AMADE
ANALYSIS AND ADVANCED MATERIALS FOR STRUCTURAL DESIGN

A novel methodology to measure the transverse Poisson’s ratio in the elastic and plastic regions for composite materials

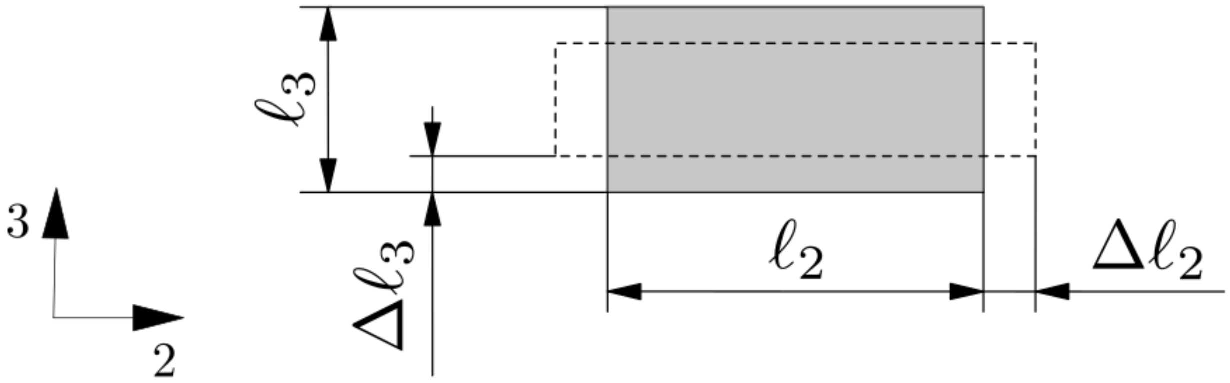
I. R. Cózar, J.J. Arbeláez-Toro, P. Maimí, F. Otero, E. V. González, A. Turon, P. P. Camanho

Introduction 01

Introduction

- What is the transverse Poisson's ratio (ν_{23})?
  - The transverse Poisson's ratio is the negative quotient of the out-of-plane transverse strain (ε_{33}) to the applied in-plane transverse strain (ε_{22}):

$$\nu_{23} = -\frac{\varepsilon_{33}}{\varepsilon_{22}}$$

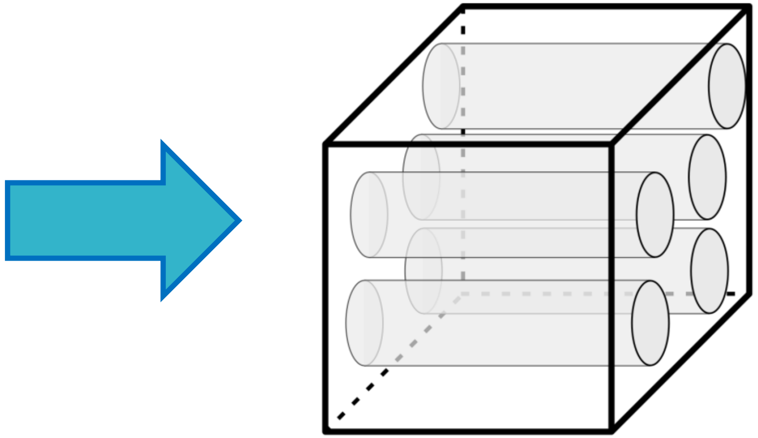


$$\varepsilon_{33} = \frac{\Delta\ell_3}{\ell_3}$$

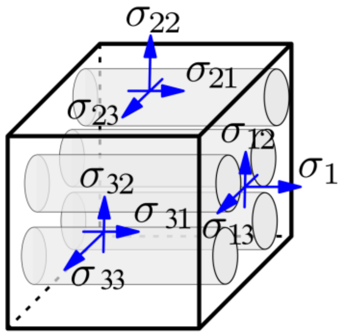
$$\varepsilon_{22} = \frac{\Delta\ell_2}{\ell_2}$$

Introduction

- Why is the elastic transverse Poisson's ratio (ν_{23}) crucial?
  - Fibre reinforcement polymers (FRP) behave as a homogenous transversely isotropic material. They have a plane of symmetry with respect to a rotation about the fibre–oriented axis.
  - Five elastic material properties are required in the generalised Hooke's law:



Introduction



- Why is the elastic transverse Poisson's ratio (ν_{23}) crucial?
  - Fibre reinforcement polymers (FRP) behave as a homogenous transversely isotropic material. They have a plane of symmetry with respect to a rotation about the fibre–oriented axis.
  - Five elastic material properties are required in the generalised Hooke's law:

E_{11}: Longitudinal Young's modulus

E_{22}: Transverse Young's modulus

G_{12}: Longitudinal shear elastic modulus

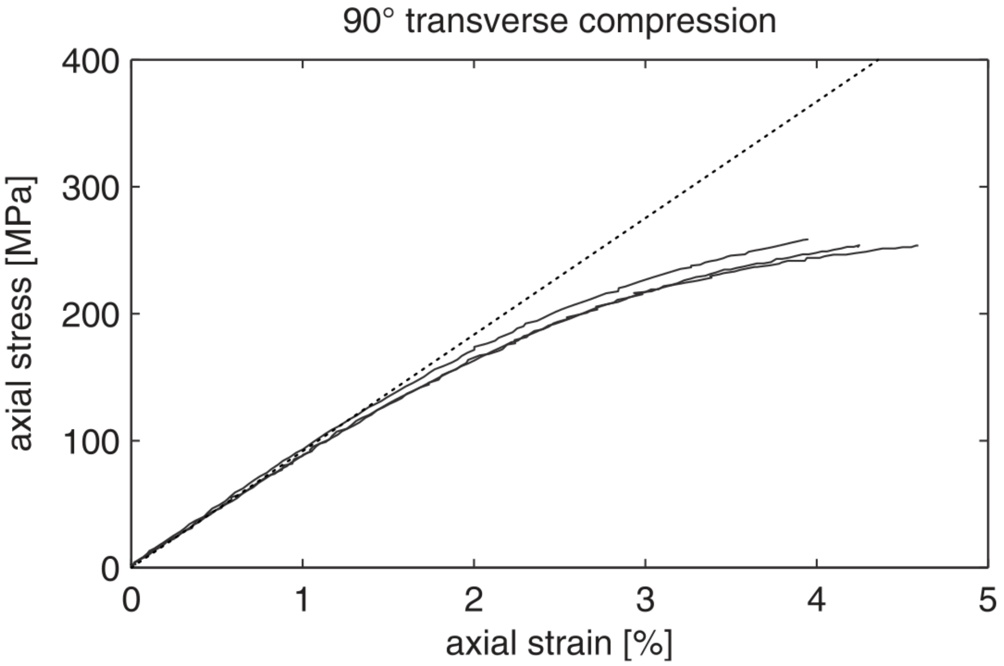
ν_{12}: Longitudinal Poisson's ratio

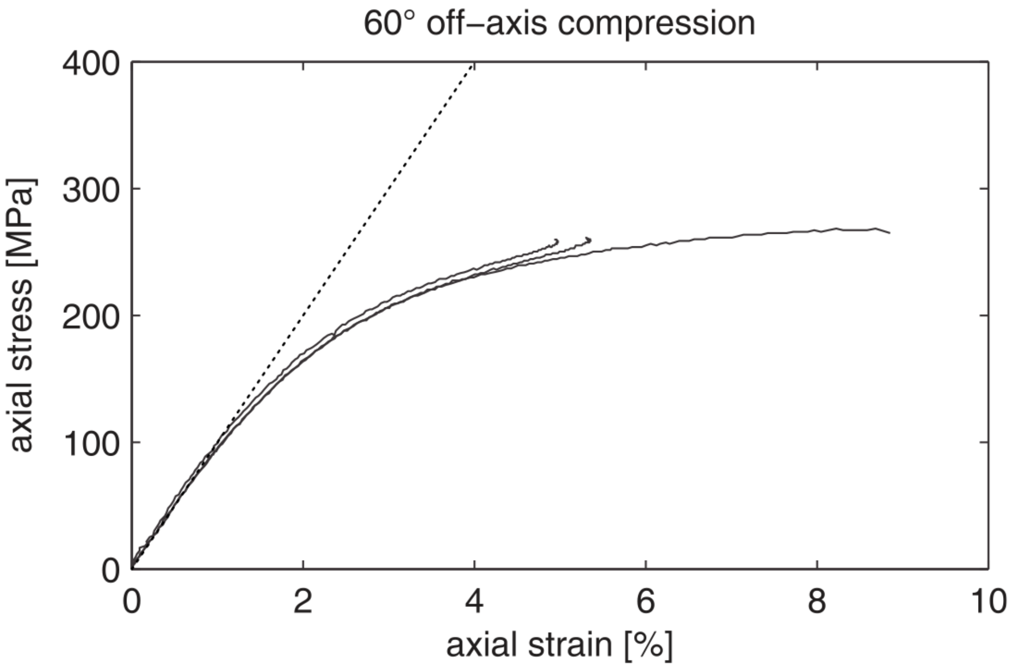
ν_{23}: Transverse Poisson's ratio

$$\boldsymbol{\varepsilon^e} = \begin{bmatrix} \frac{1}{E_{11}} & \frac{-\nu_{12}}{E_{11}} & \frac{-\nu_{12}}{E_{11}} & 0 & 0 & 0 \\ \frac{-\nu_{12}}{E_{11}} & \frac{1}{E_{22}} & \frac{-\nu_{23}}{E_{22}} & 0 & 0 & 0 \\ \frac{-\nu_{12}}{E_{11}} & \frac{-\nu_{23}}{E_{22}} & \frac{1}{E_{22}} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{2(1+\nu_{23})}{E_{22}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{12}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix} \boldsymbol{\sigma}$$

Introduction

- Why is the plastic transverse Poisson's ratio $\left(\nu_{23}^{p}\right)$ crucial?
  - FRPs show nonlinear response under certain loading conditions, such as compressive or shear loading states in the directions governed by the matrix.
  - The evolution of the plastic strains is governed by the plastic transverse Poisson's ratio $\left(\nu_{23}^{p}\right)$.

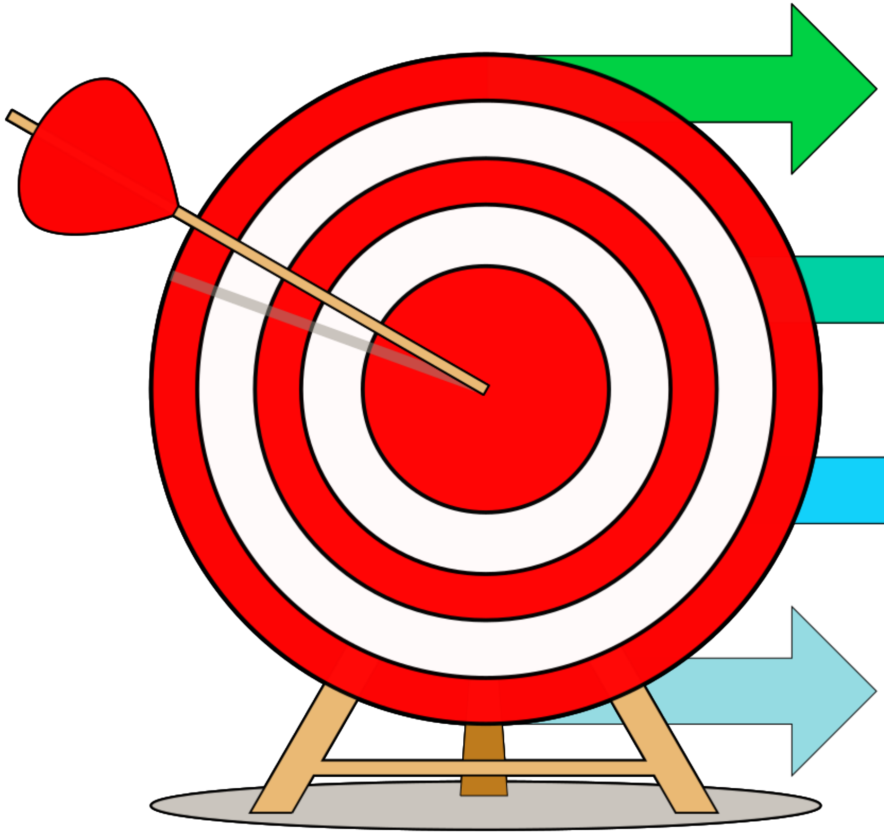




Images extracted from Koerber, H., Xavier, J., & Camanho, P. P. (2010). High strain rate characterisation of unidirectional carbon-epoxy IM7-8552 in transverse compression and in-plane shear using digital image correlation. Mechanics of Materials, 42(11), 1004-1019.

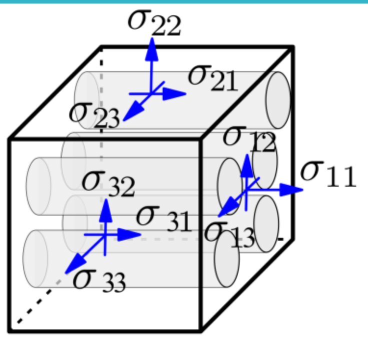
Introduction

- Main objectives:



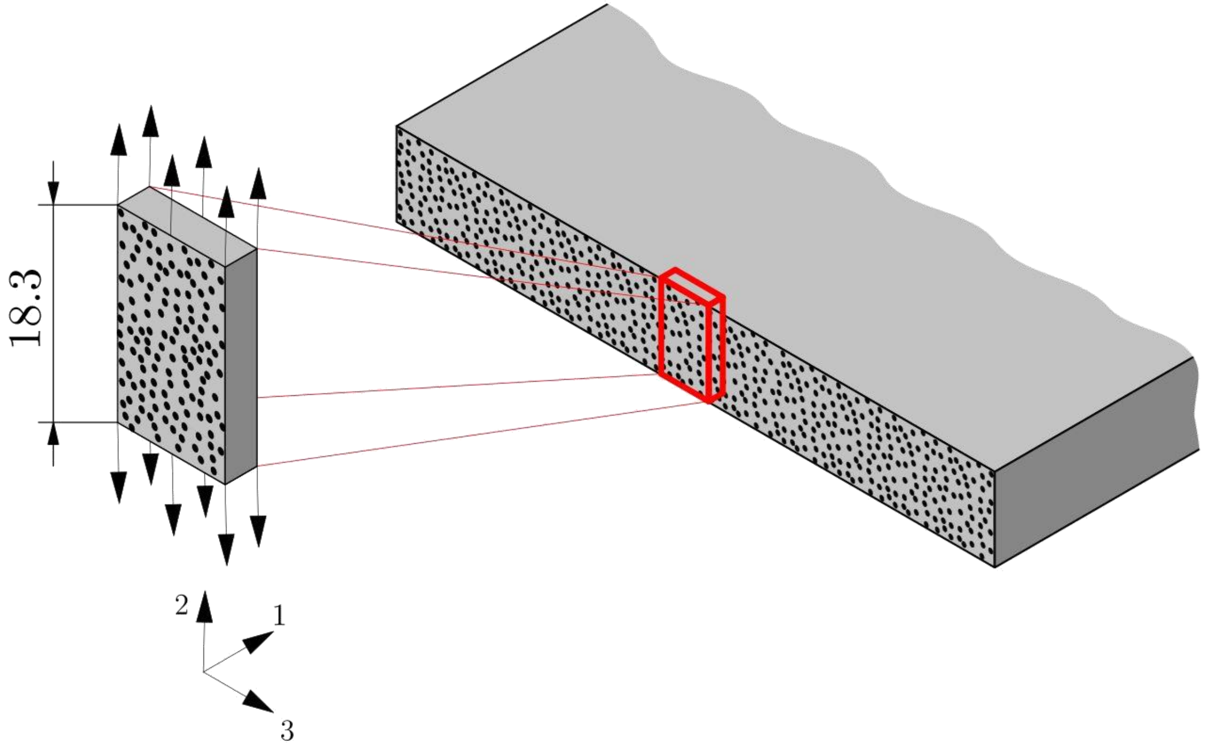
- ❑ Measure the elastic transverse Poisson's ratio.
- ❑ Measure the plastic transverse Poisson's ratio.
- ❑ Define a simple test set-up.
- ❑ No increase the commonly test matrix used in the characterisation of FRPs.

Introduction



➢ How is the transverse Poisson's ratio measured in the literature?

❑ Through-the-thickness test:



- Specimen length is limited to panel thickness. For example, Khaled *et al.* used a unidirectional laminate with 96 plies.
- Curing thick laminates can lead to significant residual stresses which can cause delamination and residual shape distortions.
- Specific grips are required to transfer the load from the hydraulic grip into the specimen.
- It is not the standard test in the commonly used test matrix, a specific panel must be then manufactured.

Khaled, B., Shyamsunder, L., Hoffarth, C., Rajan, S. D., Goldberg, R. K., Carney, K. S., ... & Blankenhorn, G. (2018). Experimental characterization of composites to support an orthotropic plasticity material model. Journal of Composite Materials, 52(14), 1847-1872.

Introduction

- How is the transverse Poisson's ratio measured in the literature?

  - Ultrasonic wave propagation and mechanical tests:

    I. The elastic modules $(E_{11}, E_{22}$ and $G_{12})$ are obtained from uniaxial tests.

    II. Several ultrasonic pulse transmission tests are performed at different directions and the components of the stiffness tensor are calculated as

$$C_{ijkl} = \rho \dot{u}_{i,l}^2$$

where C_{ijkl} are components of the stiffness tensor, ρ is the apparent mass density and $\dot{u}_{i,l}$ is the ultrasonic phase velocity.

    III. Transverse Poisson's ratio is estimated from the stiffness tensor.

Kohlhauser, C., & Hellmich, C. (2012). Determination of Poisson's ratios in isotropic, transversely isotropic, and orthotropic materials by means of combined ultrasonic-mechanical testing of normal stiffnesses: application to metals and wood. European Journal of Mechanics-A/Solids, 33, 82-98.

Introduction

➢ How is Poisson's ratio measured in the literature?

❑ Ultrasonic wave propagation and mechanical tests:

- Six test are required:
  - Three ultrasonic wave propagation tests.
  - Three uniaxial tests.

- Ultrasonic-mechanical tests leads to significant errors in the estimation of the longitudinal and transverse Poisson’s ratios.

- The plastic Poisson’s ratios cannot be estimated.

Kohlhauser, C., & Hellmich, C. (2012). Determination of Poisson’s ratios in isotropic, transversely isotropic, and orthotropic materials by means of combined ultrasonic-mechanical testing of normal stiffnesses: application to metals and wood. European Journal of Mechanics-A/Solids, 33, 82-98.

Methodology 02

Methodology – Material and methods

- The analysed material to illustrate the proposed methodology is a carbon fibre-reinforced poly-ether-ether-ketone (PEEK) used in the TREAL project.

- Two different tests are employed:

  - Transverse tensile test with a unidirectional laminate of 11 plies ($[90]_{11}$) to measure the elastic transverse Poisson's ratio in tension (ν_{23T}).

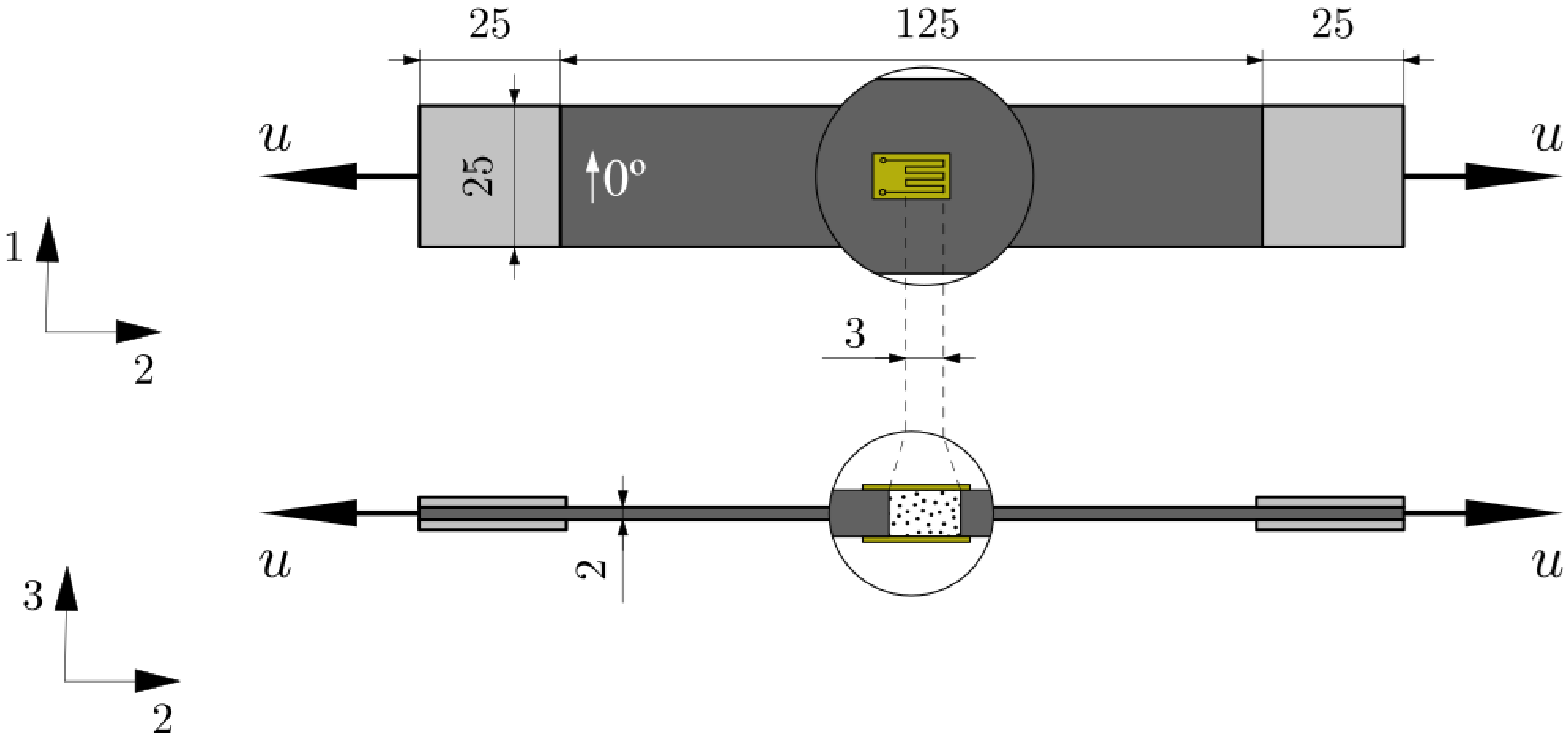
Methodology – Material and methods

- The analysed material to illustrate the proposed methodology is a carbon fibre-reinforced poly-ether-ether-ketone (PEEK) used in the TREAL project.

- Two different tests are employed:
  - Transverse tensile test with a unidirectional laminate of 11 plies ($[90]_{11}$) to measure the elastic transverse Poisson's ratio in tension (ν_{23T}).
  - Transverse compressive test with a unidirectional laminate of 22 plies ($[90]_{22}$) to measure the elastic transverse Poisson's ratio in compression (ν_{23C}) as well as in the plastic region (ν^{p}_{23C}).

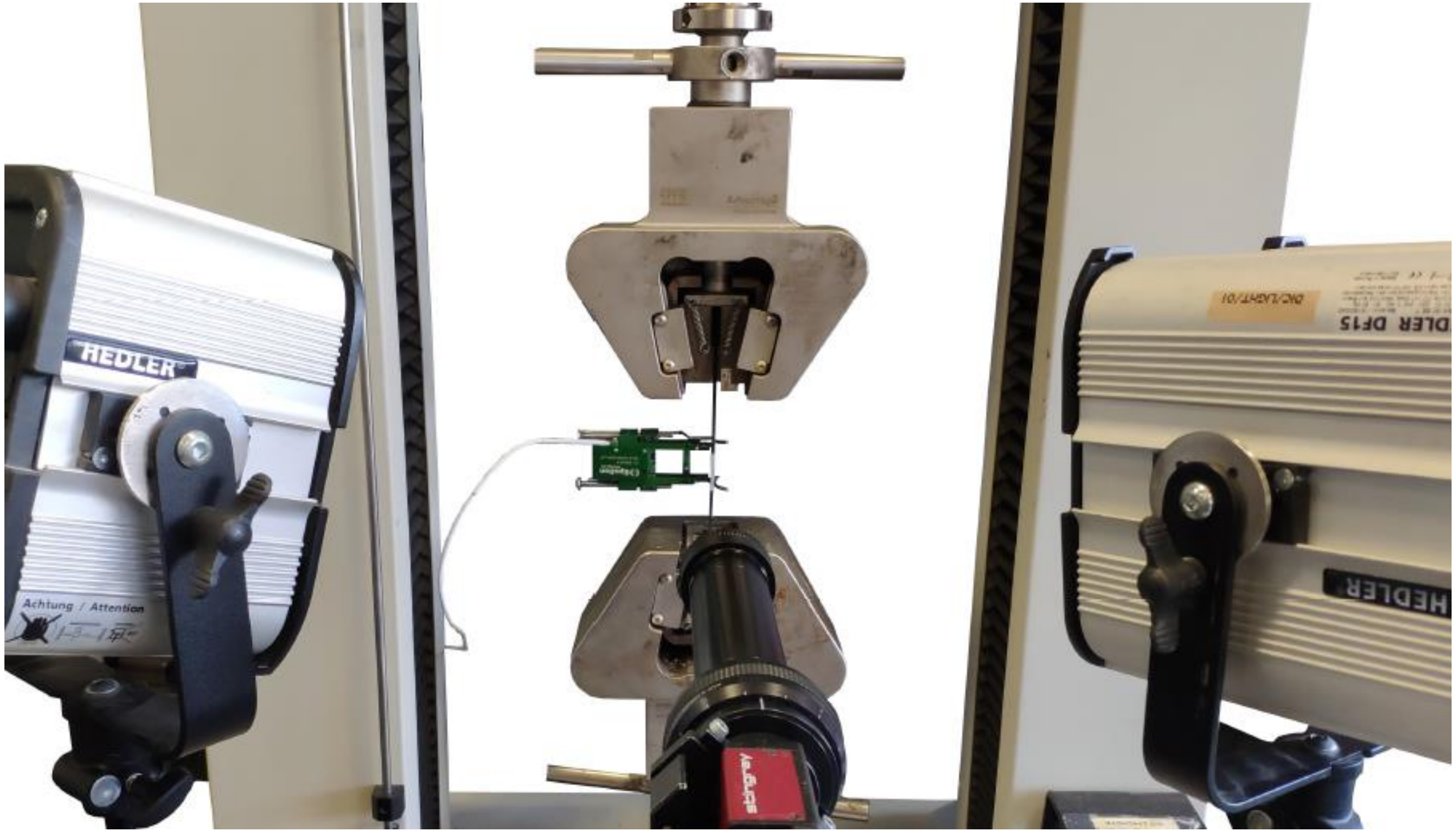
Methodology – Elastic transverse Poisson's ratio in tension (ν_{23T})

- Elastic transverse Poisson's ratio in tension is measured following the ASTM-D3039M standard and using DIC equipment with a uniditectional laminate of $[90]_{11}$.



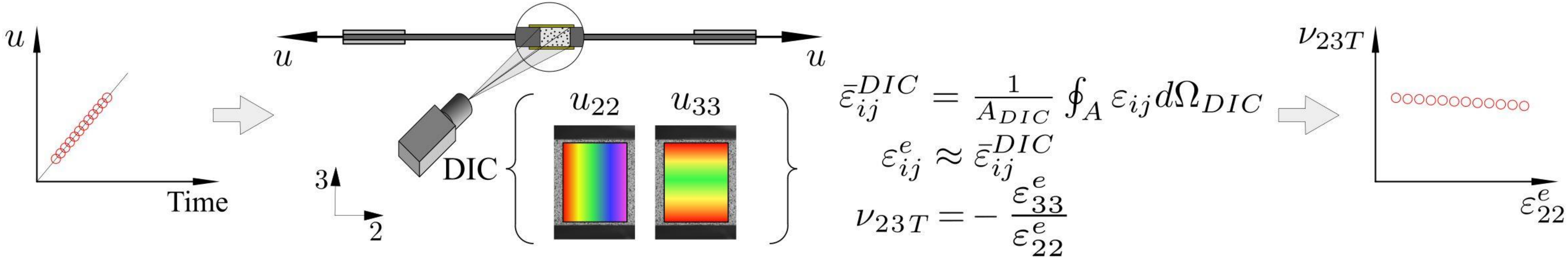
Methodology – Elastic transverse Poisson's ratio in tension (ν_{23T})

- Elastic transverse Poisson's ratio in tension is measured following the ASTM-D3039M standard and using DIC equipment with a uniditectional laminate of $[90]_{11}$.



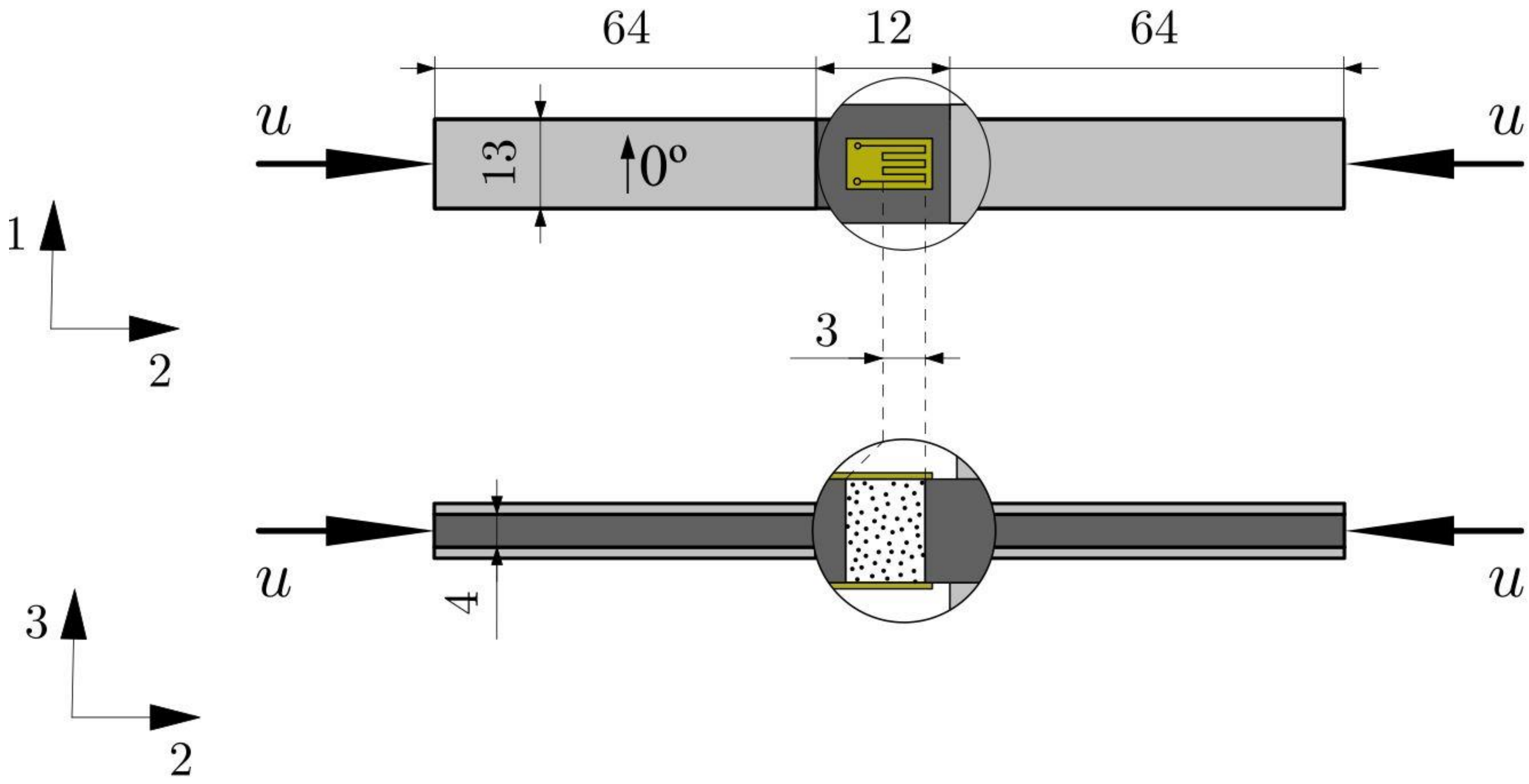
Methodology – Elastic transverse Poisson's ratio in tension (ν_{23T})

- Elastic transverse Poisson's ratio in tension is measured following the ASTM-D3039M standard and using DIC equipment with a uniditectional laminate of $[90]_{11}$.



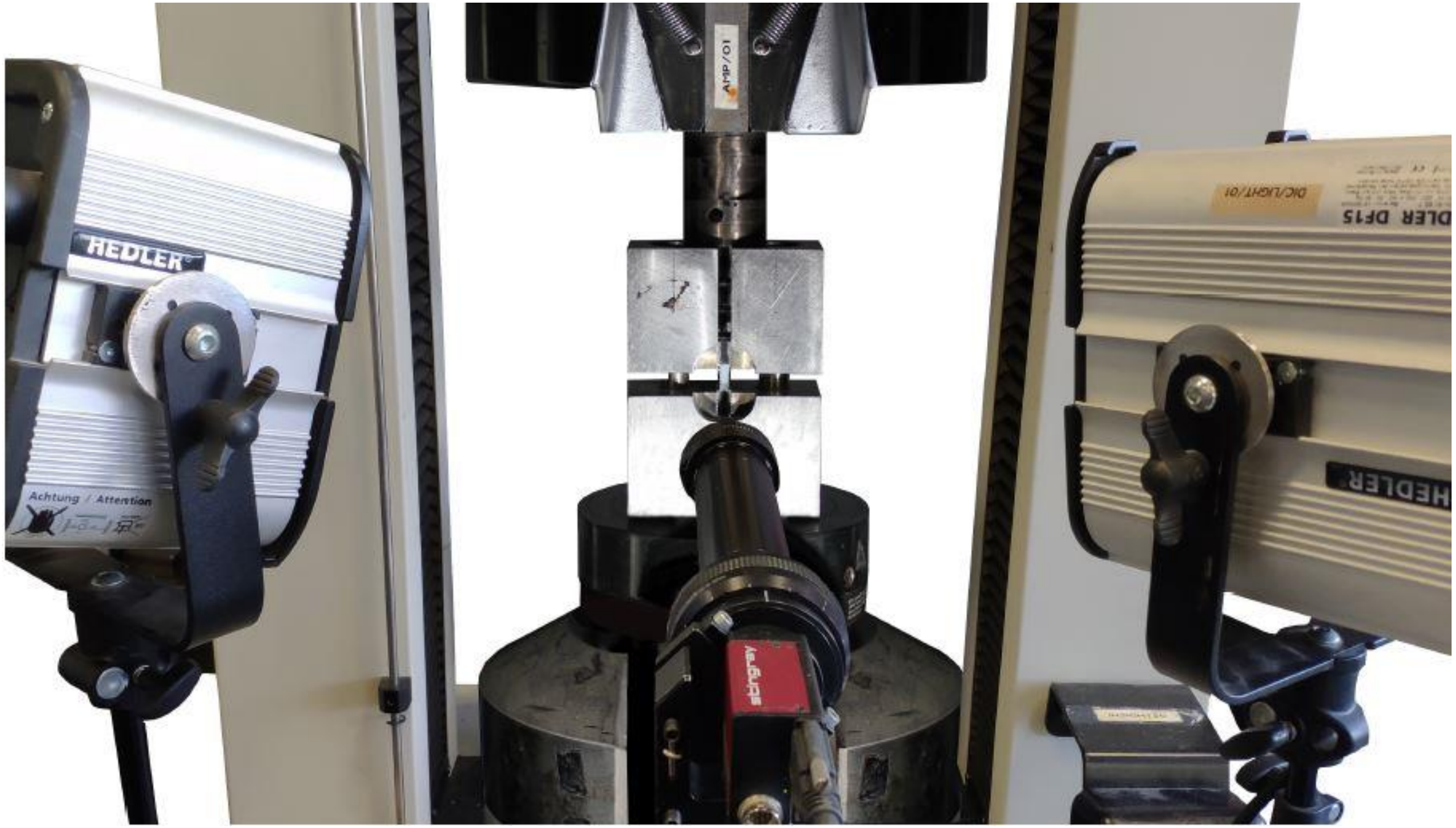
Methodology – Elastic transverse Poisson's ratio in compression

- Transverse Poisson's ratio in compression is measured following the ASTM-6641M standard and using DIC equipment with a uniditectional laminate of $[90]_{22}$.



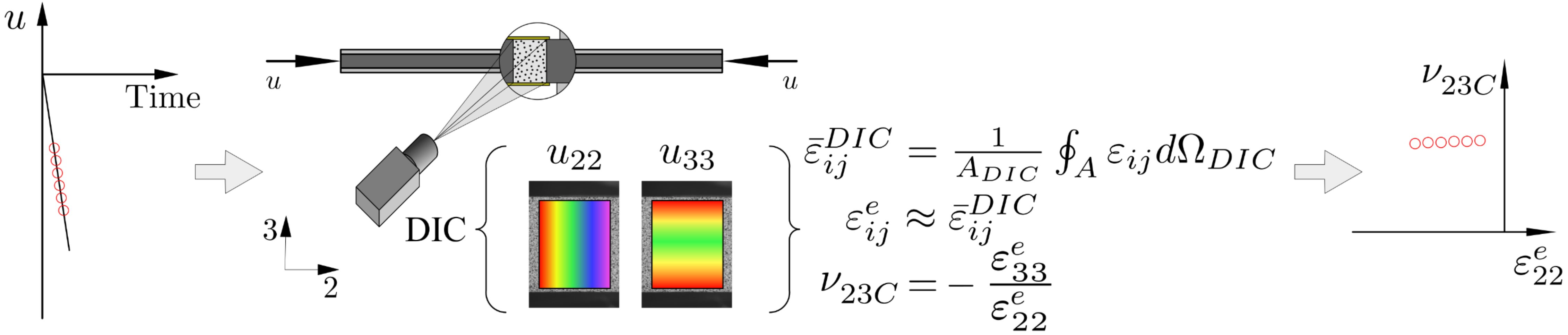
Methodology – Elastic transverse Poisson’s ratio in compression

- Transverse Poisson’s ratio in compression is measured following the ASTM-6641M standard and using DIC equipment with a uniditectional laminate of $[90]_{22}$.



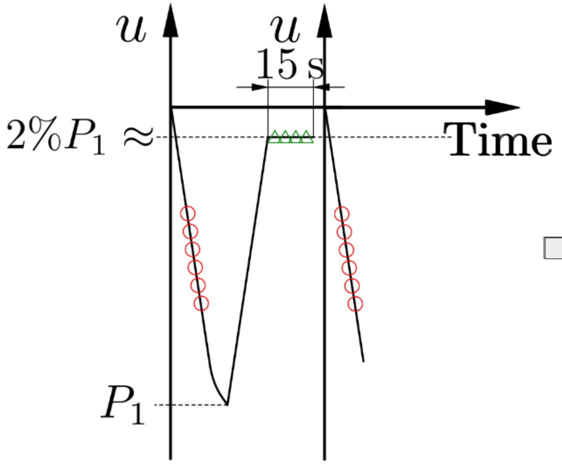
Methodology – Transverse Poisson's ratio in compression

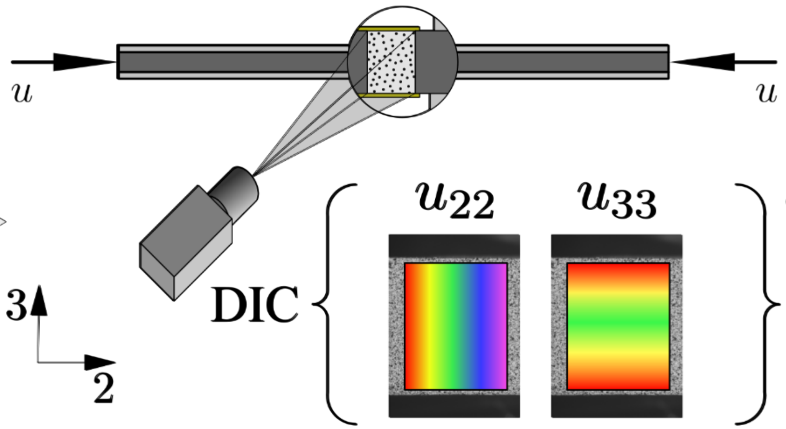
- **Elastic transverse Poisson's ratio in compression (ν_{23C})**



Methodology – Transverse Poisson's ratio in compression

- **Plastic transverse Poisson's ratio in compression $\left(\nu_{23C}^{p}\right)$**

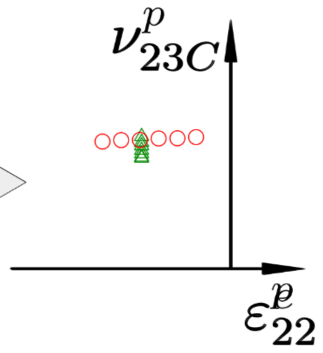




$$\bar{\varepsilon}_{ij}^{DIC} = \frac{1}{A_{DIC}} \oint_A \varepsilon_{ij} d\Omega_{DIC}$$

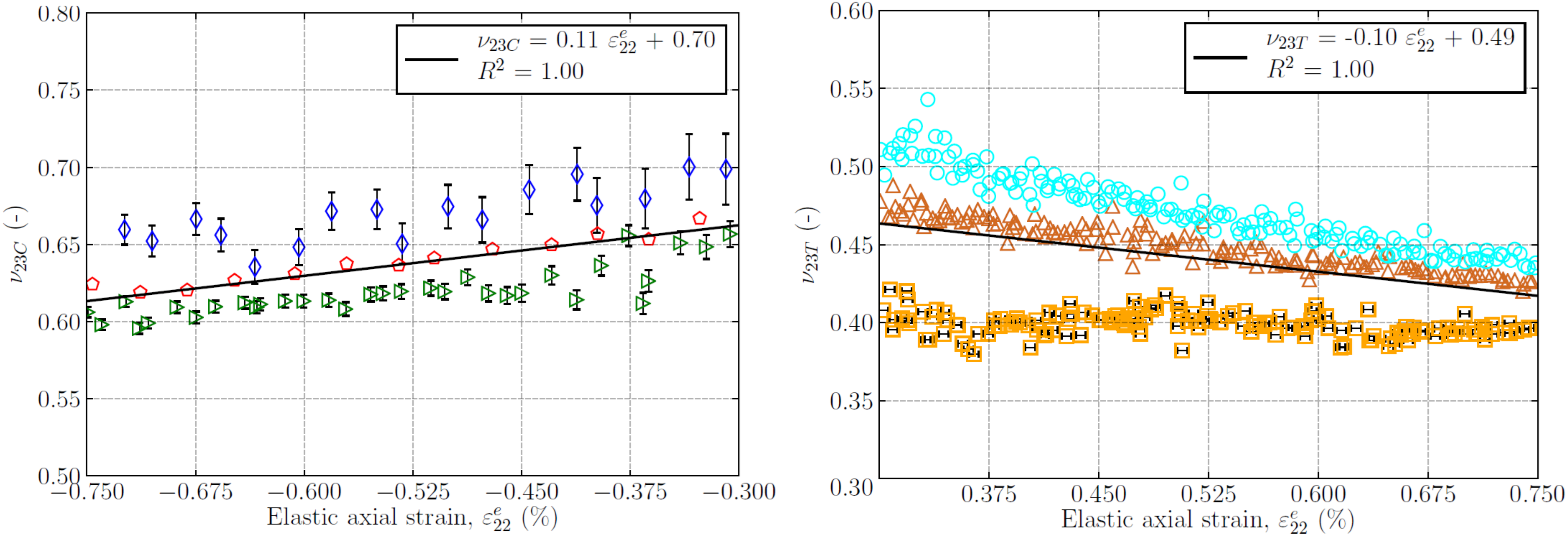
$$\varepsilon_{ij}^{p} \approx \bar{\varepsilon}_{ij}^{DIC}$$

$$\nu_{23C}^{p} = -\frac{\varepsilon_{33}^{p}}{\varepsilon_{22}^{p}}$$

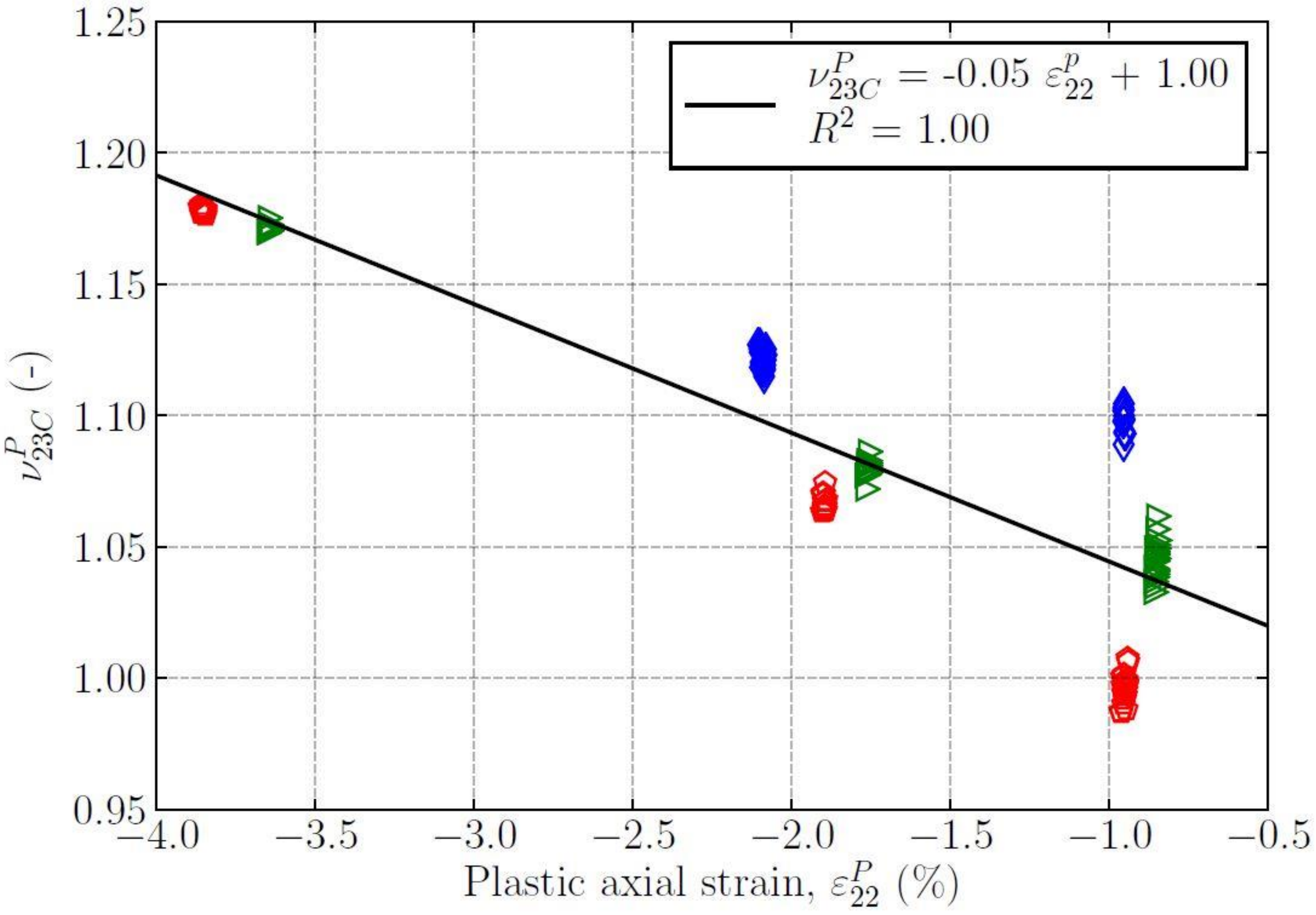


Results and Discussion 03

Results – Elastic transverse Poisson's ratio (ν_{23})



Results – Plastic transverse Poisson's ratio in compression

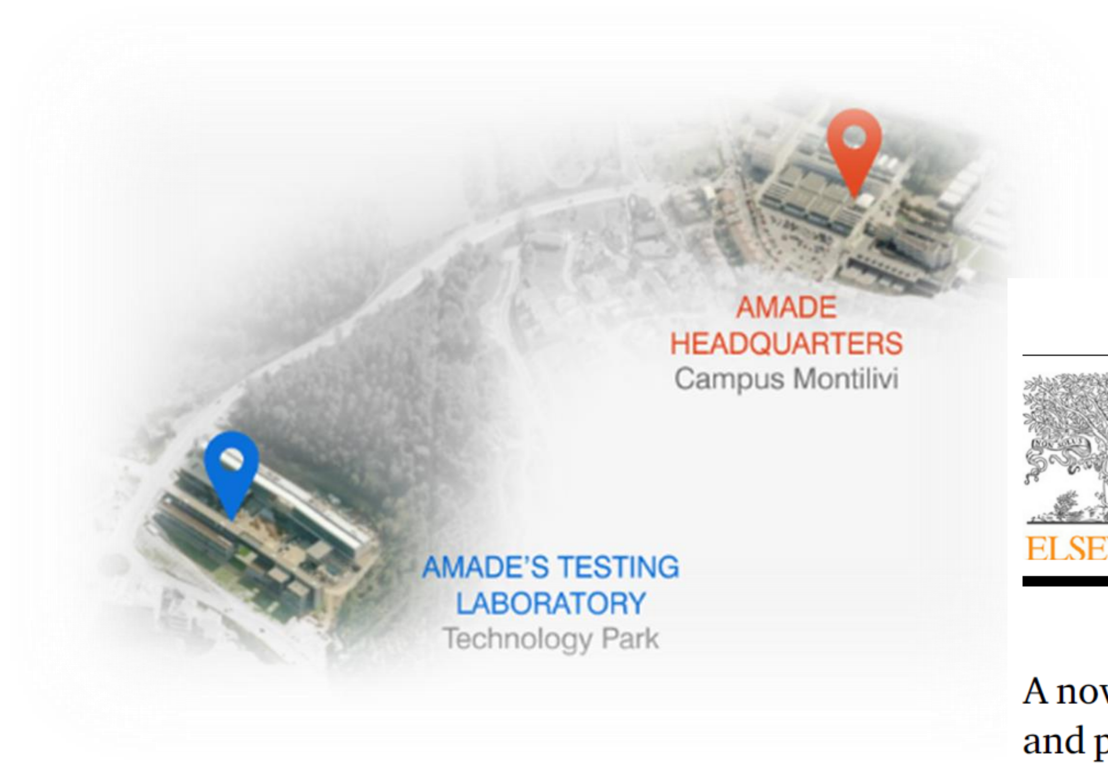


ivan.ruiz@udg.edu

Concluding remarks 04

Concluding remarks

- A new methodology to measure the elastic transverse Poisson's ratio was proposed.
- A linear relationship between the elastic transverse Poisson's ratio and axial transverse strain was found.
- A new methodology to measure the plastic transverse Poisson's ratio in compression was proposed.
- No volumetric plastic strains were observed at small values of the compressive plastic strains.
- The analysed material behaves as a frictional material under significant amount of compressive plastic strains.



http://amade.udg.edu

testlab.amade@udg.edu

AMADE
ANALYSIS AND ADVANCED MATERIALS
FOR STRUCTURAL DESIGN

Composites Part B 272 (2024) 111098

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/composites

ELSEVIER

A novel methodology to measure the transverse Poisson's ratio in the elastic and plastic regions for composite materials

I.R. Cózar [a,*], J.J. Arbeláez-Toro [a,b], P. Maimí [a], F. Otero [c,d], E.V. González [a], A. Turon [a], P.P. Camanho [e,f]

[a] *AMADE, Polytechnic School, University of Girona, Campus Montilivi s/n, 17071 Girona, Spain*
[b] *Faculty of Engineering, Instituto Tencnológico Metropolitano, Medellín, Colombia*
[c] *CIMNE, Universitat de Politècnica de Catalunya, 08034 Barcelona, Spain*
[d] *Department of Nautical Science and Engineering, Universitat Politècnica de Catalunya, Pla de Palau 18, 08003 Barcelona, Spain*
[e] *DEMec, Faculdade de Engenharia, Universidade do Porto, 4200-465 Porto, Portugal*
[f] *INEGI, Instituto de Ciência e Inovação em Engenharia Mecânica e Industrial, 4200-465 Porto, Portugal*