Meso-macro simulation of the draping of composite textile reinforcements

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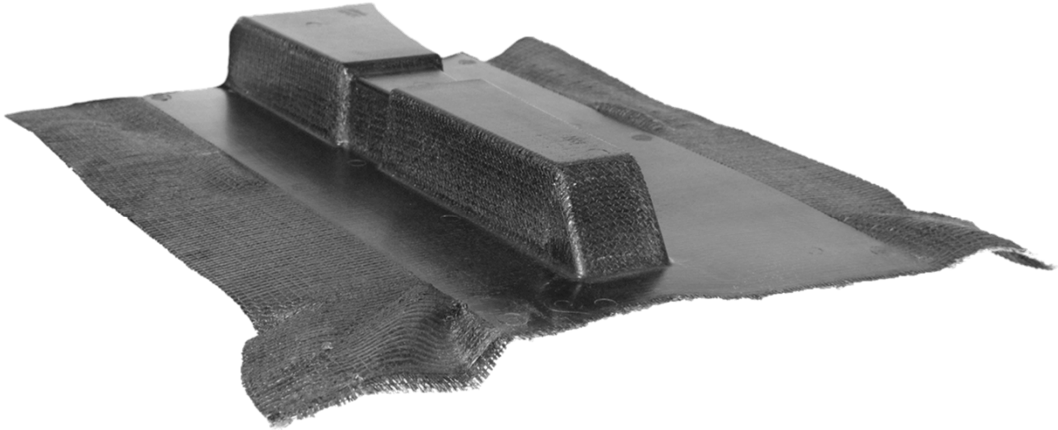
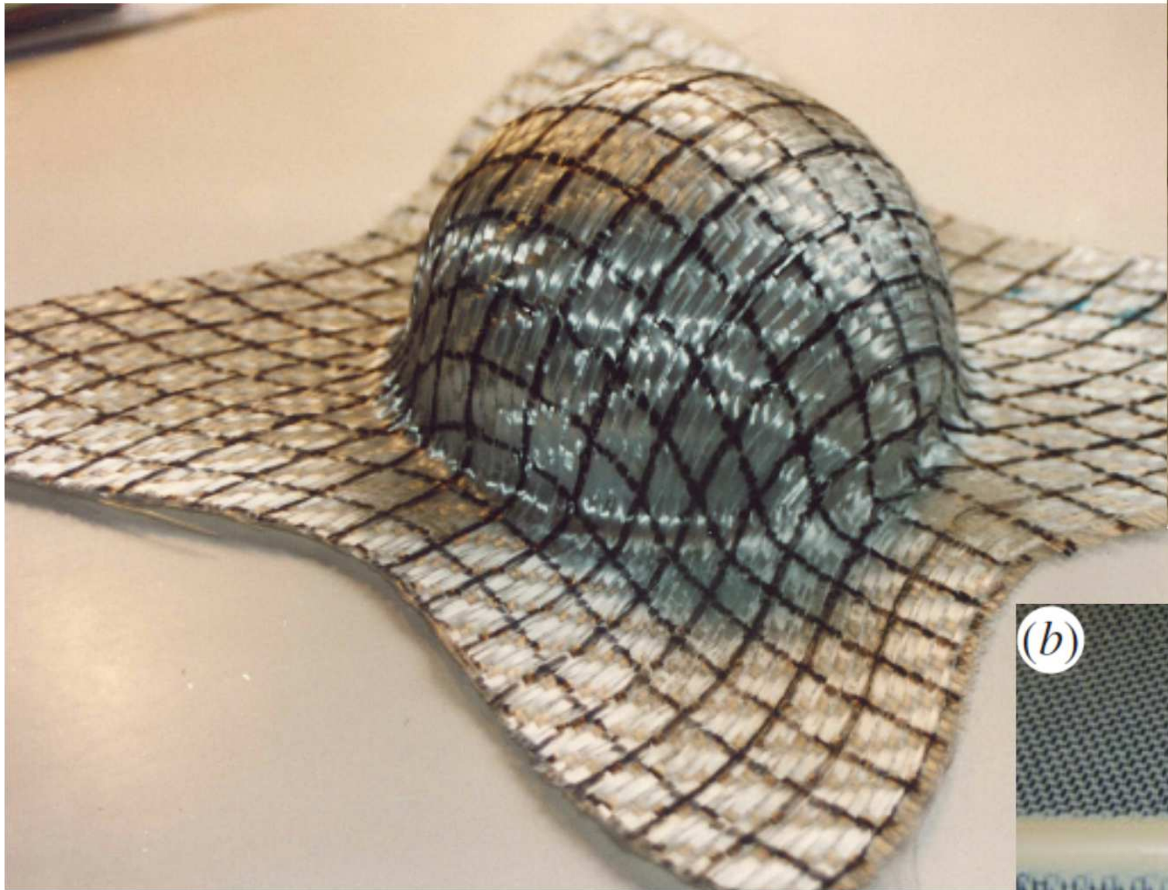
Textile composite parts with double curved geometry

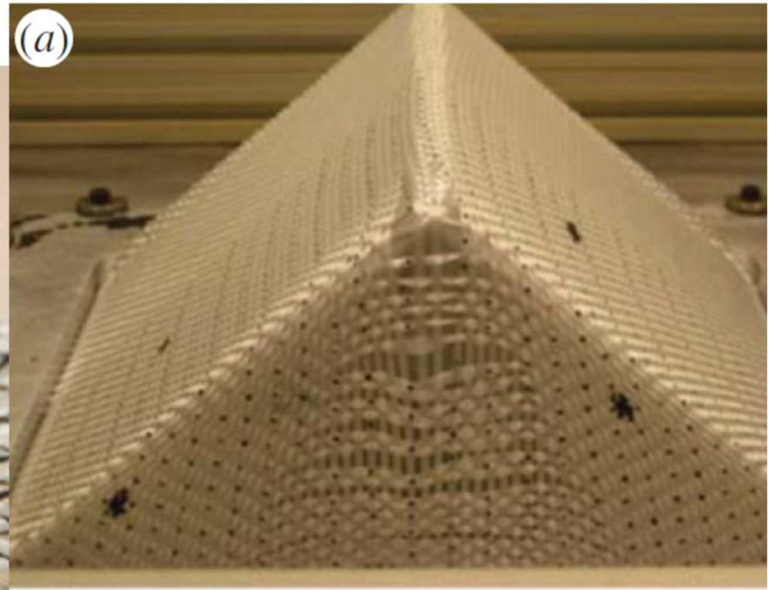
Snecma
SAFRAN Group



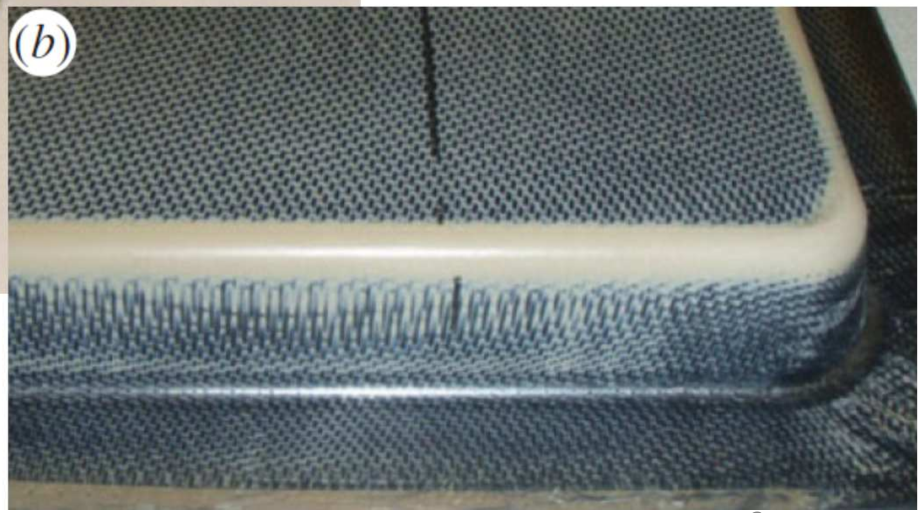
PLASTIC OMNIUM

Composite reinforcements made of continuous fibres can be considered as a **continuous medium**





[Allaoui et al, I. J. Mat. Form. 2014]



[Boisse et al, Phil. Trans. 2016]

This is not always the case.
Slippages, gaping can occur (defects)

macro

meso

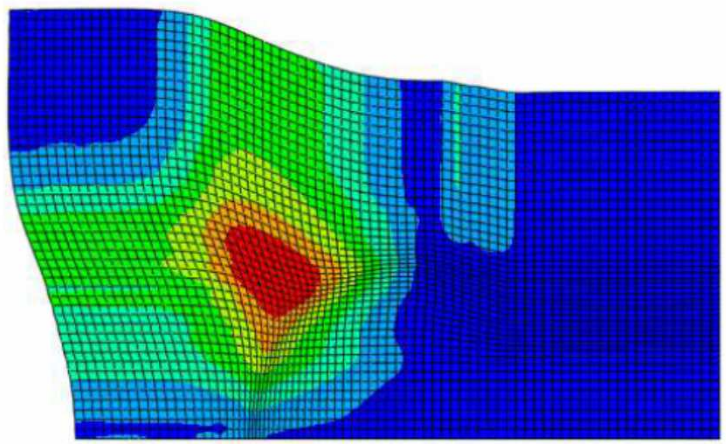
micro

Macroscopique scale
(scale of the part)

Mesoscopic scale
(scale of the yarn
and of the woven cell)

Microscopic scale
(scale of the fibre)

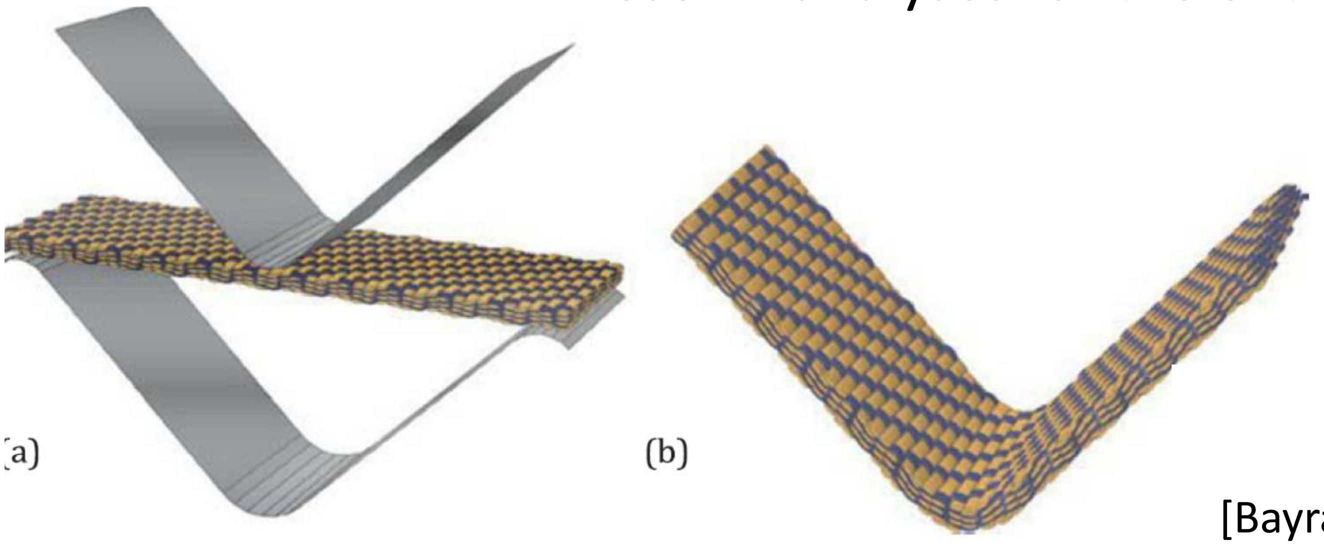
Three scales for textile reinforcement analyses



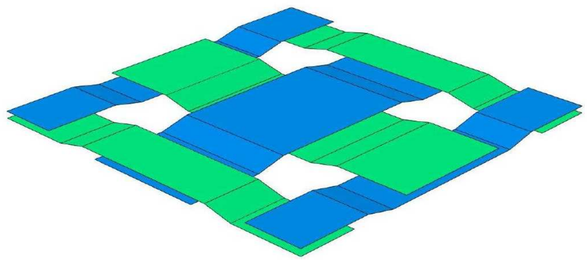
Most of the simulations
are performed at macro scale

Gaping and local buckling cannot be
simulated

Meso FE analyses for the entire preform



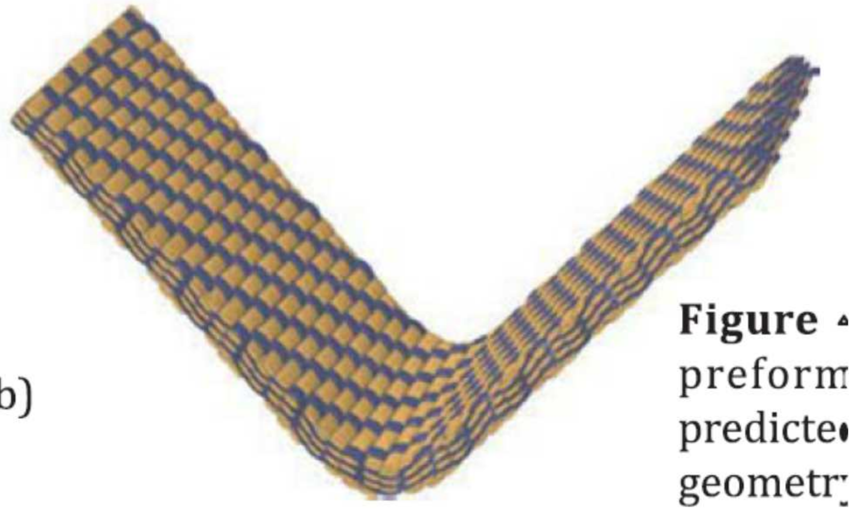
[Bayraktar et al, Sampe J. 2015]



[Gatouillat et al, Composites A 2013]

Meso FE analyses for the entire preform

(b)

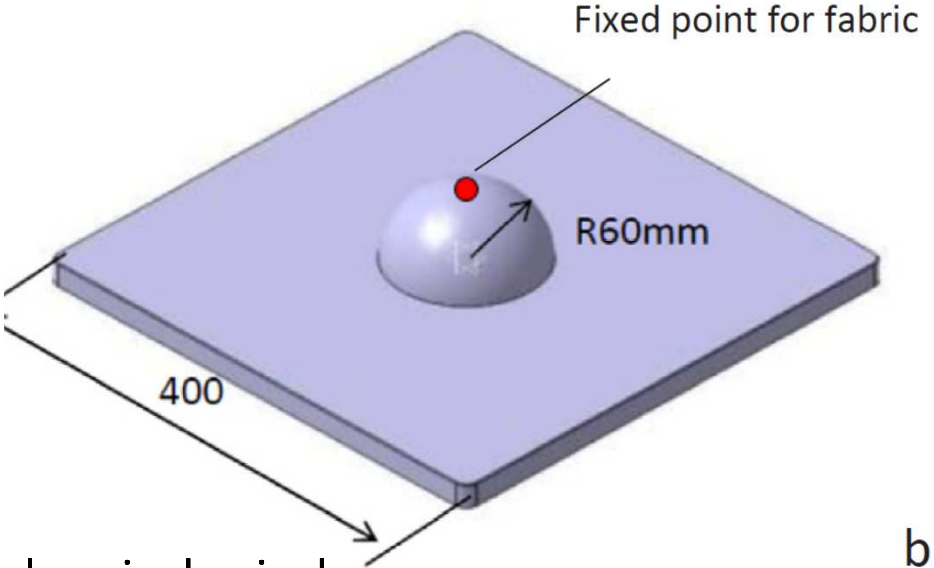


(a)

The analyses are complexe and require long calculation times

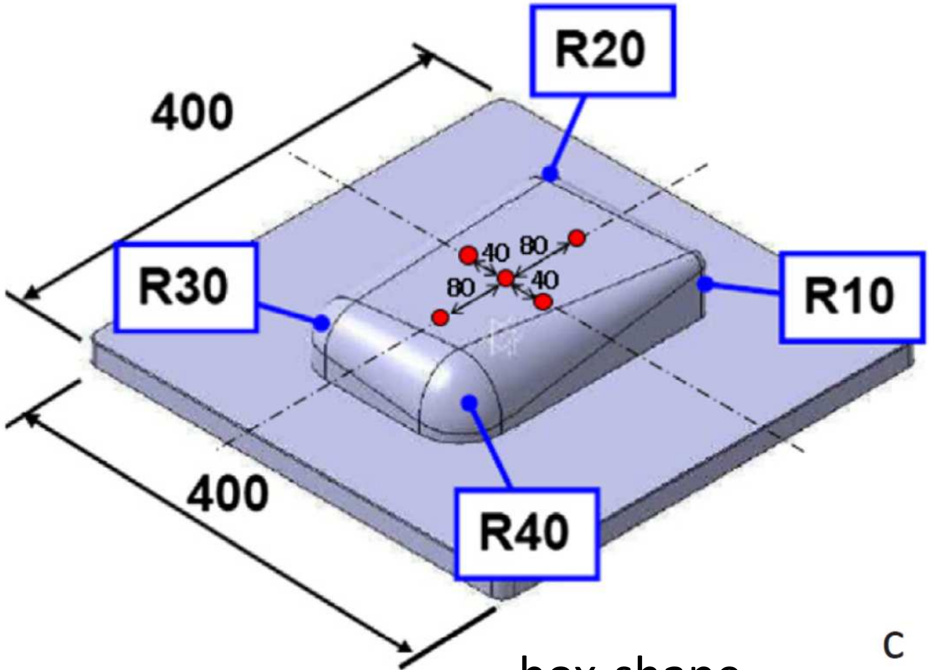
Proposed in this work: A meso-macro approach
used to limit the meso calculation to a given area.

The geometry considered (double curvature)



hemispherical

b



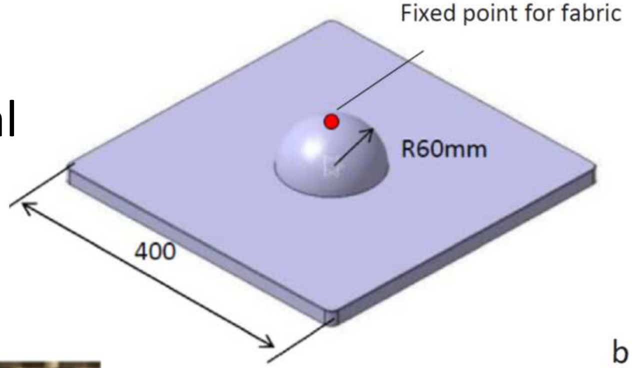
box-shape

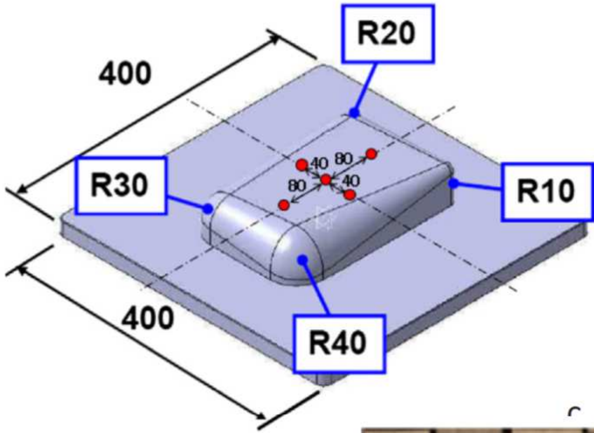
c

[Iwata et al, Composites A, 2019]

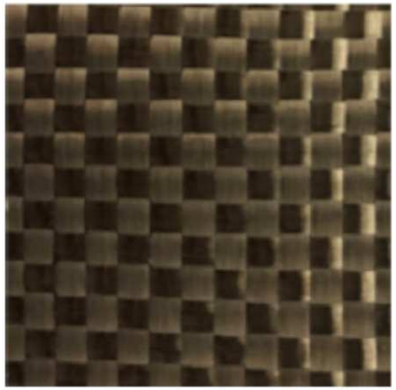
The reinforcement considered (double curvature)

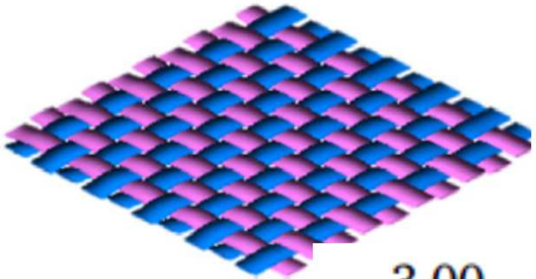
hemispherical



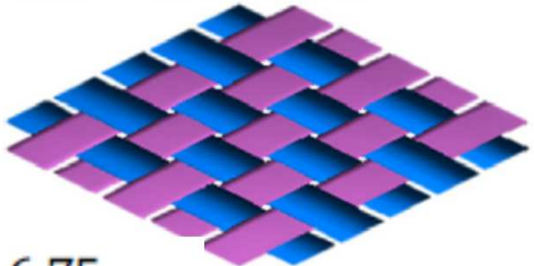


box-shape





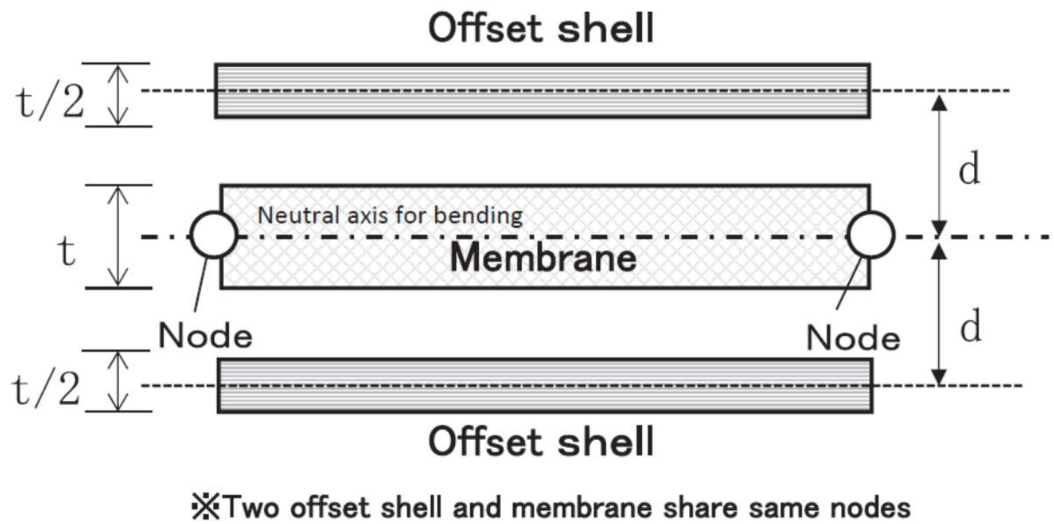
[Iwata et al, Composites A, 2019]

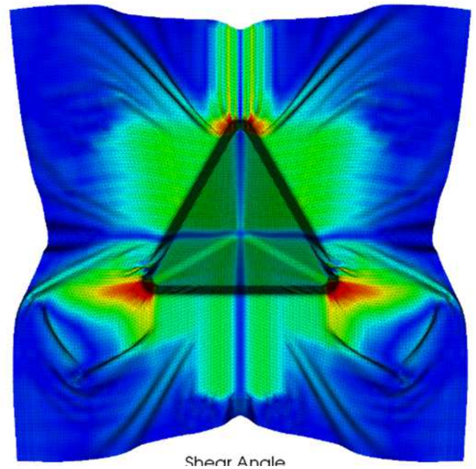


3.00	Yarn width, mm	6.75
0.323	Yarn thickness, mm	0.126
0.6%	Crimp, %	< 0.1%

Constitutive model for the fabric (macro scale)

Macro-draping model, proposed by Nishii et al. [ECCM-16, 2014],

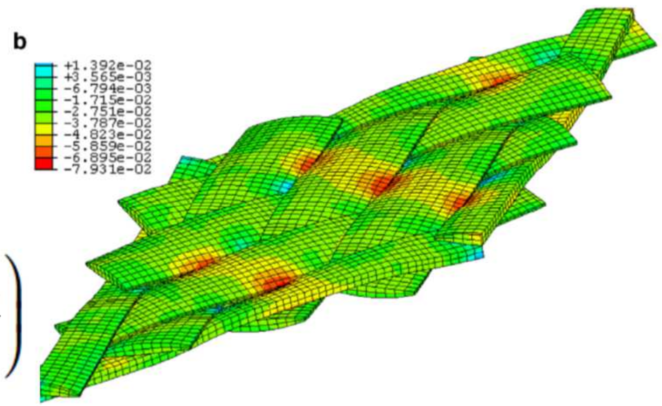




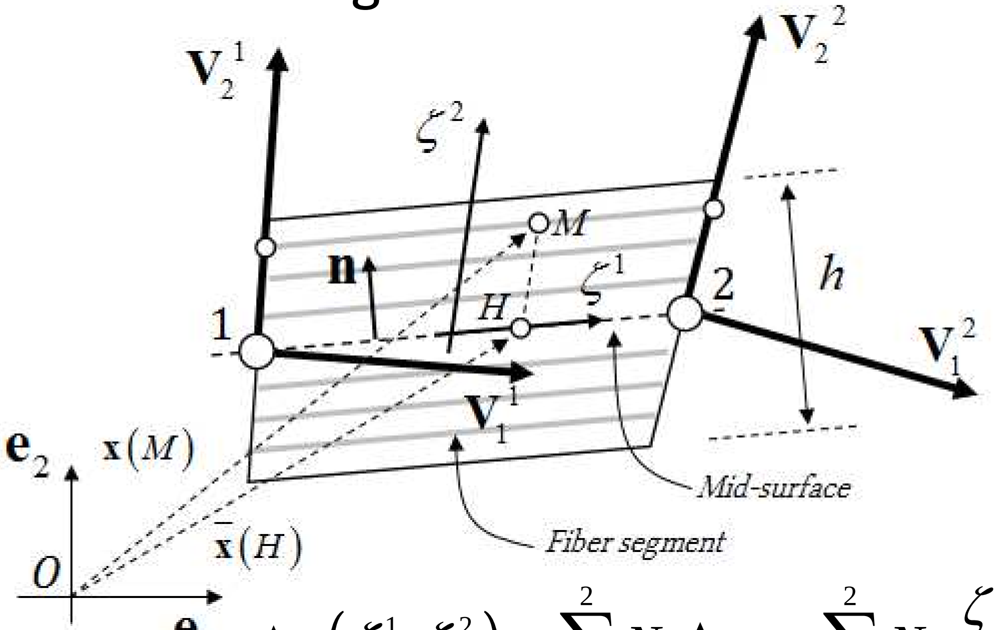
Constitutive model for the yarn (meso scale)

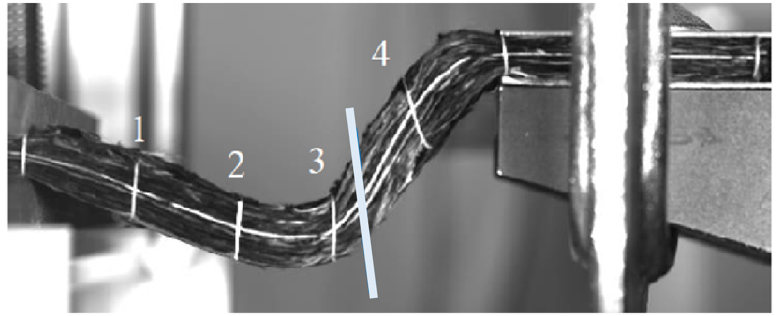
$$\underline{\underline{S}} = 2\frac{\partial w}{\partial \underline{\underline{C}}}$$

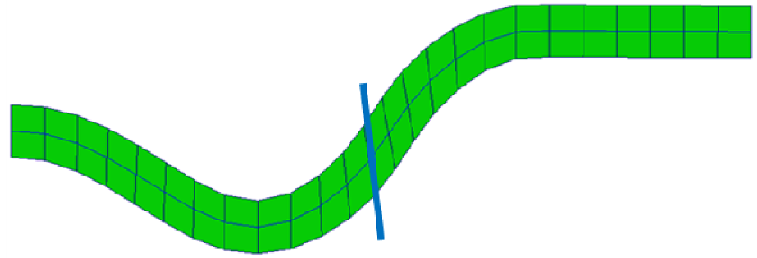
$$\underline{\underline{S}}_{total} = 2\left(\frac{\partial w_{elong}}{\partial I_{elong}}\frac{\partial I_{elong}}{\partial \underline{\underline{C}}} + \frac{\partial w_{comp}}{\partial I_{comp}}\frac{\partial I_{comp}}{\partial \underline{\underline{C}}} + \frac{\partial w_{dist}}{\partial I_{dist}}\frac{\partial I_{dist}}{\partial \underline{\underline{C}}} + \frac{\partial w_{cis}}{\partial I_{cis}}\frac{\partial I_{cis}}{\partial \underline{\underline{C}}}\right)$$



Ahmad Shell element made of fiber segments







$$\Delta \mathbf{u}\left(\zeta^1,\zeta^2\right)=\sum_{k=1}^{2} N_k \Delta \mathbf{u}_k-\sum_{k=1}^{2} N_k \frac{\zeta^2}{2}\,{}^i h_k \Delta \alpha_k\,{}^i \mathbf{V}_1^k$$

Internal virtual work in the element made from fibers

$$\delta W_{\text{int}}^{e}=\sum_{f=1}^{n}\int_{L^f} T^{11f}\,\delta\varepsilon_{11}{}^{f}\,dL+\sum_{f=1}^{n}\int_{L^f} M^{33f}\,\delta\chi_{33}{}^{f}\,dL$$

[Liang et al, Composites A, 2017]

Tension of fibers — Bending of fibers

The tensile stiffness is large: **quasi-inextensibility**

No shear strain energy: **possible slippage**

$$w = w(I_1, I_2, I_3, II_4, II_5) \qquad \underline{\underline{M}} = \underline{M} \otimes \underline{M}.$$

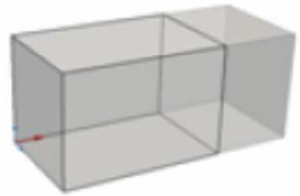
$$I_1 = \mathrm{trace}(\underline{\underline{C}}), \quad I_2 = \frac{1}{2}(\mathrm{trace}(\underline{\underline{C}})^2 - \mathrm{trace}(\underline{\underline{C}}^2)), \quad I_3 = \det(\underline{\underline{C}})$$

$$II_4 = \underline{\underline{C}} : \underline{\underline{M}} \quad \text{and} \quad II_5 = \underline{\underline{C}}^2 : \underline{\underline{M}}$$

Transverse isotropy

Élongation des fibres :

- Grandeur caractéristique : variation de longueur des fibres
- Invariant associé : $I_{élong} = I_4 = \underline{\underline{C}} : \underline{\underline{G_1}}$ Énergie associée : $W_f(I_4) = \frac{1}{8} \cdot \frac{K}{S_0} \cdot (I_4 - 1)^2$

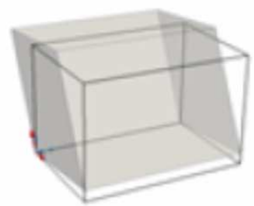


Changement d'aire dans le plan transverse :

- Grandeur caractéristique : variation d'aire de la section transverse (⊥ à la direction des fibres)
- Invariant associé : $I_{aire} = \sqrt{\frac{I_3}{I_4}}$ Énergie associée : $W_{aire}(I_4) = k_1 \cdot (I_{aire}{}^{-k_2} - 1)^2$

Changement de forme dans le plan transverse :

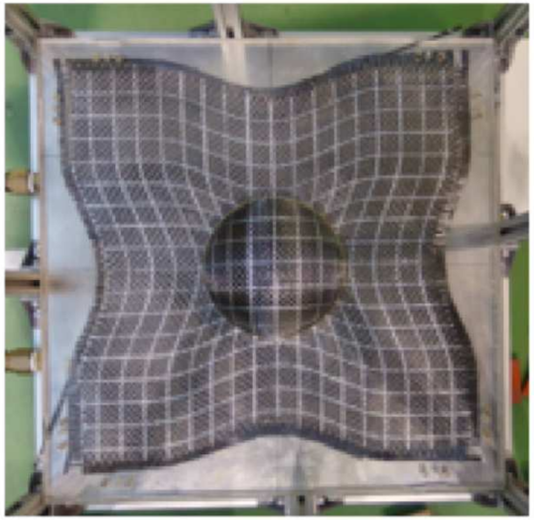
- Invariant associé : $I_{forme} = \sqrt{I_1 - \frac{I_5}{I_4} - 2 I_{aire}}$ Énergie associée : $W_{trans}^{forme}(I_{forme}) = \frac{1}{2} K_{forme} I_{forme}^2$



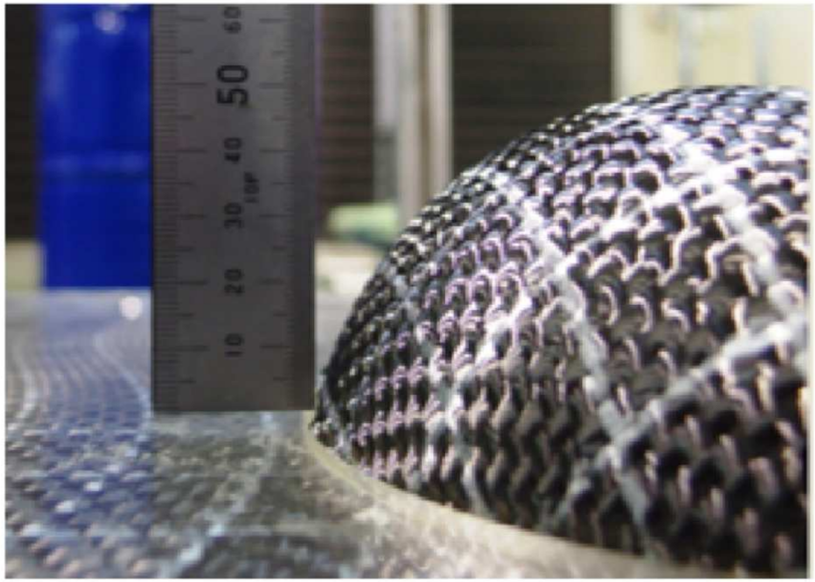
Cisaillement le long des fibres :

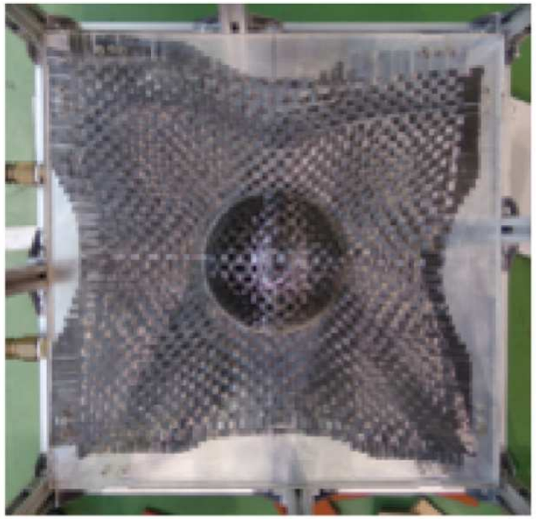
- Invariant associé : $I_{cislong} = \sqrt{\frac{I_5}{I_4} - I_4}$ Énergie associée : $W_{cislong} = \frac{1}{2} K_{cislong} (I_{cislong})^2$

[Charmetant et al, Comp. Sci. Tech., 2011]



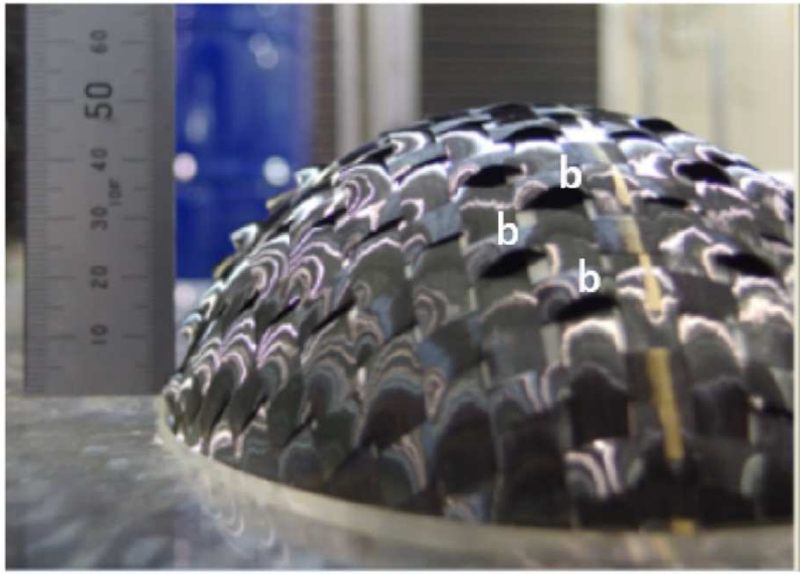
Fabric A





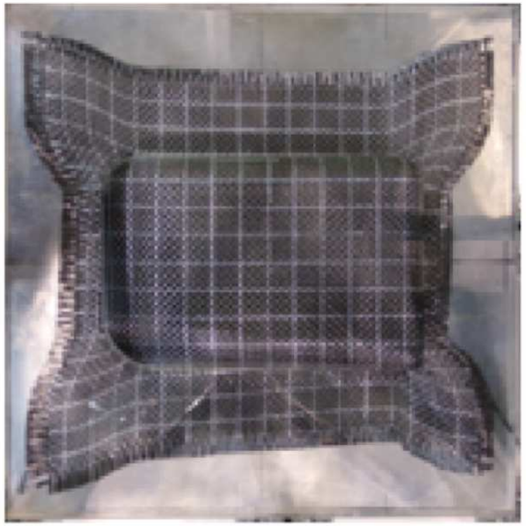
Fabric B

a

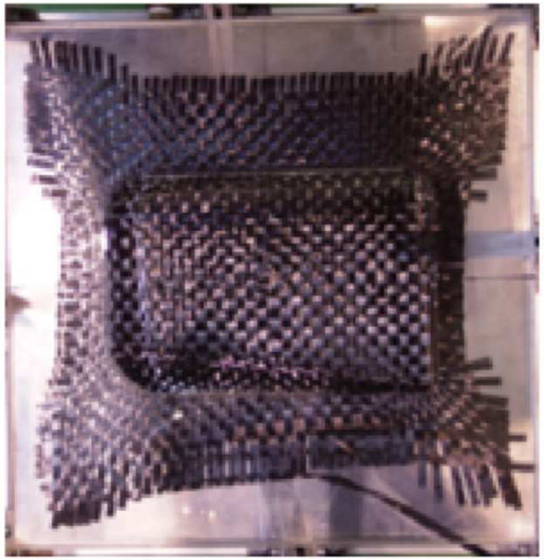


b – buckling

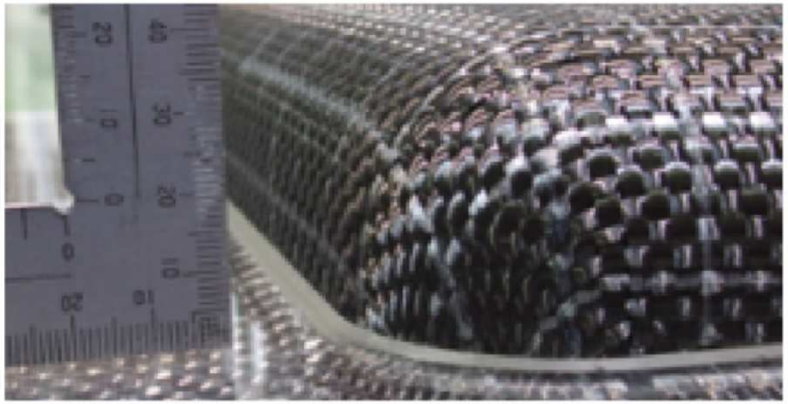
Hemispherical forming

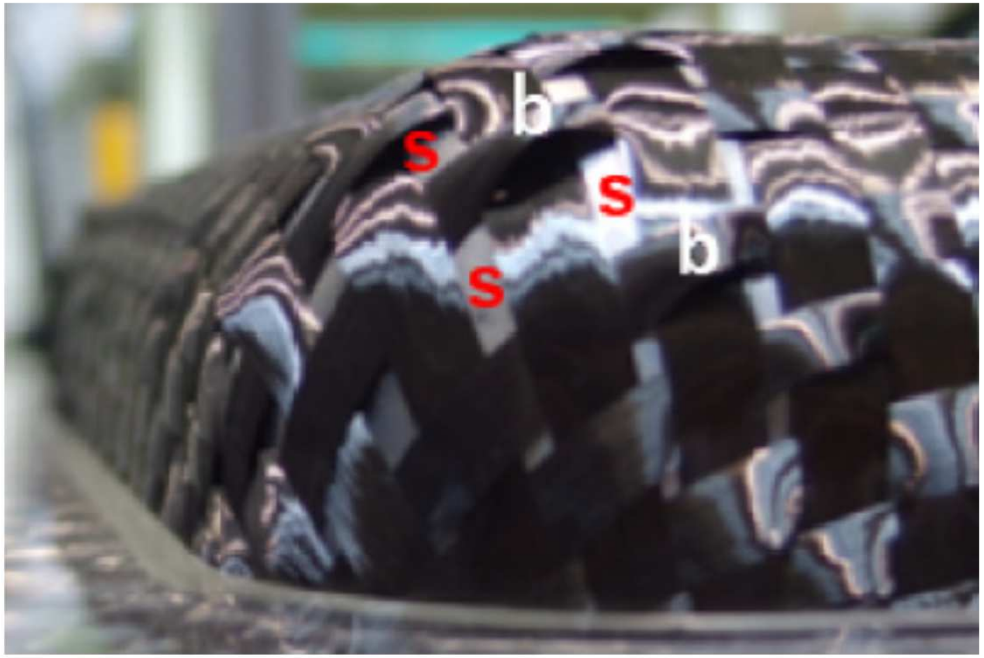


Fabric A



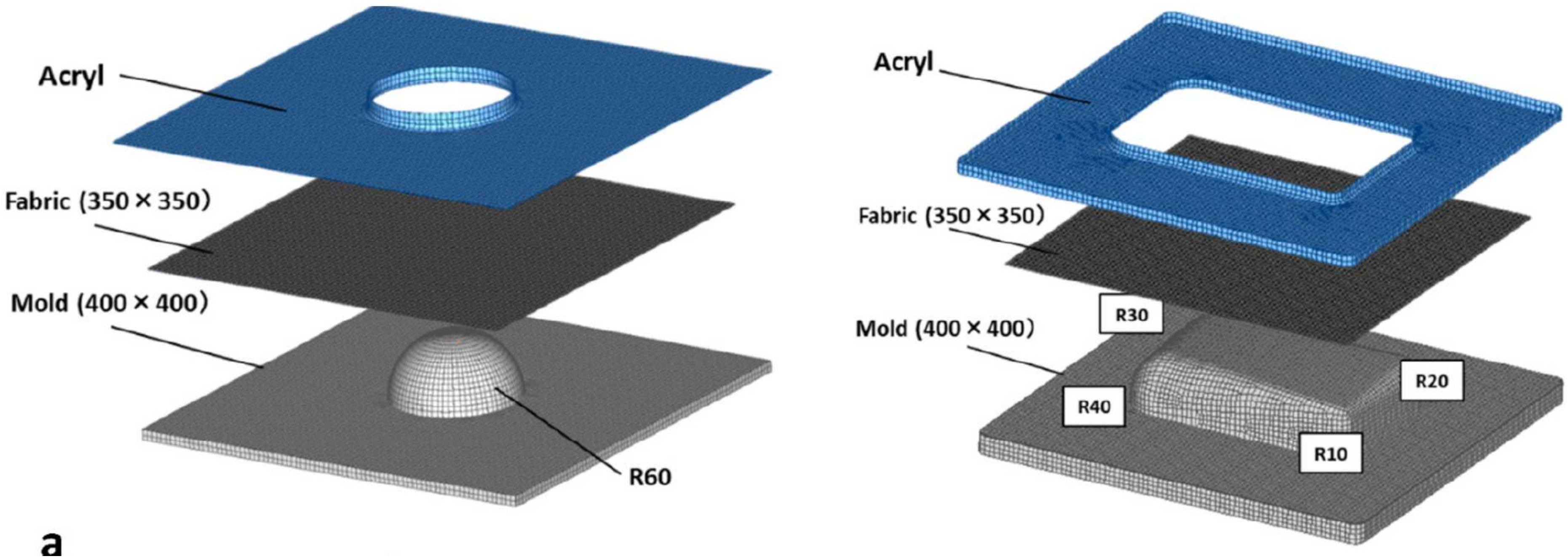
Fabric B





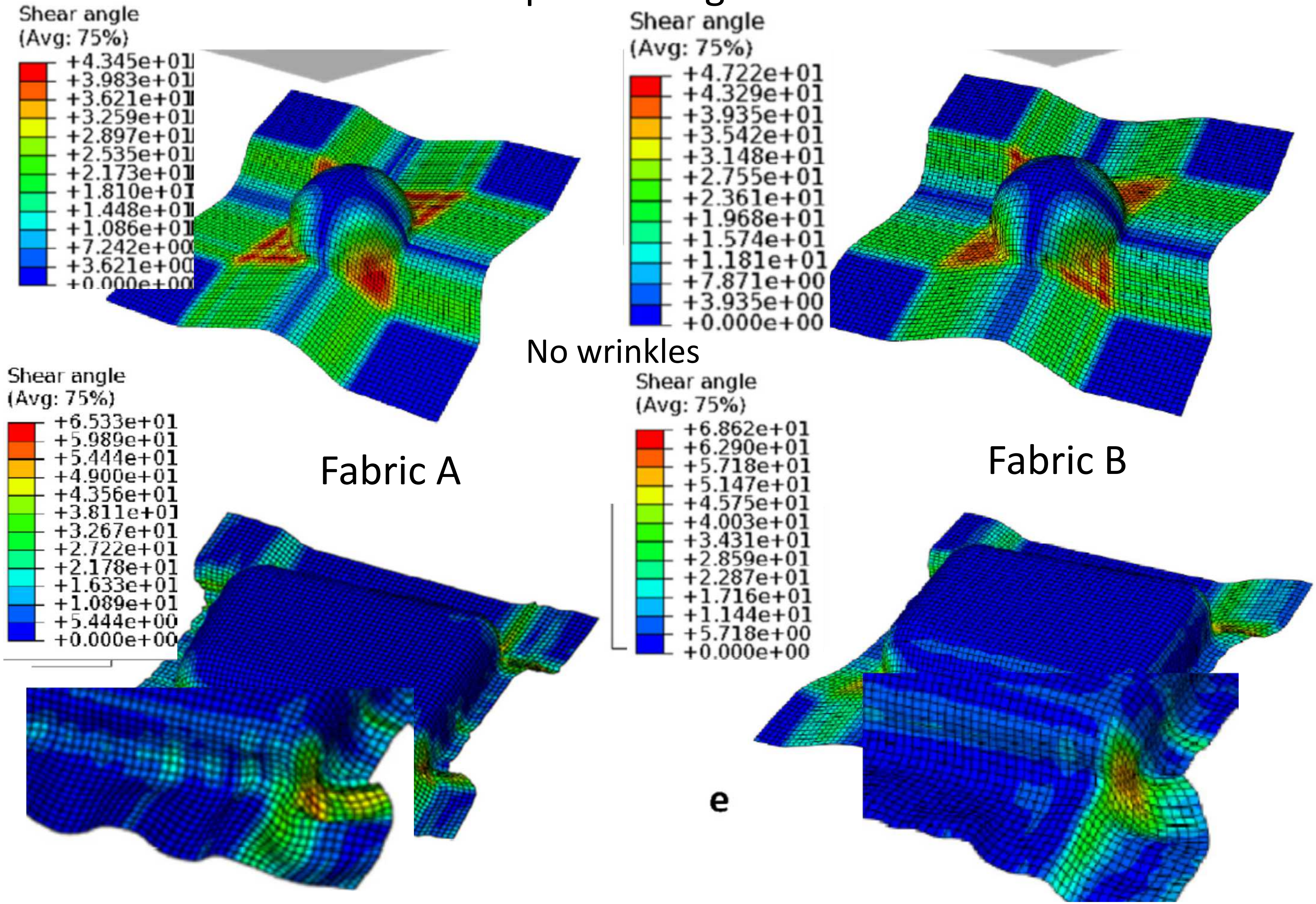
box-shaped mould

b – buckling S-sliding

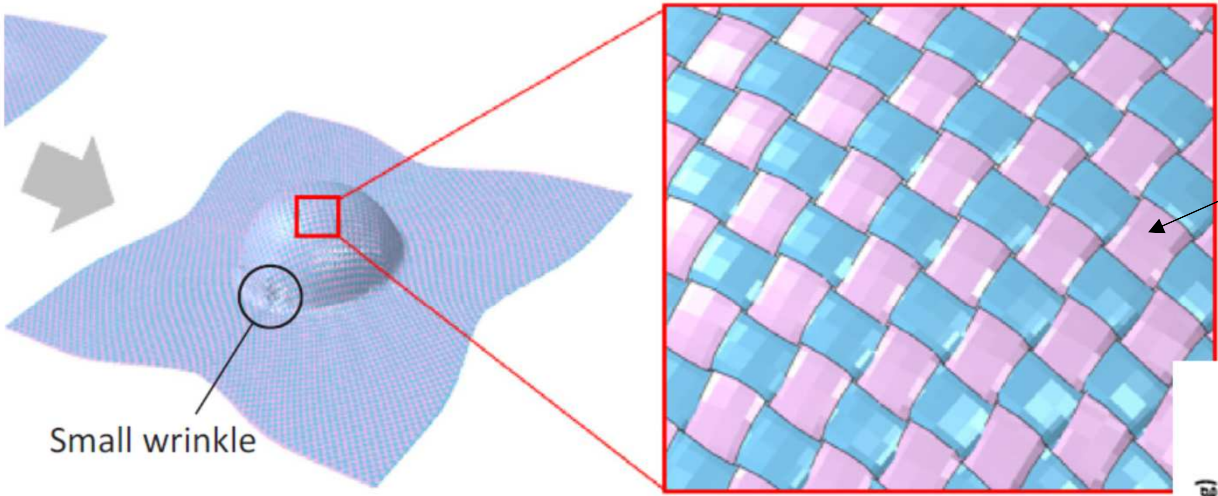


FE models for the forming simulations

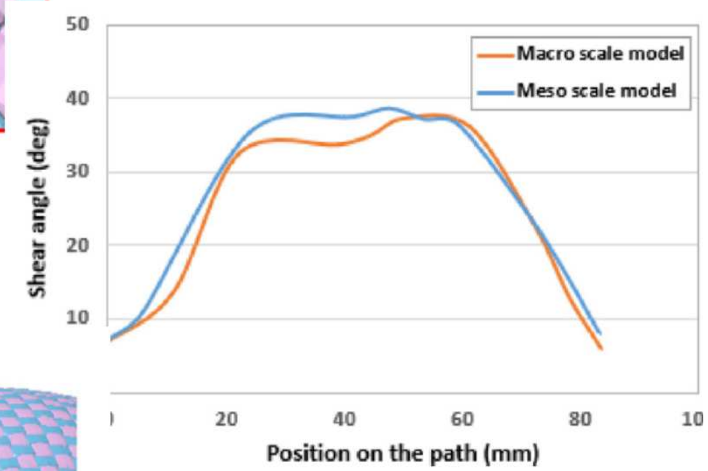
Macroscopic forming simulations



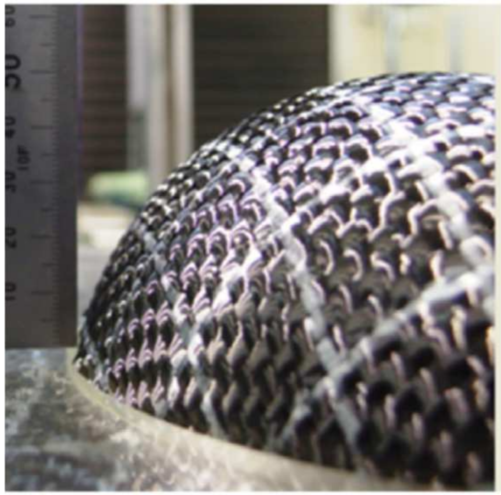
Large scale meso model (Fabric A)

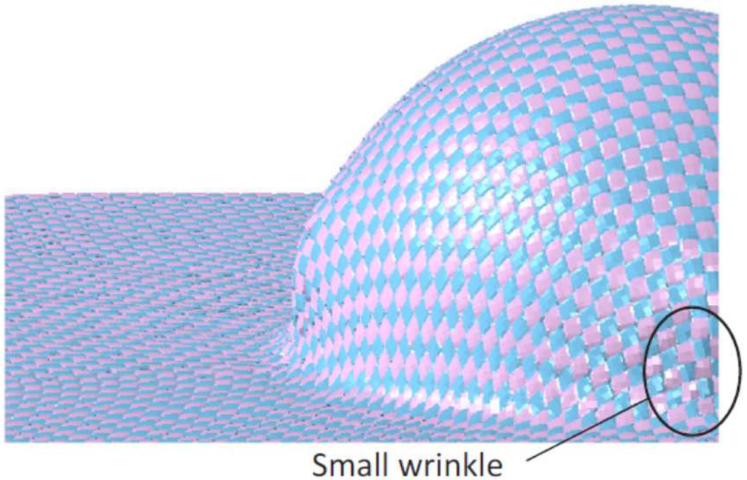


Hyperelastic behavior
of the yarn



small wrinkles appear,
which are not predicted in the macro-scale simulation





10 days of calculation

four CPUs
(Xeon E5-2690v4: 2.6 GHz)
and
memory size of 16 GB

Calculation cost, hemispherical mould.

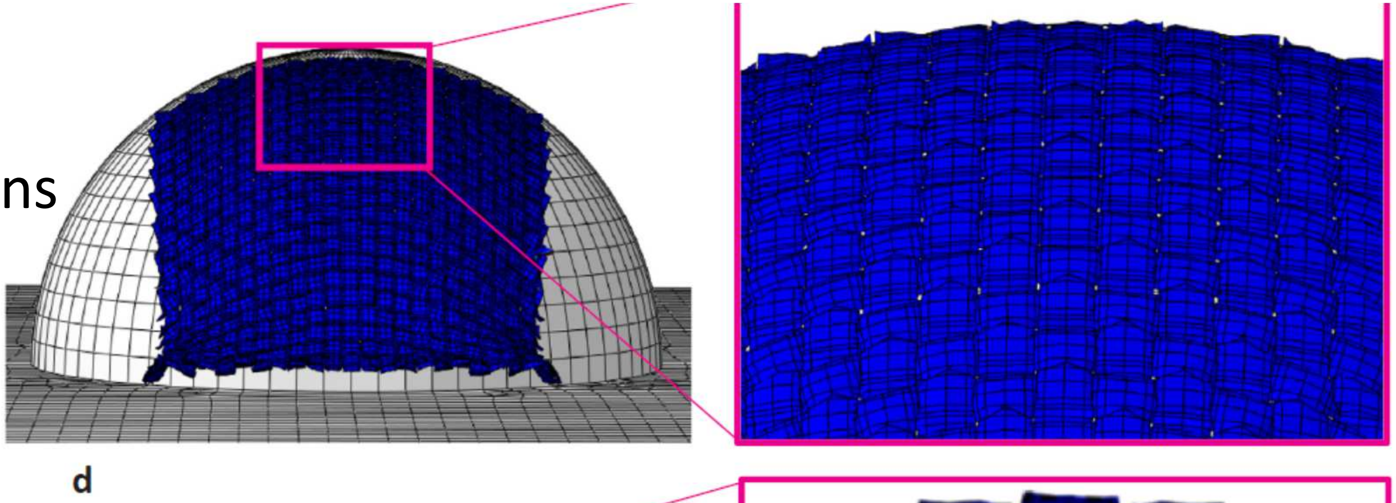
Type of simulation	Total CPU time	
	Fabric A	Fabric B
Macro scale	36 min	31 min
Large meso scale	258 h	No convergence
MMZ	44 h	15 h

Macro-meso zoom simulation of draping (MZZ)

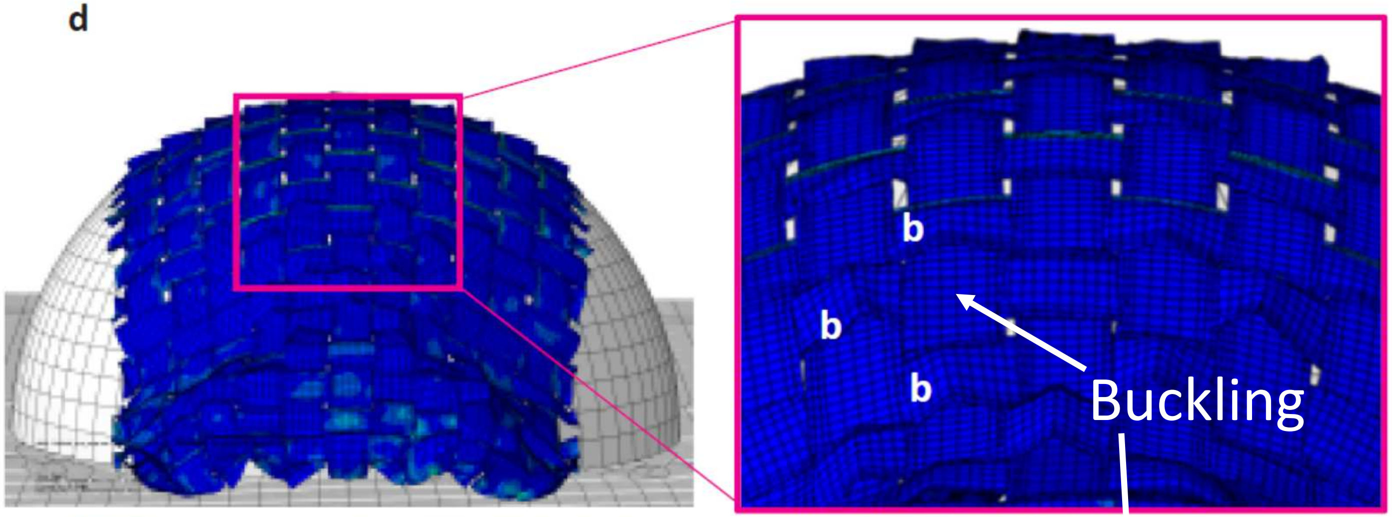
The meso-calculations use **the boundary conditions obtained from the macro-calculations**. The displacements along the edge of the meso-“patch”, were extracted from the macro-calculation results along the path corresponding to the edge. The yarns in the meso-calculation are also under contact conditions with the mould and the acrylic plate.

MMZ simulations

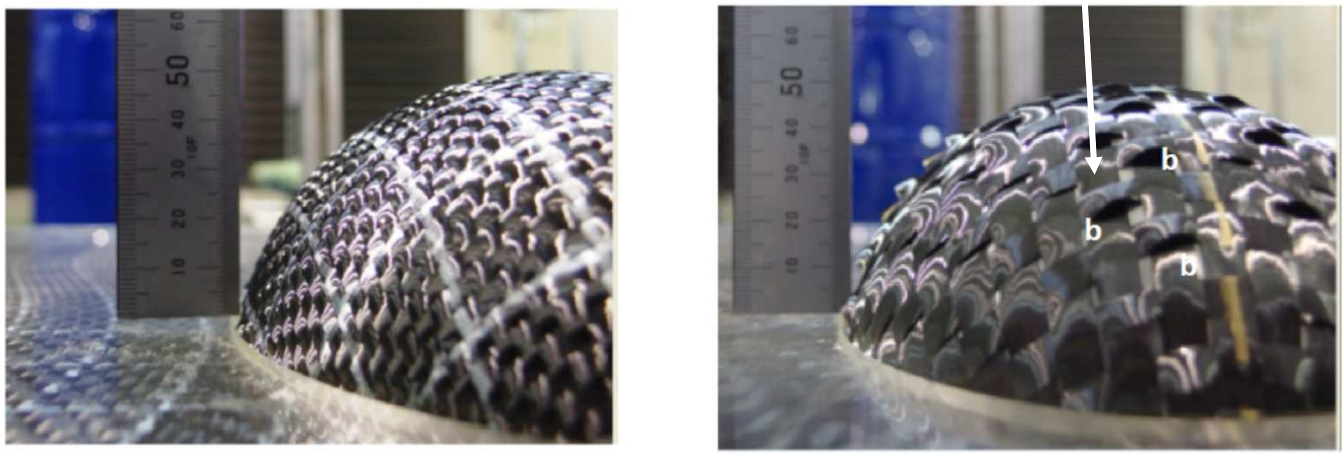
Fabric A
No buckling



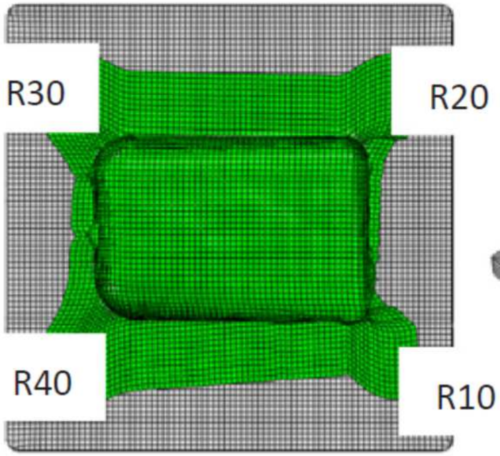
Fabric B
Some bucklings



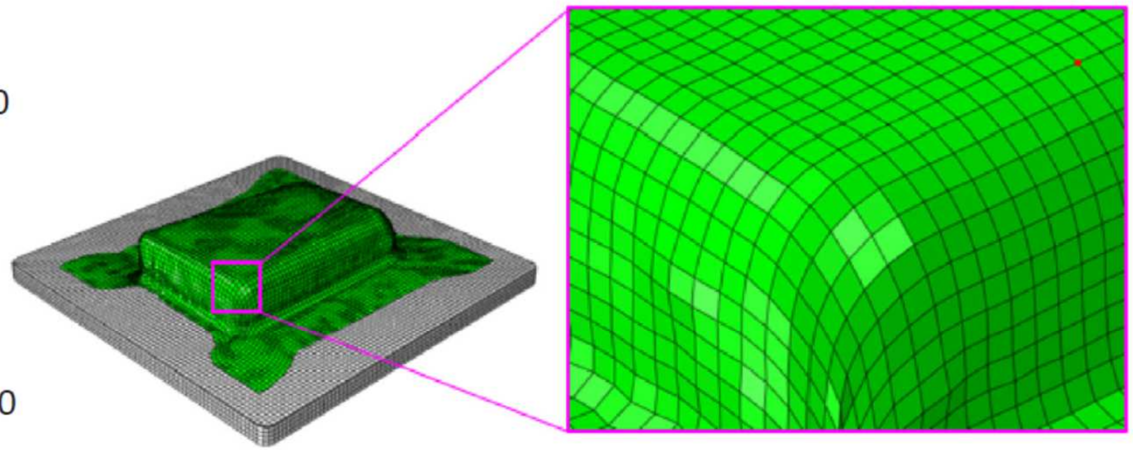
The buckling
happens in
the low-shear-angle
zone of the
draped fabric.



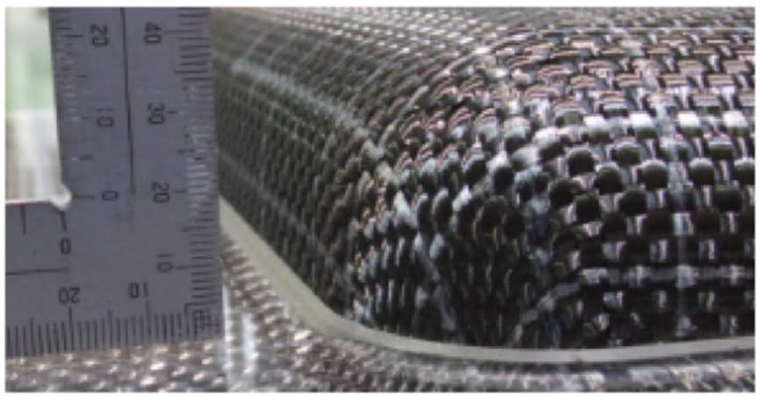
MMZ simulation : Box shape mould

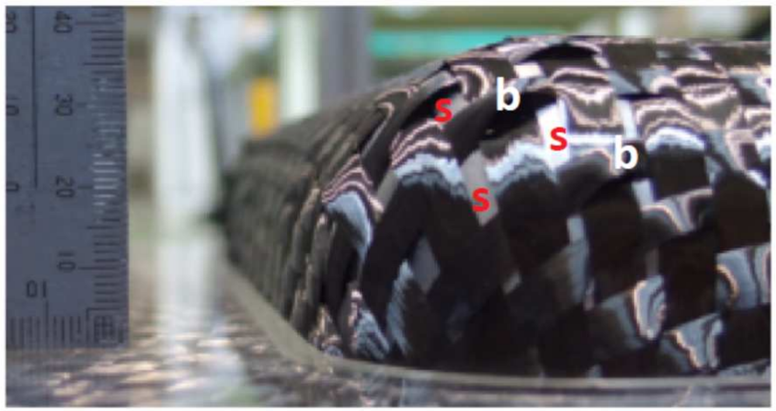


a

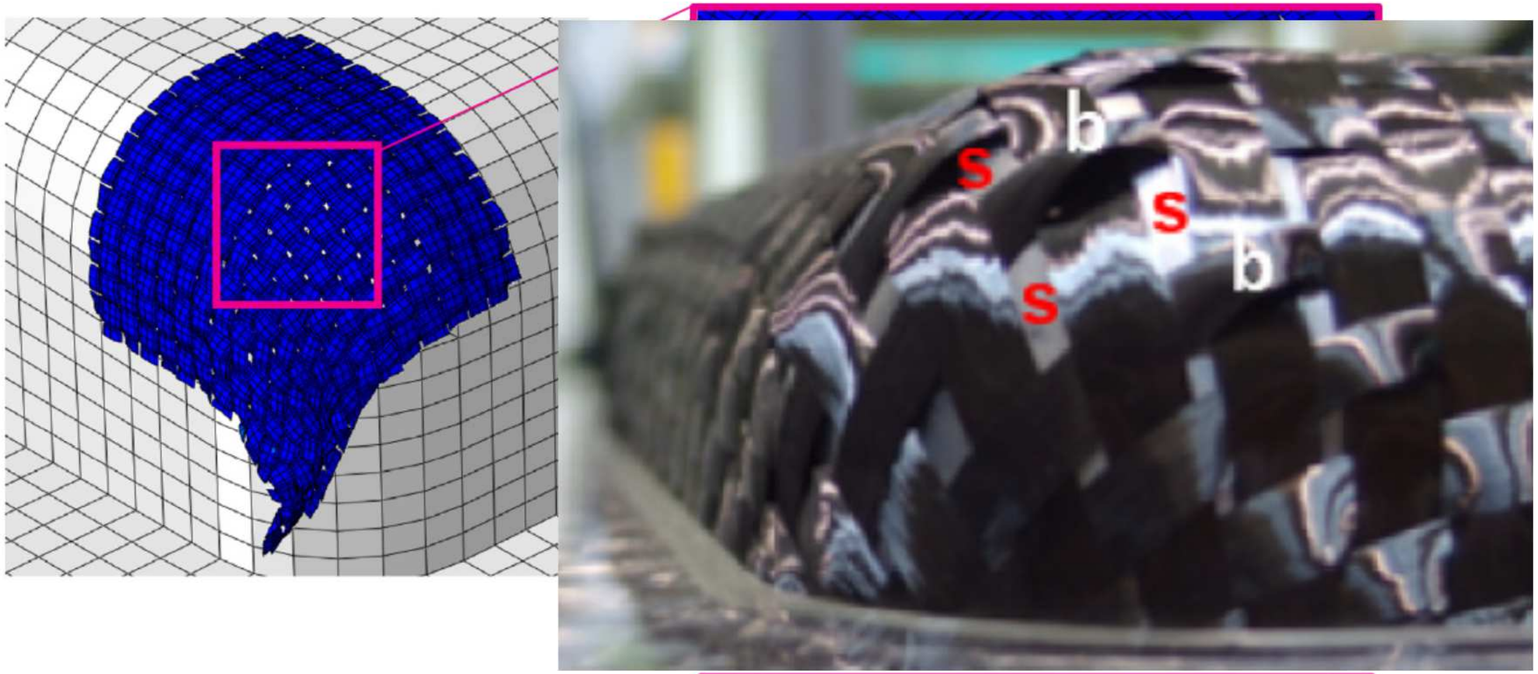


the meso-zoom region

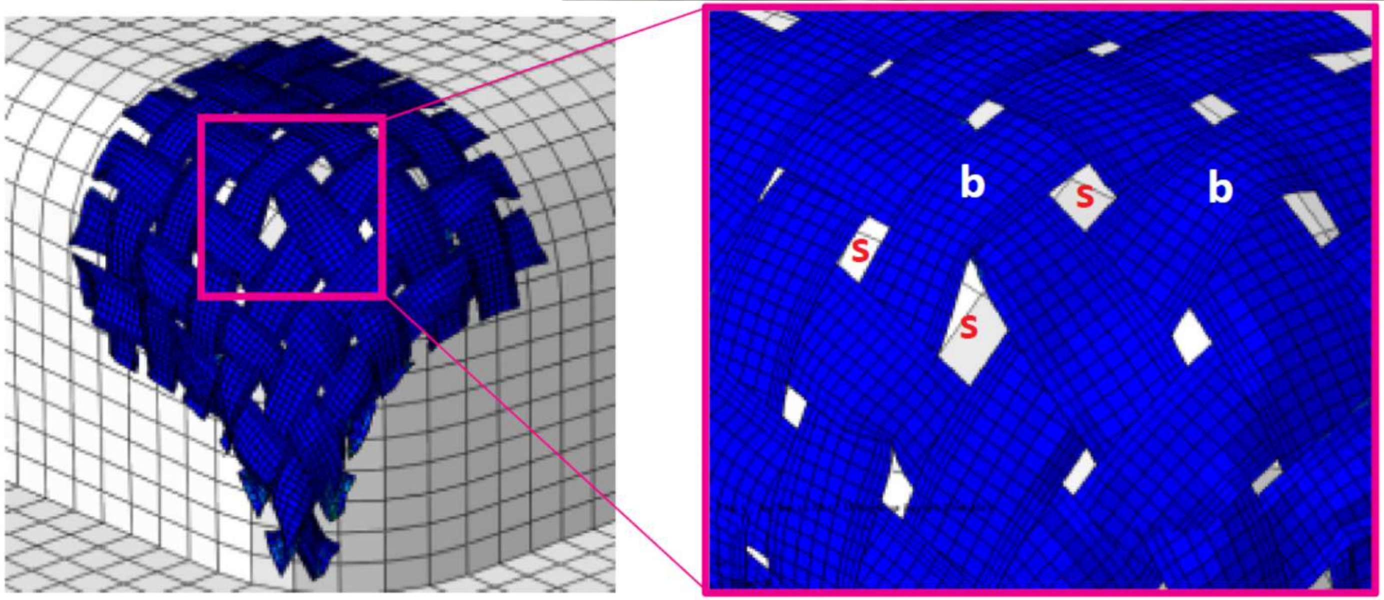




Fabric A

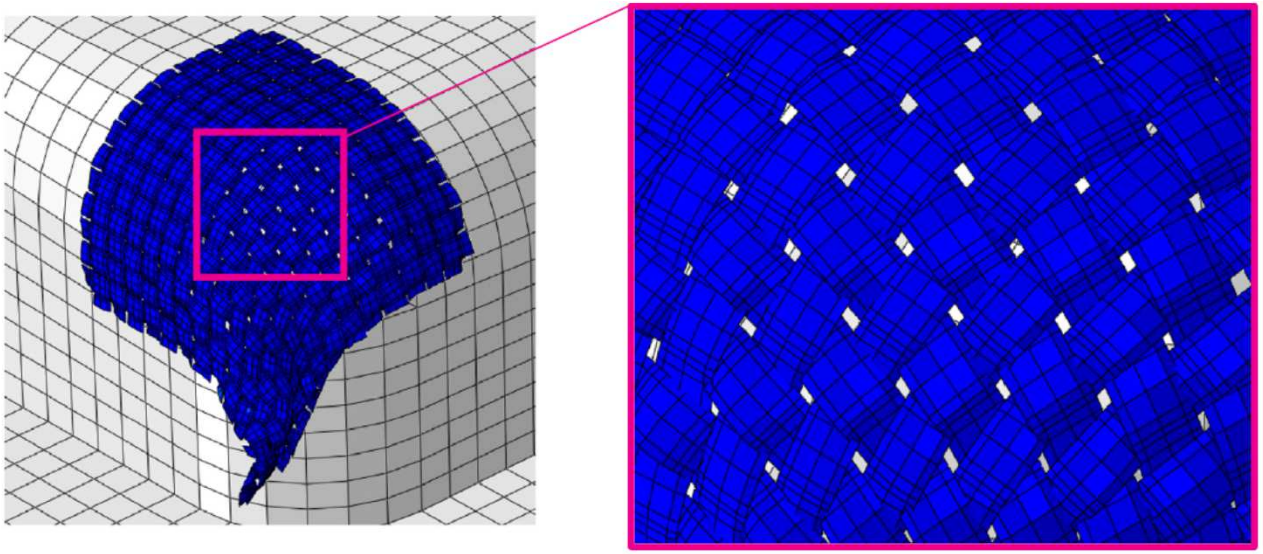


Fabric B

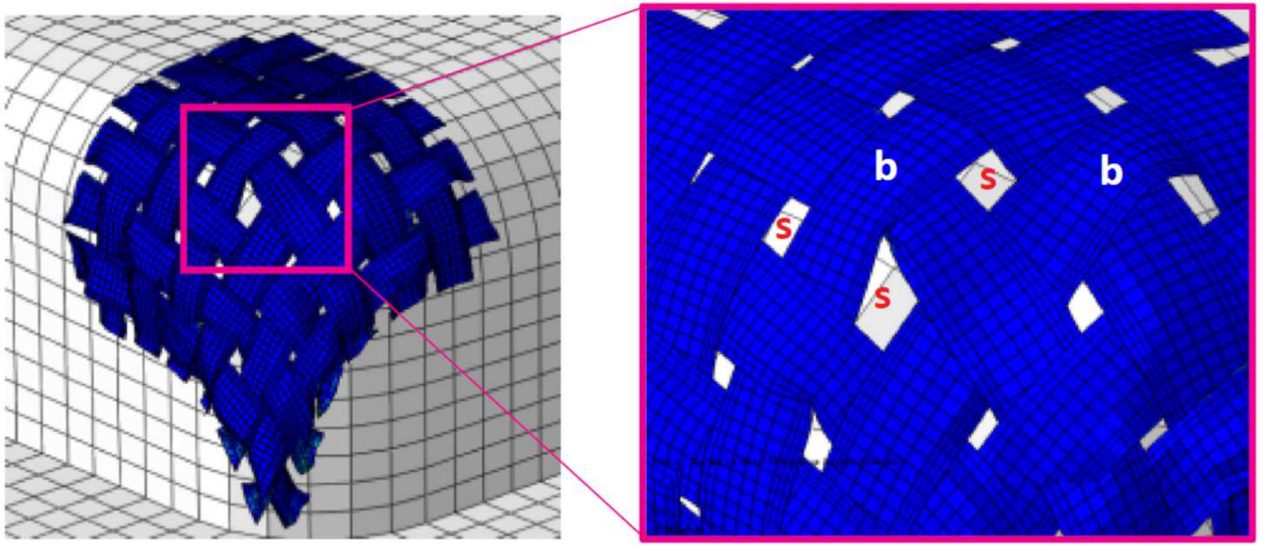


b – buckling S-sliding

Fabric A



Fabric B



More details in [Iwata et al, Composites A, 2019]

Thank you for your attention