FAILURE OF CFRP AND SFRP COMPONENTS IN AUTOMOTIVE AND AEROSPACE FIELDS

STRUCTURAL ENGINEERING - Application

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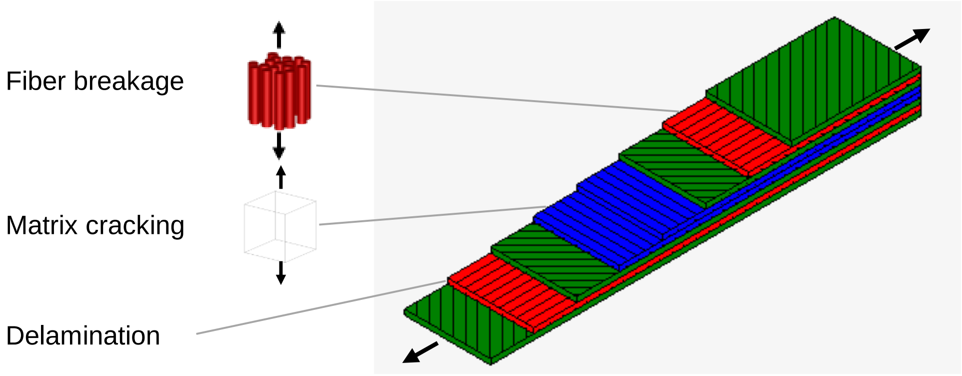
Failure of CFRP

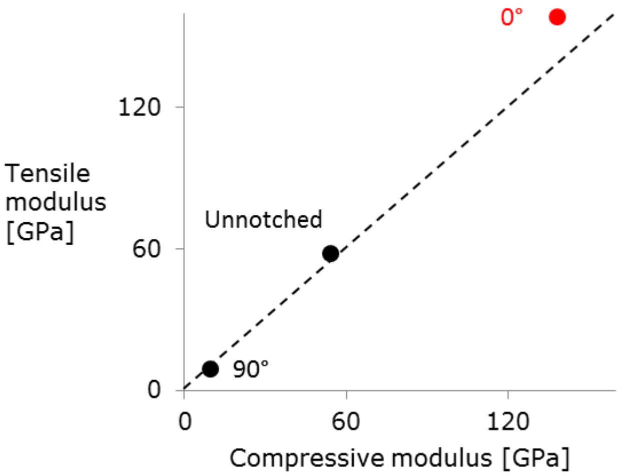
Progressive failure of CFRP components

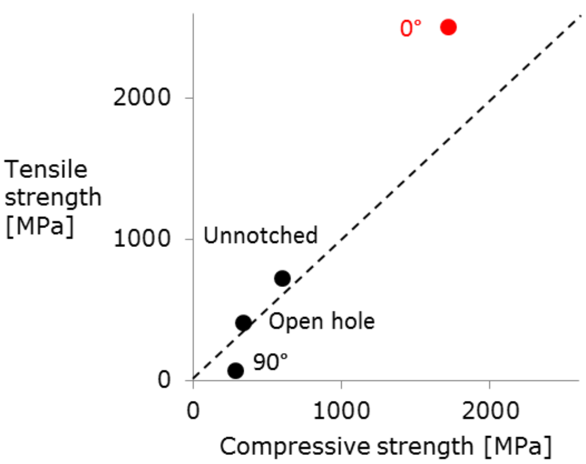
Continuous fiber composites exhibit a complex behavior

- **Various failure modes at various levels**



- **Properties anisotropy**

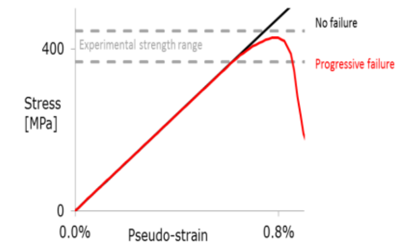




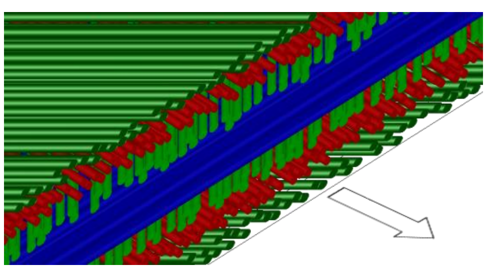
Progressive failure of CFRP components

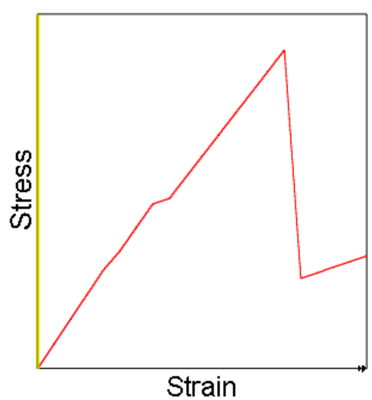
Progressive failure predicts laminate failure in a realistic way

- **Strength is monitored in multiple directions**
  - Damage is triggered when the strength value is reached (Failure)
  - Damage occurs only in the direction where failure is reached

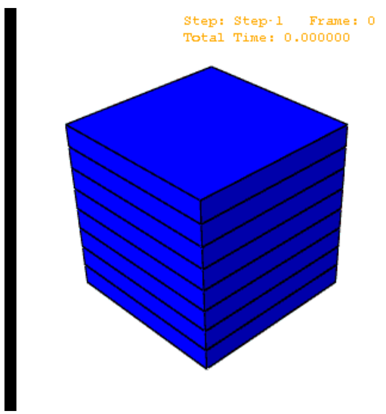


- **Stiffness degradation based on damage variables**
  (Matzenmiller et al., 1995)
- **Succession of failure events in different ply families**
  e.g., for tensile test on quasi-isotropic laminate with instantaneous damage

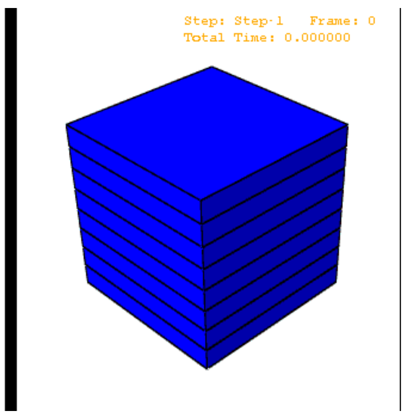




Longitudinal damage



Transverse damage



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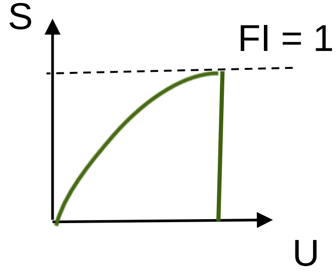
Progressive failure of CFRP components

Comparing Failure Models

- **Standard failure**
  - Elastoplastic resin
  - Elastic carbon
  - Standard failure model with element deletion based on measured strength in all directions of load
    - Differentiation between compressive & tensile strength

For all directions



Element deletion → brutal loss of stiffness in all directions

Failure prediction is driven by the failure indicators

Parameters

Axial tensile strength (X_t):

Axial compressive strength (X_c):

In-plane tensile strength (Y_t):

In-plane compressive strength (Y_c):

Transverse shear strength (S):

In-plane shear strength (S_I):

Failure indicator outputs

f_i such that $\mathcal{F}_i(\boldsymbol{\sigma}/f) = 1$, with:

$$\mathcal{F}_A(\boldsymbol{\sigma}) = \frac{\sigma_{11}^2}{X_t^2} + \frac{\sigma_{12}^2}{S^2} \text{ if } \sigma_{11} > 0, \text{ 0 otherwise.}$$

$$\mathcal{F}_B(\boldsymbol{\sigma}) = -\frac{\sigma_{11}}{X_c} \text{ if } \sigma_{11} < 0, \text{ 0 otherwise.}$$

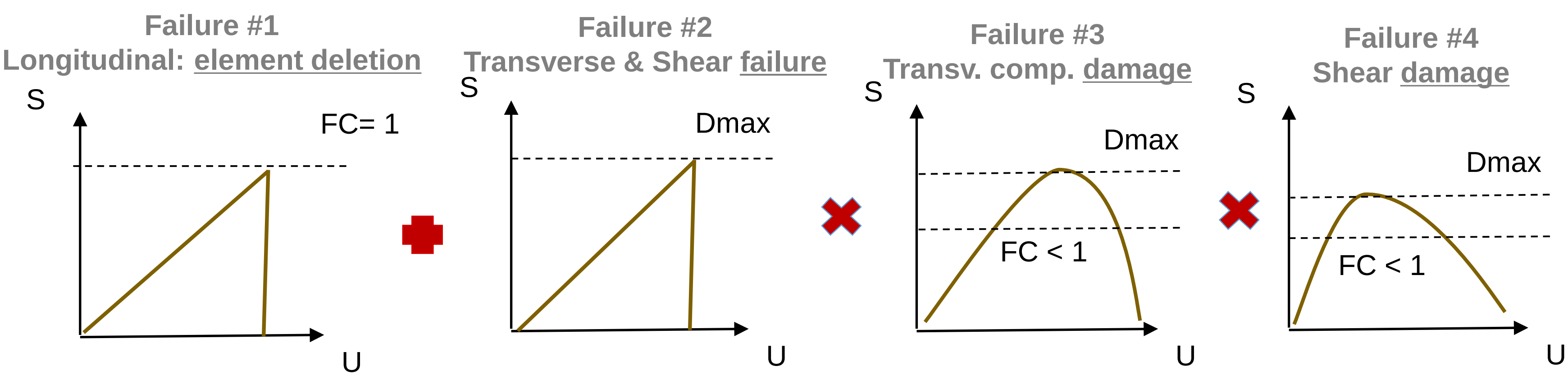
$$\mathcal{F}_C(\boldsymbol{\sigma}) = \frac{\sigma_{22}^2}{Y_t^2} + \frac{\sigma_{12}^2}{S^2} \text{ if } \sigma_{22} > 0, \text{ 0 otherwise.}$$

$$\mathcal{F}_D(\boldsymbol{\sigma}) = \frac{\sigma_{22}^2}{4S_I^2} + \frac{\sigma_{12}^2}{S^2} + \left[\left(\frac{Y_c}{2S_I}\right)^2 - 1\right]\frac{\sigma_{22}}{Y_C} \text{ if } \sigma_{22} < 0, \text{ 0 otherwise.}$$

Progressive failure of CFRP components

Comparing Failure Models

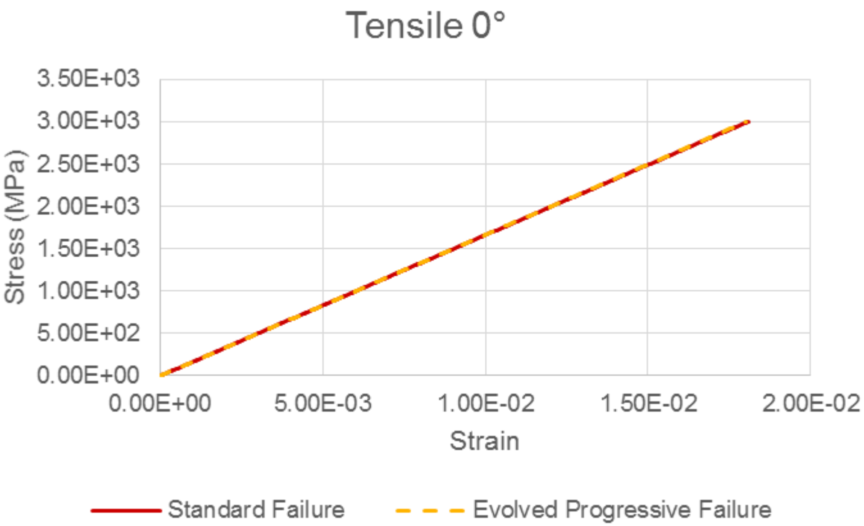
- **Evolved progressive failure**
  - Elastic resin and carbon
  - Differentiation between compressive & tensile strength
  - Evolved progressive failure based on the cumulative effect of 4 failure criteria to yield a specific failure behavior per failure mode
    - Damage is cumulative but element deletion is only triggered by longitudinal fialure

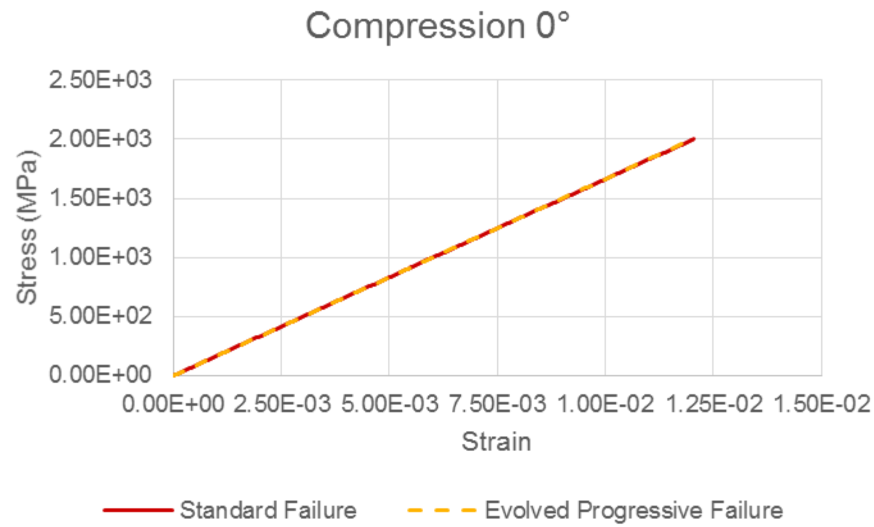


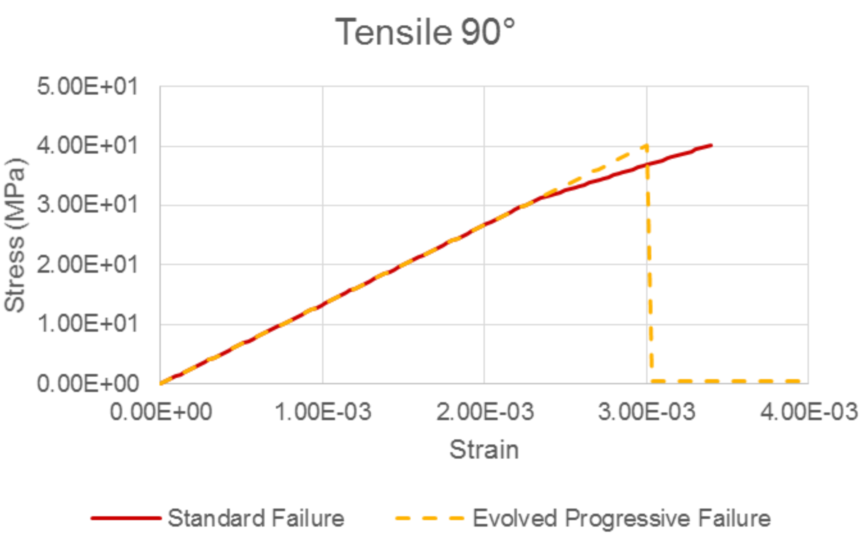
Evolved progressive failure → anisotropic definition of the damage evolution with crack propigation

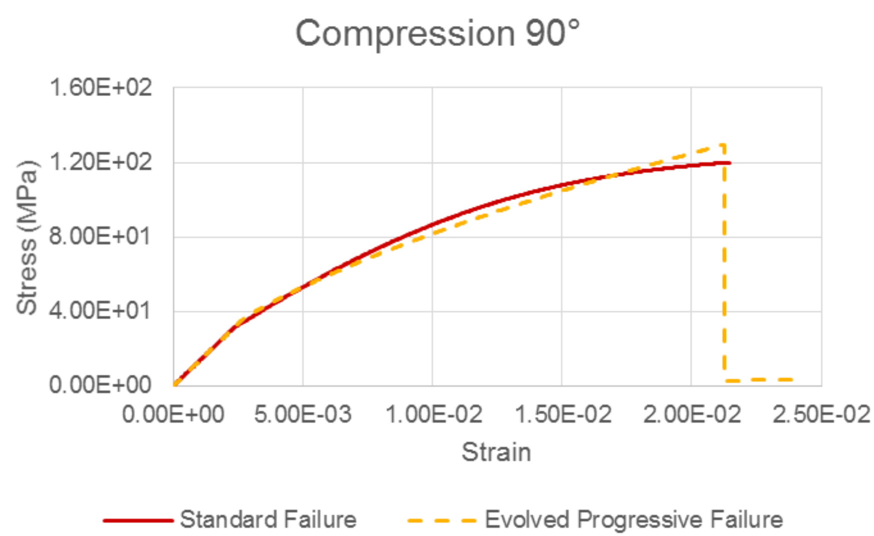
Progressive failure of CFRP components

Both Model Calibration Based on the same Behavior Targets at Single Ply Level









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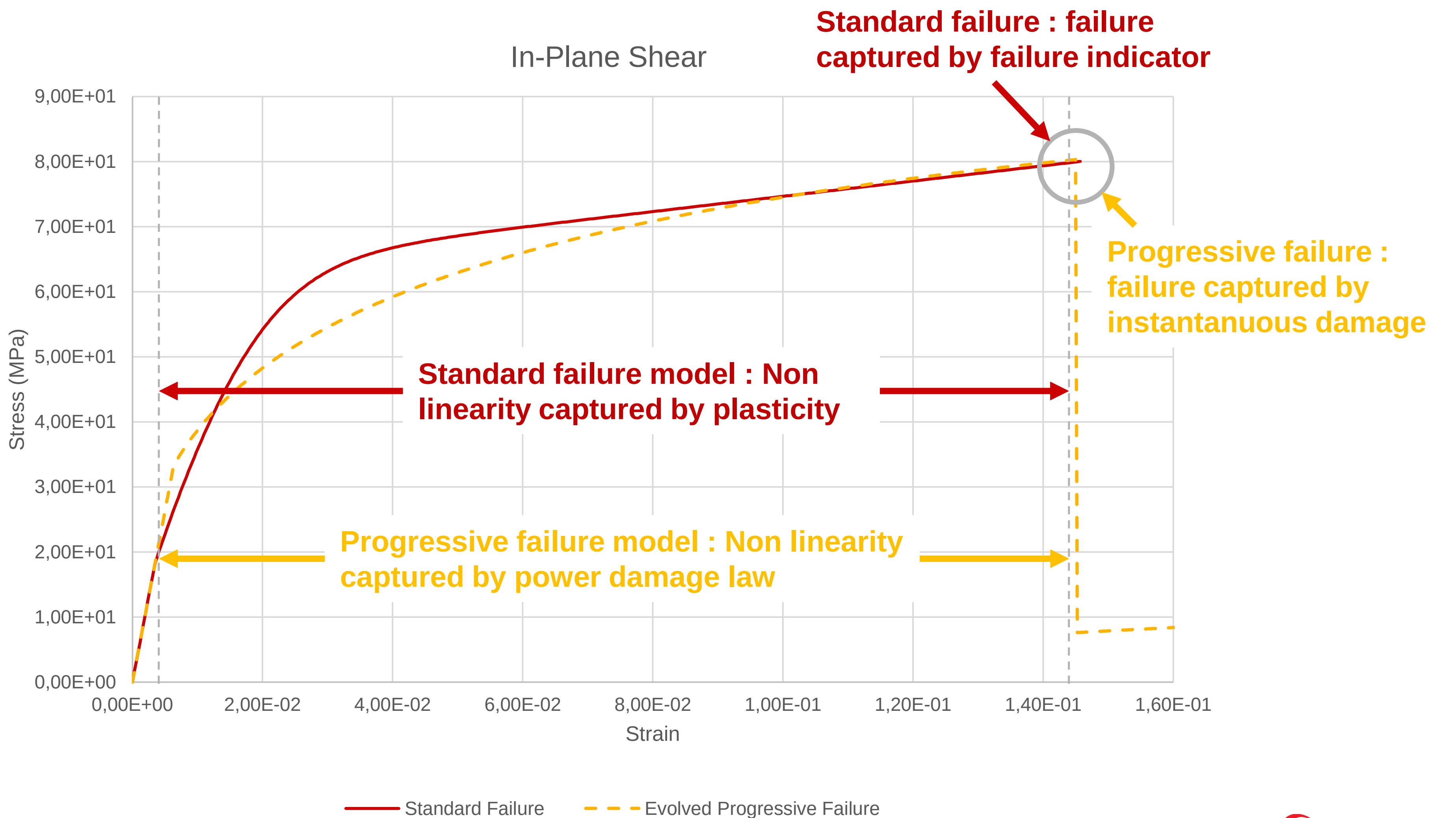
Progressive failure of CFRP components

Both Model Calibration Based on the same Behavior Targets at Single Ply Level

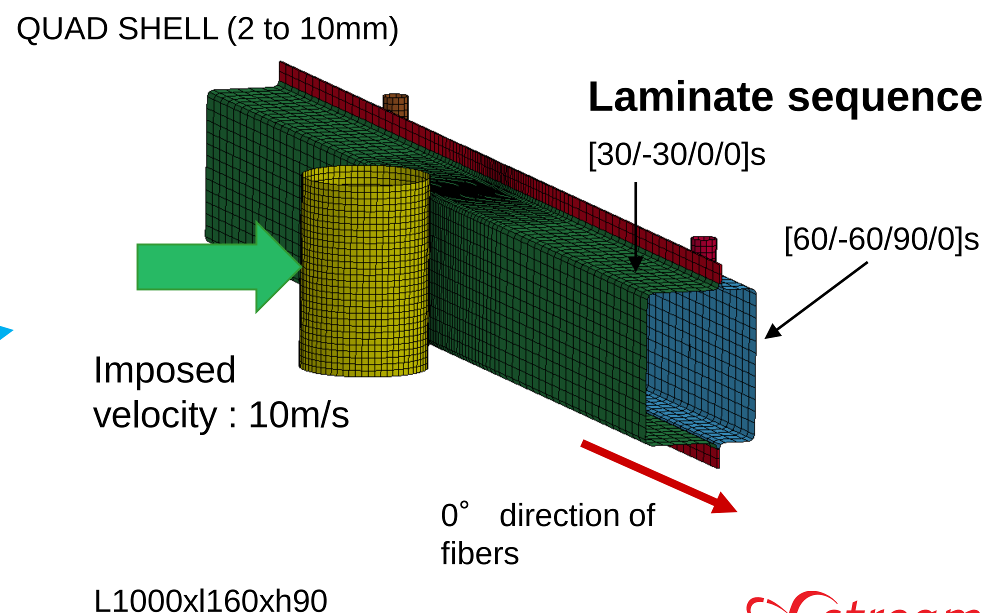
- **Focus on shear behavior**



Progressive failure of CFRP components

Application on a sub-component

- **Material**
  - UD composite : Carbon Fibers + Epoxy Resin
- **Performance**
  - Crash and strength : failure prediction and post failure behavior
- **Model**
  - 3 point bending case on a sub component model, similar to a pole side crash

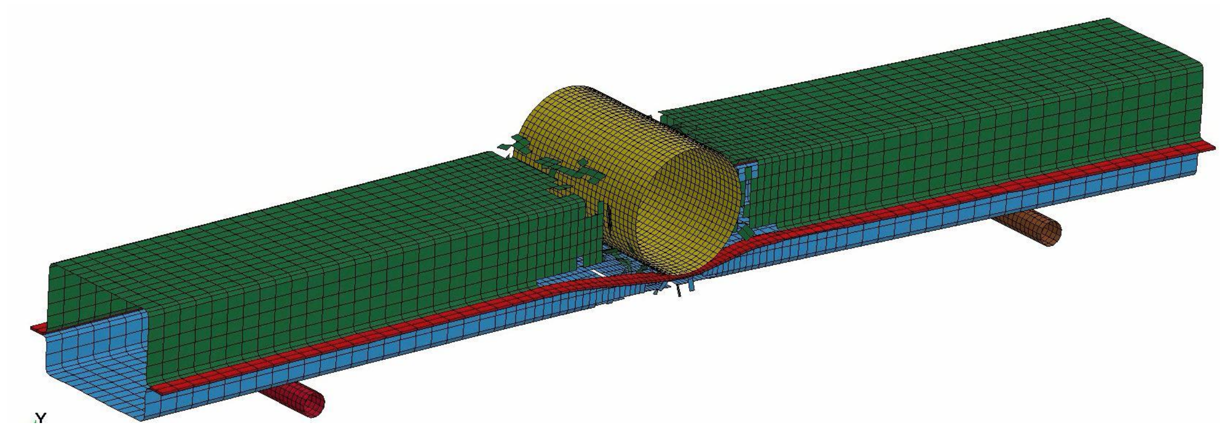


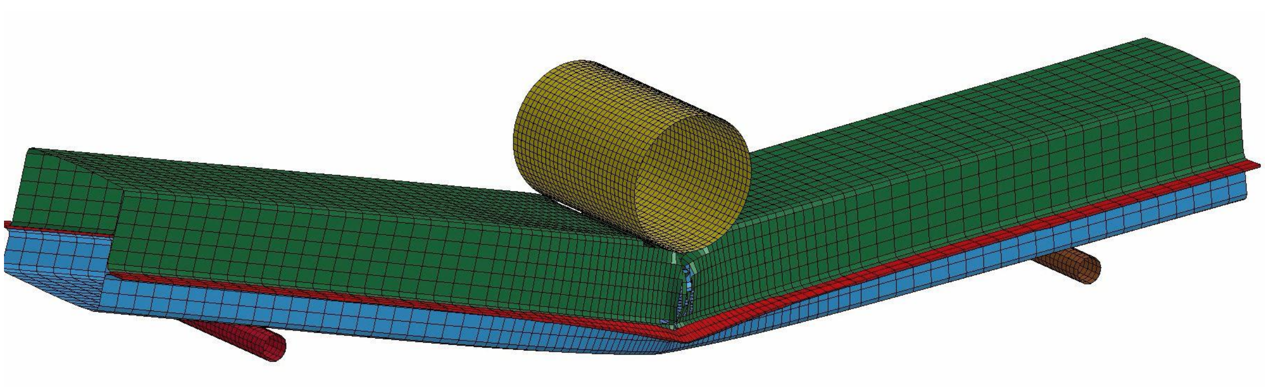
Progressive failure of CFRP components

Application on a sub-component

- **Results : Standard failure shows unrealistic deformation scenario**

Standard failure





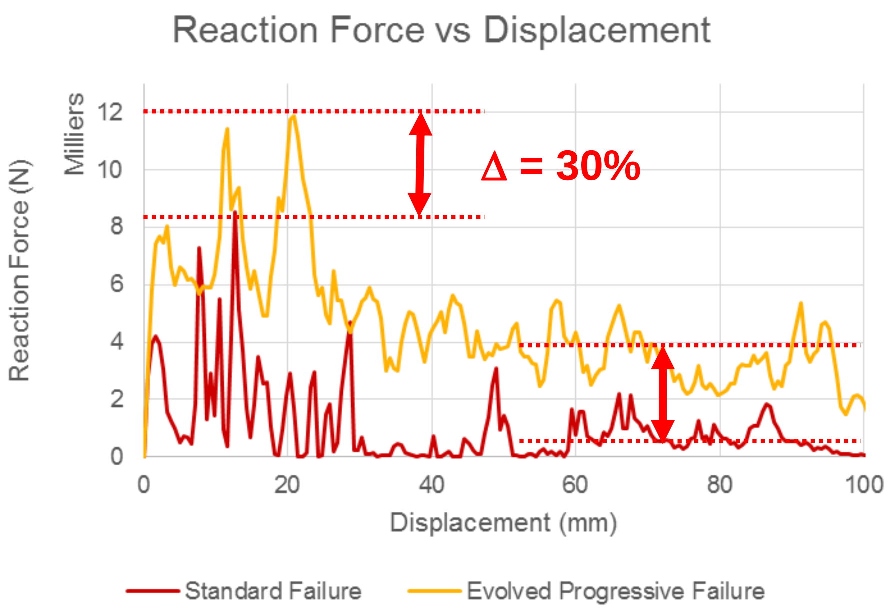
Evolved progressive failure

Progressive failure of CFRP components

Application on a sub-component

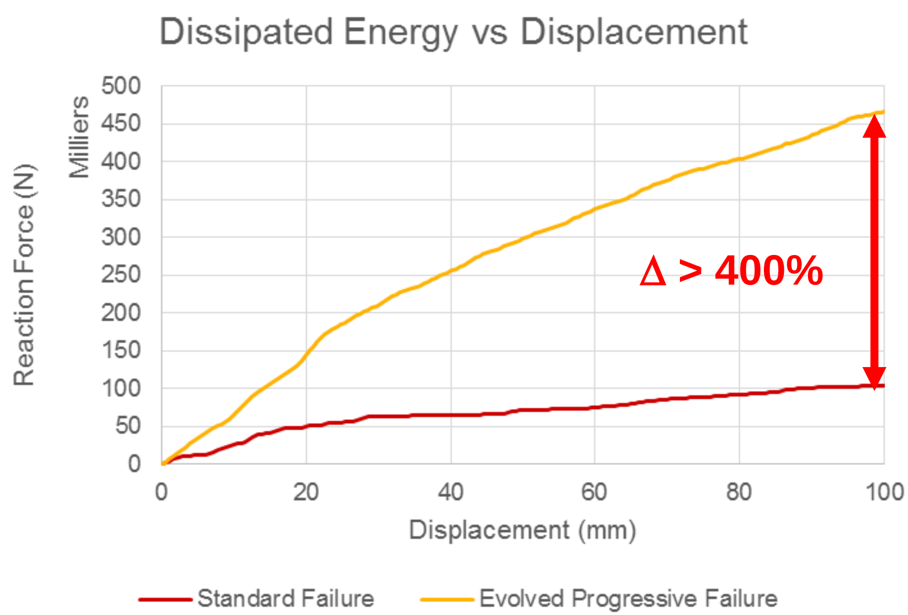
- ## Results : reaction force and dissipated energy

Standard failure underestimates the maximum force at failure by 30% compared to progressive failure



Post failure behavior of progressive failure model shows a higher residual stiffness

Standard failure underestimates the dissipated energy with a ratio greater than 4 compared to progressive failure



Failure of SFRP

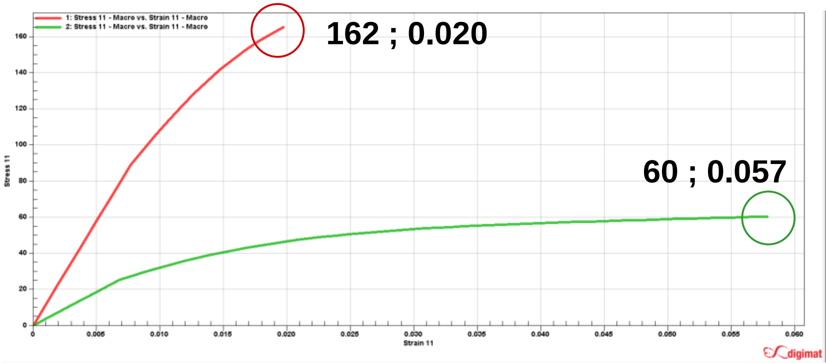
Failure of SFRP components

SFRP shows an anisotropic behavior dependent on the fiber organization

- **Dependency for Stiffness as well as Strength**

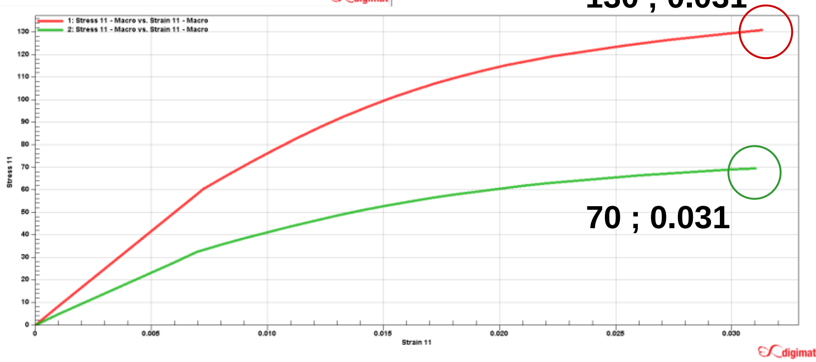
Example : PA6 GF30

Fibers highly aligned



162 ; 0.020

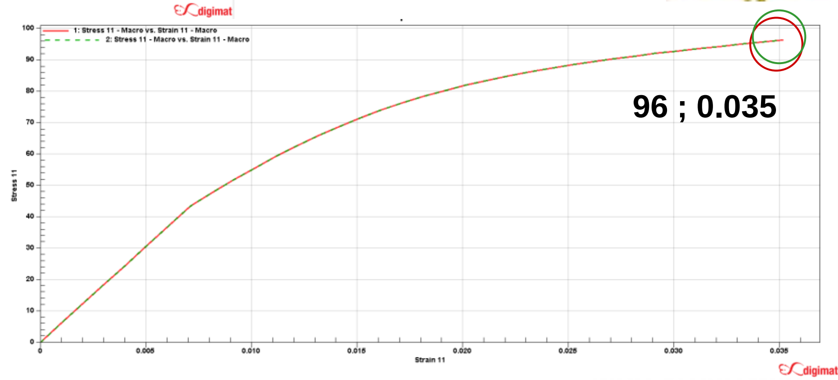
60 ; 0.057



130 ; 0.031

70 ; 0.031

Fibers random2D



96 ; 0.035

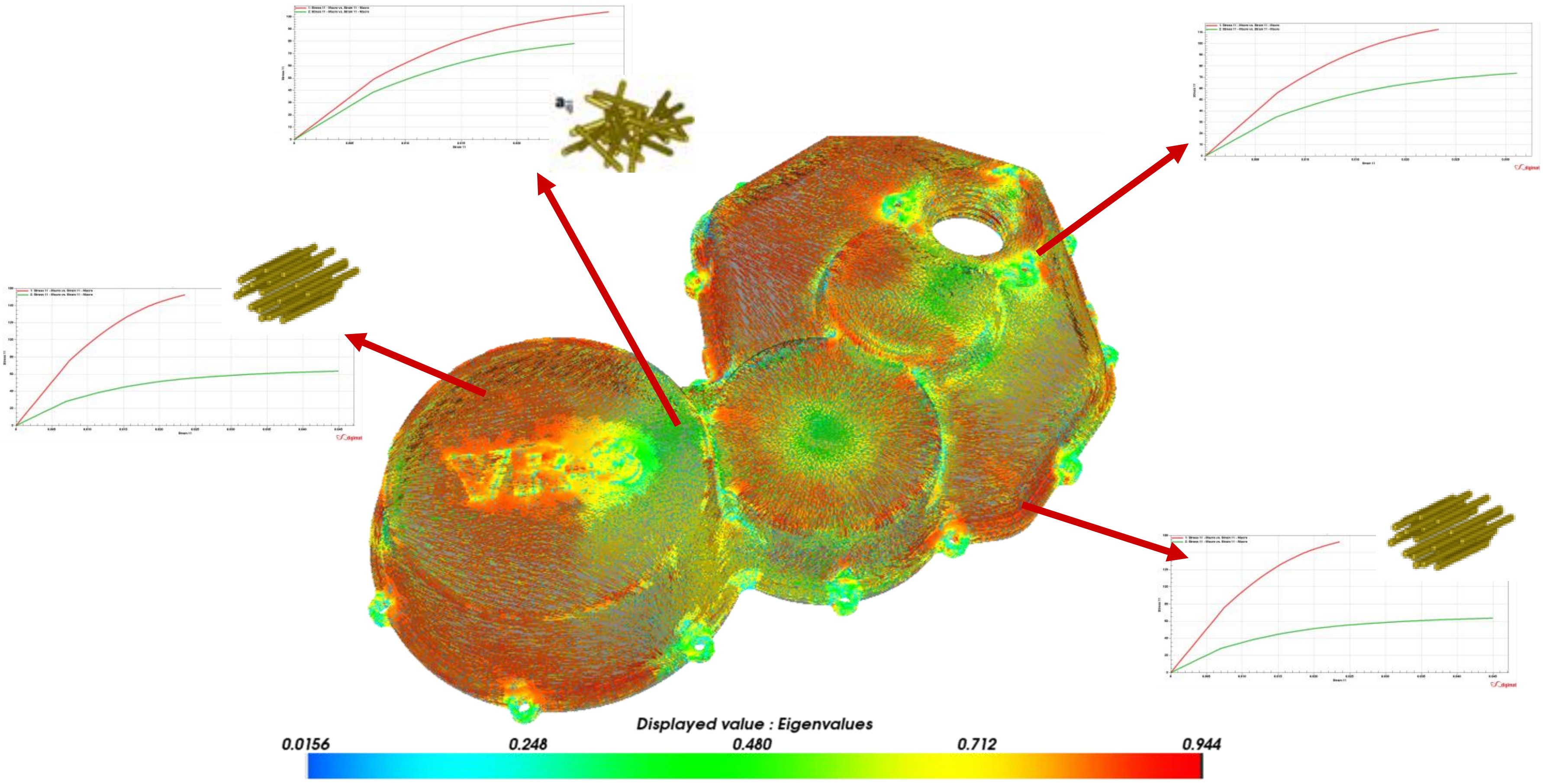
Axial tensile

Transverse tensile

Failure of SFRP components

The manufacturing process induce the fiber organization of the component

- **Heterogeneous local behavior**



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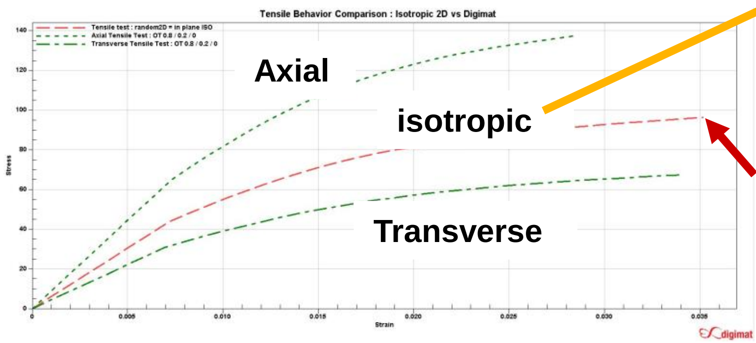
Failure of SFRP components

Application on a stone impact case on an engine cover

- **Comparison of 2 material modelizations**

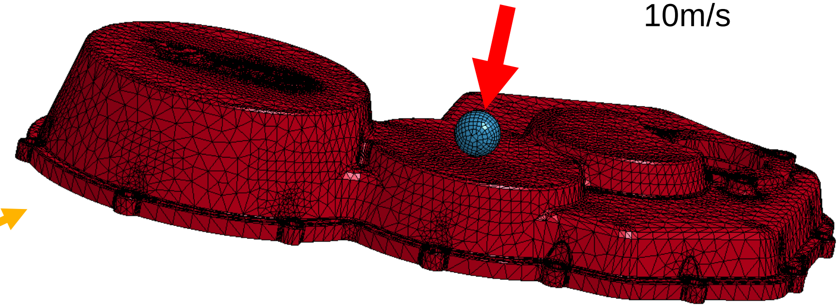
1 - Homogeneous isotropic

Unique Isotropic EP stiffness and failure material model



Strain at failure = 0.035

Stone initial velocity 10m/s

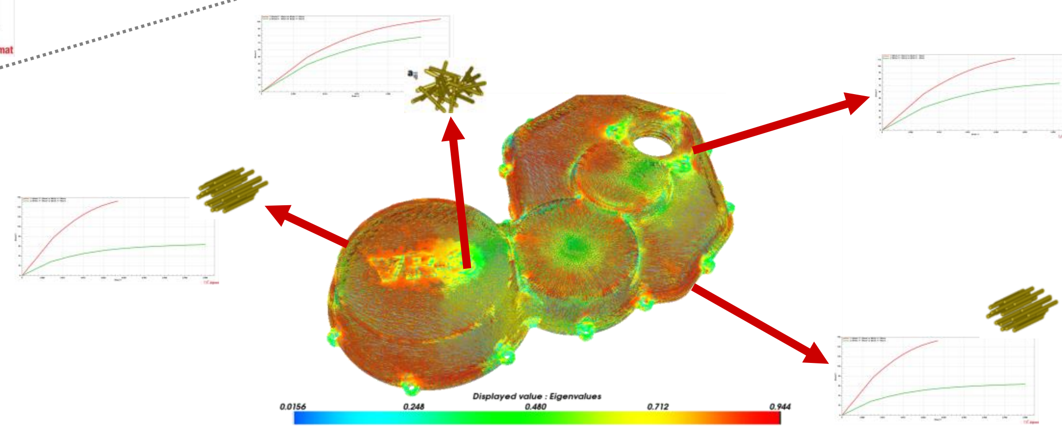


TET10 solid

2 - Heterogeneous anisotropic

Anisotropic EP stiffness and failure material model taking into account local fiber orientation tensor

Stone initial velocity 10m/s



Anisotropic stress based failure model
Differentiation in failure traction/compression

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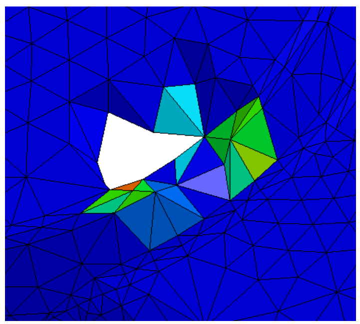
Failure of SFRP components

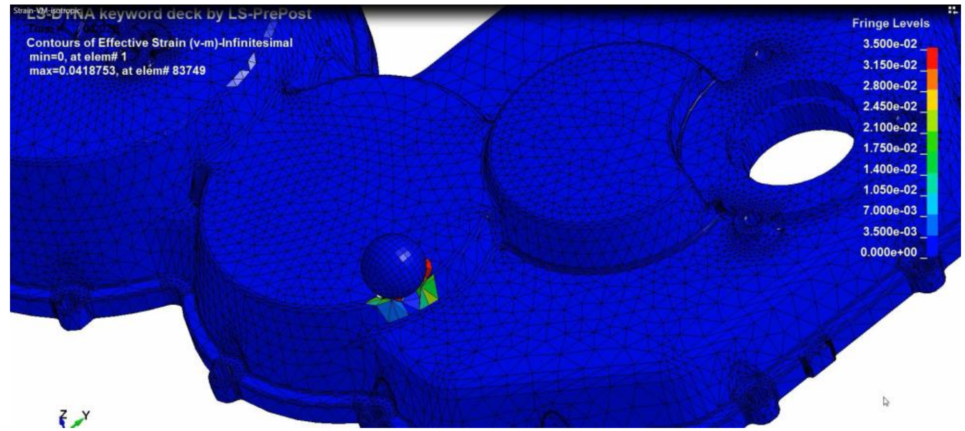
Application on a stone impact case on an engine cover

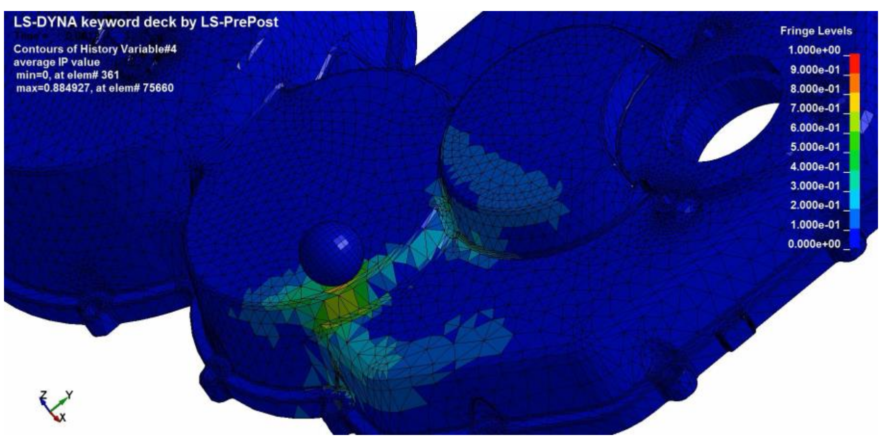
- **Results : taking into account anisotropic behavior and the fiber orientation tensor through the part influence the impact scenario**

Homogeneous isotropic
(effective strain – VM)

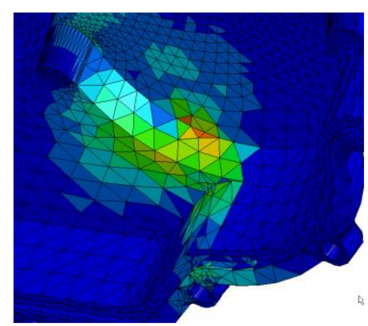
$E_{Max} > 0.035$







Heterogeneous anisotropic
(failure indicator)



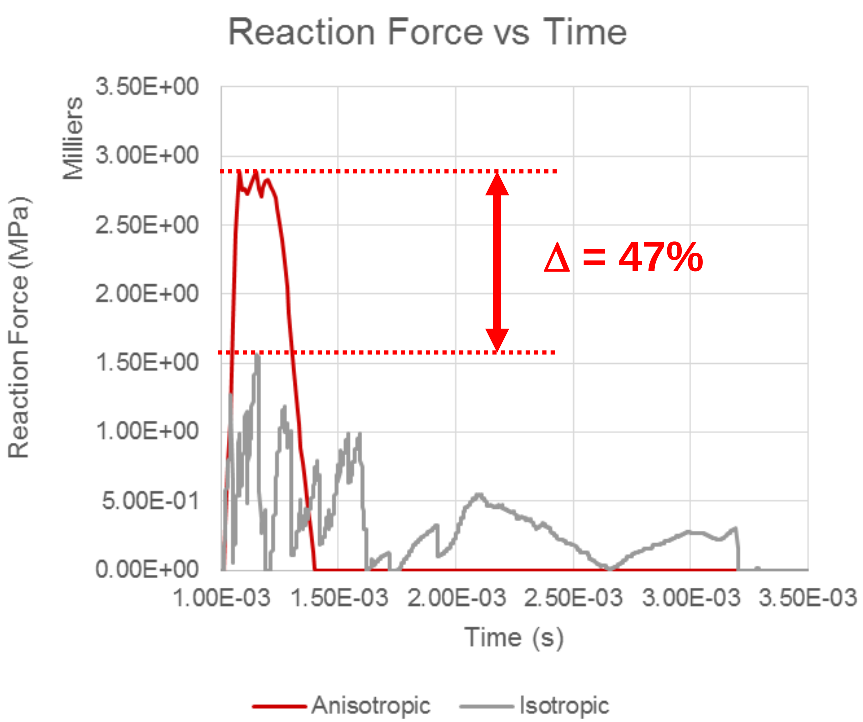
$FI_{max} = 0.88$

Failure of SFRP components

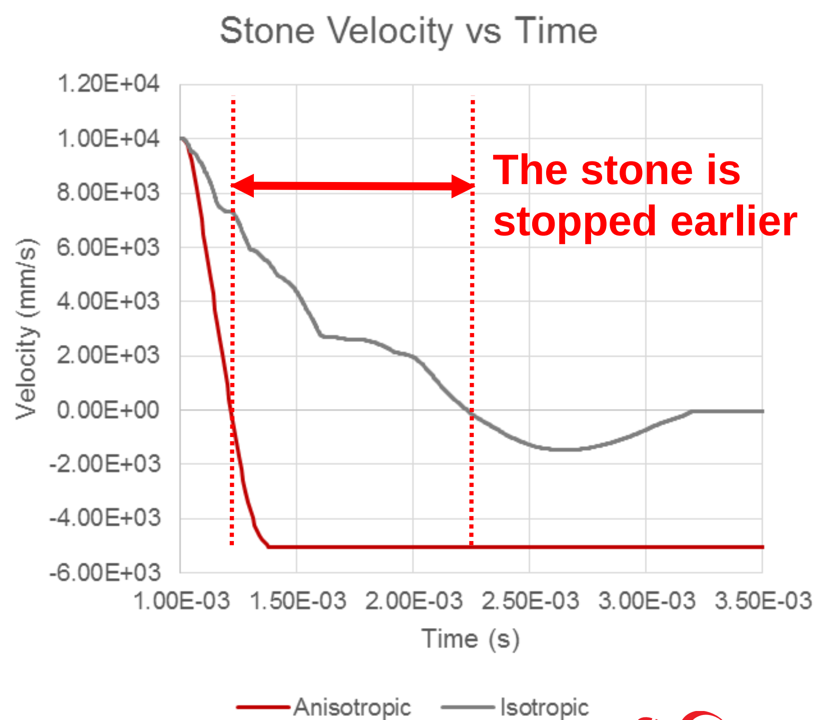
Application on a stone impact case on an engine cover

- **Results : reaction force and stone velocity**

Isotropic material model underestimates the maximum force at failure by 47% compared to anisotropic material model taking into account the fiber orientations



The anisotropic material model shows a much highest capacity of energy absorption during the impact.



Conclusions

- **CFRP**
  - A non linear anisotropic material model including a progressive failure definition based on lamina behavior exists to predict
    - The anisotropy of the stiffness, the failure initiation, the damage evolution
  - Coupled FEA is available with all current FE solvers to predict in a physical manner failure and post failure behavior of a structure
- **SFRP**
  - A non linear anisotropic material model taking into account the local fiber orientation of the material exists to predict
    - The anisotropy of the stiffness and of the failure initiation
  - The fiber orientation field from the process simulation can be mapped on the structural mesh
  - Coupled FEA is available with all current FE solvers to predict in a physical manner failure and post failure behavior of a structure

Digimat USERS' MEETING 2014

The material modeling conference

ROME

Crowne Plaza St Peter's

October 21-23, 2014

Tools, Solutions and Expertise for the end-to-end analysis of Chopped and Continuous Fiber Composite Materials and Structures.

The Highlights of DigimatUM'14 are:

- Progressive Failure analysis of CFRP coupon to Aero Structures
- End-to-end finite element analysis of material RVE
- Robust, Fast and Easy analysis of reinforced plastic parts
- Modeling of Discontinuous Fiber Composites (DFC)

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