Swedish research project:
Modelling crash behaviour in future lightweight composite vehicles

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Stuttgart
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DYNAmore Nordic

- Software
  - Sales, support and development
  - **LS-DYNA**
  - LS-Opt
  - LS-prepost
  - Digimat
  - Beta CAE
  - Oasys Primer
  - Dynaform
  - FormingSuite
  - FEMZIP
  - ...
- Training
- FE models
  - Dummies
  - Barriers
- Engineering services
- HPC clusters
- Research
- Offices
  - Linköping, Sweden
  - Göteborg, Sweden
- Subsidiary of DYNAmore GmbH

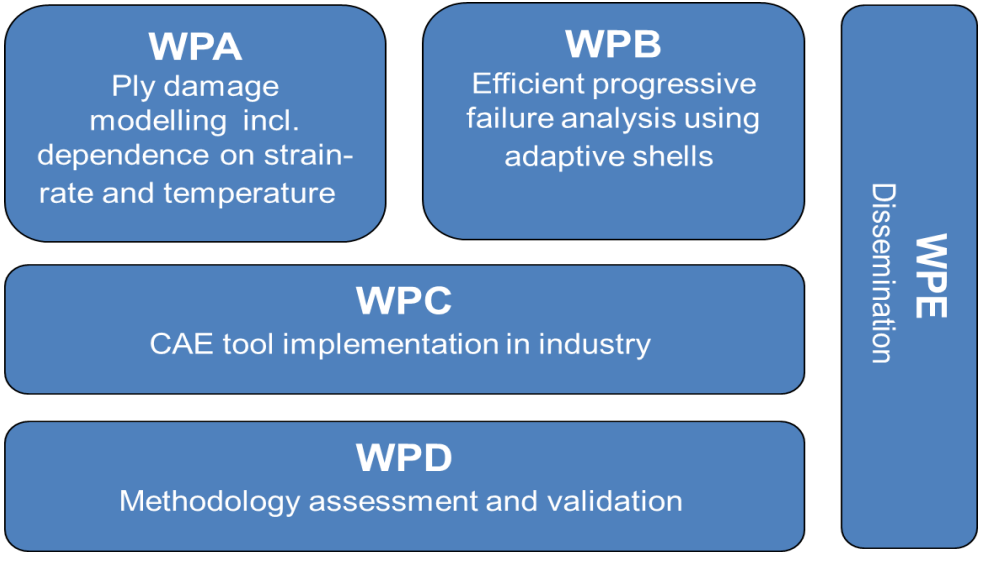
Composites (CFRP) in crash CAE

- Challenges
  - Unpredictable loading conditions
  - Material modeling
    - Stiffness
    - Progressive failure
      - Energy absorption
    - Material characterization
  - Structure modeling
    - Stress state
    - In-plane failure
    - Delamination
  - Efficiency
    - Detail vs speed
    - Time step
  - Process modeling
    - Coupling properties from manufacturing process to crash simulation
    - Various processes
      - From hand-made to high-cycle

- How the challenges are addressed in an ongoing research project
  - Modelling crash behaviour in future lightweight composite vehicles
    - FFI Crash 1-2

FFI crash 1-2

- Modelling crash behaviour in future lightweight composite vehicles
  - FFI: government Strategic vehicle research and innovation program
  - In-kind

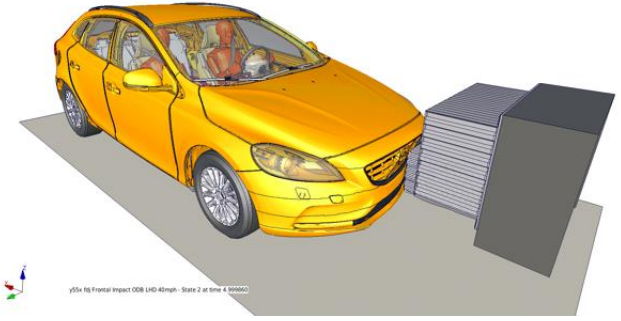


WPB

- Efficient progressive failure analysis using adaptive shells
- Chalmers
  - Johannes Främby, PhD student
  - Martin Fagerström, Associate Professor, supervisor, project coordinator
- DYNAmore Nordic
  - Jesper Karlsson, PhD, LS-DYNA developer
  - Mats Landervik, PhD, WP leader

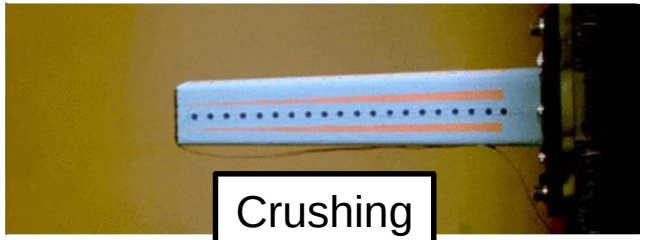
AUTOMOTIVE CRASH SIMULATIONS

Grauers, L., Olsson, R., & Gutkin, R. (2014). *Composite Structures*



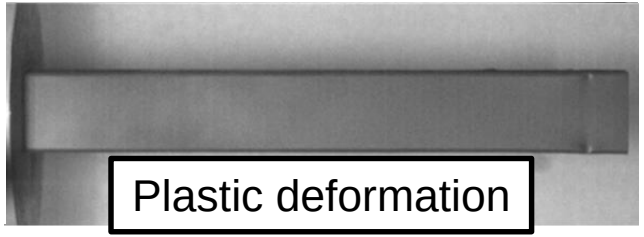
Courtesy of Volvo Car Corporation

CFRP CRASH BOX



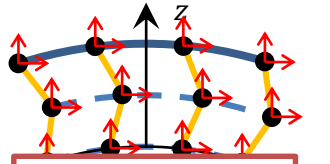
Courtesy of **Engenuity**: https://www.youtube.com/watch?v=VdP5a4k6aOY

METAL CRASH BOX

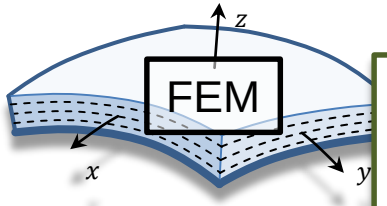


Courtesy of **DYNLab**: https://www.youtube.com/watch?v=M75xbyDER4o

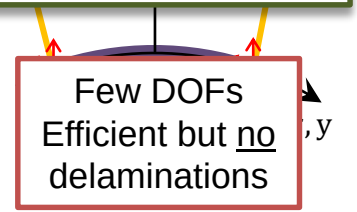
Layer Wise (LW)



Many DOFs Needed for delaminations

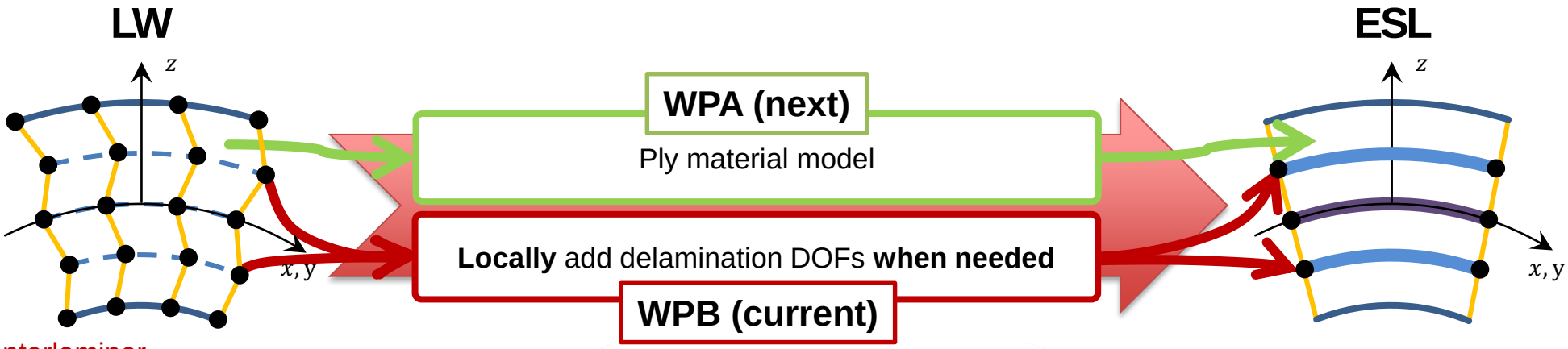


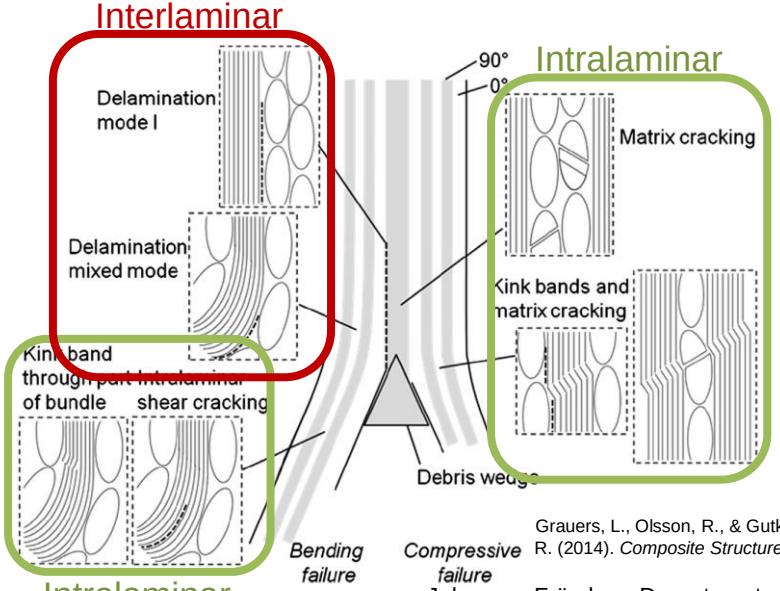
Research scope:
Develop **accurate** and **efficient** shell models for FE simulation of crash in composites



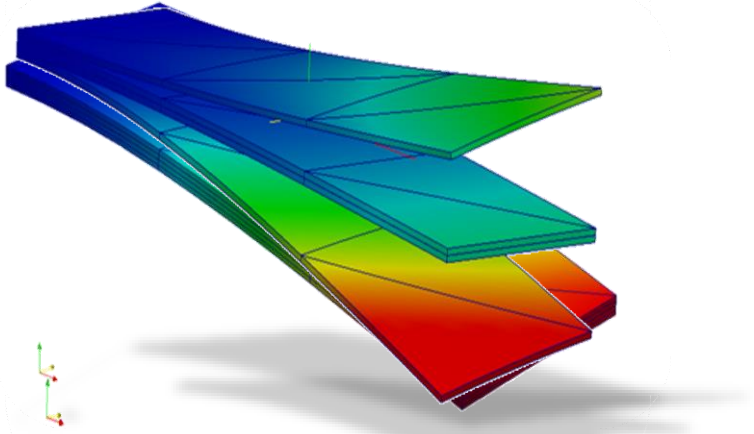
Few DOFs
Efficient but no delaminations

Equivalent Single-Layer (ESL)





Grauers, L., Olsson, R., & Gutkin, R. (2014). *Composite Structures*

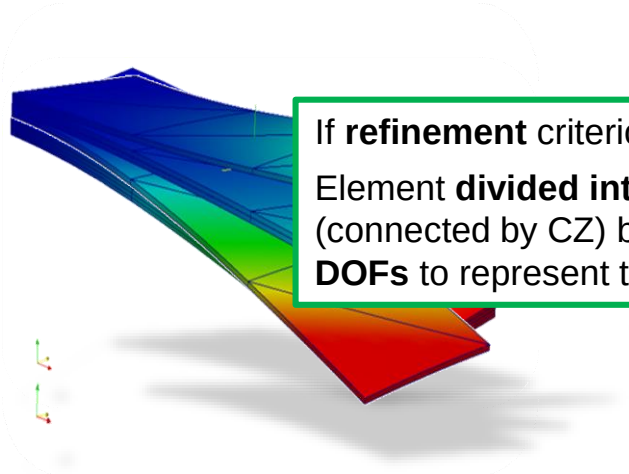


Research scope:
Develop **accurate** and **efficient** shell models for FE simulation of crash in composites

ADAPTIVE ENRICHMENT METHODOLOGY FOR SIMULATING PROPAGATING DELAMINATIONS

Främby et al (2017). *IJNME*.

1. Starts with simple ESL model;
2. Identify potential delamination areas;
3. ESL model is locally enriched with CZ;
4. If delaminations propagate, enrichments are expanded.



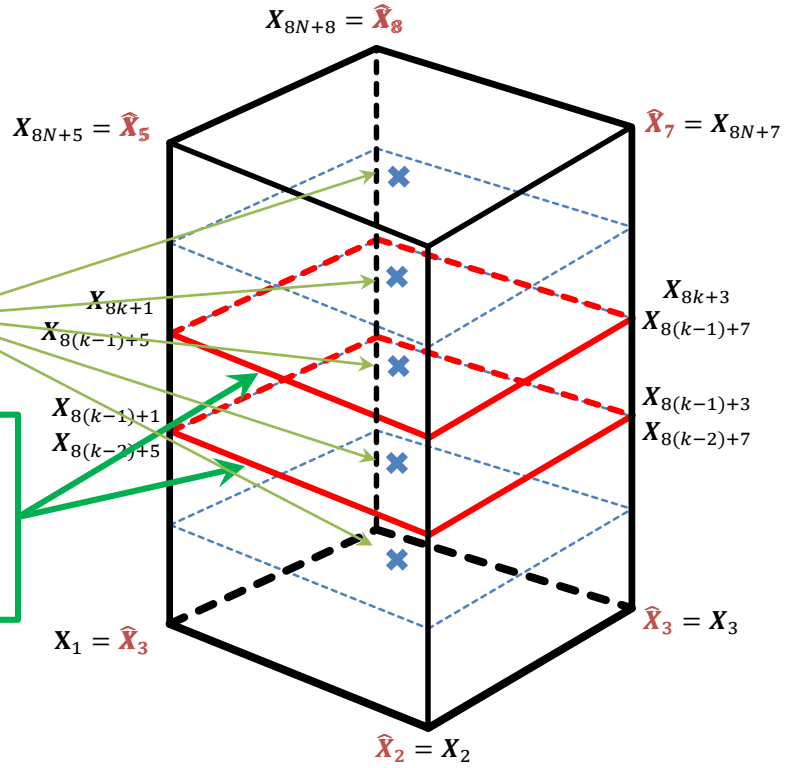
If **refinement** criterion is activated:

Element **divided into sub-elements** (connected by CZ) by assigning **global extra DOFs** to represent the interface nodes.

ADAPTIVE LS-DYNA USER ELEMENT

External user solid: 8 noded thick shell

Internal thick shell sub-elements: $8 \times N$ phantom nodes



WPA

- Ply damage modelling
- Swerea SICOMP
  - Sérgio Costa, PhD student
  - Robin Olsson, PhD, supervisor, WP leader
  - Renaud Gutkin, PhD, former supervisor, now Volvo Cars

swerea | SICOMP

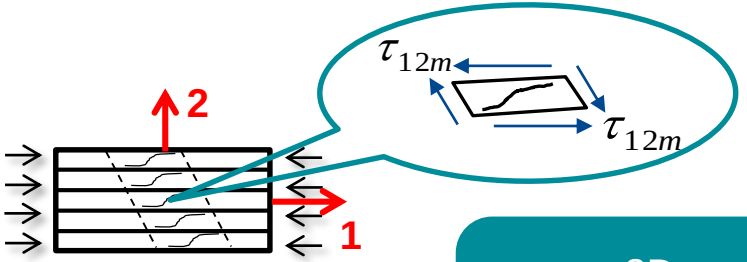
Challenges of the physically based model

Model the damage growth of the compressive modes

Challenge 1

Transverse crushing

3D model
With **transverse** friction and damage



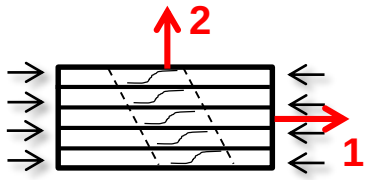
Challenge 2

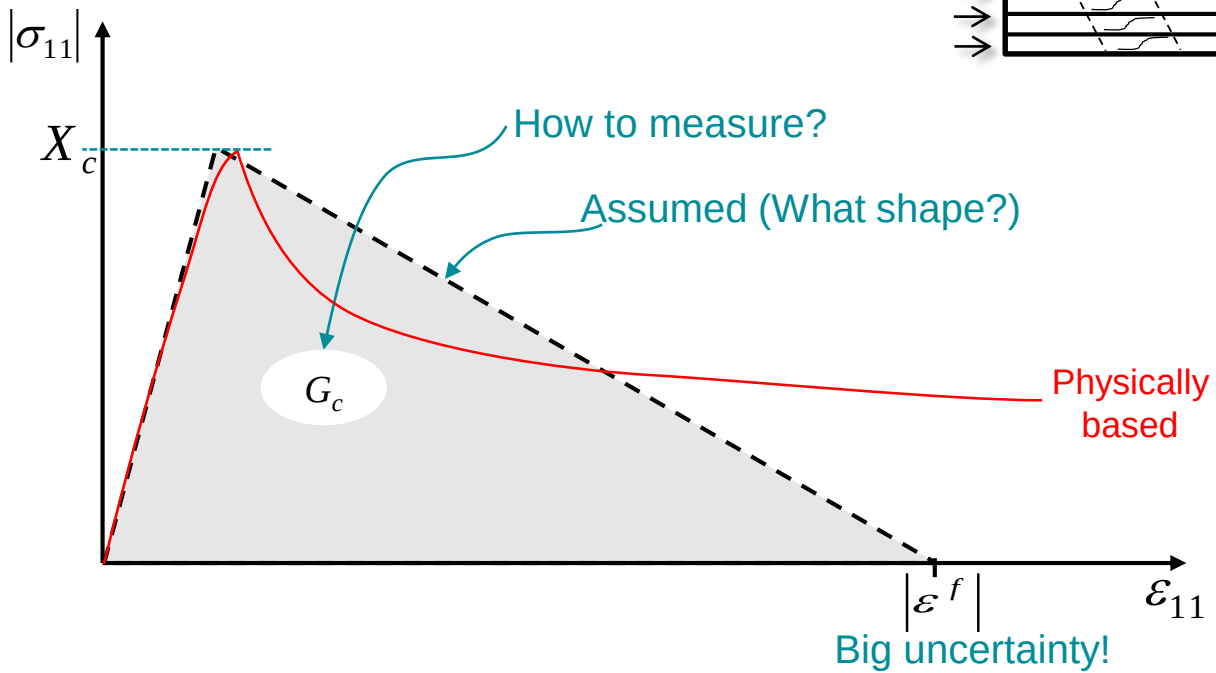
Axial crushing (Fibre kinking)

3D model
With **longitudinal** friction and damage

Challenge 2 – Fibre kinking

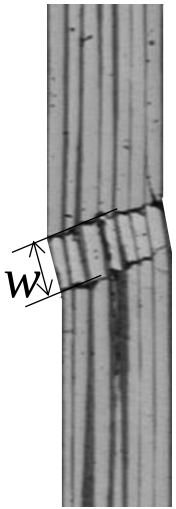
CDM: Bilinear vs Physically based

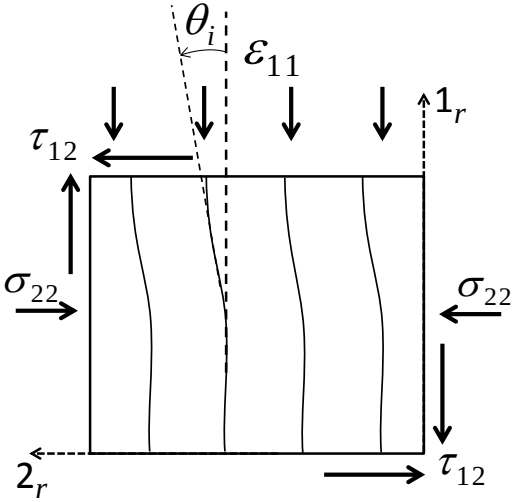


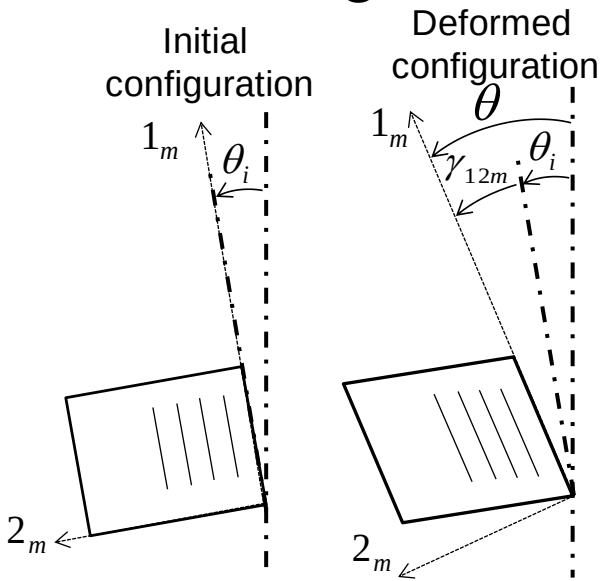


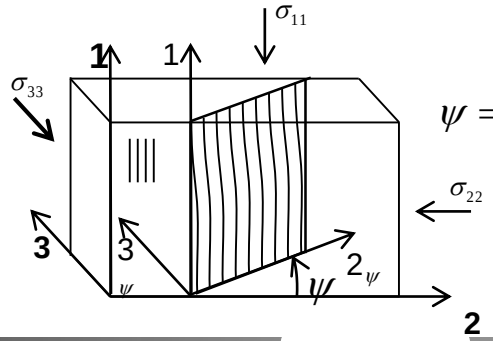
No need for fracture toughness

Mechanisms: Stresses and shear angle









3D view

$$\psi = \frac{1}{2}\tan^{-1}\left(\frac{2\tau_{23}}{\sigma_{22}-\sigma_{33}}\right)^{*}$$

*Pinho et al. (2006)

$$\theta = \gamma_{12m} + \theta_i$$

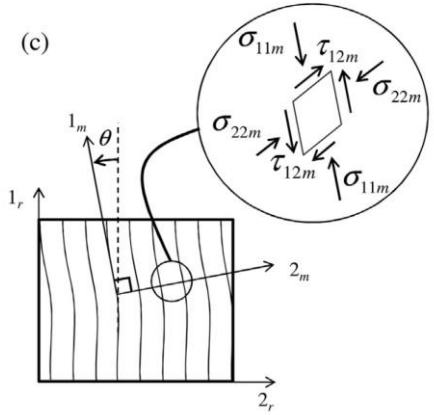
Kink-band plane – Constitutive equations

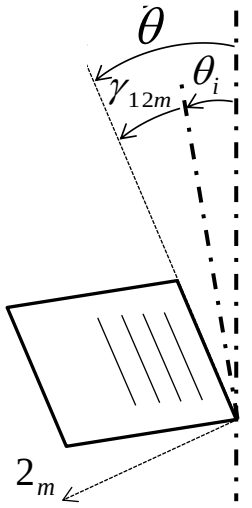
Strain compatibility

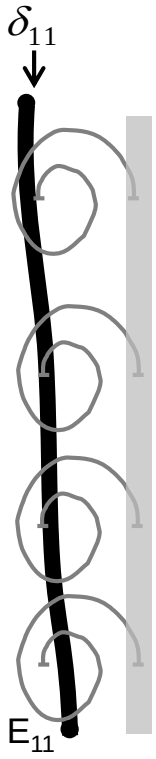
$$\boldsymbol{\varepsilon}_{\mathbf{m}} = \mathbf{T}_{\boldsymbol{\theta}} \boldsymbol{\varepsilon} \mathbf{T}_{\boldsymbol{\theta}}^{\mathbf{T}}$$

Stress equilibrium

$$\boldsymbol{\sigma}_{\mathbf{m}} = \mathbf{T}_{\boldsymbol{\theta}} \boldsymbol{\sigma} \mathbf{T}_{\boldsymbol{\theta}}^{\mathbf{T}}$$







Shear response (damage + friction)

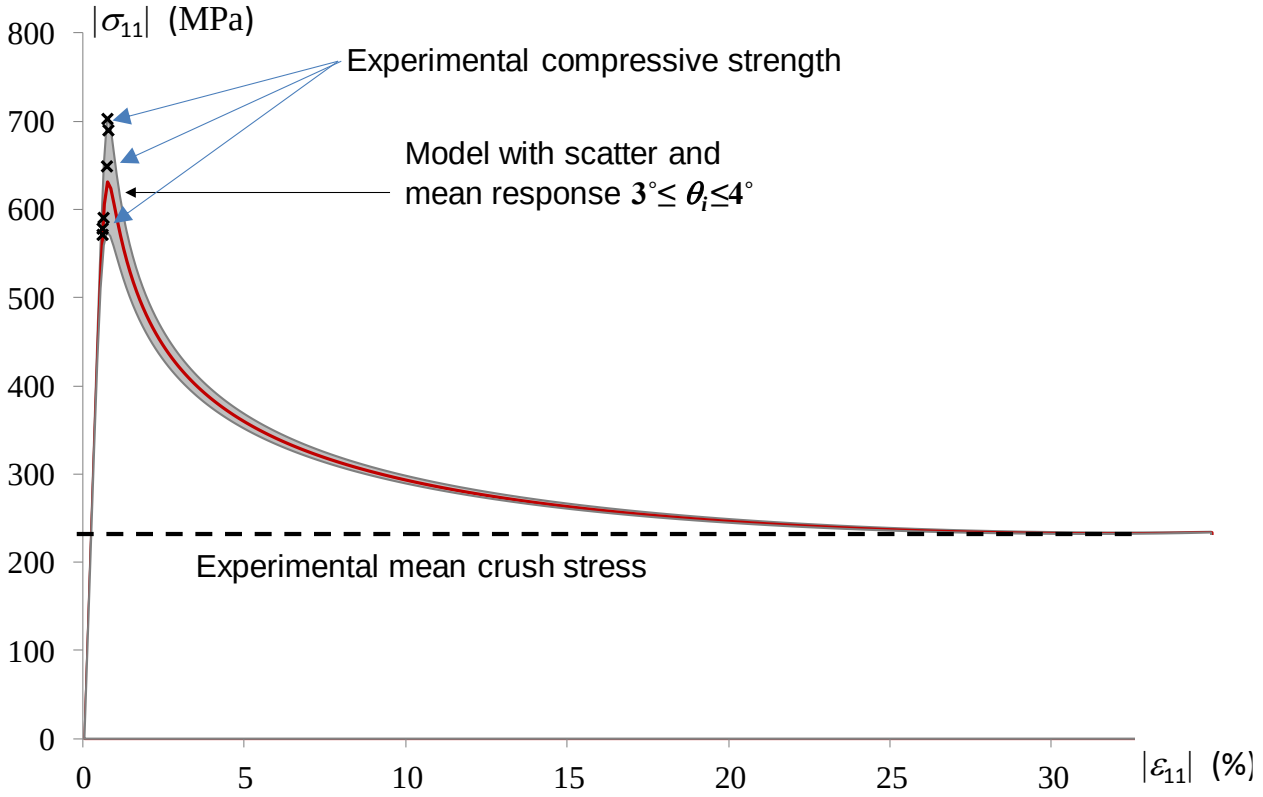
$$\tau_{12m} = G_{12}\gamma_{12m}(1-d) + d\tau^{friction}$$

Kinking stress

$$\sigma_{11} = \left[\sigma_{22}sc + \tau_{12}(c^2 - s^2) - \tau_{12m}\right]/(sc)$$

Physically based fibre kinking response

Validation at the material point



Simplify to **uniaxial stress state** and **small angles**

$$\sigma_{11} = \frac{-\tau_{12m}}{\gamma_{12m} + \theta_i}$$

Cf. Budiansky Eq.

$$X_c = \frac{S_L}{\gamma_o + \theta_i}$$

WPC

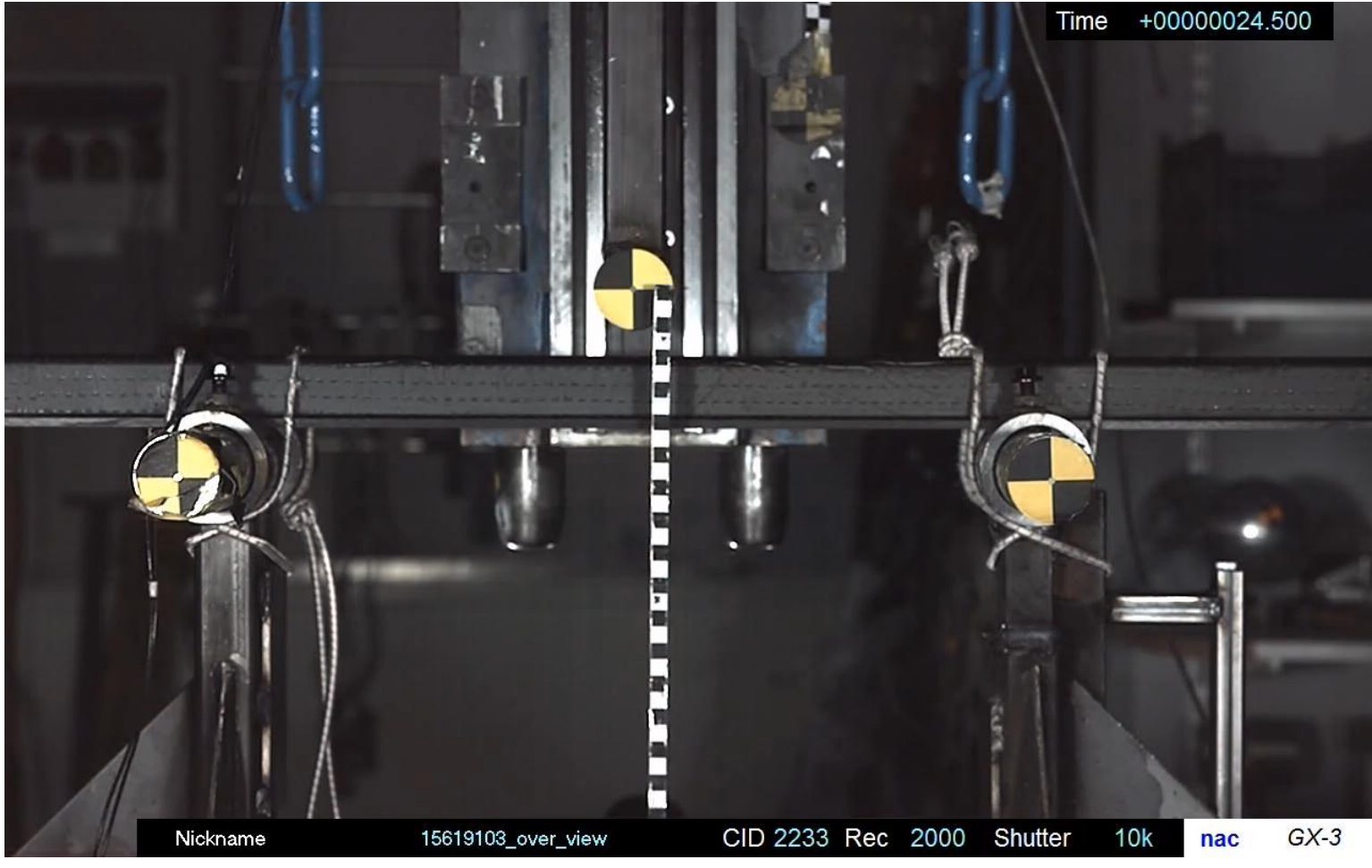
- CAE tool implementation in the industrial design process
  - Development of industrial design assessment routines and processes
  - Design of weight efficient crash protection demonstrators
  - Assessment and benchmark of Digimat
  - WP leader: Rickard Östlund, Gestamp

WPD

- Methodology assessment and validation
  - Manufacture of test components
  - Testing of components
  - Fractographic study
  - Evaluation of agreement between simulations and tests
  - WP leader: Kaj Fredin, VCC

WPC-WPD

- Components
  - Design
  - CAE
  - Manufacturing
  - Testing
  - Verification
- Example from project pt. 1
  - Composite beam in bending drop test at VCC



WPE

- Dissemination
  - **An international workshop on crash in composites**
    - 13-14 September 2018
    - **Preregistration by 15 March!**
  - Publications
  - Conference presentations
  - Training and teaching

Acknowledgements

- Slides from
  - Martin Fagerström
  - Johannes Främby
  - Sérgio Costa

Workshop: Crash behaviour of composites

Title	Speaker
Crash modelling at QUB and the ICONIC research network	Brian Falzon (Queens Univ. Belfast)
Crash modelling and experiments at Swerea SICOMP	Robin Olsson (SICOMP)
North American work on crash behaviour of composites	Reza Vaziri (Univ. British Columbia)
Crash modelling at Chalmers and in Swedish crash projects	Martin Fagerström (Chalmers Univ. Techn.)
Japanese studies of composites in crash	Jun Takahashi (Univ. Tokyo)
Novel composite microstructures for increased energy absorption	Silvestre Pinho (Imperial College)
Strain rate behaviour of composite materials	Hannes Körber (TU Munich)
German design experience for composites in cars	David Moncayo (Daimler AG)
Composite materials for cars – demands and cost issues	Kaj Fredin (Volvo Cars)
Current methods for crash simulation and testing	Johan Jergeus (Volvo Cars)

Image by courtesy of Volvo Car Group

- Venue
  - Chalmers University of Technology, Göteborg, Sweden
- Date
  - 13-14 September 2018 (two full days)
- Workshop fee
  - Maximum 250 Euro incl. dinner, two lunches and coffee
- Organizing committee
  - Martin Fagerström, Chalmers
  - Robin Olsson, Swerea SICOMP
- Registration
  - **Pre-register by 15 March 2018**
    - www.chalmers.se/crashworkshop2018
  - Notification of acceptance by 1 April
  - Full registration after acceptance by 1 May

Thank you!

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