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Ingénierie des Systèmes, Mécanique, Énergétique

Mise en Forme de renforts secs ou co-mélés à base de fibres végétales. Quelles pistes adopter pour réaliser des pièces complexes sans défaut ?

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Aussois 22/01/14

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PRISME Laboratory

- ✓ 96 Lecturers, 70 PhD students, 8 Engineers, technicians, admin
- ✓ 2 main Areas:
  - ➢ Automatics, Robotics, imaging
  - ➢ Fluid, Mechanics, Materials, Energenitics,
- ✓ **Project teams**
- ✓ Aerodynamics
- ✓ Energy, Combustion, Engines
- ✓ Combustion and Explosions
- ✓ Dynamique des Matériaux et des Structures
- ✓ Civil Engineering research
- ✓ **Mechanics of heterogeneous materials**
  - ➢ Mechanics of membranes and refractory materials
  - ➢ Mechanics of human tissus
  - ➢ **Manufacturing processes of composite materials**

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Composite materials forming

For numerous applications, large planar parts with low curvatures are manufactured.

What about more complex shape parts ?

What about thick structural parts

Bonet
RTM

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Which type of part ?

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Still possible to gain weight in structures ?

Manufacturing of complex geometries

Manufacturing thick parts (eventually with complex geometries)

Thick structural parts

Thick circular cylindrical part

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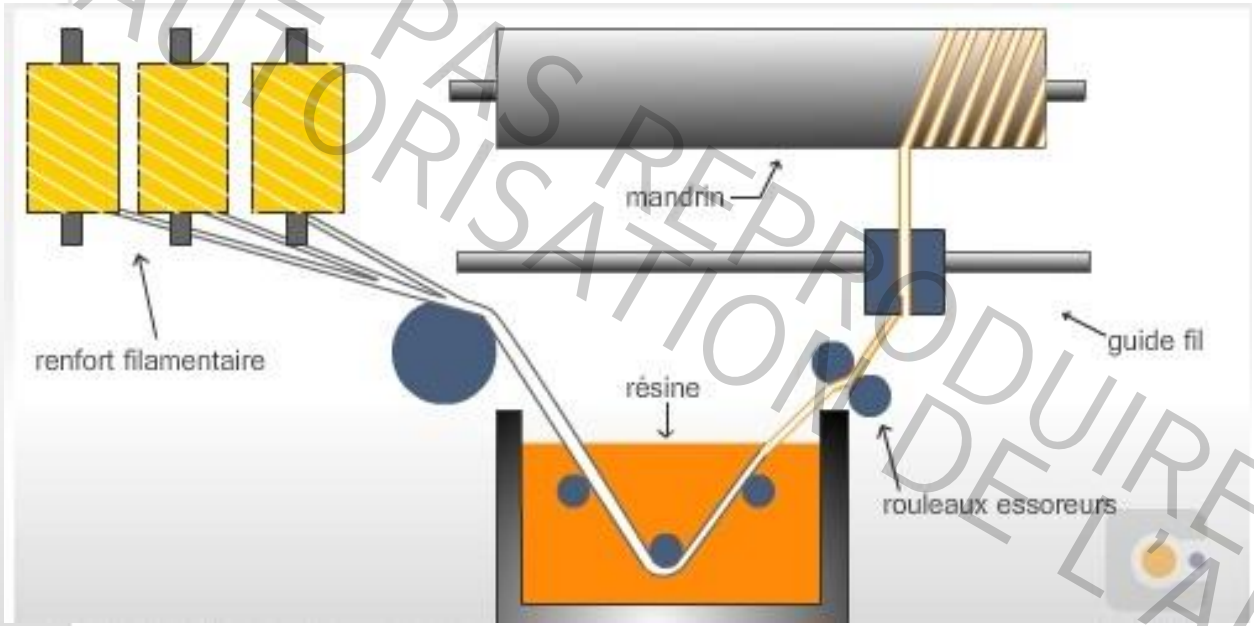
Which process?



Process:
Filament winding

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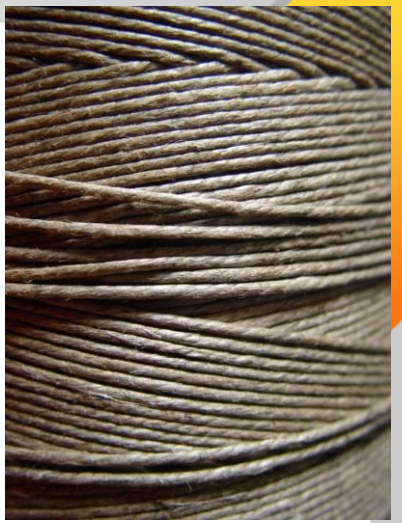
Which reinforcement material



Reinforcement material

Use of spun yarns

- Convenient for processing
- Requires large quantities of energy to produce the yarn
- Fibres are not really aligned and may be difficult to impregnate:
  - Not optimum mechanical properties

Use of tows with aligned fibres

- Need of careful processing
- Requires lower quantities of energy
- Leads to higher surface covering
- Provides higher mechanical properties due to aligned fibres

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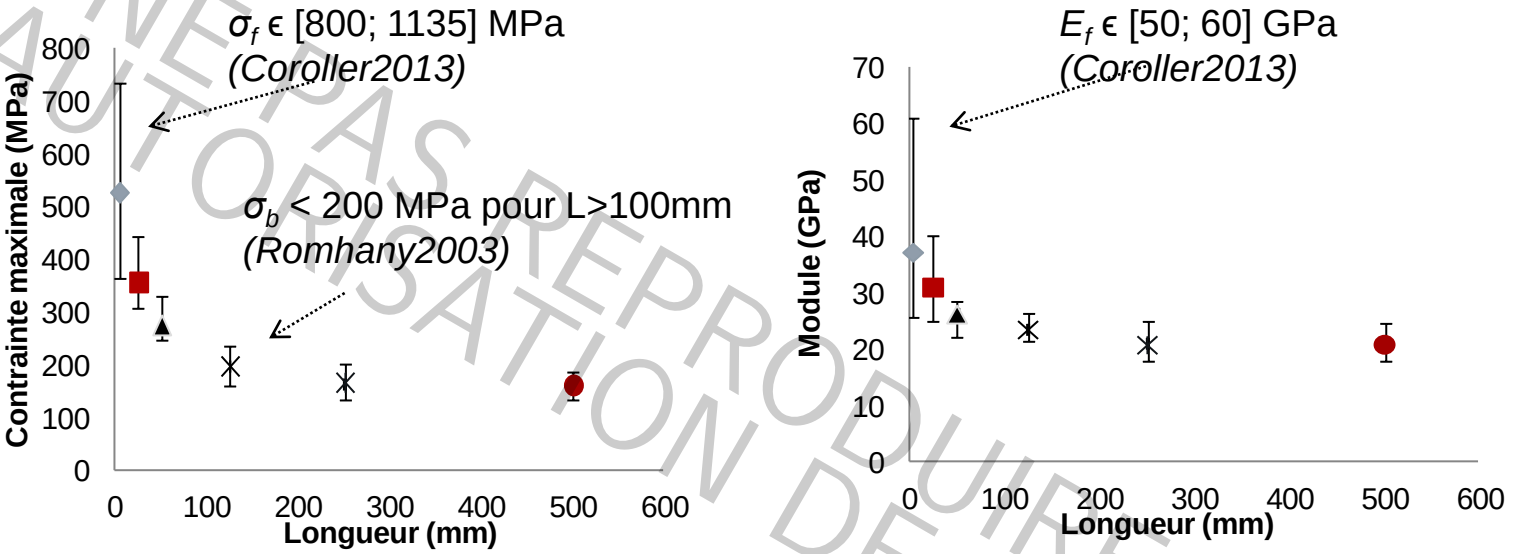
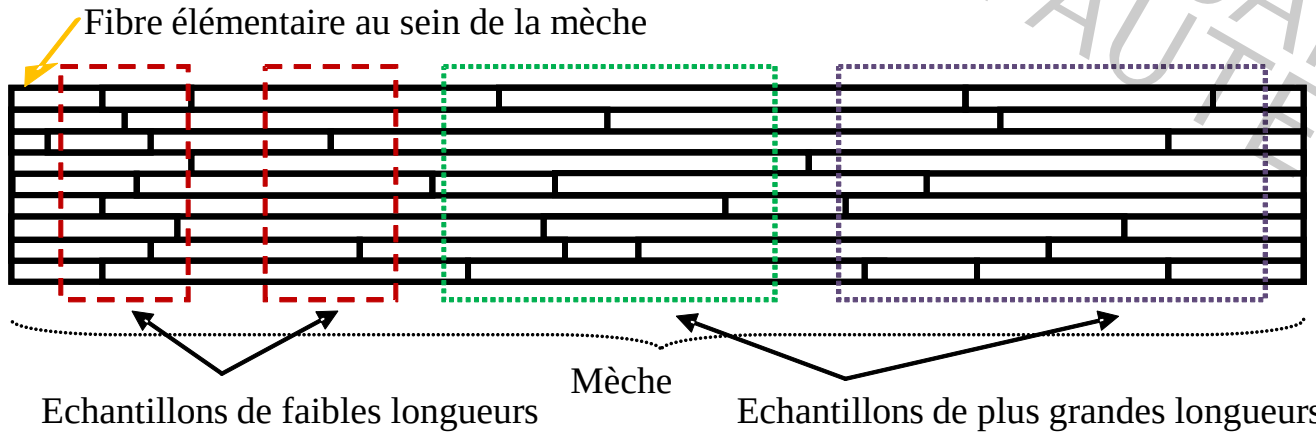
Influence of the sample length



L_s=250 mm



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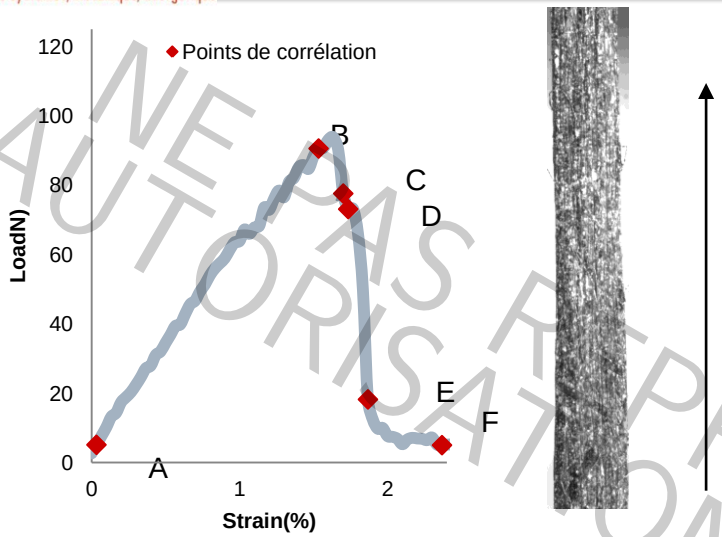
Single tow tension

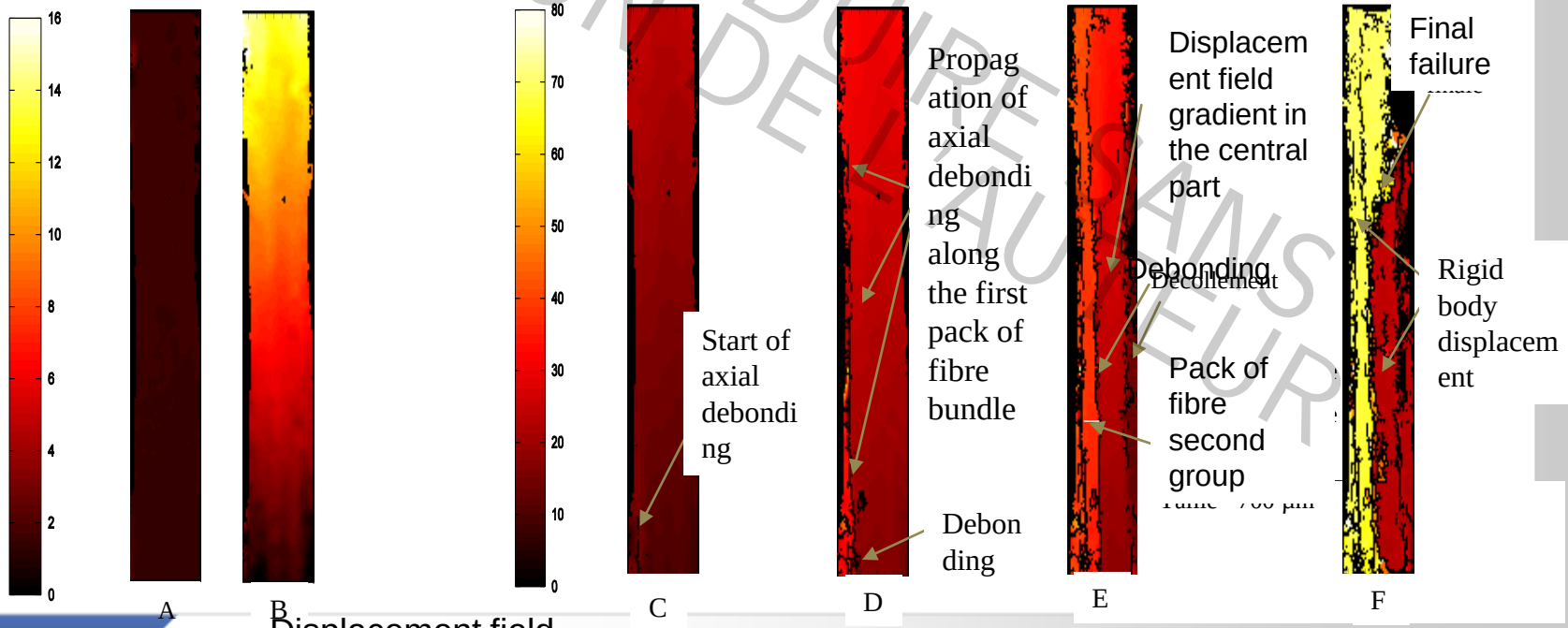


Traitement par corrélation d'images (7D)

Ratio mm/pixel : $1{,}39 \times 10^{-2}$

Grid step: 5 px

Size of pattern: 30 px



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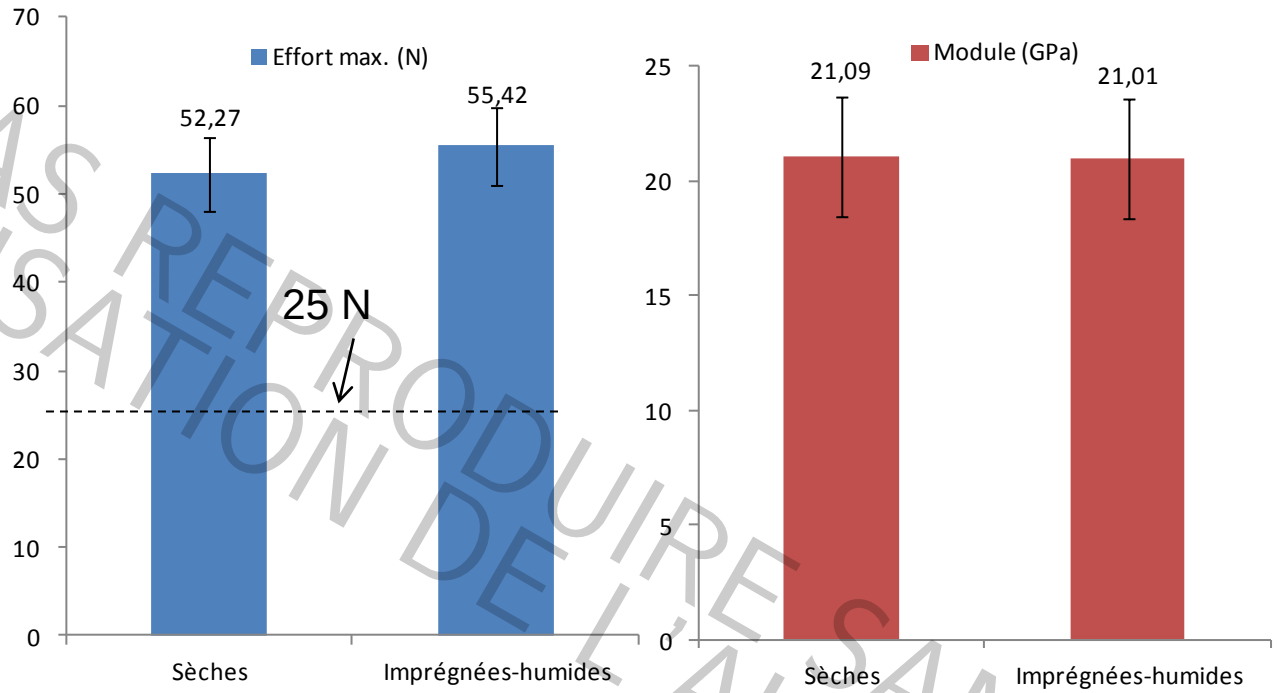
Behaviour of the roving in the process conditions

- *Epoxy Sicomin SR 1500*
- *Imprégnation au rouleau*



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•Cohesion remains after impregnation of the roving by epoxy resin

• Tensions sustained by the roving are higher than the minimum tension required for filament winding.

The roving can be used for filament winding

Complex shape forming: Which process?

- ✓ Manual forming: Use of scissor cuts, and patch application
- ✓ In Situ weaving
- ✓ Sheet forming

Sheet forming process used at PRISME Orleans as the ratio accessible shape/cost/cadency is promissing

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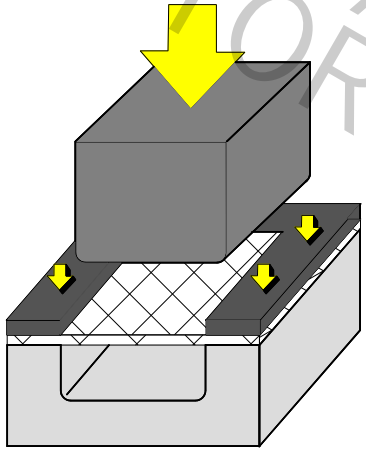
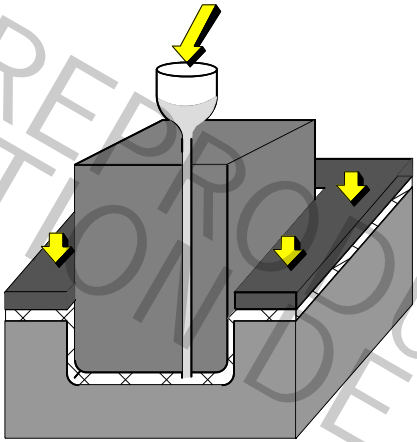
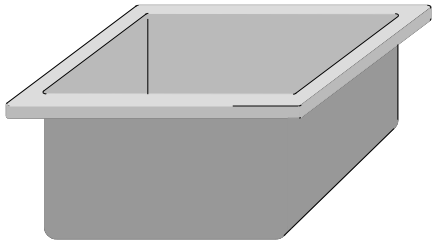
How to manufacture these parts ? RTM process, Moulding of comingled fabrics, Stamping, ……

RTM process (Resin Transfer Moulding)







1 Forming of dry reinforcements

2 Injection of resin

3 Composite part

Phase 1 also concerns manufacturing processes such as comingled reinforcement moulding, or stamping of consolidated thermoplastic sheets.

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Composite materials forming: The sheet forming device

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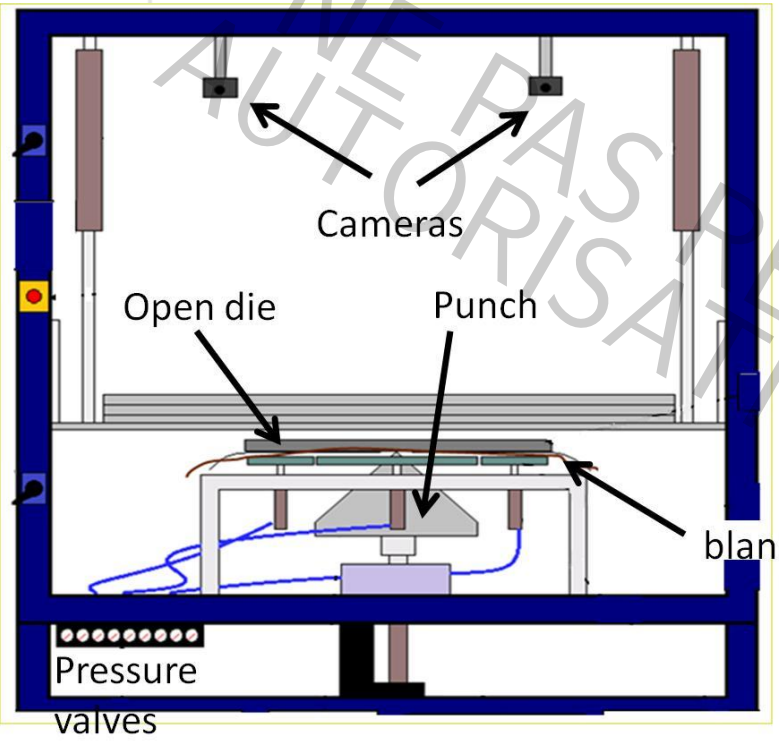
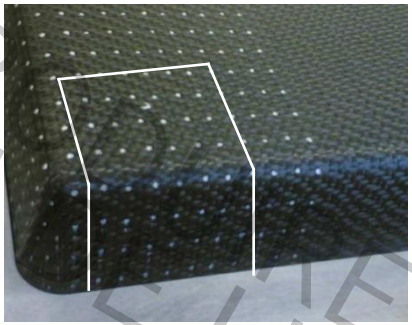
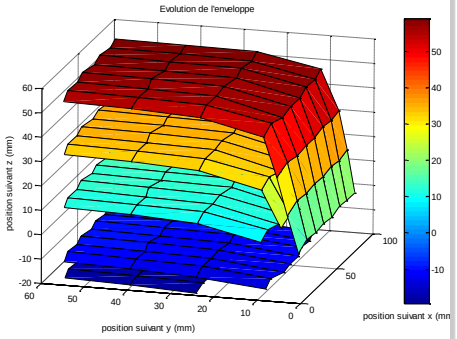
Collaboration with EADS-IW



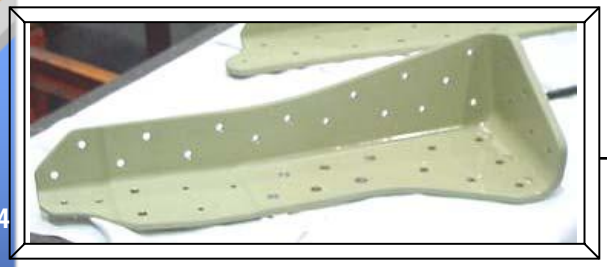
Measure information at the mesoscopic scale during forming.

3D Displacement and strain





- The punch and the dye can be changed



Triple point

Prism

Square box

tetrahedron

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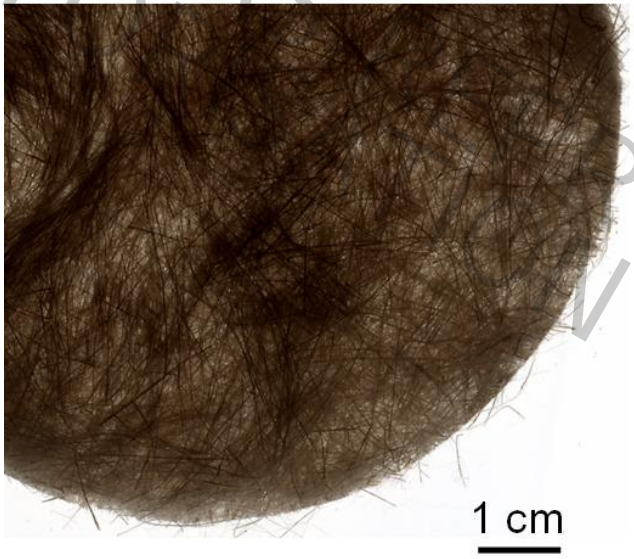
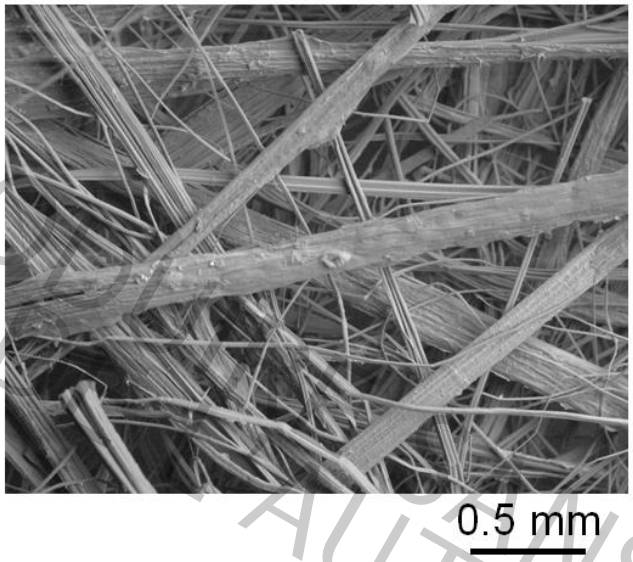
Which reinforcing material ?

Non woven materials : Flax mat





Not realistic for deep forming.

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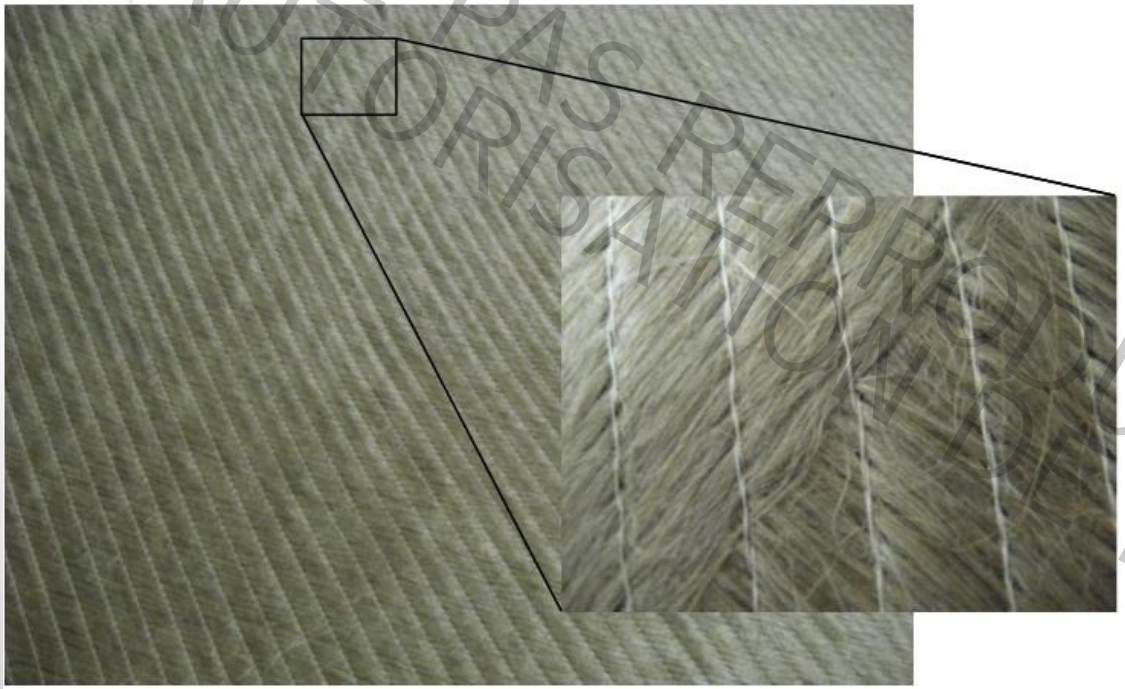
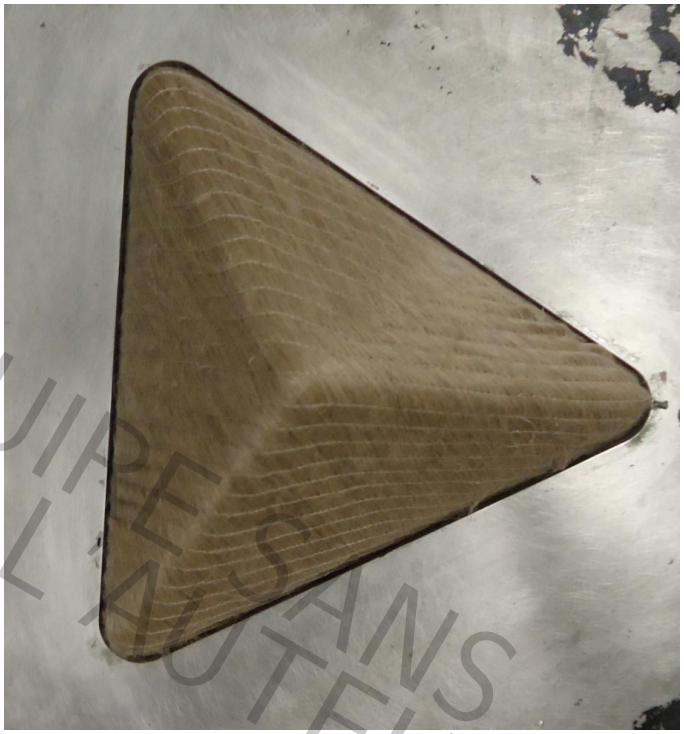
Which reinforcing material ?

Non crimped fabric





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Still under investigation for complex parts.

Studied reinforcement

Structural or semi structural parts are targeted.

✓ Need to use an aligned fibres reinforcement.

- Woven fabric, or Non Crimped fabric (NCF)

One reinforcements available on the market and optimised for large panels have been studied.

Reinforcement 1: A non balanced Plain weave fabric 260 g/m^2, made with untwisted tows (500 tex) from Groupe Depestele (France).

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Fabric characterisation

During the process, different modes of deformation take place

- Biaxial tension
- In-plane shear
- Bending

Each mode needs to be investigated to understand and define the limits of the fabric.

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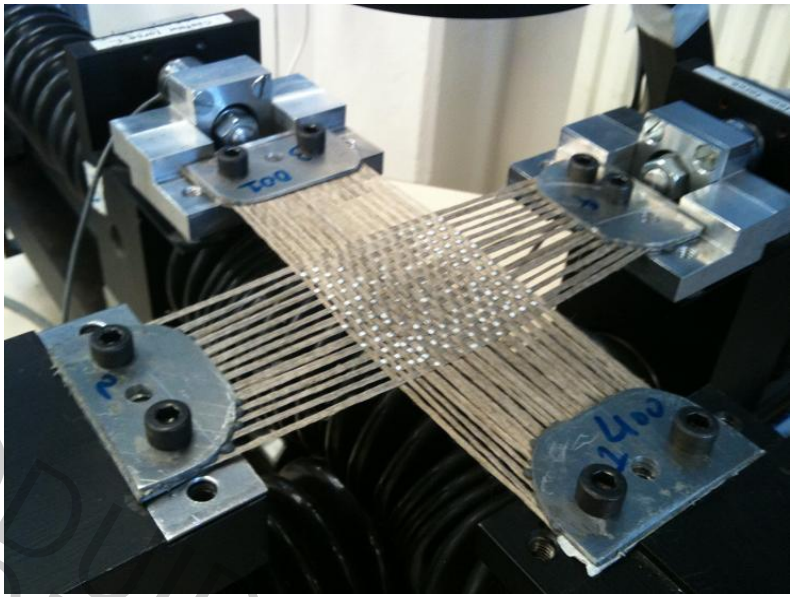
Mechanical behaviour: biaxial tension test



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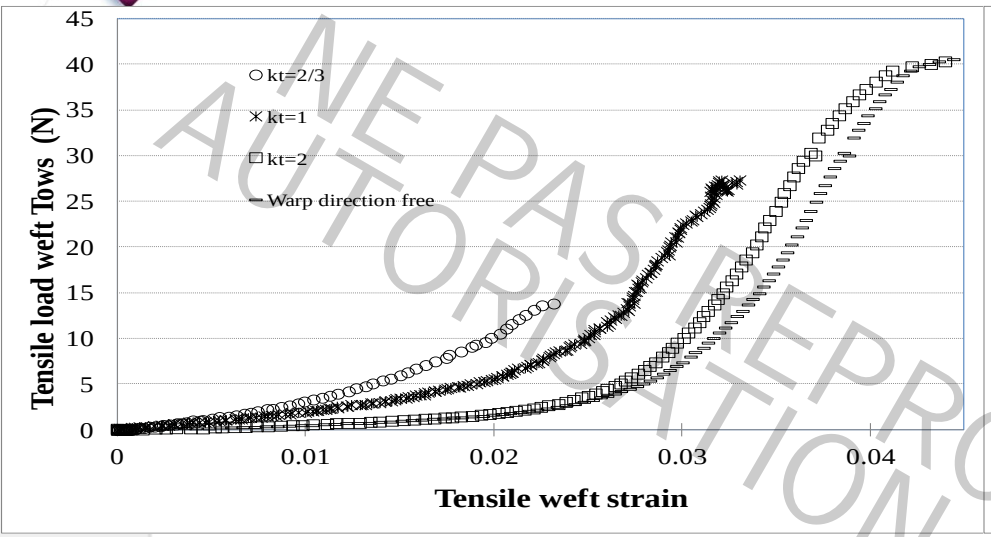
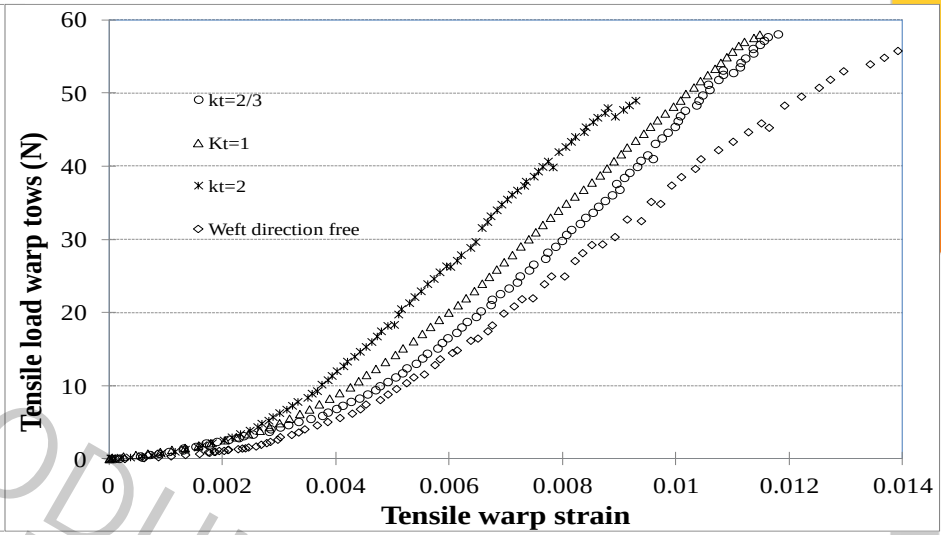
Biaxial tension tests have been carried out for orientations 0 and 90° to study the strain at which sliding of packs of fibres within the tow is supposed to take place.

Mechanical behaviour: biaxial tension tests 2





$$kt = \varepsilon_{we}/\varepsilon_{wa}$$

- ✓ Weft direction: First failure (sliding of packs of fibres within the tow) takes place for tensile strains < 4%
- ✓ Warp direction: First failure (sliding of packs of fibres) takes place for tensile strains < 1.4%

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Mechanical behaviour: Bending

Bending stiffness is very low:

- Good for drapability
- Could be a problem if wrinkling may happen

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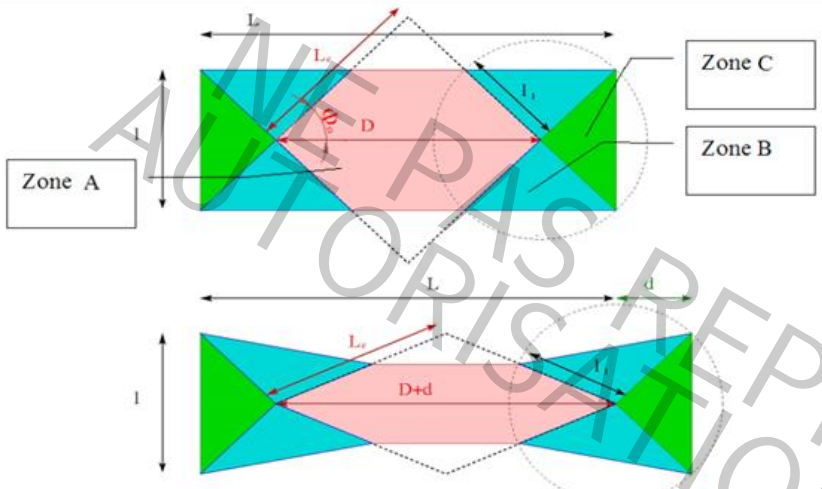
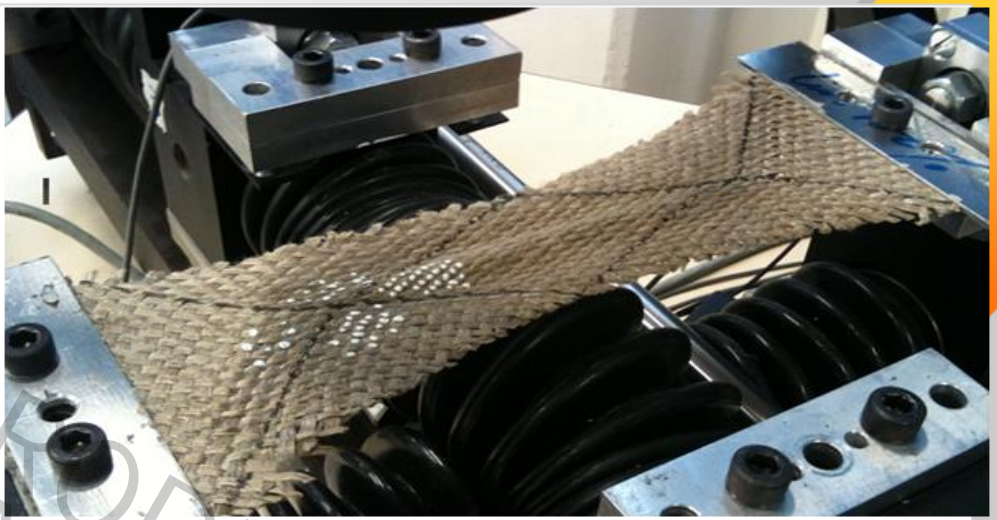
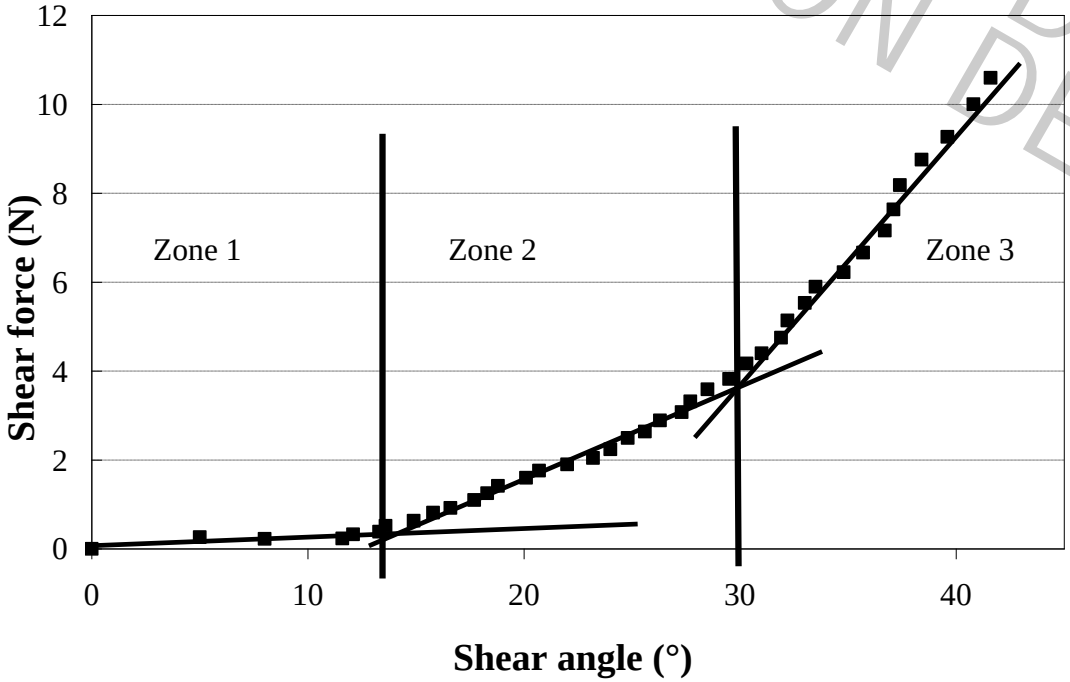
Mechanical behaviour : in-plane shear
Wrinkling defect







The stiffness of the fabric is week: rotation of the yarns, friction

➔ Lateral contact and compression between neighbouring yarns

➔Stiffness ↗ strong non-linéarity

➔ Locking angle

➔ **Out of plane bending of the fabric takes place due to its week bending stiffness**

➔**Wrinkles appear**

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Tow sliding defect

- To delay the appearance of wrinkles, it is possible to increase the tension of the membrane
- Need to increase the tension with care, because tow sliding may appear

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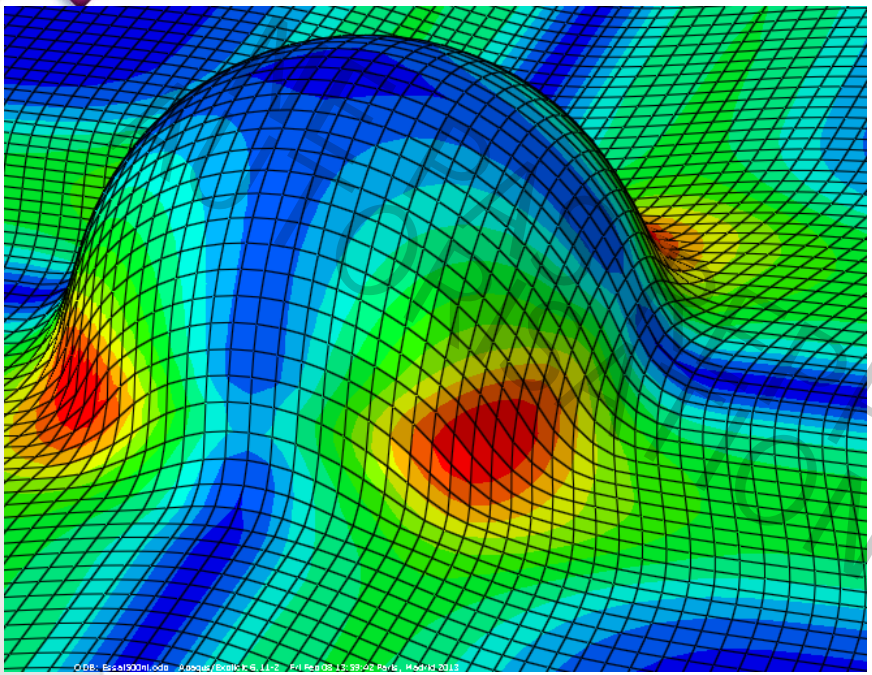
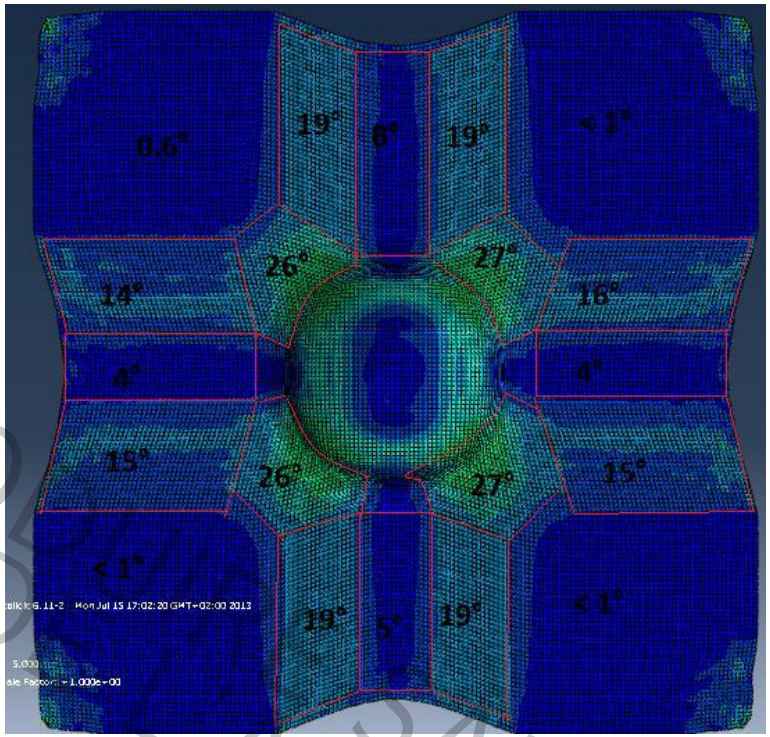
Simulation of the forming process





- Permits to predict the zones where high in-plane shear takes place
- Permits to identify the zones where wrinkling may happen
- **Does not permit to predict tow sliding, and other defects such as the ones encountered in complex shapes**

Need to use an experimental approach of the forming process

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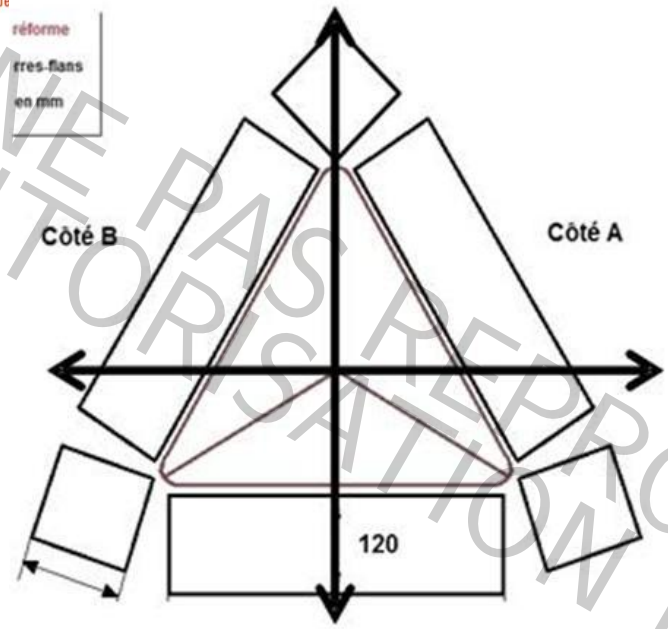
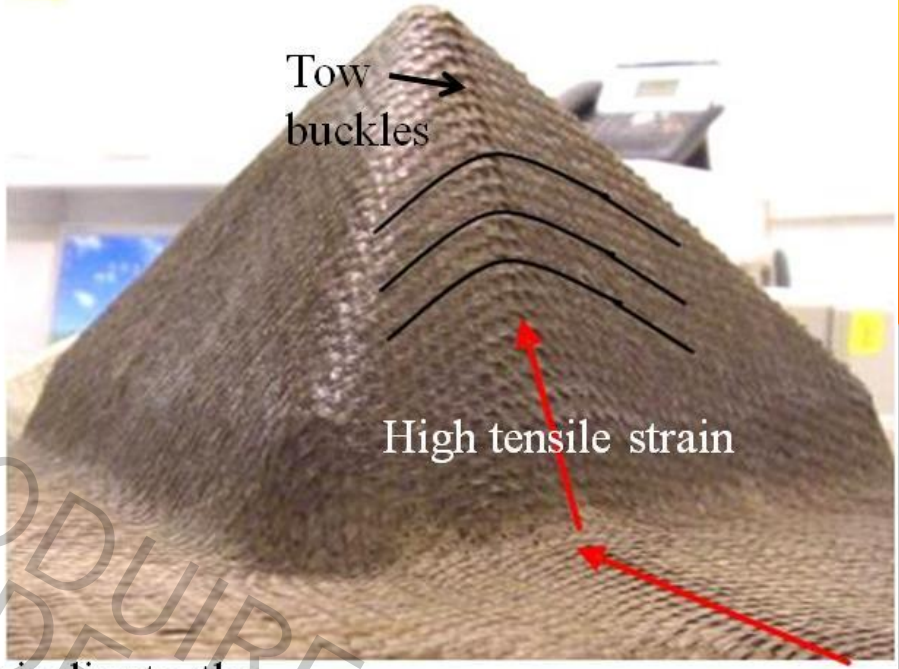
Experimental sheet forming : Presence of defects



(a)



(b)

The arrows indicate the location of the defect zone

- Tow buckling
- Too high tensile strain

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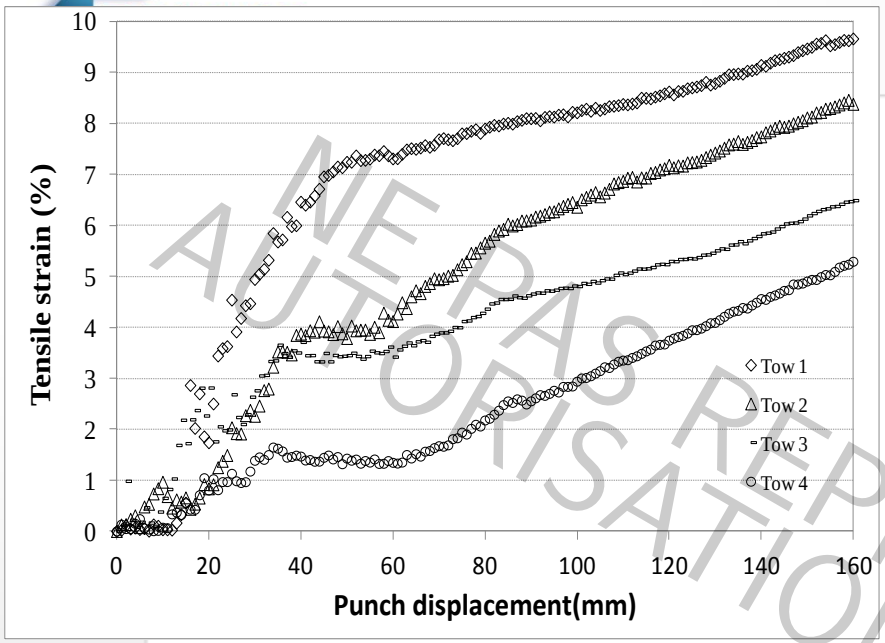
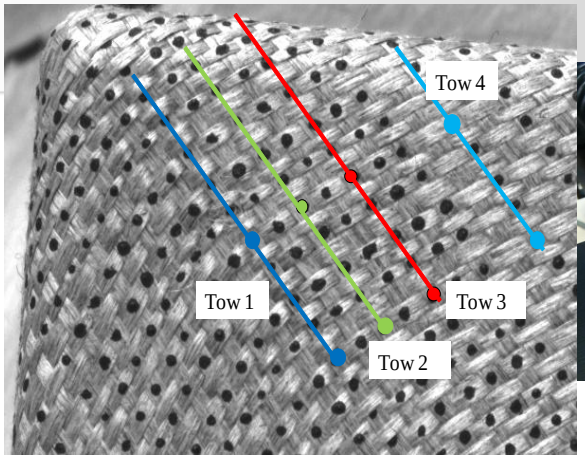
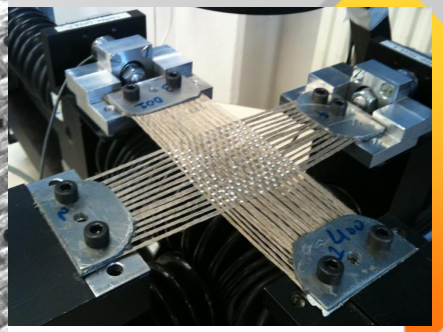
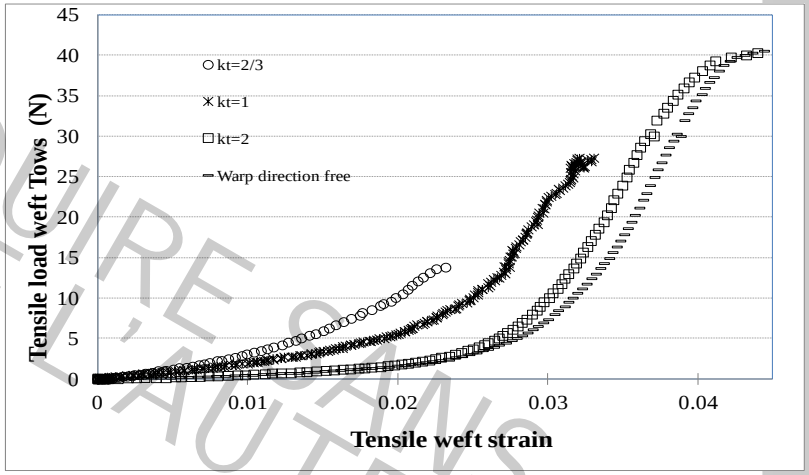
Tensile strain of selected tows









- The strain at which tows loose their load capacity occurs for tensile strains > 4%
- Sliding of fibres takes place and locally, the density of fibre decreases, and local mechanical properties may be affected
- **Probably worth to decrease the tension of the vertical tows**

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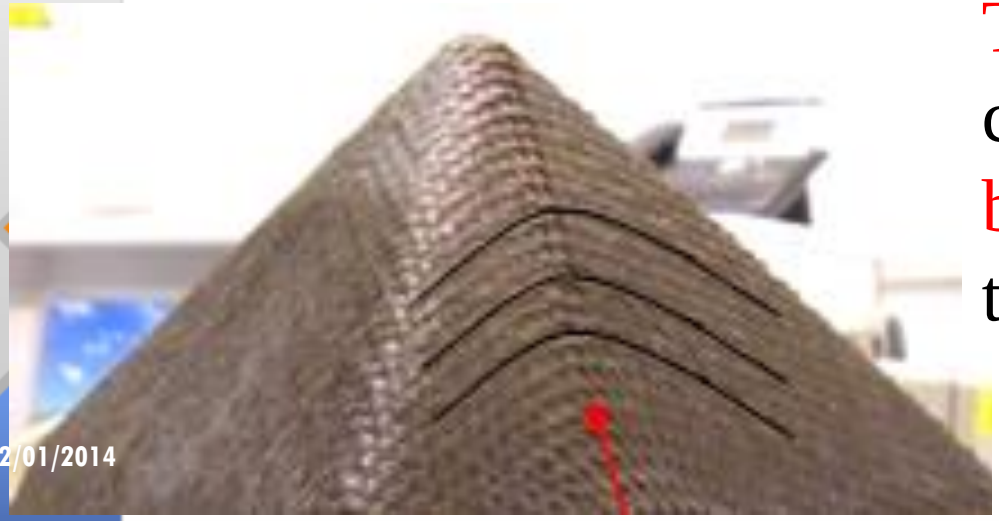
Ouagne P, Soulat D, Tephany C, Duriatti D, Allaoui S, Hivet G. Mechanical characterisation of flax based woven fabrics and in situ measurements of tow tensile strain during the shape forming. *Journal of Composite Materials,* 2013; 47: 3498 – 3512.

Observed defect: Tow buckling

Tow buckles (out of plane bending of tows) on a face

Tow buckles on one edge



Tow buckles are the consequence of in plane bending of horizontal tows

Ouagne P., Soulat D., Hivet G., Allaoui S., Duriatti D. "Analysis of defects during the preforming of a woven flax reinforcement". *Advanced Composite Letters*, 20 (2011) 105-108.

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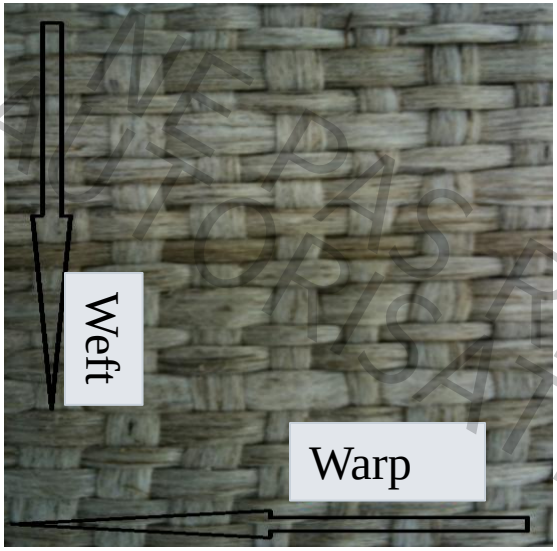
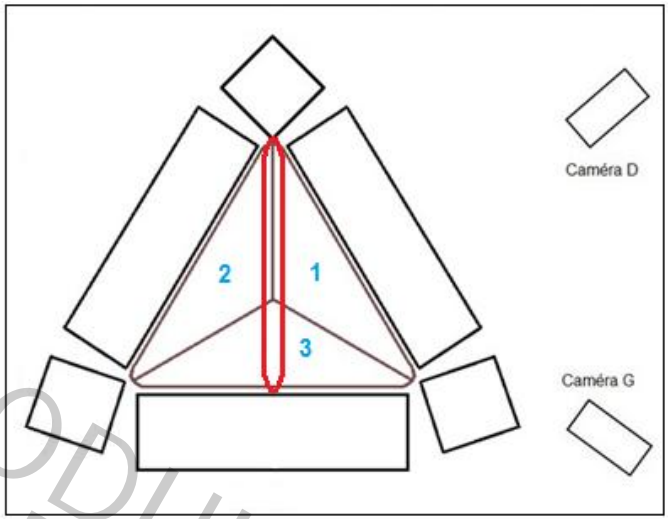
Tetrahedron shape: localization of the tow buckles





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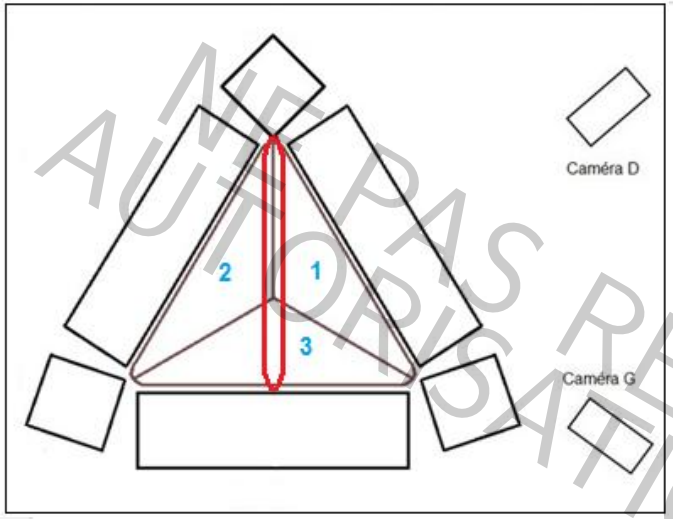
- Buckles appear on edge 1 and on face 3 around the tow passing by the triple curvature point (top of tetrahedron)
- With 1 bar blank holder pressure, the average height of the buckles is about 1 mm on edge 1 and between 2 and 0.5 mm on face 3
- No buckles on faces 1 and 2

Tetrahedron: localization of the buckles



Bending angle of the horizontal yarns at 1 bar

Face number	1	2	3
Bending angle (°)	138	136	146

•The Bending angles of the horizontal tows around the vertical tow passing by the triple point are more severe on face 1 and 2 than in face 3.

• Tow buckles are only visible on face 3

• The in plane bending angle is not a sufficient criterion to predict the occurrence of buckles.

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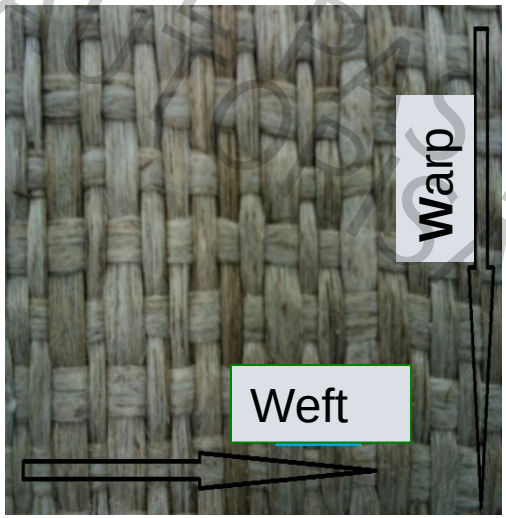
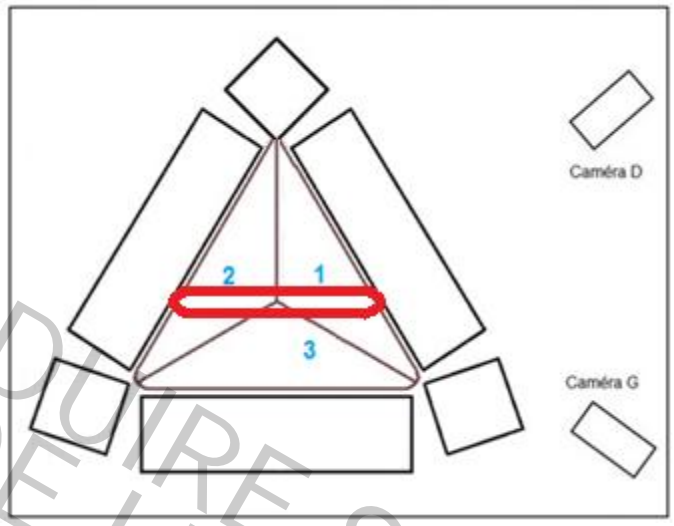
Tetrahedron: localization of the buckles 2

Influence of the fabric orientation: 90° rotation





- The buckles are situated in faces 1 and 2 around the yarn passing by the triple point
- No buckles are observed on face 3 and on edge 1
- The size of the buckles is equivalent as in case 0°orientation at 1 bar blank holder pressure

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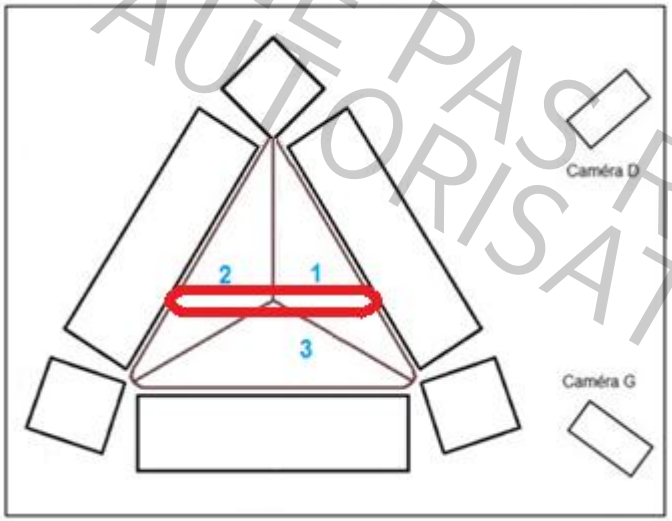
Tetrahedron: localization of the buckles 3

Influence of the fabric orientation: 90° rotation



Face number	1	2	3
Bending angle (°)	138	141	143

- The angles on face 1 are slightly more severe than for faces 2 and 3
- The bending angle values are not responsible for the change in the buckles location
- The reinforcement orientation is crucial especially for not balanced fabrics

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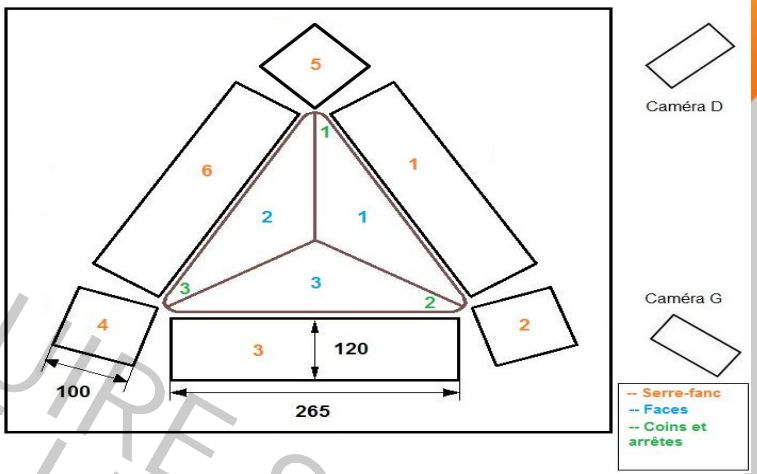
Tetrahedron: localization of the buckles

Influence of the blank holder pressure on the buckles size

- By increasing the corner blank holder pressure, the size of the buckles decreases on face 3 for orientation 0 °
- The size of the buckles remain constant on Edge 1 for the different pressures



Blank holder pressure (bar)	1	1.5	2
Size of the buckles (mm) Face 3	1	0.9	0.5

Increasing the blank holder pressure may damage the fabric: Tow sliding

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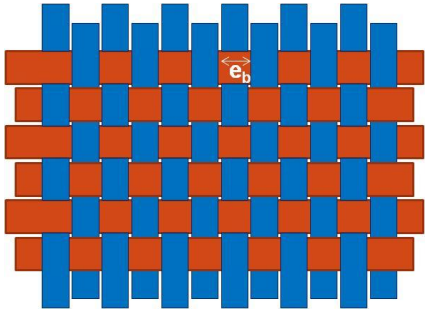
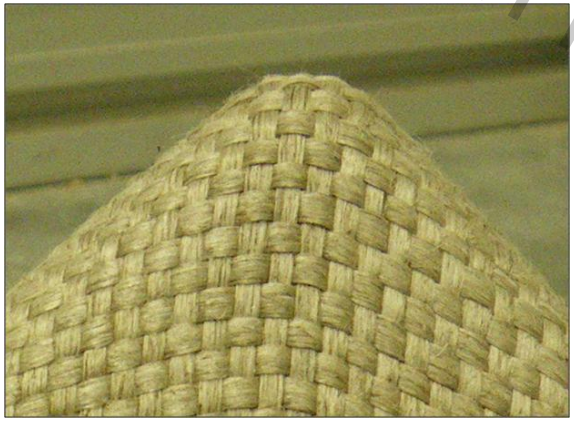
Which solutions to prevent tow buckles ?

Ways to prevent buckles

Architecture of the fabric

A specific plain weave architecture with warp and weft tows arranged close together was designed and manufactured by Groupe Depestele





No buckles in the faces or along the edges

Ouagne P, Soulat D, Moothoo J, Capelle E, Gueret S. Complex shape forming of a flax woven fabric; Analysis of the tow buckling and misalignment defect. *Composites: Part A* 2013; 51: august, 1-10.

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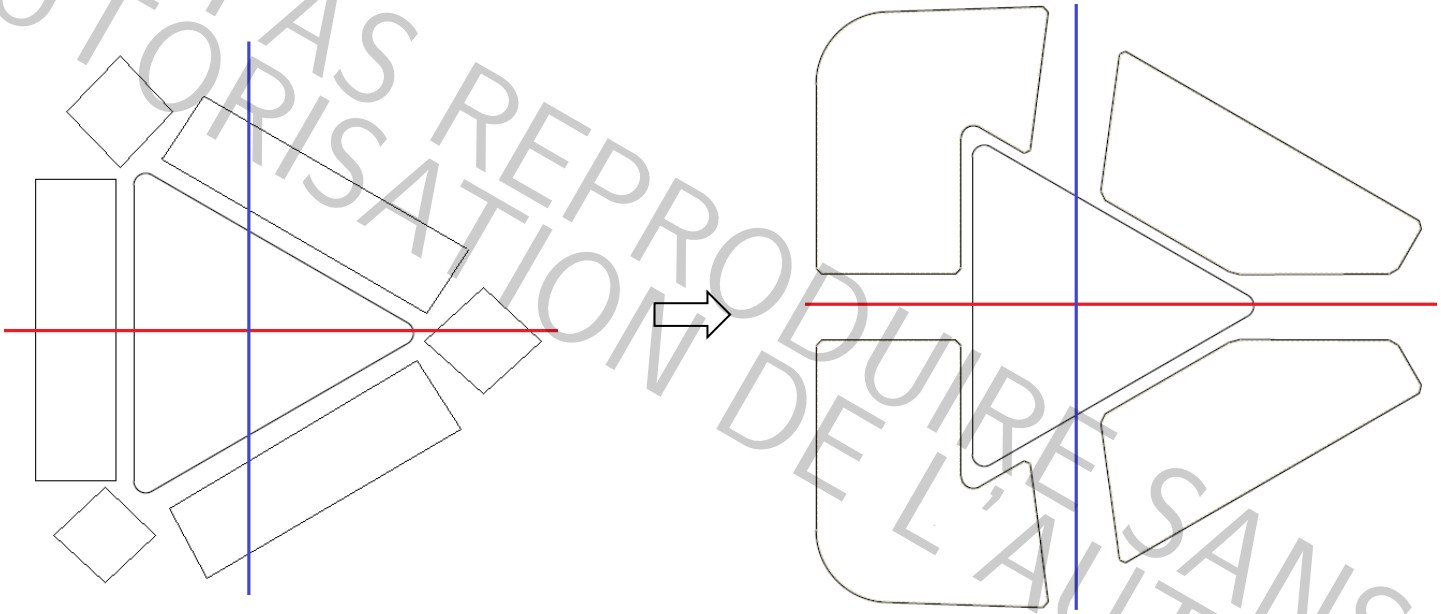
Which solutions to prevent defects 2

Ways to prevent buckles

Process parameters: design of new blank holder geometry



- Need to decrease the tension of the tows passing by the top of the shape
- Need to increase the tension in the tows showing buckles.

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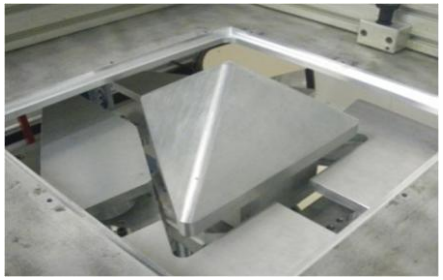
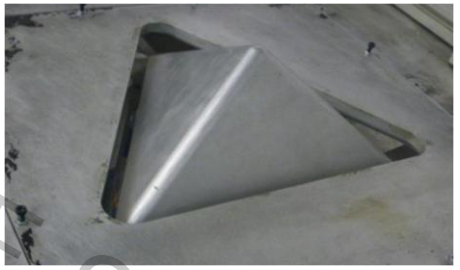
Which solutions to prevent defects 3

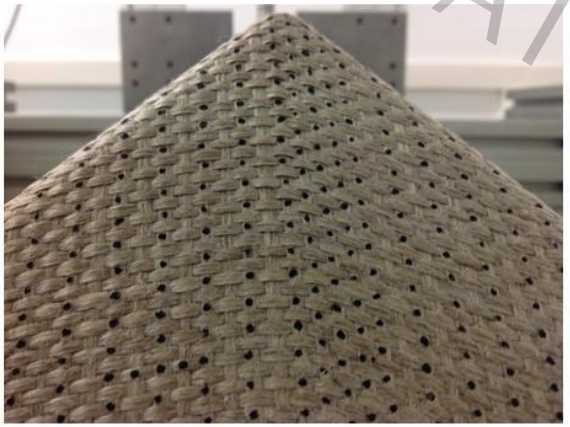
Ways to prevent buckles

Process parameters

Specially designed blank holders were used to apply pressure more specifically to the plain weave fabric.







Tow buckles do not appear on the Faces or on Edge 1

It is possible to get rid of tow buckles by applying the right blank holder pressures at the right position.

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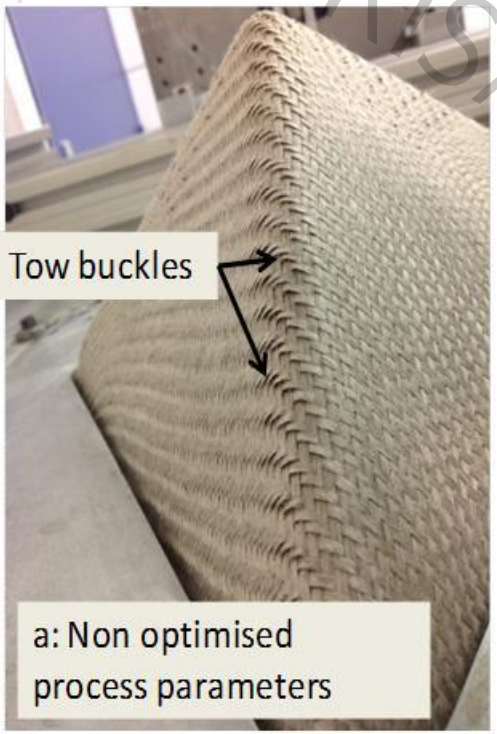
Which solutions to prevent defects 4

Ways to prevent buckles

Process parameters

Specially designed blank holders were used to apply pressure more specifically to a twill weave fabric which previously exhibited large tow buckles.



a: Non optimised process parameters

b: optimised process parameters

The tow buckles disappeared on Faces and almost disappeared on Edge 1

It totally disappeared if a compression load is applied to the membrane.

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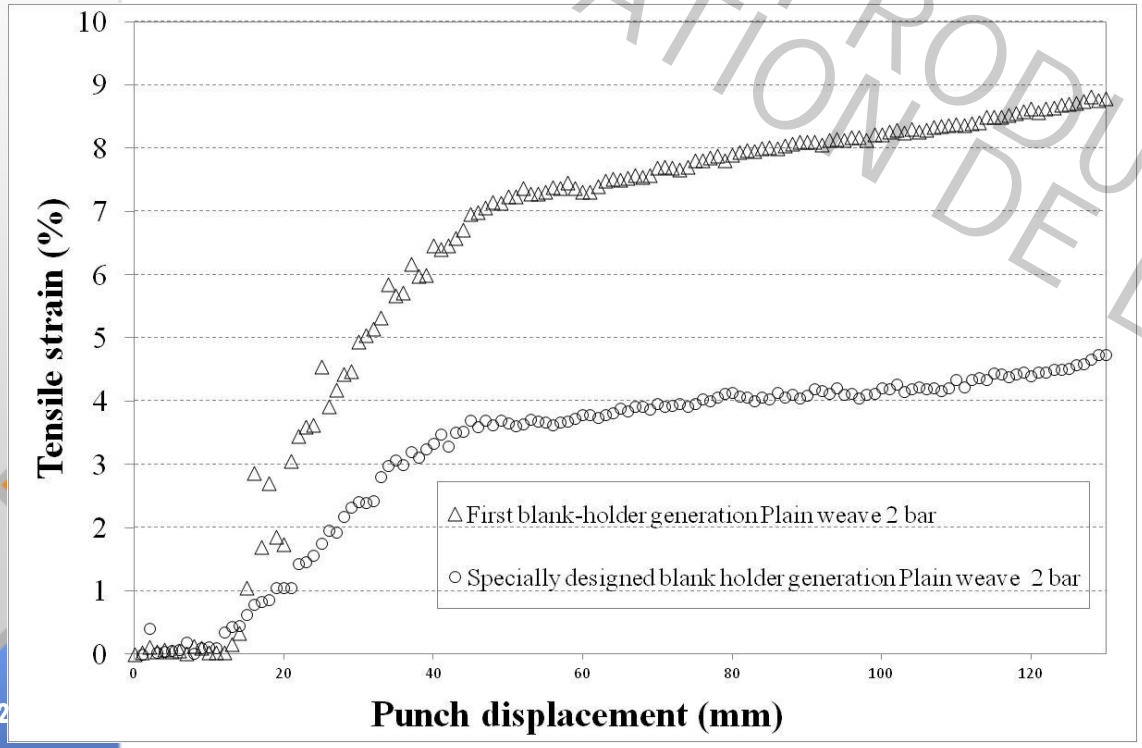
Which solutions to prevent defects 5

Way to prevent too high strain in tows

Process parameters

It consists in applying locally lower blank holder pressures where it is necessary by using specifically designed blank holders.



The strain of the tightest tow is of about 4 % (the level at which loss of fibre density may occur).

The tension in this tow should be reduced by improving the process parameters

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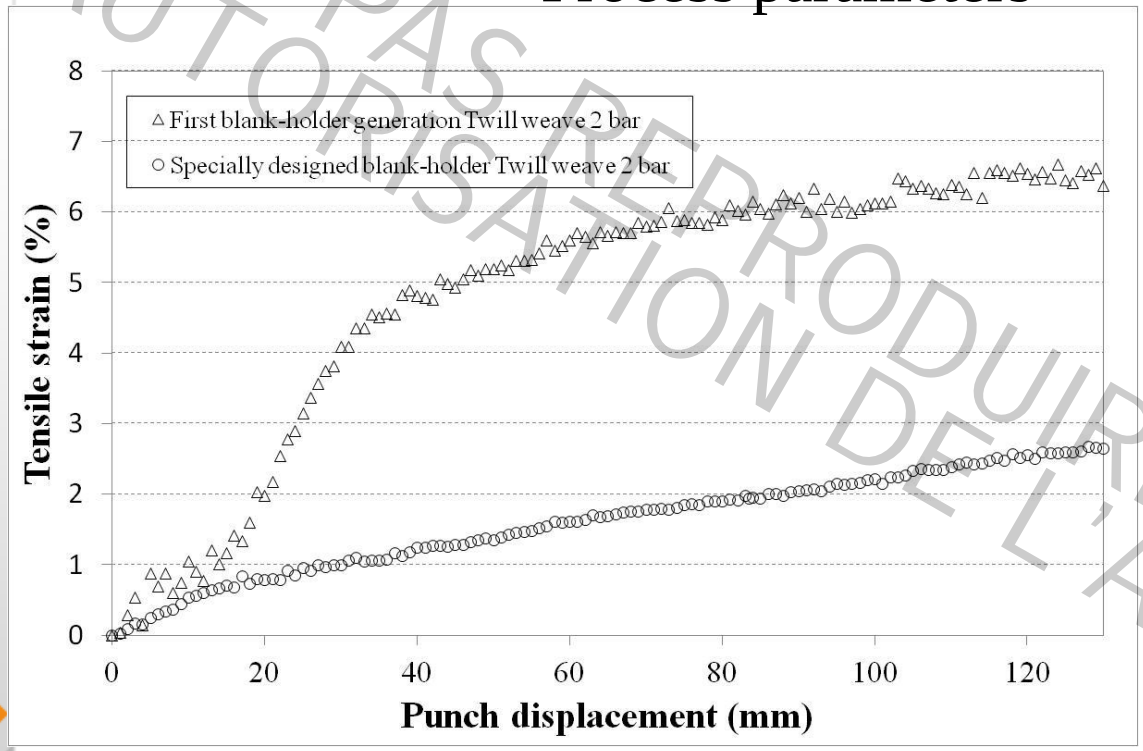
Which solutions to prevent defects 6

Way to prevent too high strain in tows

Process parameters



As for the plain weave fabric, the tension in the tightest tow of the twill weave has been reduced just above the limit at which loss of fibre density may happen.

Also need to improve the process parameters

By using the right blank holder design and right pressures, it is possible to avoid the appearance of tow buckles, as well as loss of local fibre density due to too high strains.

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Impregnation ?

When dealing about complex shape forming, different issues can be raised about impregnation of the reinforcements:

- What is the permeability of flax based reinforcements in highly sheared zone ?
- Can the tows be easily impregnated ?
- Is it possible to increase the impregnation properties at the micro scale?
- Which injection scenario would be the most convenient for these types of reinforcements ?

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Conclusions

✓ During forming, the limit at which local "failure" takes place may be reached.

✓ Loss of fibre density may occur locally at high local strain.

✓ Tow buckling may take place when complex shape forming is considered

✓ Solution exist to avoid their appearance. They are based on the architecture of the used fabric, and on the geometry of the blank holder used during forming.

✓ It was shown in this work that it is possible to avoid the appearance of both defects

✓ Some more work on the process parameters should be performed to reduce the tensions in the tows

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Thanks for your attention

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