Optimisation des propriétés mécaniques des composites renforcés de fibres de lin:
effets de la micro- et mesostructure des renforts

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°CELC (European Flax and Hemp Federation)

Contents

- **Introduction :**
  - **Composite Materials Group @ KU Leuven**
  - **Flax in the world & CELC**
  - **Flax compared to other reinforcements**
- How the reinforcement mesostructure controls the properties of flax composites
- Recent experimental results on effect of mesostructure on
  - Basic mechanical properties: strength & stiffness
  - Fatigue
  - Impact resistance and toughness

KULeuven → MTM → CMG

KU Leuven: Founded 1425, 35,000+ students

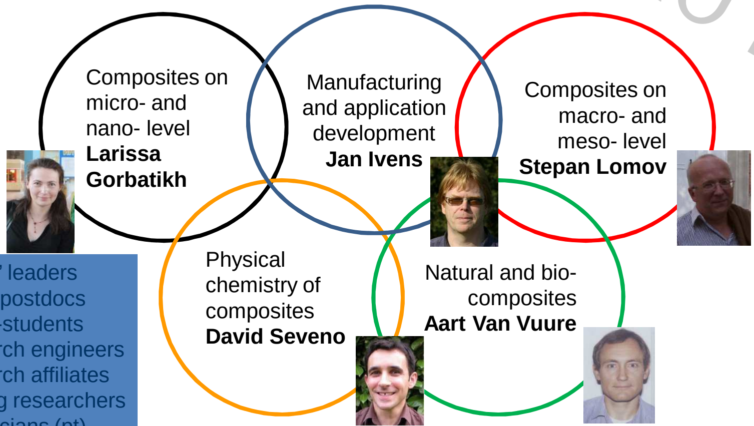
- Oldest existent catholic university in the world
- Oldest university in the Low Countries (The Netherlands + Belgium)
- Erasmus : Collegium Trilingue 1517; Mercator, Vesalius …
- 1968: split into two new universities:
  Dutch-speaking (Leuven) and French-speaking (new city: Louvain-la-Neuve)

Group Science, Engineering and Technology,
Faculty of Engineering

Department MTM:
total 150+ employees: 20 profs, 25+ post-docs,
70+ PhDs, 30+ technical and administrative

Divisions:
- Sustainable Metals Processing and Recycling (SeMPeR)
- Surface and Interface Engineered Materials (SIEM)
- Structural materials and NDT (SCALINT) -> **Composite Materials Group**

Composite Materials Group



5 'focus' leaders
5 junior postdocs
24 PhD-students
3 research engineers
3 research affiliates
4 visiting researchers
4 technicians (pt)

~15 masters' stud.

coordinated by Stepan Lomov
"backed-up" by em. prof. Ignaas Verpoest

The Composite Materials Group…

… in front of giant wallpainting by American artist Sol Lewitt at Museum M in Leuven

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Different types of natural Fibres

PLANT / Lignocellulosic FIBRES

- Wood

Softwood
Hardwood

- Stem/Bast

Flax
Jute
Hemp
Kenaf
Ramie

- Leaf

Sisal
Abaca
Pineapple
Banana
Fique
Henequen
Palm

- Seed/Fruit

Cotton
Coconut

- Grass

Bamboo
Rice

ANIMAL FIBRES

Silk
Wool

6

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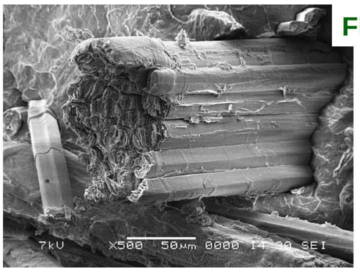
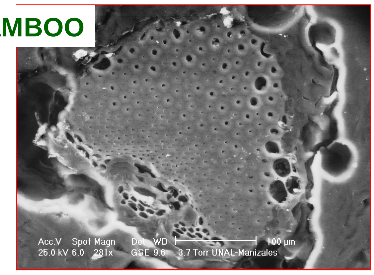
Four fibres are being studied more in depth @ K.U.Leuven…

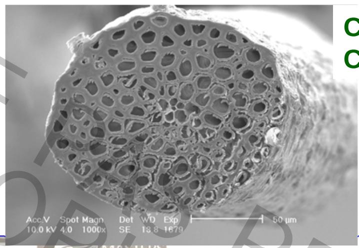
FLAX



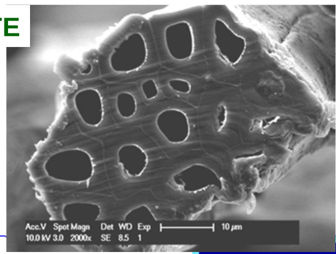
BAMBOO



COIR/ COCONUT

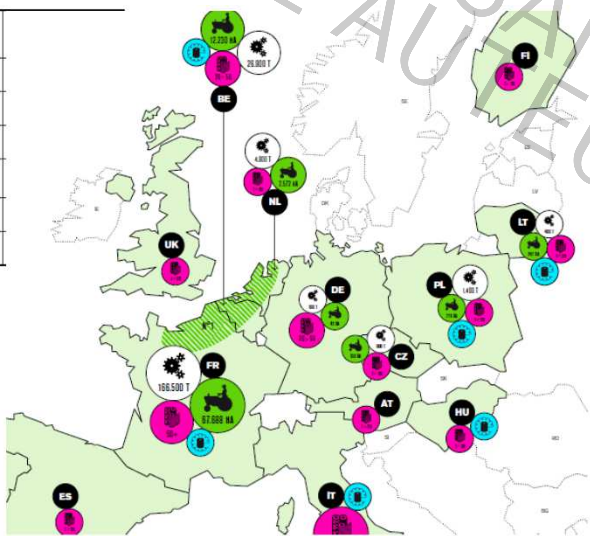


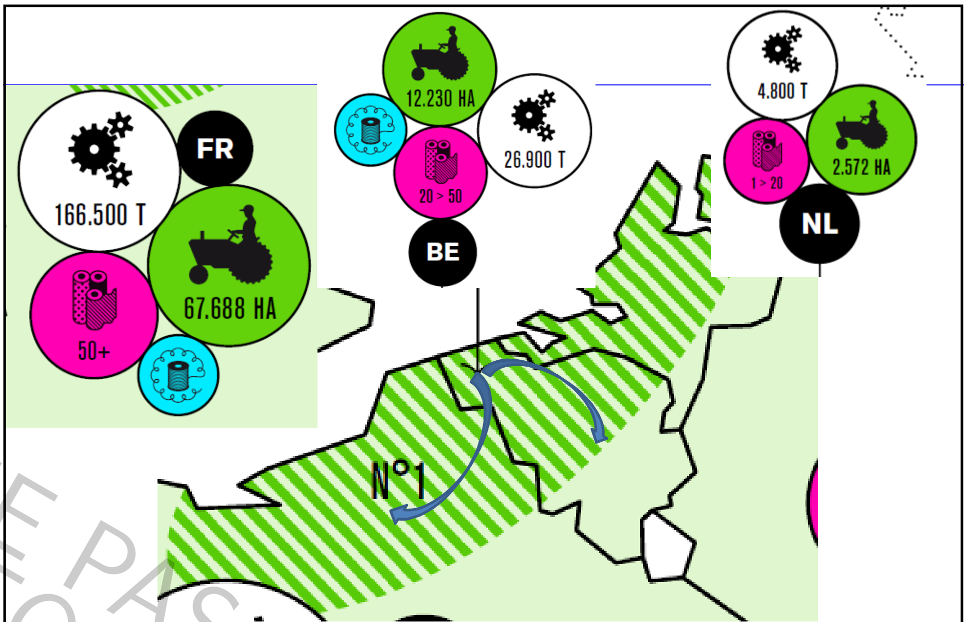
JUTE



Where is flax grown?

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





hence: French flax entrepreneurs with Flemish names: Depestele, Van Fleteren, Van Robaeys,..

2009: The European Scientific Committee - CELC

10 European experts, coming from research and bringing together competence on methods to analyse and characterise to:

- Establish State of the Art on scientific resources and existing technology
- Evocate future options and new research
- Favour open innovation and facilitate involvement of external technical competences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Coordinator of the European Scientific Committee of CELC


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France


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Aalto University
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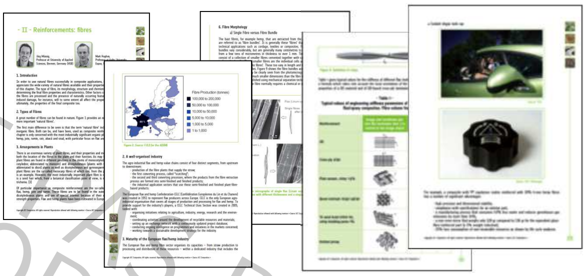
KU Leuven, Belgium
President of the European Scientific Committee of CELC

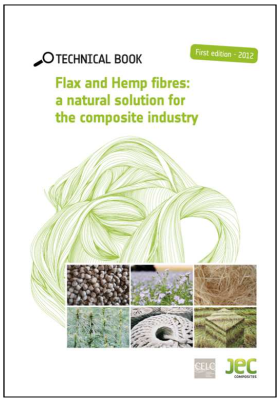

Gerhard ZIEGMANN
Prof. Dr. Eng. Institute for Polymer Materials and Plastics Processing
Clausthal University of Technology
Germany

2012: The book…

«Flax and Hemp: a natural solution for the composite industry»

- First worldwide publication on the utilisation of flax and hemp fibres to reinforce composite materials,
- Compiled by the members of the European Scientific Committee of CELC
- Published with the JEC GROUP www.jeccomposites.com





2014: Technical Data Sheets

- Technical data sheets exist for man made fibres like glass and carbon
- … and they are used frequently by those producing different composite applications
- There is no existing equivalent for the pre-forms based on flax & hemp fibres
- … a collaborative work together with CELC members

Renfort Textile pour Composites Hautes Performances

Textile Reinforcement for High Performance Composites

DEFINITION / *DESCRIPTION* — **Edition 09/2007 / *Issue 09/2007***

Type de fils *Type of yarns*	Chaîne / Warp : EC9 68 *Trame / Weft : EC9 68*
Masse nominale / *Nominal weight*	204 g/m² *6,02 oz/sqy²*
Armure *Weave style*	SERGE 2/2 *TWILL 2/2*
Poudrage *Powdering*	
Traitement *Finish*	
Largeur standard *Standard width*	1200 mm *47 in*

CARACTERISTIQUES / *CHARACTERISTICS*

Contexture nominale *Nominal construction*	Chaîne / Warp : 14,7 fils-yarns/cm *Trame / Weft : 14,7 coups-picks/cm*
Répartition en masse *Weight distribution*	Chaîne / Warp : 50 % *Trame / Weft : 50 %*
Epaisseur / *Thickness (*)*	0,16 mm

PROPRIETE MECANIQUES SUR STRATIFIE* / *MECHANICAL PROPERTIES ON LAMINATE**

Mise en oeuvre (60 min à 120°C, vide 0,85 bar, pression 3 bars)/ *Cure cycle (60 min at 120°C, vacuum 0,85 bar, pressure 3 bars)*

	Traction chaine *Warp tensile*	Flexion chaine *Warp flexural*	C.I.L. chaine *Warp I.L.S.S.*
Contrainte / *Strenght* (Mpa)			
Module /*Modulus* (Gpa)			
Normes / *Standards*			

*Nota: Les valeurs moyennes ci-dessus sont obtenues sur la base d'un stratifié epoxy de mm avec % de fibres en volume.
**NB : The above average values are obtained with epoxy laminate of mm at % of fibres in volume.*

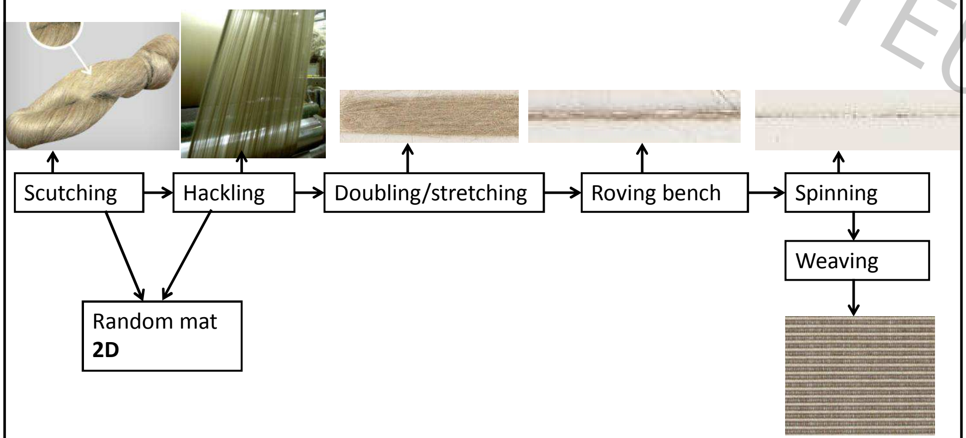
IMPORTANT

Les renseignements contenus dans la présente fiche produit sont fondés sur nos connaissances actuelles et sur les résultats d'essais effectués avec un constant souci d'objectivité. Ils doivent être adaptés à chaque cas particulier. Les performances du produit après utilisation étant liées

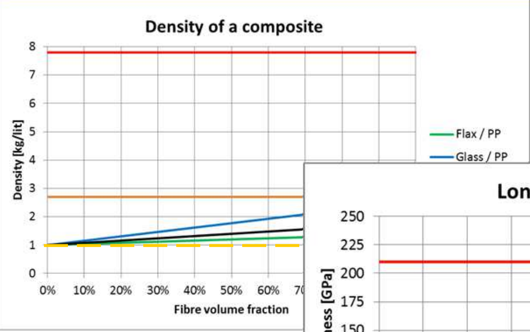
How are flax fibers produced?

Flax: from plant to textile

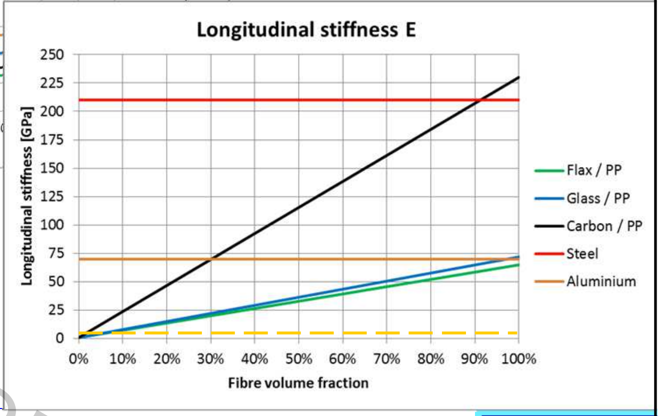
The value chain as it was up to some years ago….:
oriented towards textile markets



Flax unidirectional composites: density and stiffness



- Plastics: typically between 1 and 1.3 kg/lit



Plastics: typically between 1 and 3 GPa

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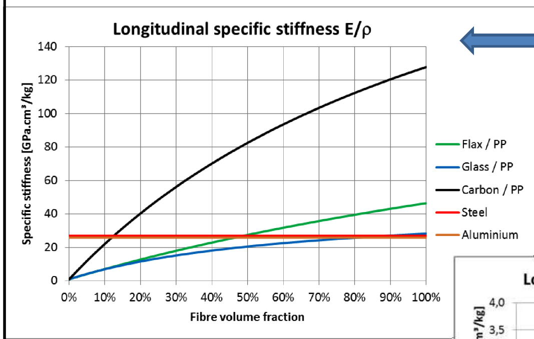
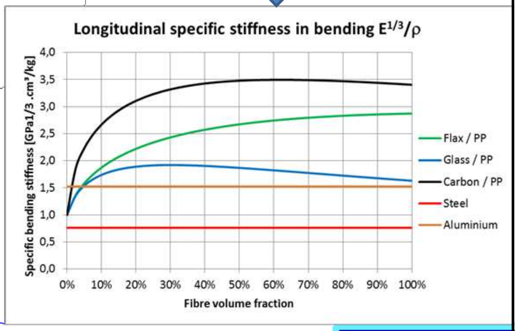
Flax fibre UD-composites: specific stiffness



for tension

for bending



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  - Basic mechanical properties: strength & stiffness
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  - Impact resistance and toughness

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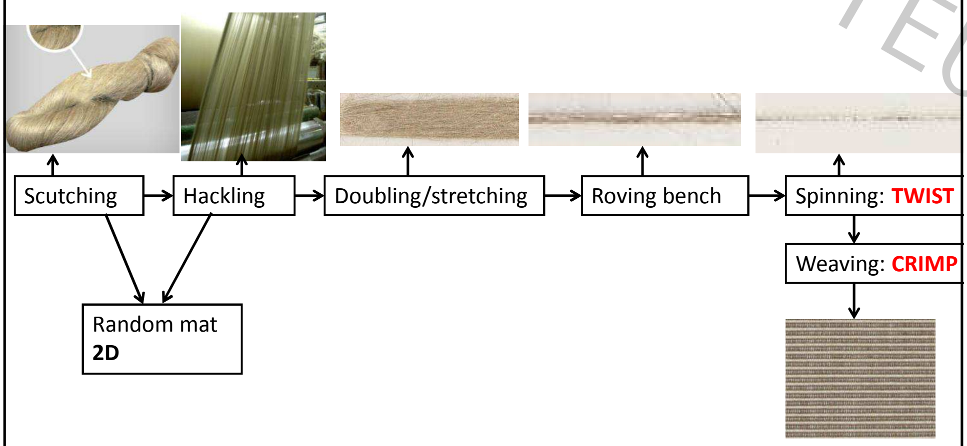
Flax: from plant to textile… for composites???

The value chain as it was up to some years ago….:
oriented towards textile markets



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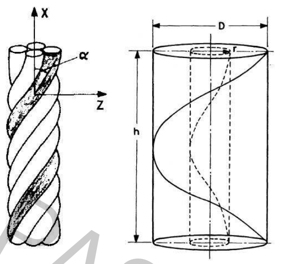
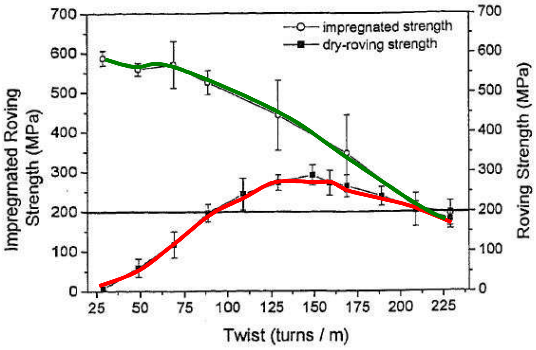
Problem 1: why twisted yarns and no rovings?

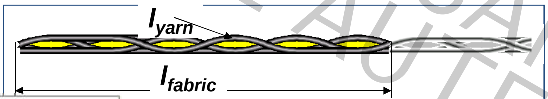
- Natural fibres are by definition discontinuous *(plants do not grow to the sky!)*
- Hence twisting is needed to keep them together during further textile operations (weaving, braiding, knitting…)
- With increasing twist in the yarn: the dry roving/yarn strength increases … but…
  - … the UD composite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

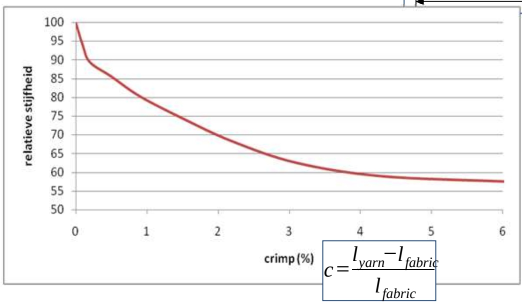




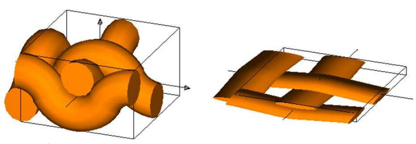
[Goutianos&Peijs, 2003]

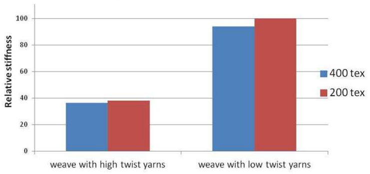
Problem 2: crimp in a weave on composite stiffness





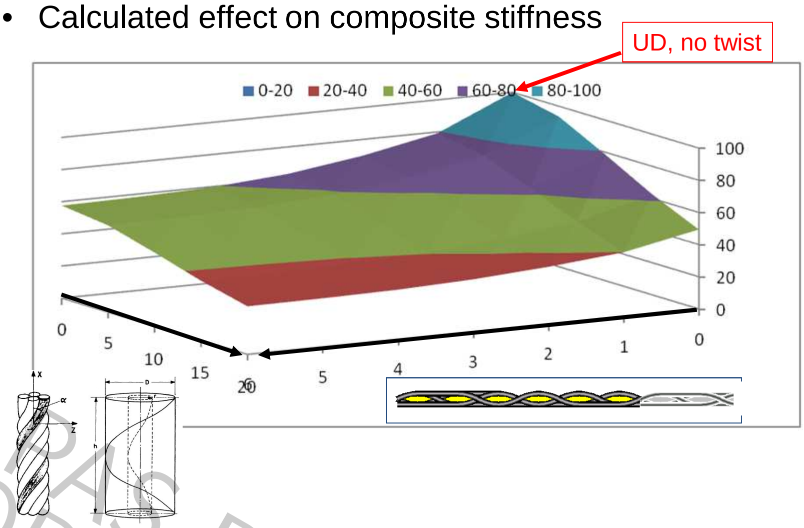
$$c = \frac{l_{yarn} - l_{fabric}}{l_{fabric}}$$





Combined effect of yarn torsion + weave crimp

- Calculated effect on composite stiffness



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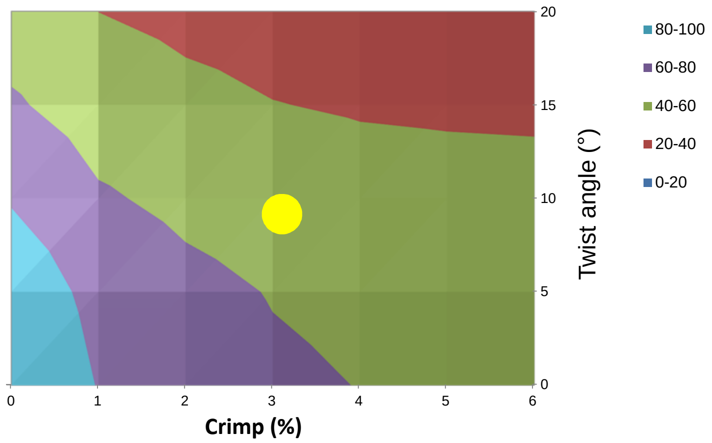
'Traditional' flax textiles: not optimised for composites!

- Only **50%** of potential is reached with **'traditional'** flax weaves, optimised for clothing, house linen,…



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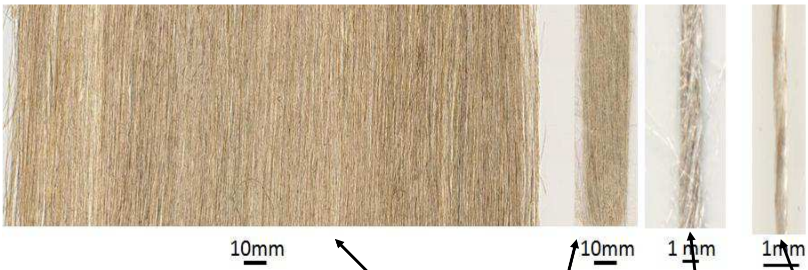
Study 1: effect of twist in long fibre UD composites

- 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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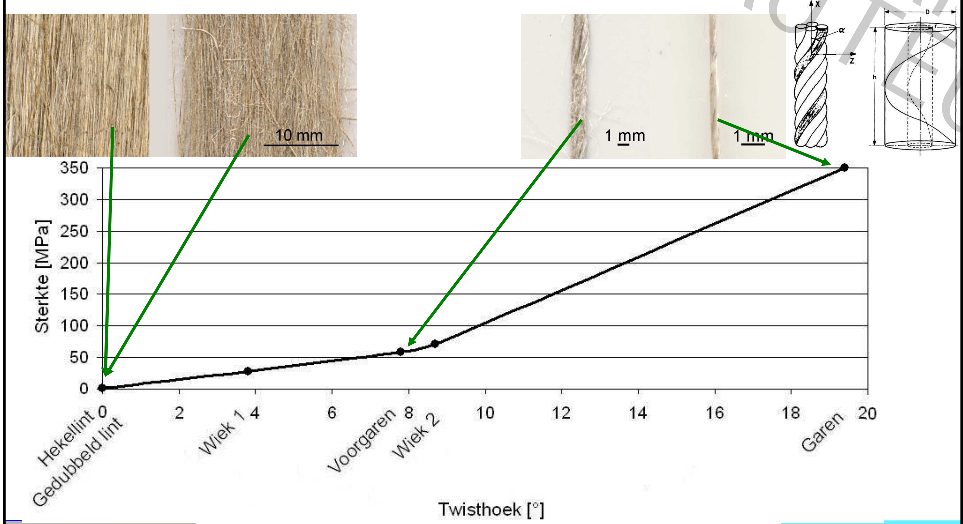
Effect of twist on flax dry yarn strength

Hackled ribbon Doubled ribbon Roving Yarn



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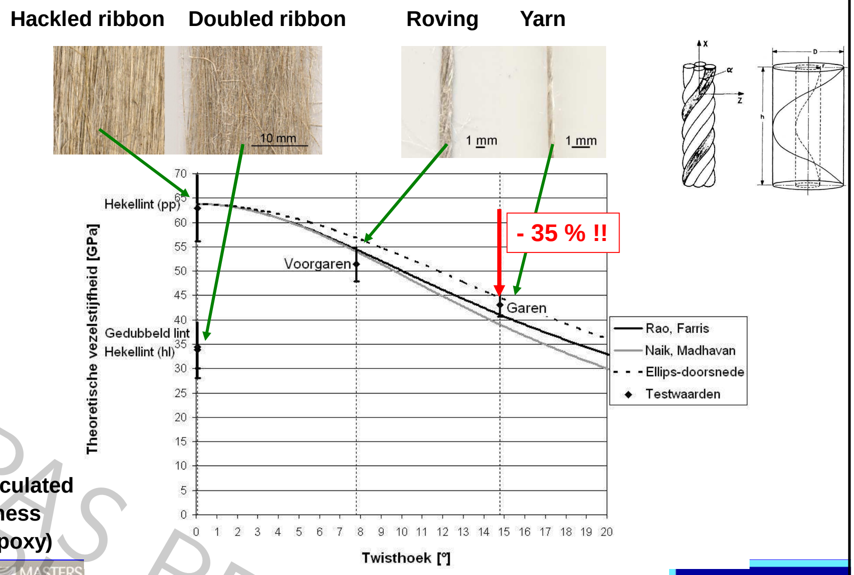
Effect of twist on UD-composite stiffness *



* Back-calculated fibre stiffness (matrix=epoxy)

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Study 2: influence of fibre length + twist

Stiffness and strength of flax fibres, back-calculated from composite stiffness and strength.

Spinning method	Flax raw fibers , turns/meter
Wet spun	A: Long fibers (250)
	B: Hackled tows (277)
	C: Scutched tows (277)
Dry spun	D: Long fibers (356)
	E: Hackled tows (404)
	F: Scutched tows (414)
Low-twist yarn	G: Long fibers (150)
	H: Long fibers (125)

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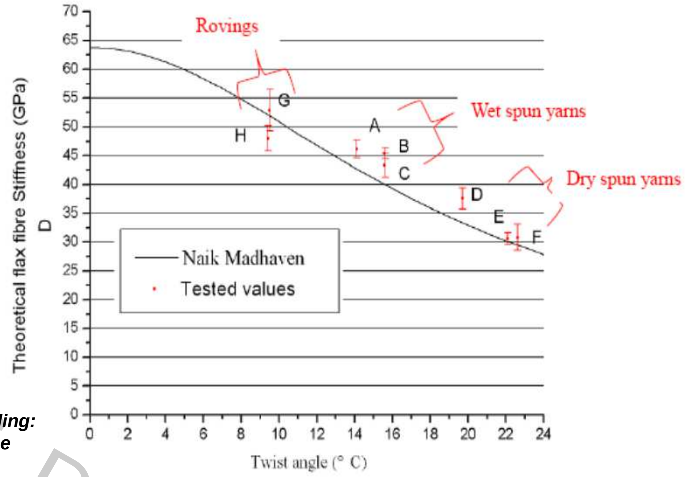
Predictive models: effect of twist + fibre length

- **Only twist angle has influence,**
- **No significant effect of fibre length (A, D >> B,C,E,F)**



Further details on modelling: see Baets et.al. , to be submitted 2011

Twist angle (°)

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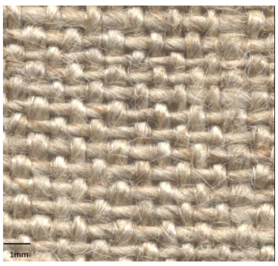
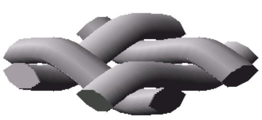
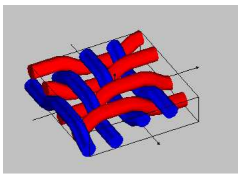
Study 3: effect of weaving on flax composite properties

- **Plain weave** **Twill weave** **Random mat**



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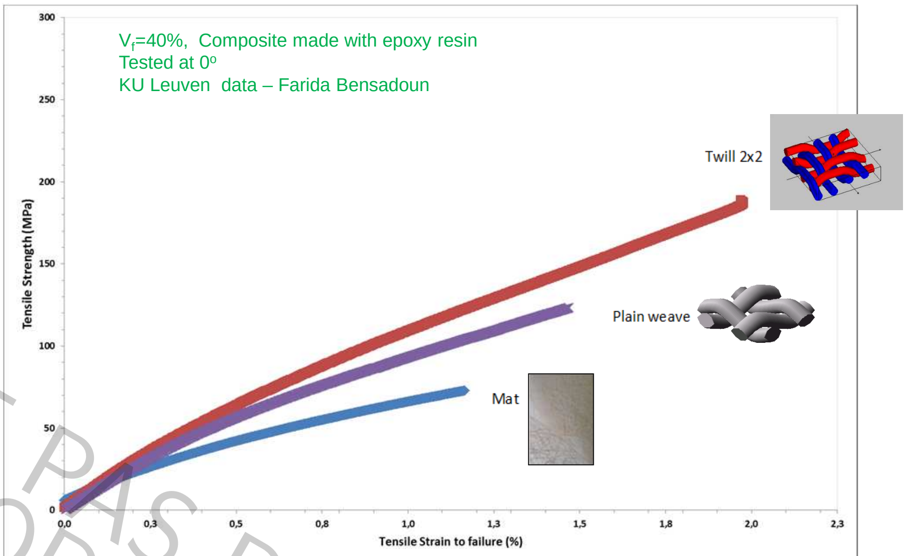
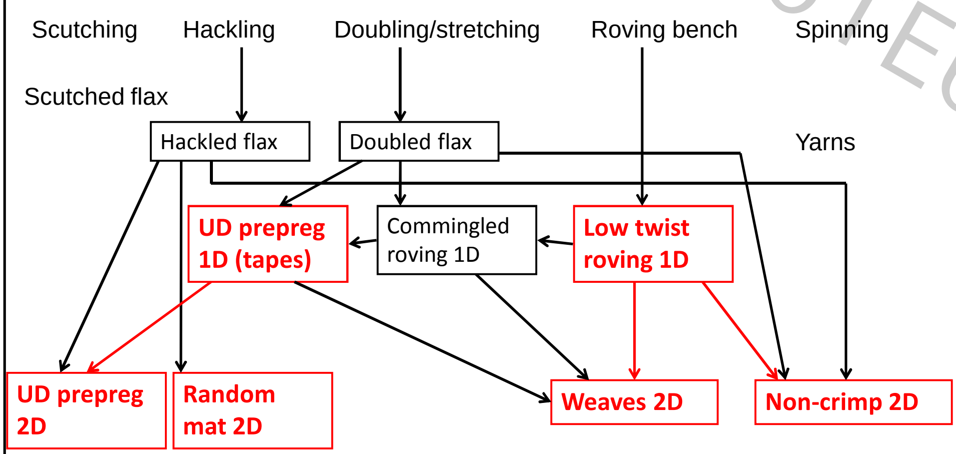
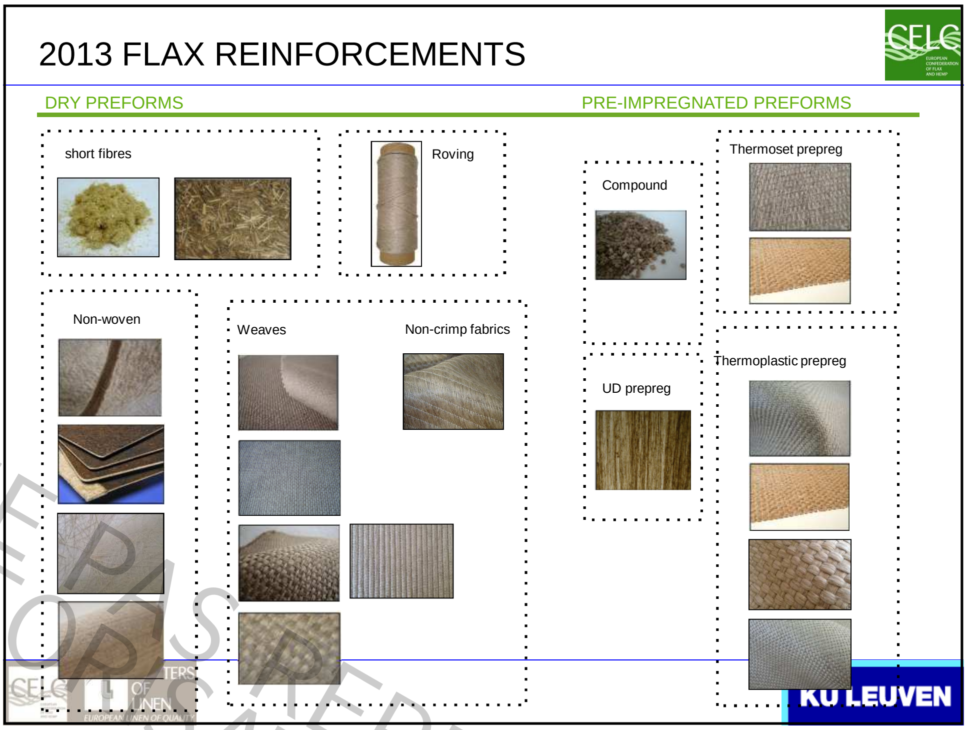
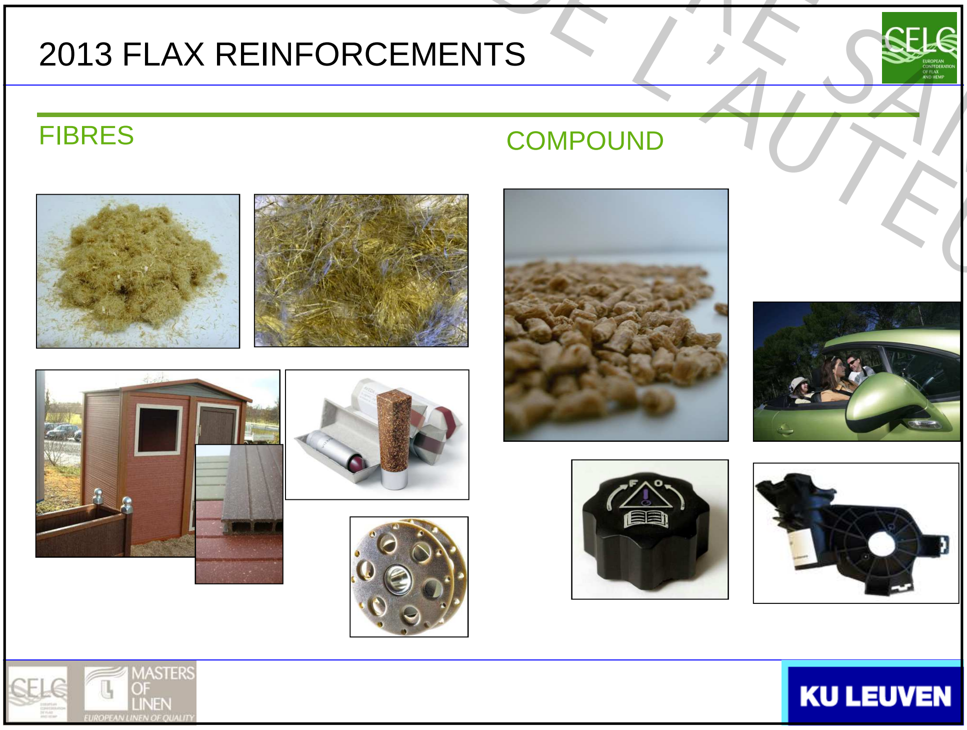
Tensile curves for different weave styles



Overview : achievements since 2009

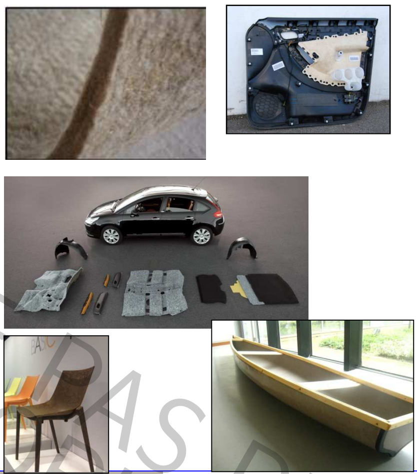



2013 FLAX REINFORCEMENTS
DRY PREFORMS
PRE-IMPREGNATED PREFORMS
short fibres
Roving
Compound
Thermoset prepreg
Non-woven
Weaves
Non-crimp fabrics
UD prepreg
Thermoplastic prepreg
KU LEUVEN

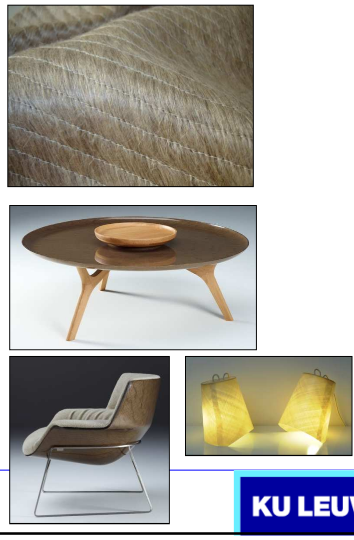

2013 FLAX REINFORCEMENTS
FIBRES
COMPOUND
MASTERS OF LINEN
KU LEUVEN

2013 FLAX REINFORCEMENTS

NON WOVEN

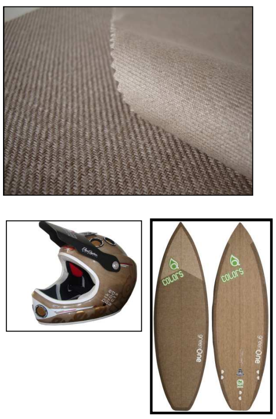


NON-CRIMP FABRIC

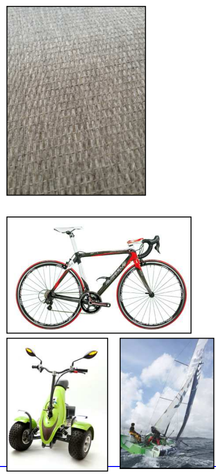


2013 FLAX REINFORCEMENTS

WEAVES



PRE-IMPREGNATED (met thermoharders)



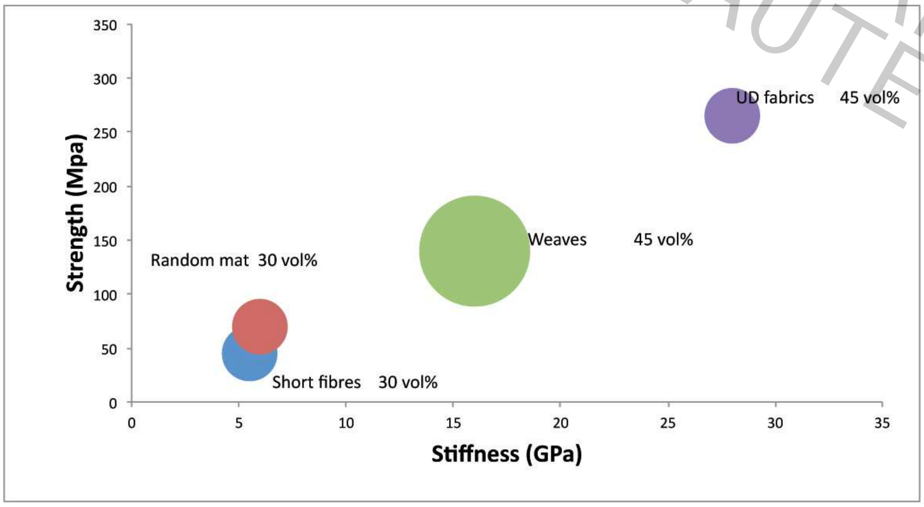
MIXED WEAVES (met thermoplasten)

2013 FLAX REINFORCEMENTS

UD PREPREGS

ROVING

The performance playground for flax composites



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  - **Basic mechanical properties: strength & stiffness**
  - **Fatigue**
  - **Impact resistance and toughness**

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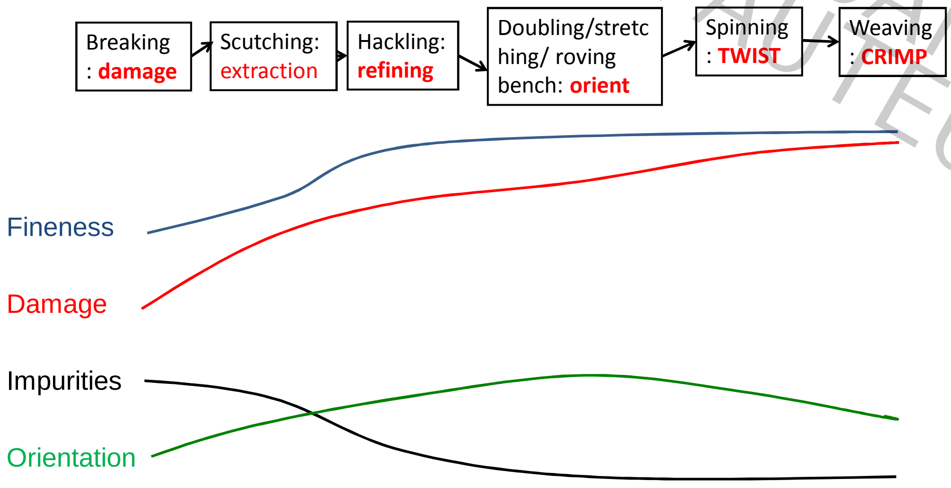
Additional effects during flax process



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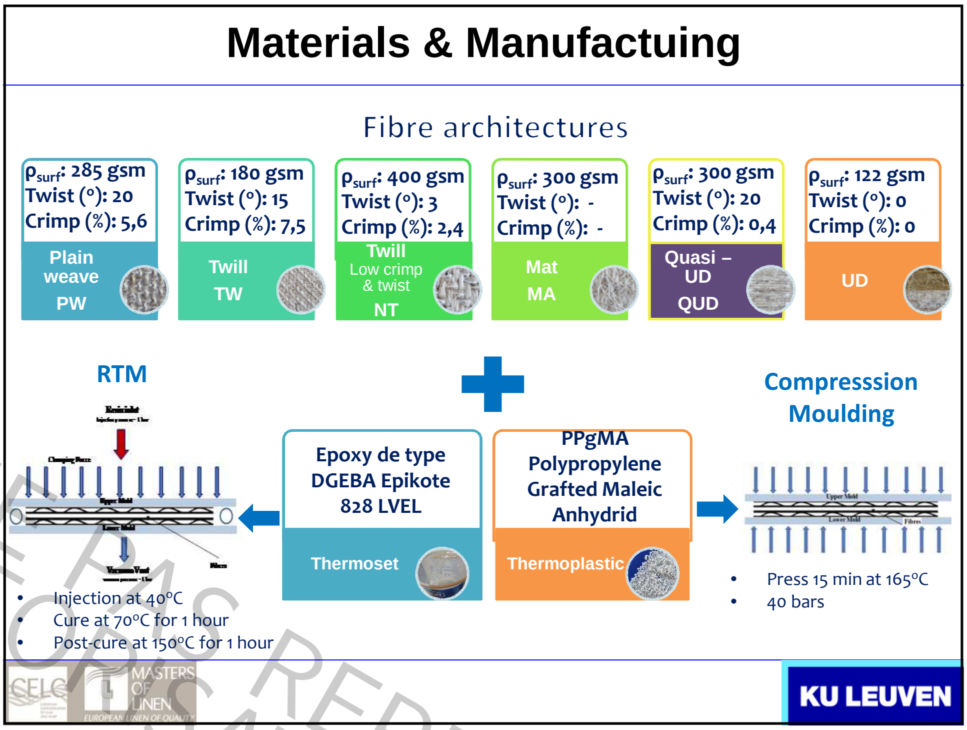
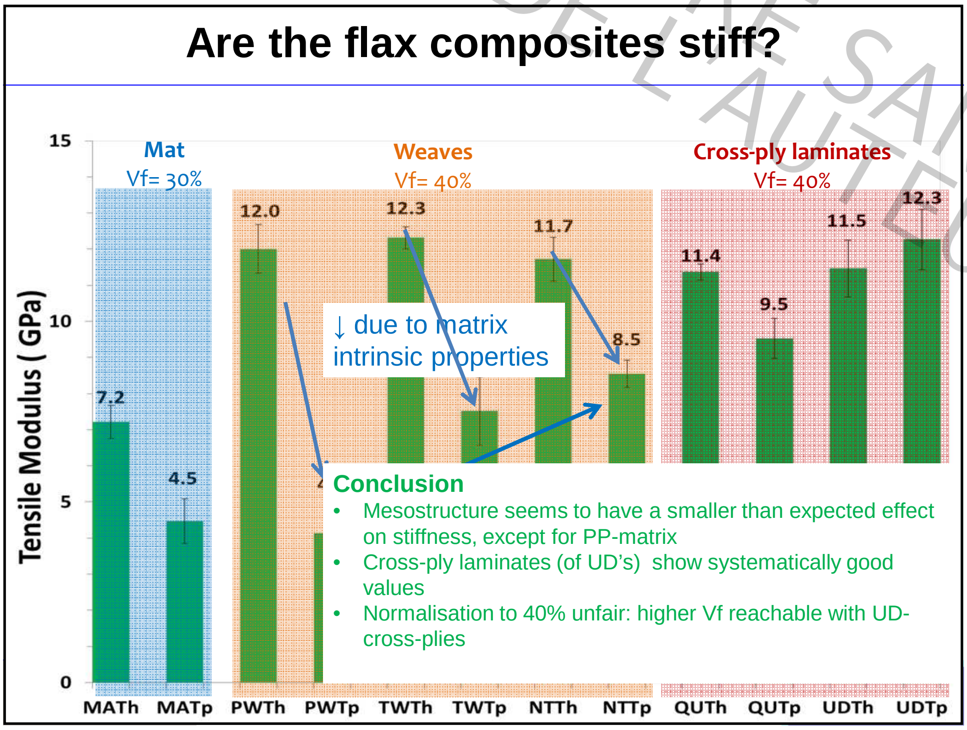
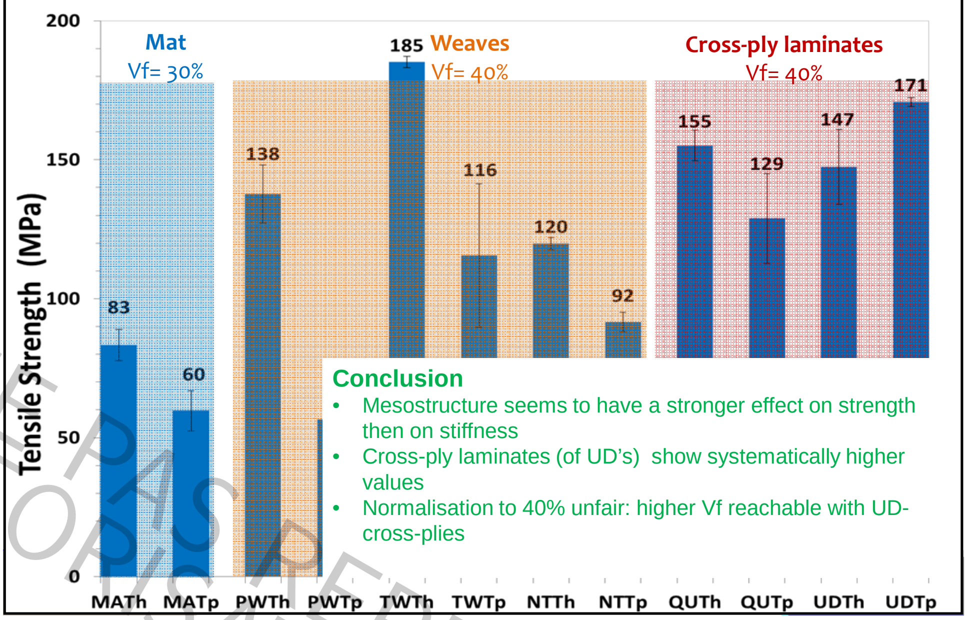

Materials & Manufactuing
Fibre architectures
ρsurf: 285 gsm Twist (°): 20 Crimp (%): 5,6
Plain weave PW
ρsurf: 180 gsm Twist (°): 15 Crimp (%): 7,5
Twill TW
ρsurf: 400 gsm Twist (°): 3 Crimp (%): 2,4
Twill Low crimp & twist NT
ρsurf: 300 gsm Twist (°): - Crimp (%): -
Mat MA
ρsurf: 300 gsm Twist (°): 20 Crimp (%): 0,4
Quasi – UD QUD
ρsurf: 122 gsm Twist (°): 0 Crimp (%): 0
UD
RTM
Compresssion Moulding
Epoxy de type DGEBA Epikote 828 LVEL
Thermoset
PPgMA Polypropylene Grafted Maleic Anhydrid
Thermoplastic
Injection at 40°C
Cure at 70°C for 1 hour
Post-cure at 150°C for 1 hour
Press 15 min at 165°C
40 bars
CELC
MASTERS OF LINEN
KU LEUVEN


Are the flax composites stiff?
Tensile Modulus (GPa)
Mat Vf= 30%
Weaves Vf= 40%
Cross-ply laminates Vf= 40%
7.2
4.5
12.0
12.3
11.7
8.5
11.4
9.5
11.5
12.3
↓ due to matrix intrinsic properties
Conclusion
Mesostructure seems to have a smaller than expected effect on stiffness, except for PP-matrix
Cross-ply laminates (of UD's) show systematically good values
Normalisation to 40% unfair: higher Vf reachable with UD-cross-plies
MATh MATp PWTh PWTp TWTh TWTp NTTh NTTp QUTh QUTp UDTh UDTp

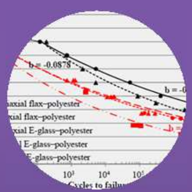
Are the flax fibres strong enough?



Conclusion

- Mesostructure seems to have a stronger effect on strength then on stiffness
- Cross-ply laminates (of UD's) show systematically higher values
- Normalisation to 40% unfair: higher Vf reachable with UD-cross-plies

Fatigue: importance and challenges



FATIGUE DATA

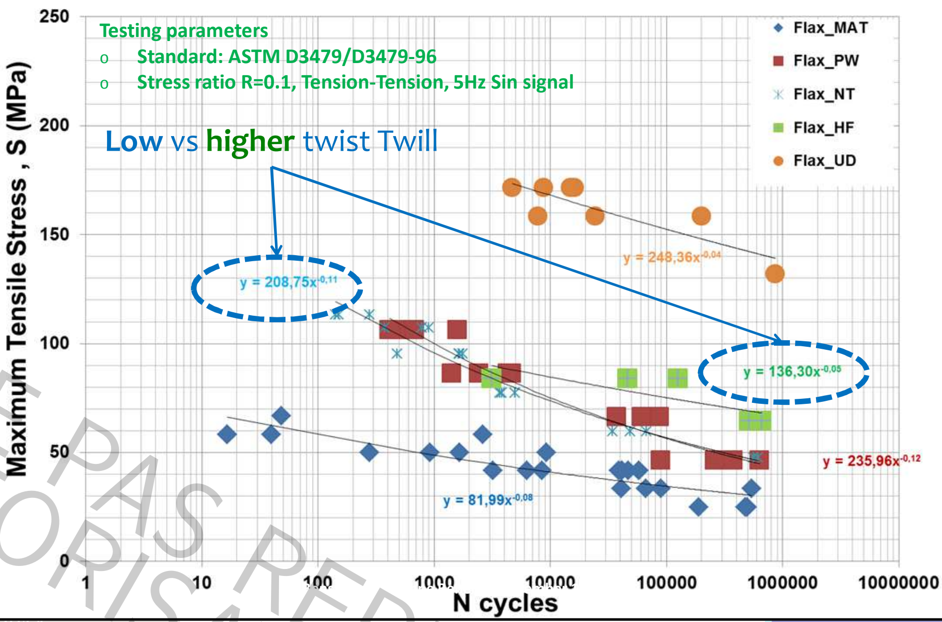
Importance

Why?

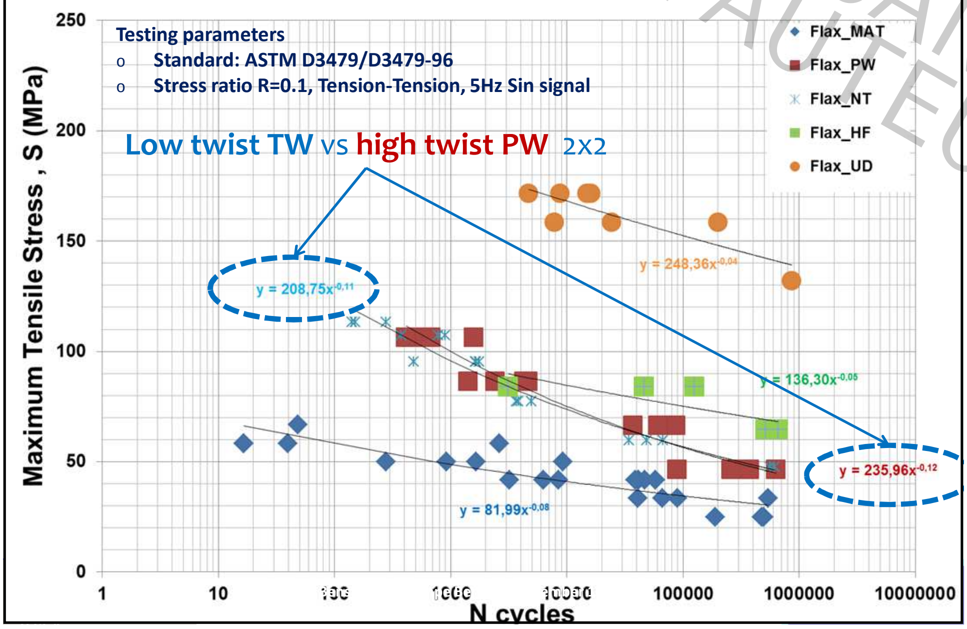
To insure long life life to high performance composites parts such as wind turbine blades

Lack of data on natural fibres composites

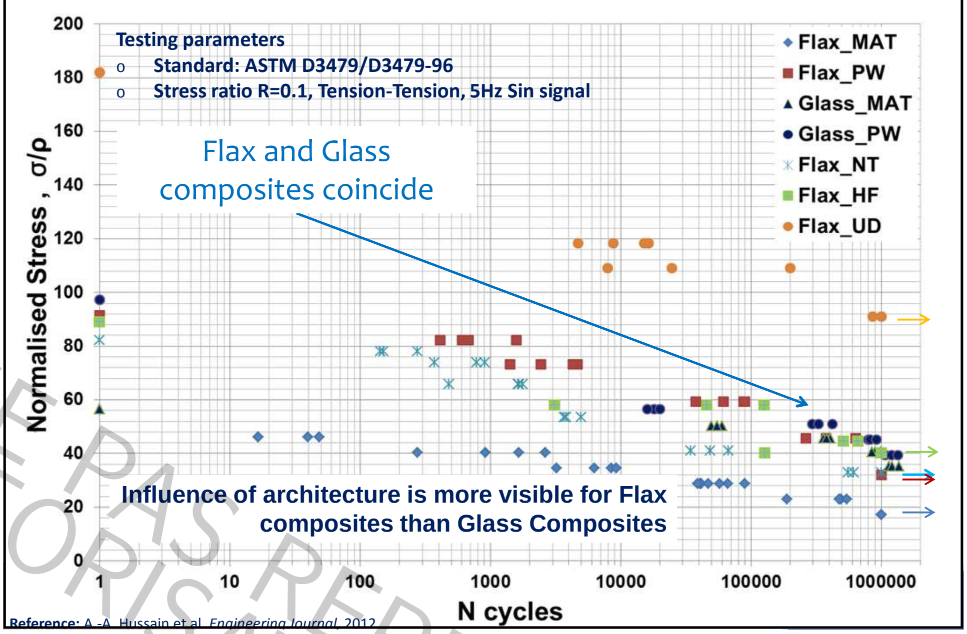
Fatigue Behaviour (1/3)



Fatigue Behaviour (2/3)



Fatigue Behaviour : *normalised to density* (3/3)

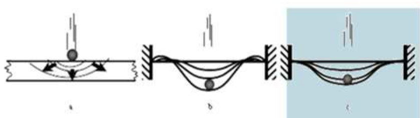


Reference: A.-A. Hussain et al, Engineering Journal, 2012

Impact performance of flax composites

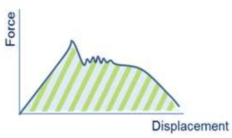
LVI IMPACT ❶ Low velocity impact < 10m/s = 36km/h

❷



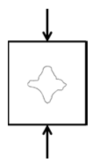
Long impact times
Quasi-static response

Absorbed energy



Damage resistance

Damage tolerance



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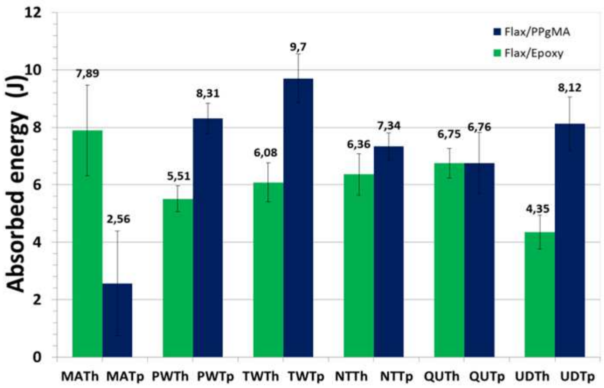
Absorbed energy at perforation

PW = plain weave
TW = twill
MA = mat
NT = non twist twill
QU = quasi UD
UD = unidirectional



Absorbed energy at perforation for thermoset and thermoplastic, values based on the full integral method, normalised to same Vf x t of 40% x 2mm.

Thermoplastics ↑ absorbed energy compared to thermosets
→ Better fibre/Matrix Adhesion
No clear influence of twist and/or crimp

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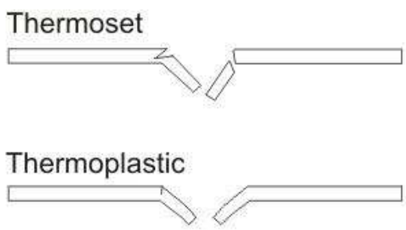
Damage modes at perforation



Perforation event for thermoset versus thermoplastic matrix material.
Thermoset systems → Load drop is sharper, characteristic for the **more brittle nature of the failure** with a clean impact hole

Thermoplastic → not seen since the ↑ perforation resistance due to the **higher strain to failure of the matrix.**

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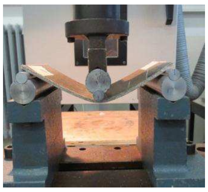
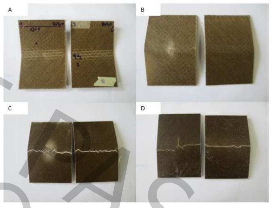
Flexural strength after *non-penetrating* impact

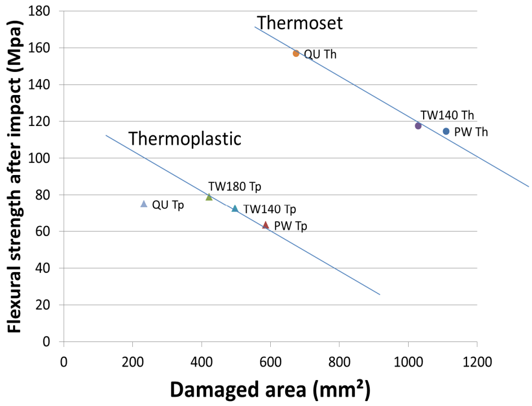


Three point bending Flexural testing after impact test on samples of 150mm x 100mm with aimed thickness of 5mm



Failure seen after three point bending test

Damage Tolerance



Damage resistance

Conclusion

The fibre architecture and the matrix type play **an important role** →Thus, designing for damage tolerance, is based on designing for good damage resistance.

Contents

- Introduction :
  - Composite Materials Group @ KU Leuven
  - Flax in the world & CELC
  - Flax compared to other reinforcements
- How the reinforcement mesostructure controls the properties of flax composites
- Recent experimental results on effect of mesostructure on
  - Basic mechanical properties: strength & stiffness
  - Fatigue
  - Impact resistance and toughness

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Outlook and future developments

- Flax fibre composites / reinforced plastics are very promising 'renewable structural materials':
  - Not only because of their **intrinsic "green"** properties
  - But also because they are **simply good composites**:
    - **Absolute stiffness** and **specific strength comparable** to glass fibre composites
    - Specific stiffness **better** than glas fibre composites → potential for weigth reduction!
    - Good **fatigue** properties, comparable to glass composites
  - The influence of the mesostructure *(twist and crimp)* is proven, but…
    - **Mesomechanical modelling is required *(ongoing)* to fully understand it's effects**