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Multiscale Modelling of Dry Fabrics: Application to Impact

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Introduction: Generalities on Dry Fabrics

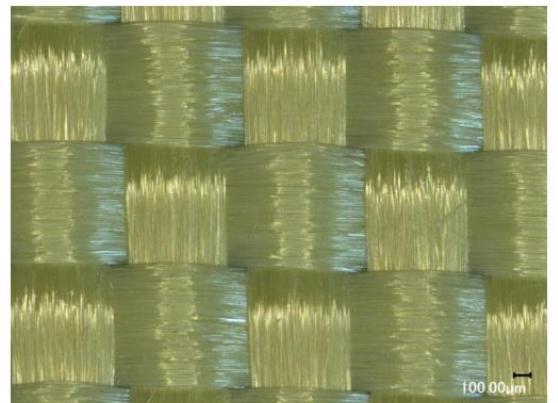
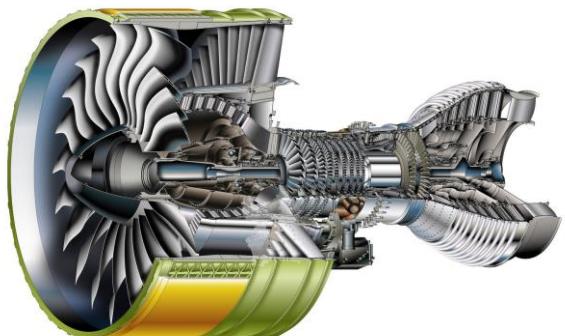
Dry Fabrics Application:

- Aeronautic
- Military
- Civil
- Structural Parts



Impact Problem:

- **Multiscale** Problem
- **Experimental Complications**
- **Different phenomena** have still to be clarified



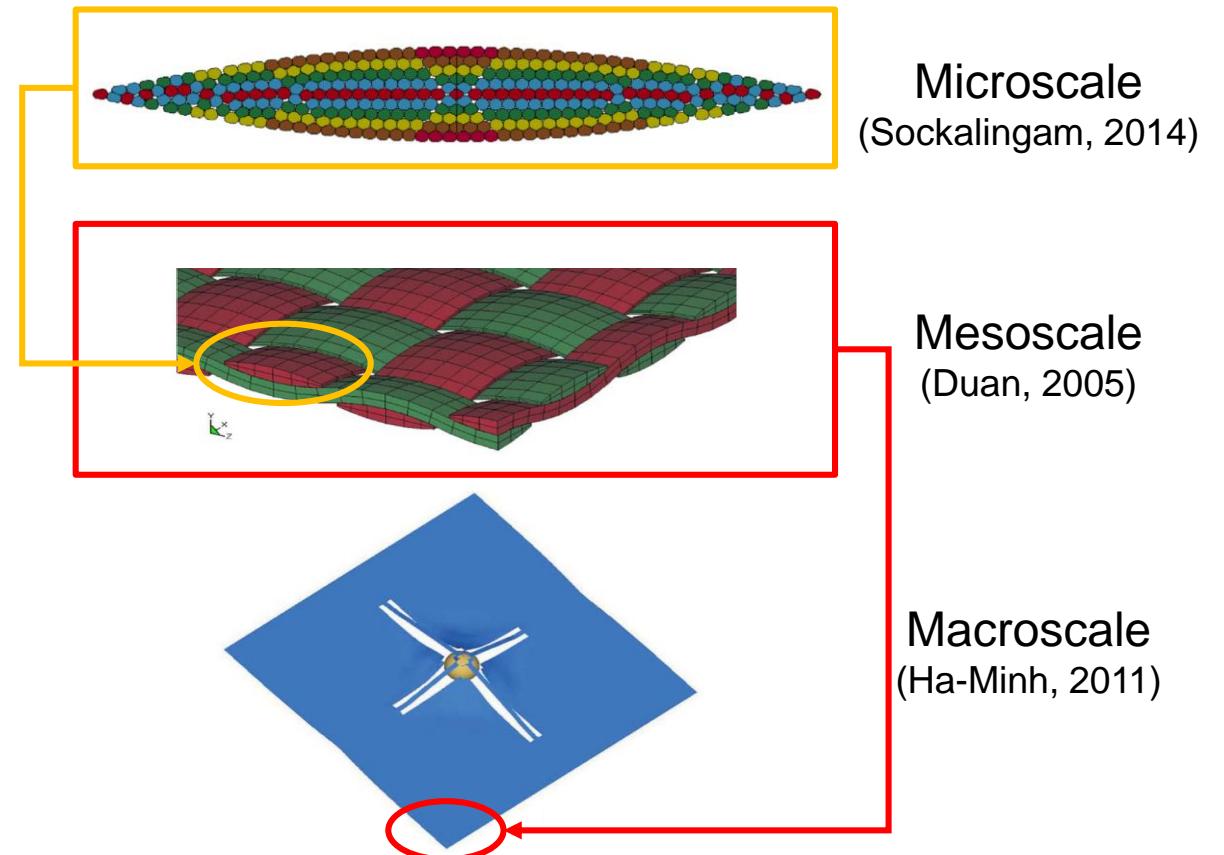
Introduction: Scientific Context and Objectives

- H2020 Marie Curie – FullComp* Project – ESR11 :

Numerical analyses of high velocity impacts using **multiscale techniques**

- Scientific Objectives:

- Rigorously analyse **scale transitions** starting from the **microscale**
- Linking microstructural observations to **mesoscopic and macroscopic properties**



*<http://www.mul2.polito.it/fullcomp/>

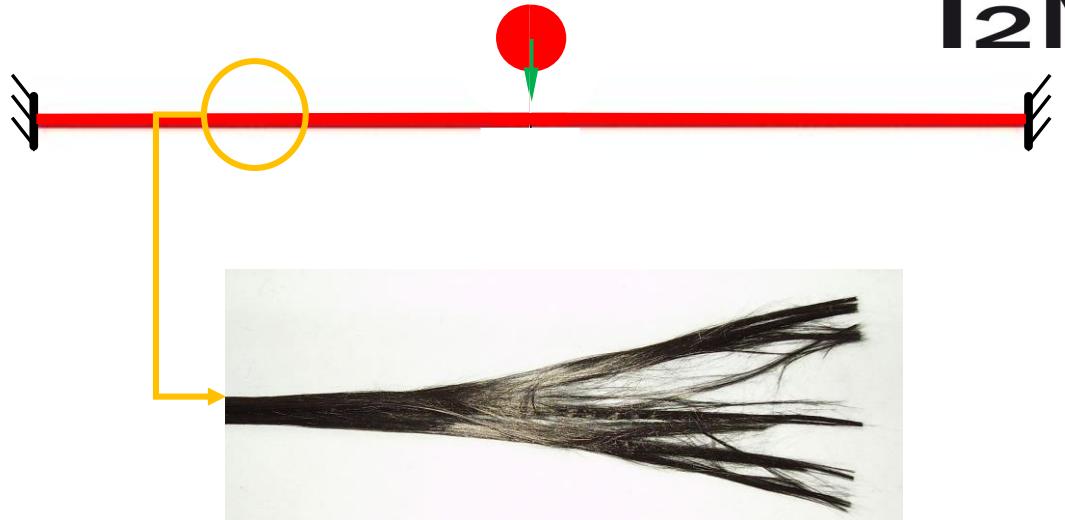
Outline

1. Transversal Impact Test on Single Yarn
2. Full Scale Microscopic Model
3. Full Scale to Reduced Scale Transition
4. Conclusion and Perspectives

Transversal Impact Test on Single Yarn

Why this test?

- Weave independent behaviour
- Inter-fibre interaction
- Natural environment for microscopic analyses
- Optimal test for dynamic properties



Concerning Transversal Impact on single yarn

- Difficulties on experimental measurements
- Few numerical bibliography (mostly 3D FEM)

References

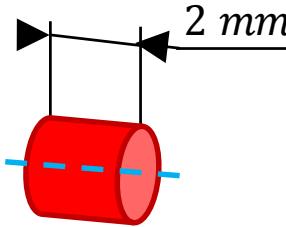
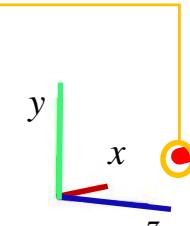
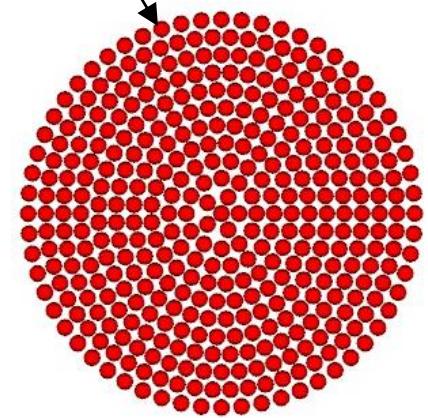
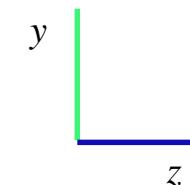
- B.Song et al., Journal of Applied Mechanics, 2011
 S. Sockalingam et al., Textile Research Journal, 2016

Full Scale Microscopic Model : Set Up*

Material:

Kevlar® KM2 600**

$\phi 12 \mu m \times 400 Fib$



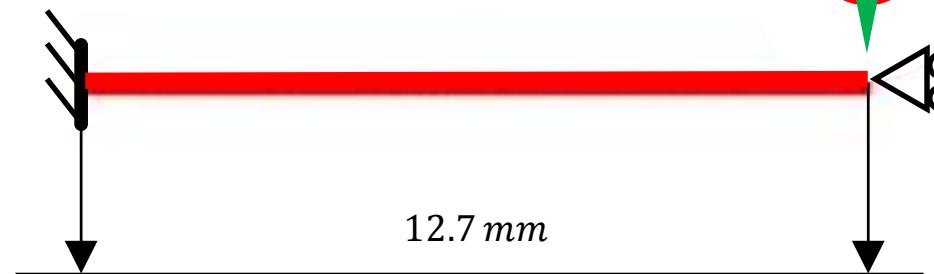
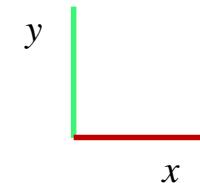
$\phi 2.2 mm$

$v = 120 ms^{-1}$ $m = 9.91e^{-6} Kg$

References

*G.Nilakantan, Composite Structures , 2013

**M.Cheng et al., Journal of Engineering Materials and Technology, 2005



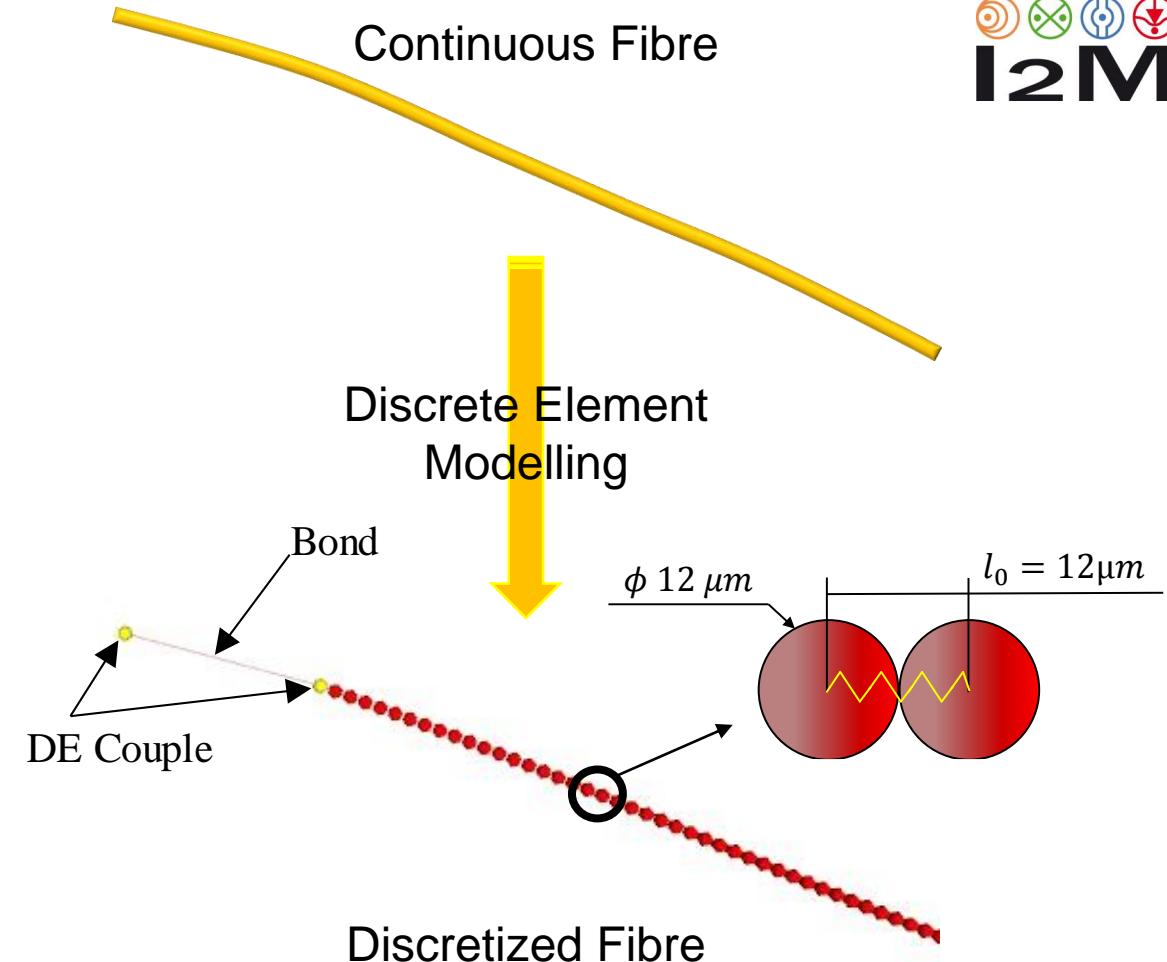
12.7 mm

Full Scale Microscopic Model: Fibre Discretization

Model has been solved using **DE code GranOO***.

Each **fibre** is discretized by a **series of spherical Discrete Elements***:

- Total fibre **weight is equally distributed** among Discrete Elements
- Material **Mechanical Behaviour** is provided by **Bonds** which connect DE couples
- **Contact** is easily managed by **Discrete Element Method**



*References

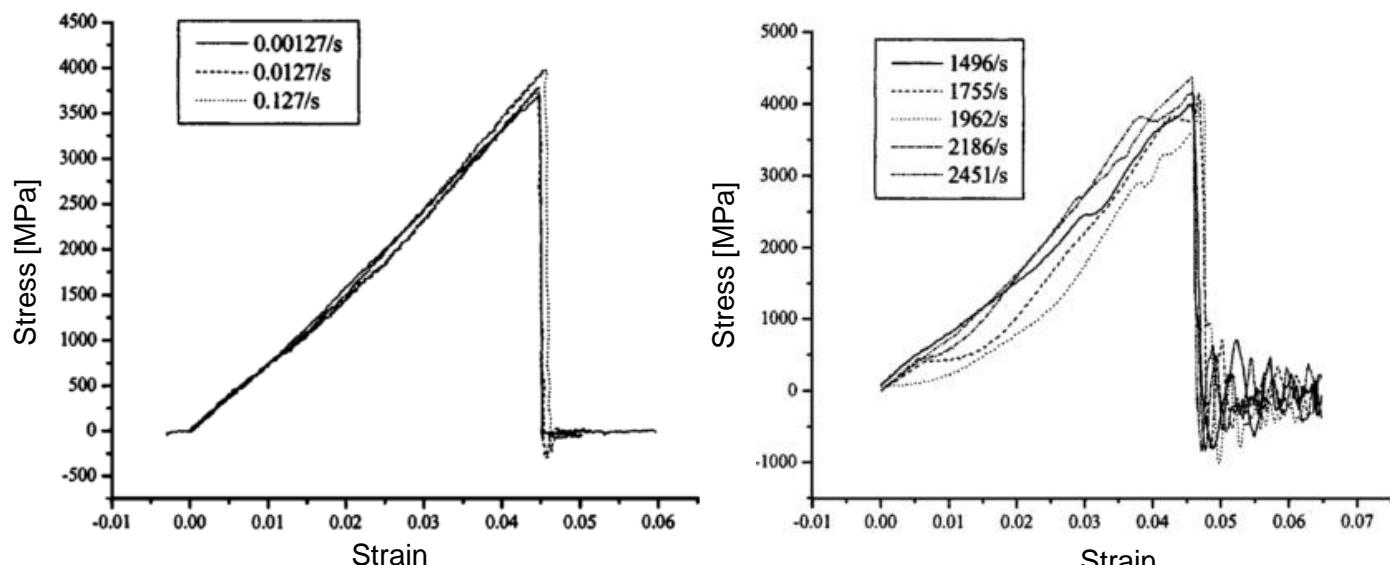
Ba Danh Le, F. Dau, Composite Part A, 2015.

J. Girardot, F. Dau, ICCM20, 2015

F. Dau, ASC-29, 2014.

Full Scale Microscopic Model: Bonds Constitutive Behaviour

Kevlar® KM2 600 fibre has been modelled as brittle and purely elastic.



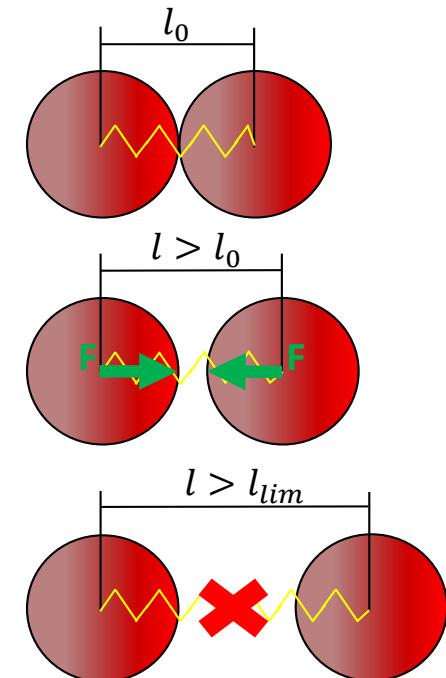
Longitudinal Elastic Response of Kevlar KM2 600 Single Fibre
(Cheng 2005)

$$F = EA\varepsilon$$

$$\varepsilon = \frac{l - l_0}{l}$$

$$\varepsilon \geq \varepsilon_{lim}$$

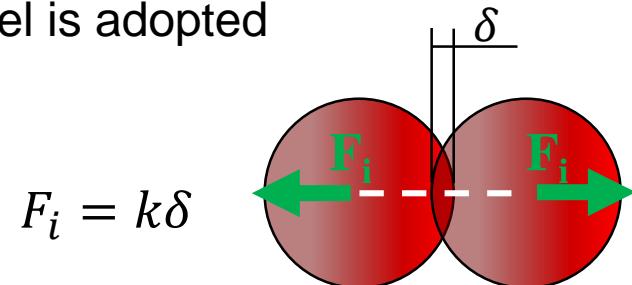
Bond disabled



Full Scale Microscopic Model: Contact Model

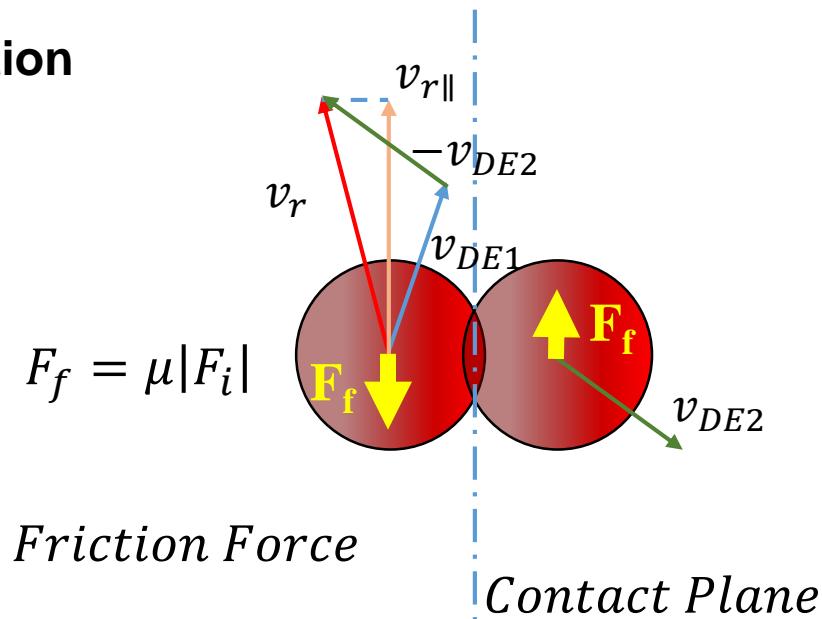
Contact is managed according to **Discrete Element Method**:

- **Spheres** are supposed to be **undeformable** (transversal mechanical behaviour obliged)
- **No contact** if two elements are **bonded**
- Indentation Stiffness k have to be big enough to **avoid interpenetration**
- **Coulombian Friction** model is adopted



$$F_i = k\delta$$

F_i = Indentation Force



$$F_f = \mu |F_i|$$

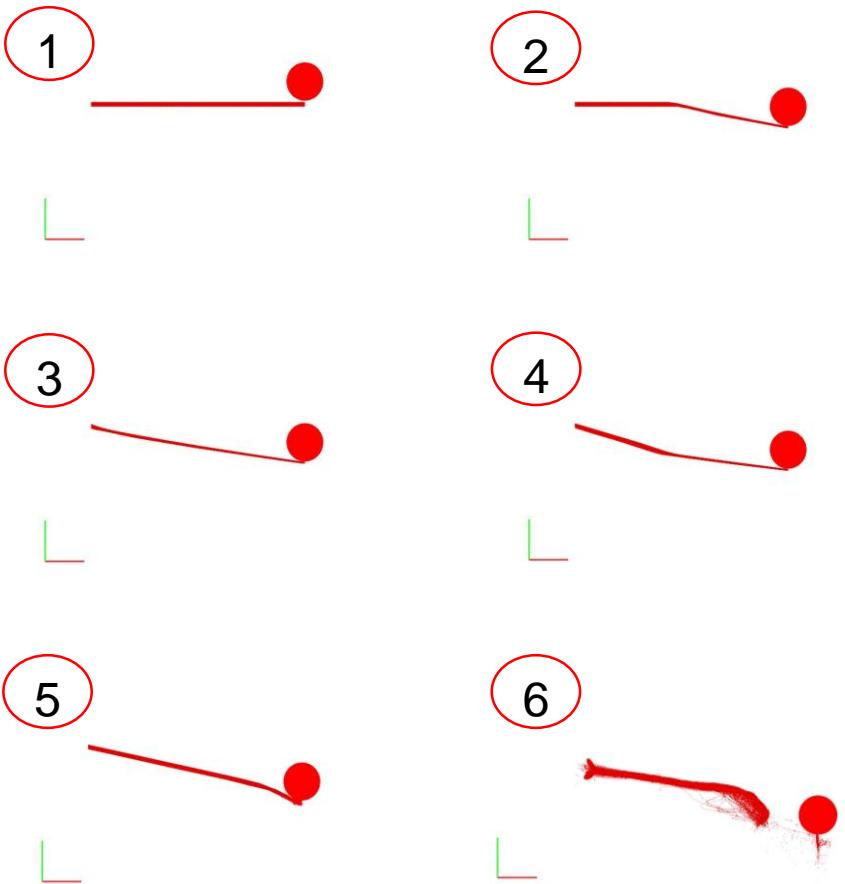
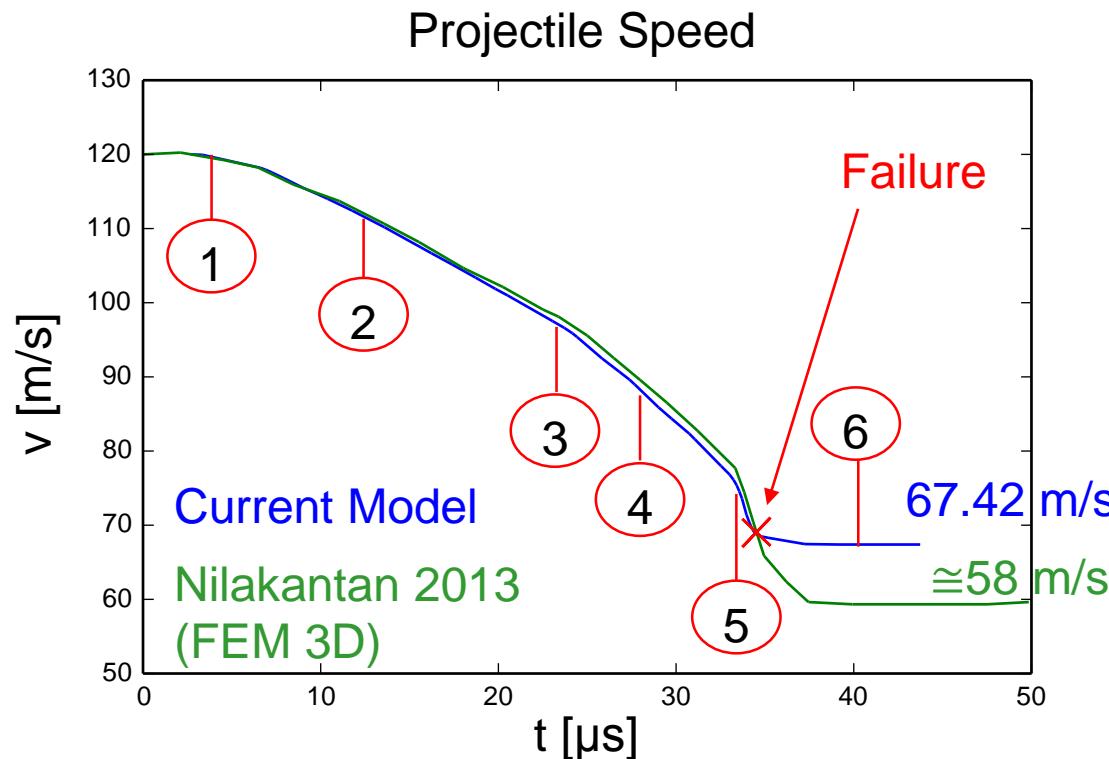
F_f = Friction Force

Contact Plane

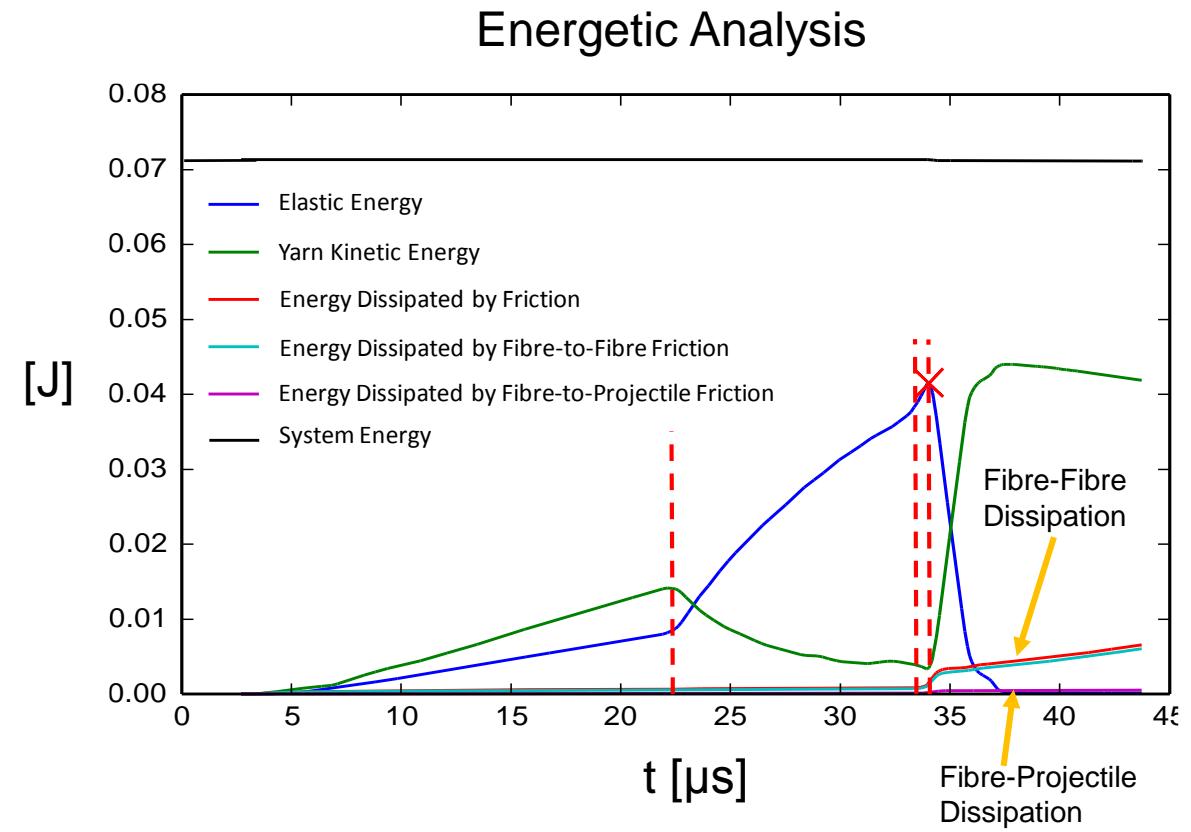
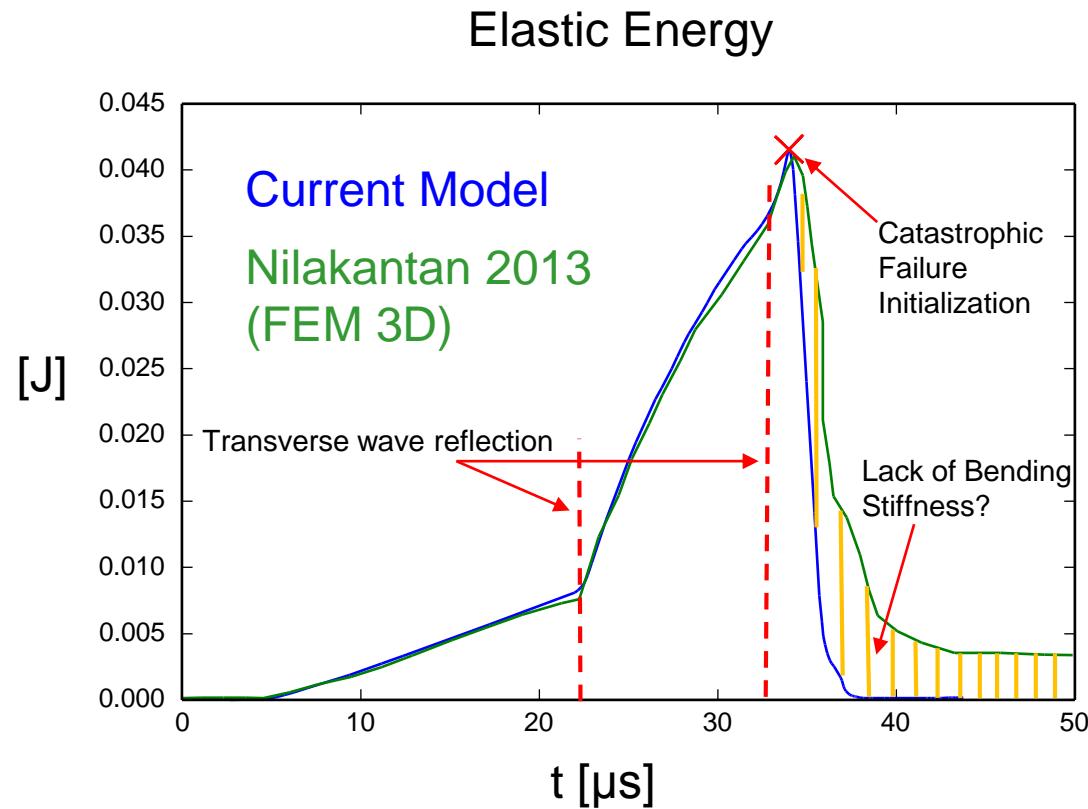
Full Scale Microscopic Model: Results

Cheng,
2005

$$\begin{cases} E_{11} = 84.62 \text{ GPa} & k = 5000 \text{ N/m} \\ \sigma_{lim} = 3.88 \text{ GPa} & \mu_{ff} = 0.2 \\ \rho = 1440 \text{ kg/m}^3 & \mu_{fp} = 0.18 \end{cases}$$



Full Scale Microscopic Model: Results



Full Scale Microscopic Model: Effect of Friction



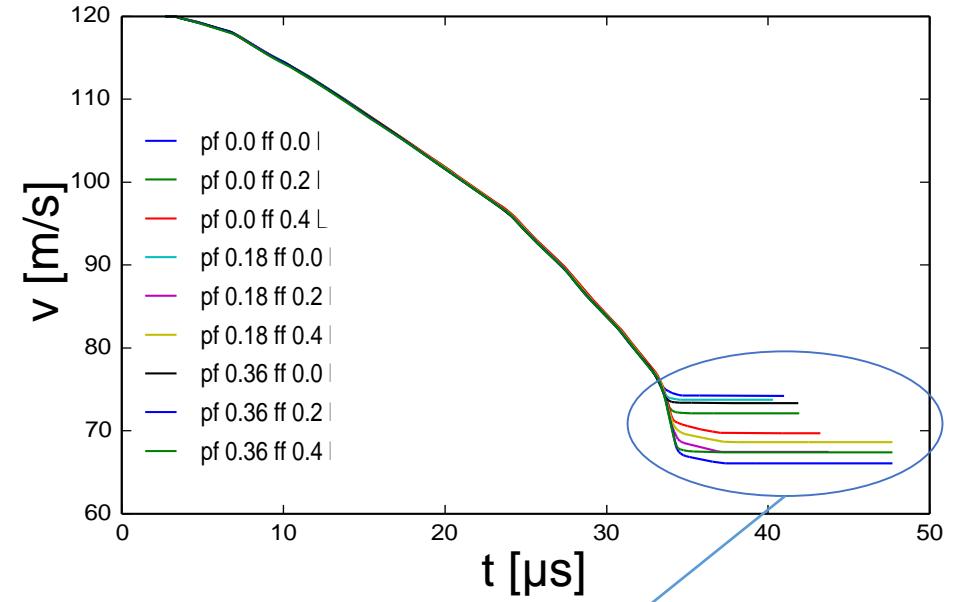
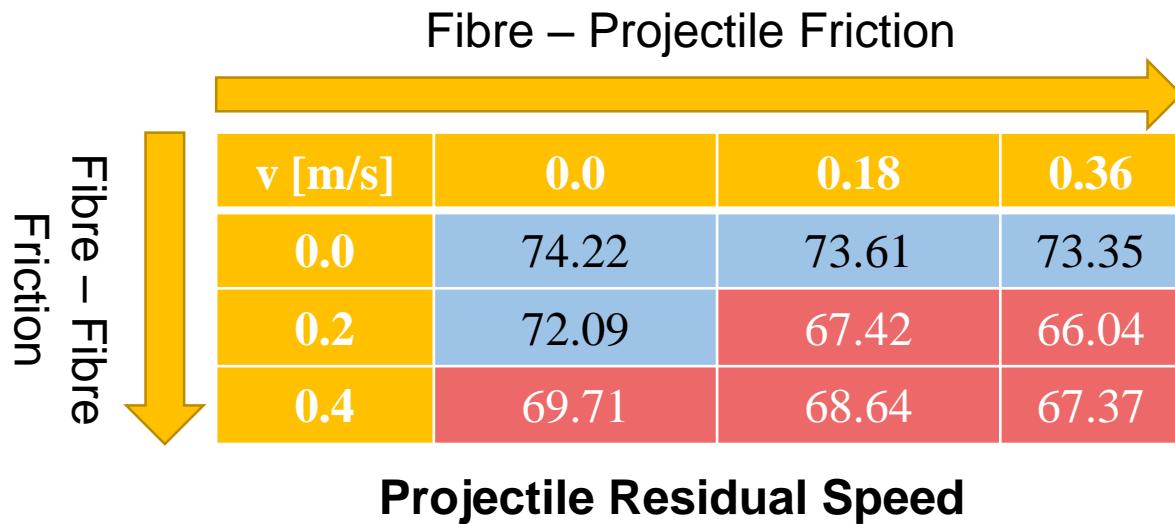
Why this test?

- 1. Validate the model**
- 2. Understand the effect of friction on failure mechanics**
- 3. Difference between inter-yarn and yarn-projectile friction**

Full Scale Microscopic Model: Effect of Friction

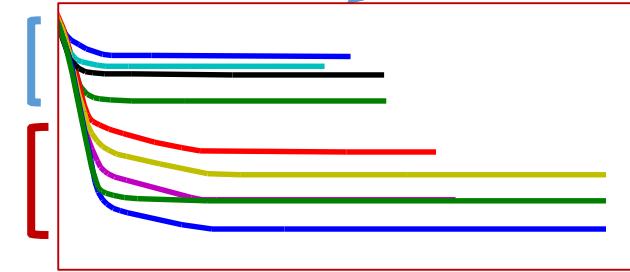
Test Campaign

- 3 values of **Fibre-Fibre friction coefficients**
- 3 values of **Fibre-Projectile friction coefficients**
- **9 different combinations**
- **Projectile residual speed analysed for all the combination**



Low Fibre-Fibre
Friction

High Fibre-Fibre
Friction



Full Scale Microscopic Model: Conclusion on Effect of Friction

Good Agreement with pre-existent works:

1. **Residual Speed** → non linear dependence from friction
2. **Friction** dissipated energy is negligible before failure

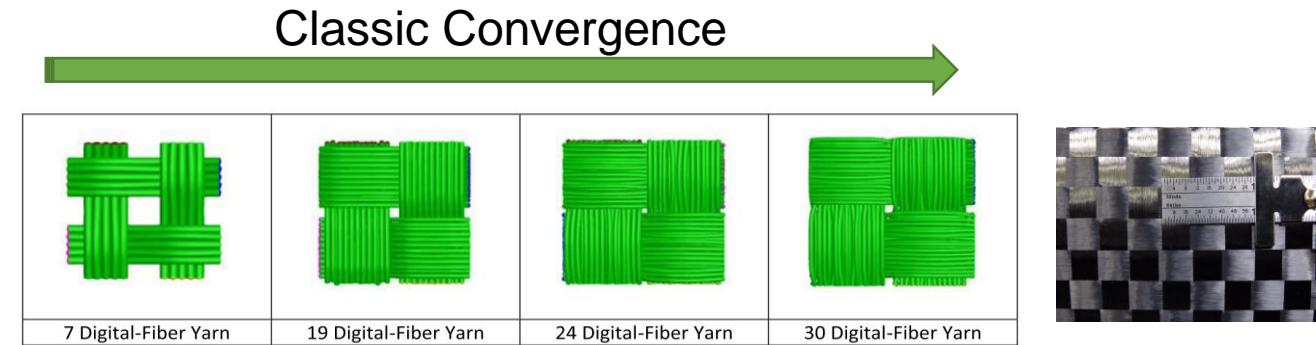
Inter-Yarn Dissipation >> Yarn-Projectile Dissipation

Full Scale to Reduced Scale Transition: State of the Art



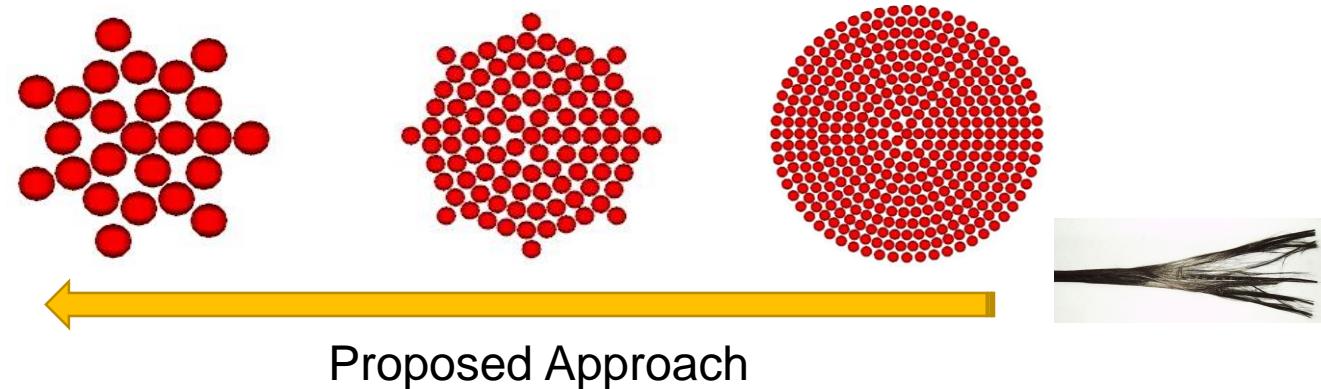
Classic Approach* :

- Convergence Analysis is **performed at the Mesoscale**
- **Coarse to fine** discretization
- **Weaving Dependent**



Proposed Approach:

- Convergence Analysis is **performed at the Microscale**
- **Weaving Independent**
- **Fine to Coarse** discretization



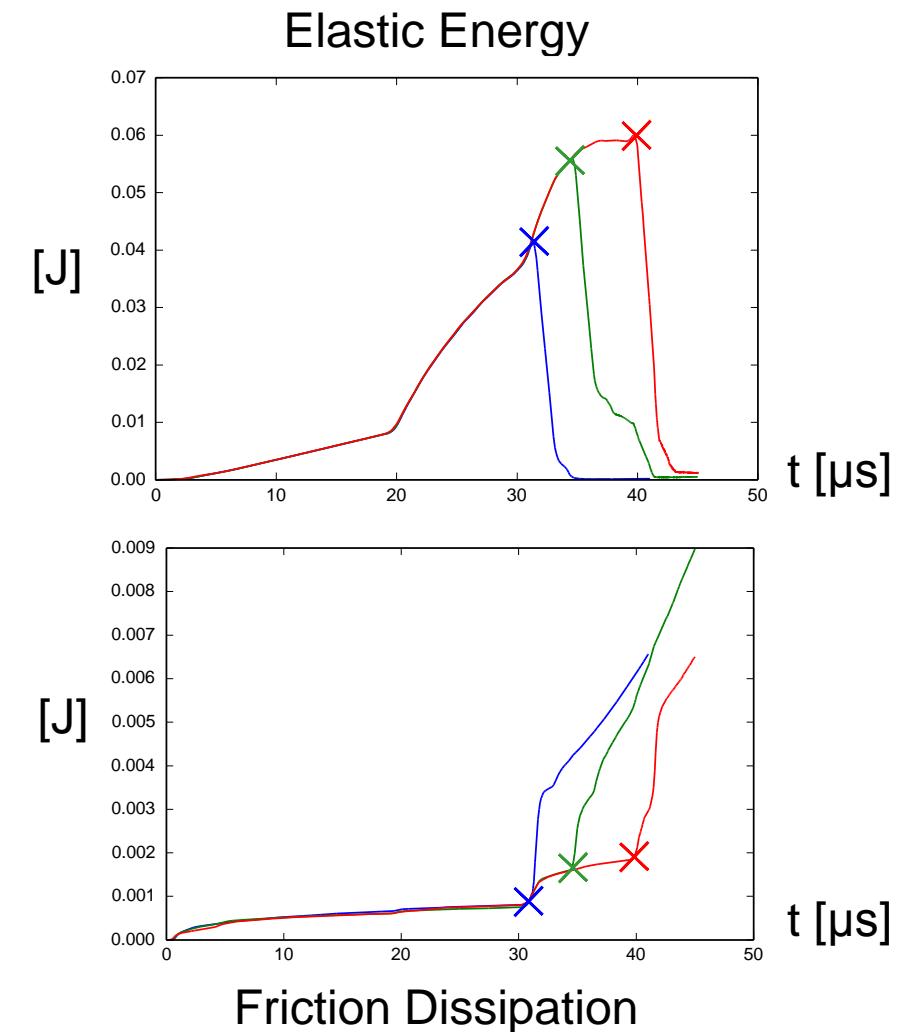
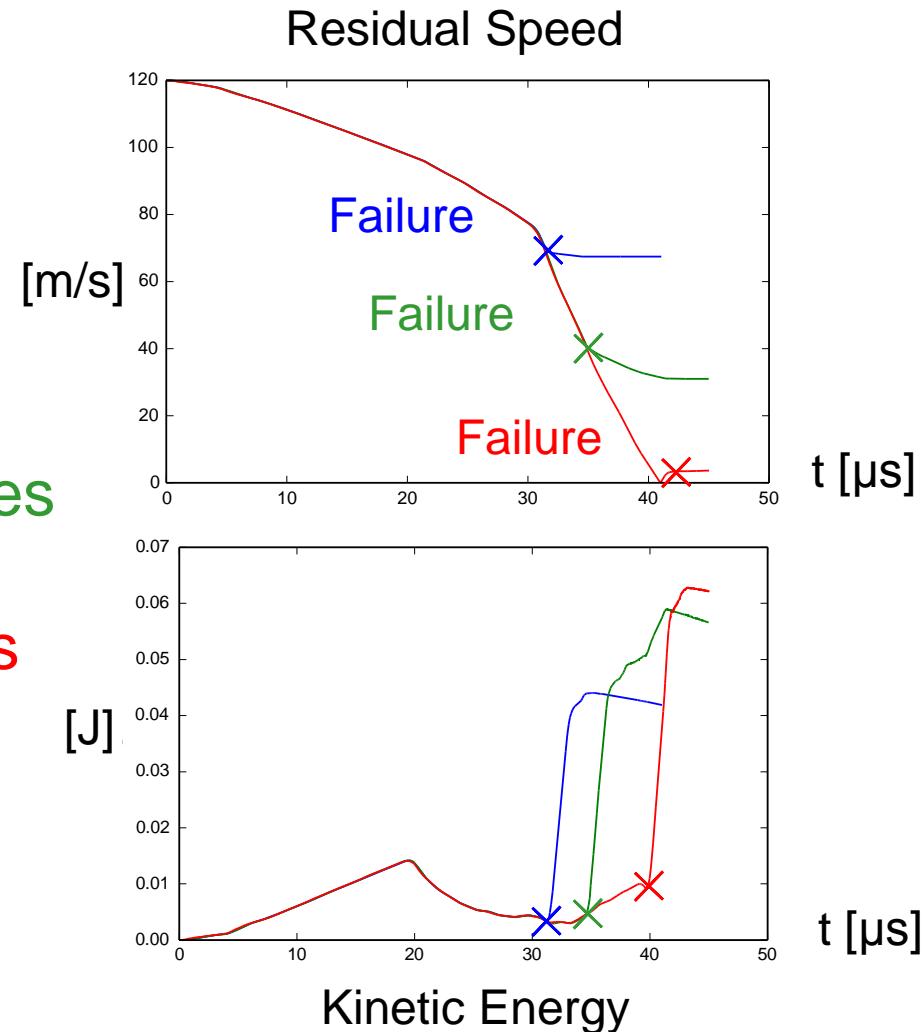
*Y.Wang et al., International Journal of Impact Engineering, 2010

Full to Reduced Scale Transition: Explorative Results

Full Model

100 Eq. Fibres

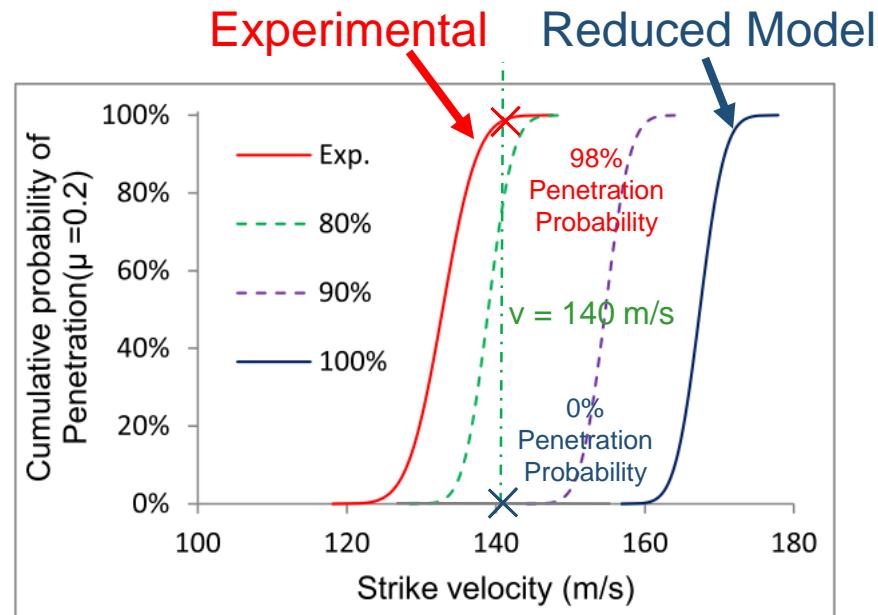
25 Eq. Fibres



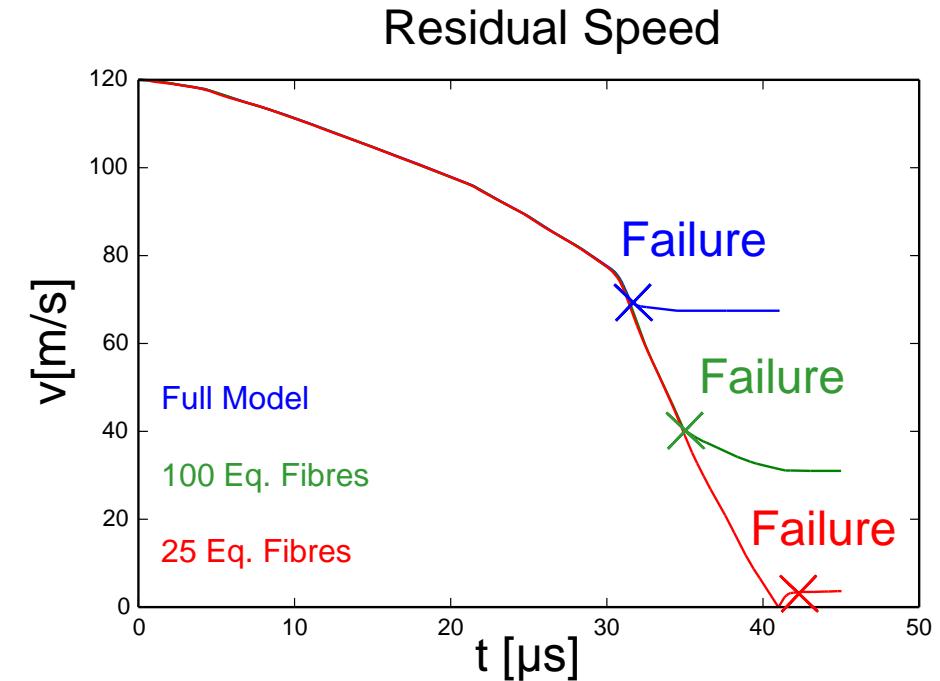
Full to Reduced Scale Transition: Explorative Results

In conclusion:

Classical multiscale approach results in stronger yarn for coarser discretization



Probability Velocity Response
(Y.Wang, 2016)



Conclusion and Perspectives

Conclusion

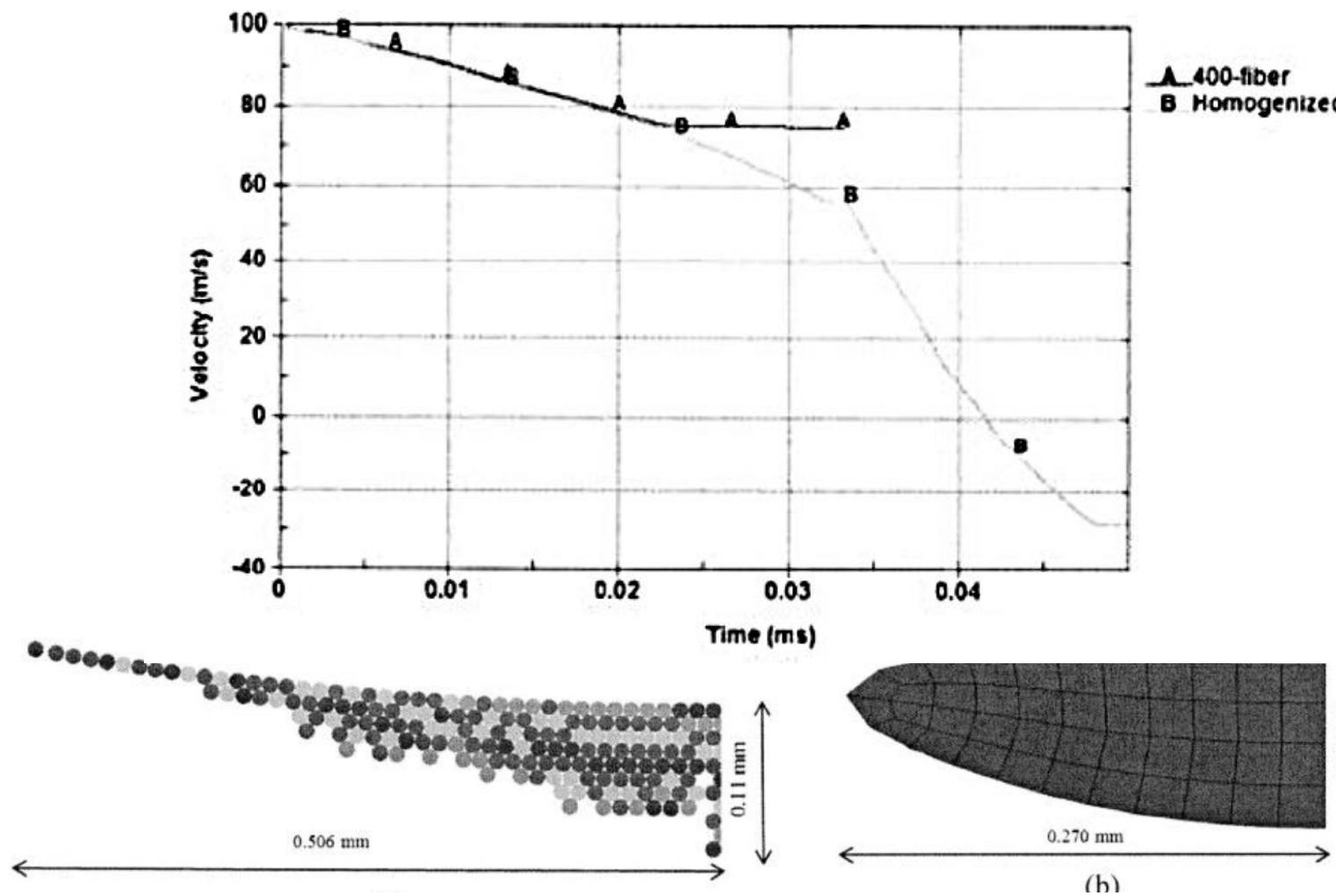
- Good Agreement with pre-existent models up to failure
- Microscale Friction effect have been explored
- Influence of scale transition on global response

Perspectives

- Full-to-Reduced Failure Criteria
- Different shaped yarns analysis
- Beam employment
- Mesoscale Applications

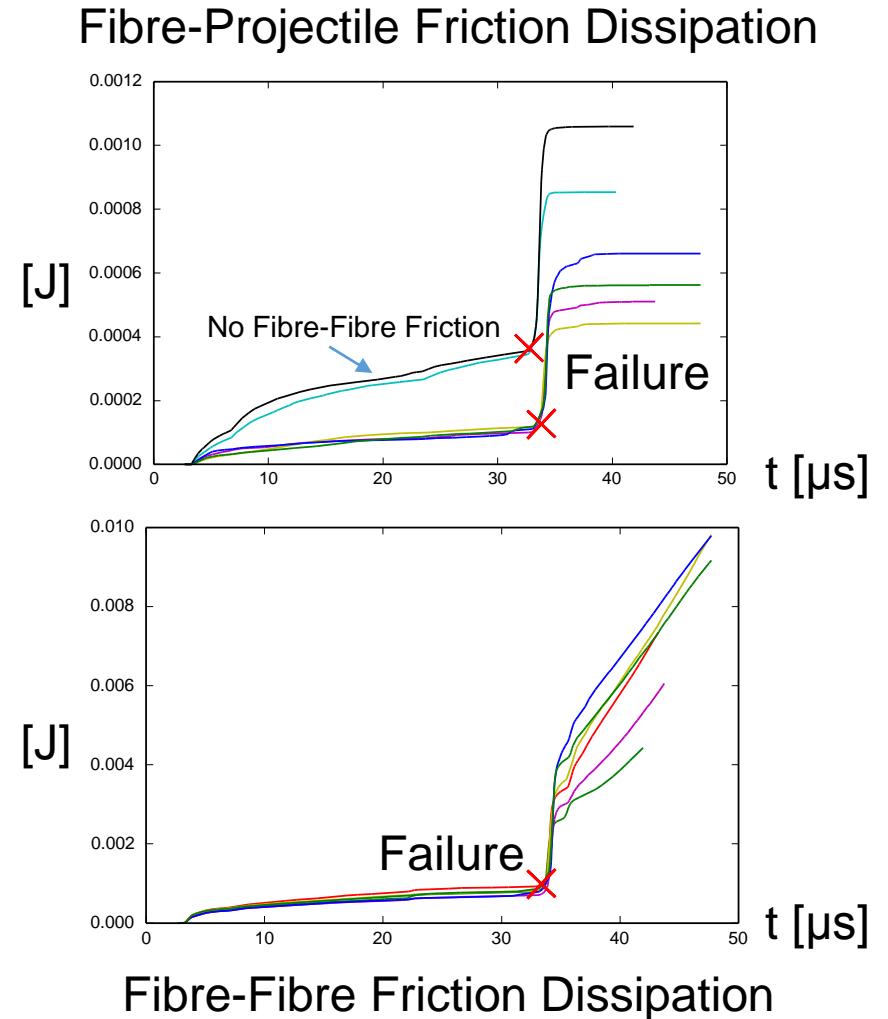
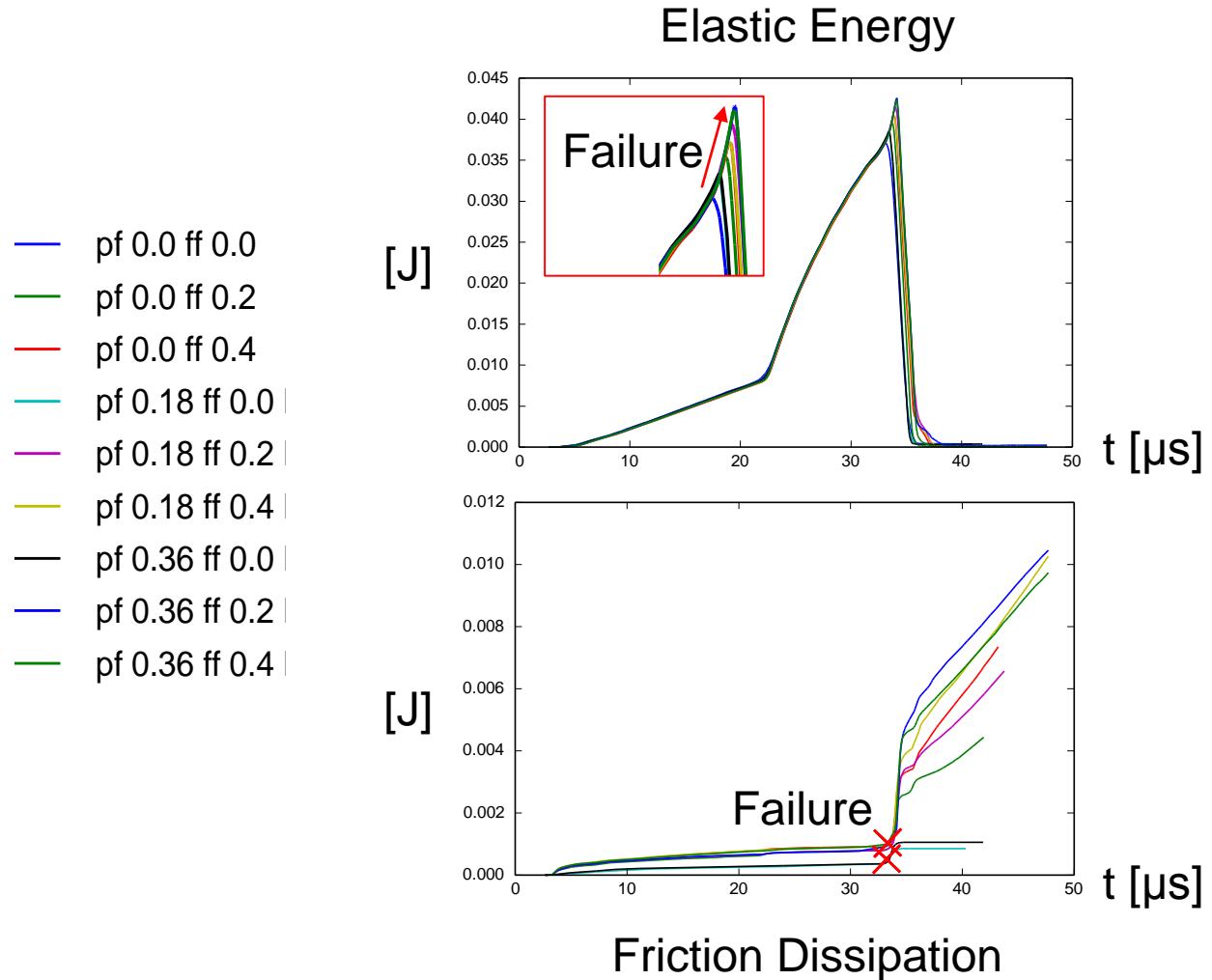
Thank You for Your Attention

Appendix 1



(Sockalingam, 2014)

Appendix 2



Appendix 3

Material Properties	GranOO Spring Model	Nilakantan (2013)
Material Model	Isotropic-Linear Elastic	Transversally Isotropic-Linear Elastic
Young Modulus Axial E_{33}	84.6 GPa	84.6 GPa
Young Modulus Transversal E_t	/	1.34 GPa
Torsional Shear Modulus G_{13}	/	24.40 GPa
ν_{31}	/	0.60
ν_{12}	/	0.24
Density	1440 Kg/m ³	1440 Kg/m ³
Limit Stress	3.88 GPa	3.88 GPa

Set up	GranOO Models	Nilakantan (2013)
Model	Symmetric	Complete
Nr. Fibres	400	400
Yarn Length	25.4mm	25.4mm
Fibre Diameter	12μm	12μm
Contact	GranOO Models	Nilakantan (2013)
Bullet-Fibres Friction	0.18	0.18
Fibres-Fibres Friction	0.20	0.20
Contact Stiffness	5e ⁵ N/m	n.d.
Bullet	GranOO Models	Nilakantan (2013)
Shape	Cylindrical	Cylindrical
Mass	9.91 mg	9.91 mg
Velocity	120 m/s	120 m/s
Radius	1.1 mm	1.1 mm