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# Fracture of Advanced Composite Materials: Experimental Basis for a Constitutive Model

*PhD Thesis*

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*and*

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# Structure of the presentation

- Motivation
- Objectives
- Experimental basis for improved constitutive models
- Conclusions and future work

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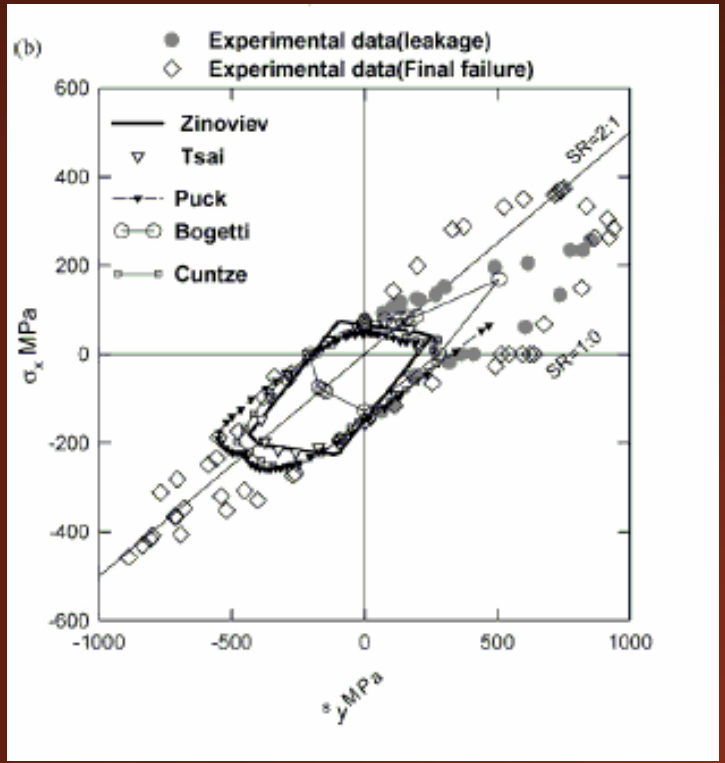
# Motivation

➢ **The existing methodologies are unreliable**




**Comparison between the predicted and measured 'initial' failure stresses for (±55º) E-glass/MY750 laminates subjected to biaxial loads**

P.D. Soden et al., Composites Science and Technology 64 (2004) 589–604 595

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# Motivation

- **The deficiencies in the models representing the mechanical behaviour of advanced composites have tremendous effects on the costs of composite structures.**

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# Objectives

- **To understand of the damage processes**

- **To develop an analytical model based on continuum damage mechanics and fracture mechanics able to represent damage onset, damage propagation and structural collapse of advanced composite structures under realistic service conditions.**

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# Experimental basis for improved constitutive models

- **How to measure the fracture toughness associated with fibre fracture under tension and compression?**
- **Is there an in-situ effect for matrix cracking under transverse compression?**
- **What are the conditions that trigger fibre kinking under transverse tension and longitudinal compression?**
- **How the transverse matrix cracks evolve under the combined action of in-plane shear stresses and transverse tension?**
- **How the damage under shear affects the elastic properties in the transverse direction?**
- **What is the effect of transverse tension/compression on the shear nonlinear response?**

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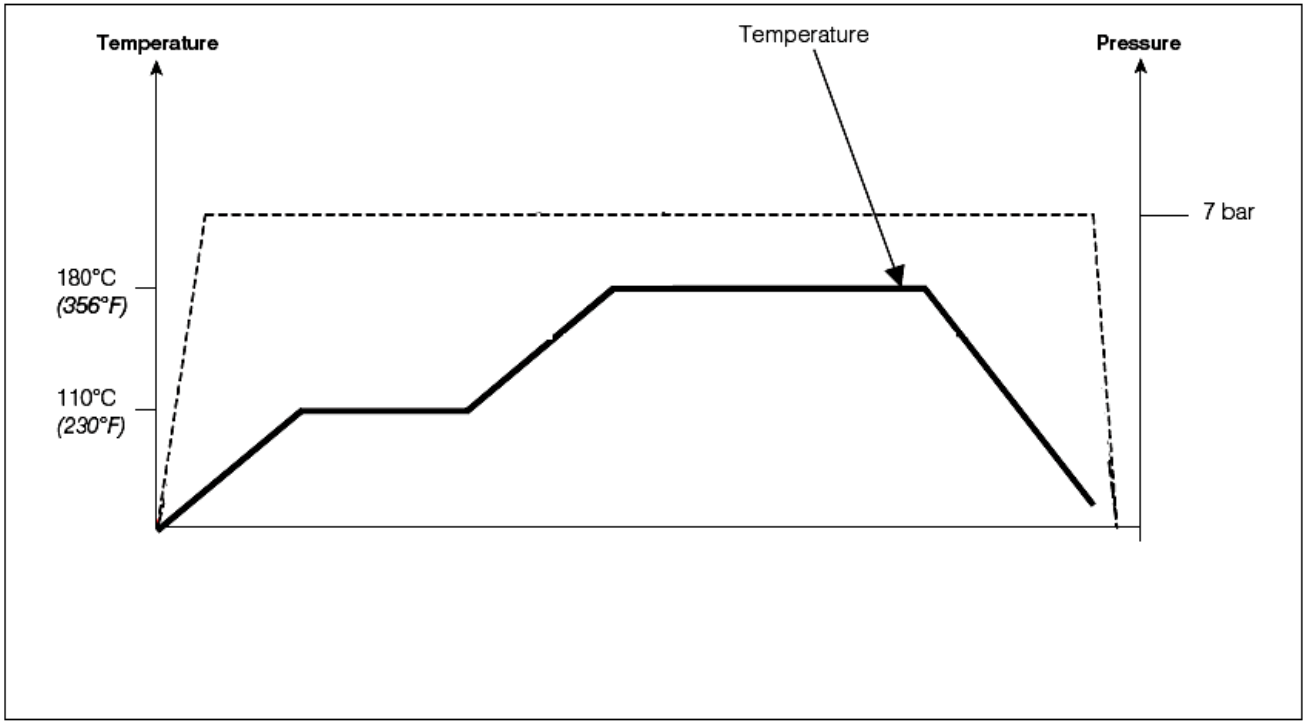
# Selection and mechanical characterization of the material

## Hexcel IM7/8552 carbon epoxy unidirectional pre-preg



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# Selection and mechanical characterization of the material

| Fibre volume fraction | 59.1% |
|---|---|
| **Elastic properties** | |
| $E_1$ (GPa) | 171.42 |
| $E_2$ (GPa) | 9.08 |
| $V_{12}$ | 0.32 |
| $V_{21}$ | 0.01695 |
| $G_{12}$ (GPa) | 5.29 |
| **Strength properties** | |
| $Y_t$ (MPa) | 62.29 |
| $S_L$ (MPa) | 92.34 |
| $Y_C$(MPa) | 199.81 |
| $X_C$ (MPa) | 1200.7 |
| $X_t$ (MPa) | 2326.23 |
| **Fracture toughness (kJ/m$^2$)** | |
| $G_{IC}$ | 0.2774 |
| $G_{IIC}$ | 0.7879 |

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➢ **Experimental basis for improved constitutive models**

Conclusions and future work

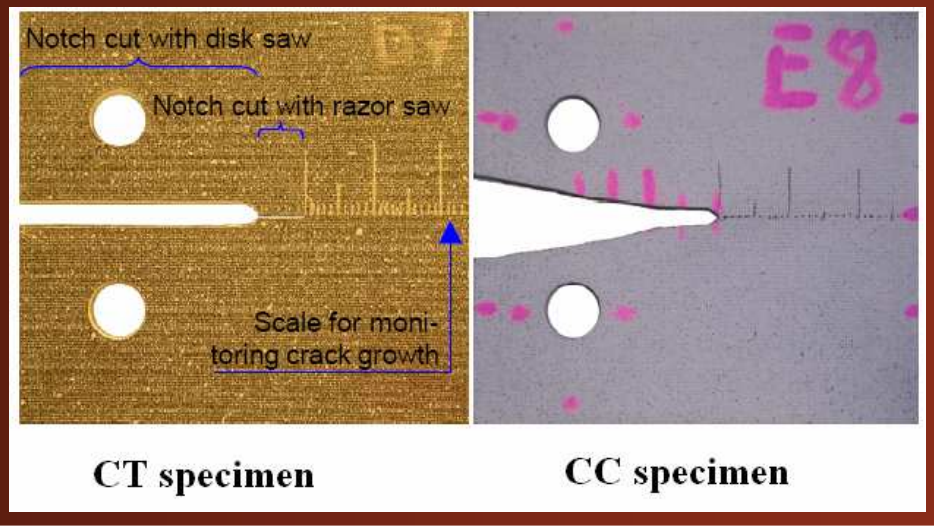
# How to measure the fracture toughness associated with fibre fracture under tension and compression?

➢**Fibre breaking can occur during longitudinal tension or compression**

➢**The energy consumed by these failure processes is greater than the failures involving any matrix or matrix-fibre debond failure**

➢**There are no standards to determine these properties**

➢**Pinho et al, measured these properties "adapting" the Compact Tension (CT) specimens used in metal, to the composite. Based in previous work, they developed the CT and Compact Compression (CC), and also develop a method to data reduction applied to orthotropic materials.**



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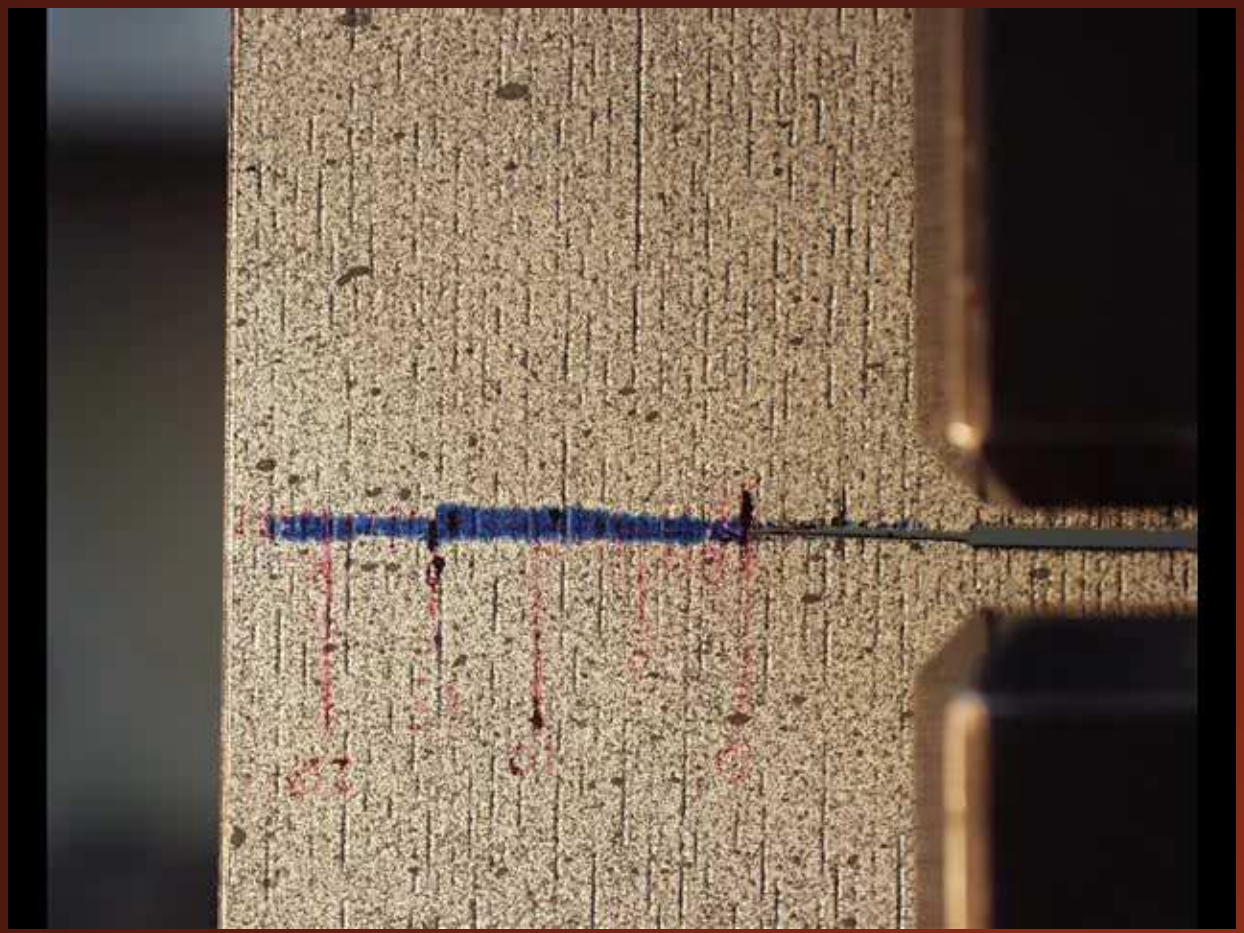

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# How to measure the fracture toughness associated with fibre fracture under tension and compression?

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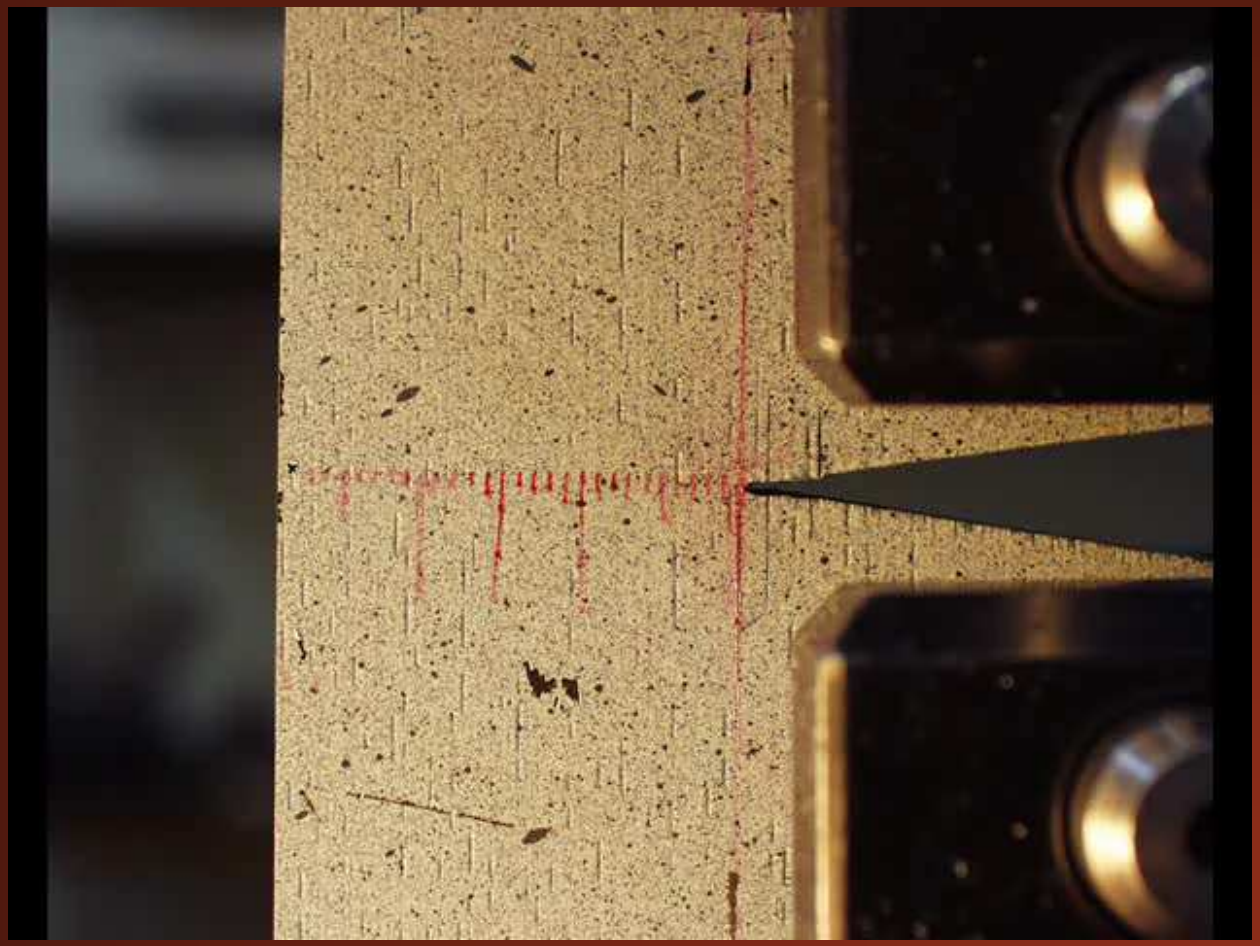

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# Is there an in-situ effect for matrix cracking under transverse compression?

➢**Several failure criterions are based in ply properties obtained by test unidirectional specimens.**

➢**It was shown that the strength of a ply in a laminated is higher than the strength obtained in the unidirectional test. This effect is known as "*In-Situ*" effect.**

➢**The "*In-Situ*" effect exists in the transversal tension strength and in the shear strength; But nothing is known about this effect on the transversal compression strength.**

| Effect of thickness of 90° layer ↓ / Effect of stiffness of external layers → | |
|---|---|
| A - $[(\pm 45)_6/90]_s$ | C - $[(\pm 60)_6/90]_s$ |
| B - $[(\pm 45)_5/90_3]_{2s}$ | D - $[(\pm 60)_5/90_3]_s$ |

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# Is there an in-situ effect for matrix cracking under transverse compression?

| Test type | Objective | Equipment | Nº of specimens |
|---|---|---|---|
| ASTM D3410- 87 compression test with AE technique | Load/Displacement curves, Stress/Strain curves, Compression Strength, Relation between AE activity and stress | Strain gauges AE sensors | 5 |
| Compression test with replica technique | Relation between crack density and stress | Cellulose acetate | 3 |

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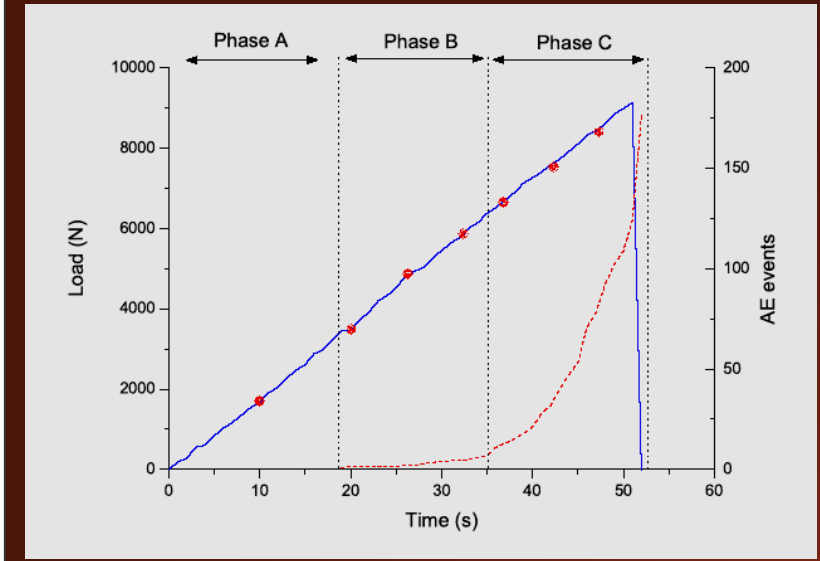
# Is there an in-situ effect for matrix cracking under transverse compression?




- **Compression Test**

  **Compare of the transverse compressive strength of 90º ply obtained for the different laminates**

- **Acoustic Emission**

  **Damage onset**

  **Damage evolution: Type and amount of damage**

  **Select the load points to the replica test**

- **Replica Technique**

  **Monitoring the formation of cracks and they position**

  **Relation between stress and crack density**

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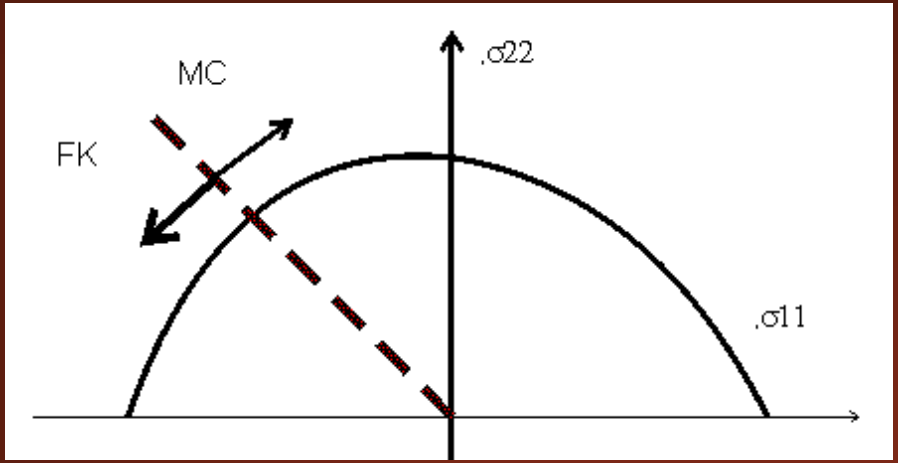
# What are the conditions that trigger fibre kinking under transverse tension and longitudinal compression?





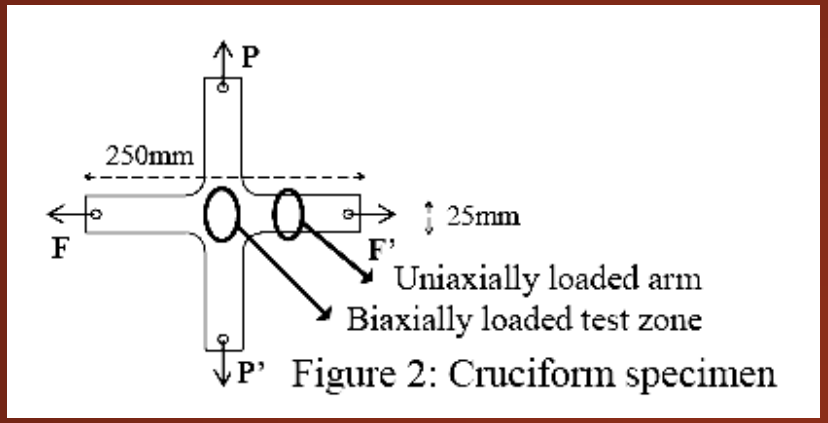


Figure 2: Cruciform specimen

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# Conclusions future work

- **The material has been selected and characterized**
- **The tests to measure the fracture toughness associated with fibre fracture under tension and compression are being performing**
- **A test matrix to analyse the existence of "In-Situ" effect on the transversal compressive strength was developed .**
- **The use of biaxial test to determine the conditions that trigger fibre kinking under transverse tension and longitudinal compression, are being planned.**
- **Try to answer the previous questions**