Imperial College London

The Composites Centre

for research, modelling, testing and training in advanced composites

Modelling Delamination in an Explicit FE Code using 3D Decohesion Elements

CompTest2004

Bristol, 21st - 23rd September 2004

Paper Nº 93

Silvestre T Pinho, Dr. Lorenzo Iannucci & Dr. Paul Robinson
Department of Aeronautics
Imperial College London

Imperial College London

The Composites Centre

for research, modelling, testing and training in advanced composites

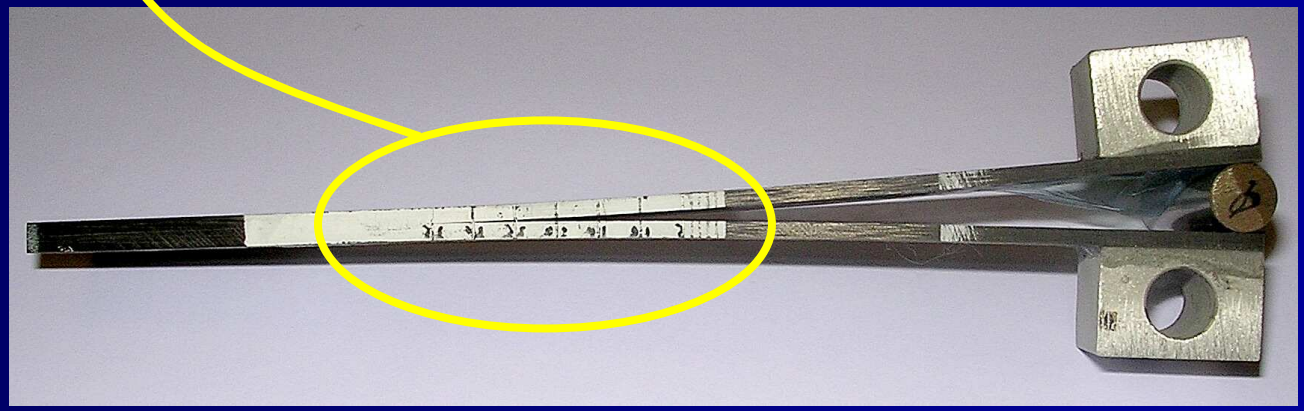
Outline

- Introduction
- Experimental tests
- Modelling delamination
  - Bilinear and 3rd order polynomial constitutive laws
  - Comparison and Applications
- Conclusions

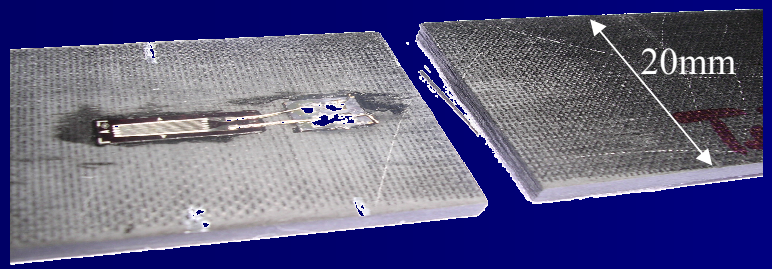
Introduction

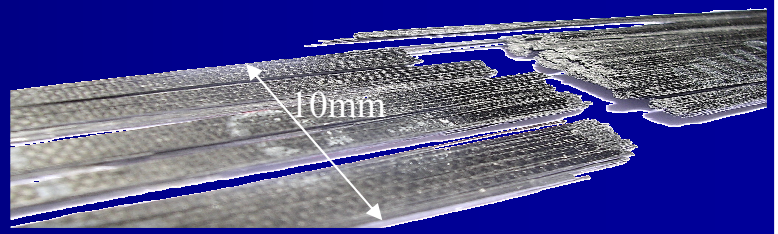
Failure modes

Delamination (interlaminar crack growth)



Other failure modes…

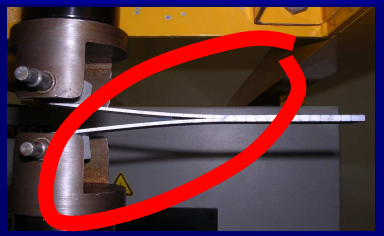


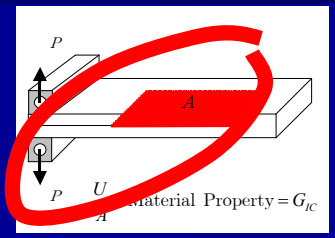


Experimental

Opening mode (Mode I)

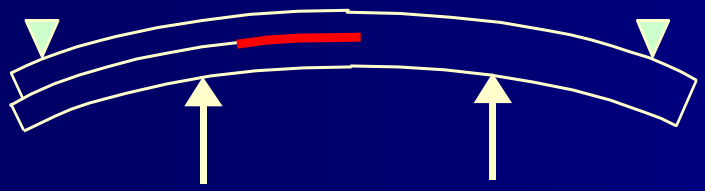
DCB test





Experimental

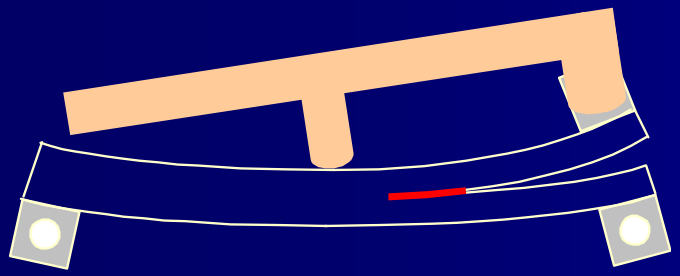
Mode II (Shearing mode)



4ENF test

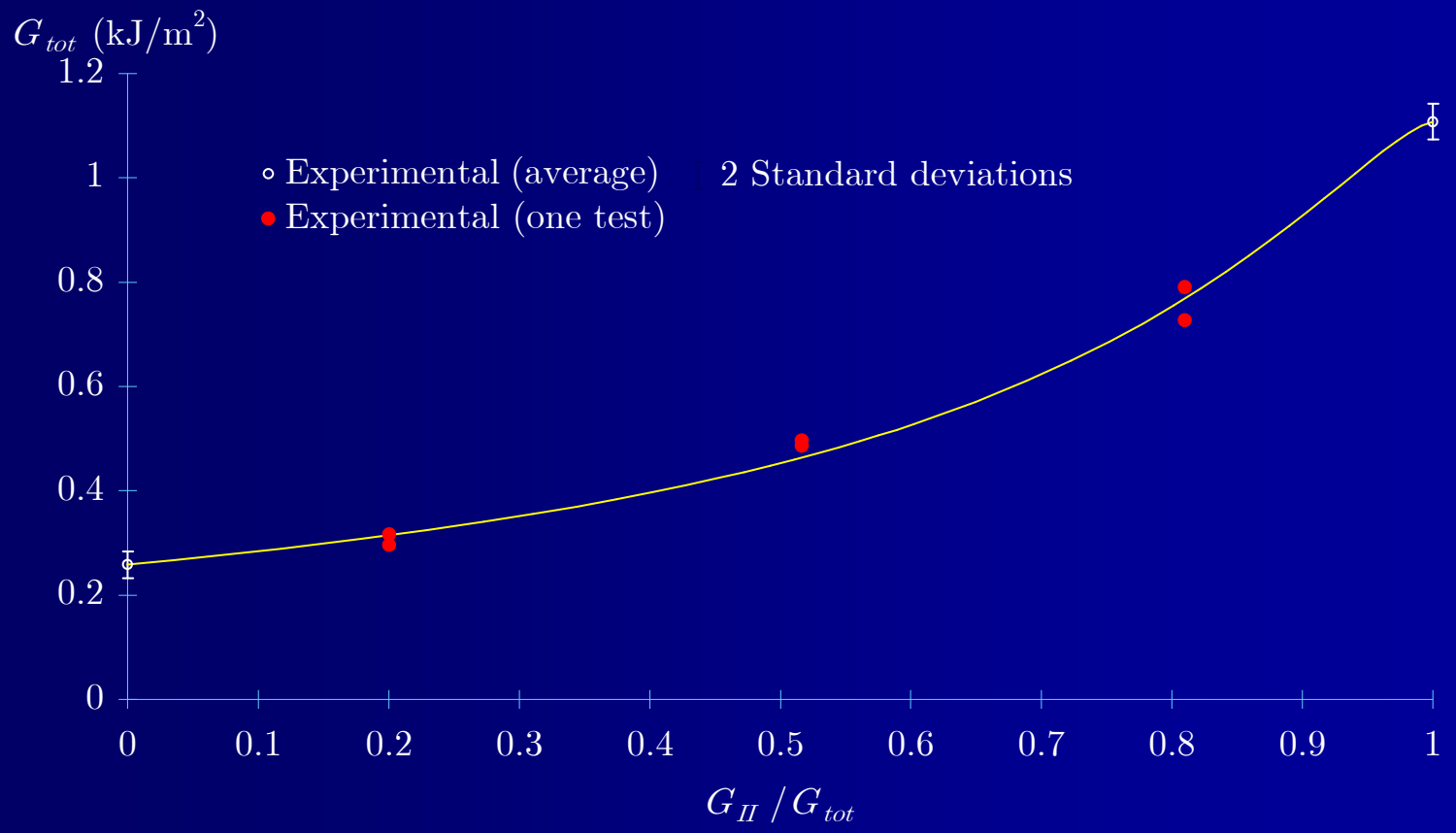
Experimental

Mixed mode I and II



Experimental

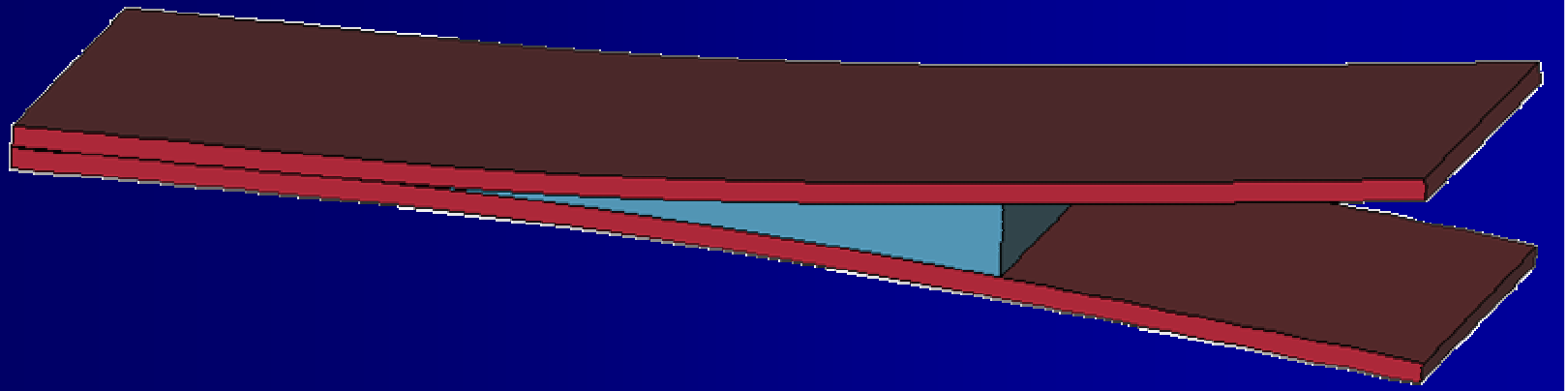
Propagation law



More details...

Modelling

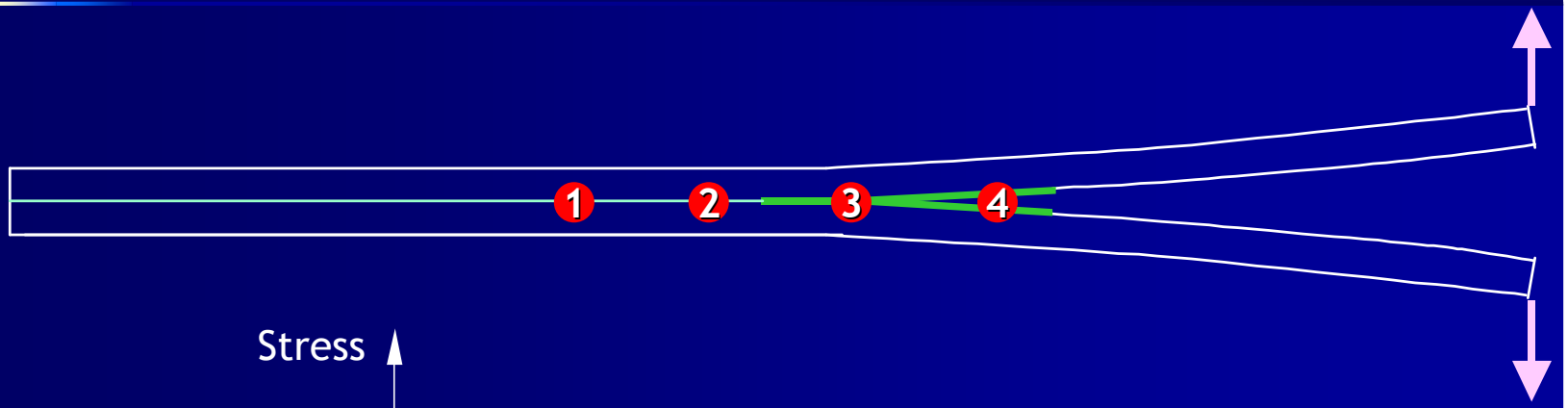
Introduction

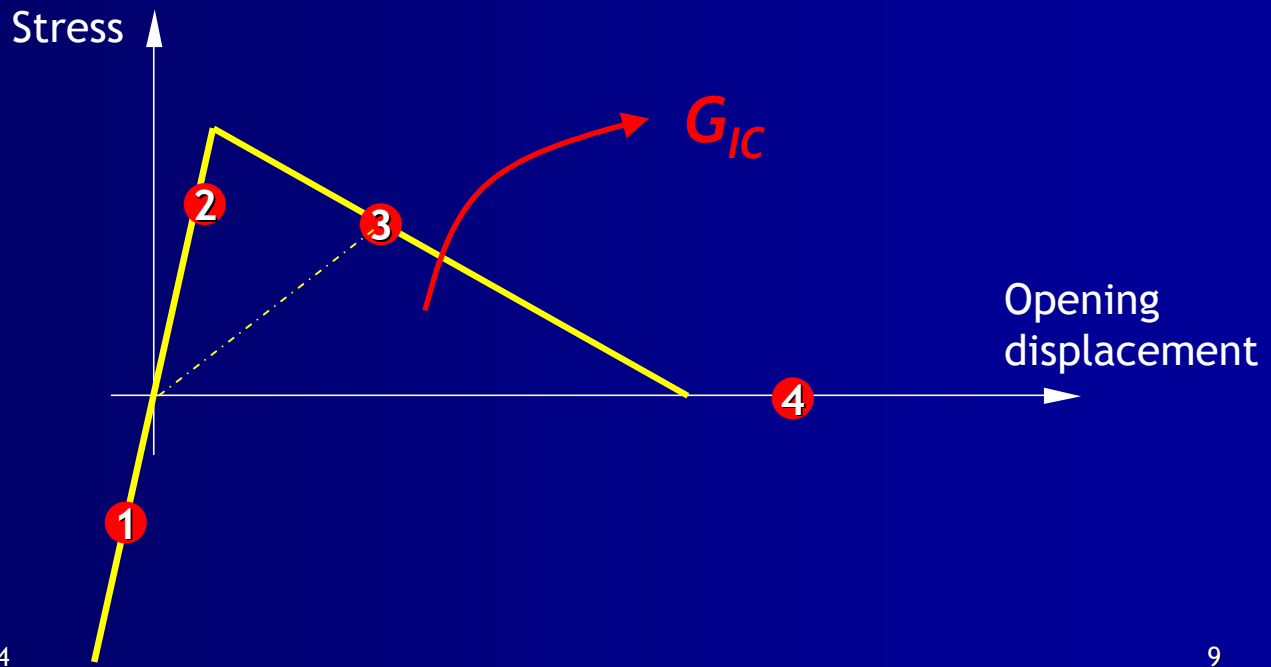


- Delamination is modelled using finite elements
- An interface element is implemented in the code LS-Dyna

Modelling

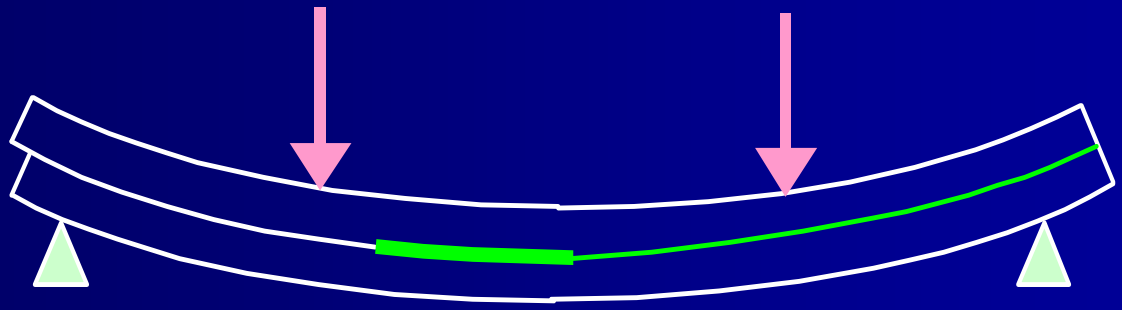
Bilinear law – Mode I





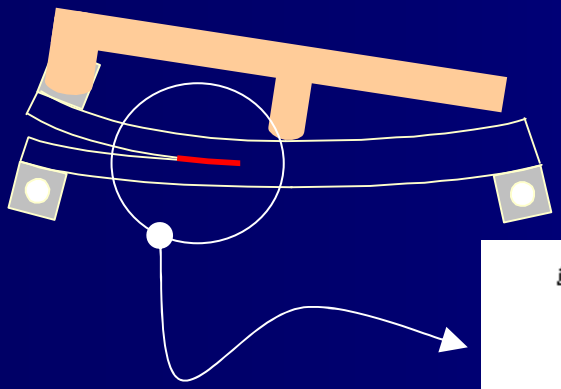
Modelling

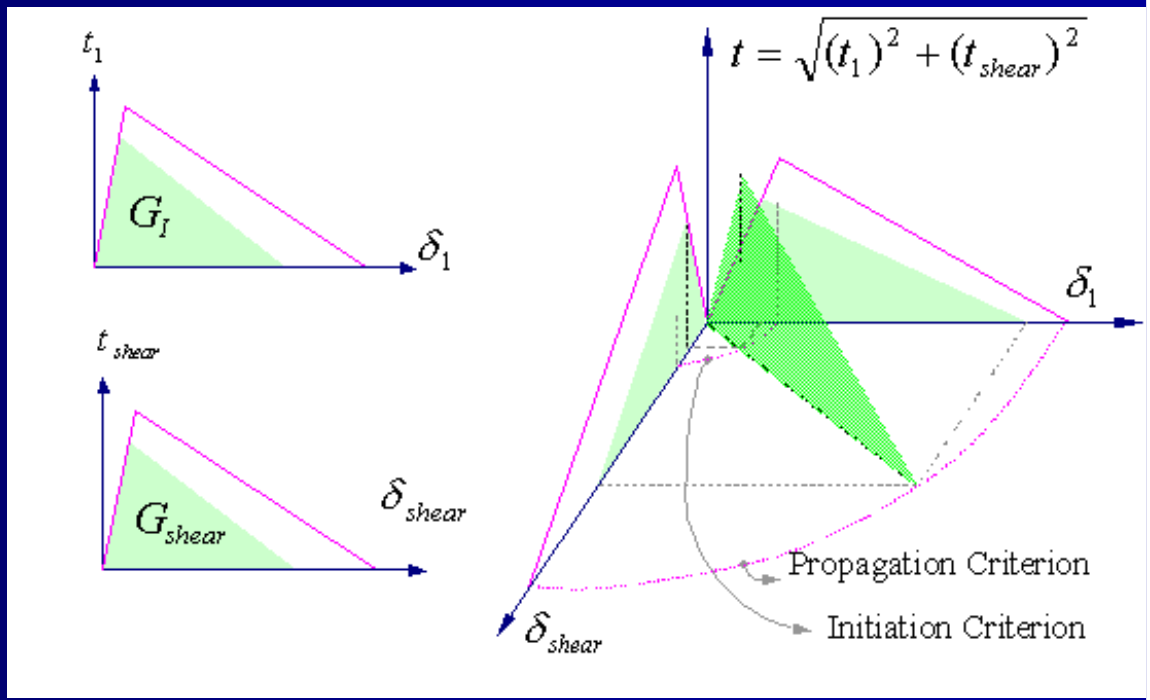
Bilinear law – Mode II



Modelling

Bilinear law – Mixed-Mode I and II





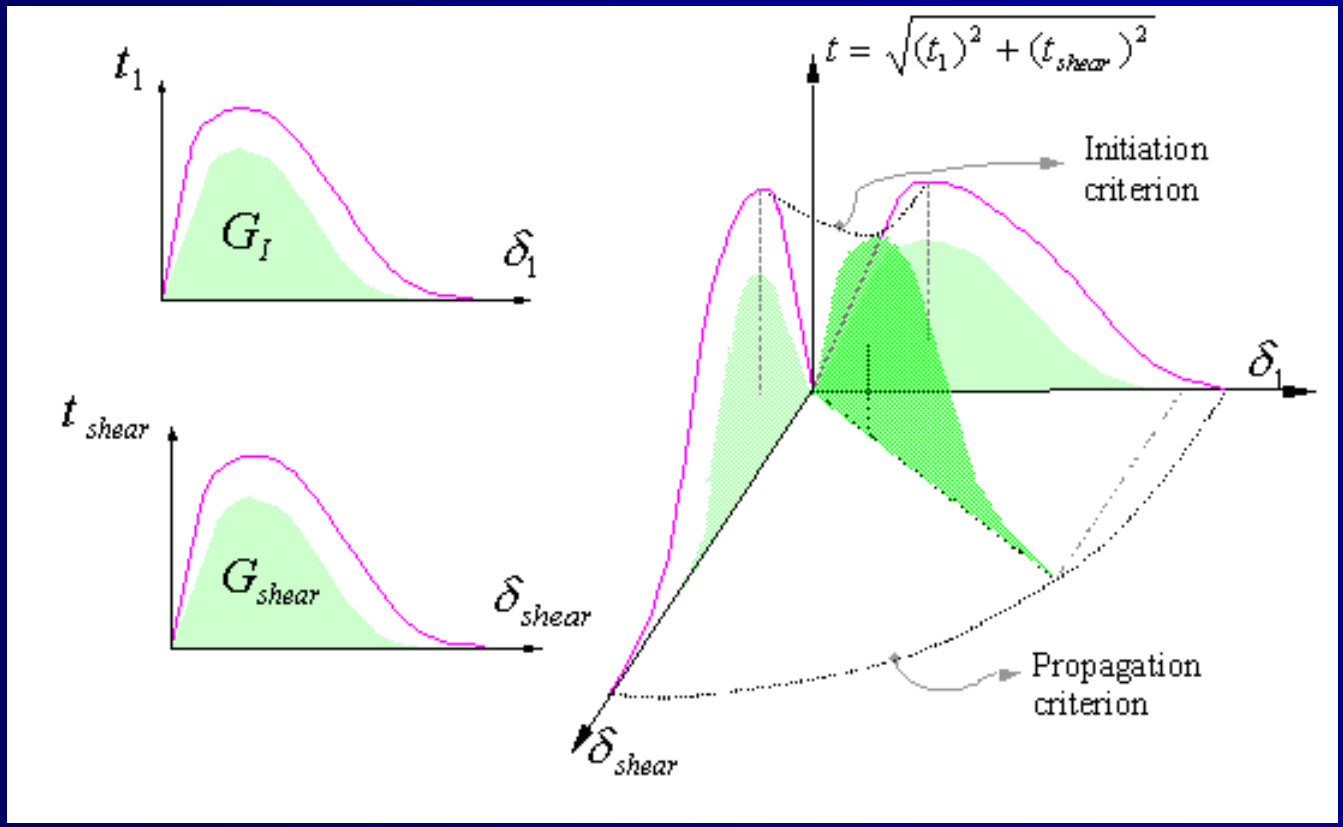
Stress displacement curves

Modelling

3rd order polynomial law

Doesn't have any discontinuity point (stability)

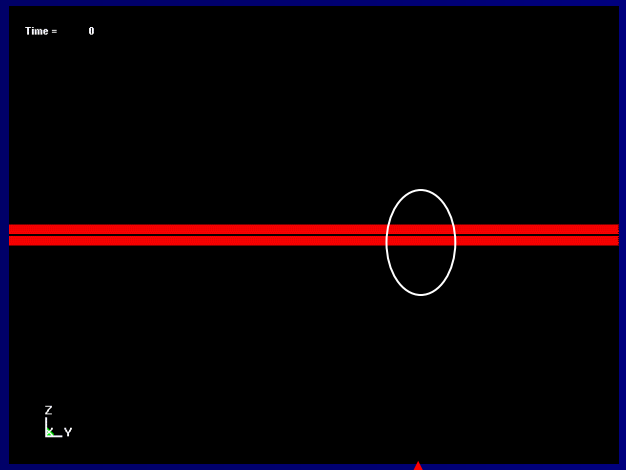
Go to Equations…

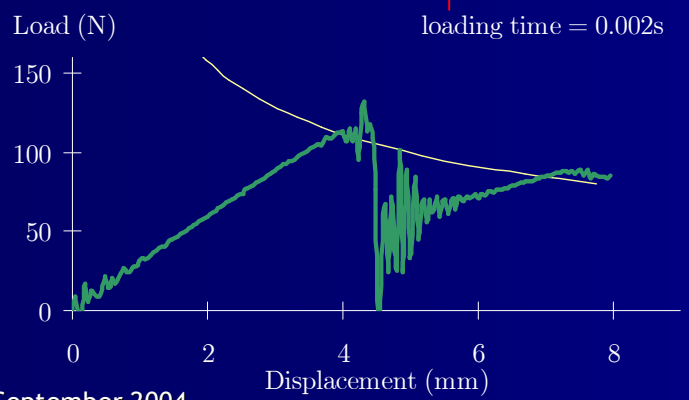


Modelling

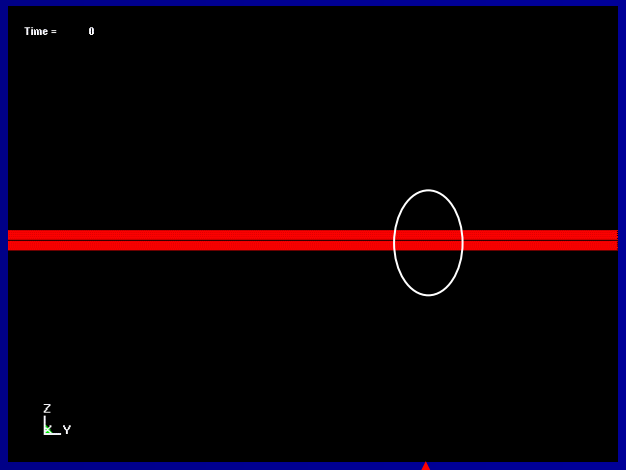
Stability - Comparison

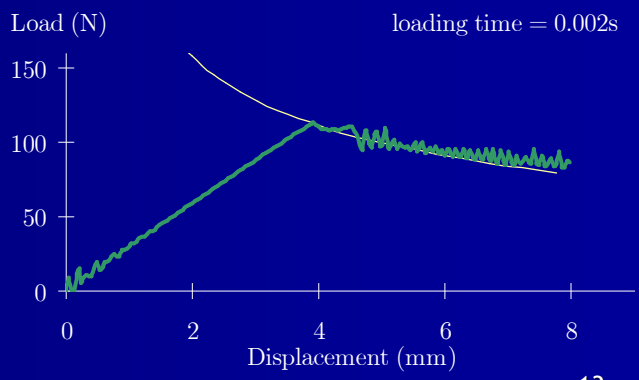
Bilinear - Unstable





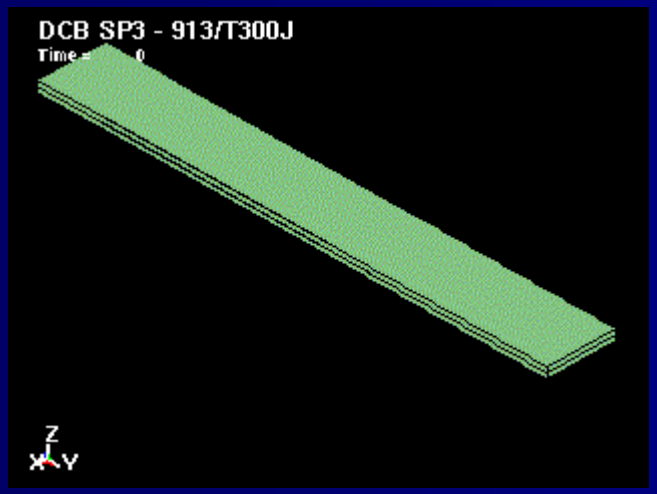
3rd order - Stable

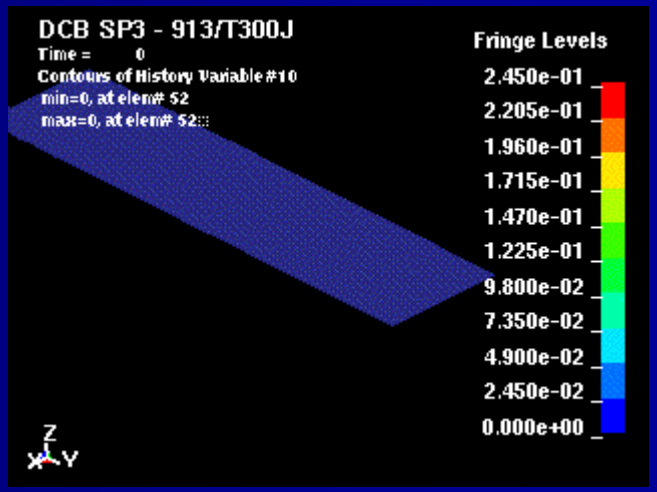


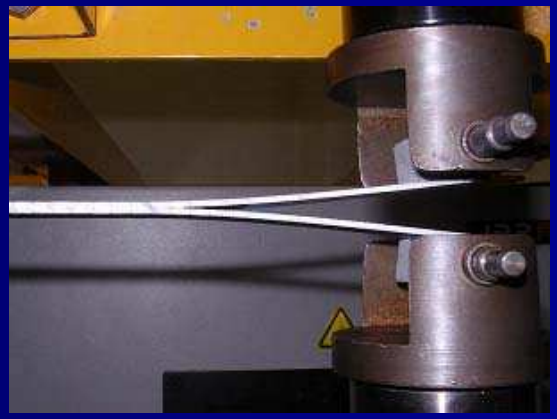


Modelling

Mode I application: DCB test

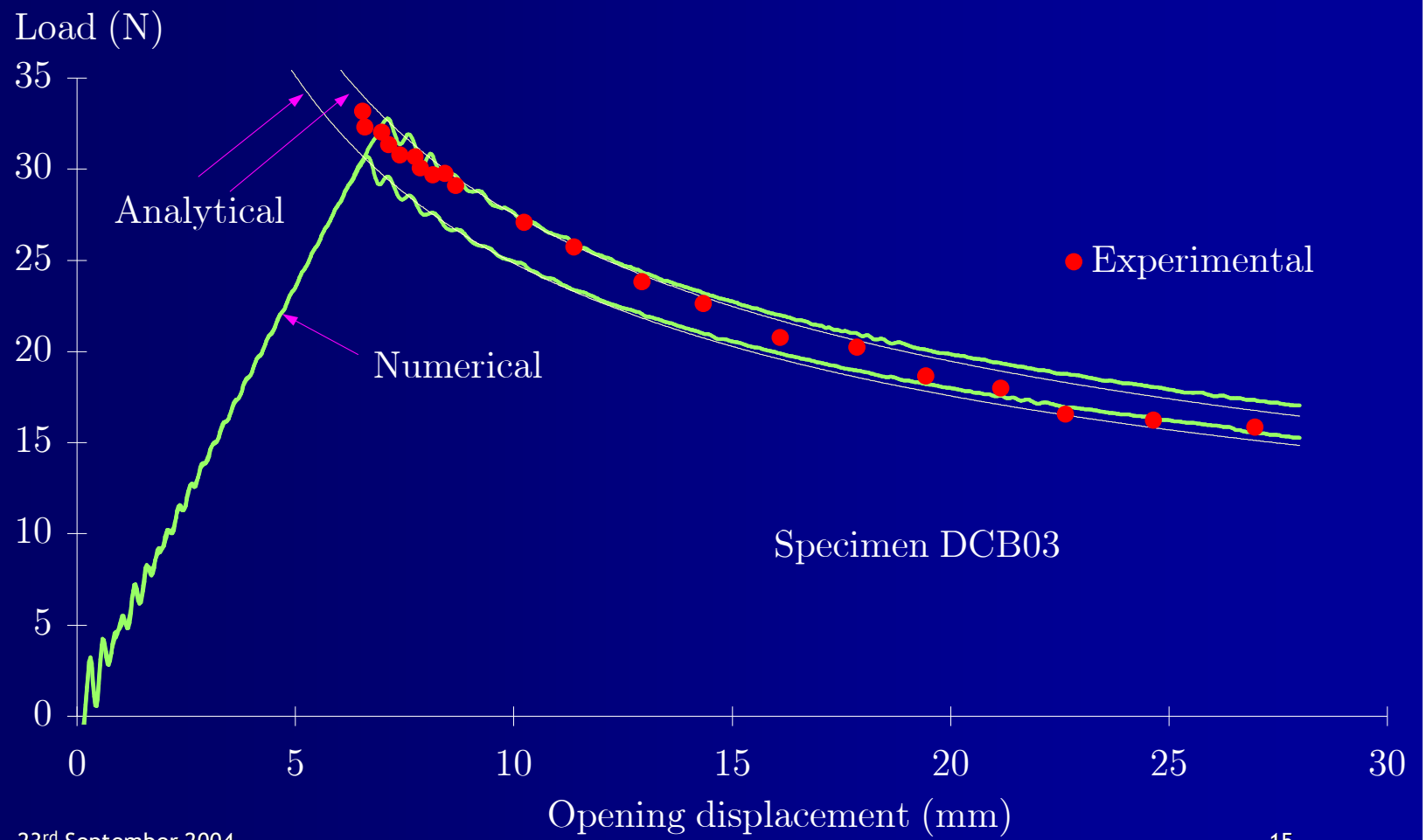






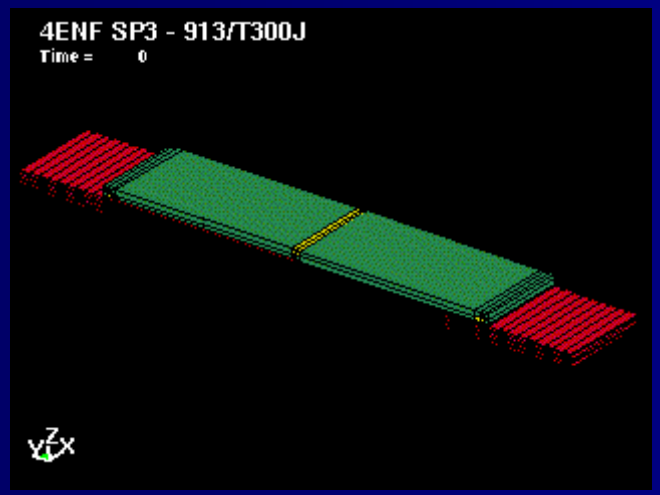
Modelling

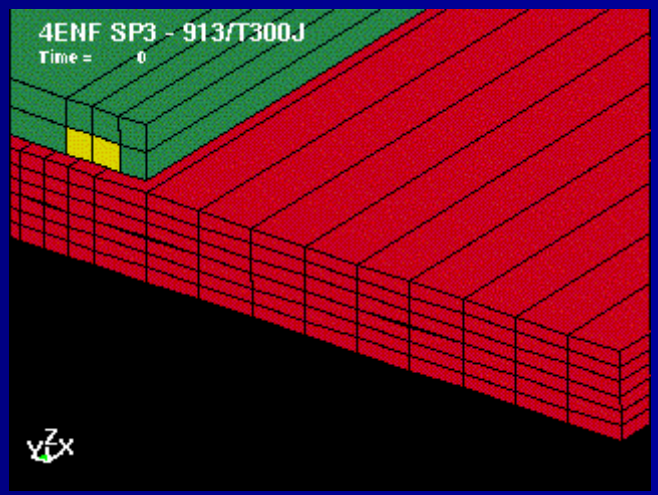
Mode I application: DCB test



Modelling

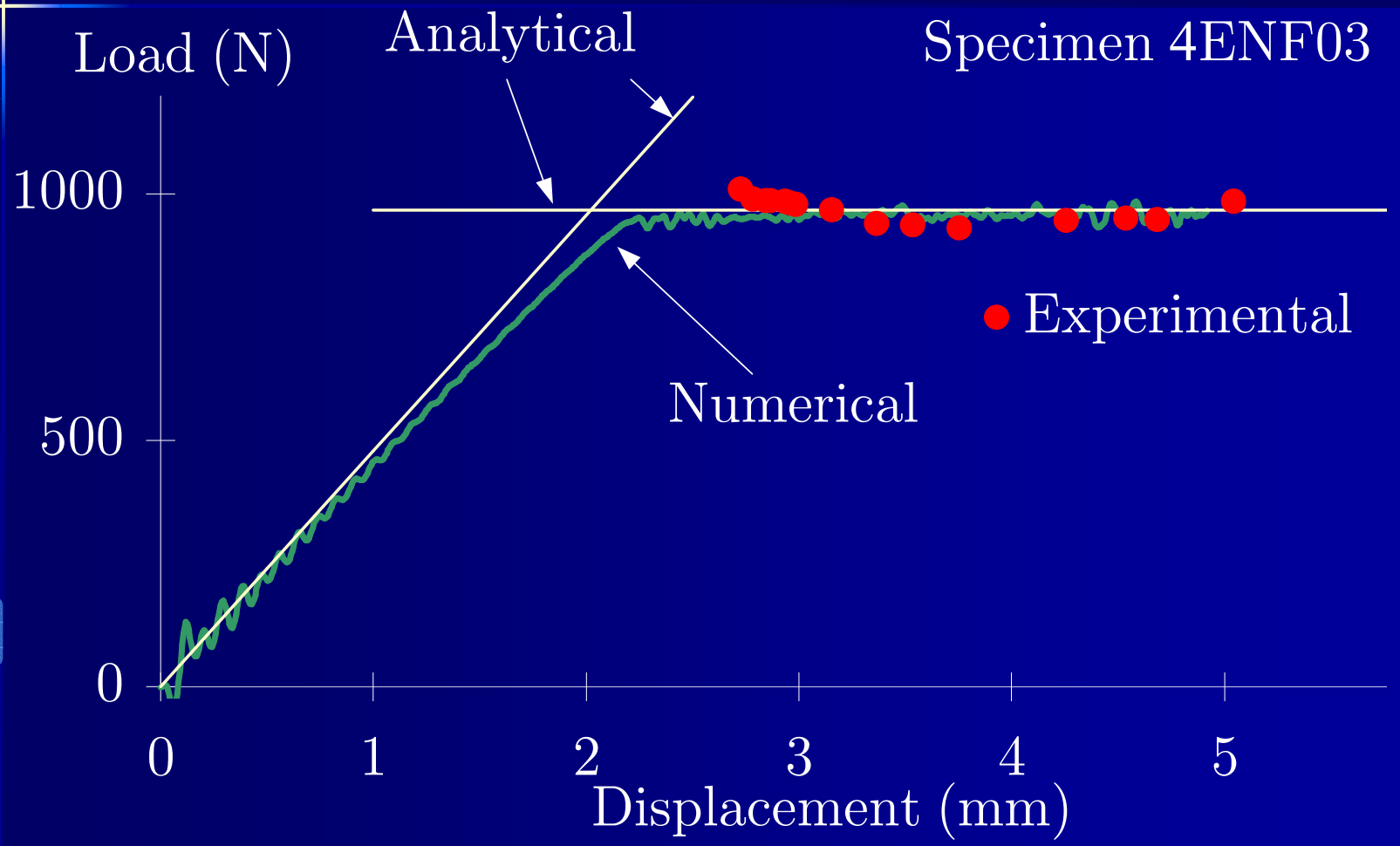
Mode II application: 4ENF test





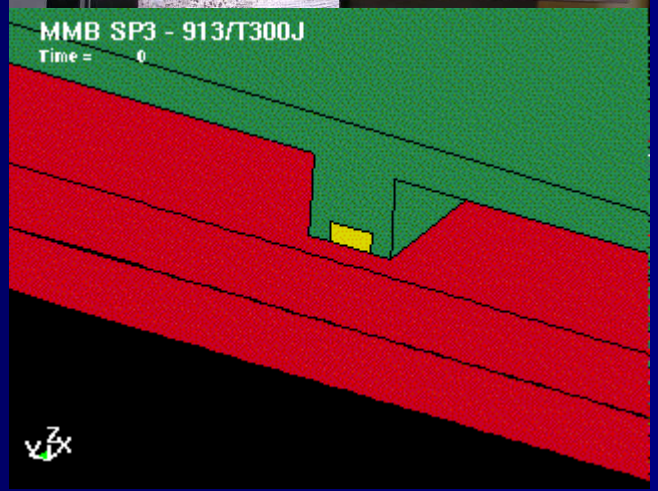
Modelling

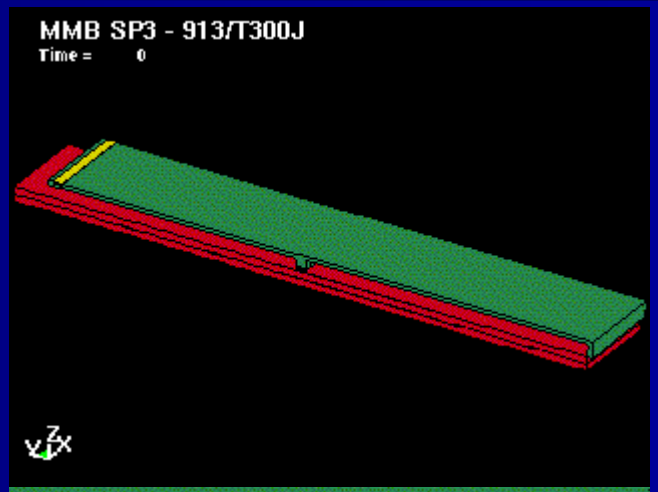
Mode II application: 4ENF test

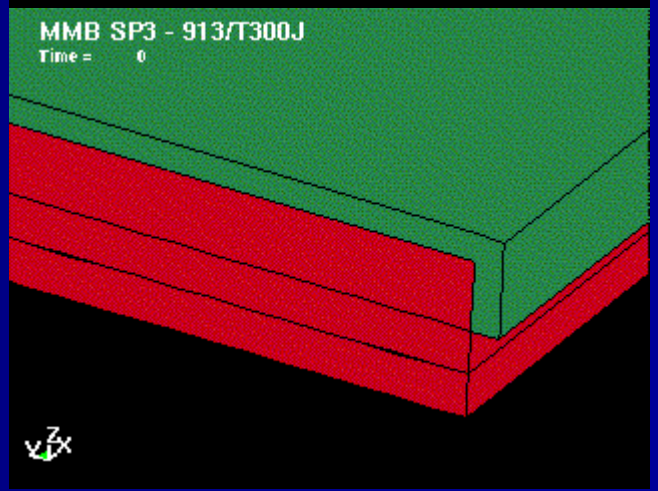


Modelling

Mixed-Mode I and II application: MMB test

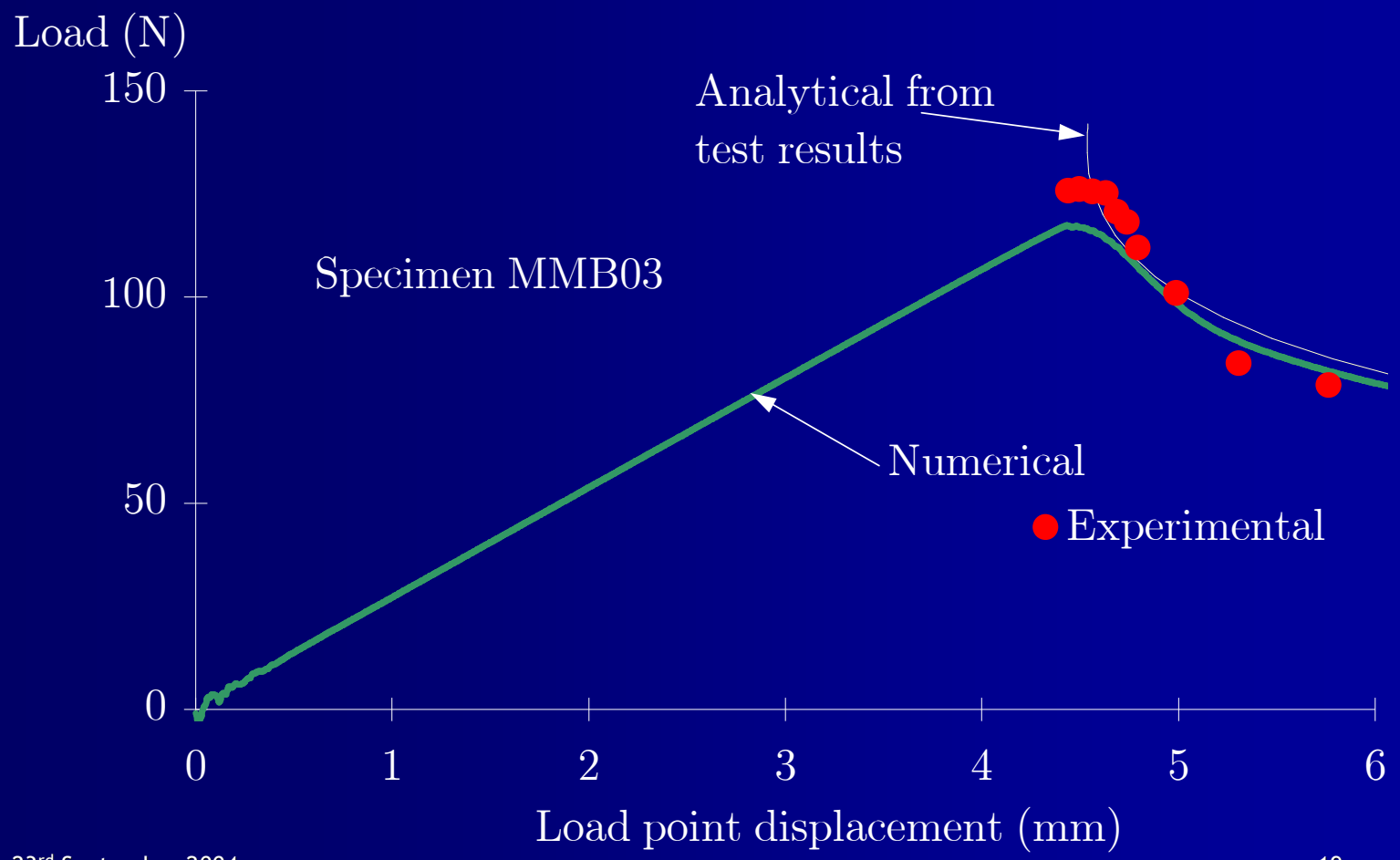






Modelling

Mixed-Mode I and II application: MMB test



Summary & Conclusions

1/2

- An interface element has been formulated and implemented in the code LS-Dyna
- It has been validated against obtained experimental data and analytical results

Summary & Conclusions

2/2

- Advantages when modelling delamination:
  - Energy absorbed correctly accounted for
  - Mesh-independent
  - No need to specify the mode of crack growth
  - No need to know if there is going to be delamination
  - Explicit code → complex structures can be modelled
- Disadvantages:
  - Adds to the complexity of the model
  - Numerical instabilities
  - Computational time increased

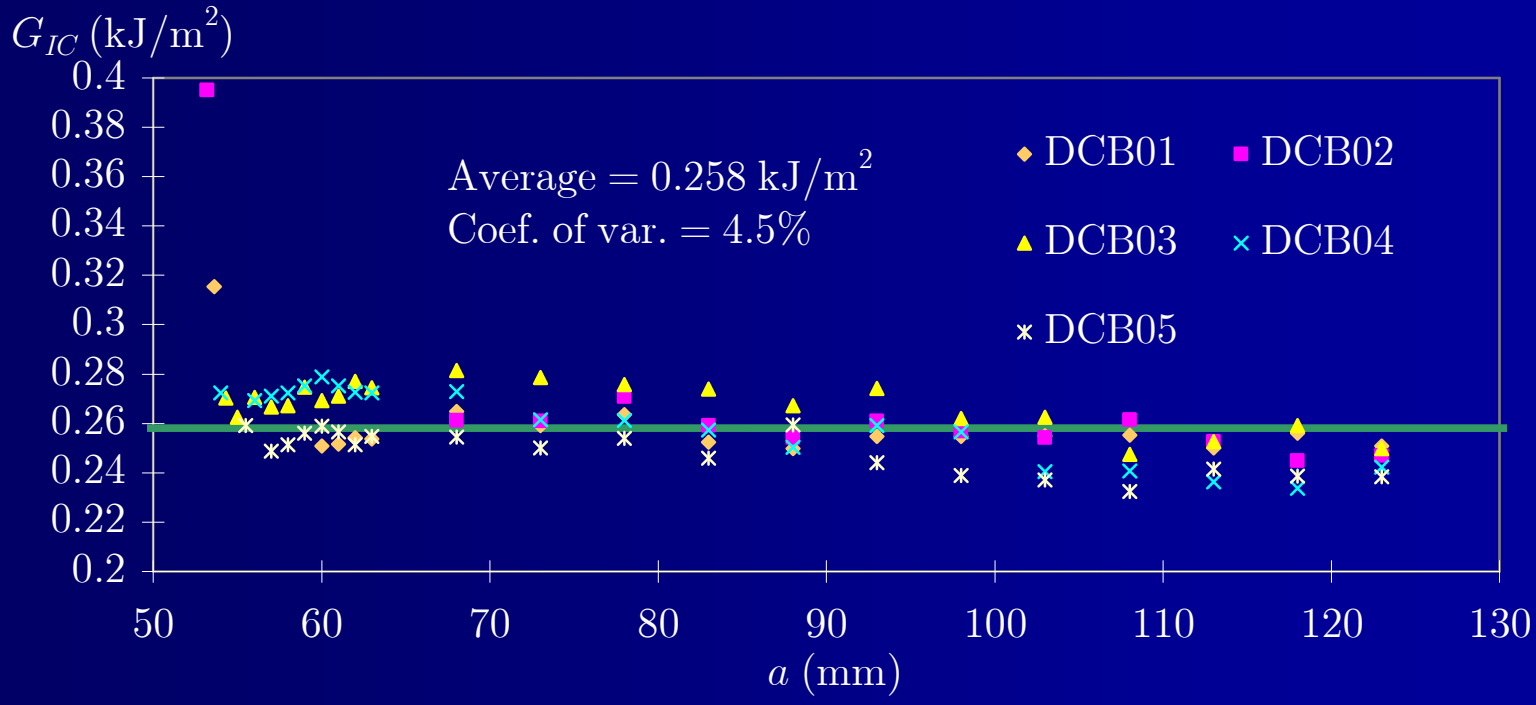
Acknowledgments

The scholarship from the Portuguese foundation
Fundação para a Ciência e Tecnologia
is acknowledged

Any Questions?

Delamination - Experimental

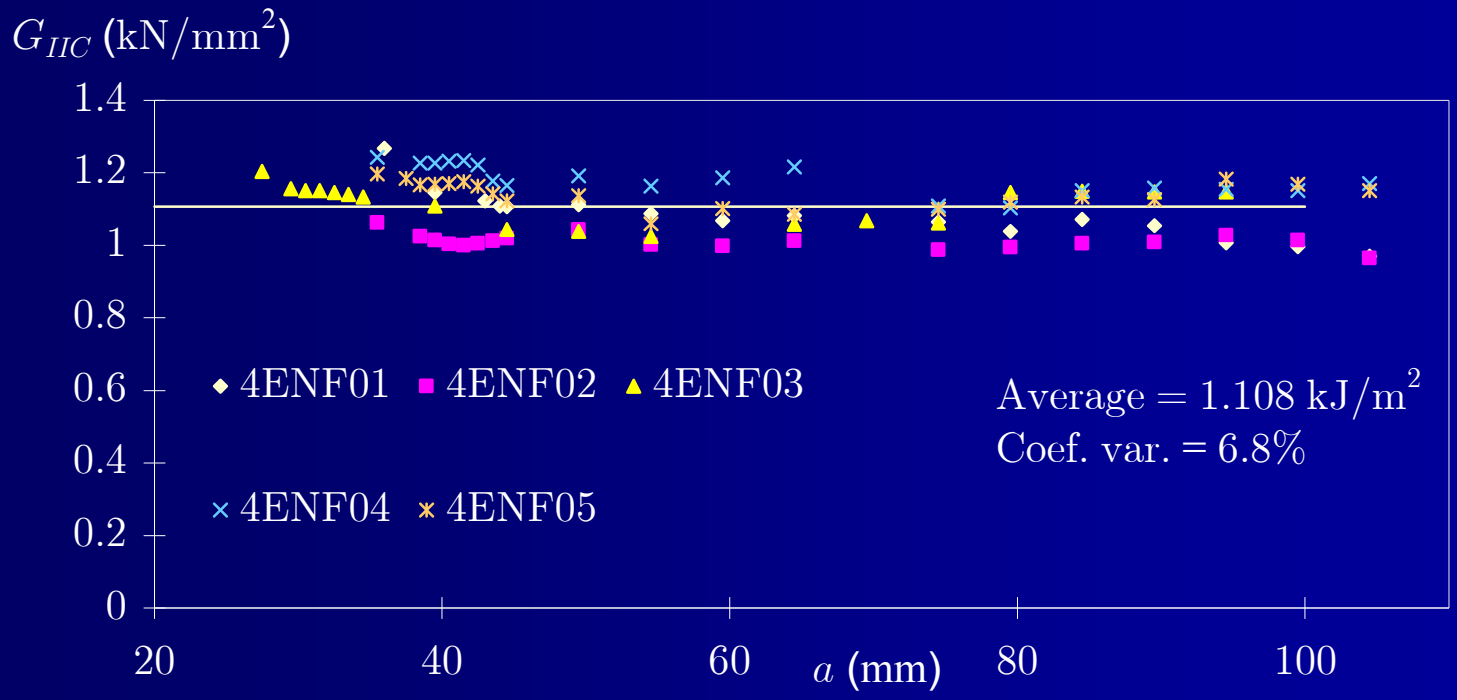
Mode I



Go back...

Delamination - Experimental

Mode II



Go back...

Delamination - Modelling

Curve law

3rd order polynomial

$$t_i = \frac{27}{4} t_i^o \left(1 - \frac{\delta_i^{\max}}{\delta_i^f}\right)^2 \frac{\delta_i}{\delta_i^f}$$

Compression

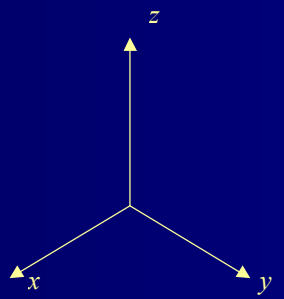
$$t_1 = K\delta_1 \Leftarrow \delta_1$$

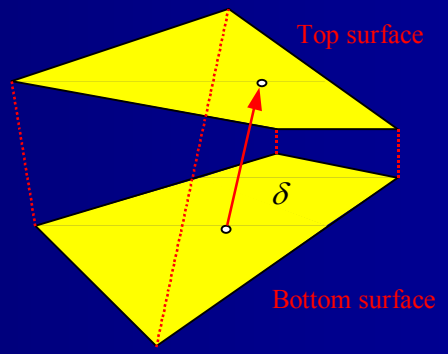
Initiation criterion

$$\left(\frac{\langle t_1 \rangle}{t_1^o}\right)^2 + \left(\frac{t_2}{t_{shear}^o}\right)^2 + \left(\frac{t_3}{t_{shear}^o}\right)^2 = 1.$$

Propagation criterion

$$\left(\frac{G_I}{G_{IC}}\right)^\alpha + \left(\frac{G_{shear}}{G_{shearC}}\right)^\alpha = 1.$$

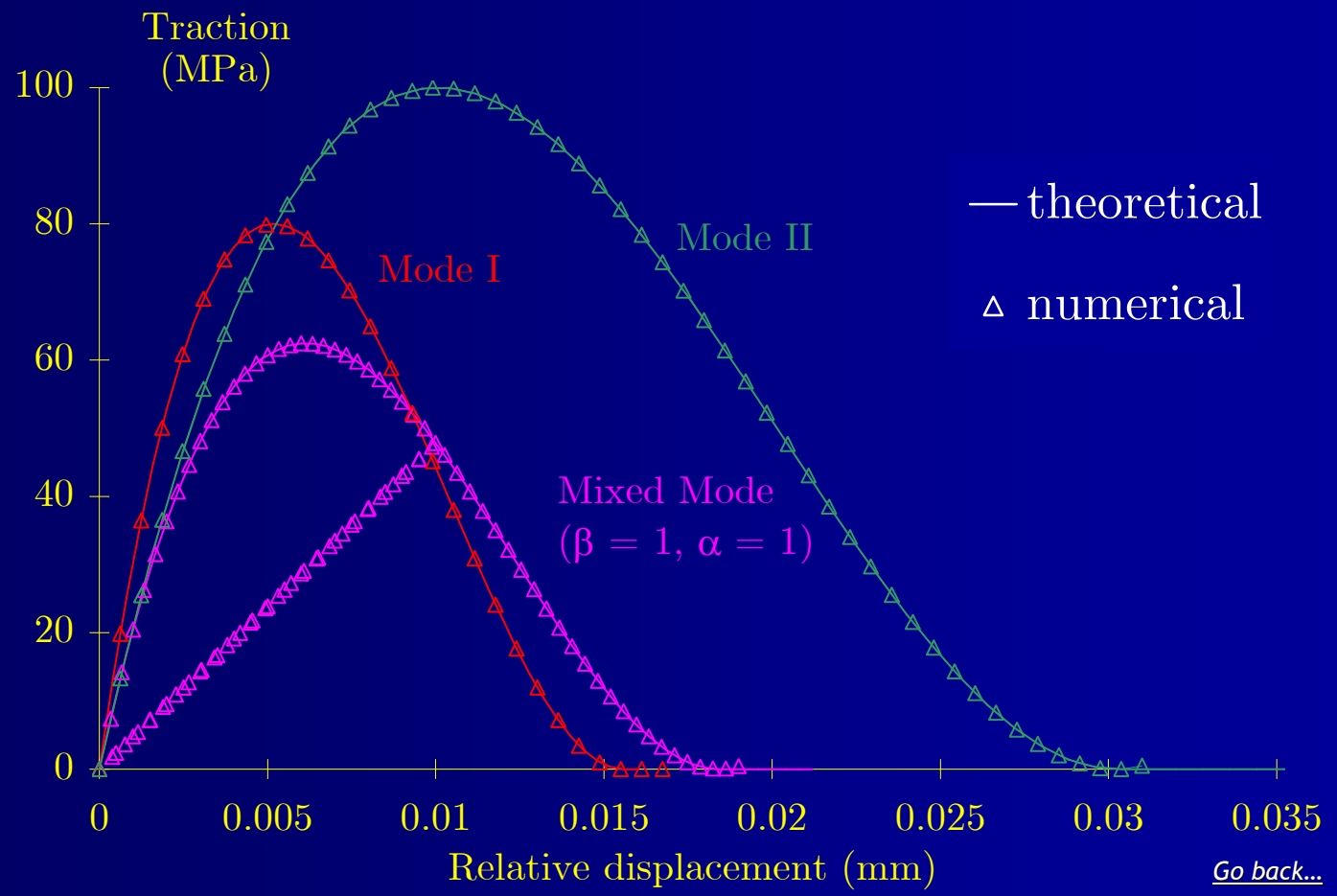




Go back...

Delamination - Modelling

Curve law



Go back...

Delamination - Modelling

Curve law

History variable

$$\lambda = \sqrt{\left(\frac{\langle \delta_1 \rangle}{\delta_I^f}\right)^2 + \left(\frac{\delta_{shear}}{\delta_{shear}^f}\right)^2}$$

Opening mode component of the maximum displacement

$$\delta_I^{\max} = \frac{\lambda_{\max}}{\sqrt{\left(\frac{1}{\delta_1^f}\right)^2 + \left(\frac{\beta}{\delta_{shear}^f}\right)^2}}$$

Shear mode component of the maximum displacement

$$\delta_{shear}^{\max} = \beta \delta_I^{\max}$$

Go back...

Crash events