Dept. of Industrial Engineering
Università degli Studi di Parma - ITALY

COMPTEST

2ND INTERNATIONAL CONFERENCE on
Composites Materials and Model Identification

Bristol, 21-23 September 2004

3D Finite Element Damage Analysis of a Twill-weave Lamina subjected to In-plane Shear

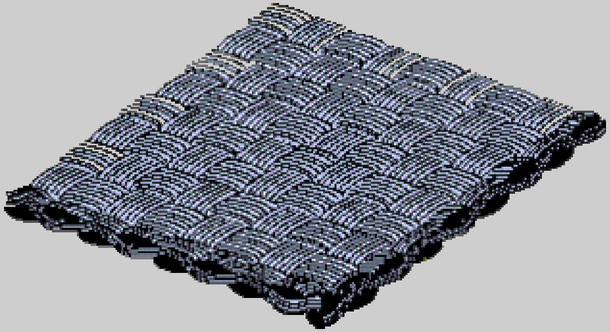
Giacomo Baruffaldi, Enrica Riva, Gianni Nicoletto

enrica.riva@unipr.it

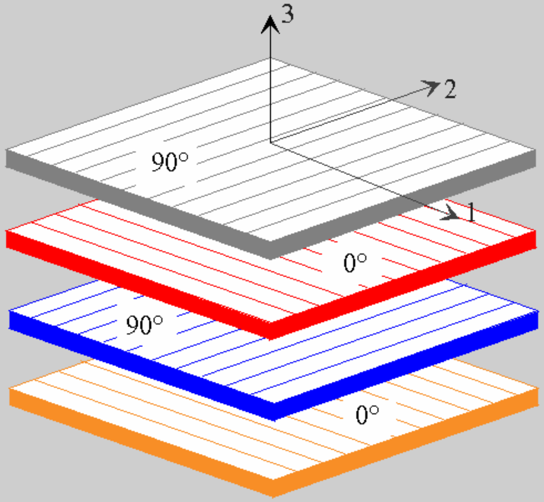
OUTLINE

- Introduction
- Definitions
- Finite Element based approch
- Results and discussion
- Conclusions and perspectives

INTRODUCTION

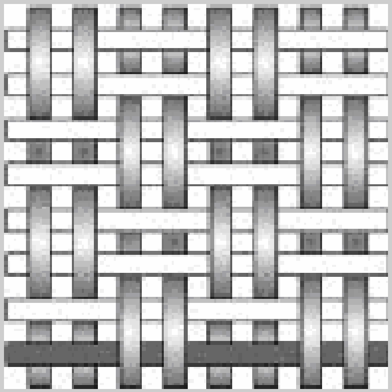


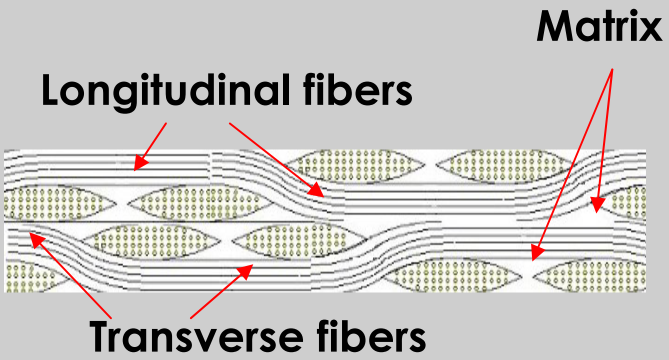
Lamina



Laminate

Basket-weave, carbon fiber and epoxy resin

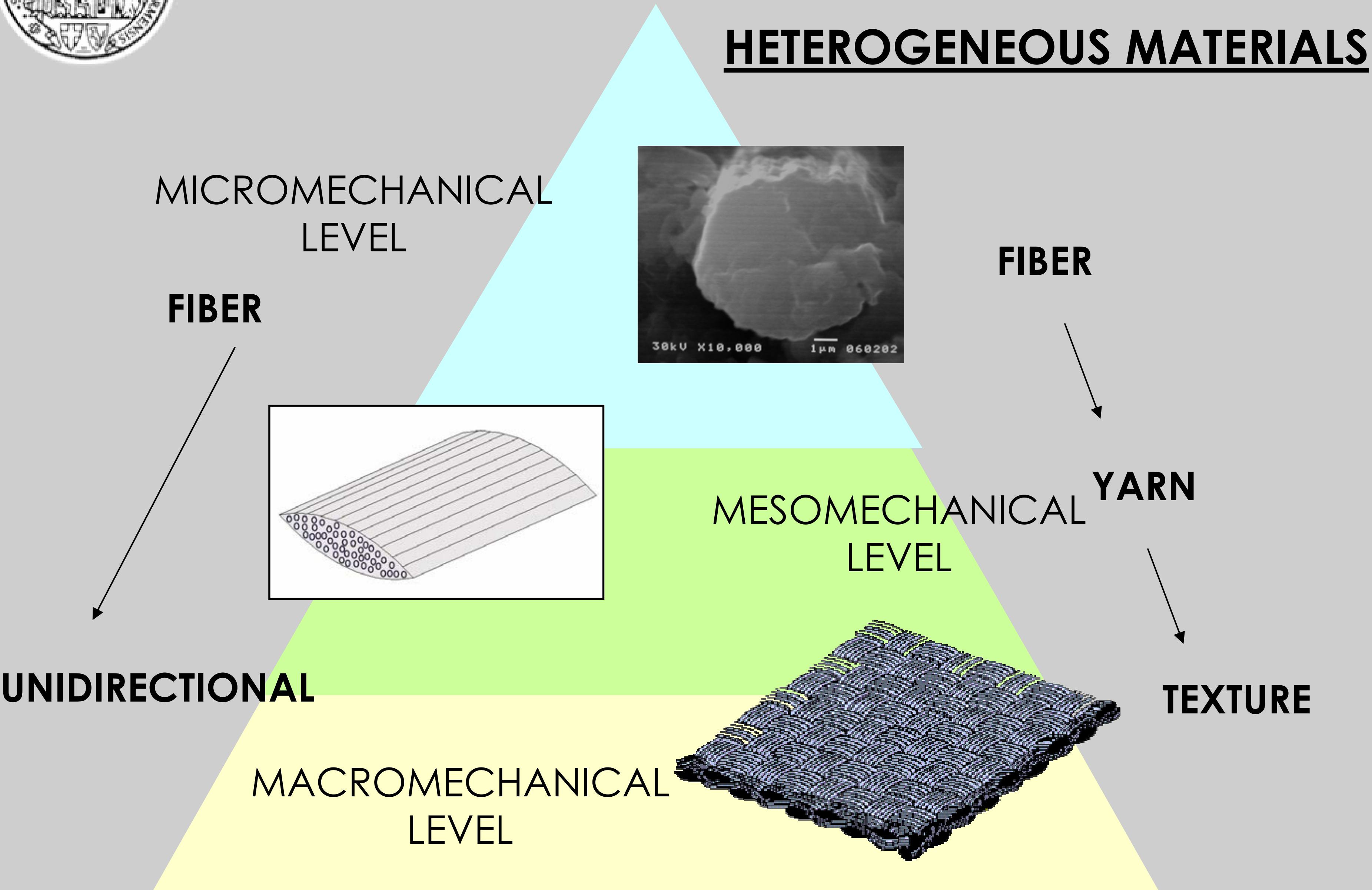




- Balanced in-plane mechanical properties
- Good impact resistance
- Easy handling and shaping

LEVELS OF ANALYSIS

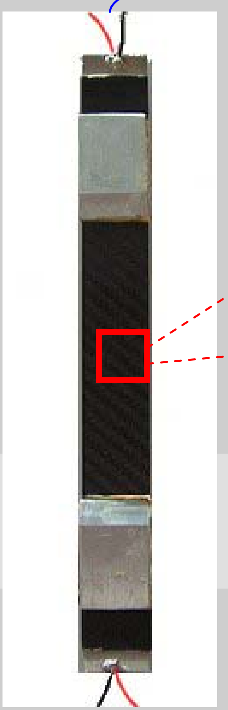
HETEROGENEOUS MATERIALS

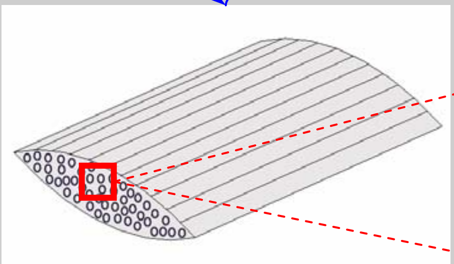


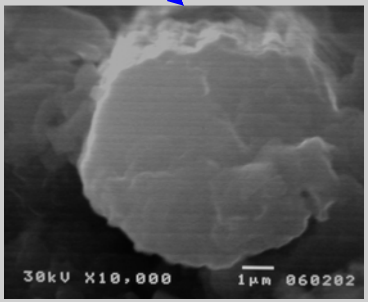
DEFINITIONS

LOCALIZATION

- Local stress-strain state (micro scale)







MESO SCALE (FIBER YARN)

MICRO SCALE (FIBER)

- Determination of the macroscopic mechanical response by homogeneization over the unit cell

MACRO SCALE (SPECIMEN)

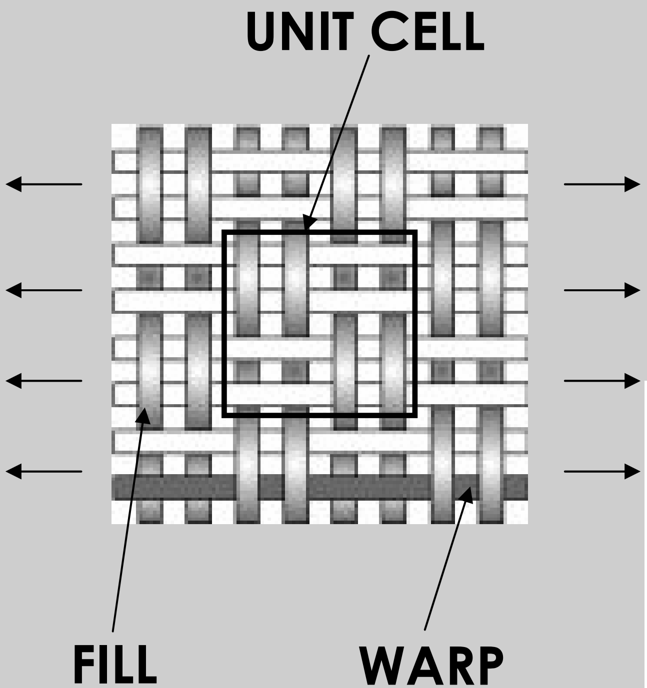
HOMOGENEIZATION

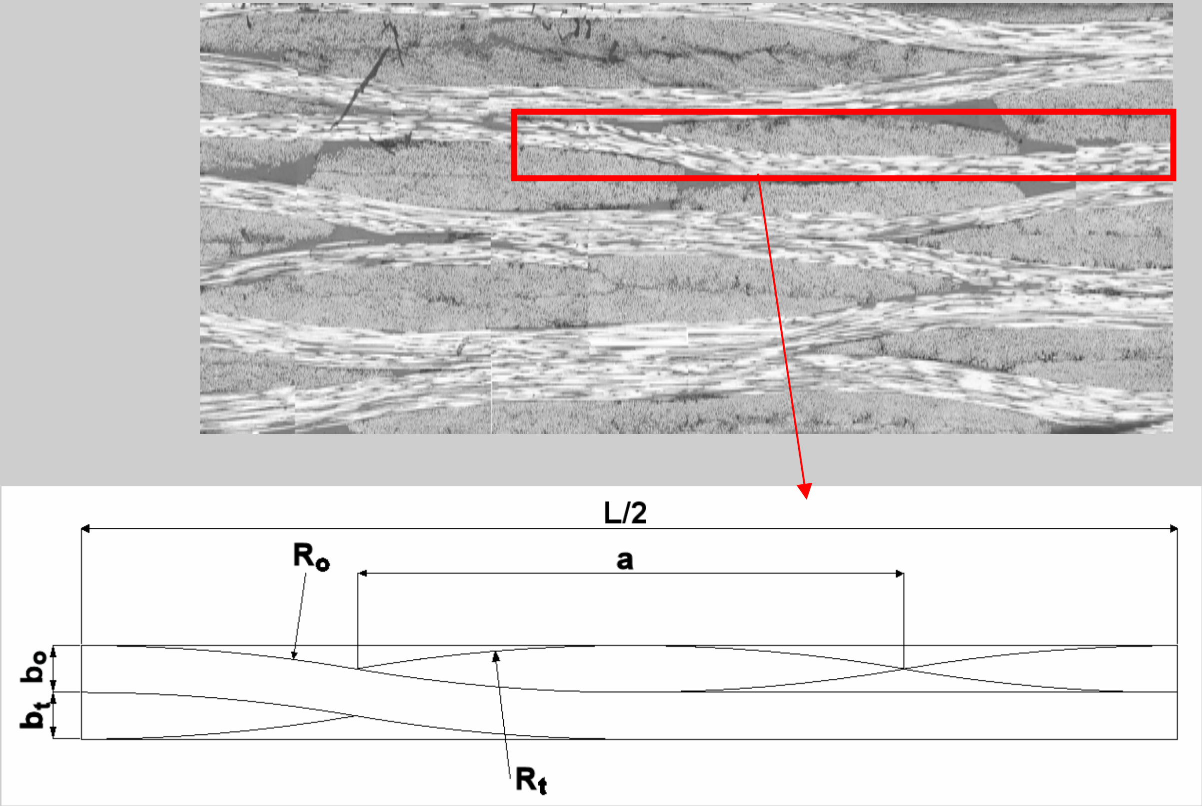
DETERMINATION OF THE MECHANICAL BEHAVIOR, INCLUDING DAMAGE DEVELOPMENT, IN A BASKET-WEAVE LAMINATE

STEPS

- Unit cell definition
- Geometric model
- Parametric fem model
- Mechanical properties of constituent materials
- Boundary conditions
- Damage development simulation

UNIT CELL

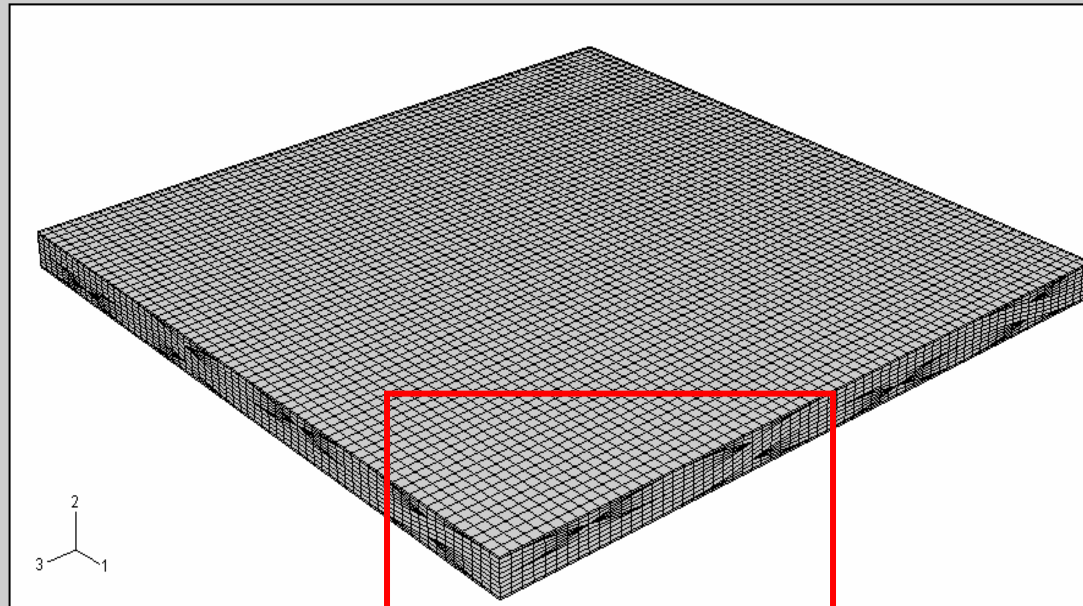


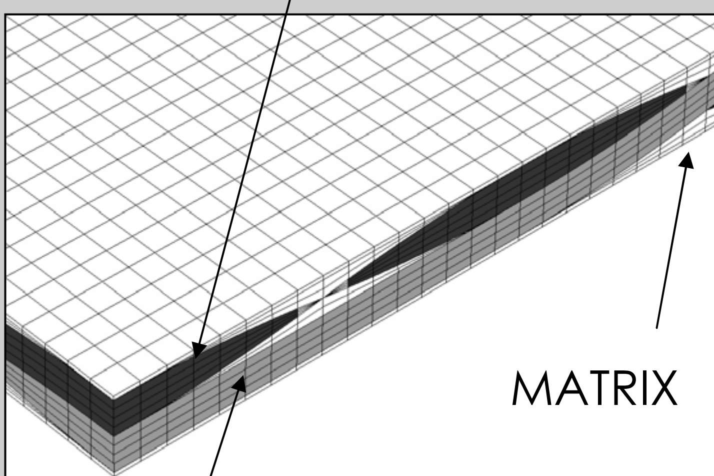


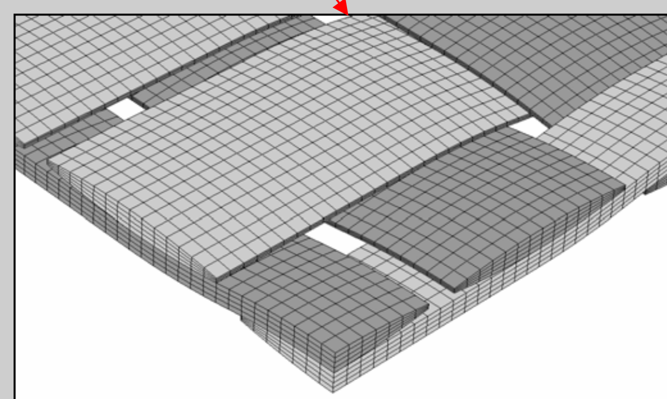
Representative unit cell dimensions [mm]					
L	a	b_o	b_t	R_o	R_t
8.168	2.042	0.171	0.171	6.112	6.112

FEM MESH

<u>PARAMETRIC</u> MODEL
BASKET-WEAVE

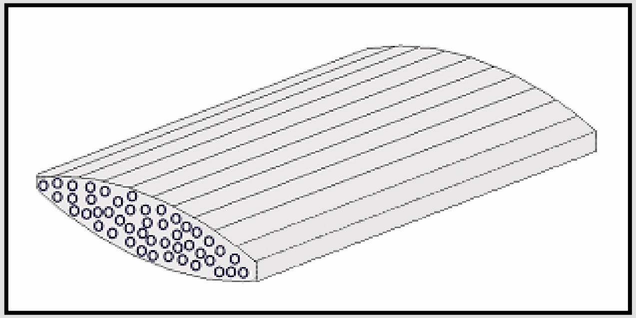


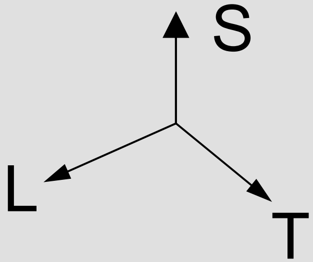




CONSTITUTIVE MATERIALS

- **CARBON FIBER YARN V_F = 70%**
  - trasverse isotropic
- **LOCAL COORDINATE SYSTEM**
  - L = longitudinal fiber direction
  - T and S = transverse fiber directions
- **EPOXY MATRIX**
  - isotropic and homogeneous
  - elastic-plastic behavior





BOUNDARY CONDITIONS

DISPLACEMENT FIELDS OF THE UNIT CELL

$$\underline{u}(\underline{x}) = \underline{u}^{o} + \underline{\underline{\Omega}}\,\underline{x} + \underline{\underline{E}}\,\underline{x} + \underline{\tilde{u}}(\underline{x})$$

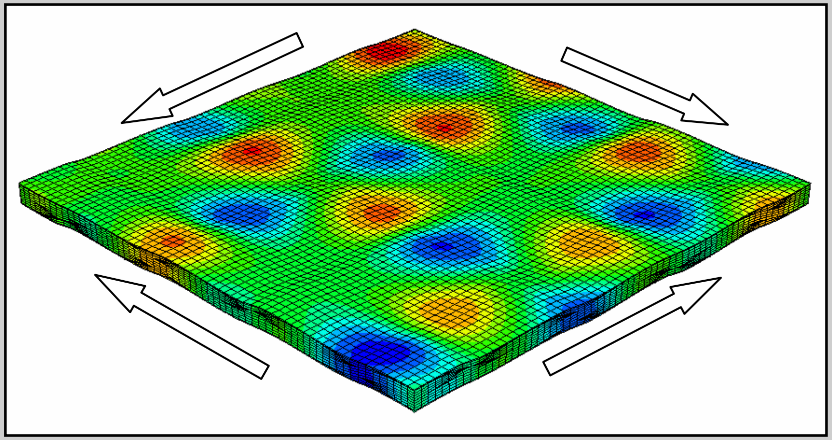
$\underline{u}^{o}$ **Rigid displacement of the unit cell**

$\underline{\underline{\Omega}}$ **Rigid rotation of the unit cell**

$\underline{\underline{E}}$ **Macroscopic homogenized strain**

$\underline{\tilde{u}}(\underline{x})$ **Periodic term (associated with mesoscopic displacement field)**

IN-PLANE SHEAR LOADING



Ref.: V. Carvelli, C. Poggi - "A homogenization procedure for the numerical analysis of woven fabric composites", Composites: Part A, 2001

BOUNDARY CONDITIONS

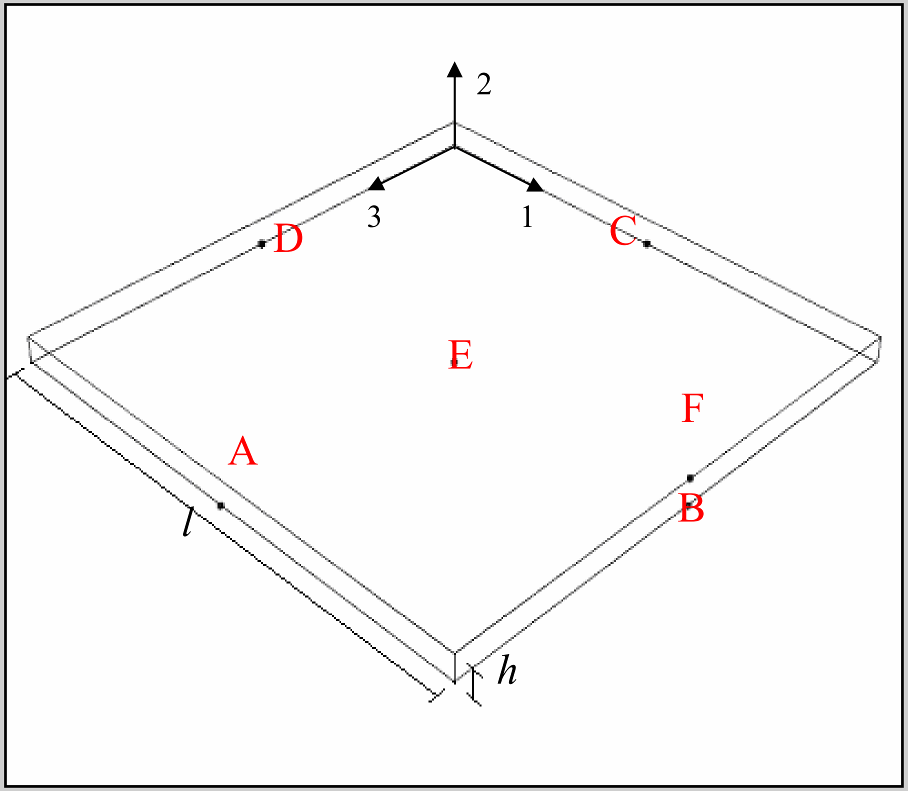
Shear loading is simulated by imposing appropriate displacement components at the reference nodes

- **Link between the corresponding nodes on coupled sides:**

$\underline{u}^{A} - \underline{u}^{C} = \underline{u}^{L} - \underline{u}^{M}$

$\underline{u}^{B} - \underline{u}^{D} = \underline{u}^{J} - \underline{u}^{K}$

$\underline{u}^{F} - \underline{u}^{B} = \underline{u}^{P} - \underline{u}^{Q}$



- **Elimination of rigid rotations:**

$$(l/h)u_3^{F} - (l/h)u_3^{B} + u_2^{A} - u_2^{C} = 0 \quad (1)$$

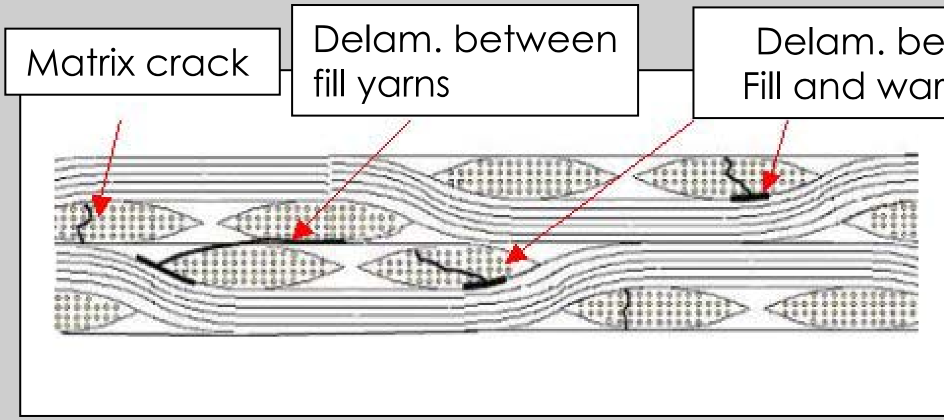
$$u_3^{B} - u_3^{D} + u_1^{C} - u_1^{A} = 0 \quad (2)$$

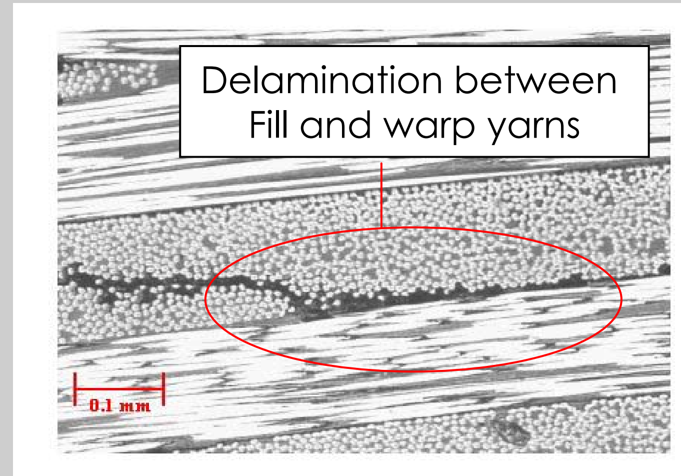
$$(l/h)u_1^{F} - (l/h)u_1^{B} + u_2^{D} - u_2^{B} = 0 \quad (3)$$

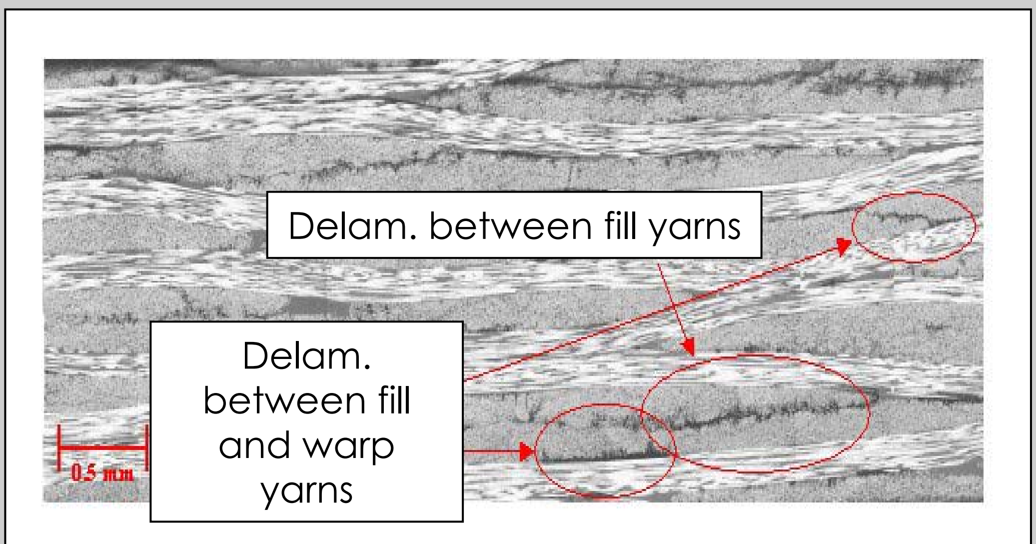
- **Elimination of rigid traslations:** $\underline{u}^{E} = 0$

EXP. OBSERVATIONS

DAMAGE IN WOVEN LAMINATES

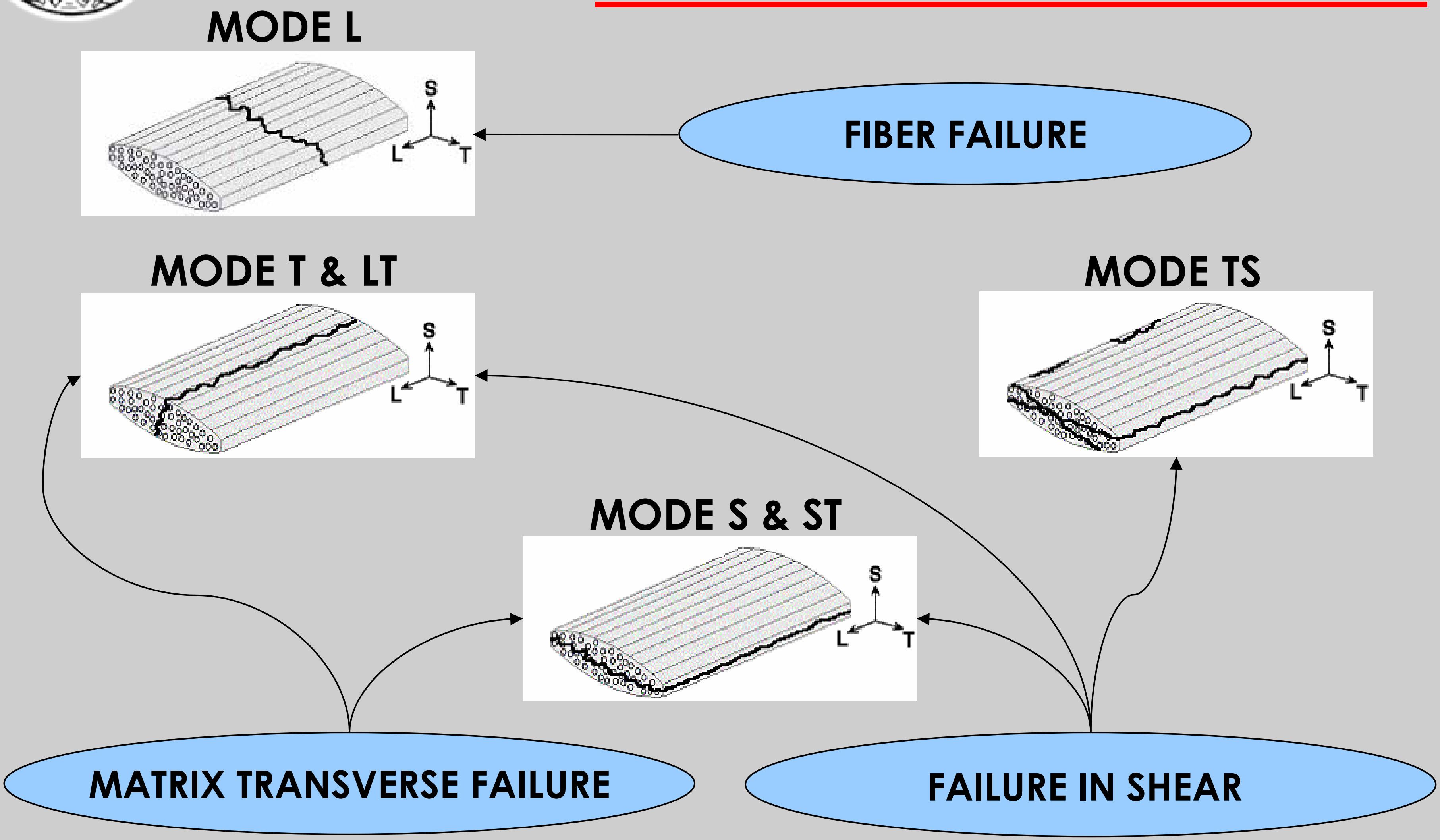






DAMAGE SIMULATION

FIBER DAMAGE MECHANISMS



Ref.: M. Zako et al. - “Finite element analysis of damaged woven fabric composite materials”, Composite Science and Technology, 2003

DAMAGE SIMULATION

σ_{ij} = Mesoscopic localized stress

X_{ij} = Mesoscopic strength

q_{ijD} = Reduced elastic modulus

q_{ij} = Elastic modulus

D_{ij} = Degradation coefficient

i,j = *L, T, S*

FAILURE CONDITIONS

$$\sigma_{ij} = X_{ij}$$

$$q_{ij\,D} = q_{ij} D_{ij}$$

Degradation coefficients D_{ij}

	D_{LL}	D_{TT}	D_{SS}	D_{LT}	D_{LS}	D_{TS}
Mode L	0.01	0.01	0.01	0.01	0.01	0.01
Mode T	1.0	1.0	0.01	1.0	0.2	0.2
Mode S	1.0	0.01	1.0	1.0	0.2	0.2
Mode LT	1.0	1.0	0.01	1.0	0.01	1.0
Mode LS	1.0	0.01	1.0	1.0	1.0	0.01
Mode TS	1.0	0.01	0.01	0.01	0.01	0.01

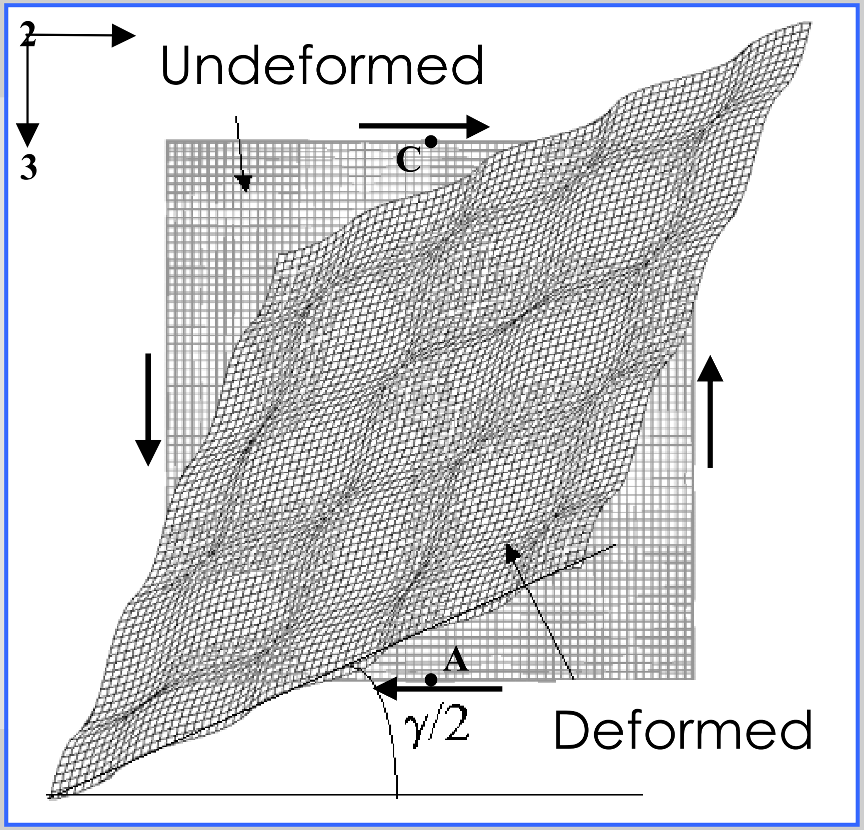
Ref.: Blackketter DM et al: "Modeling damage in a plain weave fabric reinforced composite material", Journal of Composites Technology and Research, 1993

ELASTIC RESPONSE

- **Displacement is imposed in direction 1 up to 5% strain.**

- **Elastic response**

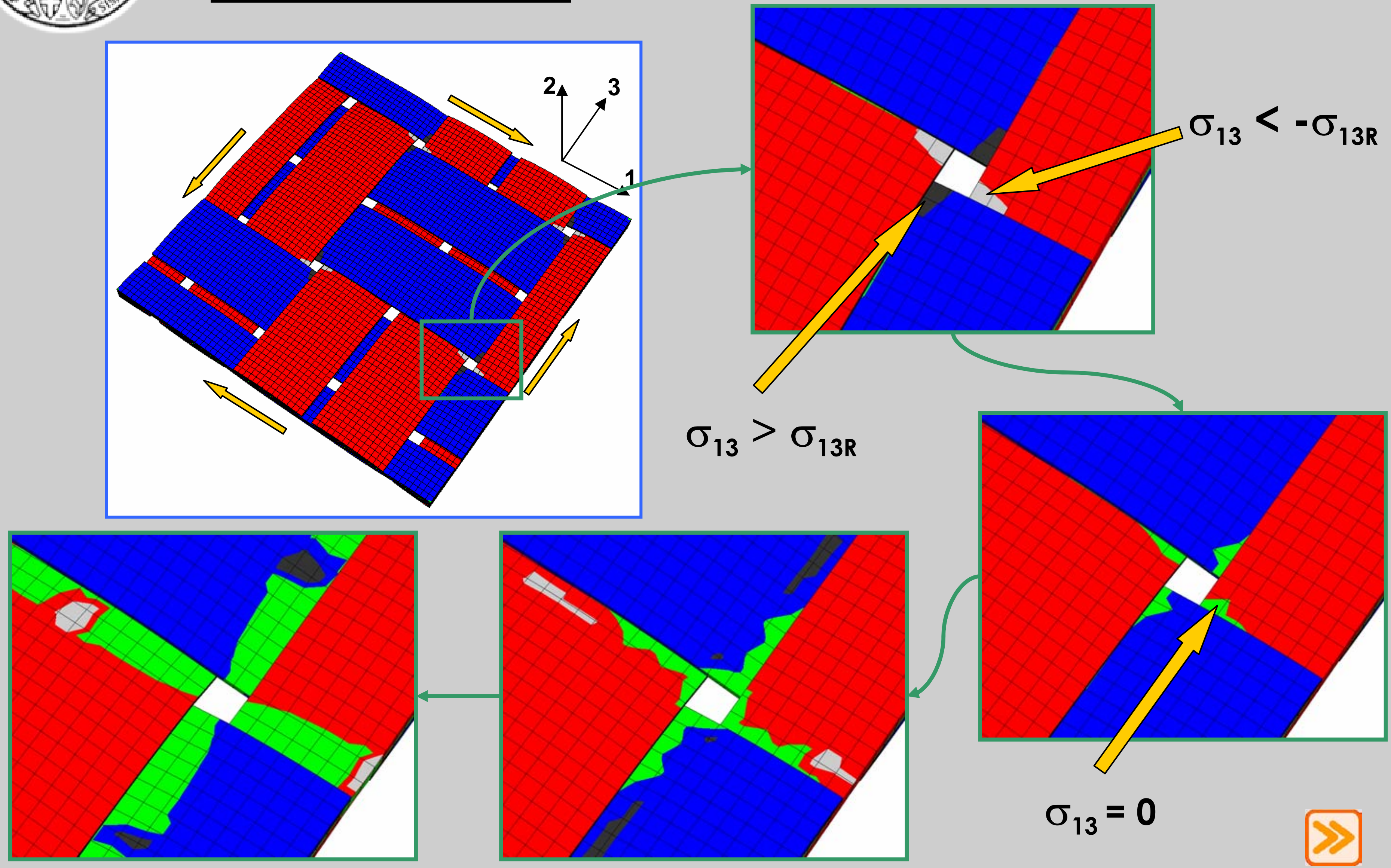
  Results for single lamina and laminate are very similar because out-of-plane displacement components (direction 2) are nearly zero in both cases.



	Experimental	FEM (Single lamina)	FEM (Laminate)
G [MPa]	3250/3850	3820	3768

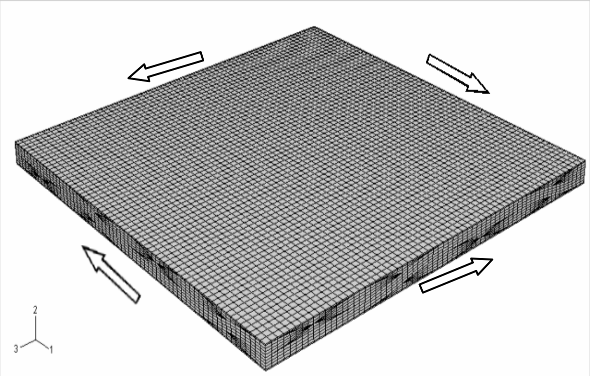
DAMAGE DEVELOPEMENT

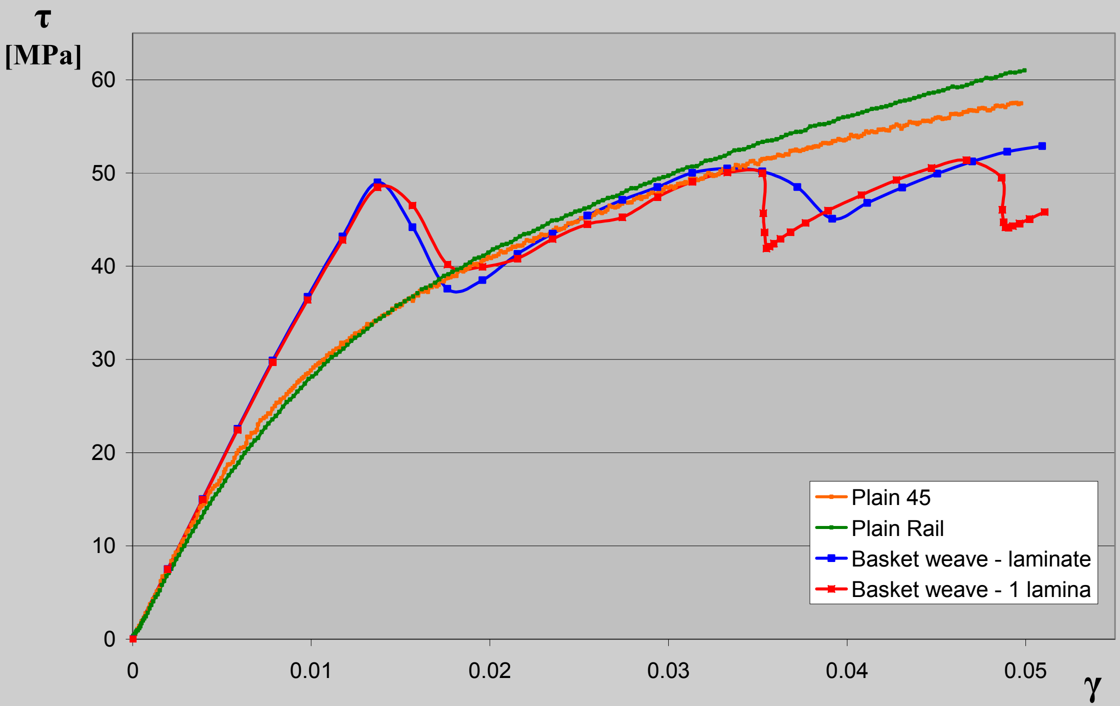
DAMAGE PROCESS



SHEAR TEST SIMULATION

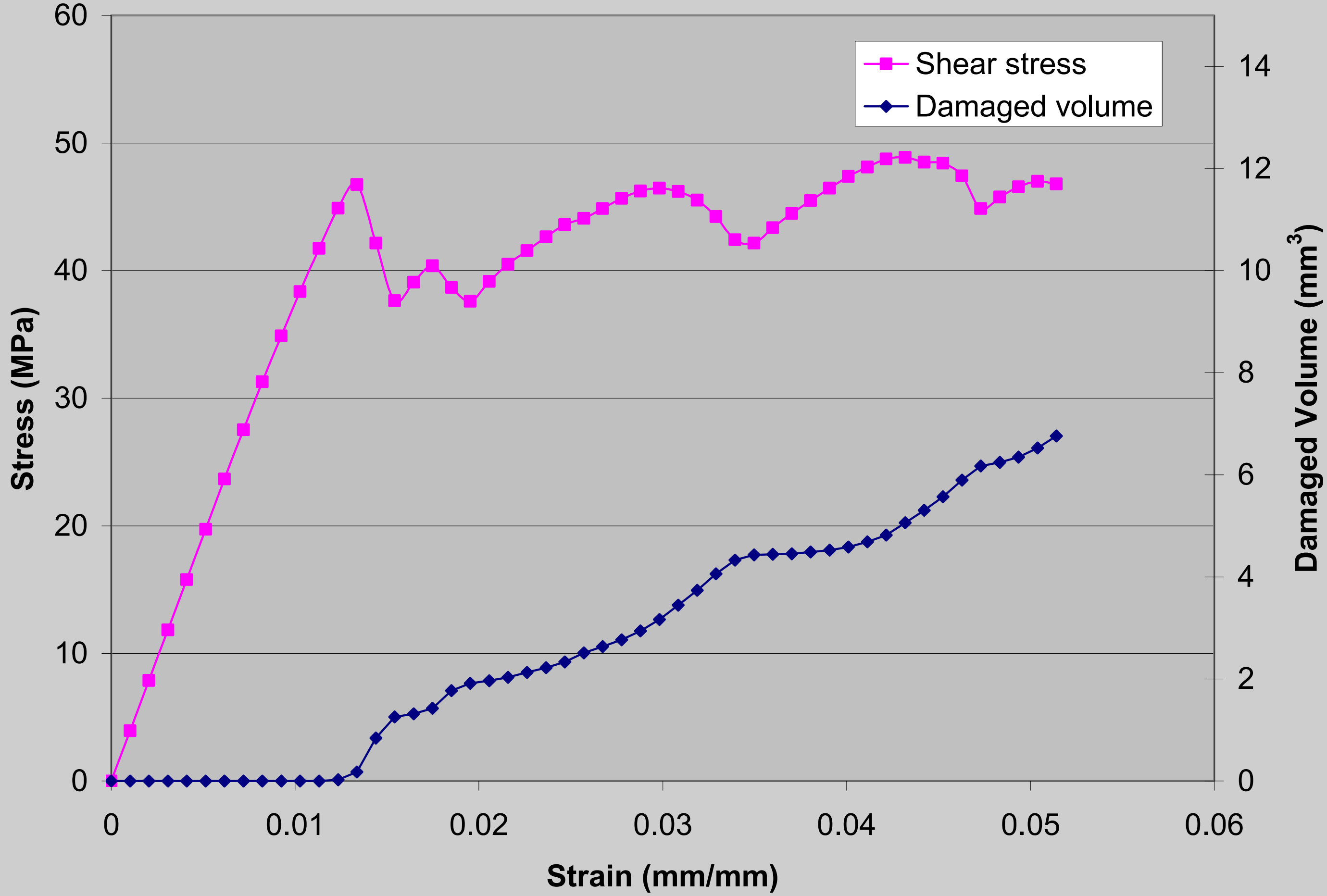
Homogenized macroscopic stress-strain curve





- Elastic shear modulus (G) is comparable to experimental results
- Maximum shear stress at initial failure is greater than experimental value (Modeling of yarn-matrix interface is under development)

DAMAGED VOLUME



- Initial damage occurs when the applied shear strain reaches 1.3%
- Large reduction of load due to initial damage

CONCLUSIONS

- The FEM model of the unit-cell provided the microscopic stresses and strains in the fiber yarns and the matrix

- The FEM analysis of the unit cell provided the macroscopic shear stress-shear strain curve of basket-weave laminate

- The damage development process in the woven laminate was simulated with a user-defined subroutine

- Initial correlation of the modeling results with experiments in terms of initial stiffness and damage evolution is encouraging

- On-going development deals with the modeling of the yarn-matrix interface