

# 2.0 rCF based composite materials: manufacturing processes and mechanical properties

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*Involved in these works*

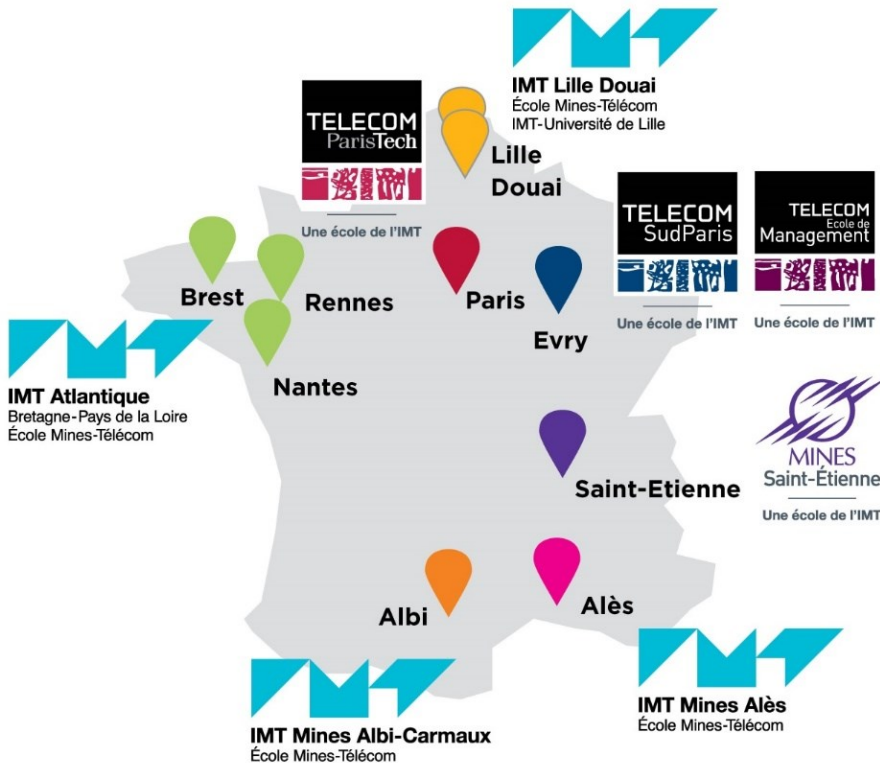
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*Sabrina Jlassi (PhD, ICA, 2019)*

*Serge Da Silva (ARC)*

## 7 engineering and 1 Business School



**IMT Belongs to the ministry  
of Industry and Economy**

 **13 700** students

- **1590** PhD
- **1080** manager students

**31 %** foreign students

**1650** Prof and Ass-Prof

**4 885** graduated per year  
**10%** by apprenticeship



**64,2 M€** research turnover

**1900** rank A publications/year

**45** industrial chairs

**74** start-up created per year in school incubators

**93%** survival after 3 years

Materials  
and processes  
for  
aeronautics  
and space



Powder  
engineering and  
Bio-health  
Biomass and waste  
engineering,  
renewable energy

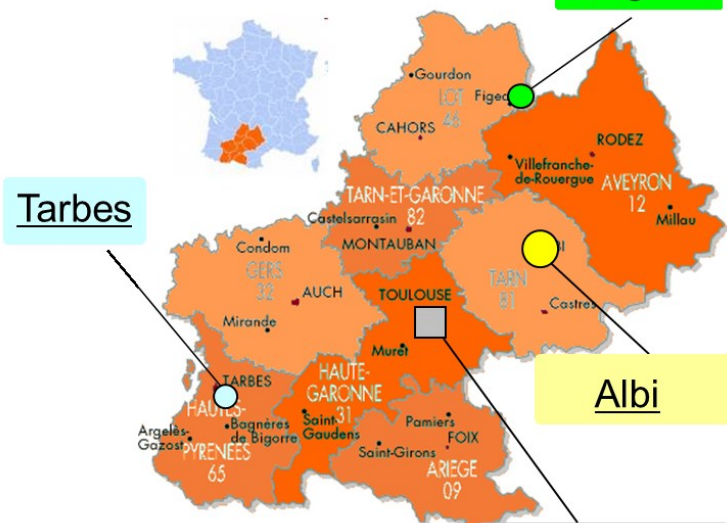


kinetics or  
organizations in  
complex,  
heterogeneous,  
collaborative and  
uncertain contexts



Joint research lab on Carbon fiber  
composite recycling

Midi-Pyrénées



INSA  
TOULOUSE

Isae  
Institut Supérieur de l'Aéronautique et de l'Espace  
SUPAERO

UNIVERSITÉ  
TOULOUSE III  
PAUL SABATIER



▪ Institut Clément Ader

Research topic : Materials and structure  
Mechanics, Mechanical systems mainly for  
aeronautics and space

▪ Staff ≈ 250 people

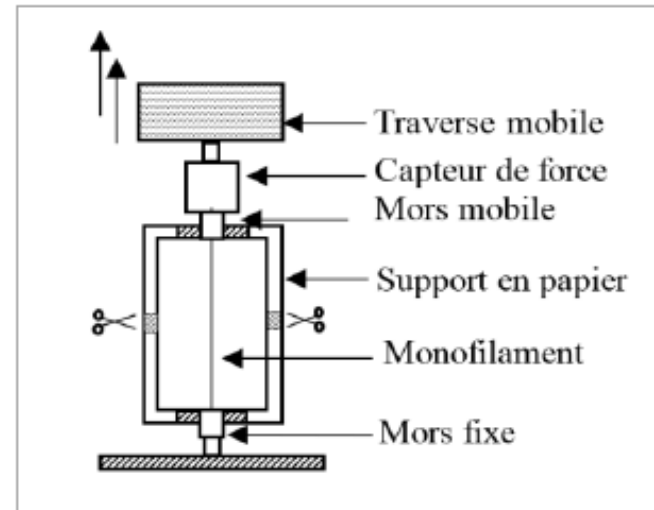
- Permanent staff :
  - 85 Prof, ass. Prof(EC)
  - 34 Ing, tech and administrative
- Non permanent staff :
  - 35 post doc, tech, resrach engineers
  - 90 PhD 's
- Composite material and structure group
  - 75 people (40 PhD's and post docs)
  - biggest team in France working on composite materials and structures in a same lab

- Properties of rCF : witch test to state on the properties of recycled fibres
- Properties of injected rCF-PA6.6 composites
- Non-woven rCF 2.0 thermoplastic composite
  - Is fibre sorting required before recycling
  - What is the optimum length of fibres for Non-woven manufacturing
  - Effect of sizing or not (vrCF (virgin recycled Carbon fibres versus rCF)
  - Optimum non-woven architecture for thermo-compression manufacturing
- Non-woven rCF 2.0 infused epoxy composites
  - Effect of stitching
  - Property comparison with rCF/PA6 and quadriaxial Glass fibre epoxy material

## ➤ Three test methodologies available

✓ Impregnated tow test : test used by the fibre manufacturer (test affected by fibres, epoxy resin, and sizing)

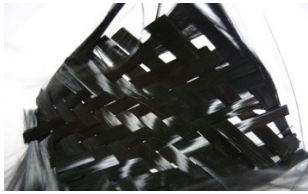
➤ Single fibre test : most used test (between 25 to 50 individual fibres)



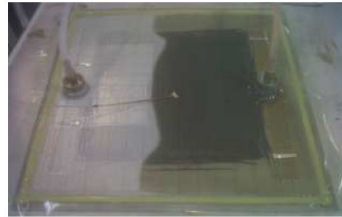
➤ Bundle test

# rCF fiber rupture stresses

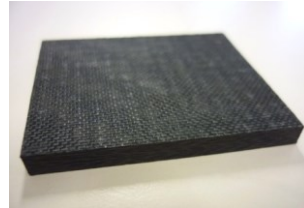
Hextow AS4C



Epoxy resin infusion



Composite sheets



Steam water  
Thermolysis

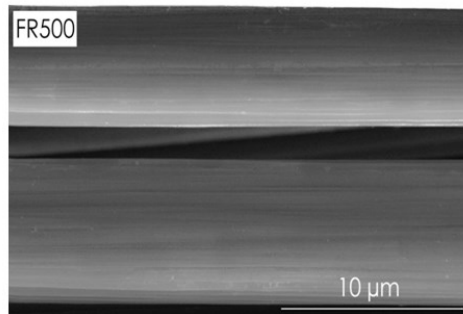
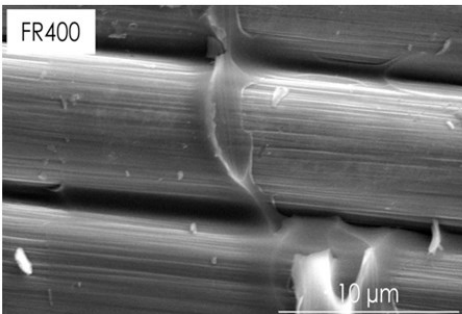
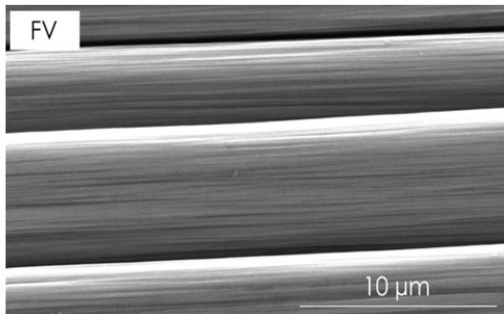
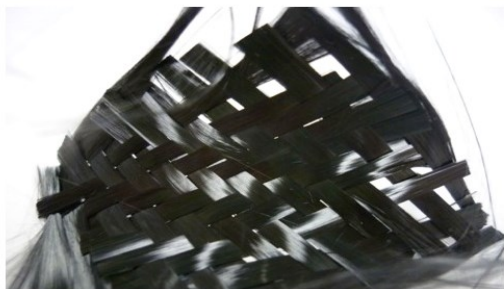


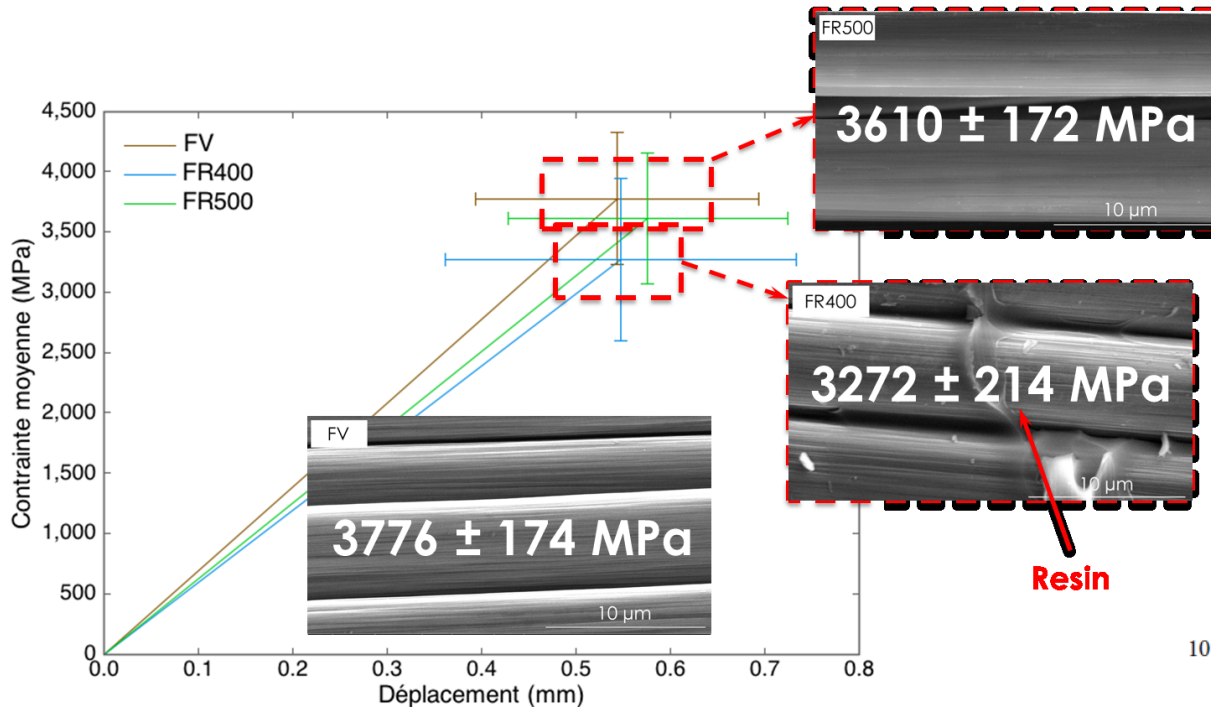
rCF

REFERENCE

400°C  
95 % resin elimination

500°C  
99 % resin elimination

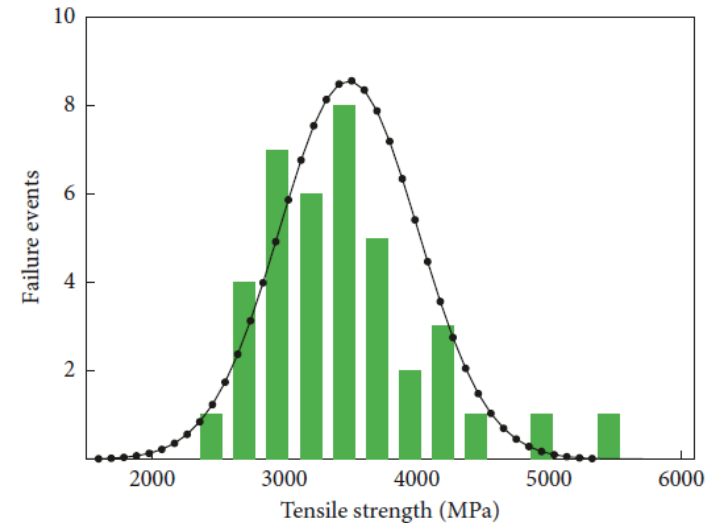


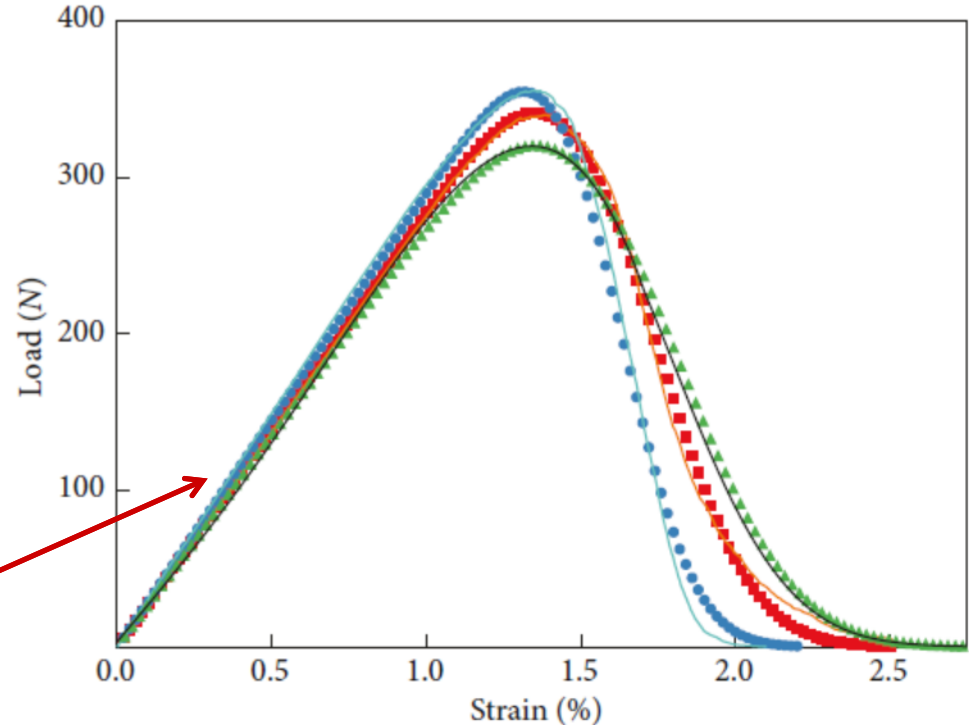
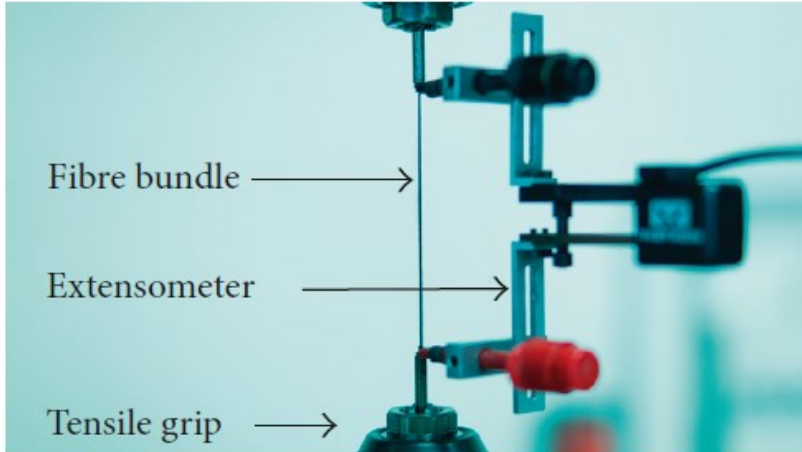


Normal probability density function and frequency histogram of failure events (FR500)

## Statistical analysis (normal distribution)

Fibre samples	Mean of tensile strength (MPa)	Standard deviation (MPa)	95% confidence interval (MPa)
VF	3776	547	146
RF400	3272	672	179
RF500	3610	540	144





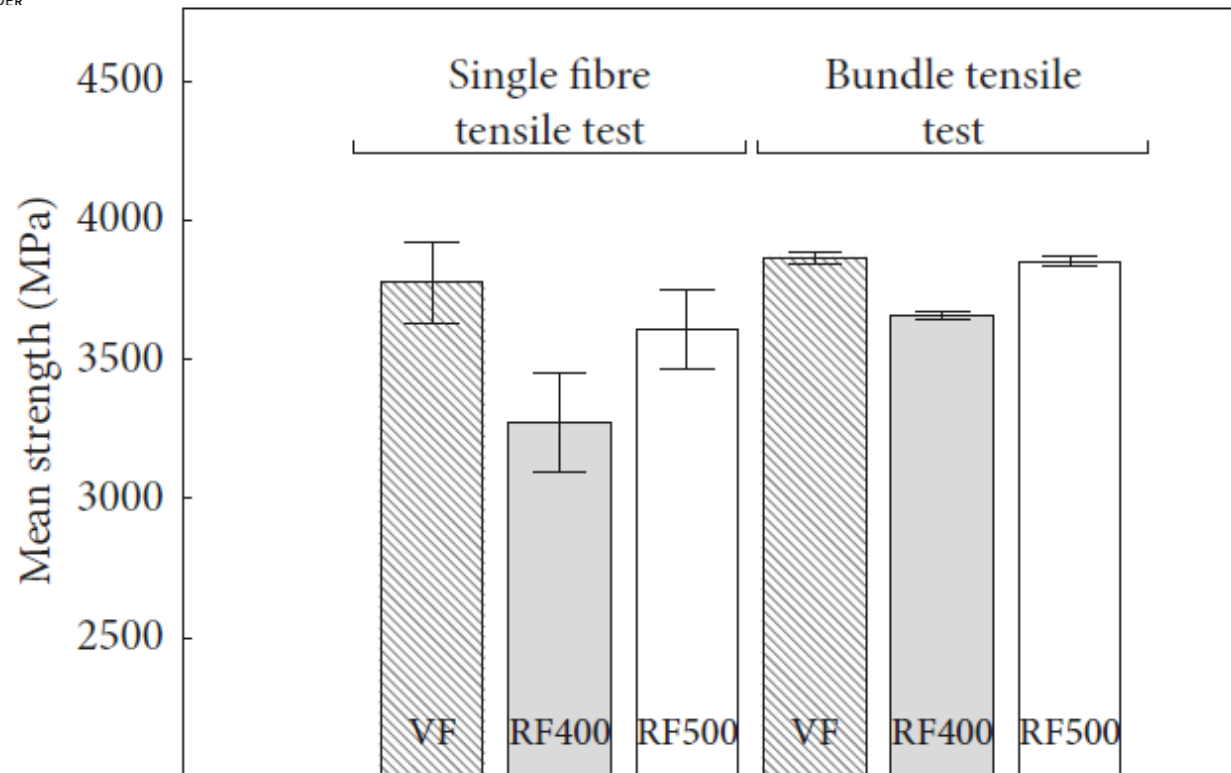
Slope of the tensile load-strain curve

Strain

$$F(\varepsilon) = N_0 \cdot A_f \cdot E_f \cdot \varepsilon \cdot [1 - P(\varepsilon)] = \mathcal{R}_0 \varepsilon \cdot [1 - P(\varepsilon)];$$



# Fibre Bundle Tensile Test results



Manufacturer data :  
4327 Mpa  
Higher than SFTT  
and BTT

Important to  
compare values  
obtained with the  
same methods

Sample number	Number of filaments tested	Mean of tensile strength (MPa)	Standard deviation (MPa)	95% confidence interval (MPa)
1	2940	3852	591	18
2	2615	3849	598	19
3	2850	3864	644	19

- **Mean strength 95% confidence interval drastically reduced with BTT tests**
- **Low dispersion between BTT results**

Fiber length:  
1 to 2 cm

vCF

rCF (FR500)

Polyamide 6,6 (Latamid 66)

Temperature :  
270 °C

Extrusion –  
IPREM EPCP Pau

Temperature :  
290 °C

INJECTION ICA - Albi

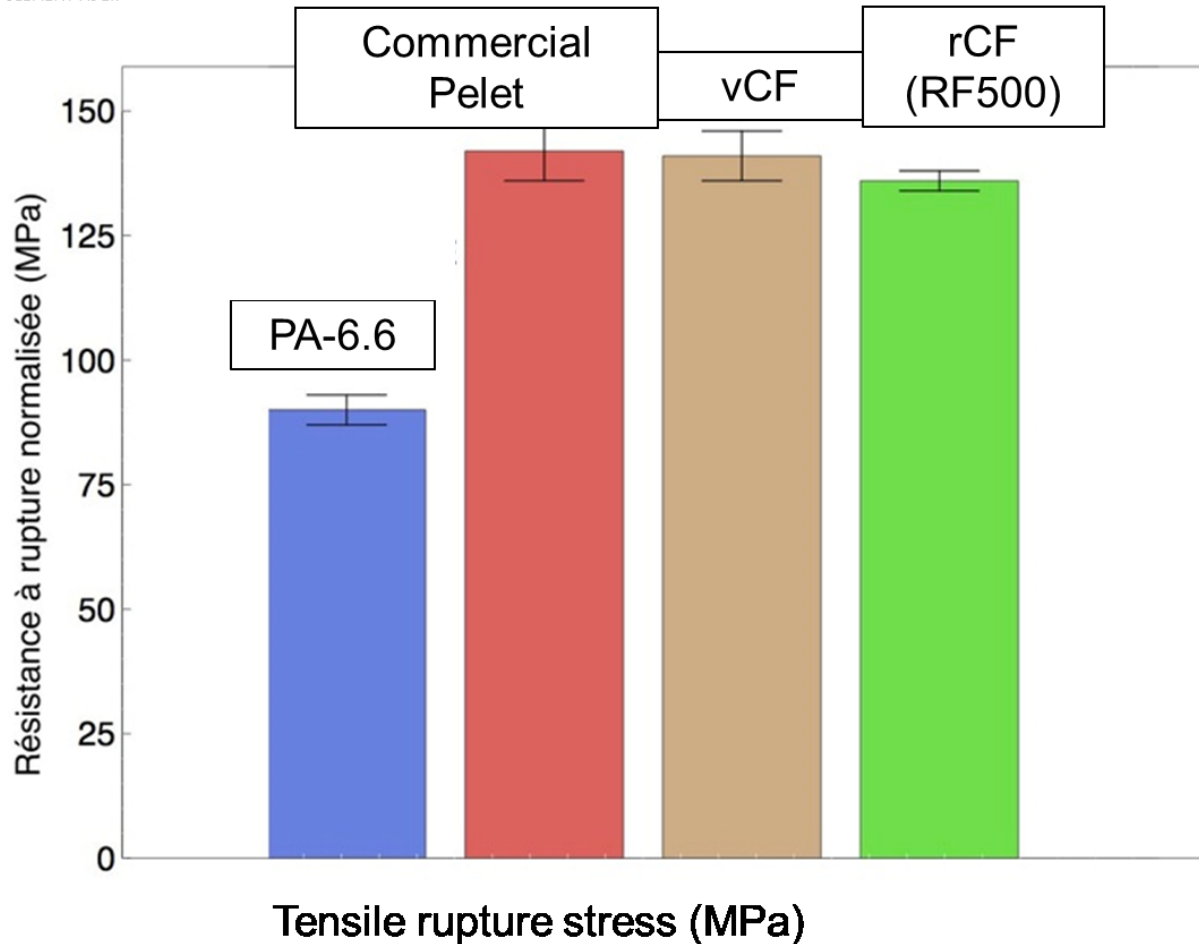
Fibre not known

Commercial CF  
reinforced Pelets



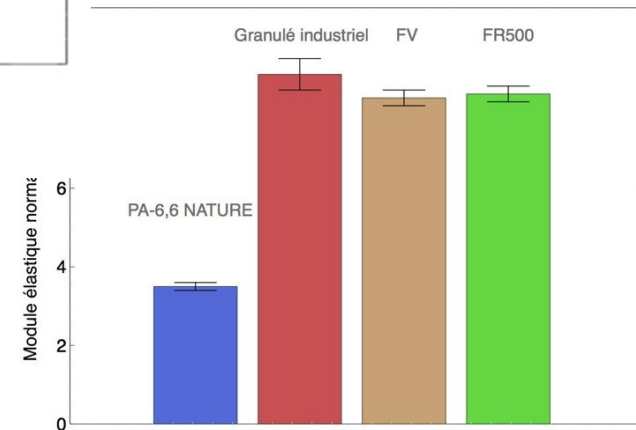
Length : 0,3 mm

Thermoplastic composite materials  
reinforced with 10% of carbon fiber Vf



- rCF/PA6.6 injected material properties are as high as commercial grades
- rCF injected properties are as close to the vCF ones

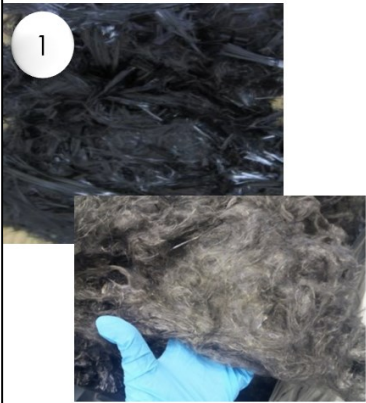
## Tensile elastic Modulus (GPa)



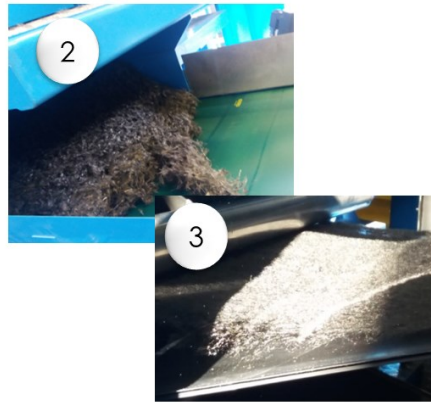


## Carding

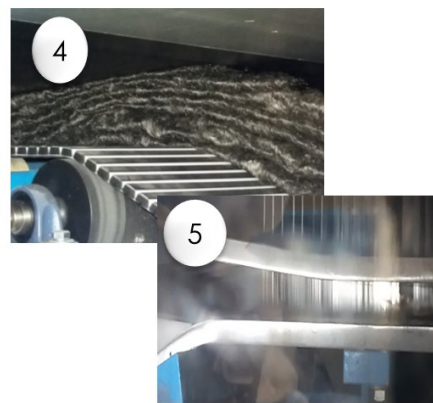
Nonwoven processing : carding/needle punching



Opening & Blending



Carding

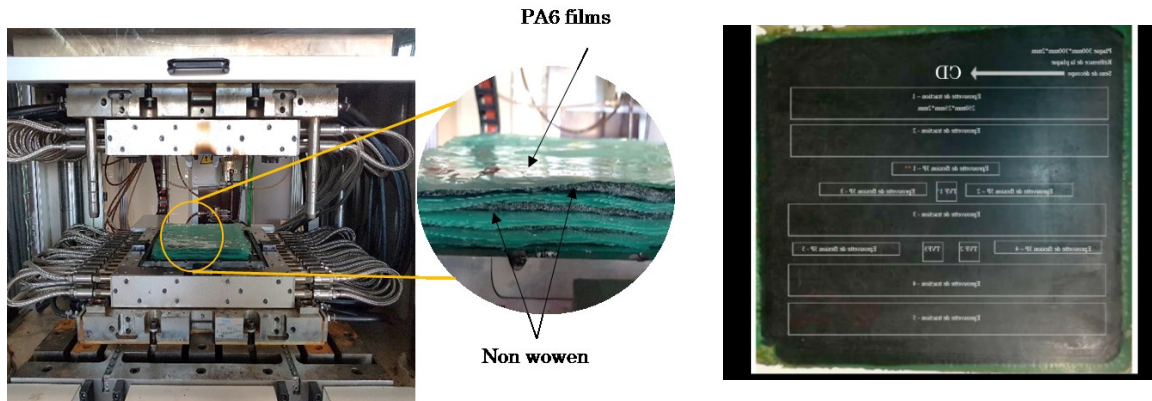


Cross-lapping & needle punching

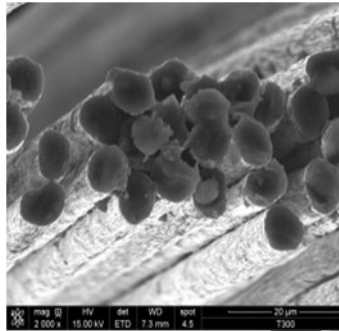


Nonwoven Fabric  
200g/m<sup>2</sup>

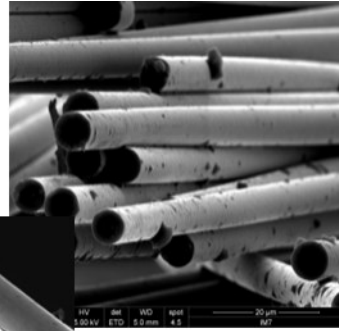
rCF composites manufactured by thermocompression film stacking or comingled non-woven



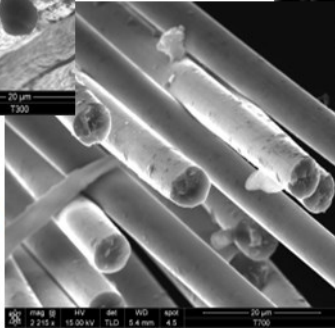
- Design of experiment approach to respond to question if fibre sorting is important or not before recycling



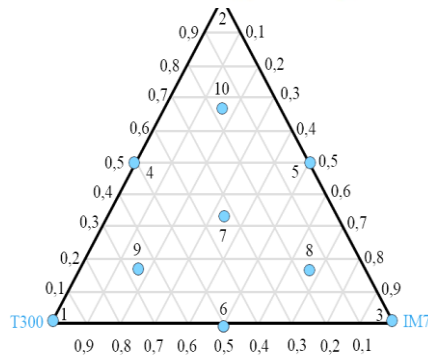
**T300**  
**(A320-A330)**



**IM7**  
**(A350)**

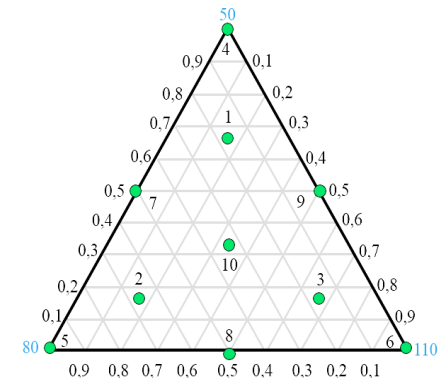
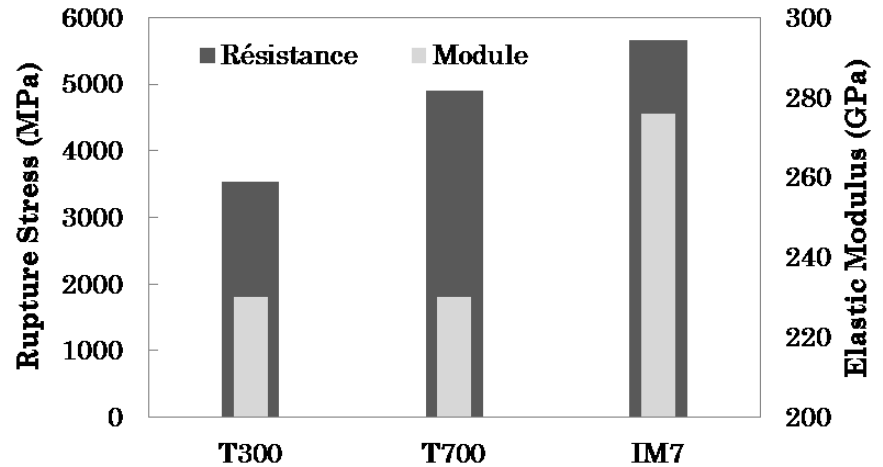


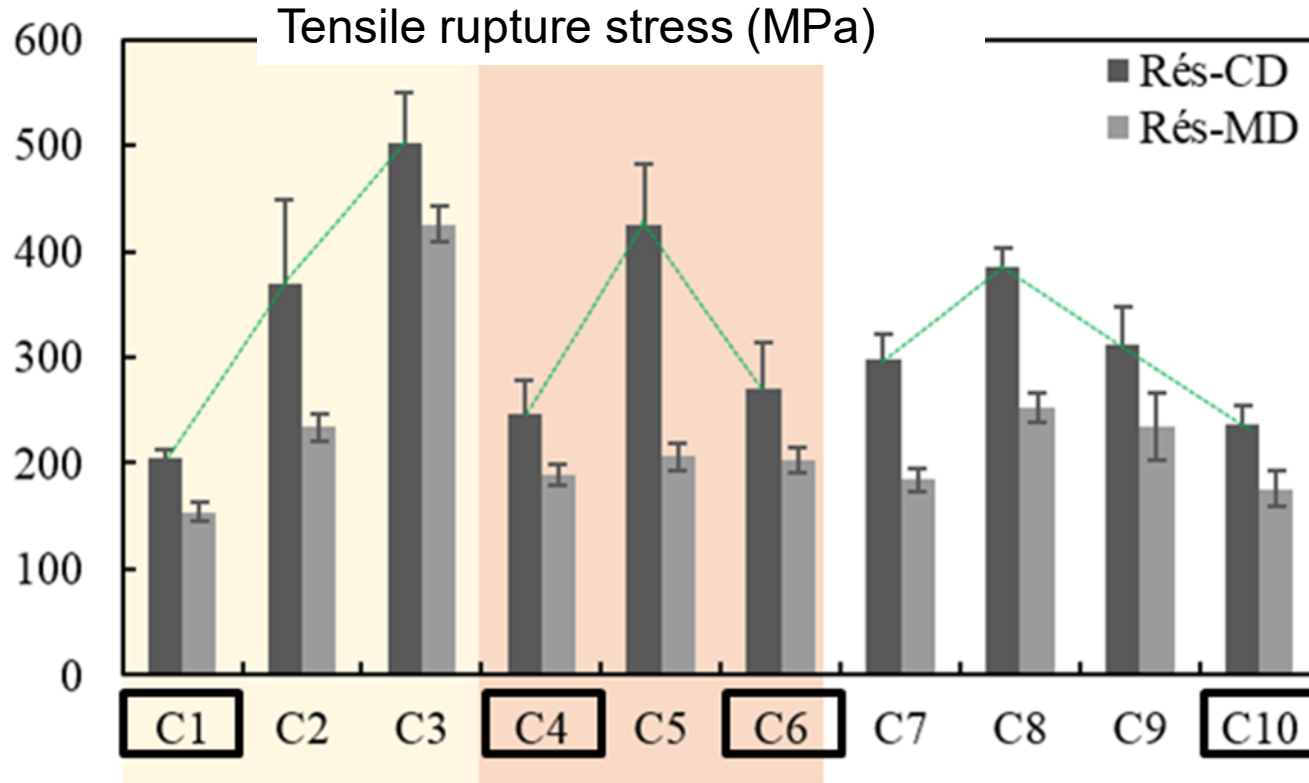
**T700**  
**(A380)**



... grades

- 3 fibre lengths : 50mm, 80mm and 110mm
- PA6 matrix



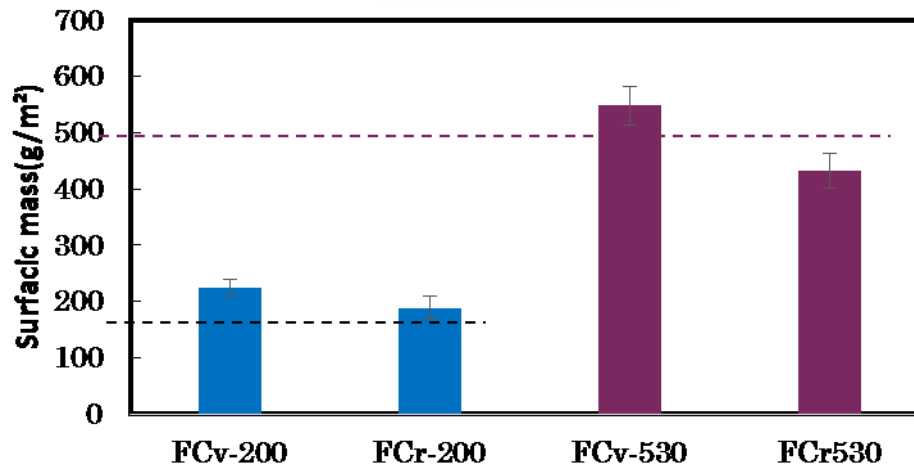
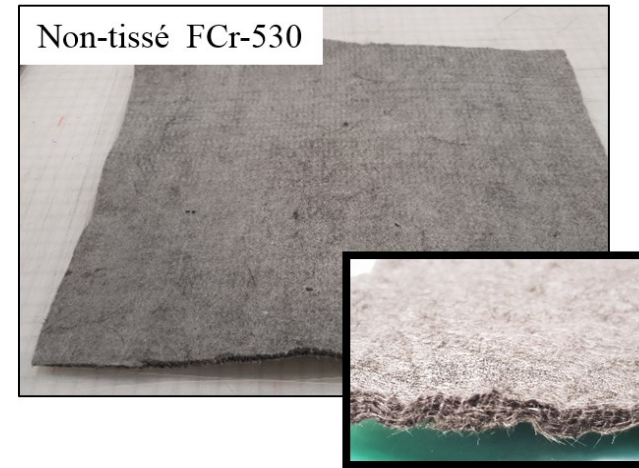
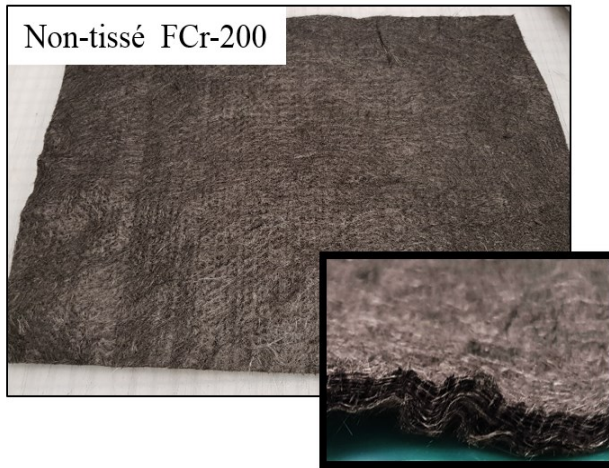


- The higher the fibre properties, the higher the composite properties : C1(T300), C2(T700), C3 (IM7)
- Material not isotropic : Cross Direction > Machine Direction
- Rupture stress is significantly affected if T300 (lowest fibre rupture stress)  $V_f$  is > than 50% (C1,C4,C6,C8)
- Detailed analysis (see PhD) shows that 80mm is the optimal length

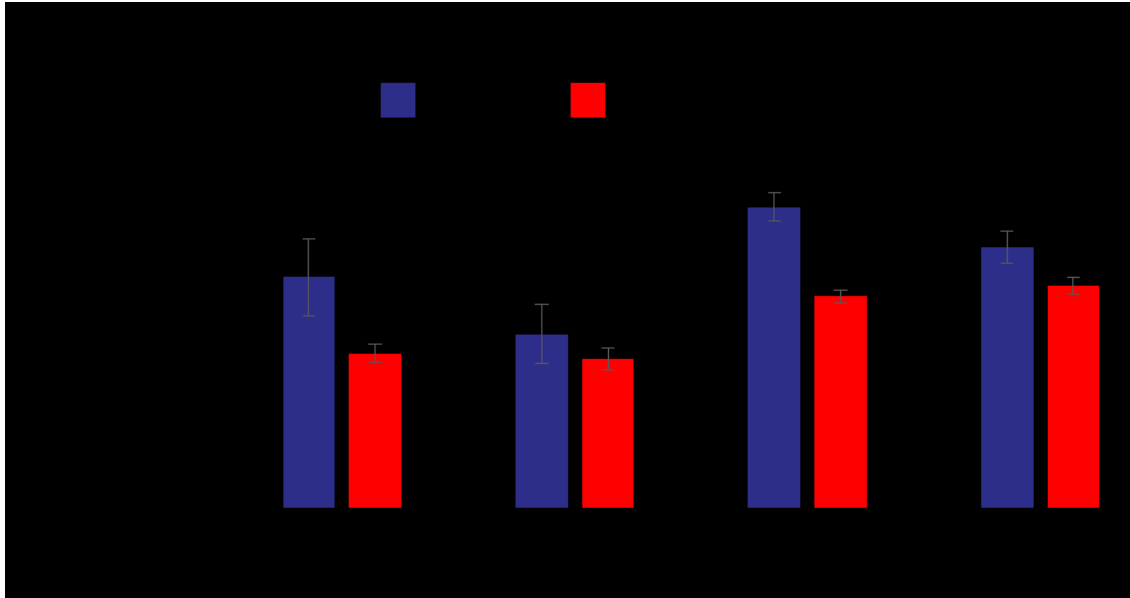
Comparison between :

vrCF and rCF,

100% CF (200g/m<sup>2</sup>) or comingled PA6 (510g/m<sup>2</sup>)

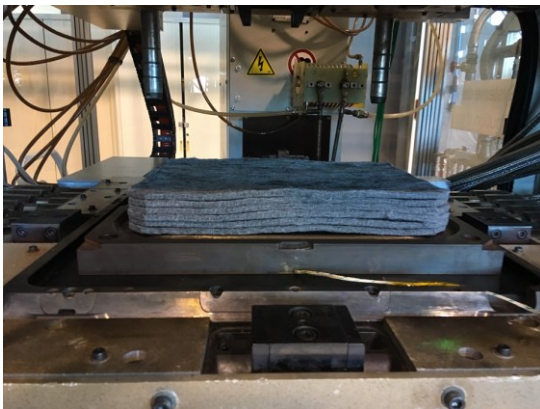


- Carding of rCF damages fibres → loss of fibres → lower areal mass of non-woven
- Higher loss when carding comingled non-woven due to increase of carding speed






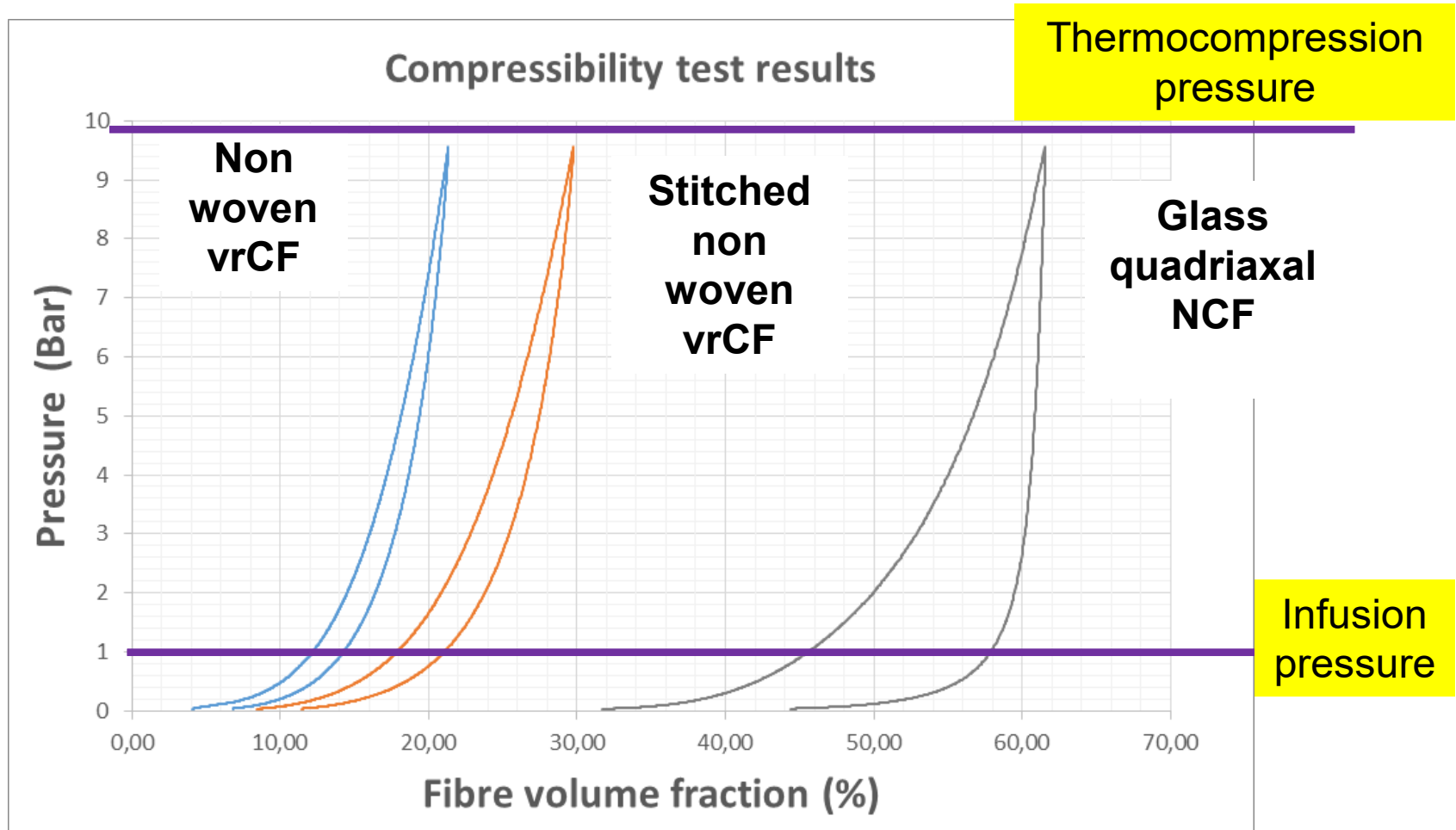
- Comingling is favorable for composite processing : higher properties due to better microstructure
- rCF non-woven are more isotropic than vrCF ones
- CD direction properties drop for rCF composites

- Comingled non-woven are well adapted for thermo-compression forming

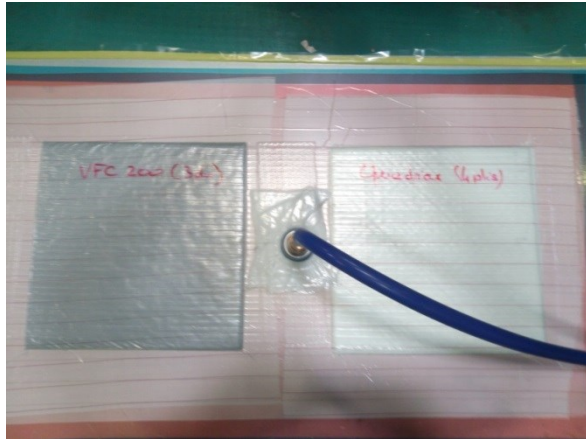




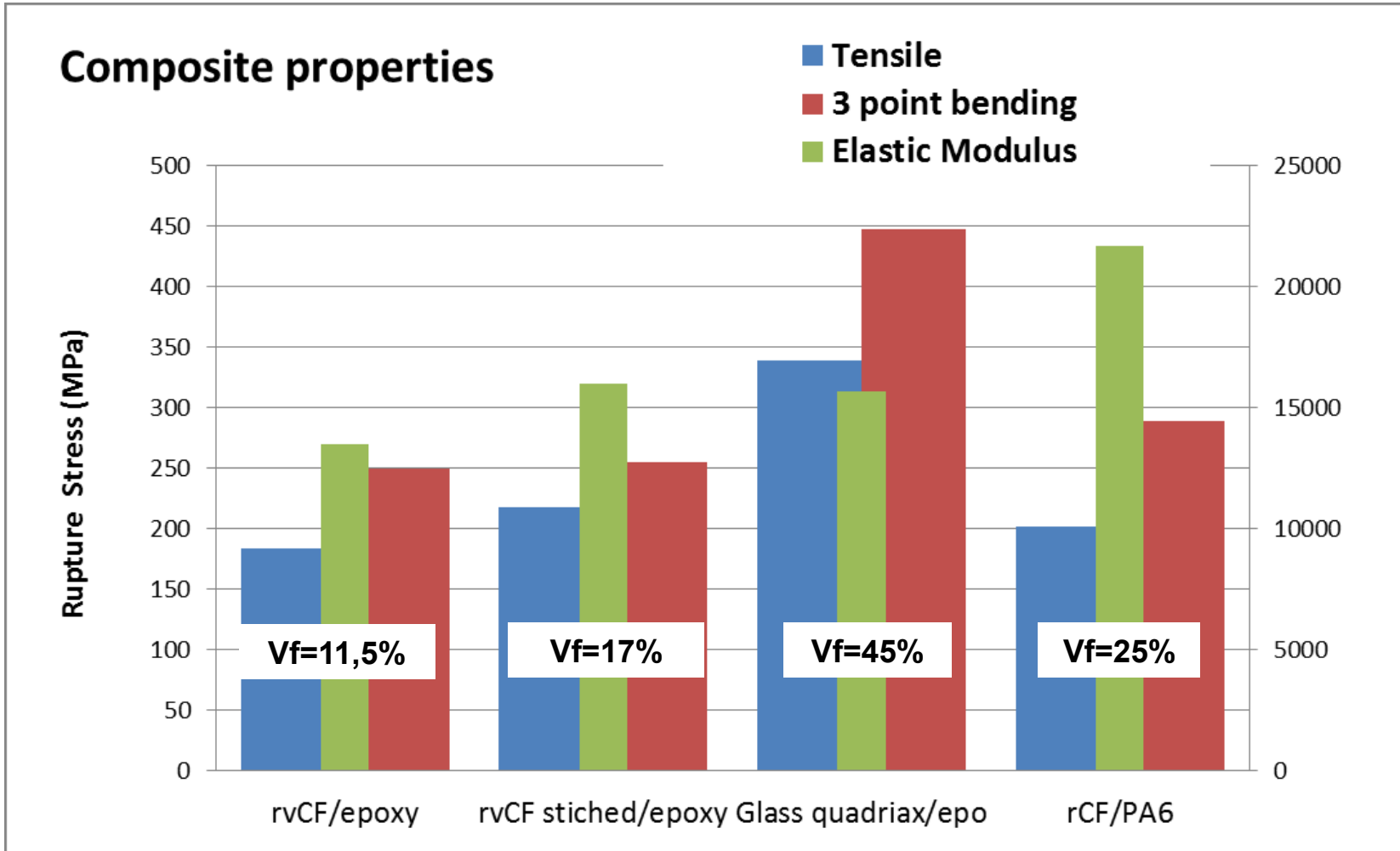
<p><b>Non woven vrCF (T700) (STFI)</b></p>	<p><b>Stiched non woven vrCF (STFI)</b></p>	<p><b>Glass quadriax (Saertex)</b></p>
		
<p><b>225 g/m<sup>2</sup></b></p>	<p><b>210 g/m<sup>2</sup></b></p>	<p><b>990 g/m<sup>2</sup></b></p>



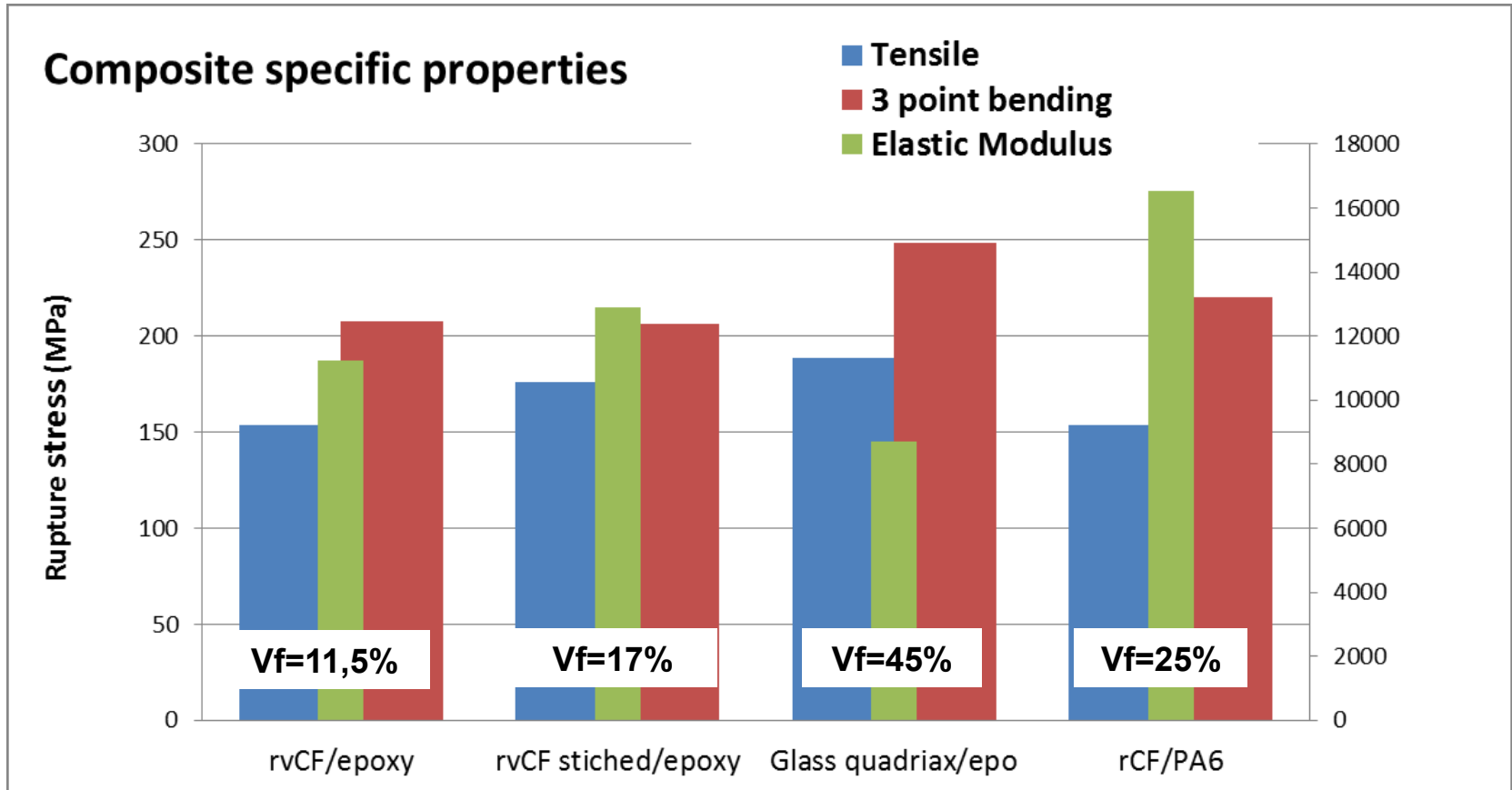
- Maximum possible fibre volume fraction depends on composite manufacturing process and fibrous architecture



- Vf after infusion is close to that expected from compressibility tests during first load increase



- For rCF materials, there is an increase in stiffness with respect to fibre volume fraction, less evident for rupture stresses



- 2.0 rCF infused materials are good candidates for replacement of glass reinforced materials in naval or automotive applications even if they have a lower fibre volume fraction

- rCF fibre mechanical property level statement requires tests on a great number of filaments : bundle tensile tests are best suited
- 2.0 injected rCF/PA6.6 materials are at the same level of properties as commercial ones. No influence of fibre desizing induced by steam-thermolysis
- Non-woven rCF materials
  - ✓ Optimum rCF length of 80 mm for non-woven carding
  - ✓ Mixing of fibres : significant impact only if volume fraction of the less performance fibre is higher than 50%
  - ✓ Commingled rCF/PA6 non-woven well adapted to thermocompression manufacturing
- Non-woven rCF epoxy infused materials are candidates for replacement of quadriaxial NCF glass fibre composites used in naval or automotive applications

# Thank you for your attention

*Team involved in these works :*

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