2.0 rCF based composite materials: manufacturing processes and mechanical properties

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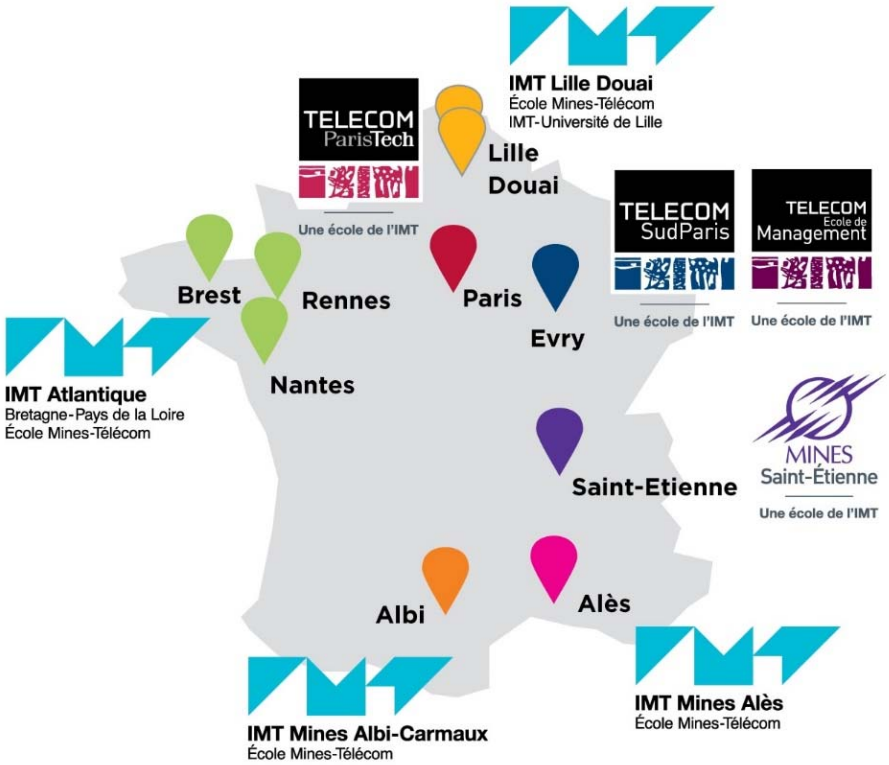
IMT: Institut Mines-Télécom

Institut Mines-Télécom

7 engineering and 1 Bussiness School



IMT Belongs to the ministry of Industry and Economy

IMT Mines Albi-Carmaux
École Mines-Télécom

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

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IMT Mines Albi-Carmaux
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Université de Toulouse

Materials and processes for aeronautics and space

ICA - Albi
UMR CNRS 5312

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UMR CNRS 5302

Powder engineering and Bio-health

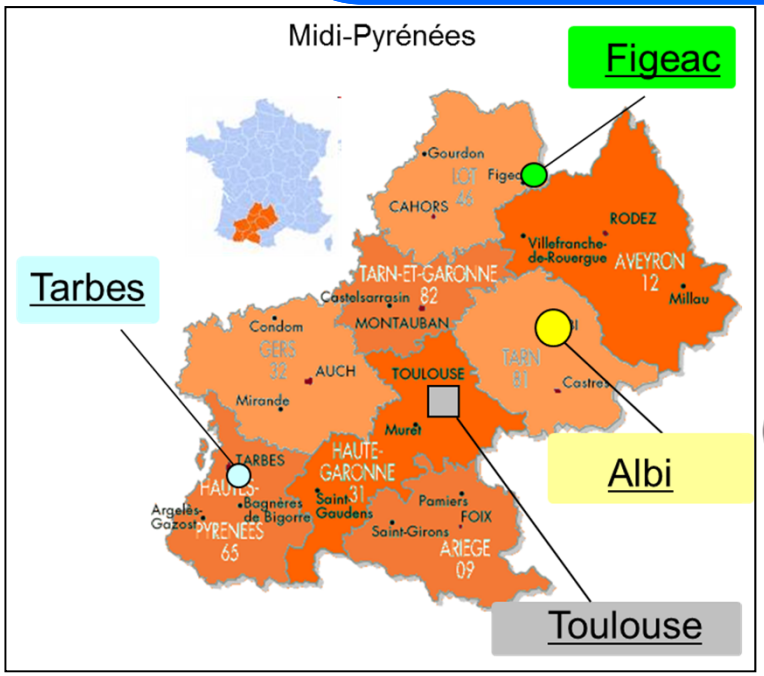
Biomass and waste engineering, renewable energy

CGI
Industrial engineering

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

Alpha Recyclage Composites

Joint research lab on Carbon fiber composite recycling



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UNIVERSITÉ TOULOUSE III PAUL SABATIER

cnrs

- **Institut Clément Ader**

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

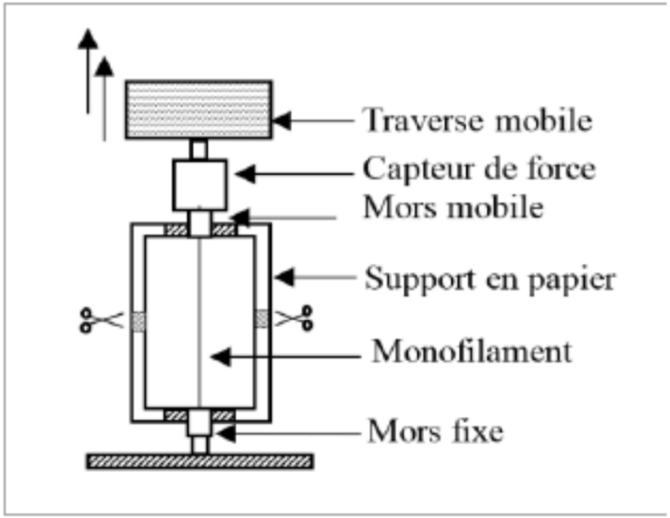
- Staff ≈ **250** people

- 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

Content

- 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

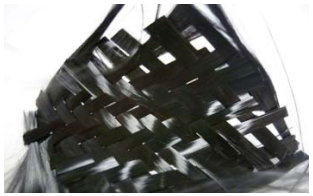
- Three test methodologies available
  - ✓ Impregnated tow test : test used by the fibre manufacturer (test affected by fibres, epoxy resin, and sizing)
  - Single fibre test : most used test (between 25 to 50 individual fibres)



  - Bundle test

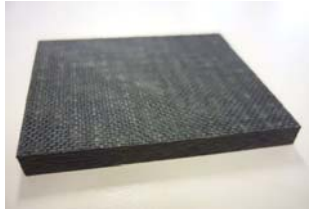
rCF fiber rupture stresses

Hextow AS4C



Epoxy resin infusion

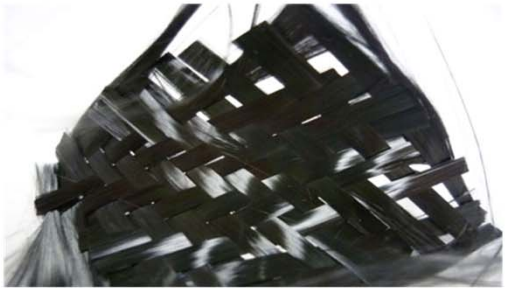
Composite sheets

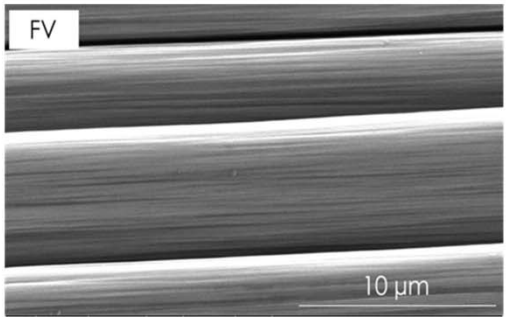


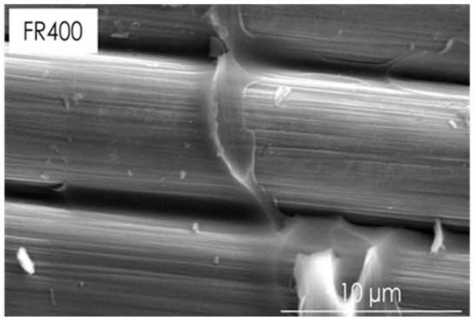
Steam water Thermolysis

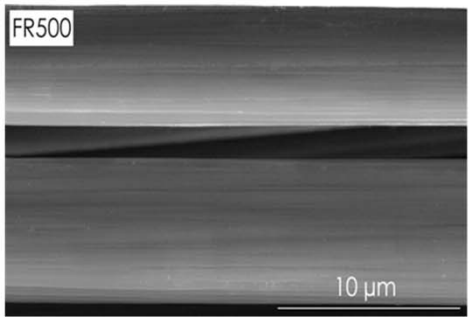
rCF

REFERENCE	400°C	500°C
	95 % resin elimination	99 % resin elimination

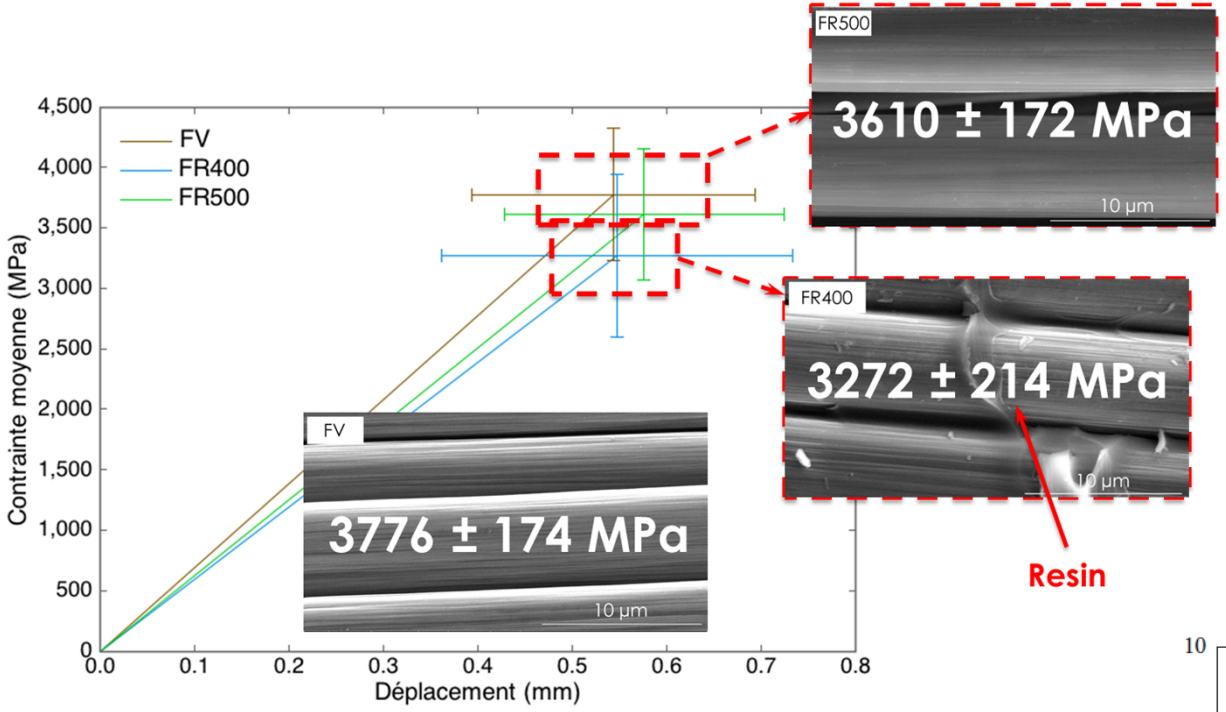




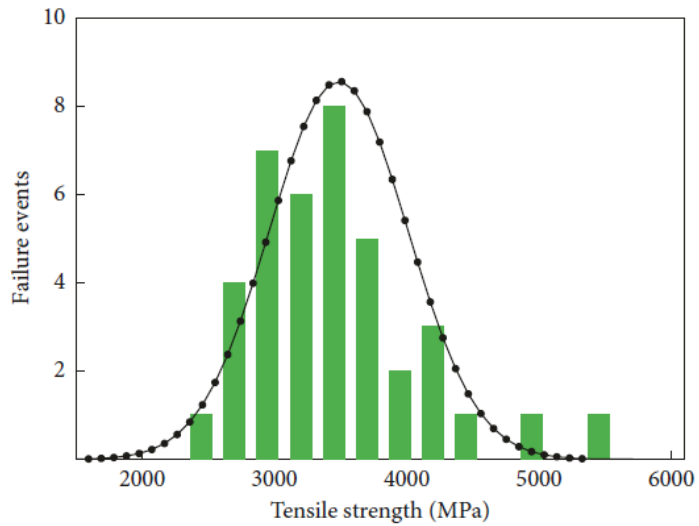




Single fibre tensile test results (40 filaments)



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

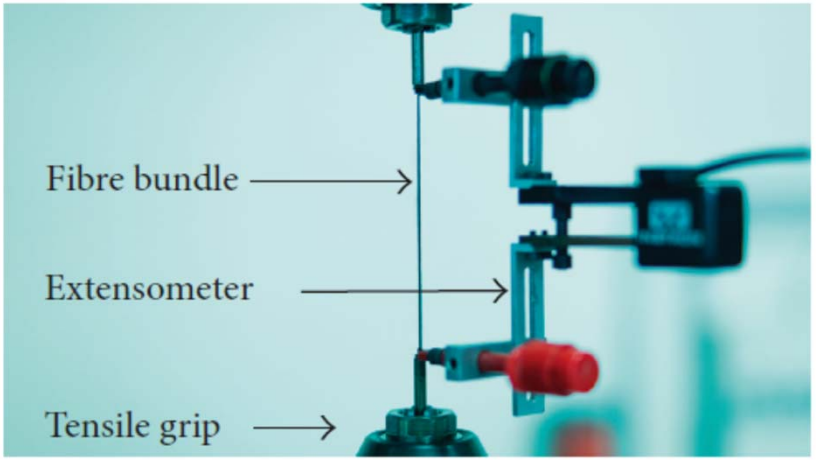


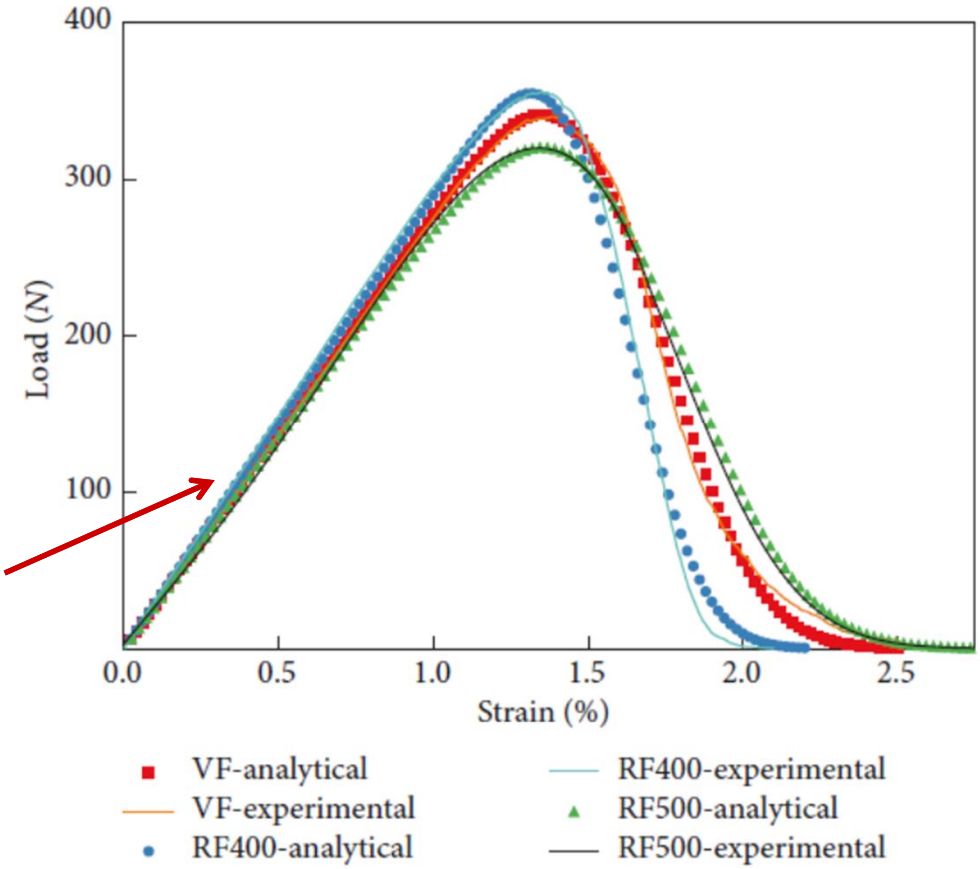
Statistical analysis (normal distribution)

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

M. Boulanghien & al, Advances in Materials Science and Engineering, 2018

Bundle Tensile Test (BTT)





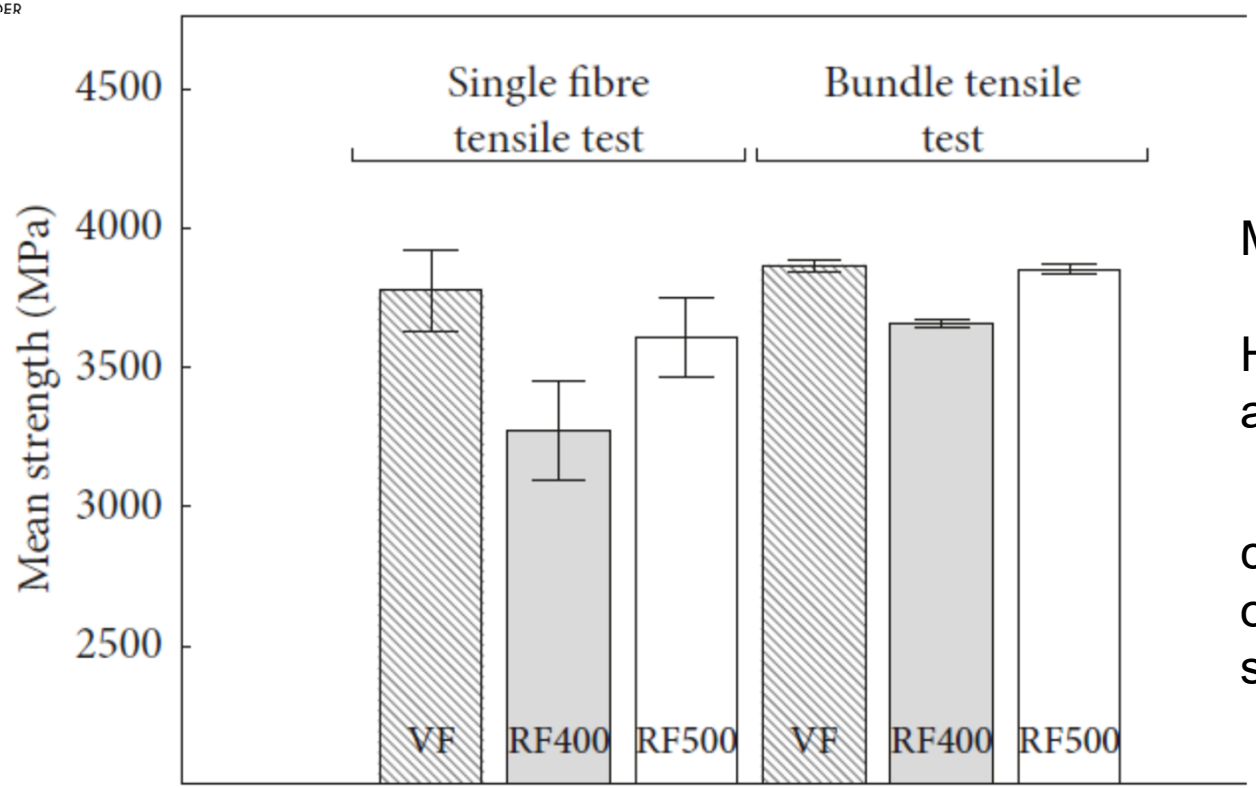
Slope of the tensile load-strain curve

Strain

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

M. Boulanghien & al, Advances in Materials Science and Engineering, 2018

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**

M. Boulanghien & al, Advances in Materials Science and Engineering, 2018

2.0 rCF /PA6.6 pellet injection

Fiber length :
1 to 2 cm

vCF

rCF (FR500)

Polyamide 6,6 (Latamid 66)

Extrusion –
IPREM EPCP Pau

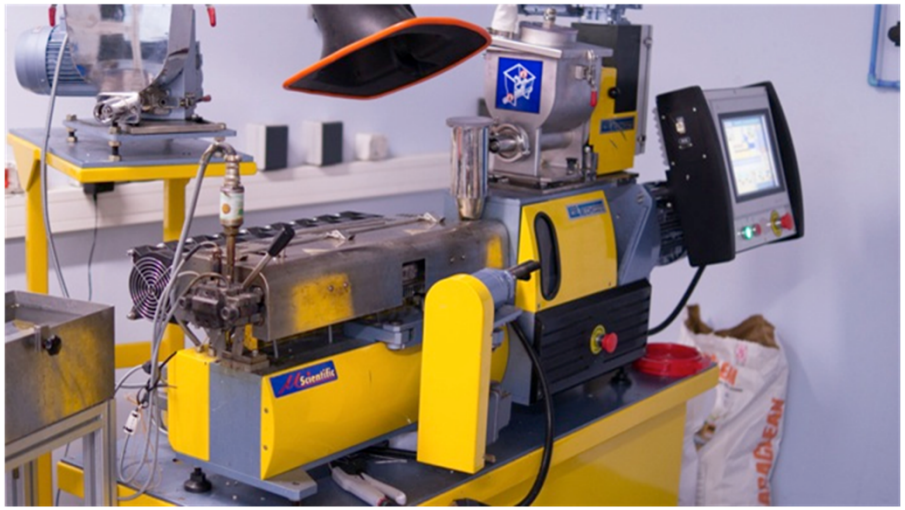
Temperature :
270 °C

Fibre not known

Commercial CF reinforeced Pelets

Tempearture :
290 °C

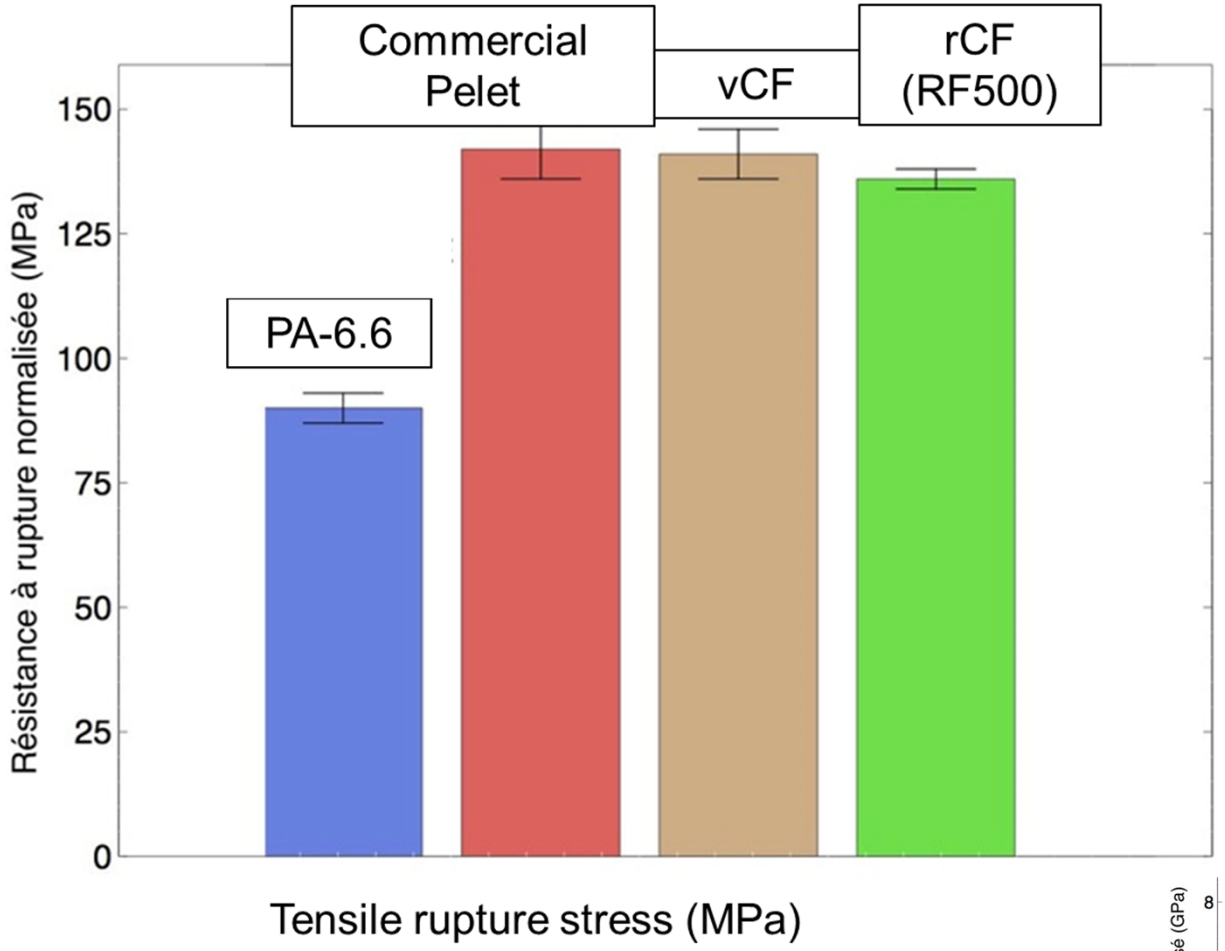
INJECTION ICA - Albi



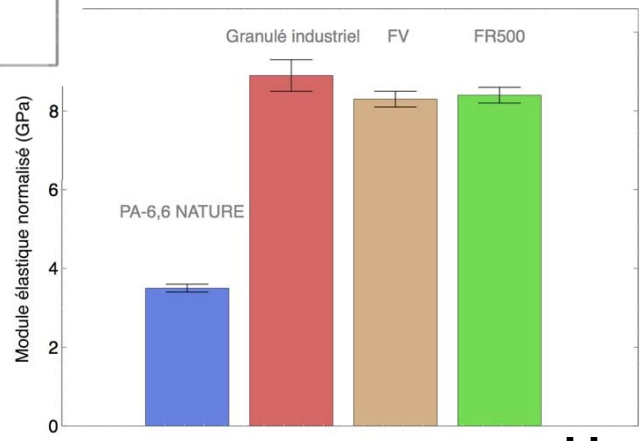
Length : 0,3 mm

Thermoplastic composite materials reinforced with 10% of carbon fiber Vf

2.0 rCF /PA6.6 pellet injection



Tensile elastic Modulus (GPa)



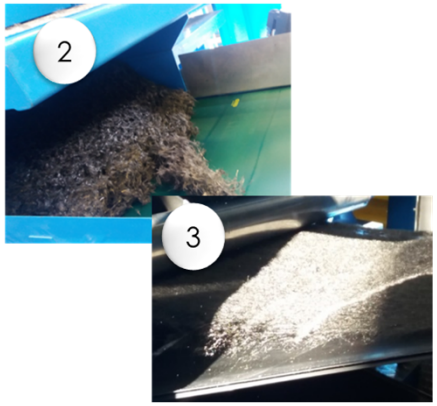
- rCF/PA6.6 injected material properties are as high as commercial grades
- rCF injected properties are as close to the vCF ones

2.0 rCF non woven composites manufacturing

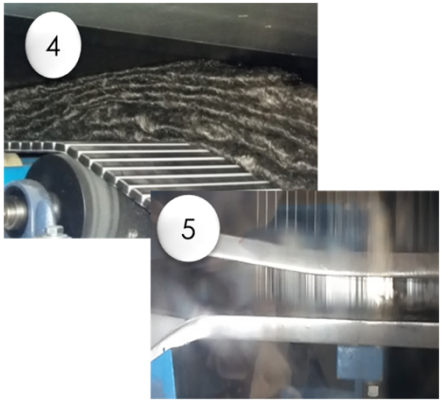
Carding

Nonwoven processing : carding/needle punching

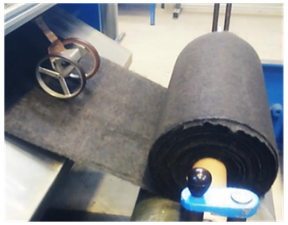
Opening & Blending



Carding

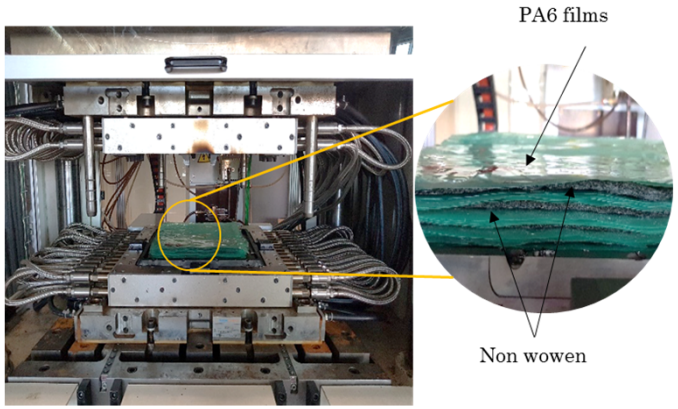


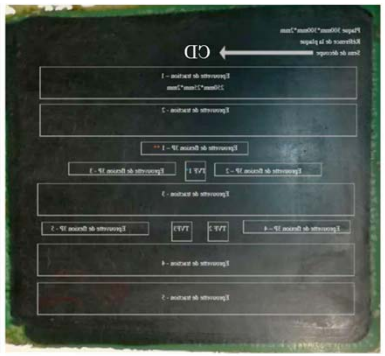
Cross-lapping & needle punching



Nonwoven Fabric
200g/m²

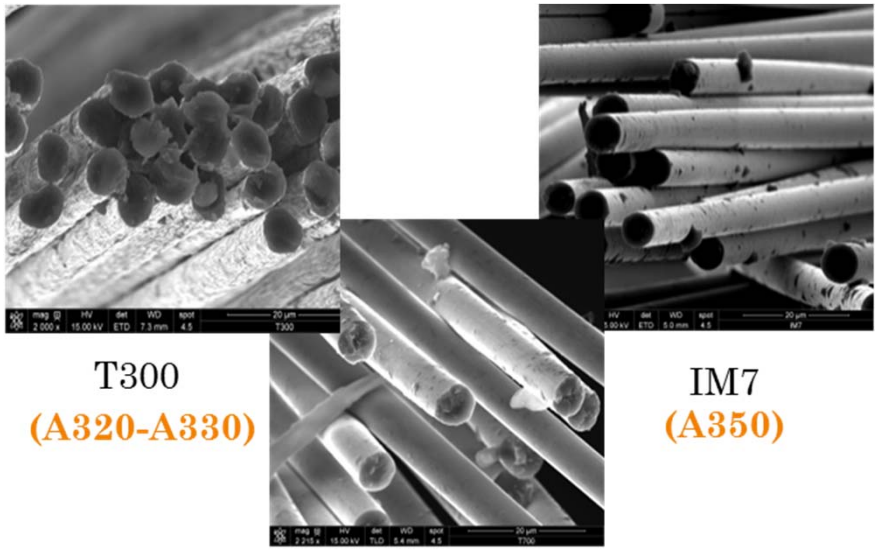
rCF composites manufactured by thermocompression film stacking or comingled non-woven

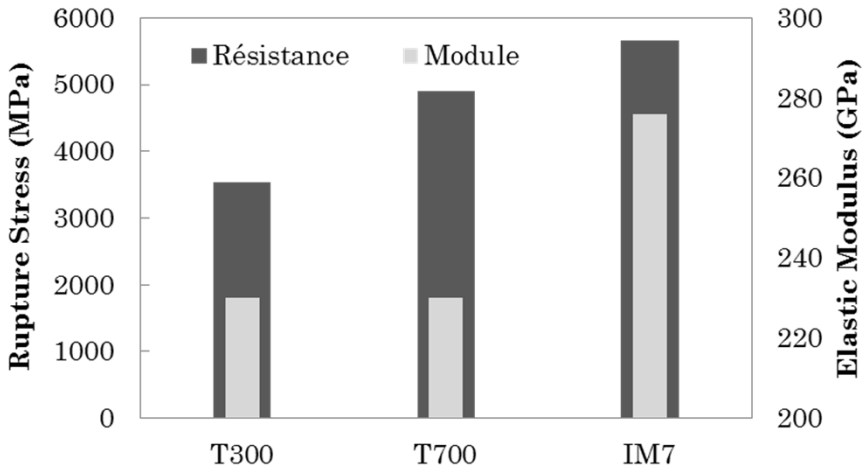


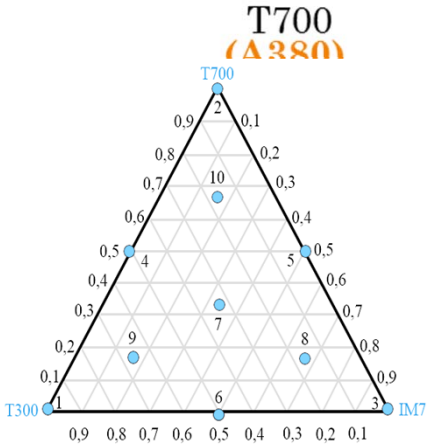


Impact of fibre grade and fibre length on non-woven vrCF PA6 composites

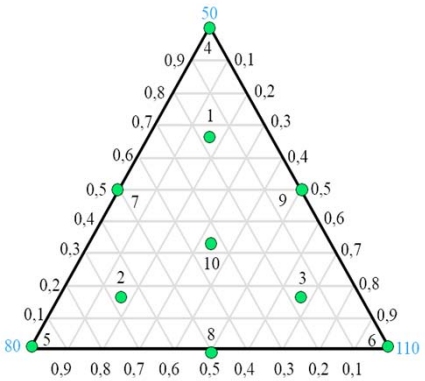
➢ Design of experiment approach to respond to question if fibre sorting is important or not before recycling





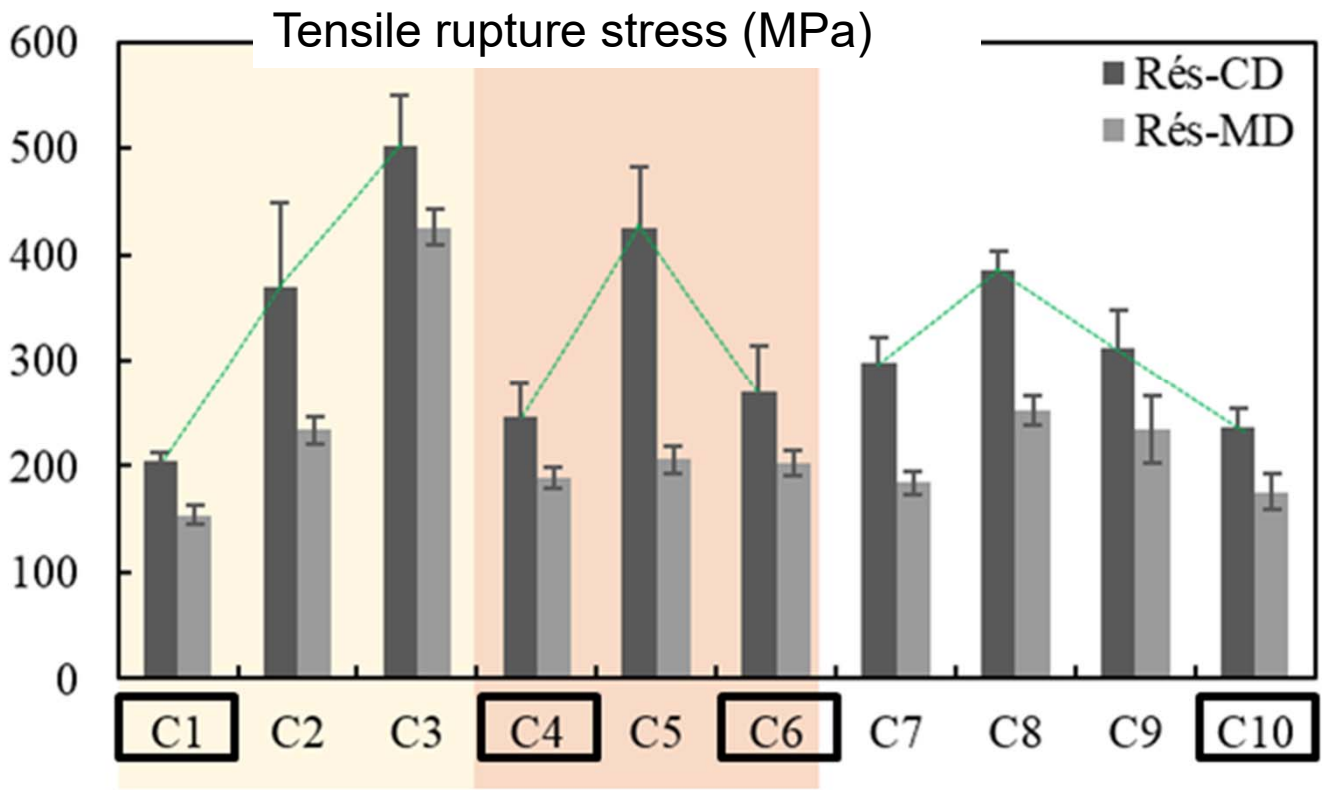


- 3 fibre grades
- 3 fibre lengths : 50mm, 80mm and 110mm
- PA6 matrix



S. Jlassi & al, ICCM18, Athens, 2018

Non-woven vrCF /PA6 composites



- 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) Vf is > than 50% (C1,C4,C6,C8)
- Detailed analysis (see PhD) shows that 80mm is the optimal length

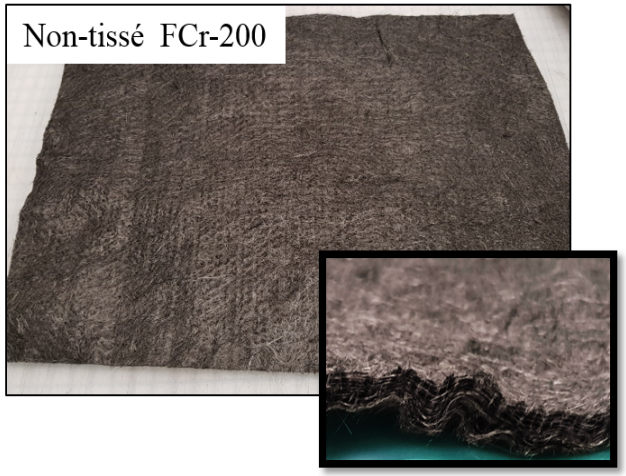
S. Jlassi & al, ICCM18, Athens, 2018

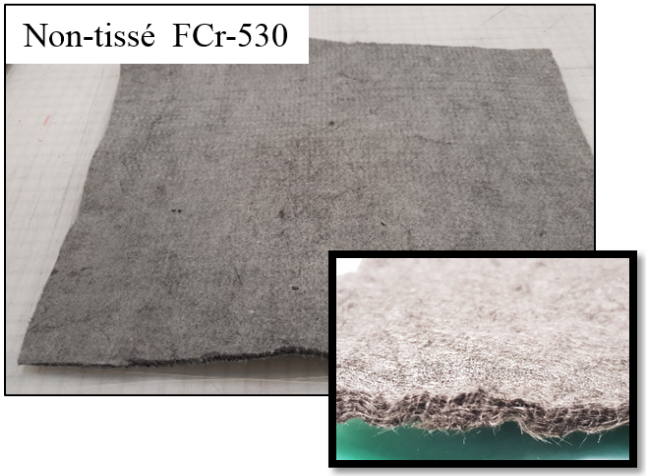
2.0 Non-woven PA6 composites

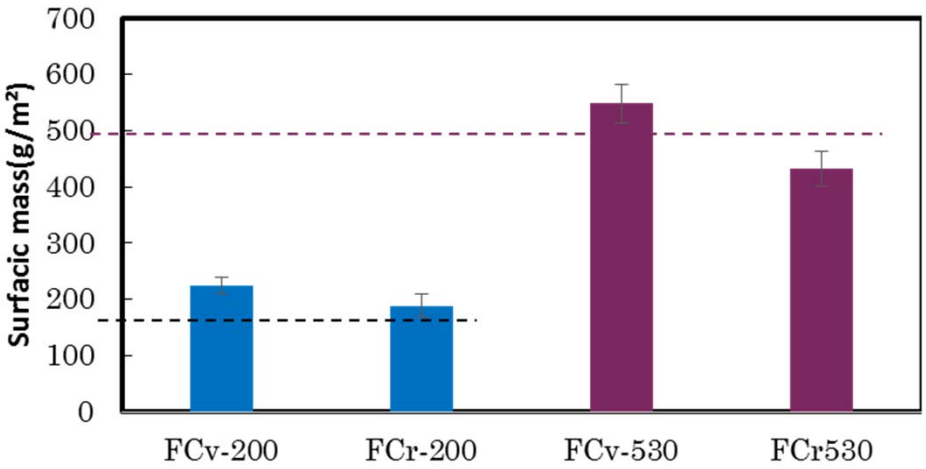
Comparison beetween :

vrCF and rCF,

100% CF (200g/m2) or comingled PA6 (510g/m2)

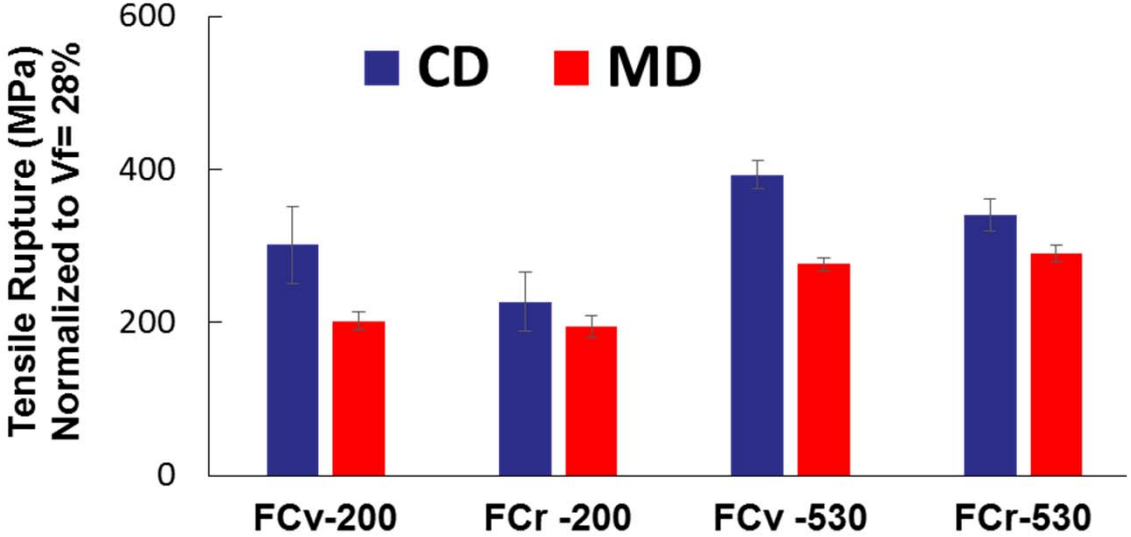






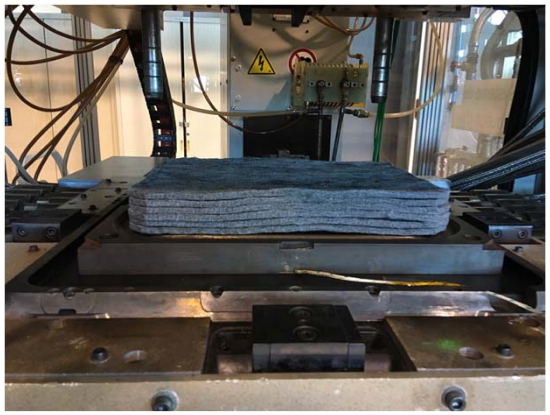
- Carding of rCF damages fibres → loss of fibres → lower areal mass of non-woven
- Higher loss when carding comingled non-woven due to increase of carding speed

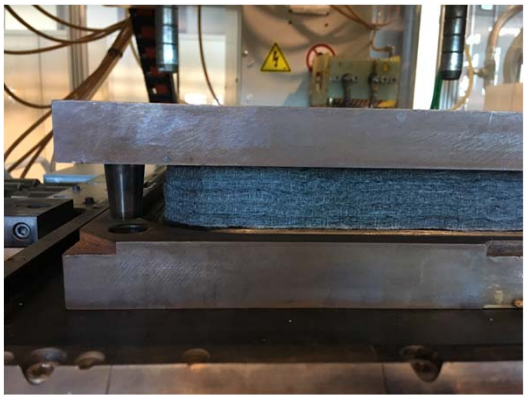
2.0 Non-woven PA6 composites



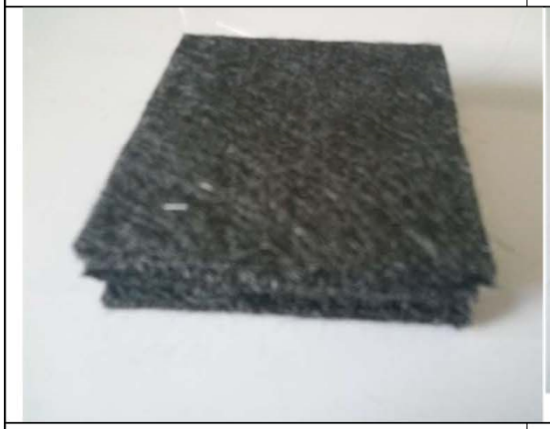
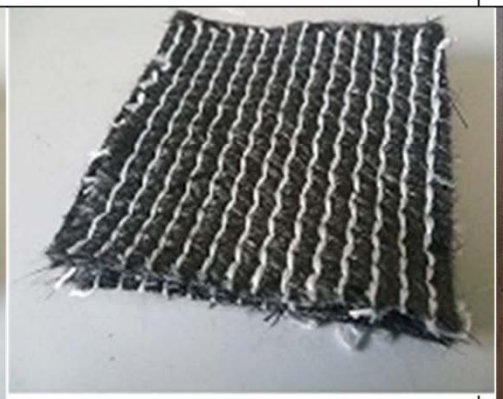
- Comingling is favorable for composite processing : higher properties due to better microstructure
- rCF non-woven are more isotropic than vrCF ones
- CD direction properties drop for rCF composites

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

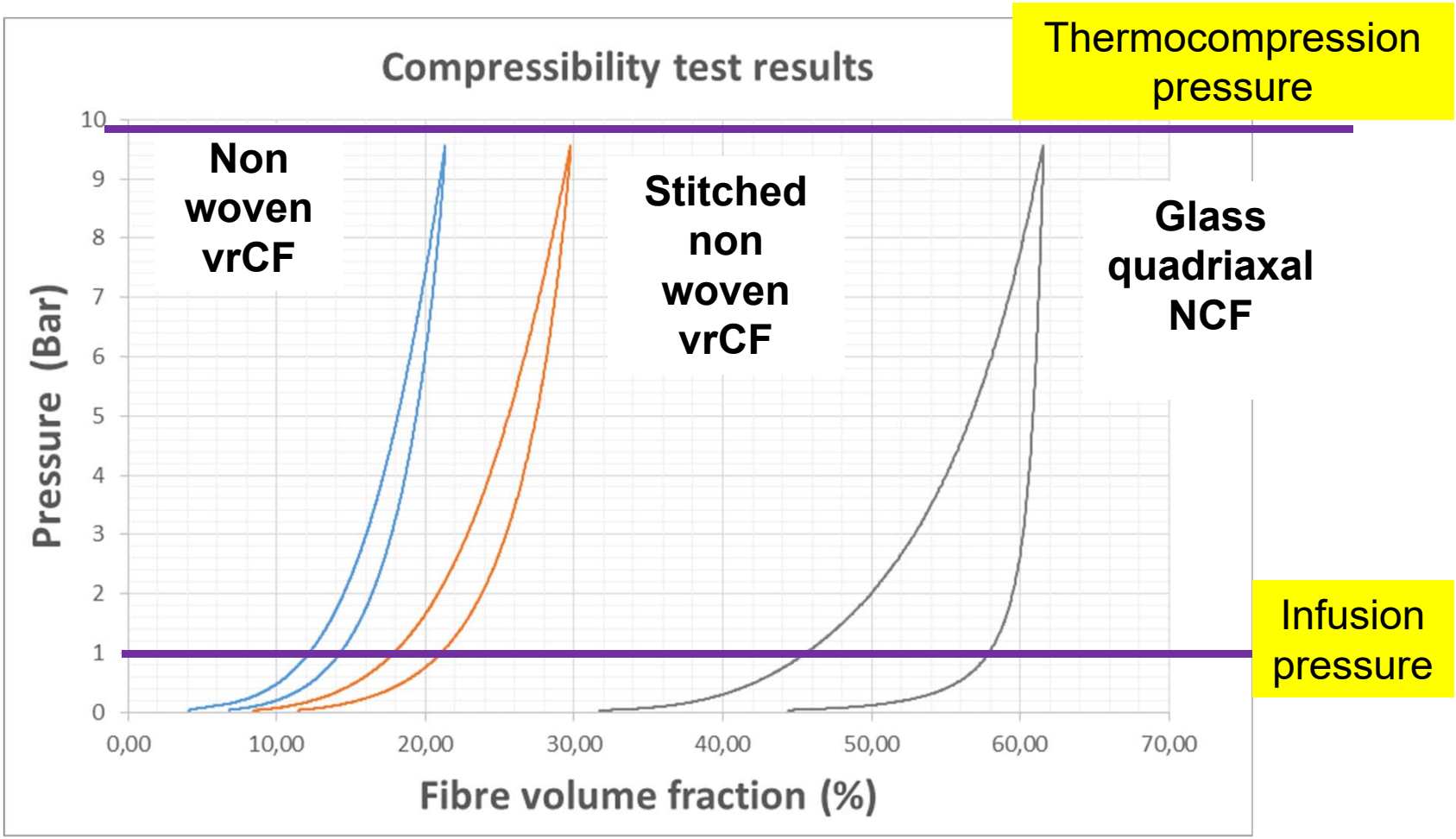




2.0 rCF non-woven epoxy infused materials

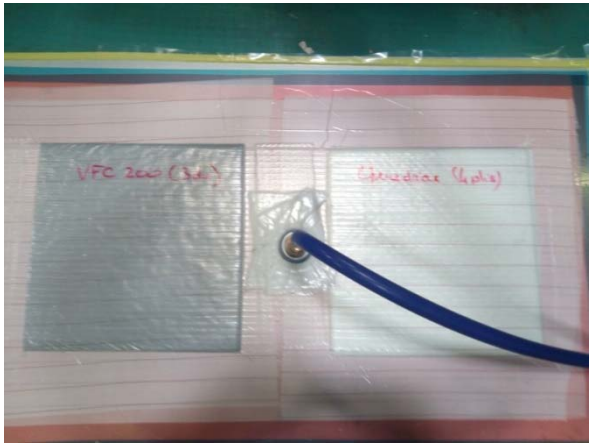
Non wowen vrCF (T700) (STFI)	Stiched non woven vrCF (STFI)	Glass quadriax (Saertex)
		
225 g/m2	210 g/m2	990 g/m2

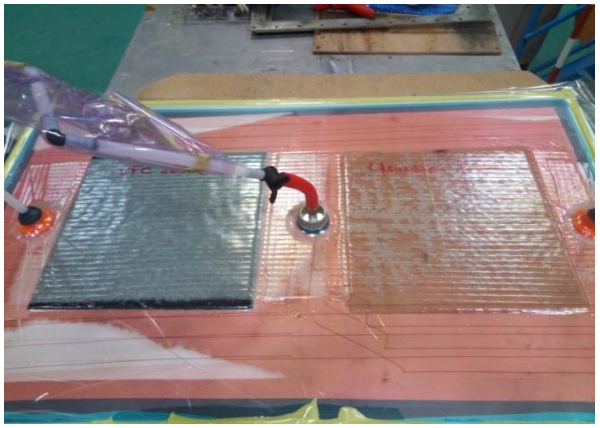
Non-woven : Fibrous architecture compressibility

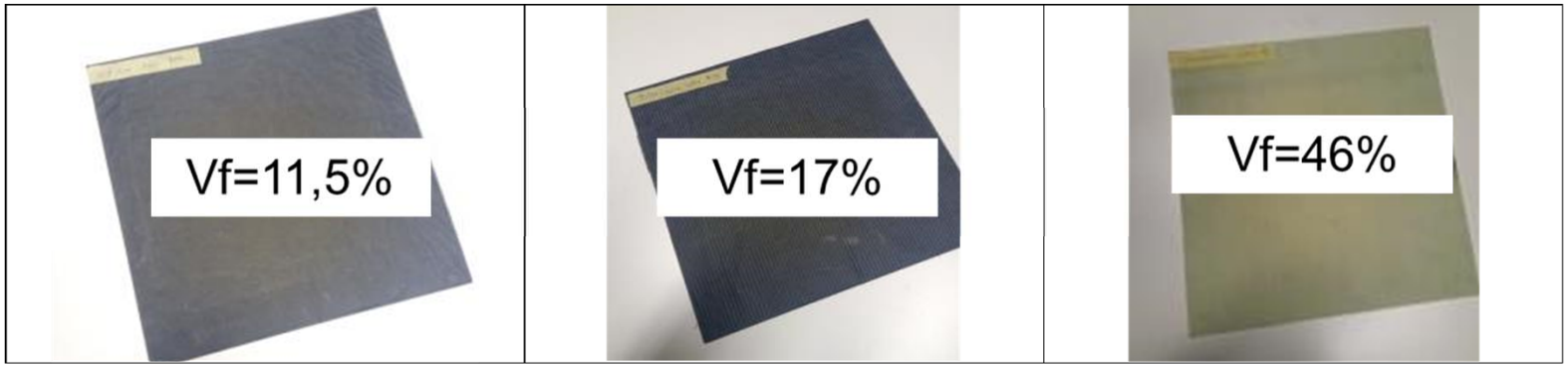


- Maximum possible fibre volume fraction depends on composite manufacturing process and fibrous architecture

Non-woven Infusion process

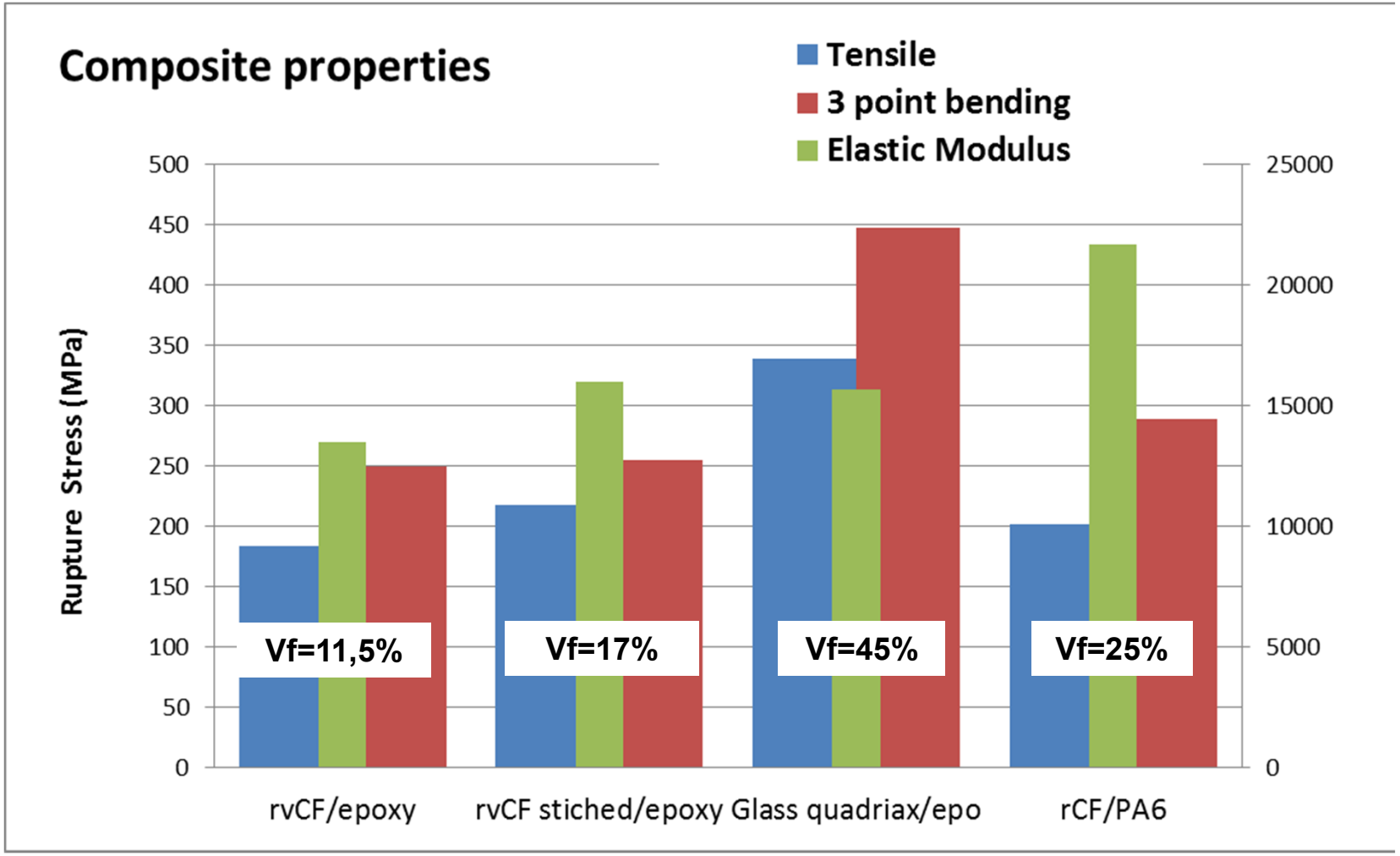






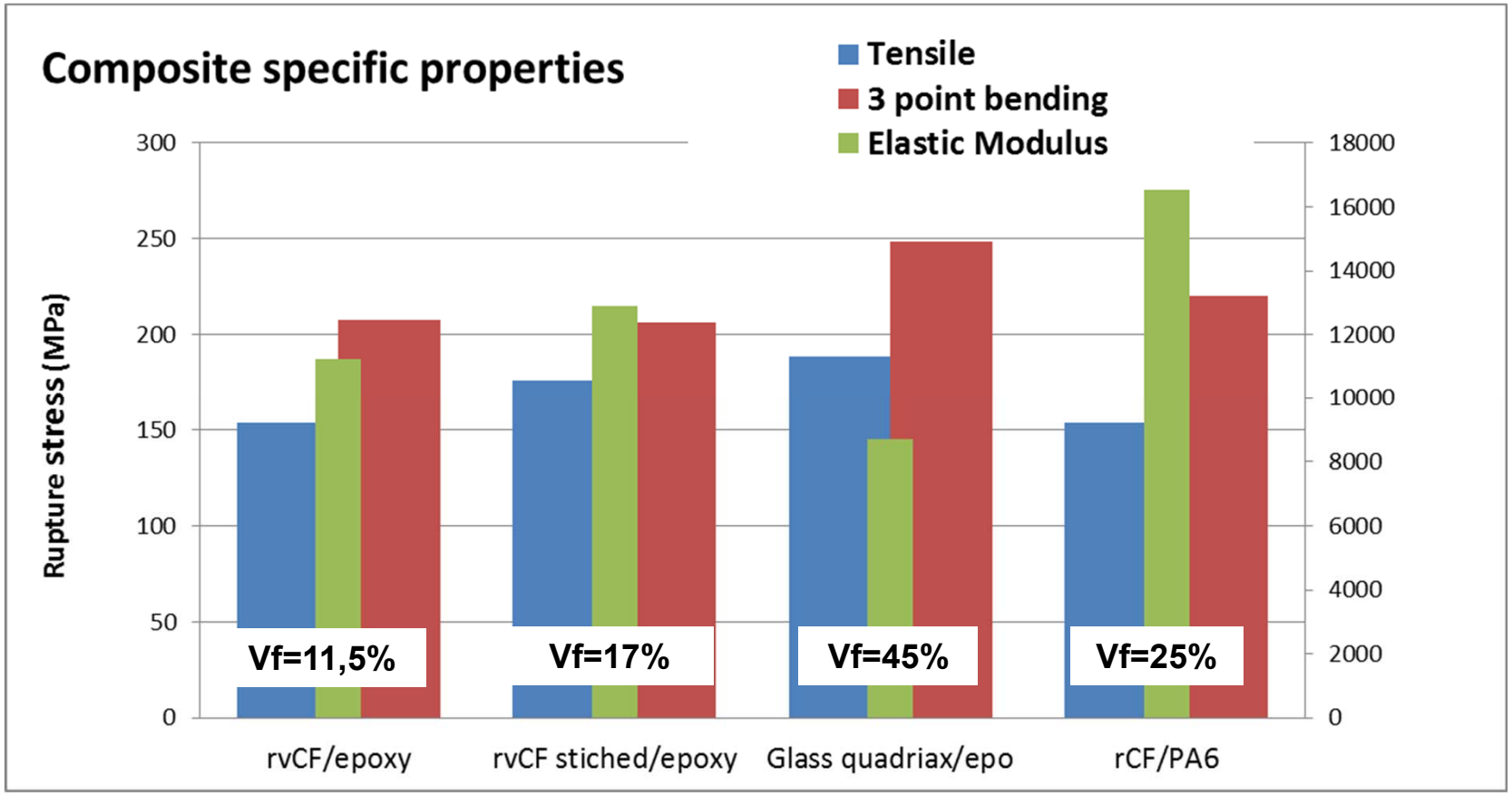
- Vf after infusion is close to that expected from compressibility tests during first load increase

2.0 rCF epoxy infused materials properties



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

2.0 rCF epoxy infused materials : specific properties



- 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

Conclusions

- 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 :

Gérard Bernhart (ICA)
Florentin Berthet (ICA),
Yannick Soudais (Rapsodee)
Maxime Boulanghien (PhD, ICA, 2015)
Sabrine Jlassi (PhD, ICA, 2019)
Serge Da Silva (ARC)