Consiglio Nazionale delle Ricerche
Istituto per i Materiali Compositi e Biomedici

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Numerical and Experimental Study of a Concentrated Indentation Force on Polymer Matrix Composites

V.Antonucci, M.Esposito, R.Marzella, and M.Giordano
Institute for Composite and Biomedical Materials , CNR
IMAST, Technological District on Polymeric and Composite Materials Engineering

Outline

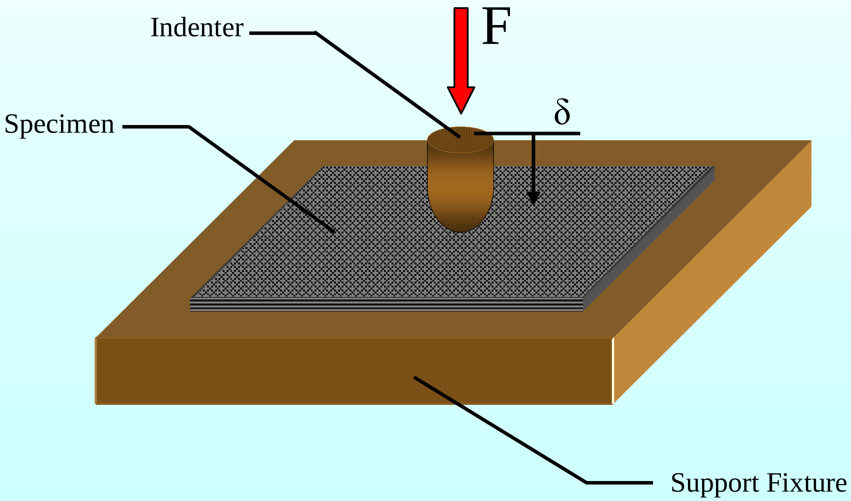
- Test case description
- FE model with Comsol Multiphysics 3.4
- Numerical results
- Experimental implementation
- Model – experimental comparison

Test case

Aim: Structural behavior simulation of composite laminates

ASTM D 6264, "Standard Test Method for Measuring Damage Resistance of Fiber-Reinforced Polymer-Matrix Composite to Concentrated Quasi-Static Indentation Force"

Indentation force by pressing a displacement-controlled hemispherical indenter into the face of the specimen



Configurations and Materials

- Composite based on polyester resin Arotran Q6530 (Ashland) and unidirectional glass fiber reinforcement (Chomarat-600 g/m^2)

- Lamina properties: literature model and experimental characterization

- Laminate
  - 8 ply, symmetric and balanced
  - 6 ply: 90°-90°-0°-0°-90°-90°

FE model

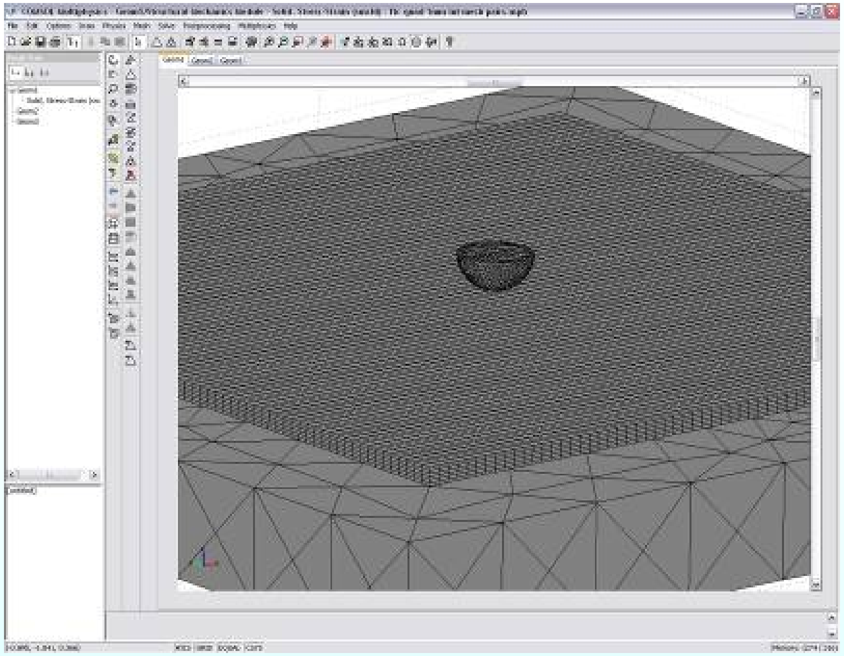
-Three domains:
composite panel, indenter and plate

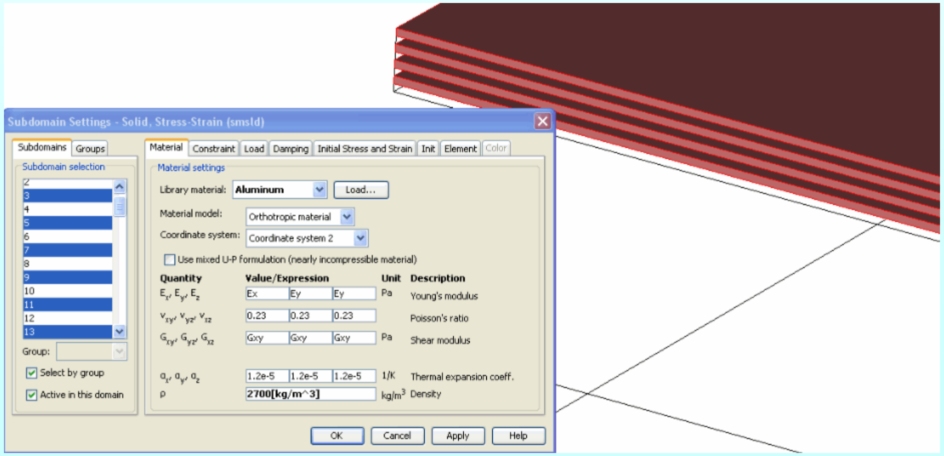
- Solid elements

The software Comsol Multiphysics is not provided of "**layered**" elements for the composites discretization

Each lamina has been modeled in order to assign different properties

The lamina properties have been defined by two reference systems: one for the even layers and one for the odd layers.





FE model- Lamina properties

The fiber volume fraction has been measured experimentally by manufacturing a composite panel by Resin Transfer Molding technology.

Glass Fiber weight = 65 g, Panel weight= 101,15 g
Glass fiber density= 2,57 g/cm^3, Polyester resin density = 1,08 g/cm^3

Vf= 43.05%

Constituent material properties

Resin E= 2,8 GPa, v= 0.42
Glass fibers E=65 GPa, v=0.25

Orthotropic lamina assumption:

5 independent constant lamina

Mixture rules for E_1 and v_{12}

$$E_1 \cong E_f V_f + E_f V_f \qquad \nu_{12} \cong \nu_{12f} V_f + \nu_{12m} V_f$$

Halpin Tsai equation for E_2 and G_{12}

$$\frac{M}{M_m} = \frac{1+\xi\eta V_f}{1-\eta V_f} \qquad \eta = \frac{(M_f / M_m) - 1}{(M_f / M_m) + \xi}$$

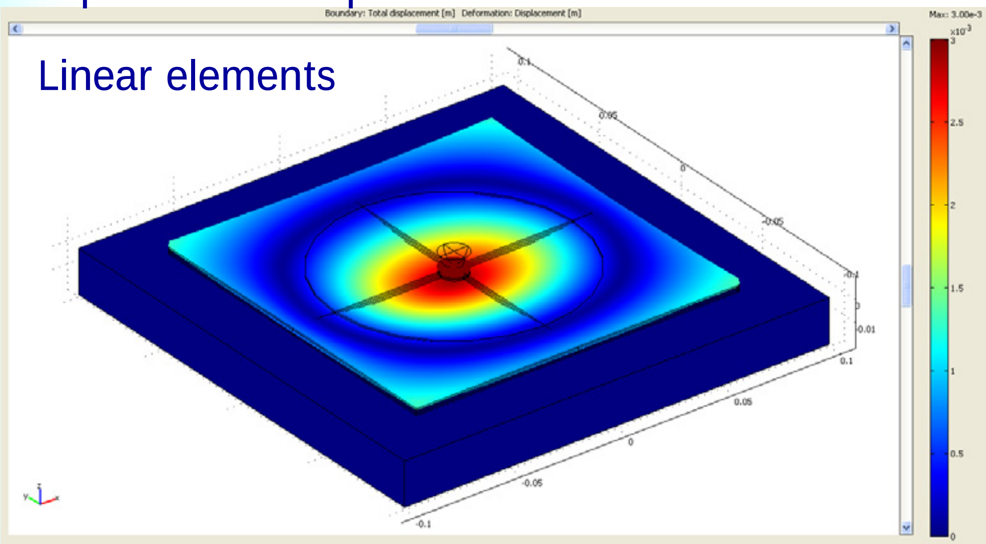
Saravanos and Chamis model for v_{23}

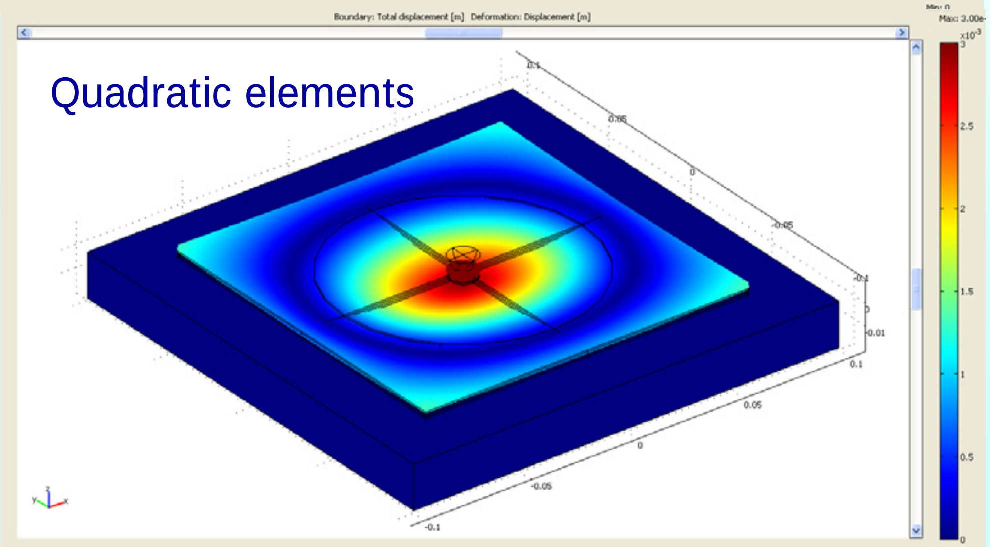
$$\nu_{23} = \frac{\nu_m}{(1 - V_f \nu_m)} + V_f \left\{ \nu_{f23} - \frac{(1 - V_f)\nu_m}{(1 - V_f \nu_m)} \right\}$$

E1 = 29,57 GPa
E2 = E3 = 7,93 GPa
G12 = G13 = 2,29 GPa
G23 = 5,92 GPa
$\nu_{12} = \nu_{13} = 0,347$
$\nu_{21} = \nu_{31} = 0,093$
$\nu_{23} = \nu_{32} = 0,495$

Numerical results
Identification of the optimal element and mesh

Displacement map





Element	1° Order	2° Order
Calculus time [s]	100.3	1216.6
Ratio	12.12	

Several simulations have been performed on the global structure and a quarter of the structure by changing the mesh type and the refining degree

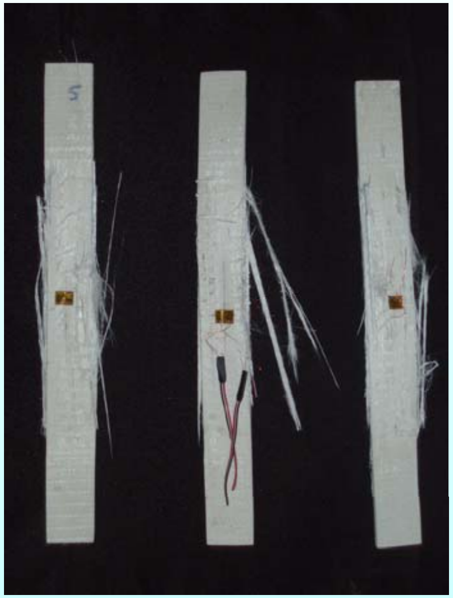
- The results are not affected by the symmetry conditions
- The mesh with quad elements is characterized by more homogenous results than those of tria elements

Quad elements with an edge of 2 2 mm have been selected

FE model- Lamina properties

Experimental characterization

The tests have been performed according with the ASTM standards (D3039 and D3518) in order to evaluate the 0° and 90° elastic moduli, the shear modulus and the Poisson coefficients ν_{12} e ν_{21}.



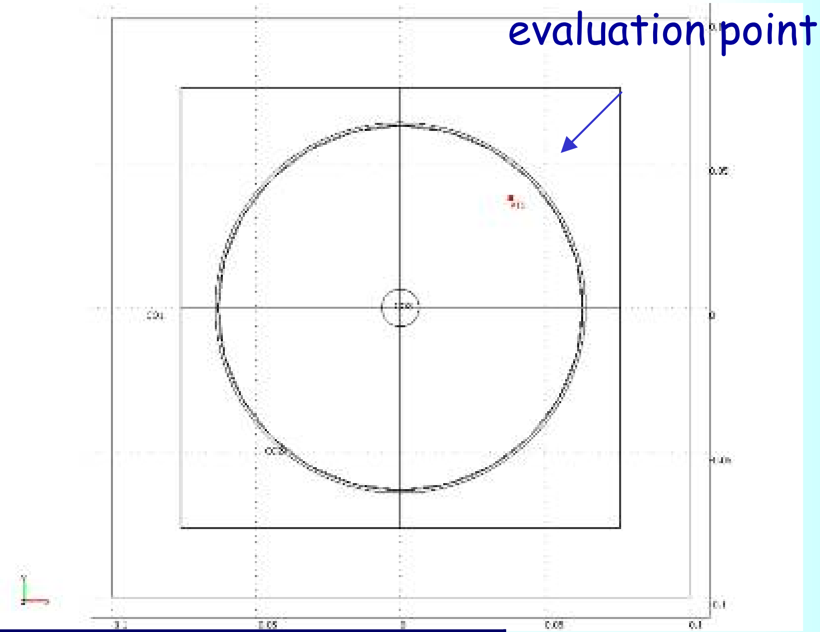
Mechanical property	Value
Elastic modulus E_1	37.09 (GPa)
Elastic modulus E_2	7.35 (GPa)
Poisson coefficient ν_{12}	0.185
Poisson coefficient ν_{21}	0.034
Shear modulus G_{12}	3.14 (GPa)
Tensile strength	660.29(MPa)
Tensile strength	73.19(MPa)
Maximum Shear Stress	44.07(MPa)

Numerical results

Entire and ¼ Structure

• N.L.G. option

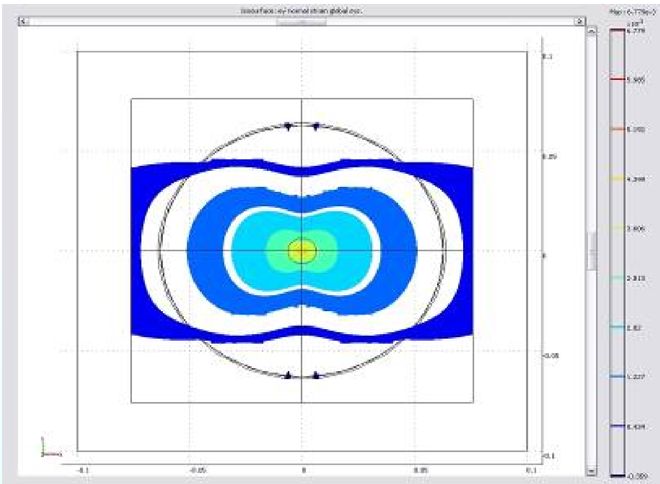
• Evaluation of deformations:
along the fiber direction between the 1° and 2nd ply and between the 5th and 6th ply at the center of the laminate quarter

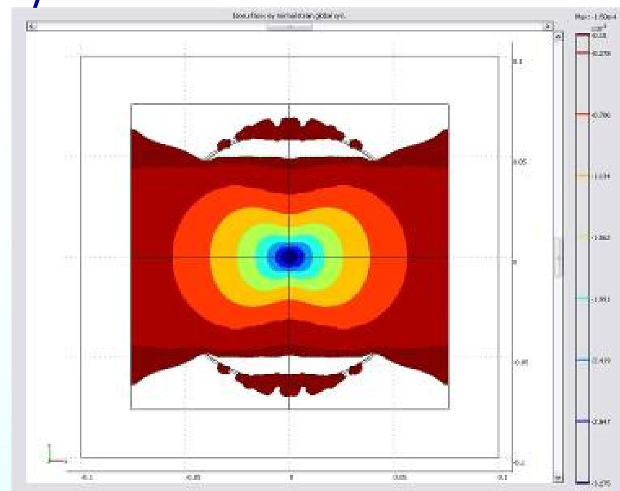


Structure	N.L.G.	Vertex displacement, mm	Deformation ($*10^{-6}$)	
			1°/2°	5°/6°
Entire	Off	1.532	506	- 510
	On	1.476	428	- 525
1/4	Off	1.532	569	- 573
	On	n.d.	n.d.	n.d.

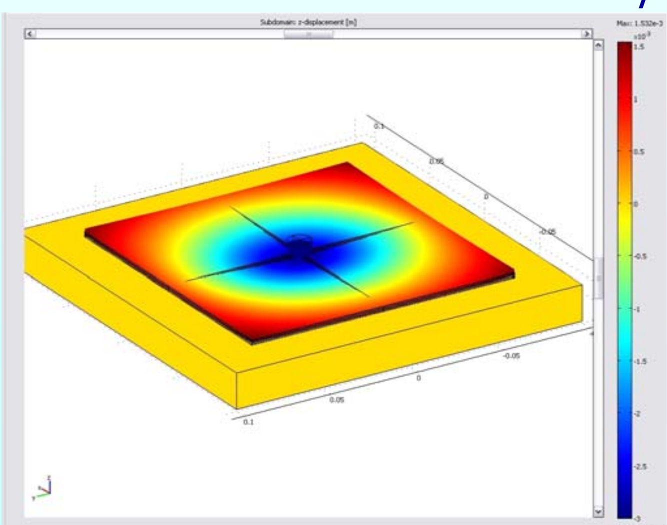
Numerical results

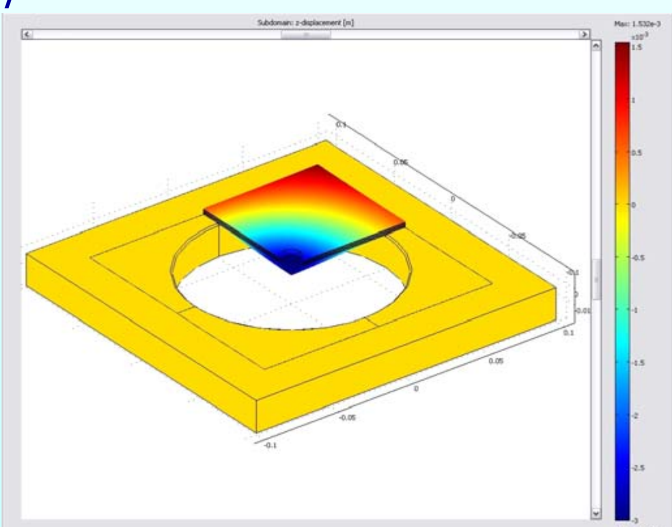
Deformation maps



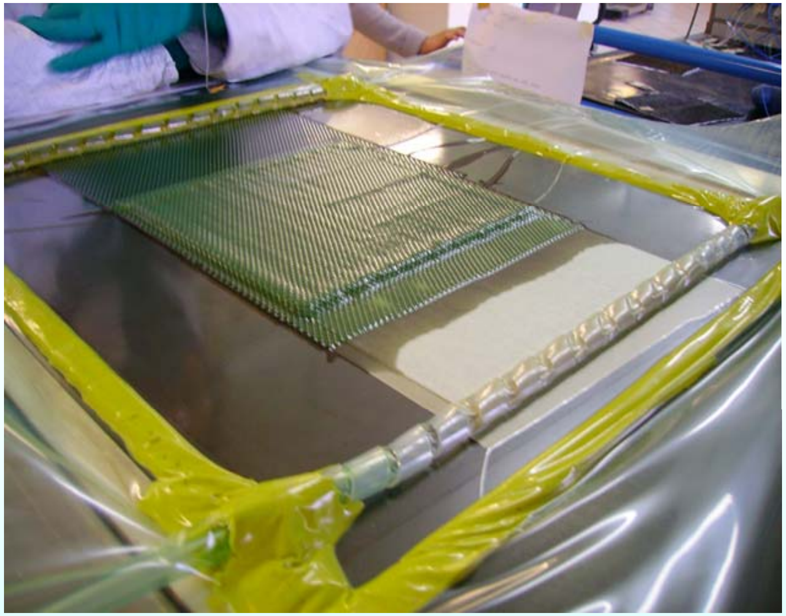


Displacement maps



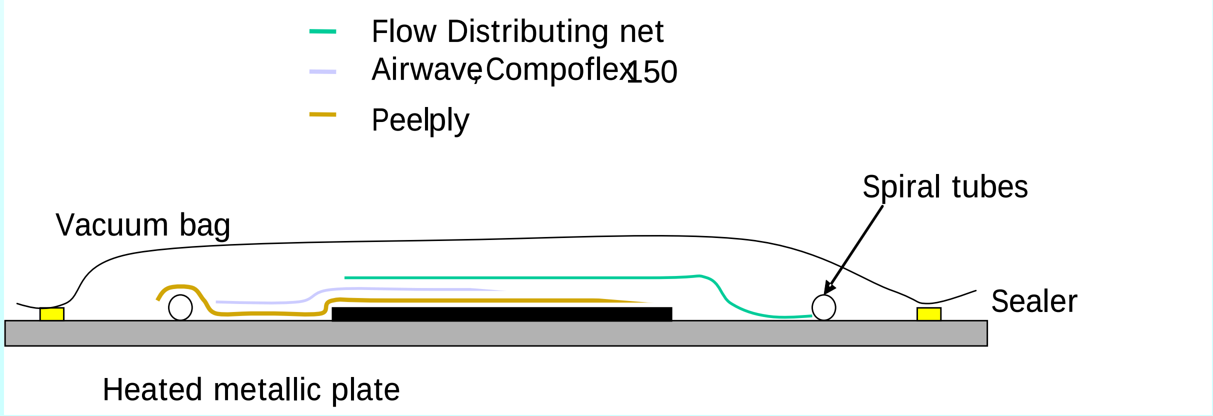


Experimental

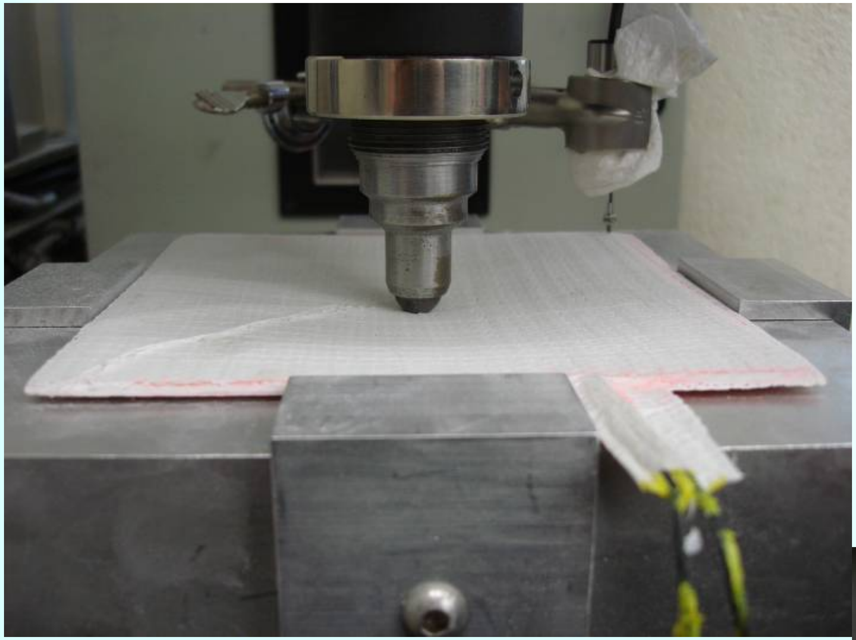


Manufacturing of the composite laminate by Vacuum Infusion Process

The Fiber Bragg sensor have been placed trough the ply during the fiber stacking



Experimental



FBG position

First panel:

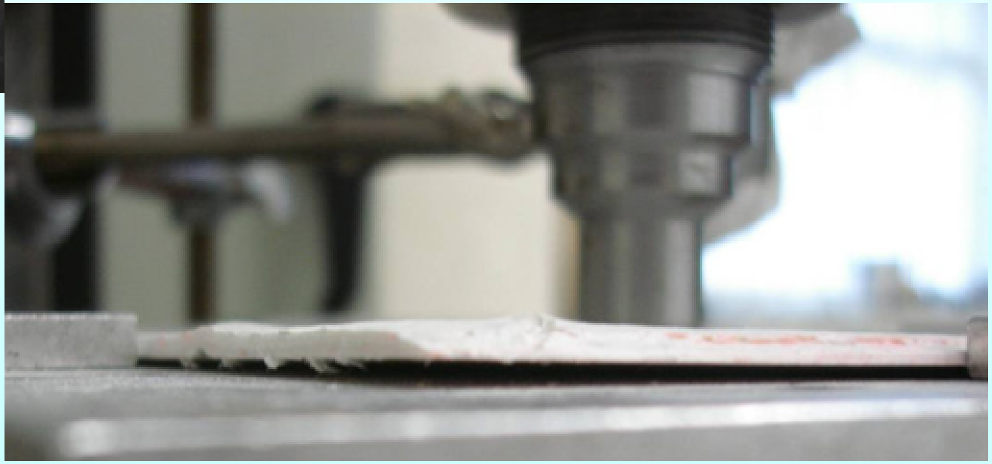
C1 (33 mm, 40 mm) T1 (29 mm, 41 mm)

Second panel

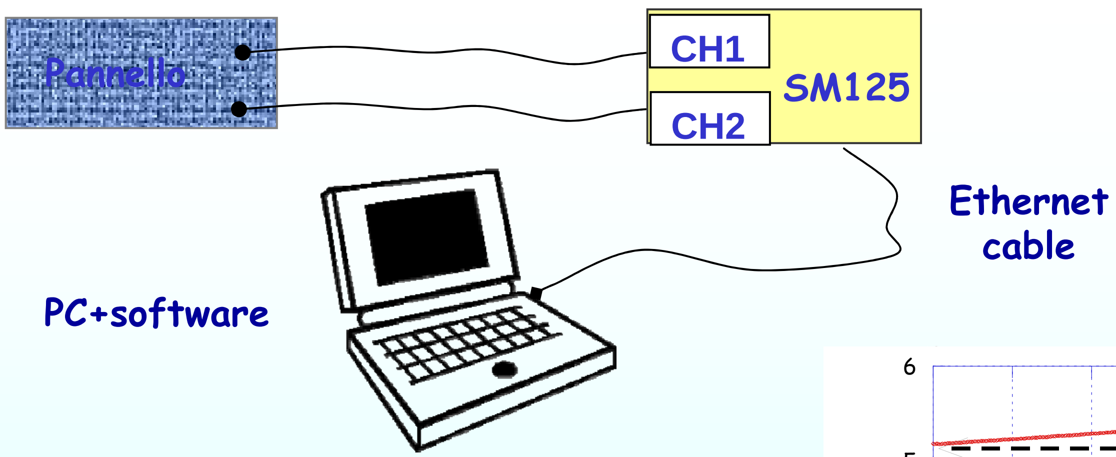
C2 (28 mm, 32 mm) T2 (33 mm, 28 mm)

"C" locations: between 1st and 2nd ply

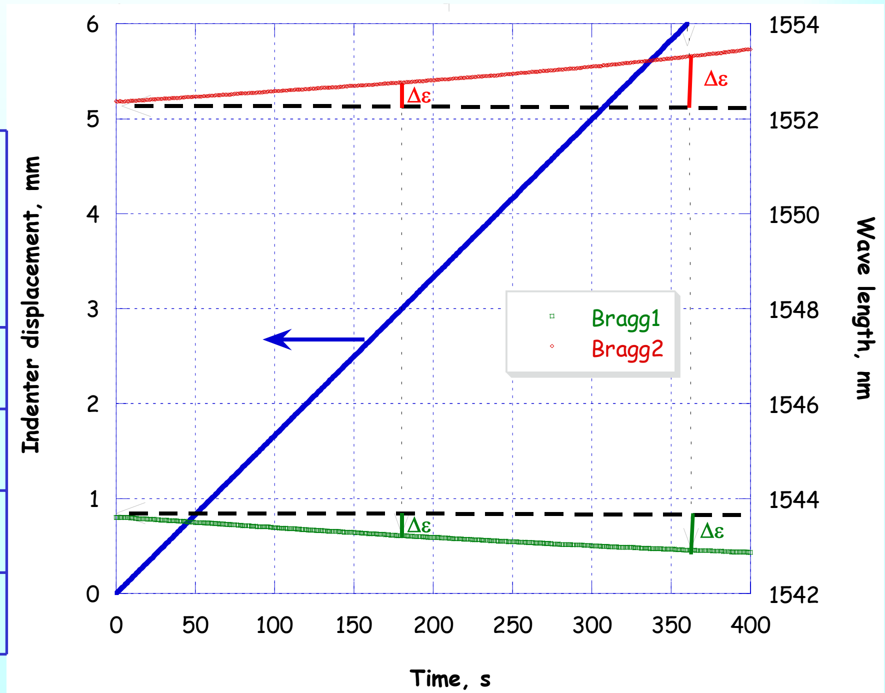
"T" locations: between 5th and 6th ply



Experimental test



Composite	Indenter displacement (mm)	Compression strain με	Tensile strain με
1	3	(-)381	396
1	6	(-)686	947
2	3	(-)1080	1190
2	6	(-)1949	1975



Numerical-experimental comparison

Numerical

Structure	N.L.G.	Strain (*10^{-6})		Strain (*10^{-6})	
		Points T1-C1		Points T2-C2	
		1°/2°	5°/6°	1°/2°	5°/6°
Entire	Off	476	- 473	855	- 847
	On	475	- 464	819	- 804
1/4	Off	476	- 545	855	- 777
	On	n.d.	n.d.	n.d.	n.d.

Maximum percentage difference: 28%

Composite/position	Experimental $\mu\varepsilon$	Numerical $\mu\varepsilon$
1/ply 1-2	396	475
2/ply 1-2	1190	855
1/ply 5-6	-381	-464
2/ply 5-6	-1080	-847

Conclusion

Numerical and experimental study of the composite damage resistance

from the experimental evaluation of the material properties to the experimental implementation of the simulated test case

Similar magnitude order between the experimental and numerical results

Thank you for your attention