Composite Technology

Sandwich structures

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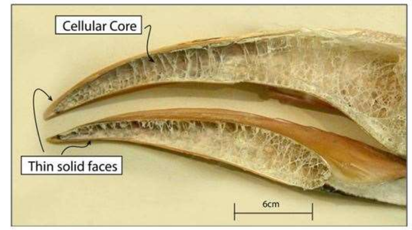
Sandwich

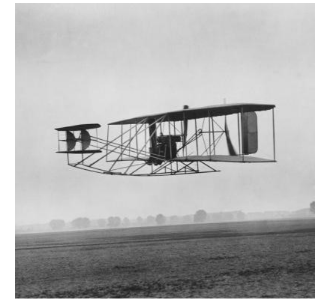
- Introduction
- Materials
- Sandwich effect
- Processing

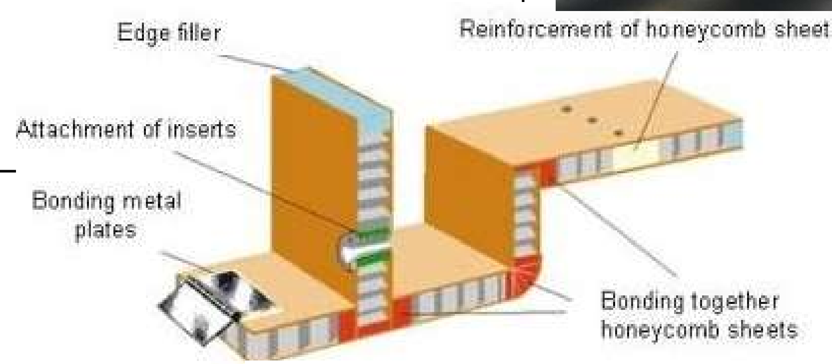
History

1820	Duleau, Fairbairn: first concept 	
1920	Fuselage	
'30	Development of structural adhesives	
WW2	MOSQUITO airplane (sandwich with BALSA core)	
1950	Honeycomb Aerospace industry	τ/ρ , E/ρ higher !!!! Bonding and cost !!!!
1960	Foam cores PVC, PU	For lower cost applications
1970	FEM	
	Processing methods Quality control Joining Cellular thermoplastic cores….	



http://www.virginia.edu/ms/research/wadley/celluar-materials.html





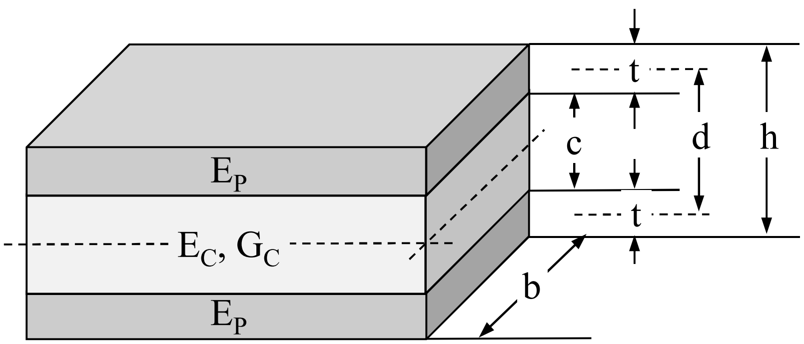
http://www.adhesives.org/adhesives-sealants/market-overview-applications/transportation

D. Zenkert: ***The handbook of sandwich construction***, EMAS 1997
ALCAN, AIREX, SIMS, EUROCOMPOSITES

Sandwich effect

$$D = \text{Bending stiffness} = \Sigma E_i I_i \qquad \text{with :} \quad I_C = \frac{b\,c^3}{12}$$

$$I_P = \frac{b\,t^3}{12} + \frac{b\,t\,d^2}{4}$$



H1 Symetric sandwich
2 identical skins

H2 Perfect adhesion between skins and core
$0.025\text{mm} < e_{adhésif} < 0.2\text{mm}$

$$D = 2\overbrace{E_P\, I_P}^{D_p} + \overbrace{E_C\, I_C}^{D_c} = \underbrace{E_P \frac{b\,t^3}{6}}_{\substack{t \ll d \\ \approx 0}} + E_P \frac{b\,t\,d^2}{2} + \underbrace{E_C \frac{b\,c^3}{12}}_{\substack{E_C \text{ small} \\ \approx 0}}$$

$$D \approx \boxed{D' = E_P \frac{b\,t\,d^2}{2}}$$

$$\text{usually :} \quad 10 < \frac{c}{t} < 50 \quad \text{et} \quad 50 < \frac{E_P}{E_C} < 1000$$

If no adhesion between skins and core : D~0

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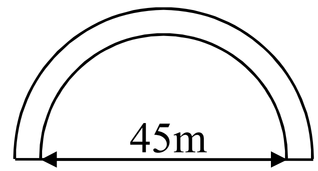
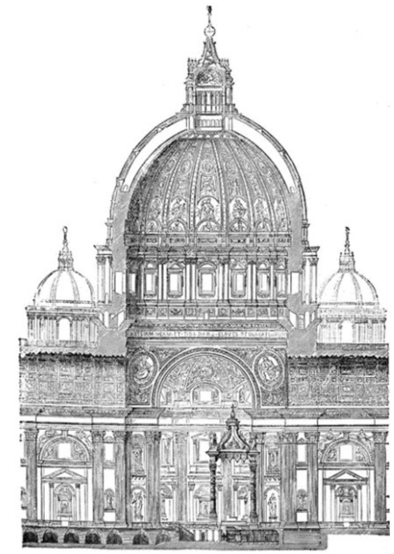
Sandwich effect

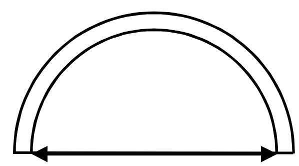
	weight	D	σ bending
t	1	1	1
2t ($^{t}/_{2}$, $^{t}/_{2}$)	~1	~ 12	~ 6
4t ($^{t}/_{2}$, $^{t}/_{2}$)	~ 1	~ 48	~ 12



Roma,
Dome of St-Peter's
Stone: kg/m²



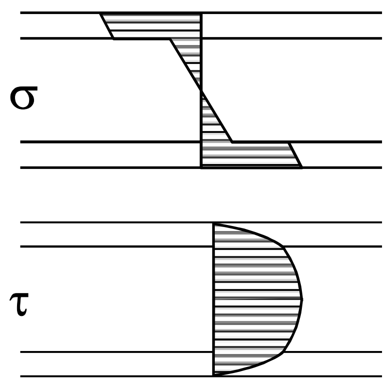
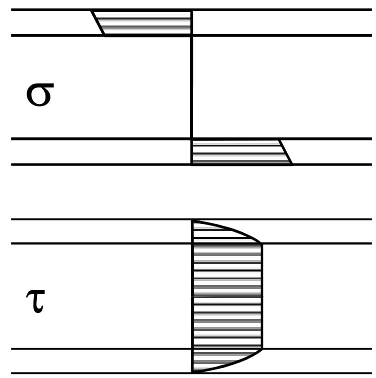
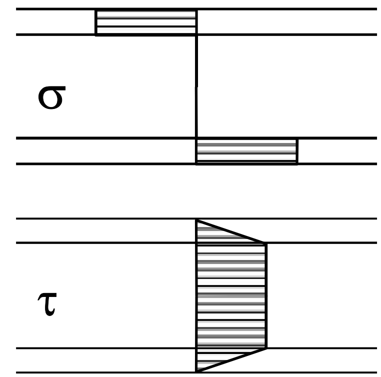
https://etc.usf.edu/clipart/73700/73702/73702_st_peters.htm



Tianjin Stadium
Sandwich
(Al skins and foam core):
kg/m²

http://www.archiexpo.fr/prod/euramax-coated-products/product-63750-1295957.html

Stress distribution (σ et τ)

	Without approximation	$E_c \ll E_f$	$E_c \ll E_f$ et $t_c \gg t_f$	
				
$\sigma_p(z)$	$\frac{M_x\, z\, E_f}{D}$	$\frac{M_x\, z\, E_f}{D_p}$	$\frac{M_x}{t\, d}$	$\frac{c}{2} < \lvert z \rvert < \frac{c}{2} + t$
$\sigma_c(z)$	$\frac{M_x\, z\, E_c}{D}$	0	0	$\lvert z \rvert < \frac{c}{2}$
$\tau_p(z)$	$\frac{T_x}{D}\frac{E_p}{z}\left(\frac{c^2}{4} + c\,t + t^2 - z^2\right)$	$\frac{T_x}{D}\frac{E_p}{z}\left(\frac{c^2}{4} + c\,t + t^2 - z^2\right)$	0	$\frac{c}{2} \le \lvert z \rvert \le \frac{c}{2} + t$
$\tau_c(z)$	$\frac{T_x}{D}\left[\frac{E_p\, t\, d}{2} + \frac{E_c}{2}\left(\frac{c^2}{4} - z^2\right)\right]$	$\frac{T_x\, E_p\, t\, d}{2D_p}$	$\frac{T_x}{d}$	$\lvert z \rvert \le \frac{c}{2}$

Stresses σ are maximum into the skins
τ is max into the core

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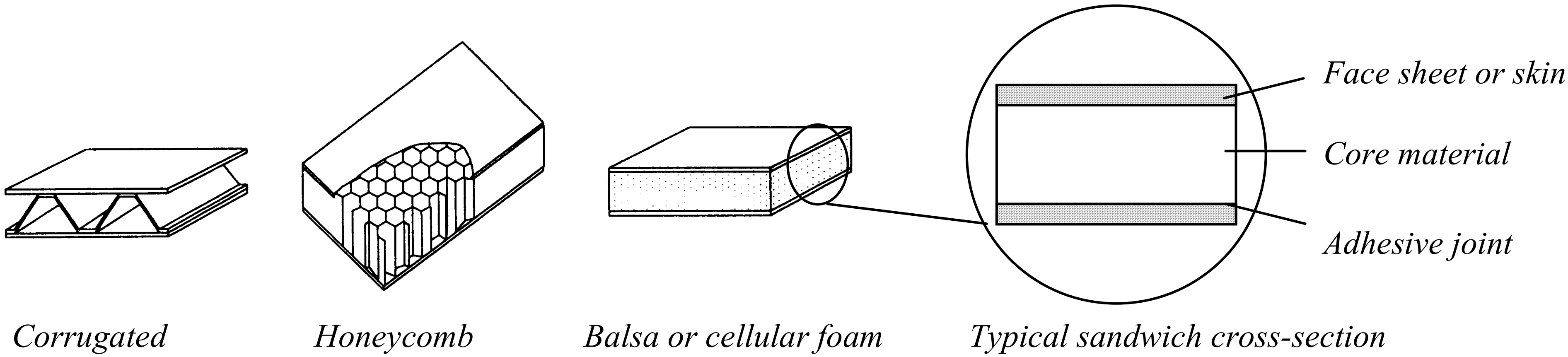
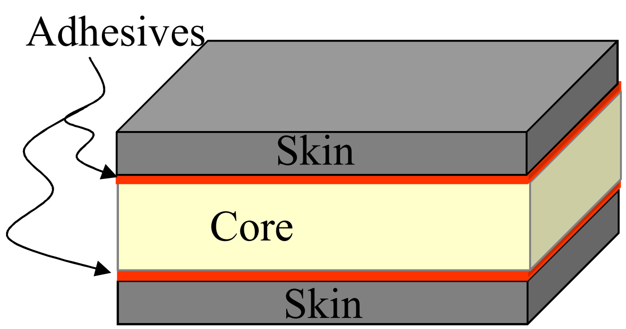
Materials


Face sheet or skin
Core material
Adhesive joint
Corrugated
Honeycomb
Balsa or cellular foam
Typical sandwich cross-section

Materials



Skins			
	ρ [kg/m³]	E [GPa]	σ [MPa]
Steel	2700-8000	70-210	200-1000
Wood	~500	~12	20-40
UD composites	~1600	40-200	1000-1200
Bi-directional composites	~1600	15-100	200-800
Mats	~1700	~10	80-150

Cores		
	ρ [kg/m³]	τ [MPa]
Honeycombs (Al/ Nomex/TP)	20-100	0.2-2
Balsa	150	2
Foam	15-80	0.2-3

+ Adhesives

Honeycombs

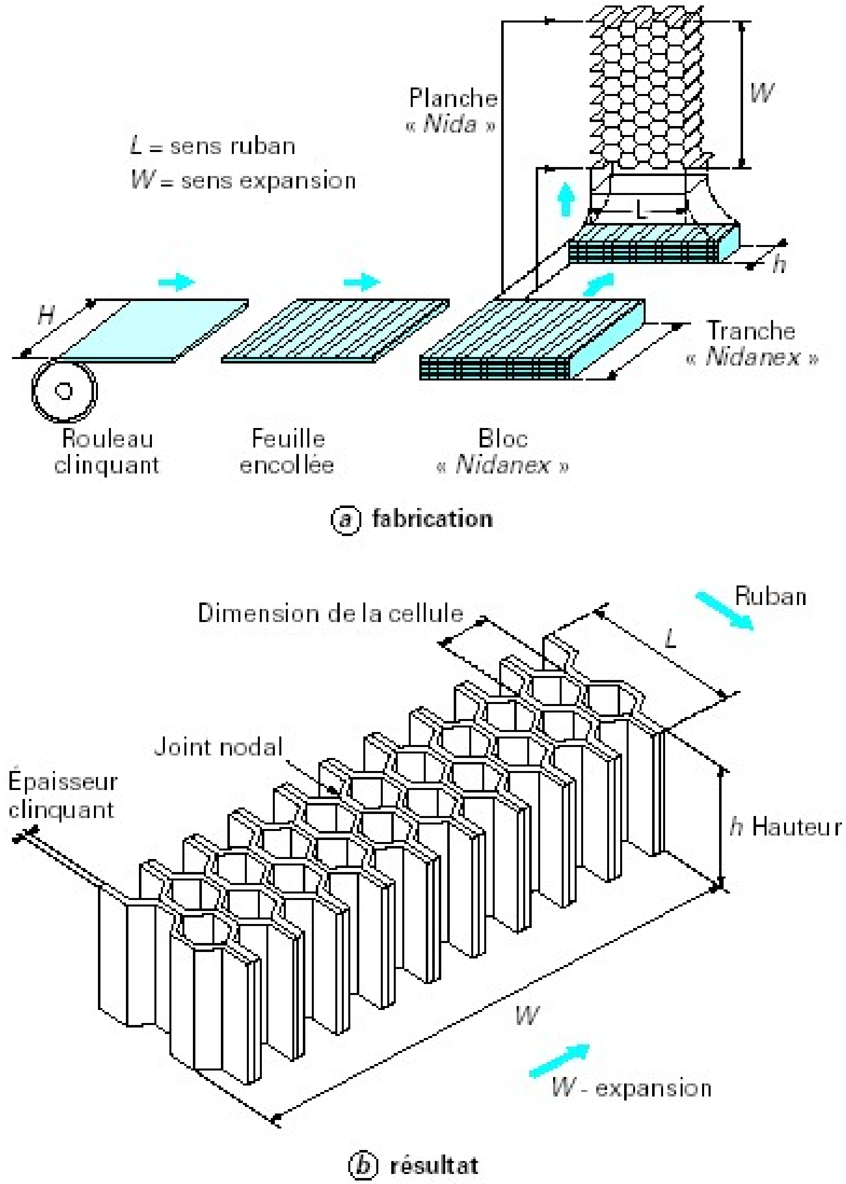
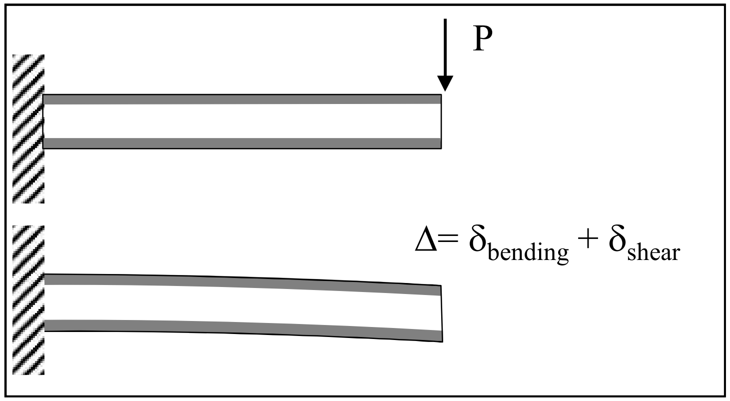


Planche
« Nida »
W
L = sens ruban
W = sens expansion
L
h
H
Tranche
« Nidanex »
Rouleau
clinquant
Feuille
encollée
Bloc
« Nidanex »
(a) fabrication
Dimension de la cellule
Ruban
L
Joint nodal
Épaisseur
clinquant
h Hauteur
W
W - expansion
(b) résultat

Sandwich beams



H $t \ll c\ ;\ E_c \ll E_p$

Bending stiffness: $D = \dfrac{E_f\, t\, d^2}{2}$

Shear stiffness: $S = \dfrac{G_c\, d^2}{c}$

Bending deformation: $\delta_{bending} = \dfrac{P L^3}{3D} = \dfrac{2 P L^3}{3E_p t d^2}$

Shear deformation: $\delta_{shear} = \int_0^L \dfrac{T_x}{S}\, dx = \dfrac{P L}{S}$

$$\boxed{\Delta = \frac{2 P L^3}{3E_p t d^2} + \frac{P L c}{G_c d^2}}$$

Sandwich:

$t = 1\text{mm}$
$c = 30\text{mm}$
$L = 500\text{mm}$
$G_c = 30\text{MPa}$ (80kg/m^3 PVC foam)
$E_f = 200\ 000$ MPa (steel)

$$\left.\begin{array}{l}\delta_{bending} = 0.43P \text{ mm/N}\\ \delta_{shear} = 0.52P \text{ mm/N}\end{array}\right\} \quad \frac{\delta_{bending}}{\delta_{shear}} = 0.83$$

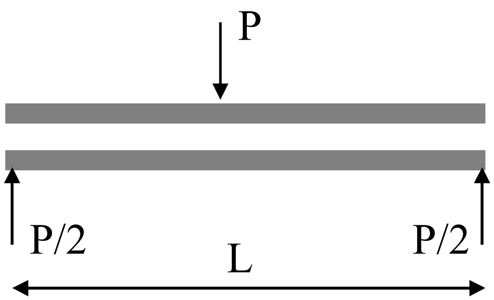
Steel beam:

$h = 30\text{mm}$
$L = 500\text{mm}$
$E_f = 200\ 000$ MPa (steel)

$$\left.\begin{array}{l}\delta_{bending} = \dfrac{P L^3}{3D} = \dfrac{4 P L^3}{E h^3} = 0.0926P \text{ mm/N}\\ \delta_{shear} = \dfrac{P L}{S} = 1.2 \dfrac{P L}{G h} = 0.0003P \text{ mm/N}\end{array}\right\} \quad \frac{\delta_{bending}}{\delta_{shear}} = 310$$

Sandwich testing

3 points bending

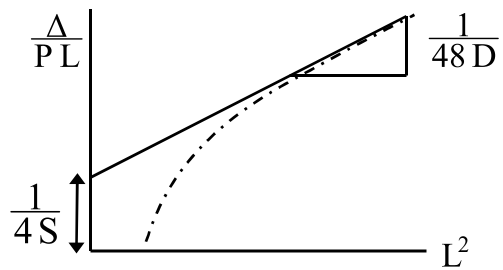


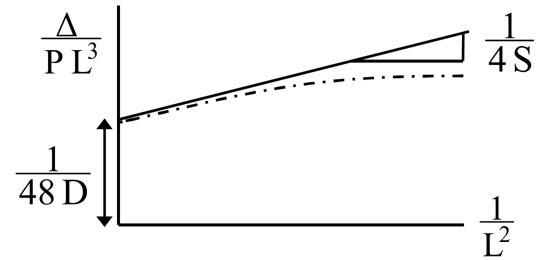
$$M_{max} = \frac{P\,L}{4} \quad \text{et} \quad T_{max} = \frac{P}{2}$$

allow to calculate σ max in the skins and τ max in the core

$$\Delta = \delta_{flexion} + \delta_{cisaillement} = \frac{P\,L^3}{48\,D} + \frac{P\,L}{4\,S}$$

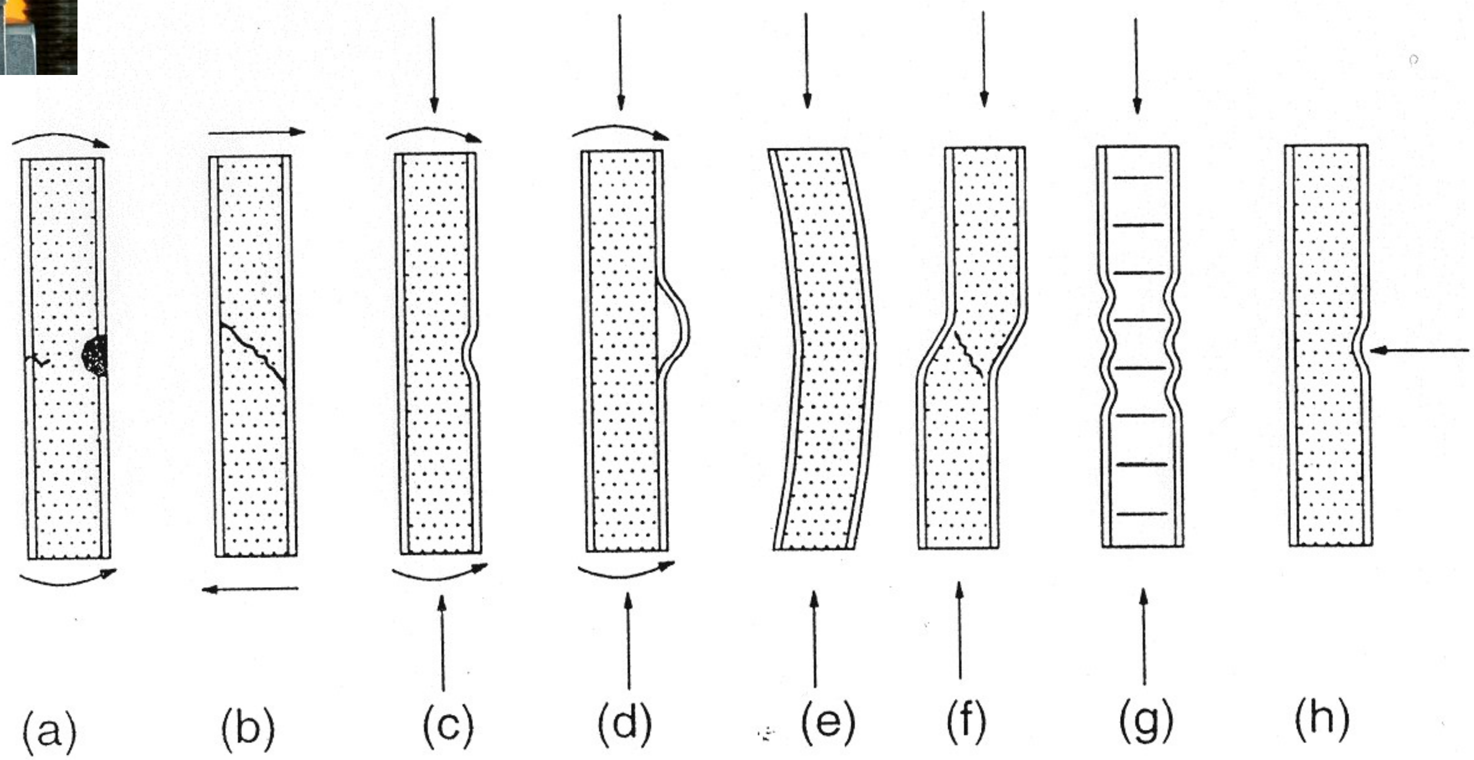
$$\frac{\Delta}{P\,L} = \frac{L^2}{48\,D} + \frac{1}{4\,S} \qquad\qquad \frac{\Delta}{P\,L^3} = \frac{1}{48\,D} + \frac{1}{4\,S}\,\frac{1}{L^2}$$





=> Measurements of D et S

Damage in sandwich



(a) Face yielding/fracture
(b) Core shear failure
(c, d) Face wrinkling
(e) General buckling

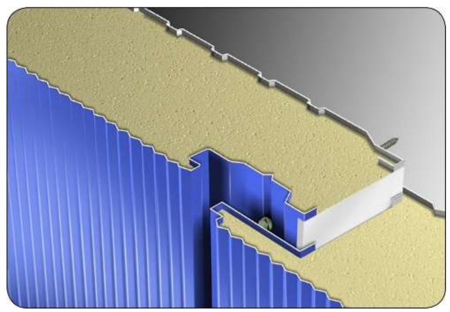
Debonding
Impact damage

(f) Shear crimping
(g) Face dimpling
(h) Local indention

Some applications

Sport (skis, boards, F1…)
Transportation
Infrastructures

http://sdshuangli.en.alibaba.com

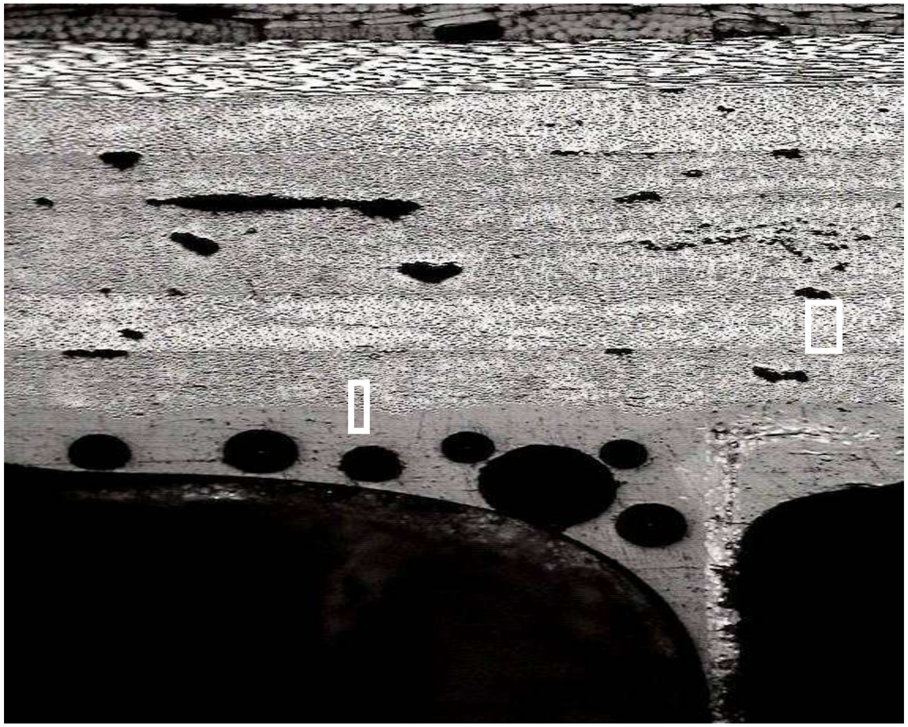


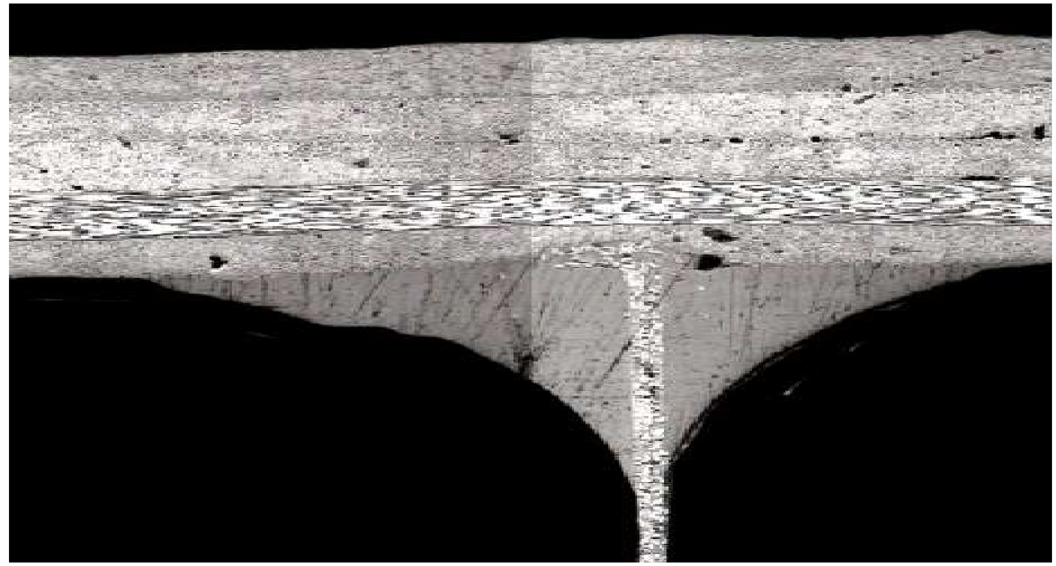
http://www.giesselogistica.eu/en/sandwichpanels/

	t_p (mm)	t_c (mm)	M_{max} (Nm) verre	M_{max} (Nm) carbone
Airplanes Racing cars	0.5	10	300	1000
Sailing boats	1.5	25	5000	19000
Large boats	5	60	99000	360000

www.hexcelcomposites.com
www.eurocomposites.com

Processing





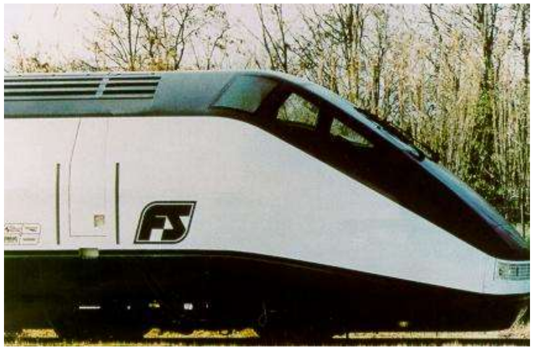
Processing methods

2 main routes

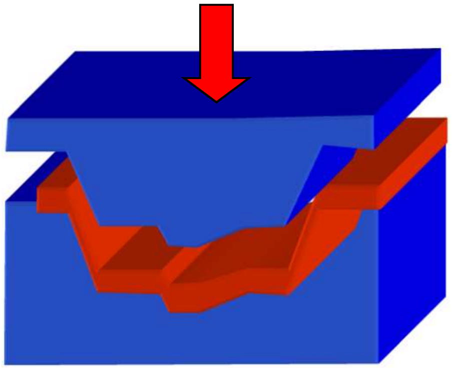
- bonding and reticulation of the two skins at same time
- processing of the skins and then bonding

Main methods

- wet lay-up
- prepregs
- liquid moulding/ RTM, VARTM, SRIM…
- continuous lamination
- others: compression, pultrusion, filament winding



Front-end cabin,
ETR500 high speed Italian train.
Vacuum-bag, FRP, PEI foam

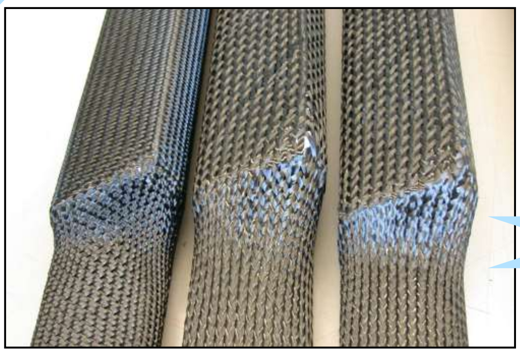


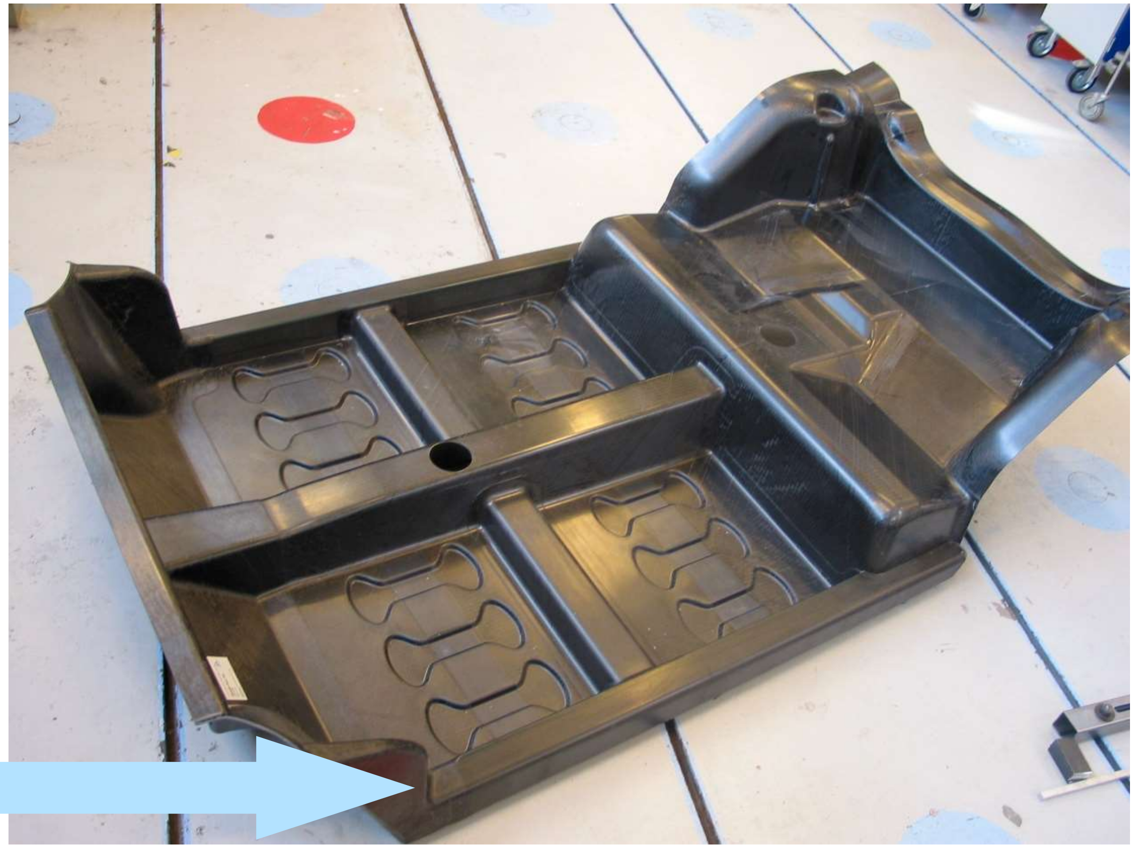
Some issues

- bonding quality
- release of foaming gaz
- spiking of skins…

Ref: K.F.Karlsson and B.T. Astrom, « Manufacturing and applications of structural sandwich components », Composites Part A, 28 A (1997), pp.97-111

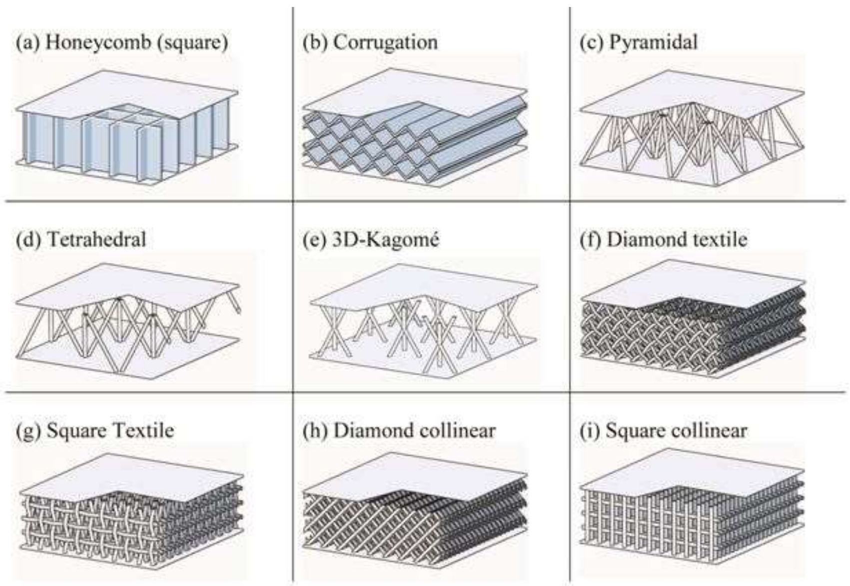
RTM





VW Lupo, prototype platform

Evolutions… cellular materials



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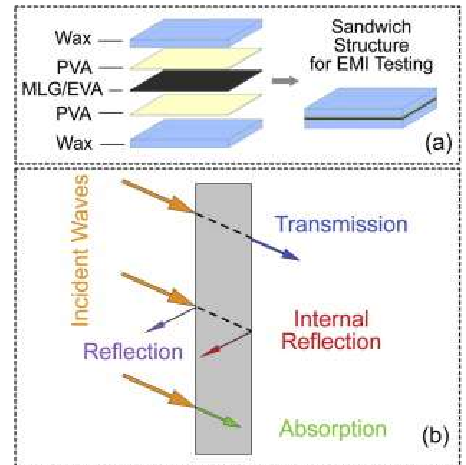
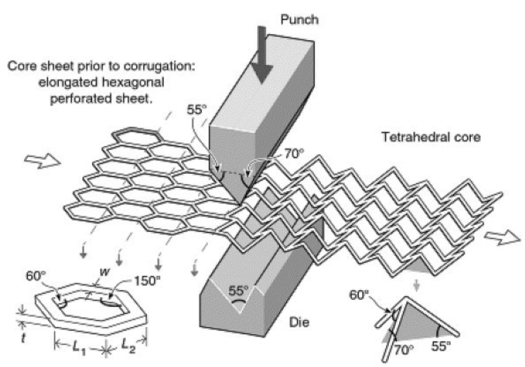
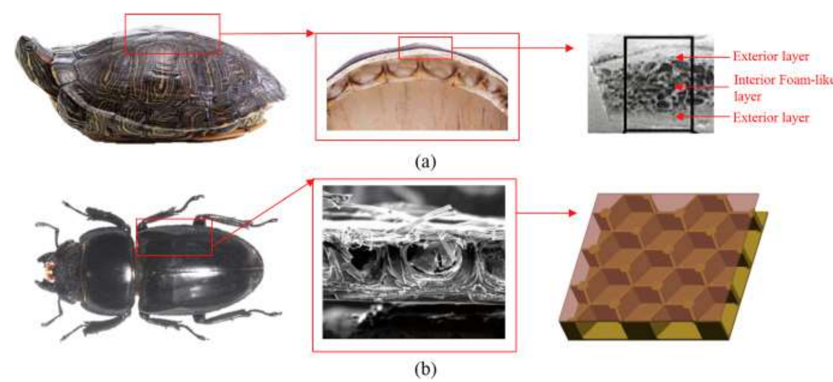


Flexible graphene/polymer composite films in sandwich structures for effective **electromagnetic interference shielding**
Carbon, Volume 66, January 2014, Pages 67-76



Fabrication and structural performance of periodic cellular metal sandwich structures
Composites Science and Technology 63 (2003) 2331–2343



Dynamic crash responses of bio-inspired aluminum honeycomb sandwich structures with CFRP panels
Composites Part B: Engineering, Volume 121, 15 July 2017, Pages 122-133

Evolutions… cellular materials

3D textiles structures for sandwich (cf Textile composites)

Cellular composites (cf Biocomposites)