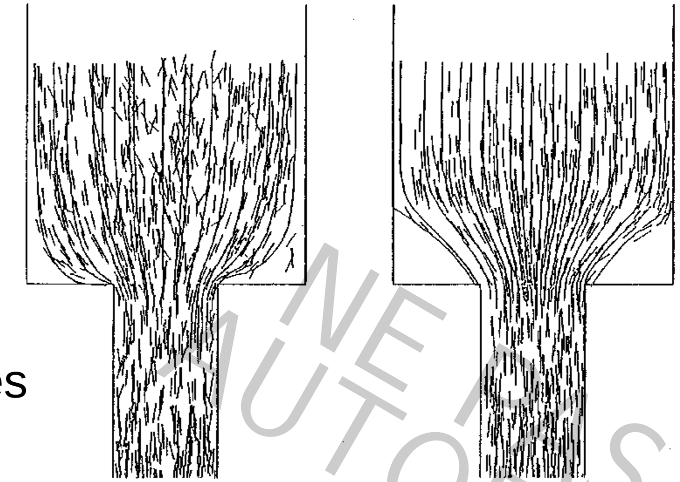
Synthèse sur le colloque
MÉCANIQUE DES MATÉRIAUX BIOSOURCÉS

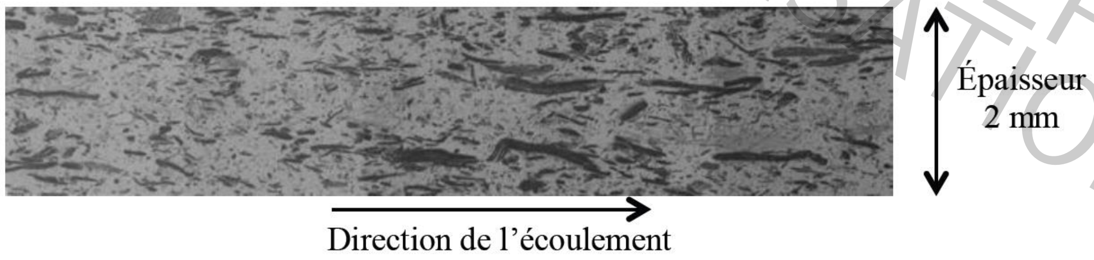
Philippe Boisse,

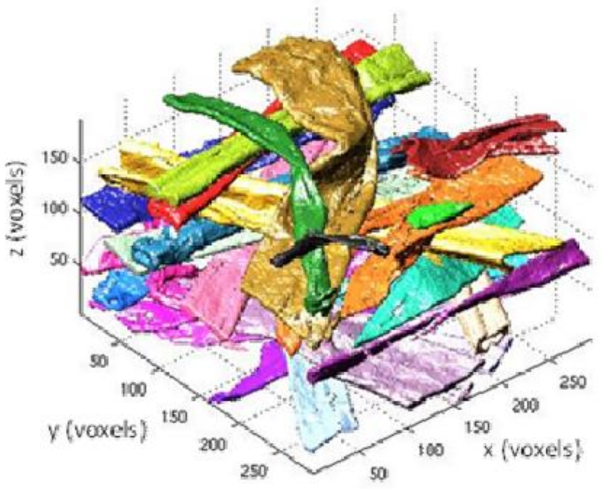
INSA-Lyon, France

Fibres courtes



[M. Vincent, Aussois 2014]





[P.J.J. Dumont et al, Aussois 2014]

Fibres continues (aile ATR72)

Peut on réaliser des pieces structurales avec des composites à fibres d’origine végétales?

Contents lists available at SciVerse ScienceDirect

Composites: Part B

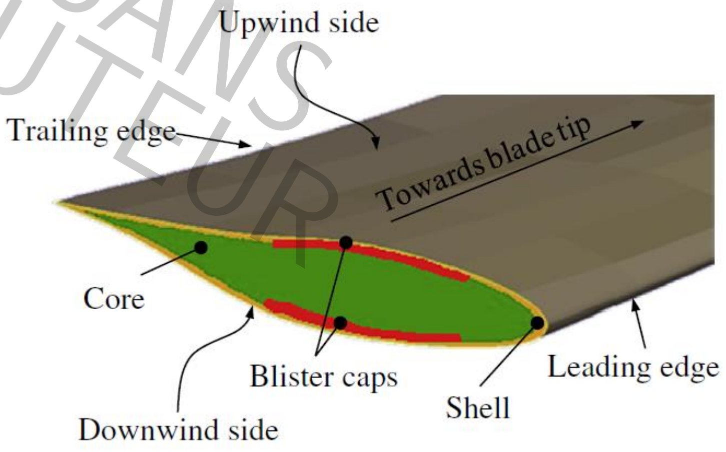
journal homepage: www.elsevier.com/locate/compositesb

Can flax replace E-glass in structural composites? A small wind turbine blade case study ☆

Darshil U. Shah, Peter J. Schubel *, Mike J. Clifford

Polymer Composites Group, Division of Materials, Mechanics and Structures, Faculty of Engineering, The University of Nottingham, Nottingham NG7 2RD, UK

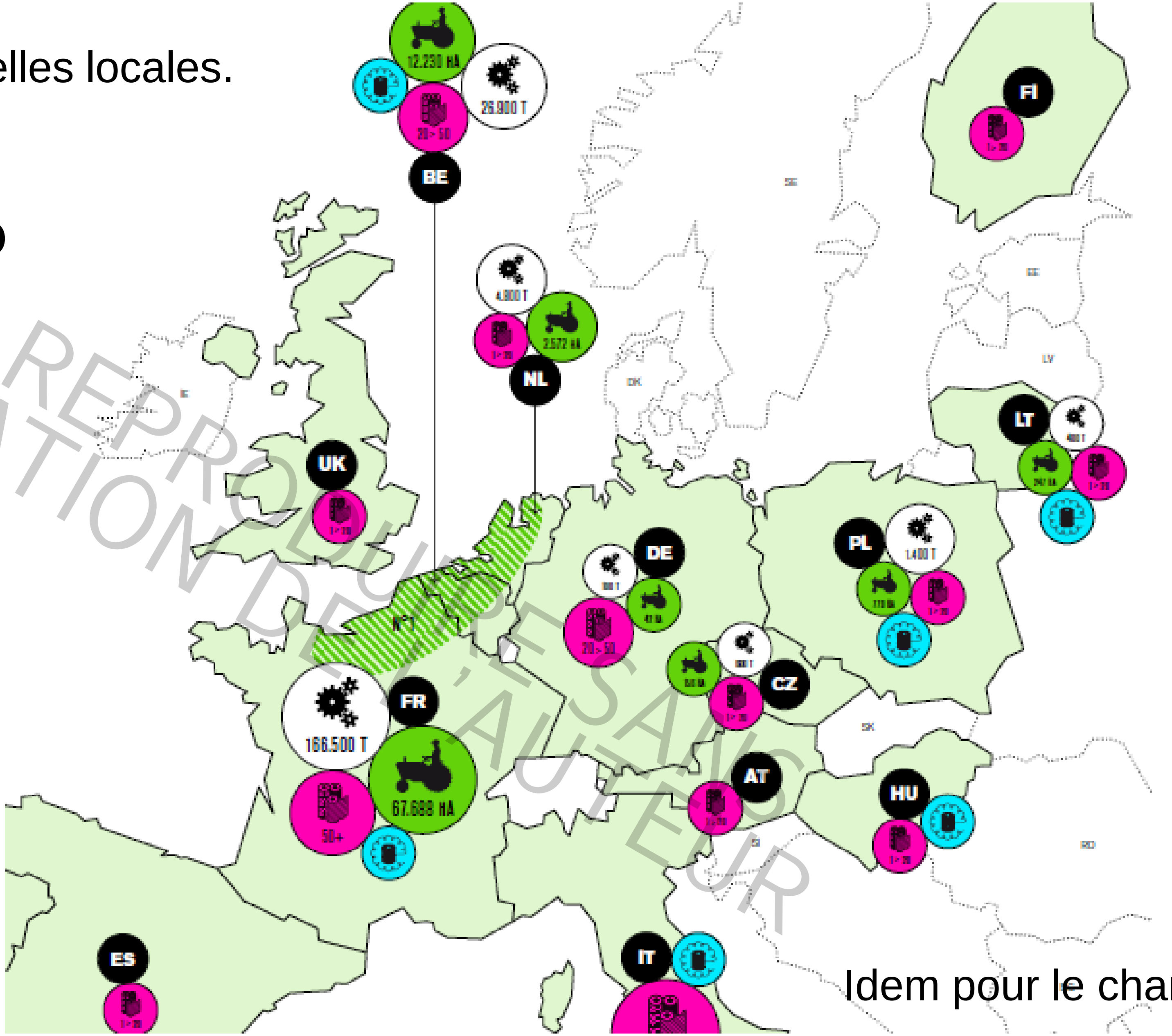
3.5-m composite rotor blades (suitable for 11 kW turbines)



Intéret : Utiliser des ressources naturelles locales.

Where is flax grown?

Member State	Flax area (ha)	Number of farms	Average size
FR	79 329	6 637	12
NL	4 523	600	8
BE	18 167	2 271	8
UK	72	n.a	n.a
DE	87	12	7
PL	3 898	2 071	2



Idem pour le chanvre

KU LEUVEN

There is a renewed and ever-increasing interest in biocomposites.
This is reflected by the increasing number of publications on biocomposites during recent years, including books and review articles. (!!)

Developing plant fibre composites for structural applications
by optimising composite parameters: a critical review

[Darshil U. Shah   J Mater Sci 2013]

By commercial application, **over 95 %** of PFRPs produced in the EU are used for **non-structural automotive** components, which are manufactured primarily via compression moulding

Other than automotive applications PFRPs are being considered for applications in:

(i) Construction and infrastructure (such as beams, roof panels and bridges)
(ii) Sports and leisure (for boat hulls, canoes, bicycle frames and tennis rackets)
(iii) Furniture and consumer goods (such as packaging, cases, urns, chairs, tables, helmets)
(iv) Pipes and tanks (for water drainage/transportation)
(v) Small-scale wind energy (as rotor blade materials)

In many of these applications, plant fibres are being employed primarily as light, cheap and 'green' reinforcements, **playing little or no structural role**.

The **structural potential** of plant fibres is revealed by the fact that bast fibres (like flax, hemp and jute) are high in cellulose content (60–80 % of the dry chemical composition)
and native cellulose has remarkable tensile stiffness (138 GPa) and strength ([2 GPa)
Therefore, investigating and eventually promoting the potential use of plant fibres in load-bearing composite components, as a **possible replacement to E-glass**, is a natural step ahead.

Properties	Plant fibres[a]	Glass fibres[b]	Carbon fibres[c]
Economy			
Annual global production of fibres (tonnes)[d]	31000000	4000000	55000
Distribution of fibres for FRPs in EU (tonnes)[d]	Moderate (~60000)	Wide (600000)	Low (15000)
Cost of raw fibre (£/kg)	Low (~0.5–1.5)	Low (~1.3–20.0)	High (>12.0)
Technical			
Density (gcm^{-3})	Low (~1.35–1.55)	High (2.50–2.70)	Low (1.70–2.20)
Tensile stiffness (GPa)	Moderate (~30–80)	Moderate (70–85)	High (150–500)
Tensile strength (GPa)	Low (~0.4–1.5)	Moderate (2.0–3.7)	High (1.3–6.3)
Tensile failure strain (%)	Low (~1.4–3.2)	High (2.5–5.3)	Low (0.3–2.2)
Specific tensile stiffness (GPa/gcm^{-3})	Moderate (~20–60)	Low (27–34)	High (68–290)
Specific tensile strength (GPa/gcm^{-3})	Moderate (~0.3–1.1)	Moderate (0.7–1.5)	High (0.6–3.7)
Abrasive to machines	No	Yes	Yes
Ecological			
Energy consumption/kg of raw fibre (MJ)	Low (4–15)[e]	Moderate (30–50)	High (>130)
Renewable source	Yes	No	No[f]
Recyclable	Yes	Partly	Partly
Biodegradable	Yes	No	No
Hazardous/toxic (upon inhalation)	No	Yes	Yes

2013 FLAX REINFORCEMENTS

UD PREPREGS

ROVING

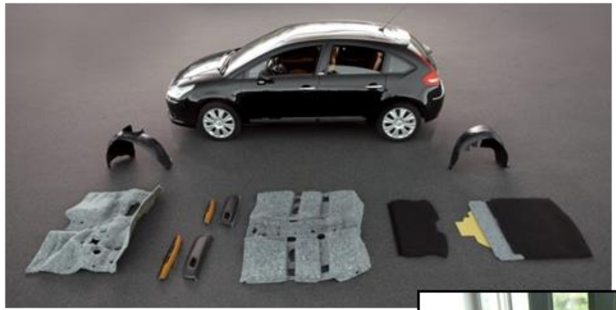
KU LEUVEN

2013 FLAX REINFORCEMENTS

CELC
EUROPEAN CONFEDERATION OF FLAX AND HEMP

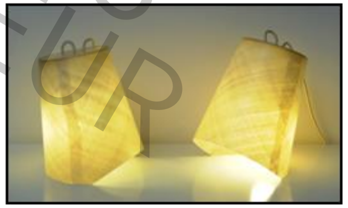
NON WOVEN





NON-CRIMP FABRIC



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2013 FLAX REINFORCEMENTS

WEAVES

PRE-IMPREGNATED (met thermoharders)

MIXED WEAVES (met thermoplasten)

Quelles matrices avec les fibres végétales?

PLA?

The use of synthetic thermoset matrices, for instance, will produce bio-based composites that are not biodegradable or strictly recyclable

They will nonetheless play a valuable role in the future increasing use of eco materials

[Darshil U. Shah J Mater Sci 2013]

Synthesis of new biobased building blocks for Polymer Synthesis
[Sylvain Caillol et al, Aussois 2014]

In recent years, the sustainability is becoming increasingly important for the chemical industry; thus, the use of renewable resources has gained interest in polymer applications. Indeed, overall demand for chemical products will increase by 50% in volume by 2020.
Thus, American studies estimate that **90% of organic chemicals will come from renewable resources by 2090**.

However, it is not sufficient to synthesize exactly the same chemicals from renewable resources, even if they are harmful. Biobased chemicals could also be very dangerous.

New processes have to be developed to **replace hazardous reactives by harmless, biobased ones.**

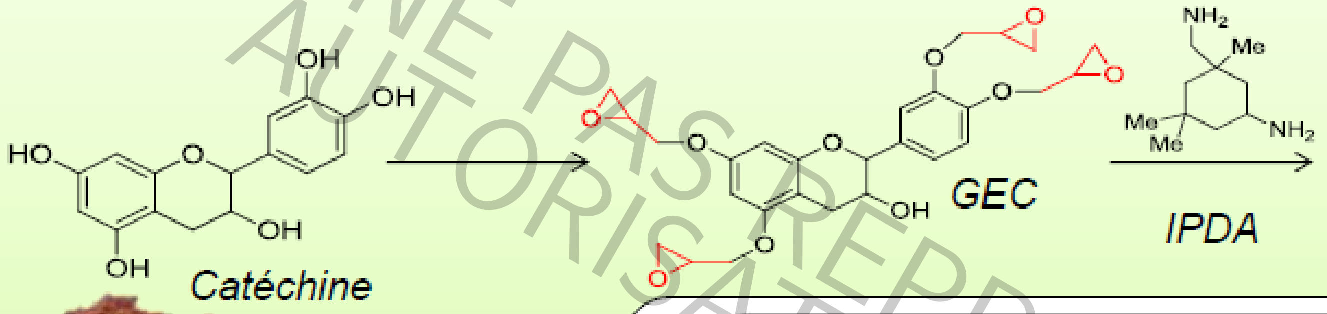
Vegetable oils are extracted primarily from the seeds of oilseed plants.

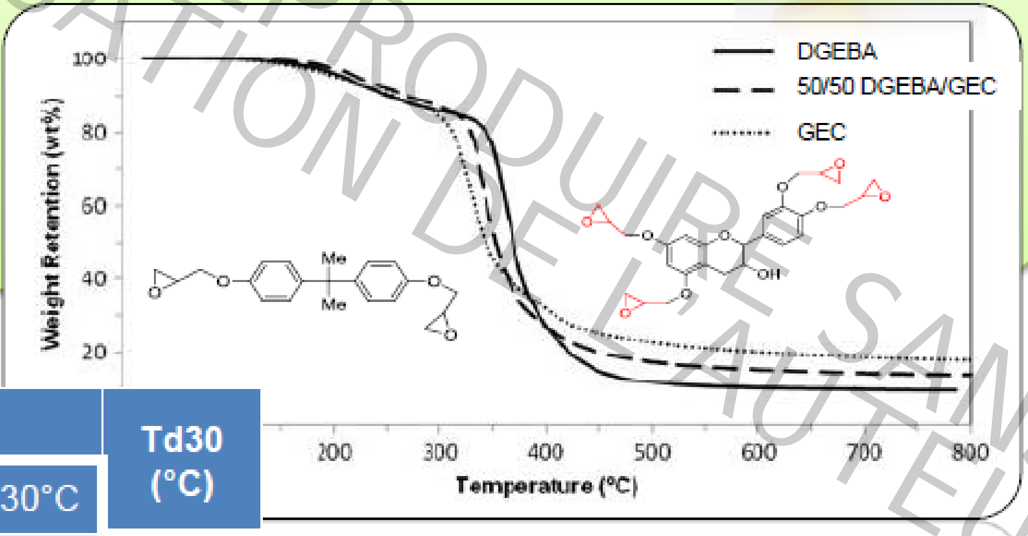
Demand for renewable resources is increasing for polymers and composite applications

The team (*Caillol, Montpellier)* synthesized new building-blocks from vegetable oils in order to synthesize biobased polyurethanes (PUs) and epoxy resin (ER) materials.

Epoxidation of natural phenol : catechin

- **Substitution of Bisphenol A in aromatic epoxy resins**





System	Tα (°C)	E' (MPa)		Td30 (°C)
		30°C	Tg+30°C	
GEC-IPD	179	1.50 10^3	36.4	334
DGEBA-IPD	140	1.29 10^3	13.6	353

H. Nouailhas et al., J. Pol. Sci. Part A: Polym. Chem., 2011, 49, 2261–2270
Patent FR 0905594, WO 2010136725

Les développements de résines biosourcées existent

Il ne faut pas confondre biosourcé et biodégradable

Il est nécessaire que des industriels développent des résines biosourcées et les commercialisent pour qu’elles soient utilisées dans les composites

Matrix type (Standard)

30 % of the PFRPs were based on the thermoset matrices,
the rest were based on the thermoplastic matrices

There is a general trend, particularly in the automotive industry, of **diminishing the use of thermoset matrices and increased use of thermoplastic matrices**

This is primarily because the latter are **faster to process**, are fabricated by a **cleaner process** (dry systems with no toxic by-products), are easier to recycle, and are less expensive (for high-volume production)

Thermosets may be more suitable for PFRPs **in structural applications**

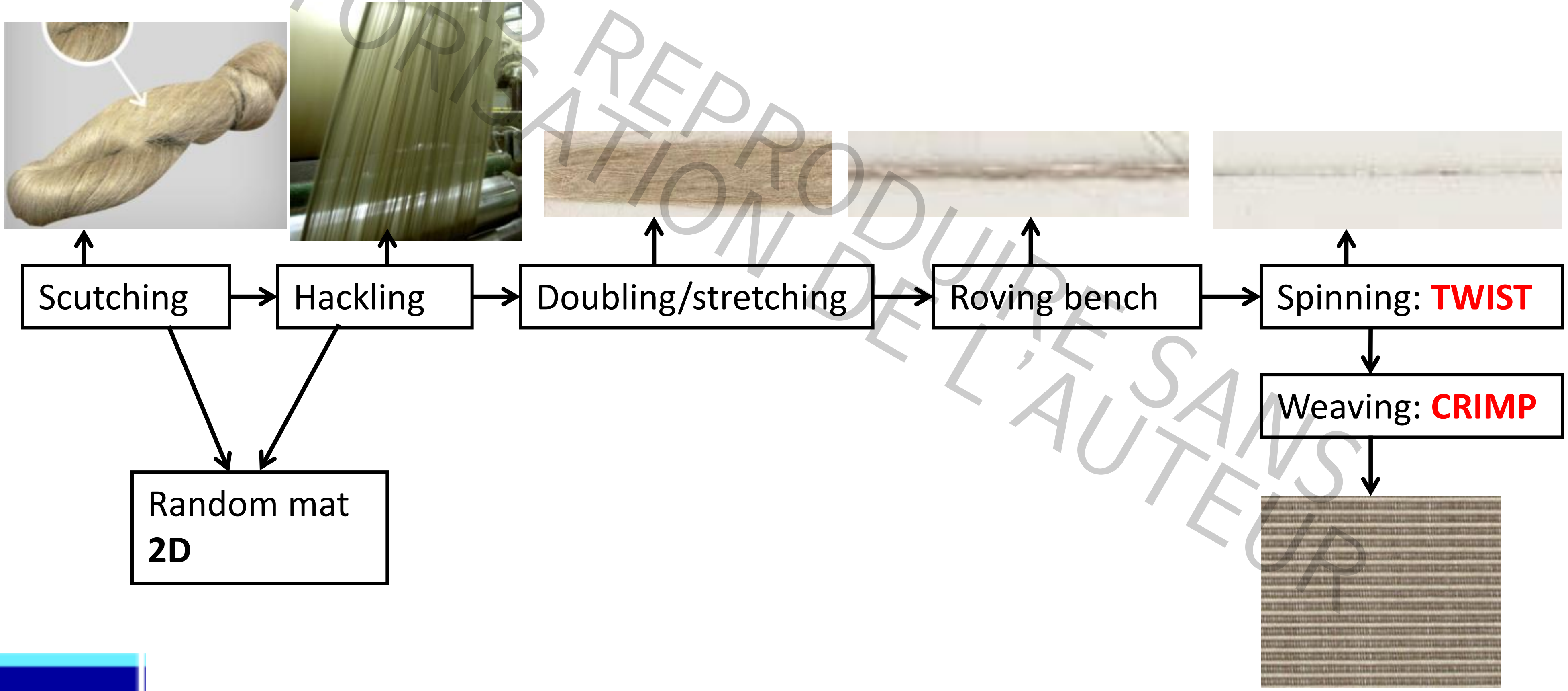
- Firstly, thermoset matrices have better mechanical properties than thermoplastics
- Secondly, the low-processing temperatures (typically below 100 °C) and viscosity (0.1–10 Pas) of thermoset matrices implies that plant fibre mechanical properties are not degraded due to high-temperature exposure
- Resin impregnation and preform wettability are easier leading to lower void content and betterinterfacial properties.
- Possibility of using liquid composite moulding techniques, such as vacuum infusion and resin transfer moulding (RTM),
- Finally thermosets have better shear properties than thermoplastics

[Darshil U. Shah J Mater Sci 2013]

Flax: from plant to textile… for composites???

The value chain as it was up to some years ago….:

oriented towards textile markets



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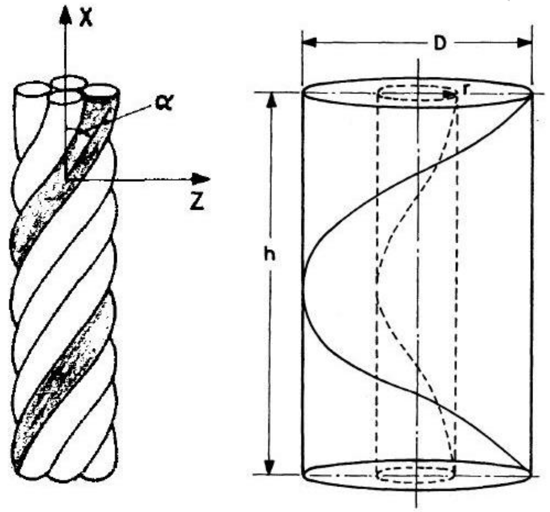
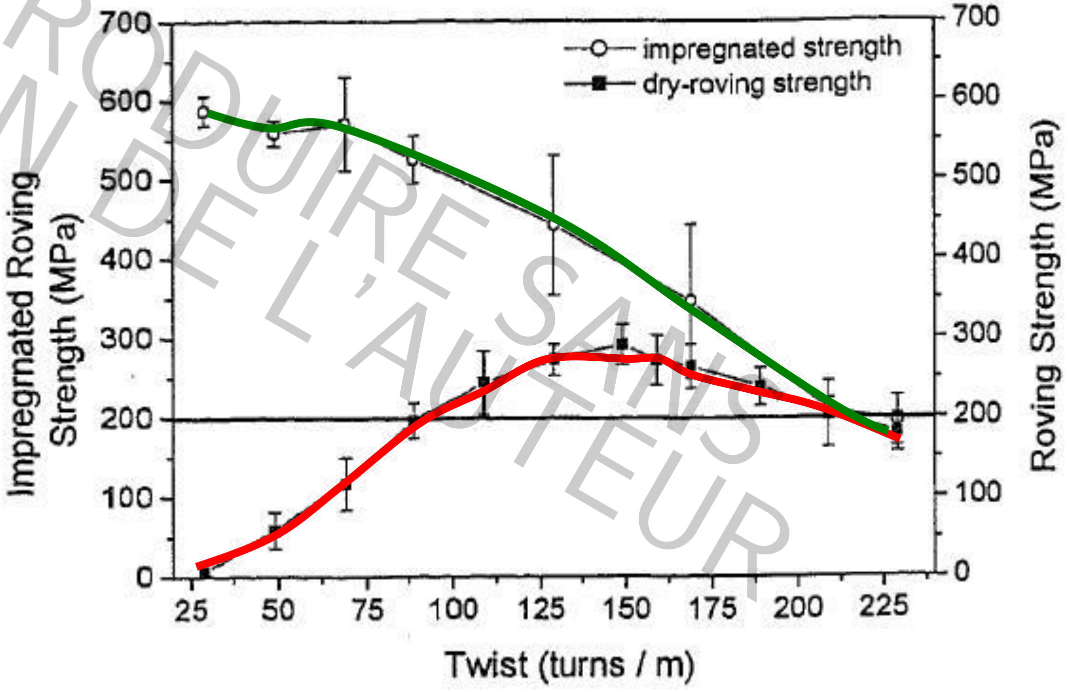
Problem 1: why twisted yarns and no rovings?

- **Natural fibres are by definition discontinuous *(plants do not grow to the sky!)***
- **Hence twisting is needed to keep them together during further textile operations (weaving, braiding, knitting…)**
- **With increasing twist in the yarn: the dry roving/yarn strength increases … but…**
  - **… the UD composite strength decreases**





[Goutianos&Peijs, 2003]

Study 1: effect of twist in long fibre UD composites

- 4 long fibre products from different stages in the flax extraction/refining/spinning process
- material provided by Terre de Lin /Safilin

	Hackled ribbon	Doubled ribbon	Roving	Yarn
Lineair weight [tex]	24 000	4 800	276	78
Twist angle [°]	0	0	7,8	19,4

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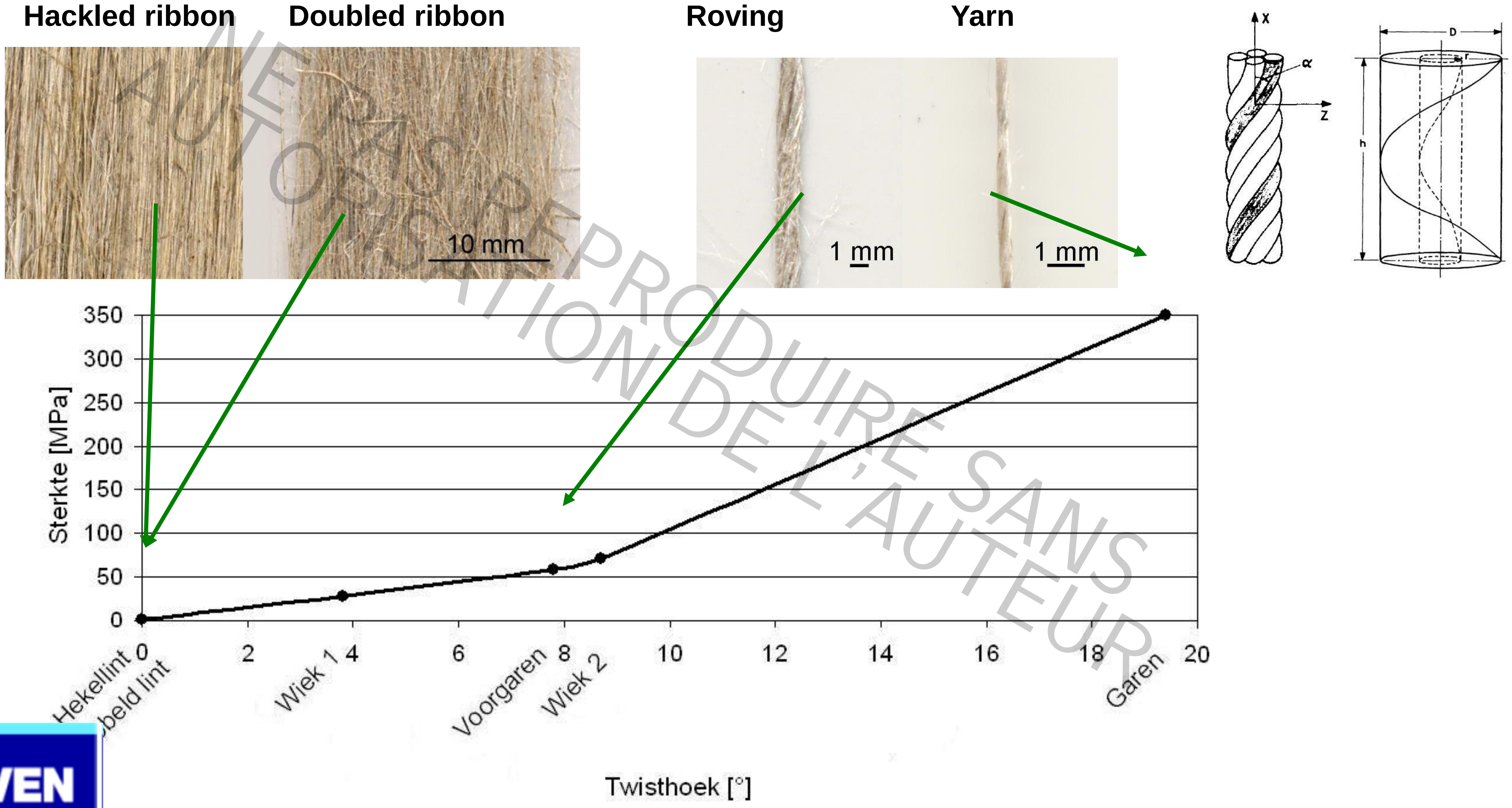
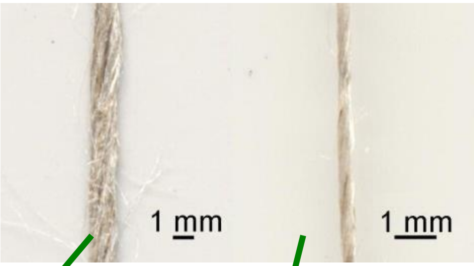
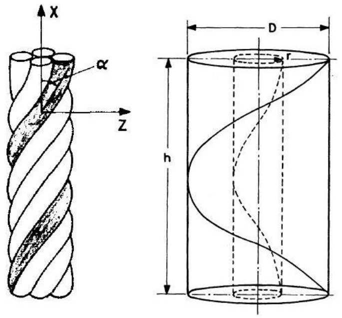
Effect of twist on flax dry yarn strength

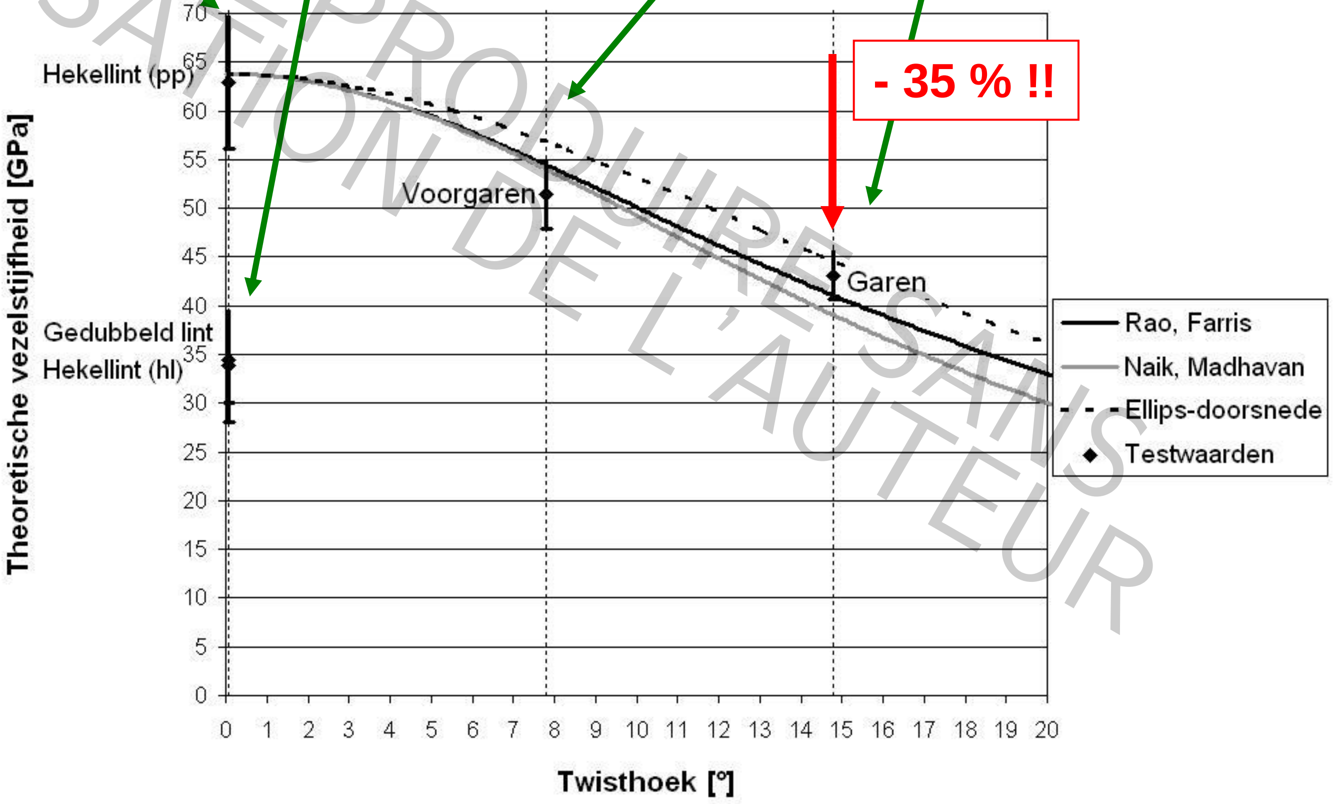


Effect of twist on UD-composite stiffness *

Hackled ribbon **Doubled ribbon** **Roving** **Yarn**







* **Back-calculated fibre stiffness (matrix=epoxy)**

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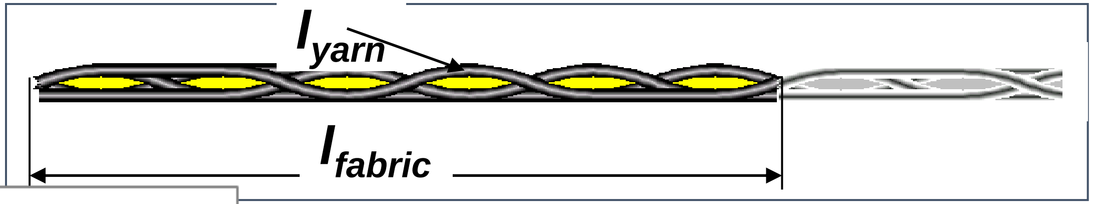
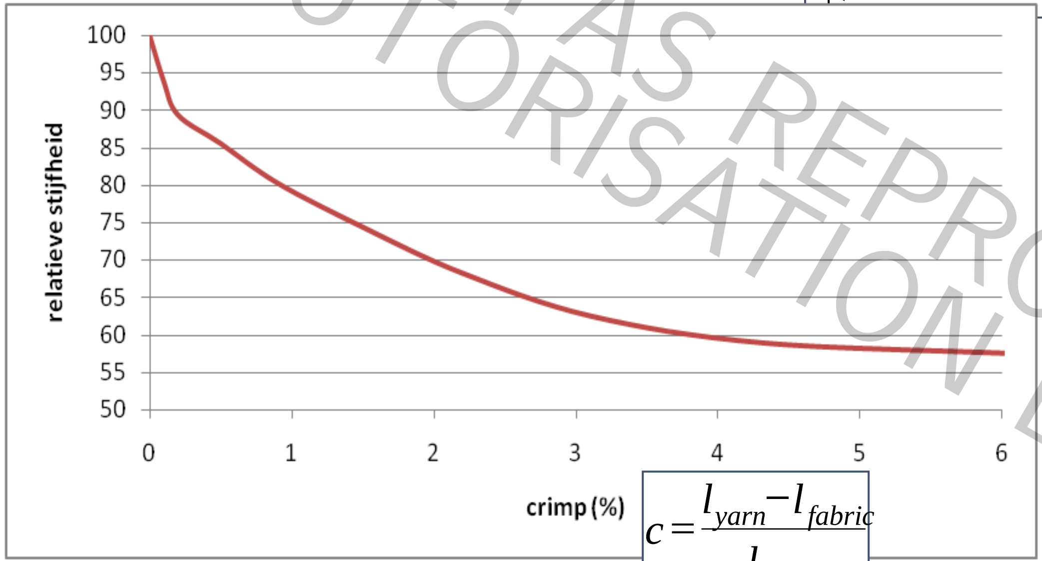
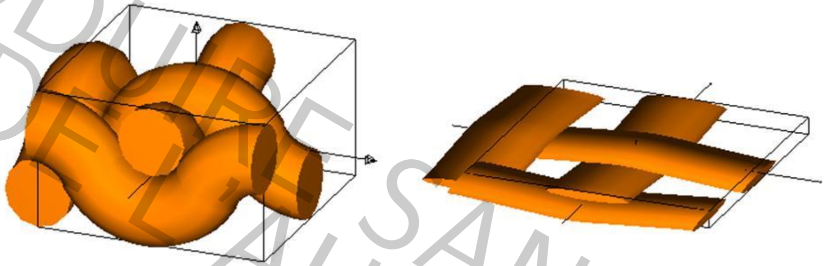
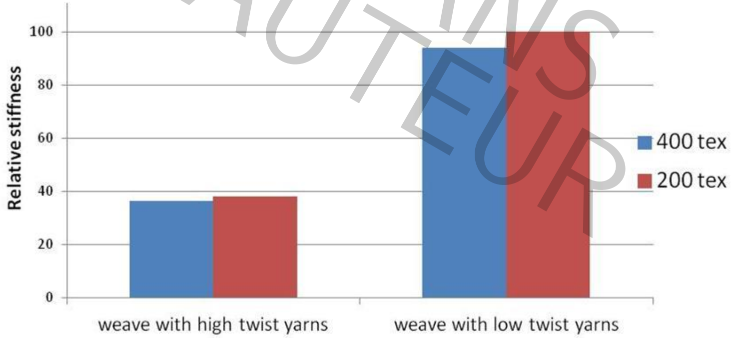
Problem 2: crimp in a weave on composite stiffness

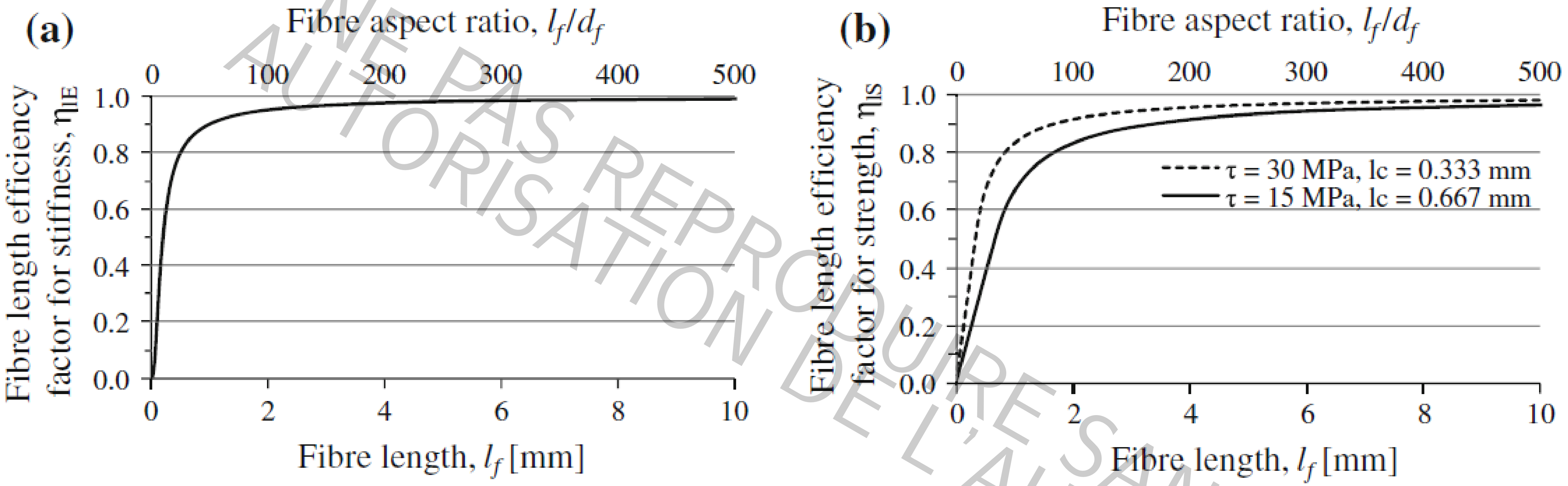




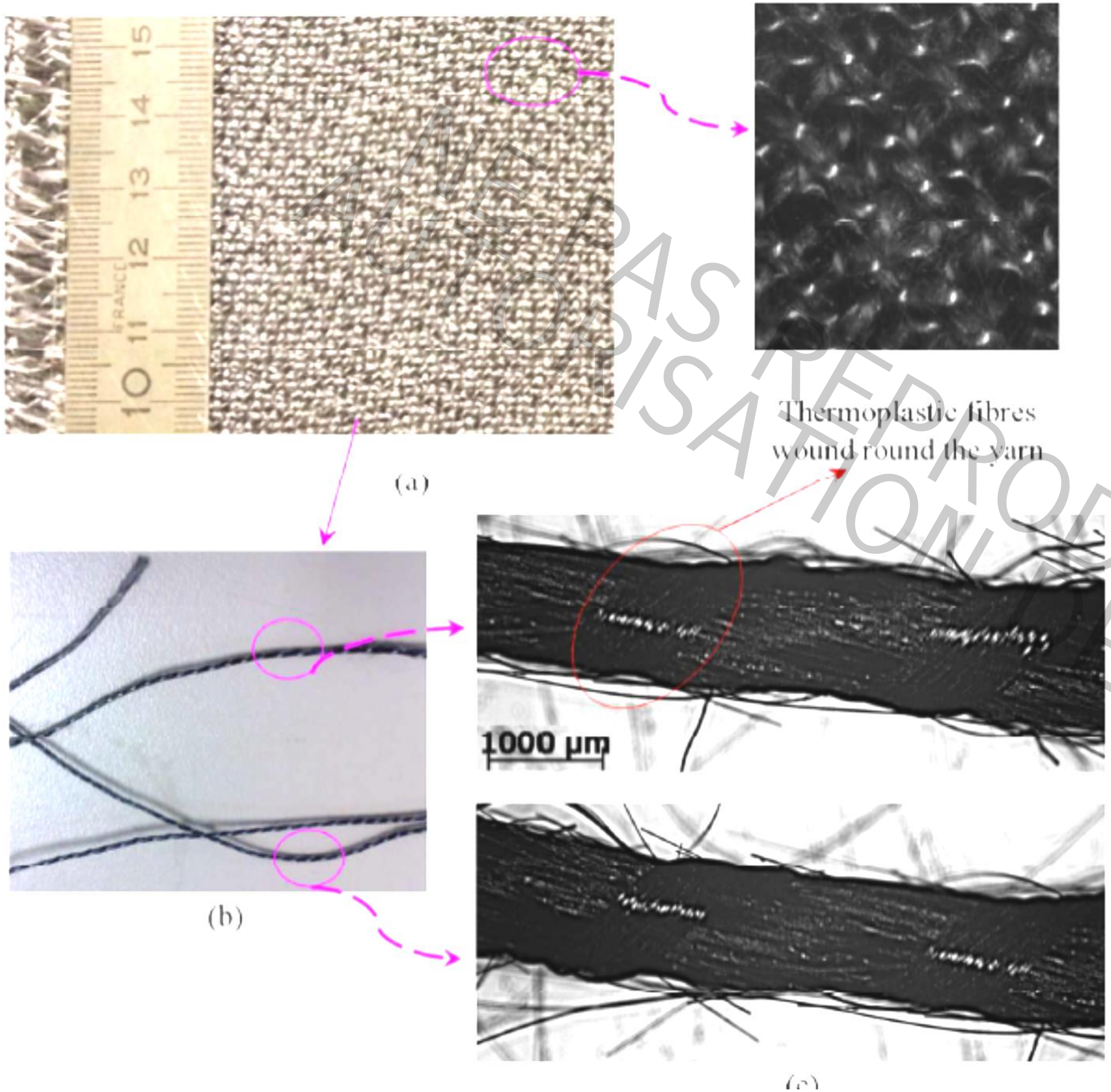
$$c = \frac{l_{yarn} - l_{fabric}}{l_{fabric}}$$







[Darshil U. Shah J Mater Sci 2013]

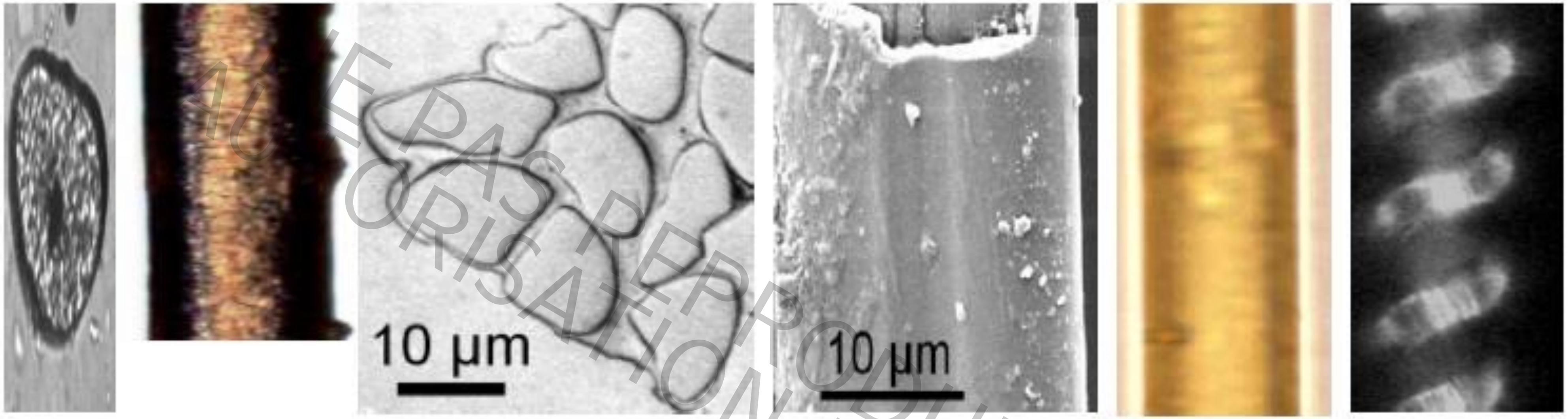


Stretch-broken carbon fibre (SBCF)
and thermoplastic resin composites

Schappe techniques, F-01150

Longueur des fibres 40 à 200 mm
(moyenne 65 mm)

[P. Wang et al, Polymer composites, in press]

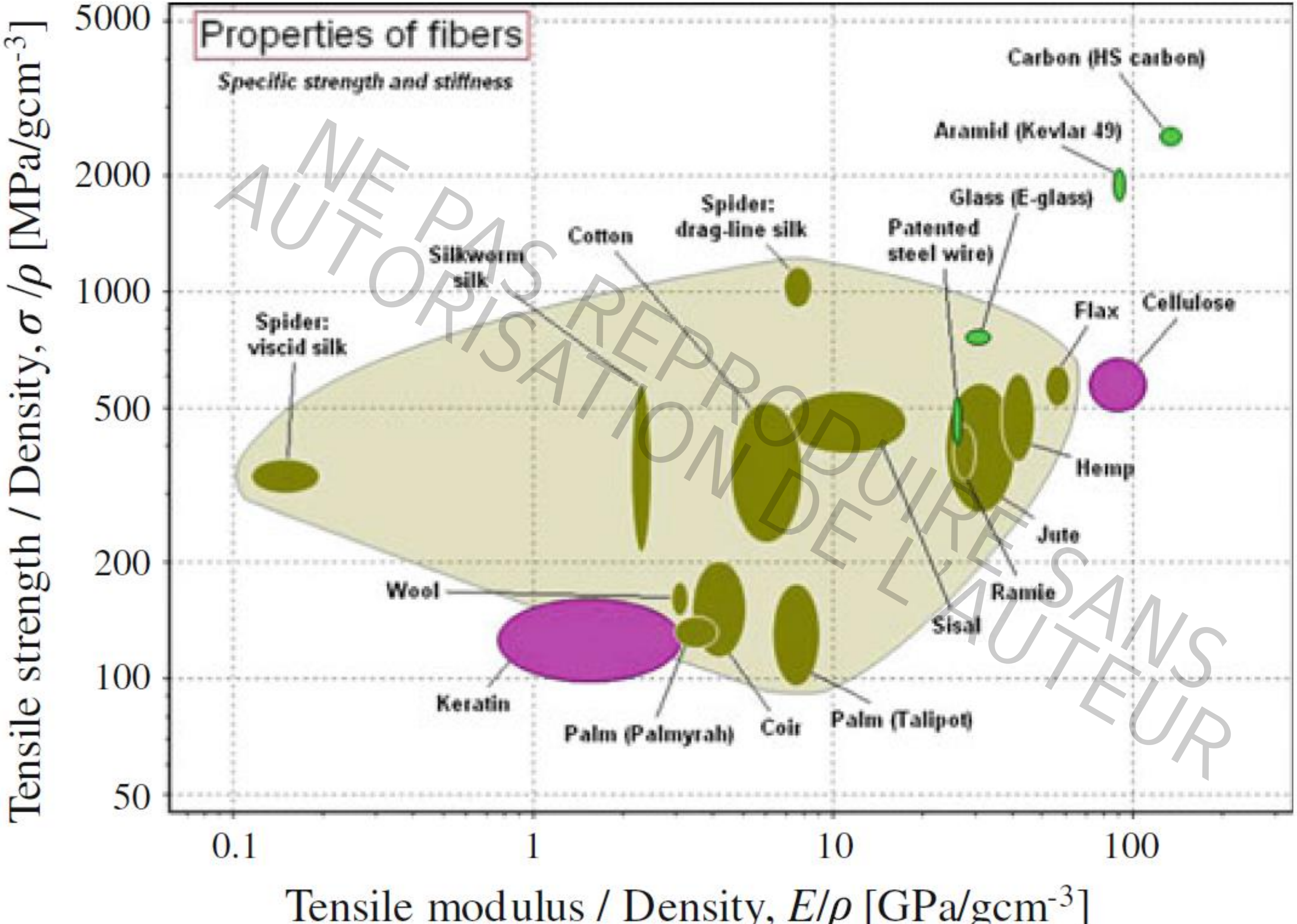


Fil de soie grège de Bombyx Mori (**jusqu'à 1500m**); fibres d'araignée

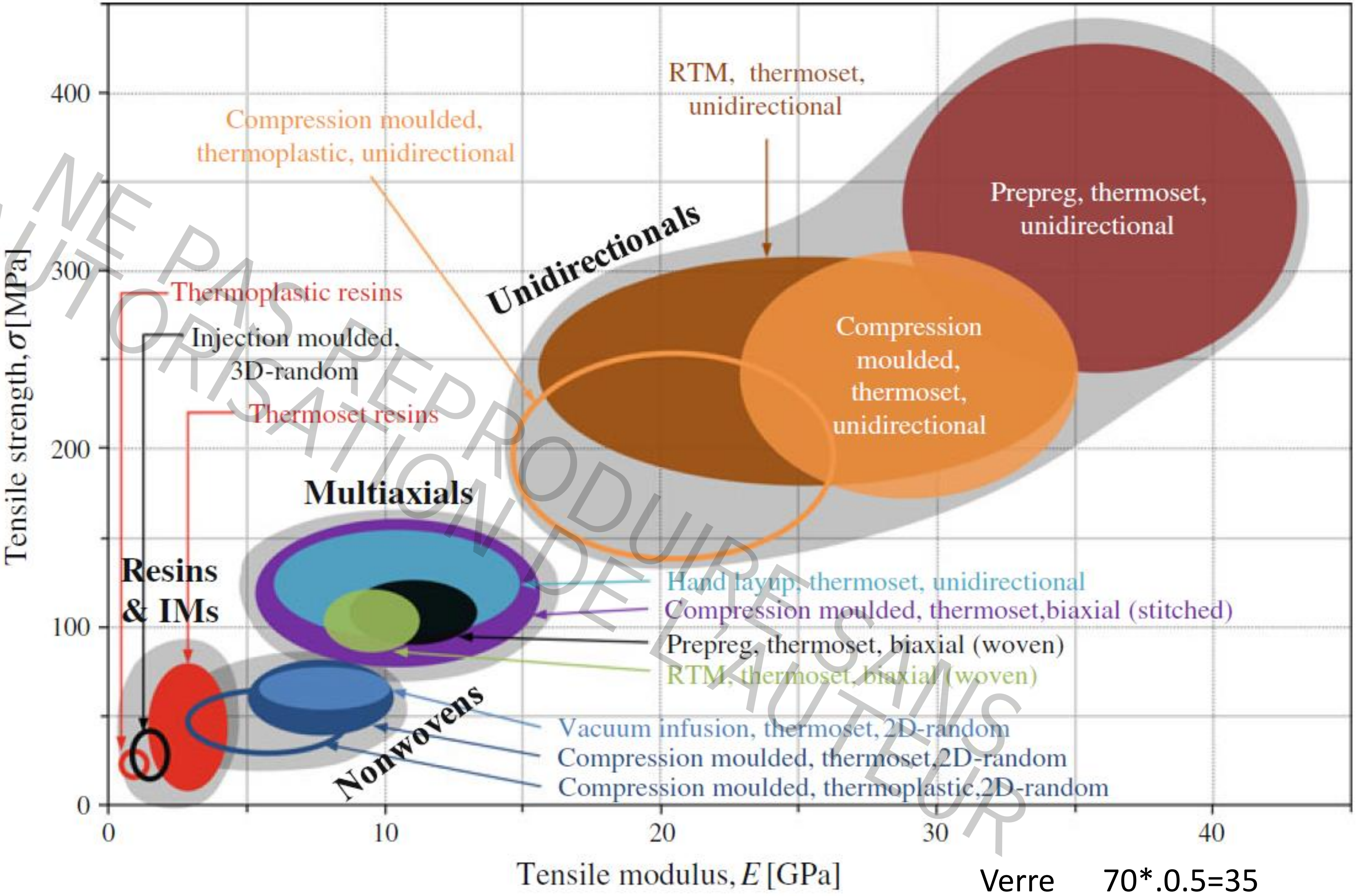
Fibres animales, des polyamides naturels

Table 3 Comparison of the mechanical properties of various plant fibres and E-glass

Fibre	Density (gcm^{-3})	Tensile modulus (GPa)	Specific tensile modulus (GPa/gcm^{-3})	Tensile strength (MPa)	Specific tensile strength (MPa/gcm^{-3})	Failure strain (%)
Bast						
Flax	1.45–1.55	28–100	19–65	343–1035	237–668	2.7–3.2
Hemp	1.45–1.55	32–60	22–39	310–900	214–581	1.3–2.1
Jute	1.35–1.45	25–55	19–38	393–773	291–533	1.4–3.1
Leaf						
Sisal	1.40–1.45	9–28	6–19	347–700	248–483	2.0–2.9
Pineapple	1.44–1.56	6–42	4–27	170–727	118–466	0.8–1.6
Banana	1.30–1.35	8–32	6–24	503–790	387–585	3.0–10.0
Seed						
Cotton	1.50–1.60	5–13	3–8	287–597	191–373	6.0–8.0
Coir	1.10–1.20	4–6	3–5	131–175	119–146	15.0–30.0
Oil palm	0.70–1.55	3–4	2–4	248	160–354	25.0
Other						
Bamboo	0.60–1.10	11–30	18–27	140–230	210–233	1.3
Wood pulp[a]	1.30–1.50	40	26–31	1000	667–769	4.4
E-glass	2.55	78.5	31	1956	767	2.5


Properties of fibers
Specific strength and stiffness
Tensile strength / Density, σ /ρ [MPa/gcm-3]
Tensile modulus / Density, E/ρ [GPa/gcm-3]
5000
2000
1000
500
200
100
50
0.1
1
10
100
Carbon (HS carbon)
Aramid (Kevlar 49)
Glass (E-glass)
Patented steel wire)
Spider: drag-line silk
Cotton
Silkworm silk
Spider: viscid silk
Flax
Cellulose
Hemp
Jute
Ramie
Sisal
Wool
Keratin
Palm (Palmyrah)
Coir
Palm (Talipot)

Verre 3500*0.5=1750
Carbone 4000*0.5=2000
Aramide 3500*0.5=1750



Verre 70*.0.5=35
Carbone 300*0.5=150
Aramide 120*0.5=60

Ashby plot for PFRPs

Plant fibres, even of the same type, have **highly variable properties**.
The variability in properties can be ascribed to the variability in fibre microstructural parameters.

The fibre micro-structural parameters, which dictate the fibre quality, are themselves influenced by

(i) Plant growth conditions (including, plant species, geographic location, climate, soil characteristics and crop cultivation),

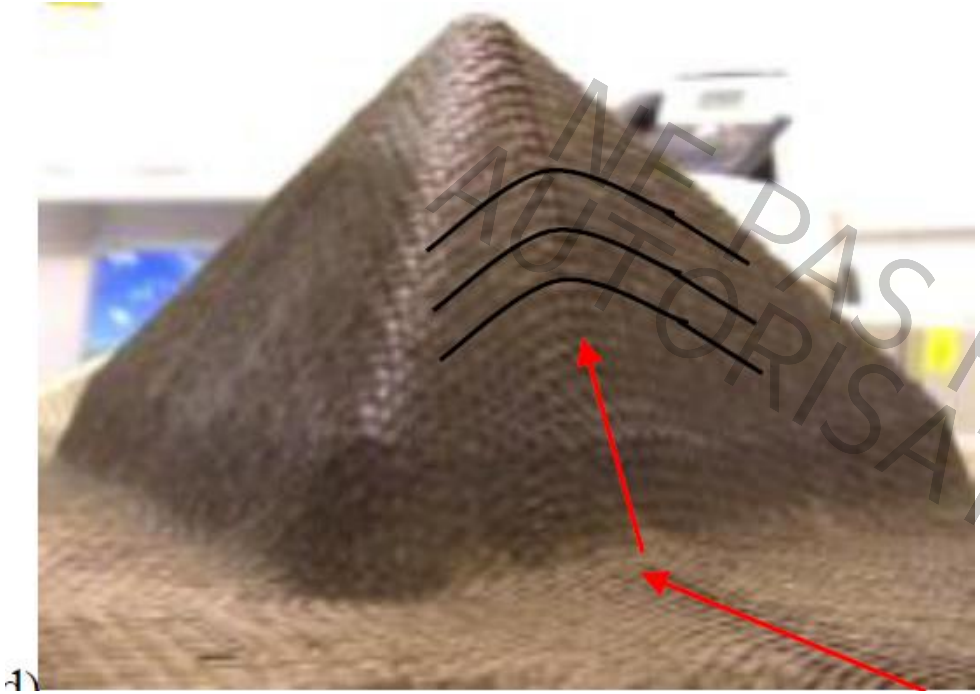
(ii) **fibre extraction and preparation** (including, age of plant, fibre location in plant, type of retting method, decortication and carding processes)

(iii) **fibre processing** (including, spinning to produce rovings from slivers and yarns from rovings, and production of mats and textile preforms from slivers/rovings/yarns).

To ensure that the quality of their products is consistent (i.e. the variability in properties is within acceptable limits) and independent of plant growth conditions,
suppliers of plant fibres/yarns typically use '**batchmixing**',
across several **crops/harvests/years**

Regarding optimising fibre extraction and processing, the resounding message of scientific studies is that an **increasing number of mechanical processing steps leads to an increase in defect count** (in the form of kink bands, for instance), a reduction in degree of polymerisation of the cellulose chains, and a subsequent reduction in fibre mechanical properties.
Minimally-processed fibres that have undergone retting and hackling produce high-quality fibres and good quality composites

Increasing twist levels have various detrimental effects on composite properties, including hindered resin impregnation, reduced wettability, increased intra-yarn void formation and **a significant quantifiable drop in tensile properties**, similar to an off-axis composite, due to increased fibre misorientation



Des préformes complexes, non développables peuvent être réalisées

[P. Ouagne et al, Aussoix 2014]

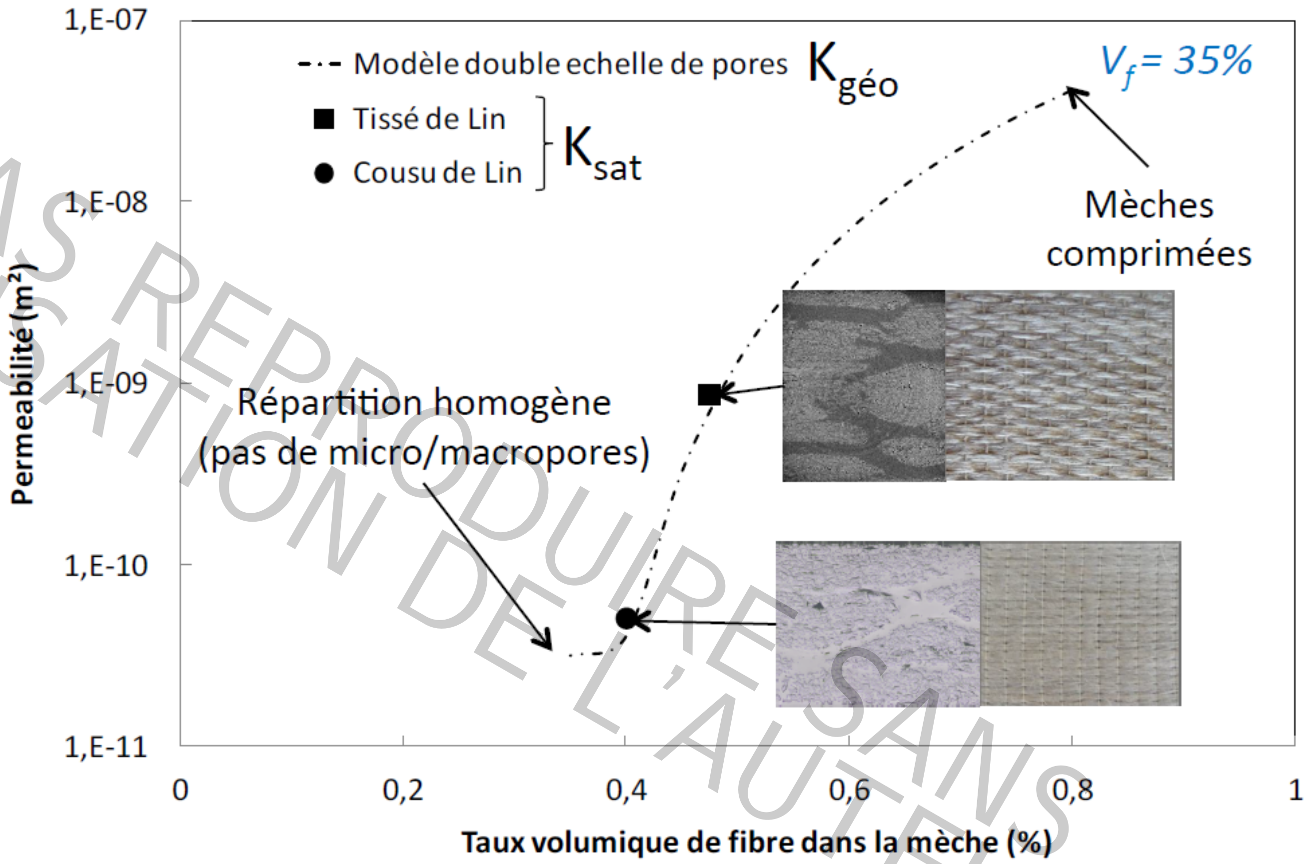
,

PRISME, Orléans

Perméabilité des préformes

Imprégnationd'une préforme,
Interaction fluide/solide

[J. Bréard et al, Aussois 2014]
LOMC– Le Havre



Influence des paramètres textiles
sur la répartition micro/macropores > perméabilité

A significant amount of work has been undertaken to explore various avenues in improving the **fibre/matrix interfacial properties**.
The two fundamental routes are fibre **surface physical/chemical modification** and matrix modification.

(iii) there is a **lack of consensus** in literature on the surface treatment parameters to use (e.g. concentration of reagent, treatment time and temperature) to achieve improvements in PFRP mechanical properties

Les traitements de surface des fibres naturelles

Des traitements de surface des fibres naturelles sont généralement nécessaires,
Pour améliorer le mouillage de celles-ci ainsi que la résistance au cisaillement inter faciale,
et d’autre part pour diminuer le caractère hydrophile des fibres naturelles

Ces traitements peuvent se classer en trois catégories

Les traitements physiques

Les traitements physicochimiques

Les traitements chimiques

[A. Bergeret et N. Le Moigne, Aussois 2014]
Centre des Matériaux des Mines d’Alès

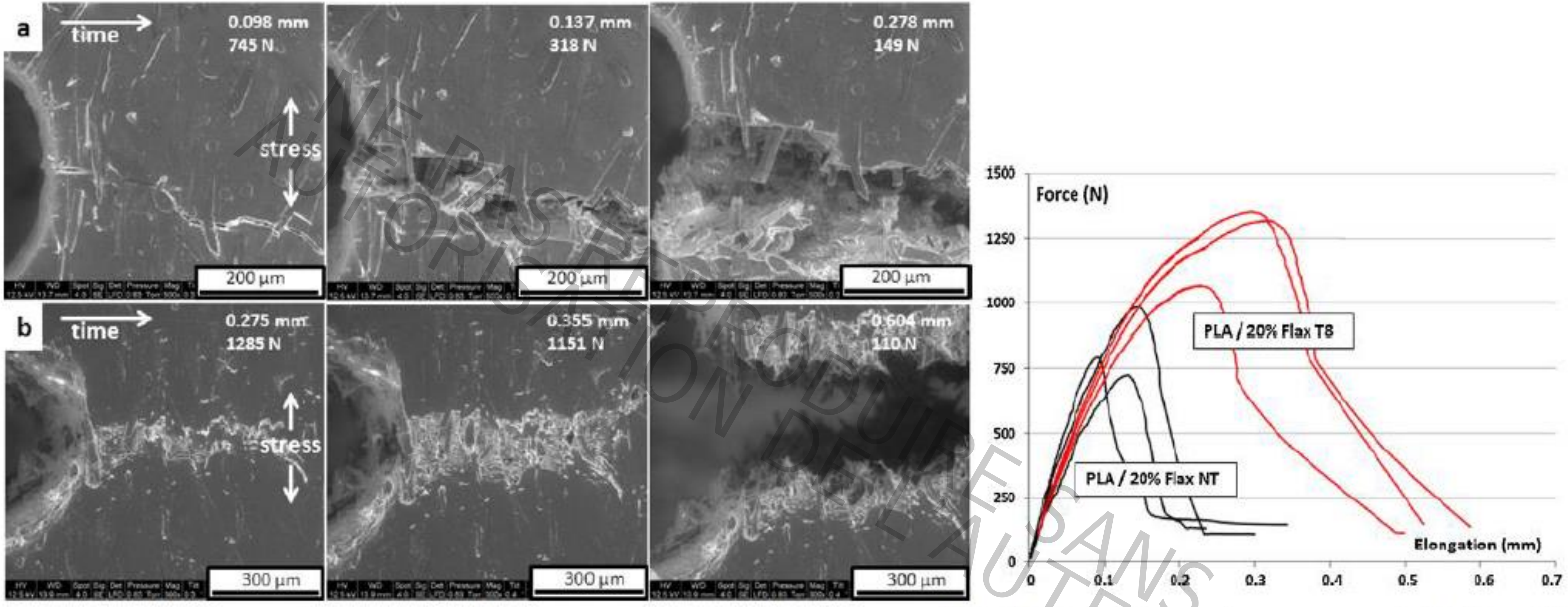
Les traitements de surface des fibres naturelles

On the other hand, if the reinforcing fibres are 'long', that is more than 10 times the critical fibre length, improvements to the interfacial shear strength (through fibre surface pre-treatment) have negligible effect on the length efficiency factor

[Shah J Mater Sci 2013]

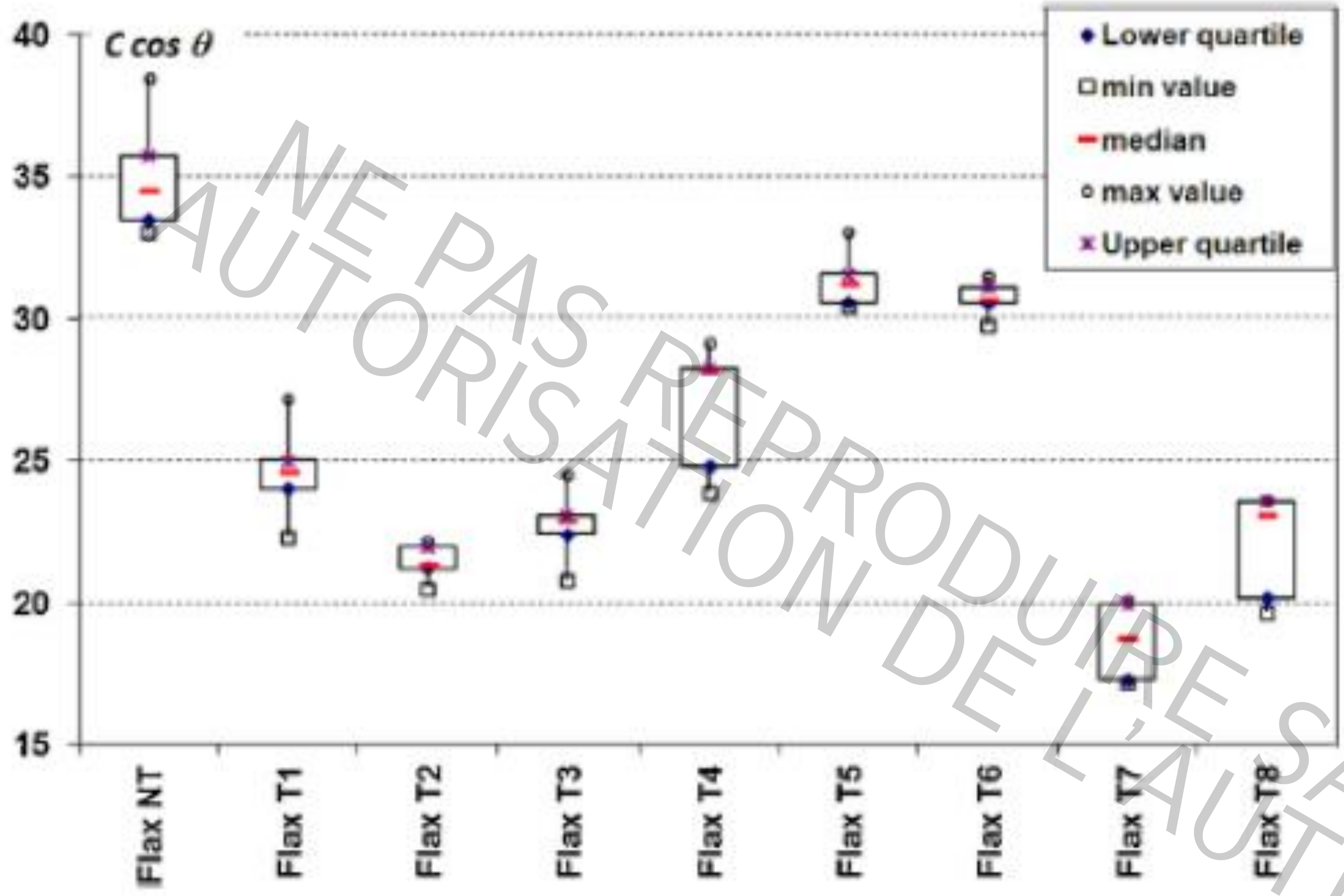
En ce qui concerne l'incorporation des fibres de lin dans une matrice biosourcée et biodégradable telle que l'acide polylactique (PLA), plusieurs études récentes ont montré que l'interface PLA/lin est intrinsèquement de bonne qualité.

[A. Bergeret et N. Le Moigne, Aussois 2014]
Centre des Matériaux des Mines d'Alès



Propagation de fissure sur PLA _ 20% fibres Non traité et traité

[A. Bergeret et N. Le Moigne, Aussois 2014]
Centre des Matériaux des Mines d'Alès

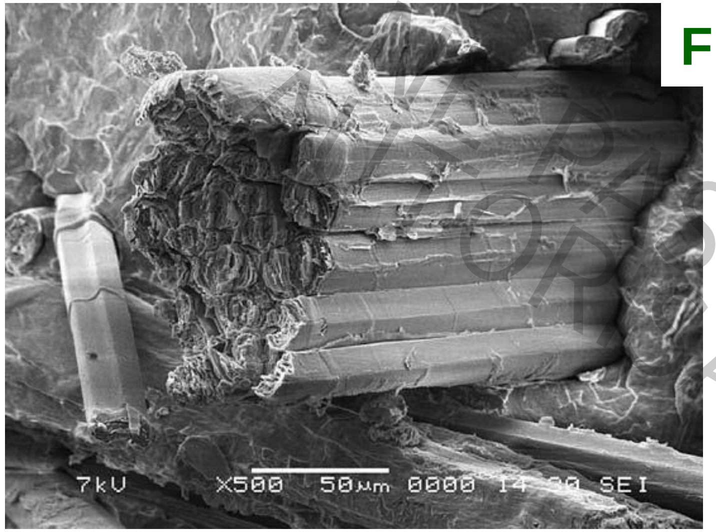


Propriétés de surface des fibres de lin évaluées à partir du paramètre Ccosθ

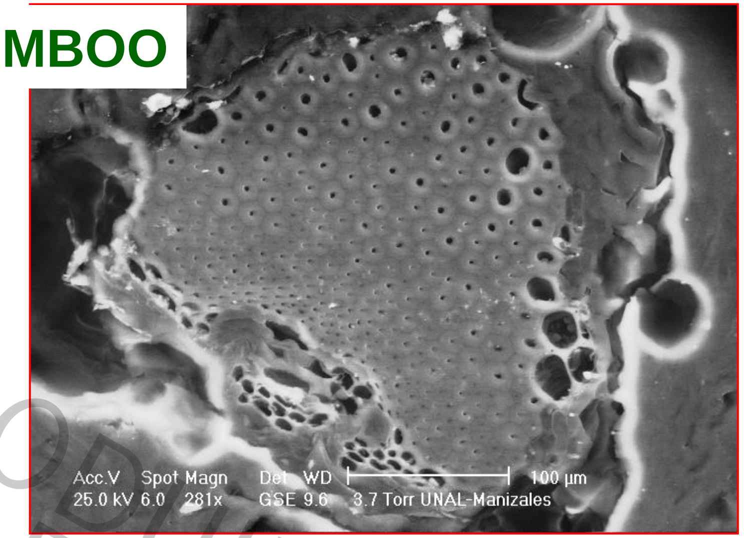
[A. Bergeret et N. Le Moigne, Aussois 2014]
Centre des Matériaux des Mines d'Alès

La complexité de la fibre naturelle est une spécificité

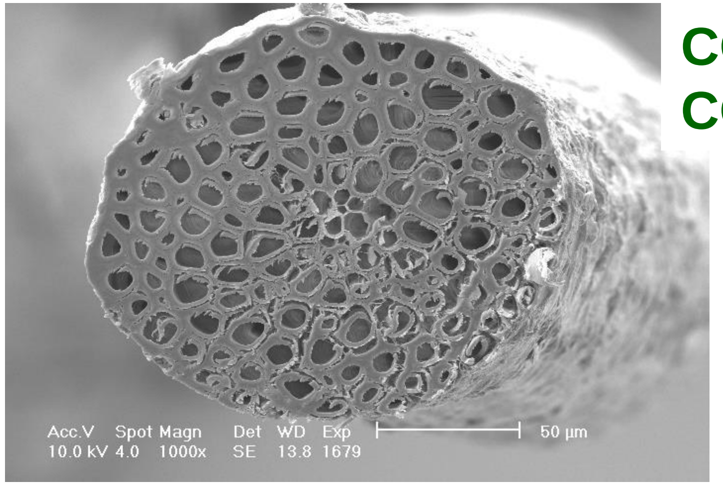
FLAX



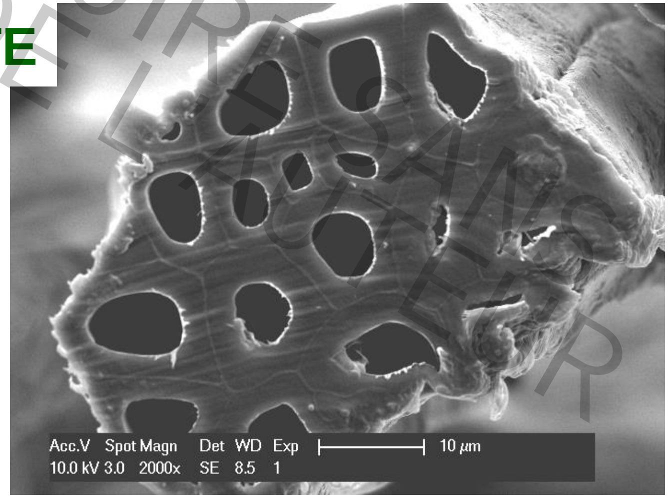
BAMBOO



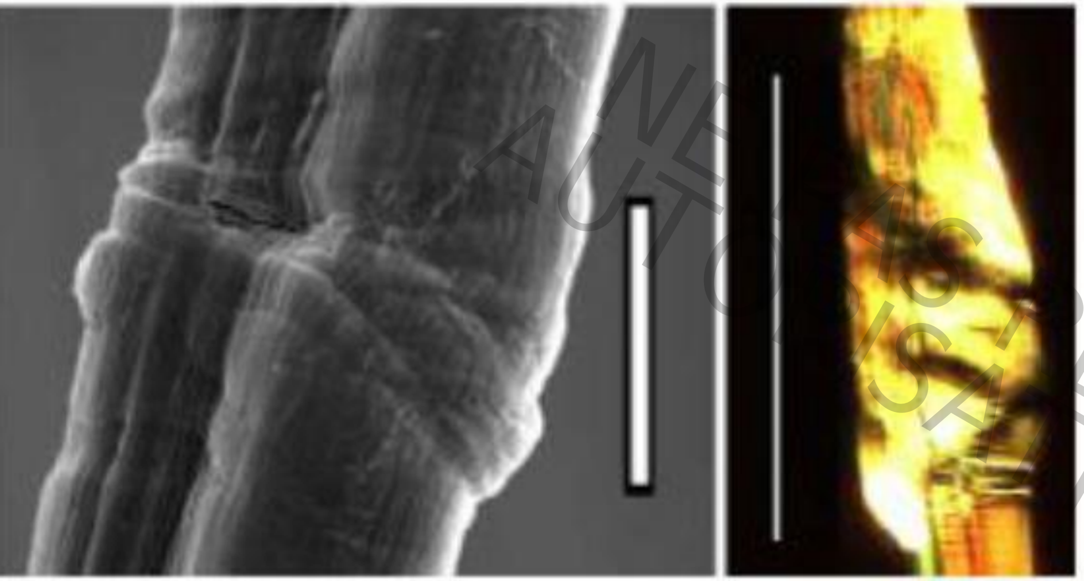
COIR/ COCONUT



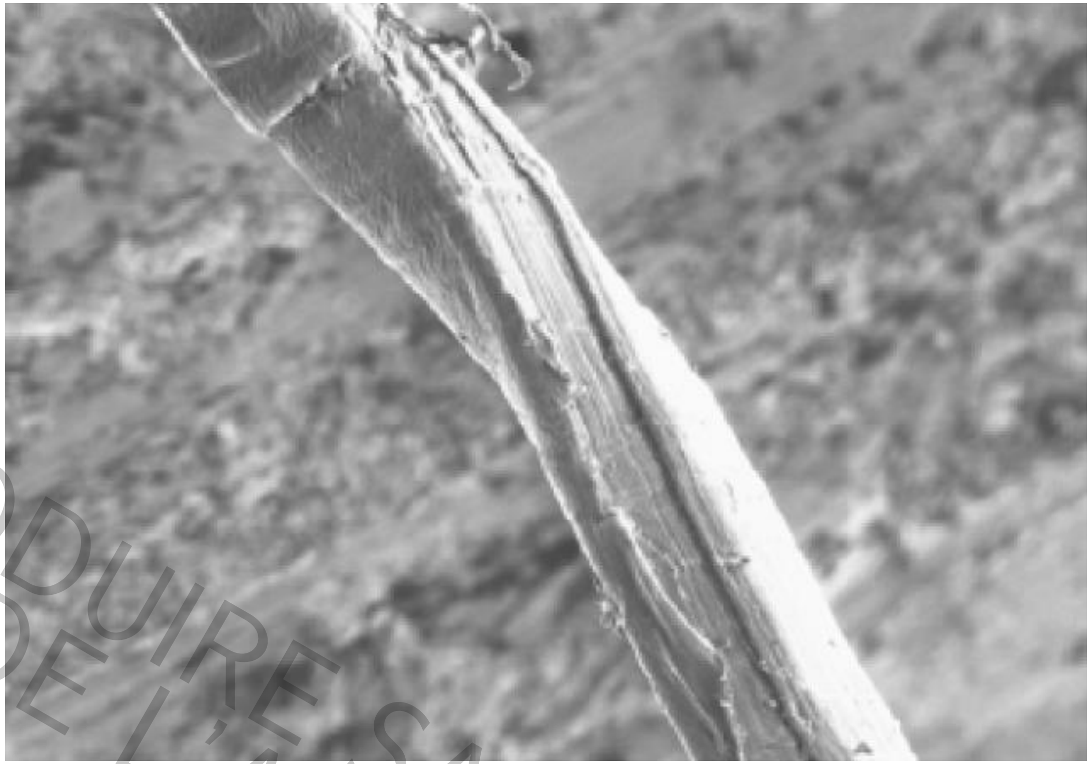
JUTE



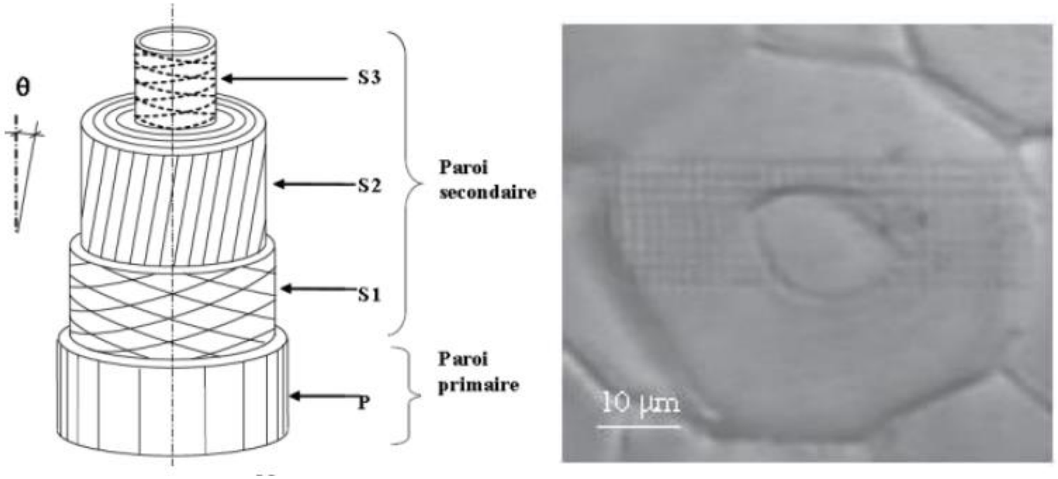
La complexité de la fibre naturelle est une spécificité



Genoux, chanvre [Thygesen et al, 2006]



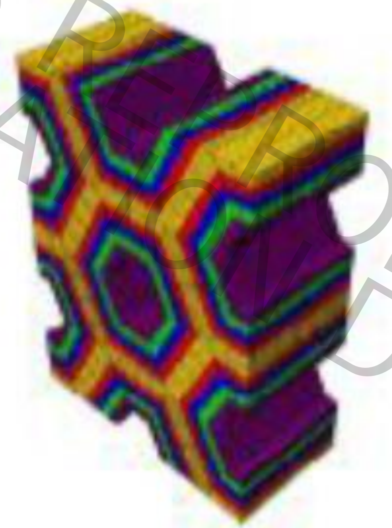
[V. Placet, et al, Aussois 2014]
FEMTO-ST Besançon



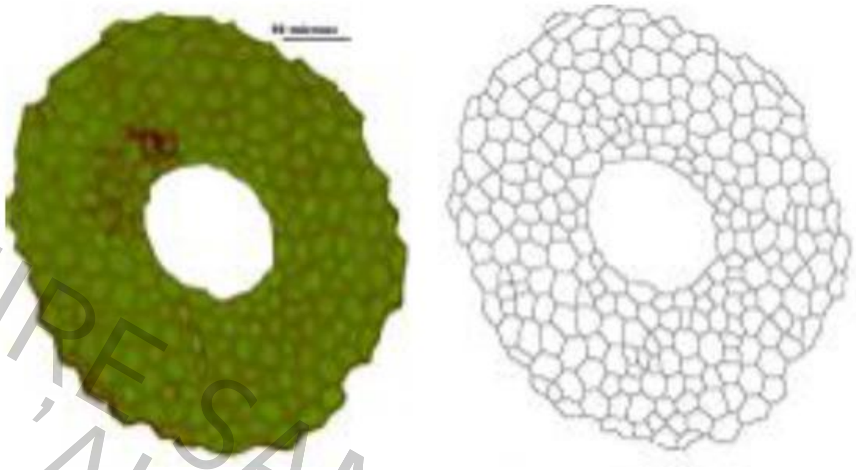
[Bourmaud et Baley, 2012]

Ceci conduit à des analyses numériques spécifiques aux différentes échelles

Essai virtuel sur une fibre de bois
(Kent Persson 2000)

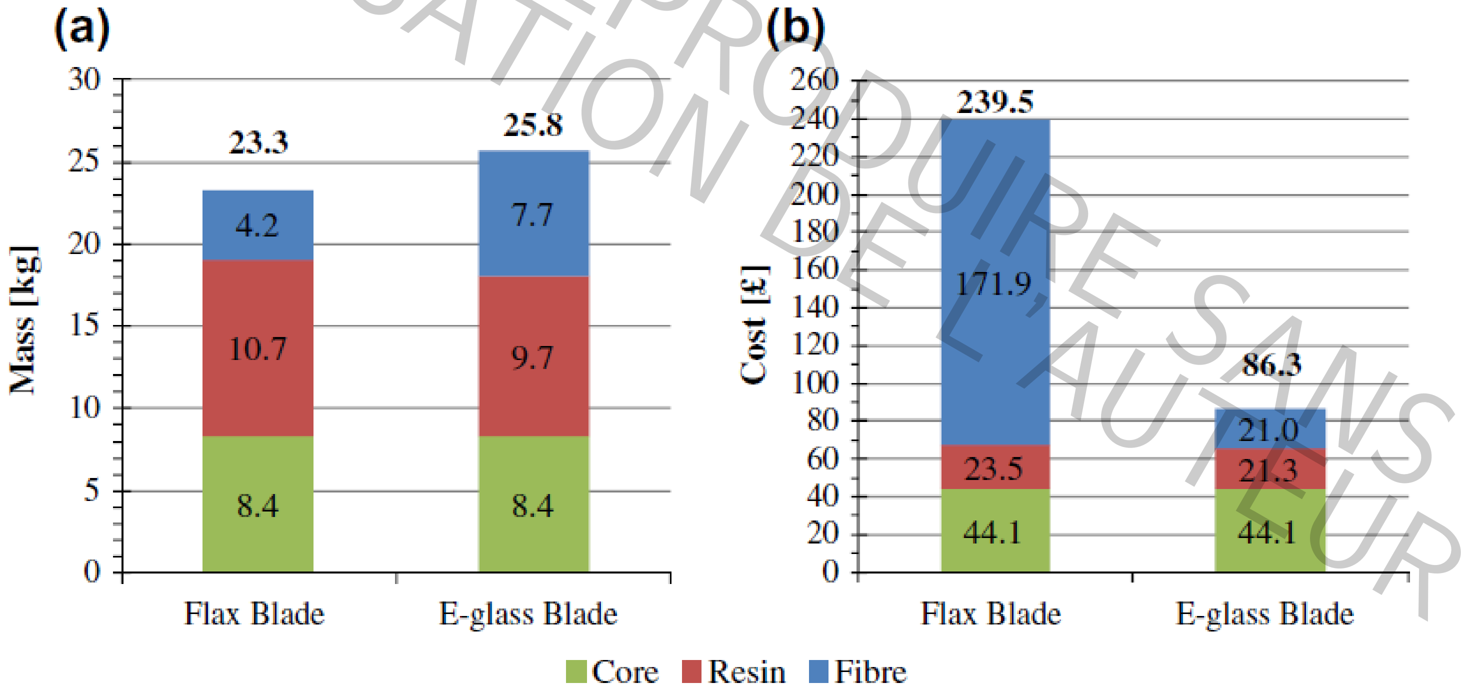


Volume élémentaire représentatif
du bois
d'après Qing et Mishnaevsky (2009)



Reconstruction surfacique
d'une section de faisceau de fibres
(Beakou et Ntenga 2011)

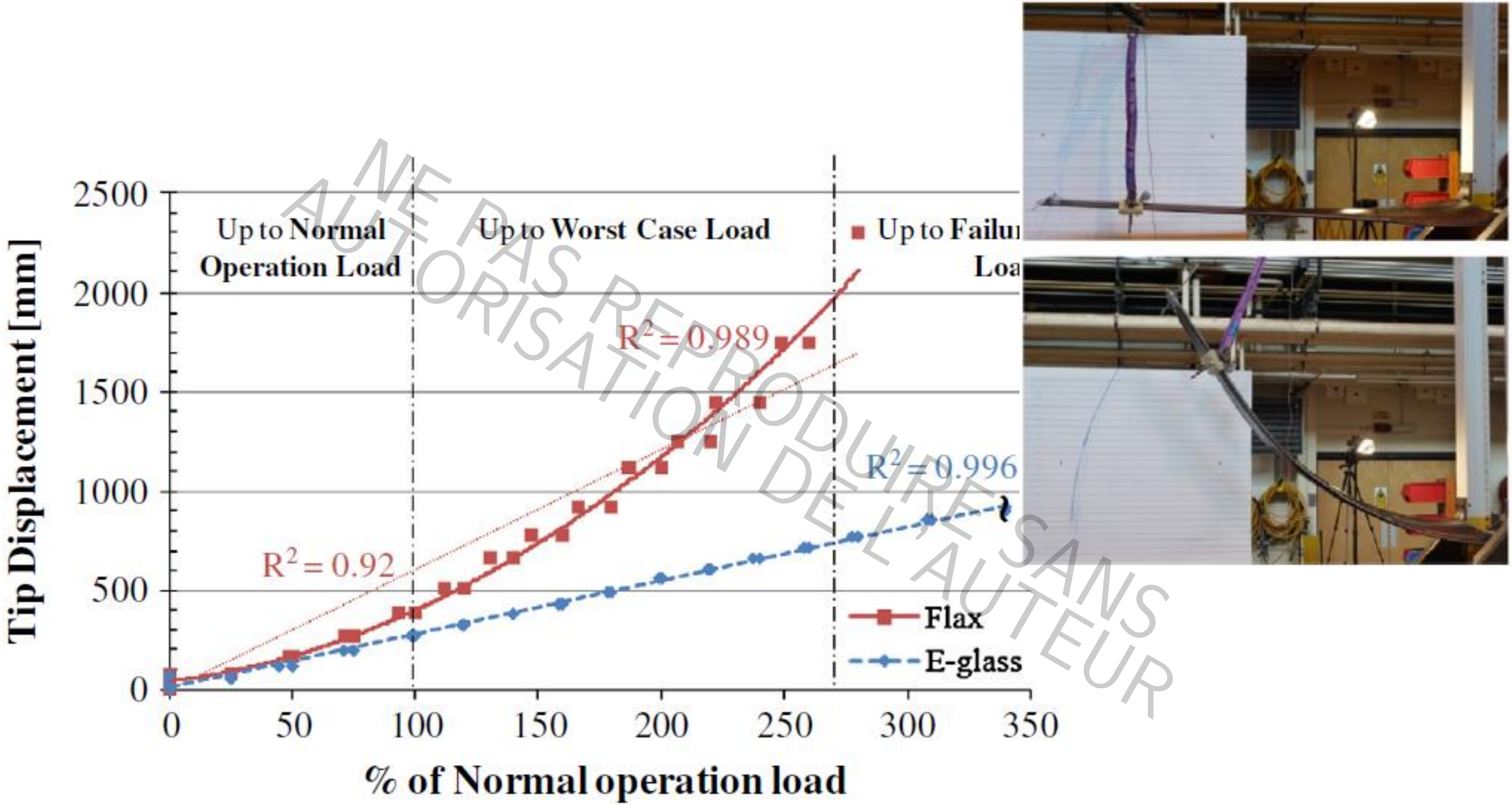
Images of the (a) flax/polyester and (b) E-glass/polyester blades.



Comparison of the (a) mass and (b) materials cost of the flax and E-glass blades.

Static flap-bending tests, conducted in accordance to certification standards, confirm that **like the E-glass blade, the flax blade satisfies the structural integrity requirements under 'normal operation' and 'worst case' loading.**

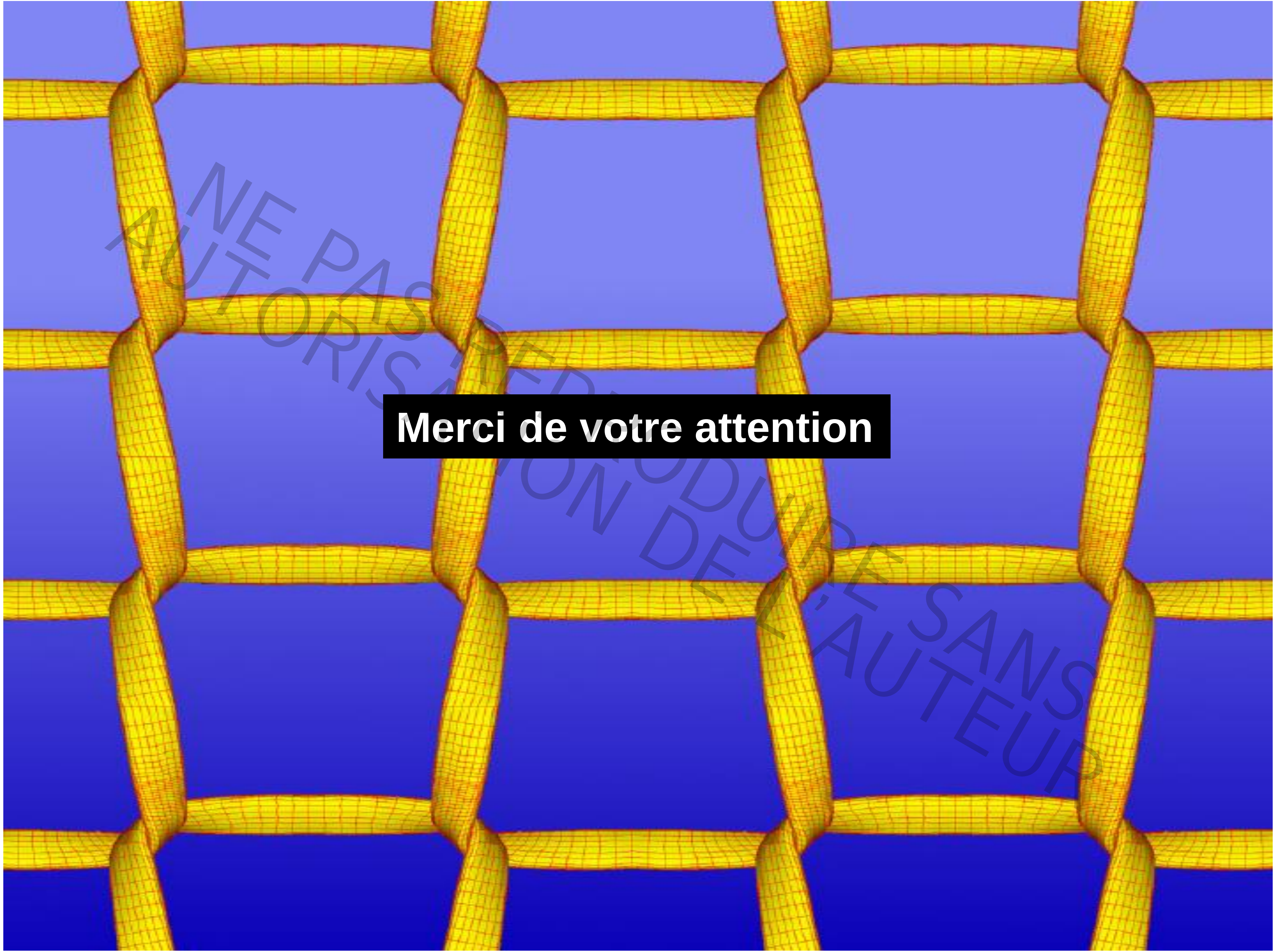
It is consequently claimed that **flax is a potential structural replacement to E-glass** for similar composite small wind turbine blade applications


Tip Displacement [mm]
2500
2000
1500
1000
500
0
0
50
100
150
200
250
300
350
% of Normal operation load
Up to Normal Operation Load
Up to Worst Case Load
Up to Failu
Loa
$R^2 = 0.92$
$R^2 = 0.989$
$R^2 = 0.996$
Flax
E-glass

Les spécificités des composites biosourcés

- La complexité de la fibre
- La longueur finie de la fibre
- Le caractère hydrophile
- L'interface fibre matrice
- La variabilité
- Les matrices biosourcées peu nombreuses pour l'instant

- La réalisation d'applications peut montrer le potentiel effectif de ces matériaux


Merci de votre attention