

Les composites polymères : MSE340-2025

Introduction-**Conclusions**

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Matériaux, procédés, propriétés

CALENDRIER	MSE 340 COMPOSITES			
	TP composites	Cours composites		
	lu 8-12h MED	lu 14-16h MXG110		
lundi, 8 septembre 2025		Cours	Intro aux composites	PEB/VM
lundi, 15 septembre 2025	Organisation	Cours	Constituants des composites	VM/PEB
lundi, 22 septembre 2025	férié	férié		
lundi, 29 septembre 2025	TP	Cours	Bases théoriques de la mise en œuvre des composites	VM
lundi, 6 octobre 2025		Cours	Procédés de mise en œuvre des composites	VM
lundi, 13 octobre 2025	TP	Cours	Procédés de mise en œuvre des composites	VM
lundi, 20 octobre 2025				
lundi, 27 octobre 2025		Cours	Intro à la mécanique des composites	DEF
lundi, 3 novembre 2025	TP	Cours		
lundi, 10 novembre 2025		Cours		
lundi, 17 novembre 2025	TP	Cours		
lundi, 24 novembre 2025		Cours		
lundi, 1 décembre 2025	TP	Cours		
lundi, 8 décembre 2025		Cours		
lundi, 15 décembre 2025	TP	Cours		
EVALUATION: 1/3 rapports des TP, 2/3 examen				

Learning outcomes

A la fin de ce cours l'étudiant doit être capable de:

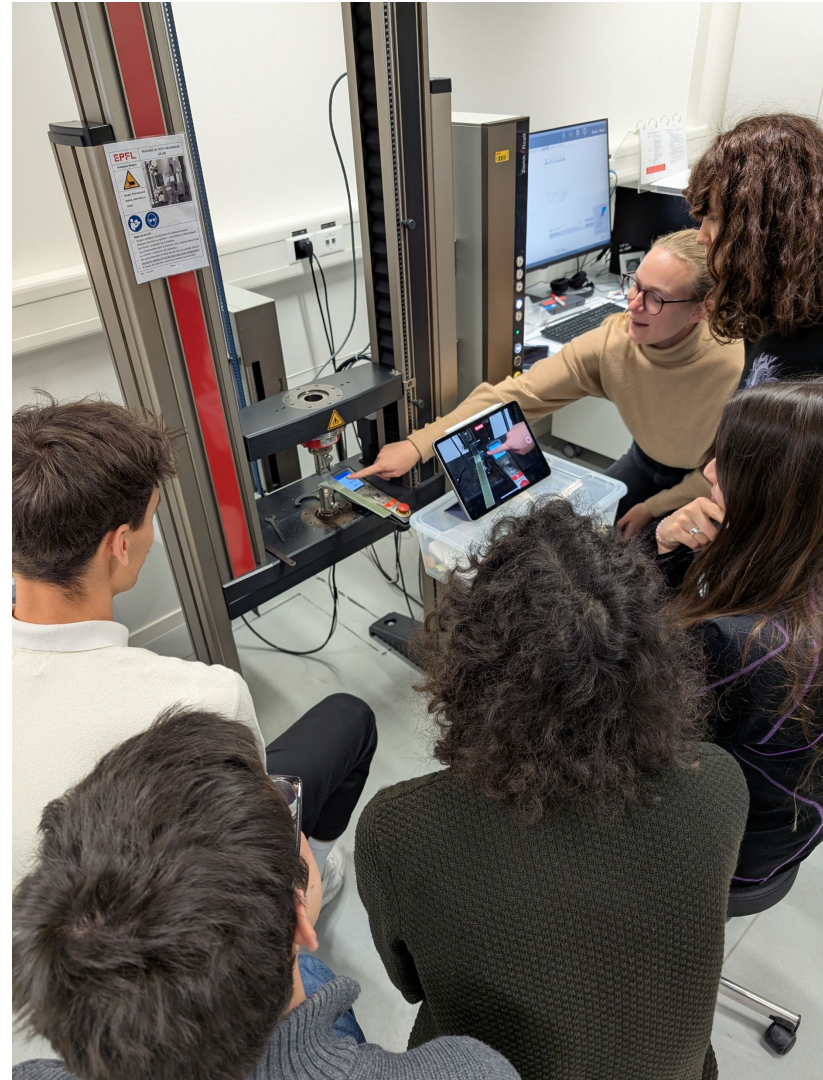
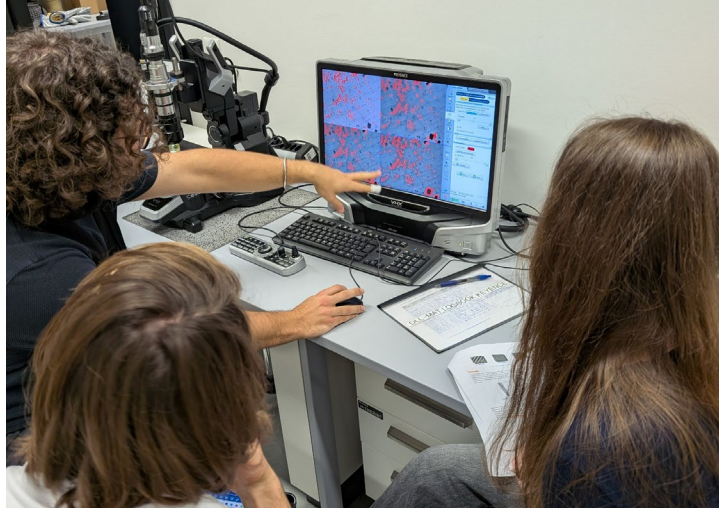
- Appliquer les méthodes de calculs pour déterminer les propriétés mécaniques des matériaux anisotropes
- Dimensionner des structures en composites (simples)
- Proposer des matériaux en choisissant leur composition et les procédés de fabrication pour une application donnée
- Comparer les matériaux composites entre eux
- Discuter les tests de caractérisation des composites
- Distinguer les avantages et limitations des procédés.
- Dialoguer avec des professionnels d'autres disciplines.
- Utiliser les outils informatiques courants ainsi que ceux spécifiques à leur discipline.

5 TP sur la mise en oeuvre et les propriétés des composites
Examen oral en Janvier

TP



TP



Constituants

Renforts

B: Flexibilité

Flexion d'une poutre cylindrique:

E module, I moment d'inertie

$$I = \pi d^4 / 64$$

R rayon de courbure
et M moment de flexion

$$R = EI / M = E \pi d^4 / 64 M$$

Donc R est proportionnel à d^4 .

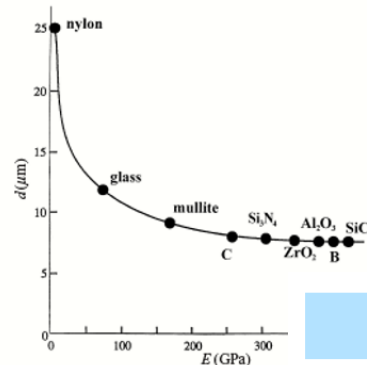


Figure 1
Diameter of various fibers with a flexibility of a 25 μm diameter nylon fiber. Given a diameter, it is possible to produce, in principle, a flexible fiber from a polymer, a metal, or a ceramic.

Les matrices polymères

Thermodurcis

- Avantages**
- + Résines liquides à T ambiante
 - + Facilité de mise en oeuvre (EP, UP)
 - + Durcissement entre 5 et 180°C (EP)
 - + Prix raisonnable
 - + Grande variété de formulation possibles
 - + Bonne adhésion aux fibres
 - + Amorphe

- Inconvénients**
- Volatilité, toxicité, allergies
 - Résistance à l'humidité
 - Résistance aux chocs
 - Contrôle de la réaction chimique

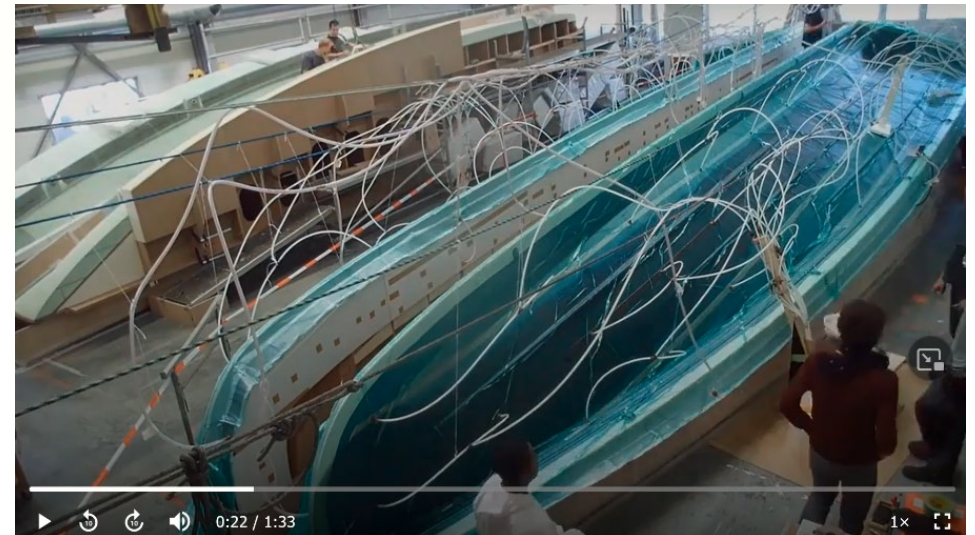
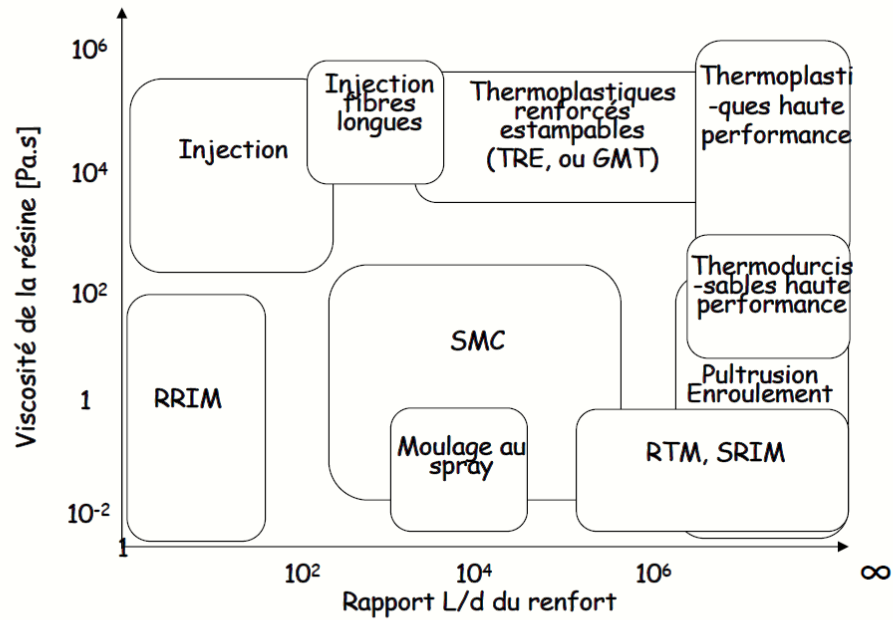
Thermoplastiques

- Avantages**
- + Mise en oeuvre rapide, par élévation de T
 - + Procédés de mise en oeuvre des thermoplastiques utilisables avec les fibres courtes
 - + Bonne résistance à l'humidité
 - + Recyclage aisé

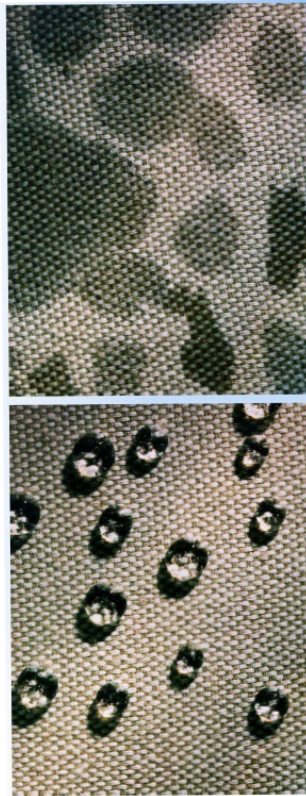
- Inconvénients**
- Souvent peu résistantes à la T
 - Retrait au moulage (matrices s-c)
 - Mauvaise résistance chimique
 - Adhésion aux fibres souvent problématique
 - Propriétés mécaniques faibles, fluage

Vitrimères : Nouvelles résines (depuis 2010 environ), basées sur une chimie de réseaux covalents adaptatifs (CAN), par exemple entre alcool et ester, qui sont réticulés mais peuvent être reformés en chauffant, et mieux recyclés.

Mise en oeuvre

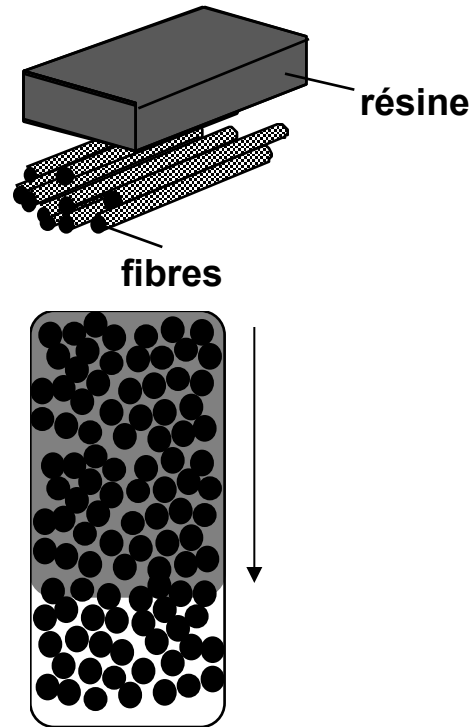


Les phénomènes



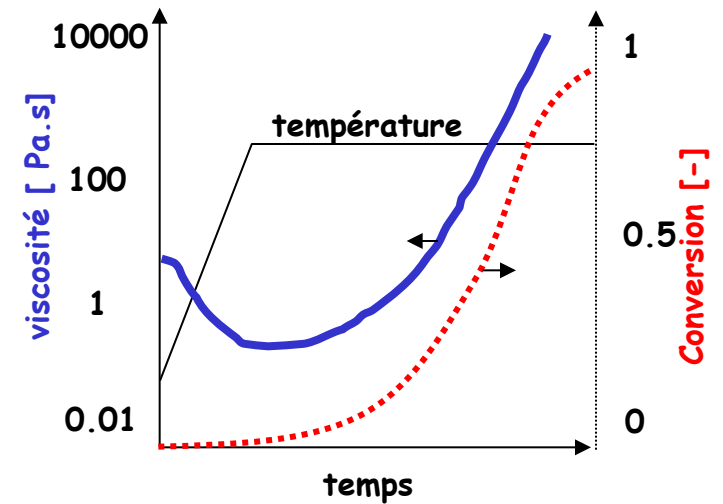
Mouillabilité
Tensions de surface

...



Imprégnation
Perméabilité

....



Transformation de la matrice

? mise en oeuvre

Quel polymère et quelles fibres pour un pare-chocs de voiture ?

Décrivez la mise en œuvre par SMC ?

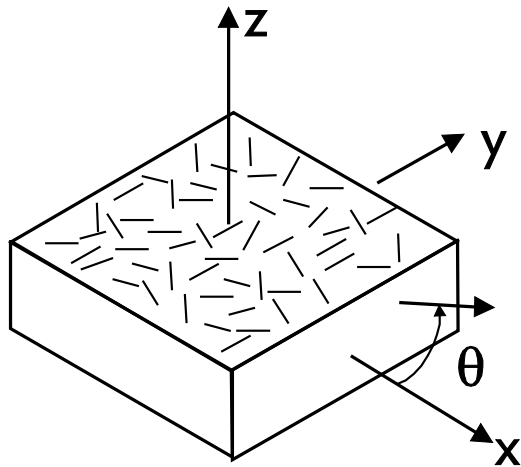
Citez 3 résines thermodurcissables ?

Comment pouvons nous déterminer la perméabilité ?

...

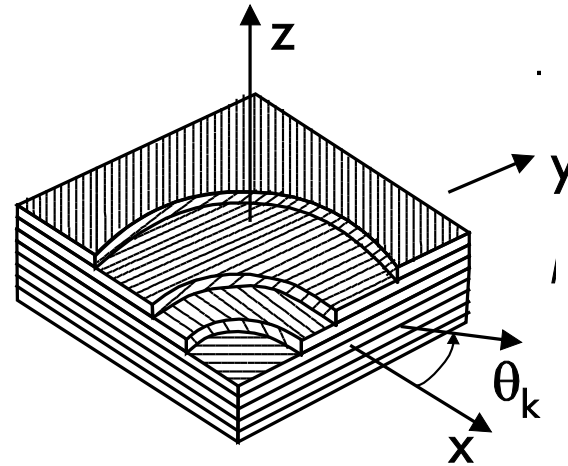
Mécanique des composites : propriétés

Composites à fibres courtes



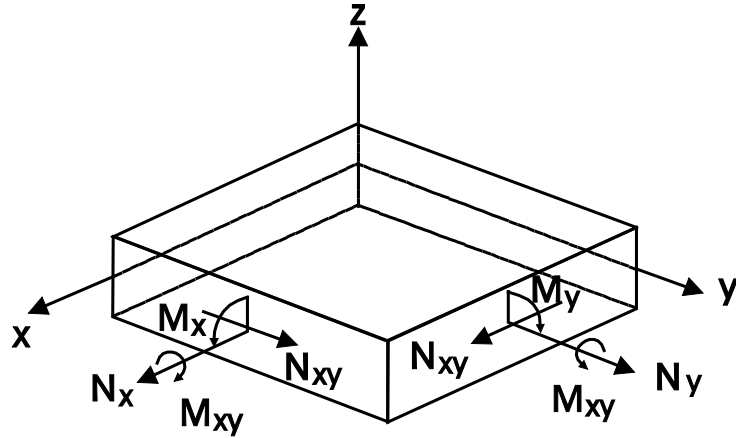
$$E_I = E_f V_f \left[1 - \frac{\tanh(\beta \ell / 2)}{\beta \ell / 2} \right] + E_m V_m$$

Stratifiés

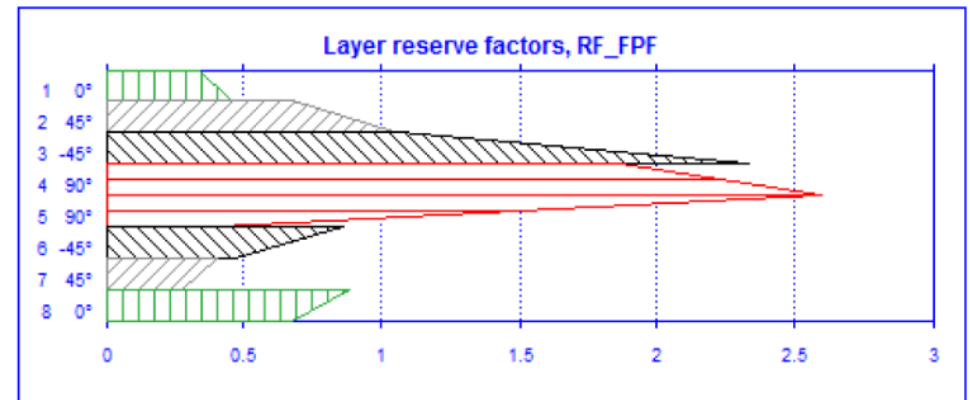
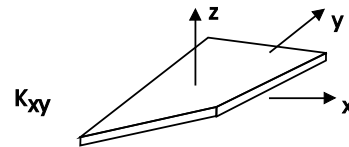
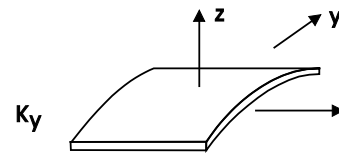
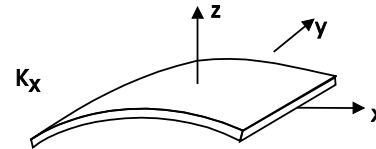


$$E_x = \frac{A_{11} A_{22} - A_{12}^2}{h A_{22}}$$

Résistance des matériaux composites



$$\begin{bmatrix} N \\ M \end{bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{bmatrix} \varepsilon^0 \\ \kappa \end{bmatrix}$$



? propriétés des anisotropes

Comment calculer le module transverse
d'un composite unidirectionnel ?

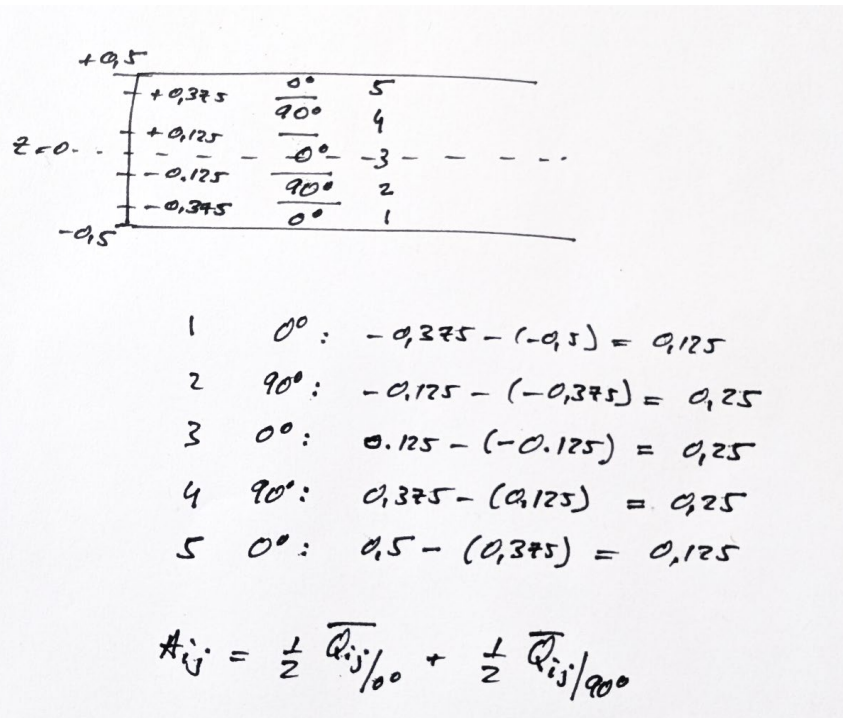
Comment se déforme un stratifié
sous l'effet d'un moment de flexion ?

Pourquoi les contraintes sont différentes
dans chaque pli d'un stratifié ?

Comment augmenter un Reserve Factor ?

Exercices

Exo7: en augmentant le nombre de strates, A ne change pas, B diminue. Calculs avec des épaisseurs égales des plis, ? quid si avec des plis d'épaisseurs différentes



The diagram shows a 5-layer laminate with thicknesses of 0.125 for each layer. The total thickness is 0.5. The layers are numbered 1 to 5 from bottom to top. The material properties for each layer are given as $Q_{ij}/0.125$.

Layer	Material Properties $Q_{ij}/0.125$
1	0°
2	90°
3	0°
4	90°
5	0°

Below the diagram, the calculations for the reduced stiffness A_{ij} are shown:

$$\begin{aligned}
 1 \quad 0^\circ: & -0.375 - (-0.5) = 0.125 \\
 2 \quad 90^\circ: & -0.125 - (-0.375) = 0.25 \\
 3 \quad 0^\circ: & 0.125 - (-0.125) = 0.25 \\
 4 \quad 90^\circ: & 0.375 - (0.125) = 0.25 \\
 5 \quad 0^\circ: & 0.5 - (0.375) = 0.125
 \end{aligned}$$

The final formula for A_{ij} is given as:

$$A_{ij} = \frac{1}{2} \overline{Q_{ij}/0.125} + \frac{1}{2} \overline{Q_{ij}/0.125}$$

Exercices

Cours MSE 340 Composites Polymères 2025, Exo B avec ESACOMP : résistances, critères de rupture Exemples de déterminations de la rupture du premier pli et de l'optimisation des facteurs de réserve pour éviter les ruptures.

La même approche est utilisée pour valider vos choix de matériaux et de structure du stratifié pour votre bouteille sous pression et votre snowboard.

Laminate FPF analysis

Laminate : C 045905

Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/-45a/-45a/90a)SE h = 1.84 mm

Ply	1	E ₁	E ₂	G ₁₂	ν_{12}	G ₃₁	G ₂₃
	mm	GPa	GPa	GPa		GPa	GPa
a E.EpoxyUD-23029950	0.23	38	9	3.6	0.3	3.6	3.46154

X ₁	X ₂	Y ₁	Y ₂	S	R	Q	X _{1,eqn1}	X _{2,eqn2}	Y _{1,eqn1}	Y _{2,eqn2}	S _M
MPa	MPa	MPa	MPa	MPa	MPa	MPa	%	%	%	%	%
44	930	570	33	110	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : 5kN sur 10 cm

Modified : Sun Nov 11 18:15:35 2012

Type : Forces and moments (Var.E)

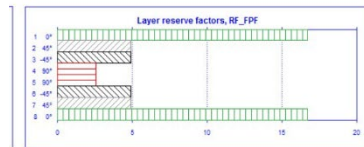
N_x = 50000 Nm N_y = 0 Nm
M_x = 0 Nm M_y = 0 Nm
Q_x = 0 Nm Q_y = 0 Nm

Factor of safety : FoS_N = 1
Failure criterion : Tsai-Wu, Max strain, Von Mises, Out-of-plane shear, Out-of-plane s
Failure crit. param : Tsai-Wu F₁₂=0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

FPF Mode FPF-only Mode Crit. layers ILS Crit. interf.

RF = 2.00 2i 2.00 2i (90°) - -



Layer reserve factors - FPF

Ply	theta	RF
1	a 0 1	3.1674 11
2	a 45 1	16.74
3	a -45 1	2.495 2i
4	a 90 1	4.95
5	a -90 1	2.495 2i
6	a 90 1	2.60 2i
7	a -90 1	2.60 2i
8	a 45 1	2.495 2i
9	a -45 1	2.495 2i
10	a 90 1	3.1674 11
11	a 0 1	16.74

Laminate FPF analysis

Laminate : C 045905

Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/-45a/-45a/90a)SE h = 1.84 mm

Ply	1	E ₁	E ₂	G ₁₂	ν_{12}	G ₃₁	G ₂₃
	mm	GPa	GPa	GPa		GPa	GPa
a E.EpoxyUD-23029950	0.23	38	9	3.6	0.3	3.6	3.46154

X ₁	X ₂	Y ₁	Y ₂	S	R	Q	X _{1,eqn1}	X _{2,eqn2}	Y _{1,eqn1}	Y _{2,eqn2}	S _M
MPa	MPa	MPa	MPa	MPa	MPa	MPa	%	%	%	%	%
a	930	570	33	110	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : 5kN sur 10 cm et Mx500Nm sur 25 cm

Modified : Sun Nov 11 19:20:02 2012

Type : Forces and moments (Var.E)

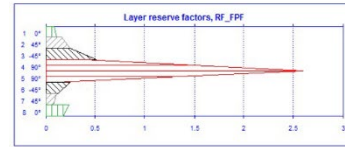
N_x = 50000 Nm M_x = 2000 Nm
N_y = 0 Nm M_y = 0 Nm
Q_x = 0 Nm Q_y = 0 Nm

Factor of safety : FoS_N = 1
Failure criterion : Tsai-Wu, Max strain, Von Mises, Out-of-plane shear, Out-of-plane s
Failure crit. param : Tsai-Wu F₁₂=0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

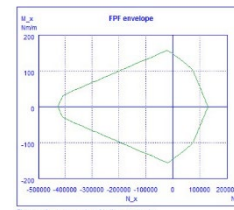
FPF Mode FPF-only Mode Crit. layers ILS Crit. interf.

RF = 0.07 2i 0.07 2i 7(45°) - -



Layer reserve factors - FPF

Ply	theta	RF
1	a 0 1	2.00 10/2i
2	a 45 1	0.11
3	a -45 1	5.0 16 a
4	a 90 1	0.25
5	a -90 1	0.51
6	a 90 1	8.0 40 20i
7	a -90 1	2.60
8	a 45 1	4.0 25 20i
9	a -45 1	0.13
10	a 90 1	1.0 11 2i
11	a 0 1	0.07
12	a 0 1	6.0 23 11
13	a 0 1	0.17



Failure criterion : Tsai-Wu, Max strain, Von Mises, Out-of-plane shear, Out-of-plane s
Failure crit. param : Tsai-Wu F₁₂=0.5
Stress/strain recovery : layer top/bottom

Laminate : C 045905

Modified : Sun Nov 11 17:28:27 2012

Lay-up : (0a/-45a/-45a/90a)SE h = 1.84 mm

Py : E.EpoxyUD-23029950

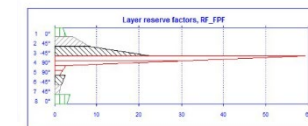
N_x = 50000 Nm M_x = 100 Nm
N_y = 0 Nm M_y = 0 Nm
Q_x = 0 Nm Q_y = 0 Nm

Factor of safety : FoS_N = 1
Failure criterion : Tsai-Wu, Max strain, Von Mises, Out-of-plane shear, Out-of-plane s
Failure crit. param : Tsai-Wu F₁₂=0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

FPF Mode FPF-only Mode Crit. layers ILS Crit. interf.

RF = 1.13 2i 1.13 2i 7(45°) - -



Layer reserve factors - FPF

Ply	theta	RF
1	a 0 1	4.10 10/2i
2	a 45 1	2.74
3	a -45 1	8.0 40
4	a 90 1	5.0 19 2i
5	a -90 1	2.60 2i
6	a 90 1	1.23
7	a -90 1	1.34 2i
8	a 45 1	1.71
9	a -45 1	1.52 2i
10	a 90 1	1.13
11	a 0 1	3.86 11
12	a 0 1	2.81

Laminate FPF analysis

Laminate : 045905 8mm

Modified : Sun Nov 11 22:01:22 2012

Lay-up : (0a/-45a/-45a/90a)SE h = 7.36 mm

Ply	1	E ₁	E ₂	G ₁₂	ν_{12}	G ₃₁	G ₂₃
	mm	GPa	GPa	GPa		GPa	GPa
a E.EpoxyUD-23029950	0.23	38	9	3.6	0.3	3.6	3.46154

X ₁	X ₂	Y ₁	Y ₂	S	R	Q	X _{1,eqn1}	X _{2,eqn2}	Y _{1,eqn1}	Y _{2,eqn2}	S _M
MPa	MPa	MPa	MPa	MPa	MPa	MPa	%	%	%	%	%
a	930	570	33	110	70	41.5385	2.44737	1.5	0.366667	1.22222	1.944

Load : 5kN sur 10 cm et Mx500Nm sur 25 cm

Modified : Sun Nov 11 22:02:53 2012

Type : Forces and moments (Var.E)

N_x = 50000 Nm M_x = 2000 Nm
N_y = 0 Nm M_y = 0 Nm
Q_x = 0 Nm Q_y = 0 Nm

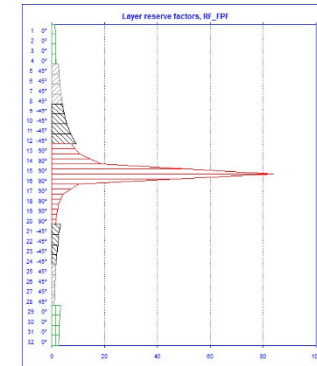
Factor of safety : FoS_N = 1

Failure criterion : Tsai-Wu, Max strain, Von Mises, Out-of-plane shear, Out-of-plane s
Failure crit. param : Tsai-Wu F₁₂=0.5
Stress/strain recovery : layer top/bottom

Laminate reserve factors

FPF Mode FPF-only Mode Crit. layers ILS Crit. interf.

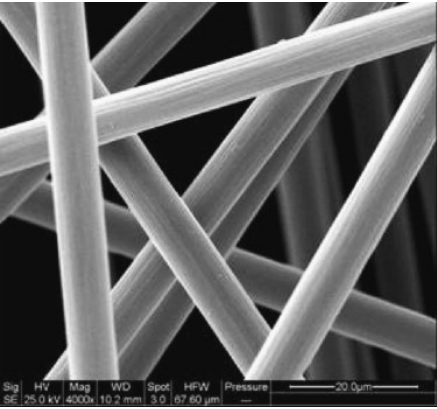
RF = 1.11 2i 1.11 2i 28(45°) - -



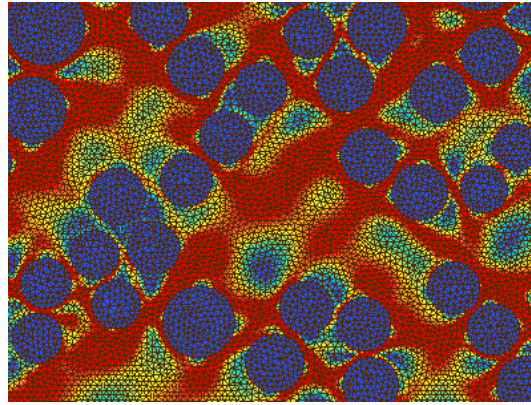
Layer reserve factors - FPF

Ply	theta	RF
1	a 0 1	4.10 10/2i
2	a 45 1	1.44
3	a -45 1	5.14 10/2i
4	a 90 1	1.54
5	a -90 1	1.67
6	a 90 1	1.67 10/2i
7	a -90 1	1.81
8	a 45 1	15.271 a
9	a -45 1	19.297 a
10	a 90 1	3.29
11	a -90 1	22.39 a
12	a 90 1	3.69
13	a -90 1	23.399 a
14	a 45 1	4.92
15	a -45 1	24.425 a
16	a 90 1	4.92
17	a -90 1	26.492 a
18	a 45 1	5.84
19	a -45 1	27.544 a
20	a 90 1	7.18
21	a -90 1	28.718 a
22	a 90 1	9.32
23	a -90 1	29.743 2i
24	a 90 1	16.68
25	a -90 1	31.1668 2i
26	a 90 1	32.1897 2i
27	a -90 1	83.52
28	a 90 1	30.832 2i
29	a -90 1	10.38
30	a 90 1	25.1838 2i
31	a -90 1	4.36
32	a 90 1	16.436 2i
33	a -90 1	2.70
34	a 90 1	1.276 2i
35	a -90 1	8.202 2i
36	a 90 1	1.09
37	a -90 1	3.44 20i
38	a 90 1	2.85
39	a -90 1	13.285 20i
40	a 90 1	2.43
41	a -90 1	12.243 20i
42	a 90 1	2.12
43	a -90 1	10.212 20i
44	a 90 1	1.88
45	a -90 1	6.162 2i
46	a 90 1	1.45
47	a -90 1	3.145 2i
48	a 90 1	1.31
49	a -90 1	1.31 2i
50	a 90 1	1.20
51	a -90 1	1.20 2i
52	a 90 1	1.11
53	a -90 1	0 1
54	a 90 1	21.354 11
55	a -90 1	3.28
56	a 90 1	3.06
57	a -90 1	1.356 11
58	a 90 1	2.86
59	a -90 1	14.286 11
60	a 90 1	2.69

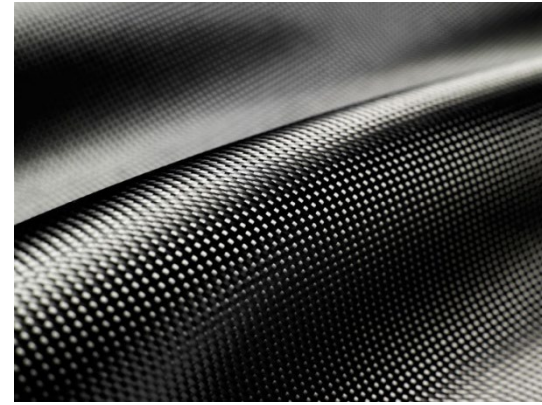
www.....composites.....



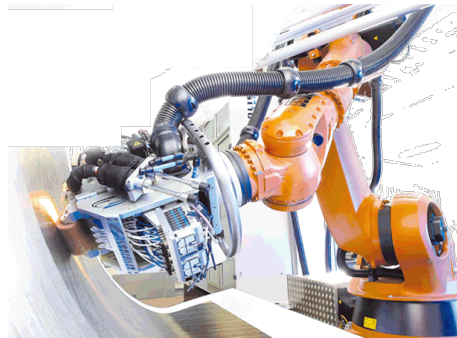
www.reinforcedplastics.com



www.onera.fr



blog.motorlegend.com



www.coriolis-composites.com



Boeing



BMW i8 automobile.challenges



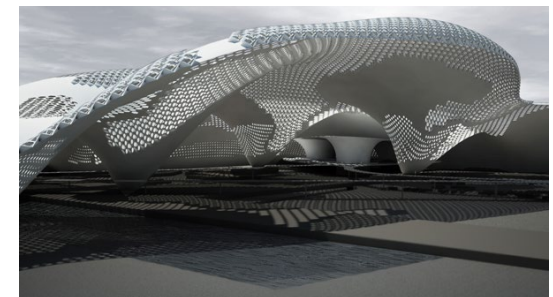
www.decision.ch



Samsonite zedomax.com

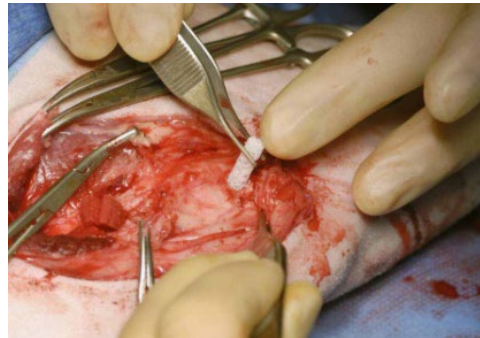
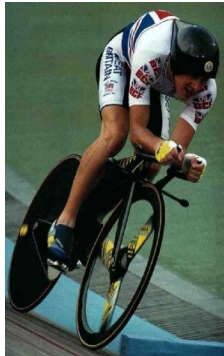


Hublot



www.evolo.us

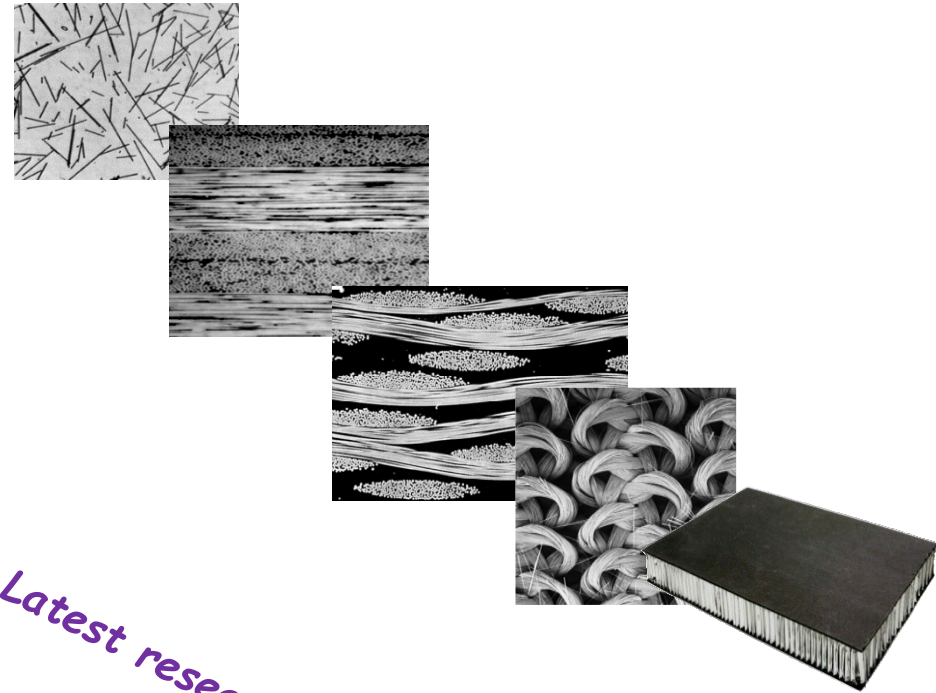
Composite materials?



Your composite product...

Ready for the future...

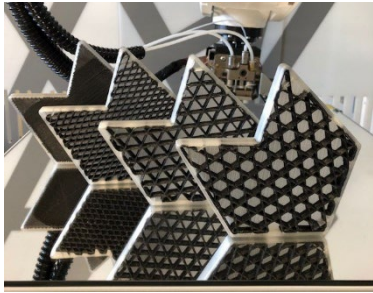
- Introduction aux composites
- Constituants
- Théorie et procédés de mise en œuvre
- Micromécanique, Macromécanique
- Illustrations de choix de matériaux, de mise en œuvre, de conception...
- Quelques principes de recyclage
- Exercices
- Bases pour le cours MSE 440 de Master
 - Sandwich structures and textiles composites
 - Structural design and joining with composites
 - Towards sustainable composites
 - Biocomposites for biomed, sport...
 - Cost modelling-a tool for sustainable innovation
 - Smart composites
 - Nanocomposites



*Latest research, innovation and...
...your composite products*

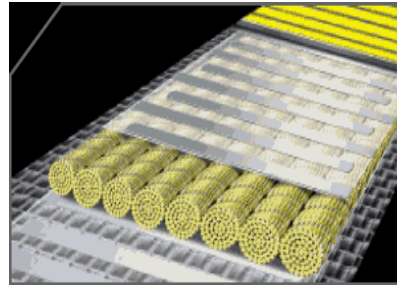
R&D&A

3D printing



Anisoprint

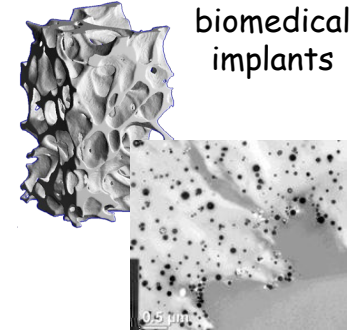
Functional composites



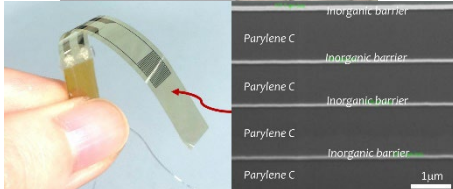
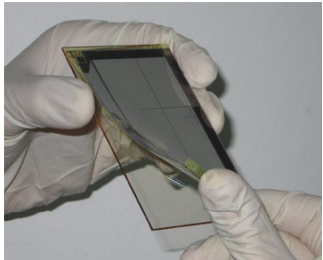
Biocomposites



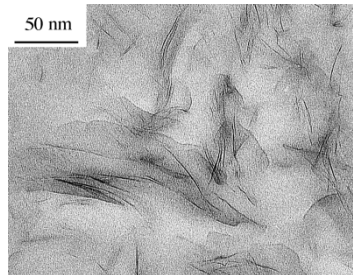
Resorbable
biomedical
implants



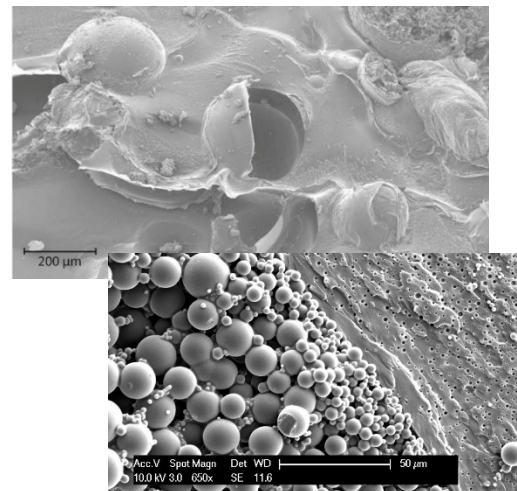
Thin films and micro devices



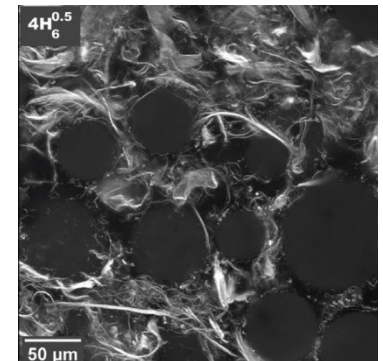
Nanocomposites



Self-healing composites



Hydrogel composites



Your composite product...

Durable smartphone case made of recycled composites



Composites Technology

Driver gloves for Formula 1

The temperature elevation for a heat flux of $10,000 \text{ W/m}^2$ during 30s was recorded. The result obtained on our glove is shown in Figures 3c and 3d and is compared to the initial Formula 1 glove in Figures 3a and 3b below.

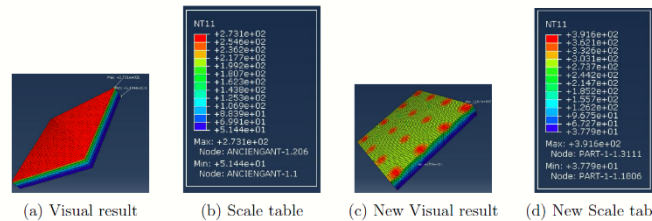


Figure 3: Results of the Abaqus simulation for a reference fabric and for the new product

Composite photovoltaic blinds

Composite technologies-MSE-440-Team 5



Ecofriendly shelters

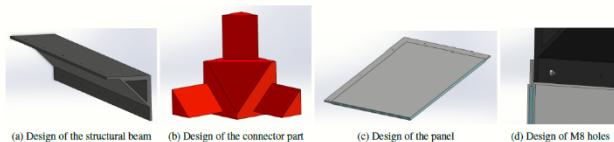
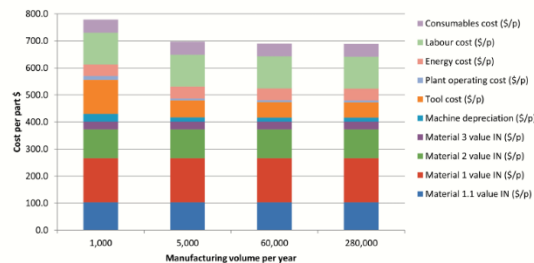


Figure 1: Design of main elements of the house



Piezochromatic composite in hydrogen pressure vessels

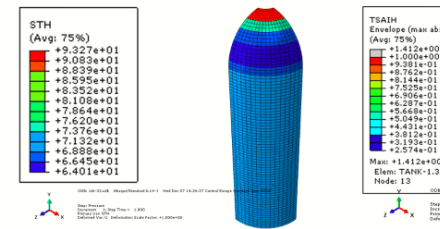


Figure 5: Final thicknesses of fibers on the pressure vessel [mm].

Figure 6: Tsai Hill Failure criterion for envelope and weakest ply.

Composite Greenhouse



Figure 5: 3D views of the greenhouse structure design

Ergonomic air tank



Fig. 1: Pressurized ergonomic portable compressed air tank

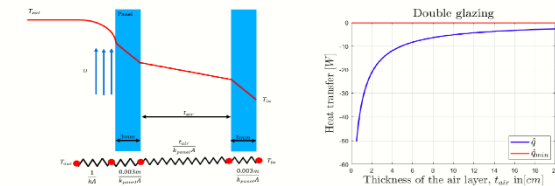


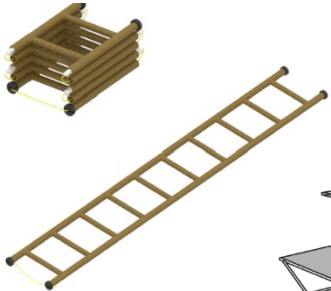
Figure 1: Sketch of the double glazing case. There is only convection outside and conduction inside the panel and in the air trapped between the two panels. Between these panels, convection is neglected because the system is airtight

Figure 2: Heat transfer in function of the thickness of the air layer between the two panels. The red line represent the minimum heat transfer.

Your composite product...

Masters-2023

Composite ladder



Camping kit

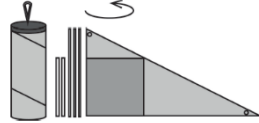


Figure 1: Sketch kit folded

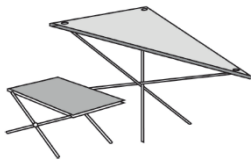
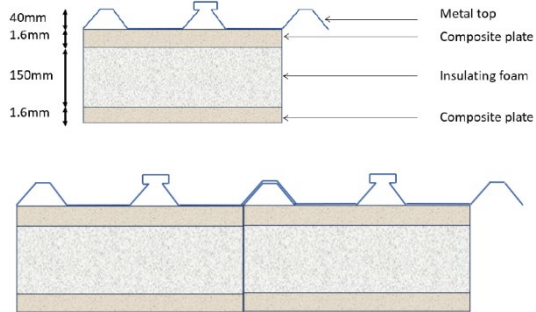
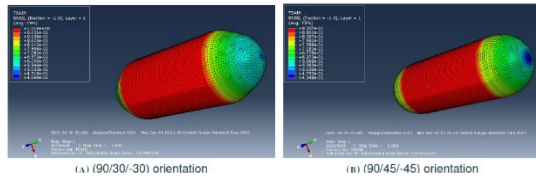


Figure 2: Sketch kit unfolded

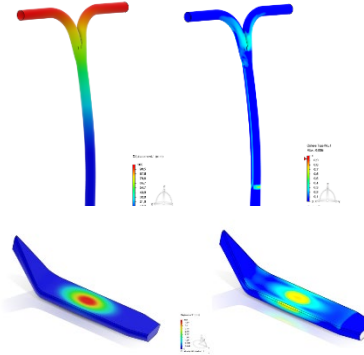
Roof panels



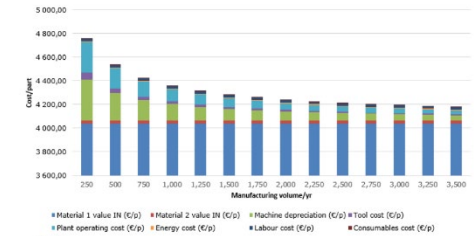
Oxygen cylinders



Rental Electric Scooter - Flax fibers deck & steering pole



Cost per E-scooter (CHF/p)



Biodegradable flower pots

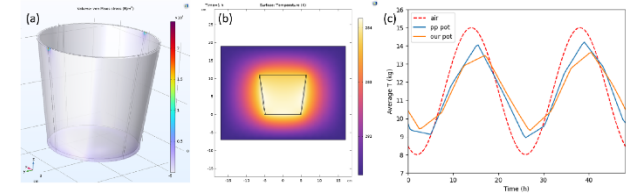
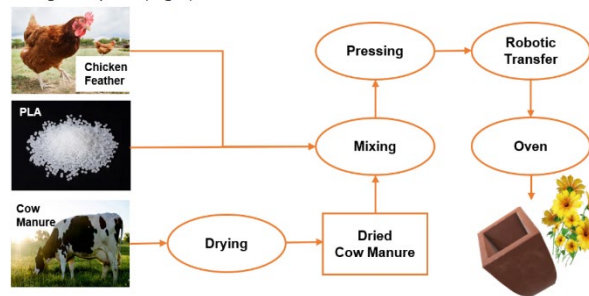
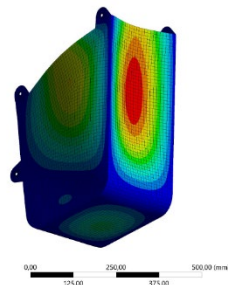


Figure 1. (a) The loading test on flower pots. (b) Time-dependent thermal simulation setup. (c) Temperature variance in the center of the pot during 2 days. The red dash line is the reference air temperature in the environment where the flower pot is put.

Battery tray for electric motorcycle



Composite longboard

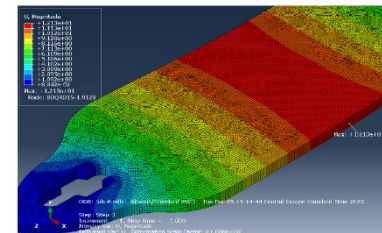
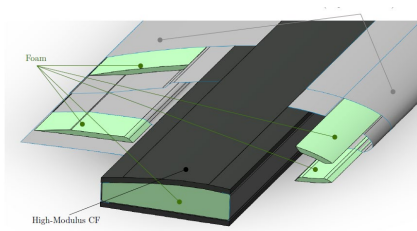
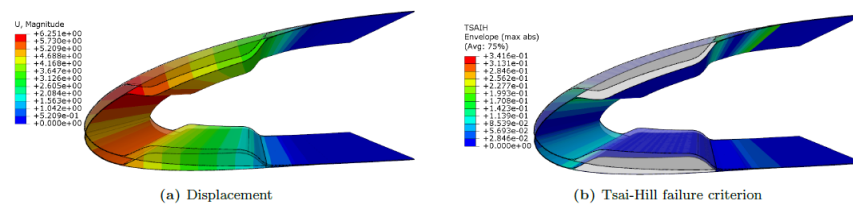


Figure 3: Deflection of the board under load

Your composite product...



Morphing wing



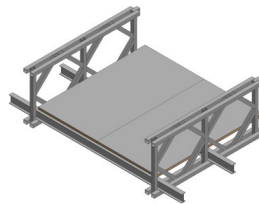
Mussel composites



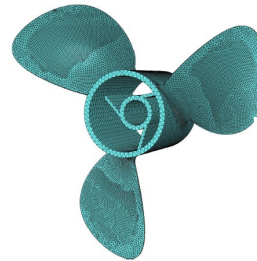
Adaptive thermoformable cast



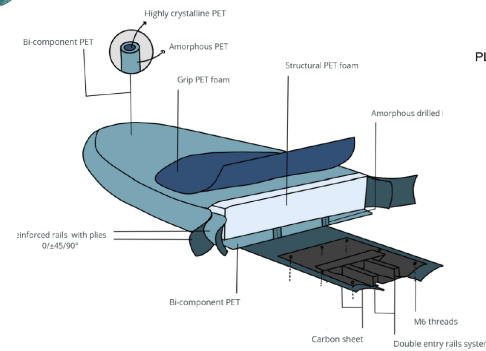
Portable bridge



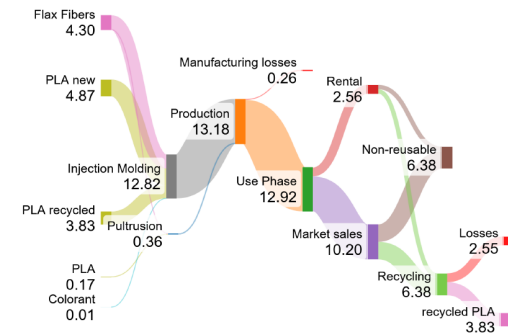
Boat propeller



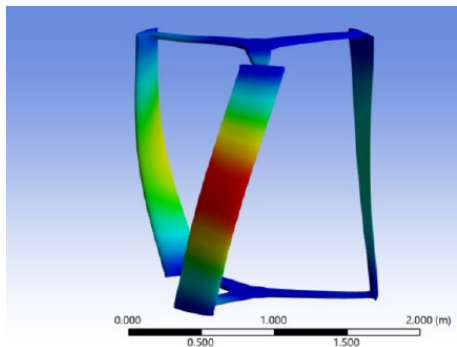
Fully recyclable wingfoil



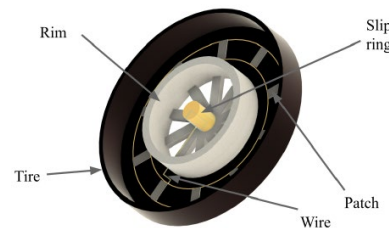
Material flow for tent pegs



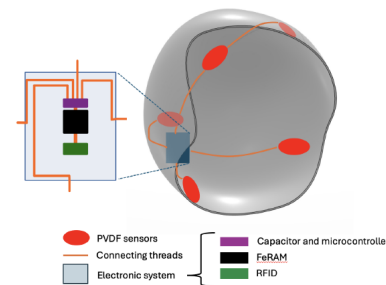
Turbine blade for tidal power generation



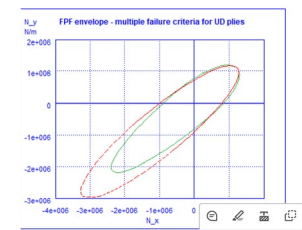
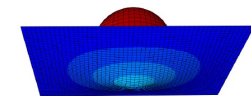
Smart tires



Smart Helmet

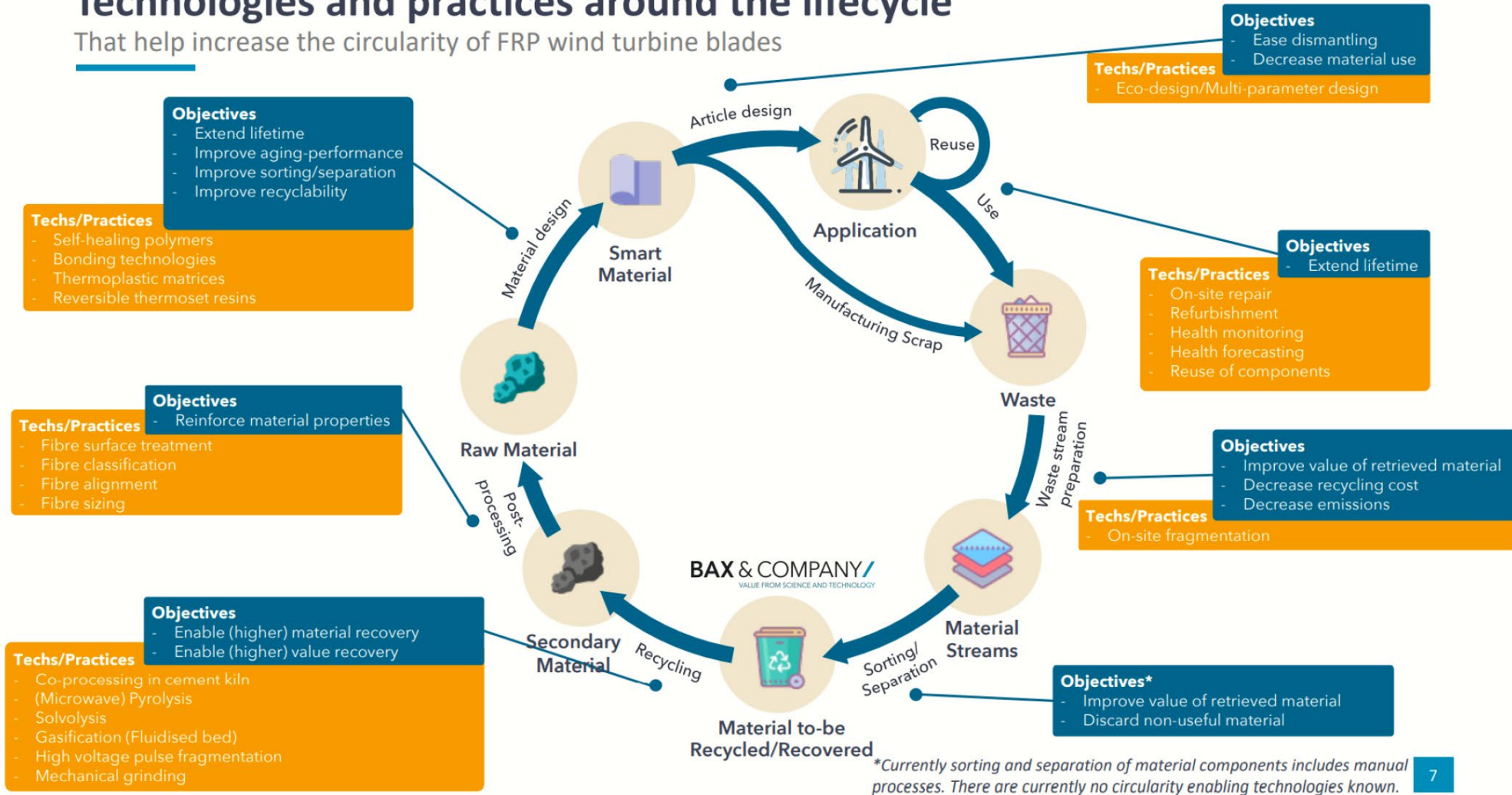


Self healing boat hull



Technologies and practices around the lifecycle

That help increase the circularity of FRP wind turbine blades



Examen

- MSE 340 Composites: 1/3 TP + 2/3 examen
- Oral le 26, 27, 28 janvier
- 5 min de préparation et 15 minutes de réponses
- 3 questions: Constituants/Mise en œuvre/Mécanique
- Liste de passage (Moodle, fichier partagé...)

<https://docs.google.com/spreadsheets/d/1AdceYzxcfnBBv2dMmMsSmPywlx7BwzG7KMQ8y7OKWUA/edit?gid=0#gid=0>

- Révision : le résumé, les exos, les questions