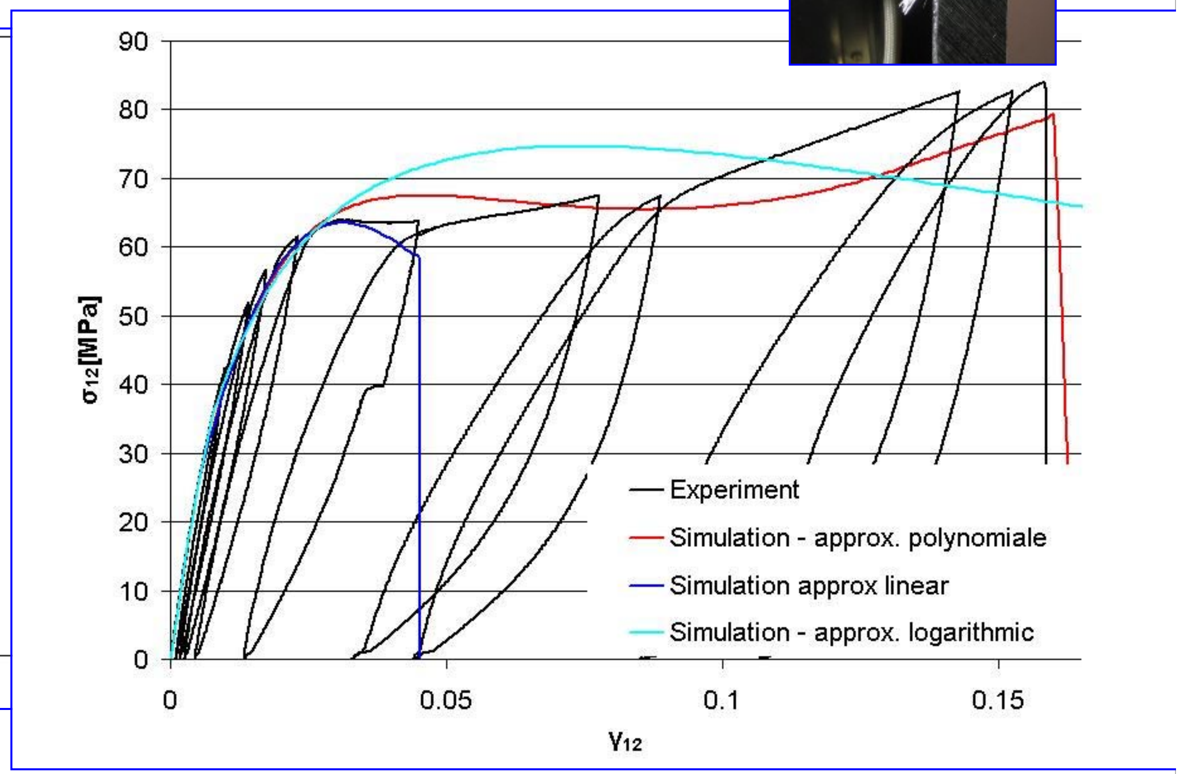


- Example on high strain UD (T800/M21 – 35% rubber content)

**Damage law**



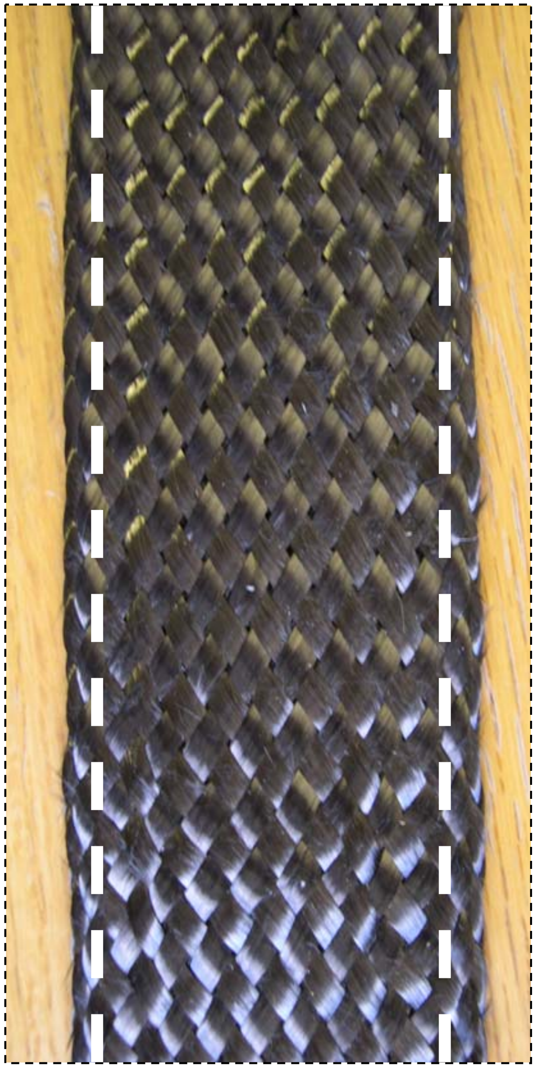

**Simulation**

# III. The meso-scale damage model: Adaptation to braids

## 3. Edge effect

- Significant edge effect caused by fibre continuity
- Increase of strength and strain at failure
- Low braid angle results in a high increase (fibre loading)
- Same damage law for cut and uncut coupons?
- Equivalent damage evolution and hardening function
- High degree of delamination also present in uncut specimen



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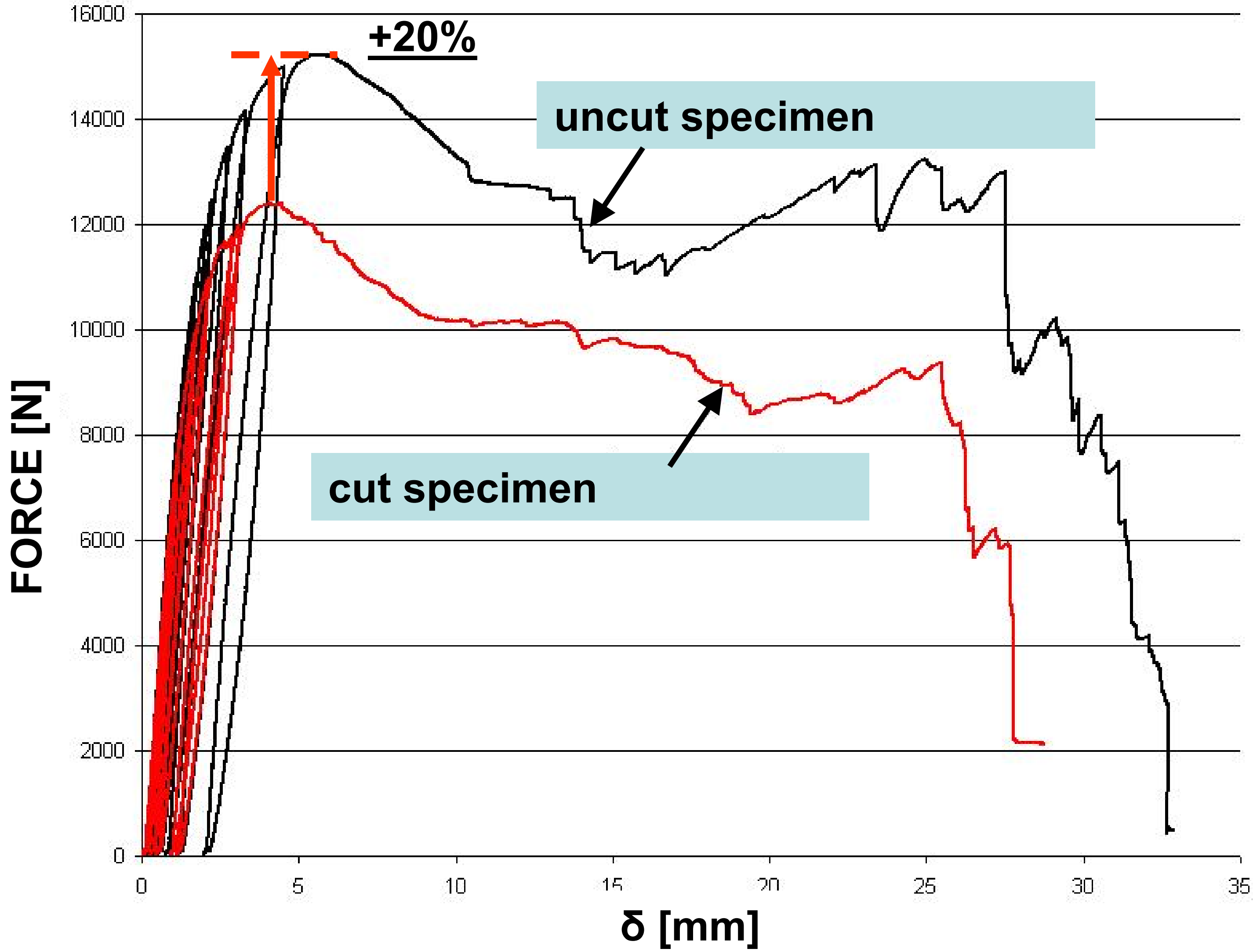
# III. The meso-scale damage model: Adaptation to braids



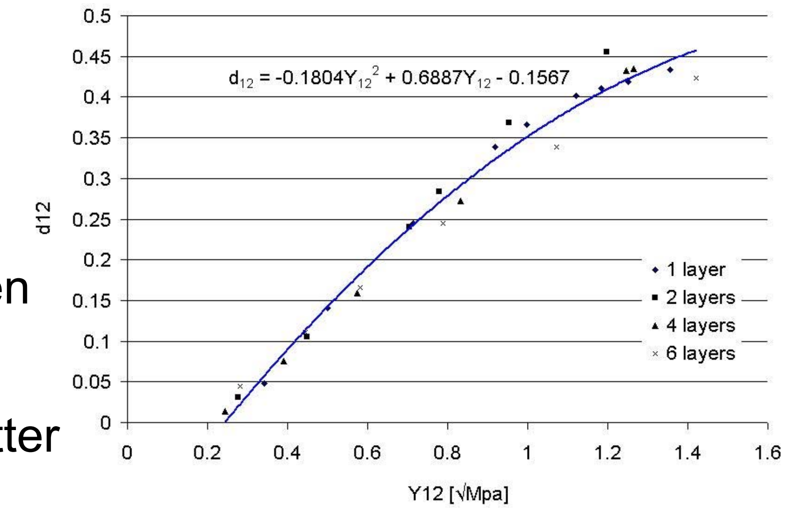
## CUT & UNCUT Comparison - Cyclic Test on [±45] laminate

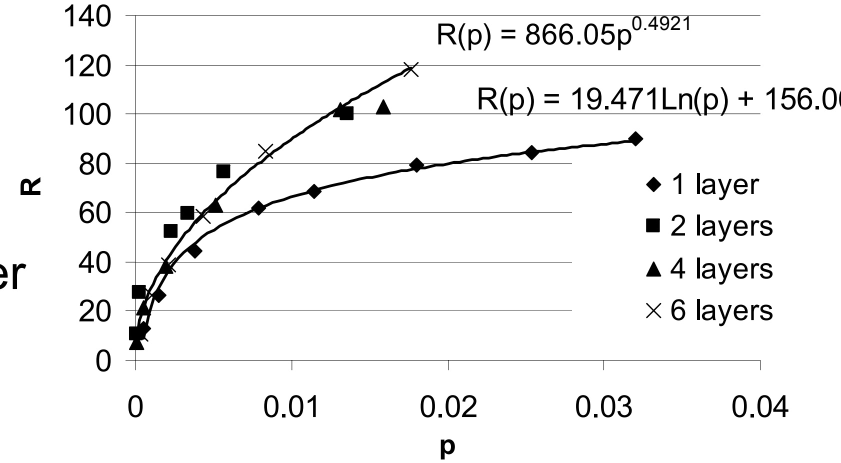


# III. The meso-scale damage model: Adaptation to braids

## 3. Lay-up effect study

- Tests on 1, 2, 4 and 6 layer coupons
- 1 & 2 layer coupons have large voids between tows
- 4 & 6 layer coupons – good coverage and better thickness consistency
- Comparable damage evolution and hardening functions
- High degree of fibre rotation for single layer
- Use of log function for hardening law for 1 layer coupon



# III. The meso-scale damage model: Adaptation to braids

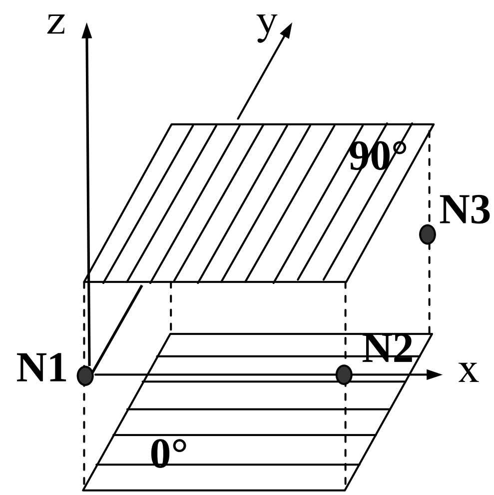
## 3. Modelling & Results

→ Damage model implemented in Pam-Crash™

- Two super-imposed shell elements containing 1 ply each and sharing same nodes
- Use of a linear damage law gives premature failure
- Under prediction of the stress and softer response

→ Modified model

- Use of logarithmic and polynomial damage law approximations gives good failure prediction
- Unable to predict post peak load where delamination is non-negligible



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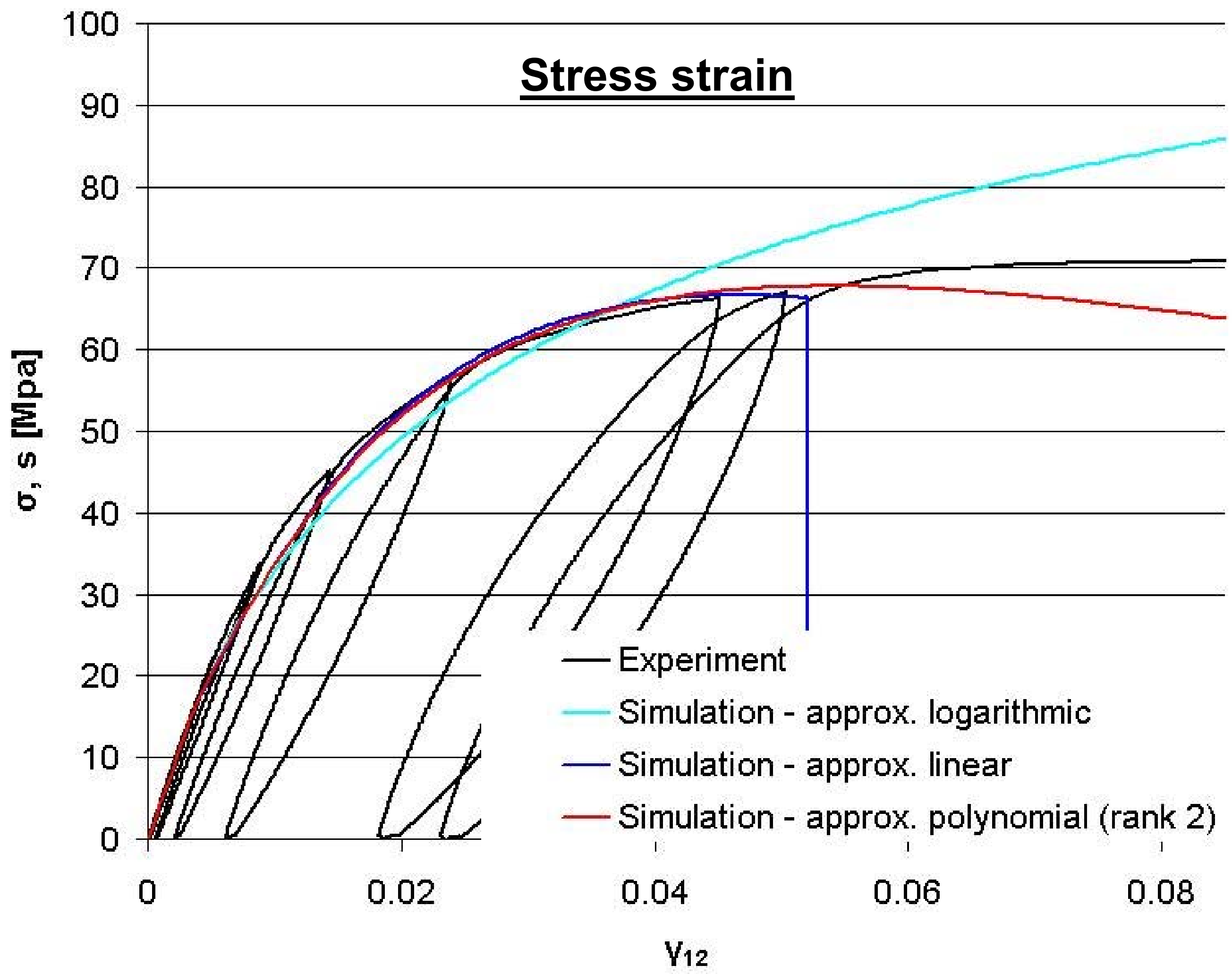
# III. The meso-scale damage model: Adaptation to braids



## 3. Modelling & Results



# VI. Conclusions – Next steps



## → Conclusions

- Adaptation of a ply damage model to braided composites
- Edge effect and lay-up studies
- Better understanding on the shear failure mechanism
- Non-linearity of the damage law
- Implementation of logarithmic and polynomial approximations

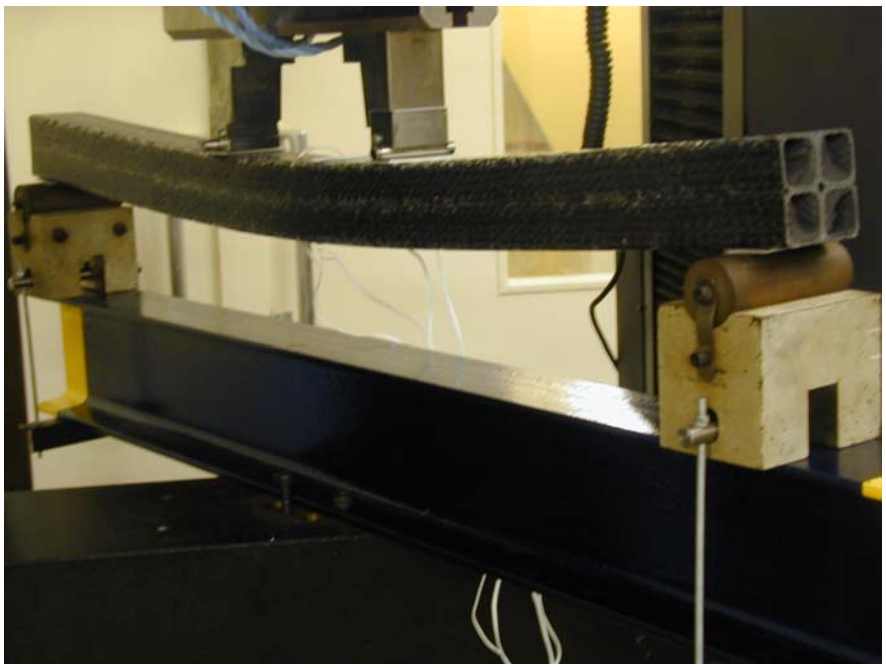
## → Next steps

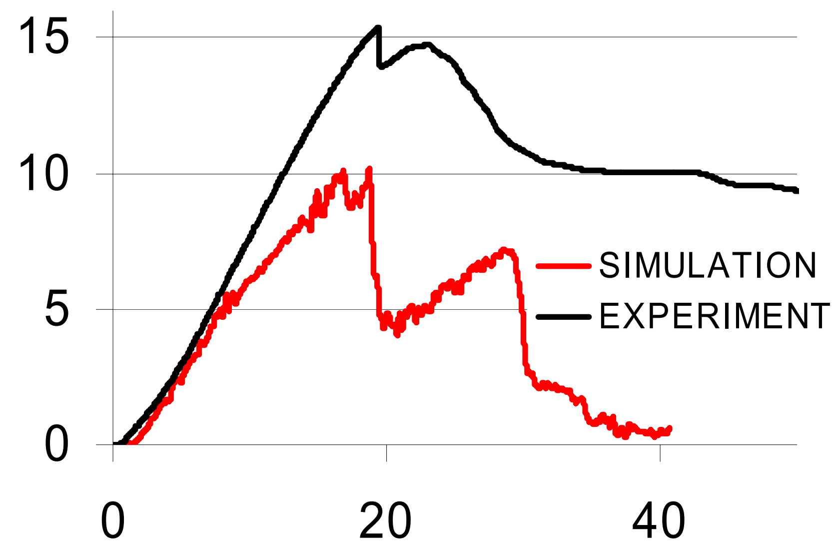
- Determination of delamination effect (Mode I, II, III)
- Delamination modelling after peak load (energy absorption)
- Eventual simulation using 4 beam elements joining element nodes
- Beam and tube modelling for energy absorbers (e.g car bumper)

# VI. Conclusions – Next steps

- Interest in braided beam
- Simulation using linear approximation for damage law

→ Premature failure






**Test and simulation on 4 point bending beam**