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New strategies for optimal natural fibre reinforced sandwich parts

**Neue naturfaserverstärkte Produkte -
vielseitig und funktionssicher**

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Göttingen, 09. November 2004

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Overview of the Presentation

Overview

- **Introduction**
 - Sandwich construction
 - Core material types
- **Sandwich materials today**
 - Paper honeycomb production today
 - Production concepts of packaging industry
- **New strategy for honeycomb core production and sandwich panel production**
 - TorHex paper honeycomb material and production process
 - Production line for in-line panel production
- **New strategy for sandwich material selection and optimization**
 - Performance per cost
 - Sandwich materials selection charts for bending stiffness versus density and cost
- **Sandwich panel and part examples**
 - Examples of natural fibre reinforced sandwich panels and parts
- **Conclusions**

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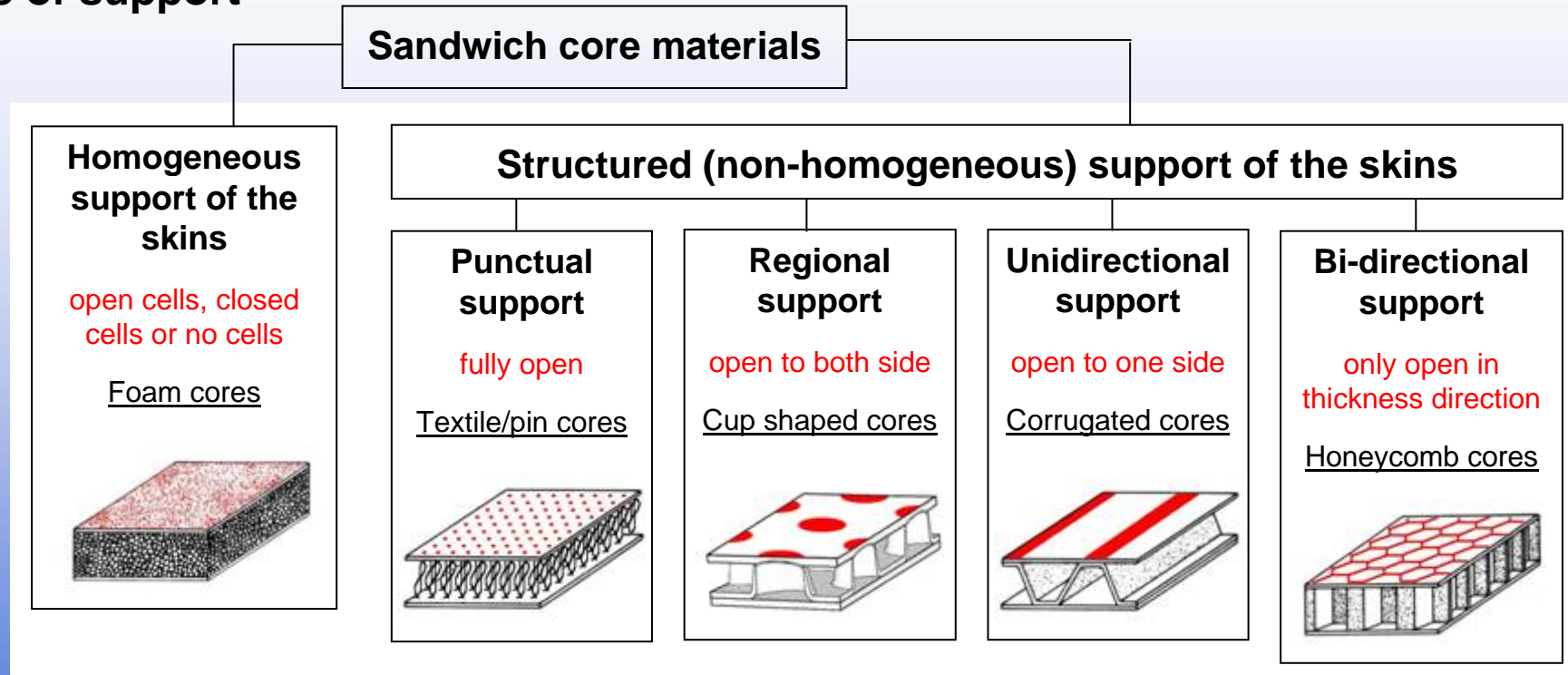


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Sandwich Core Material Types

Type of support



Examples:

PU-foam,
PP-foam (EPP)

Woven or knitted
sandwich fabrics

Cup shaped
core panels

Corrugated boards,
Twin sheet panels

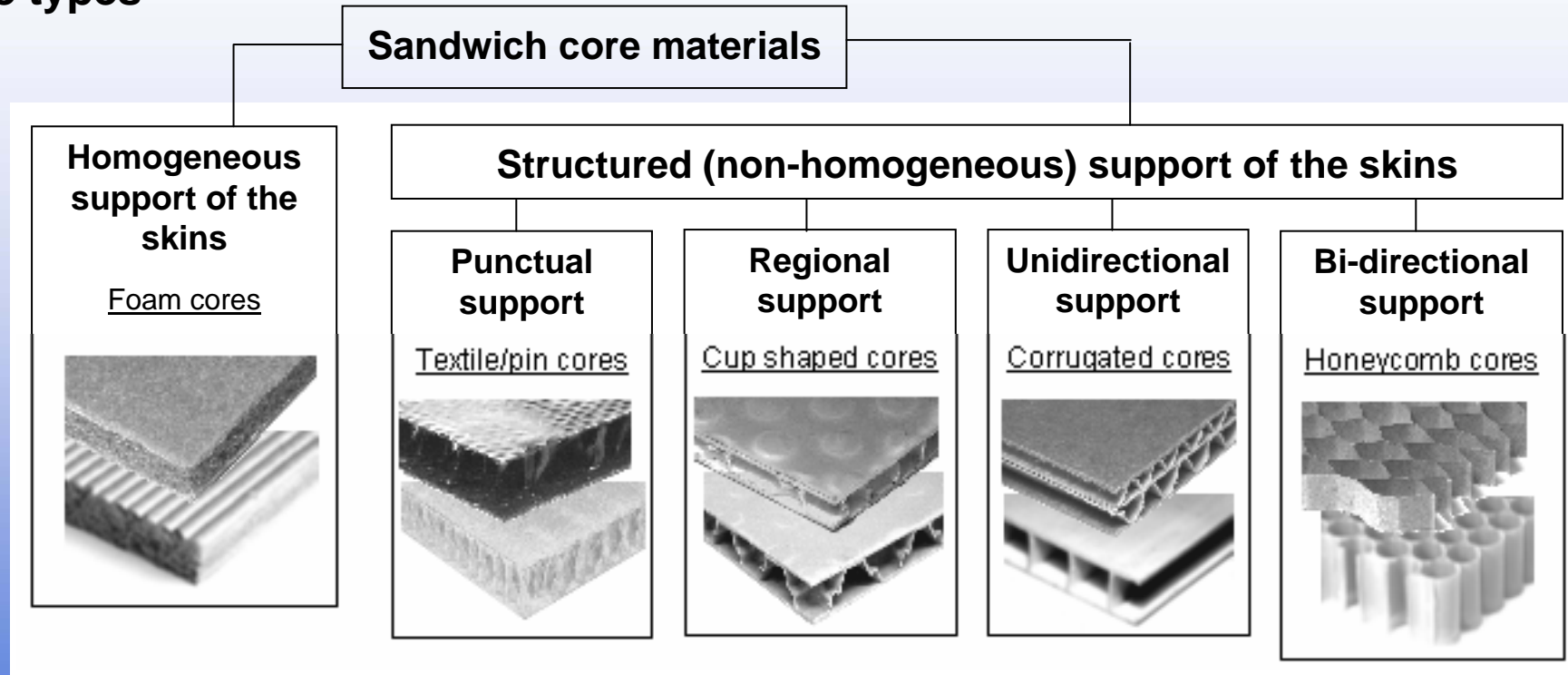
Expanded honeycombs
Extruded honeycombs

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Sandwich Materials in Transportation Today

Core types



Main problem:

low compression properties

low shear properties

low shear properties

low properties perpendicular to the corrugations

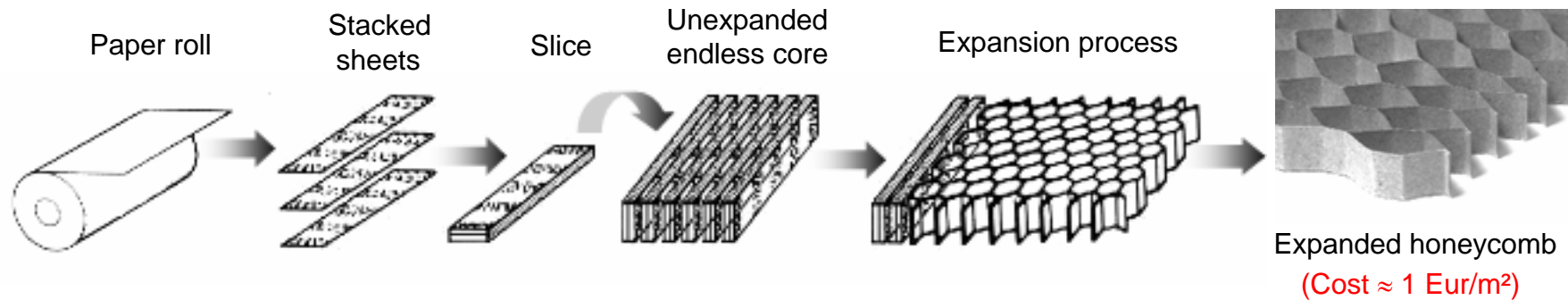
very high manufacturing costs

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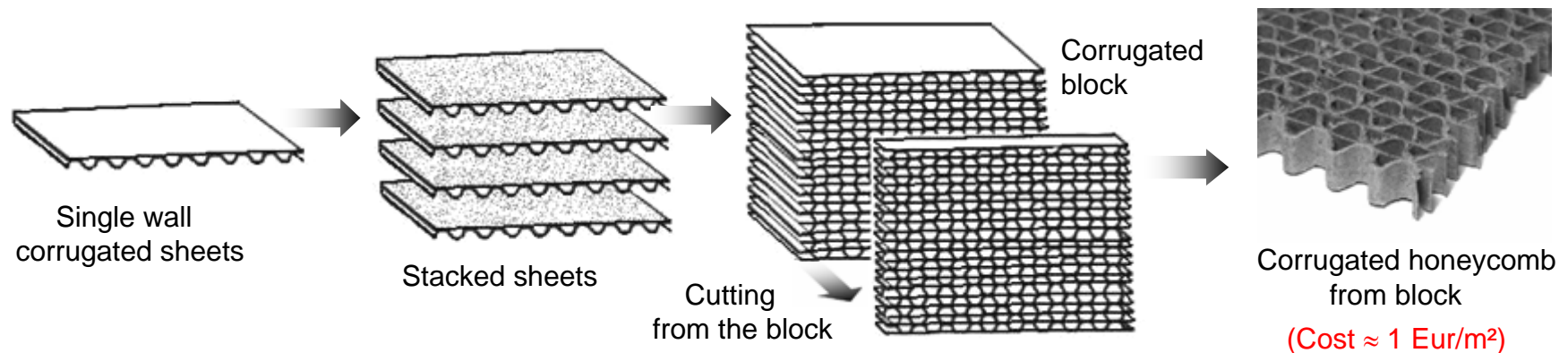


Paper Honeycomb Production Today

Paper honeycomb production via expansion



Paper honeycomb production via corrugated block



Both processes

- Require the cutting and handling of several sheets
- Result in rather slow expensive production

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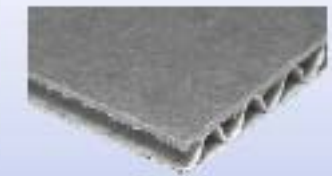
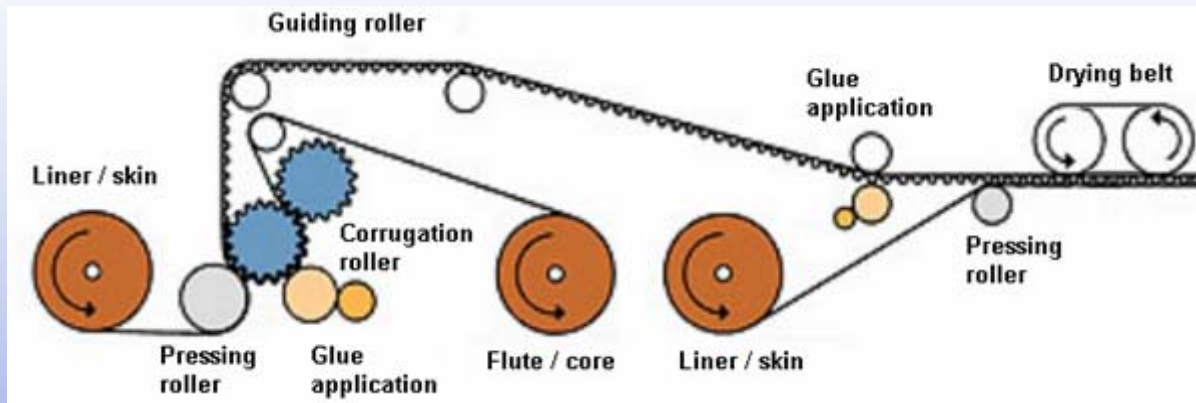


Paper honeycomb cores

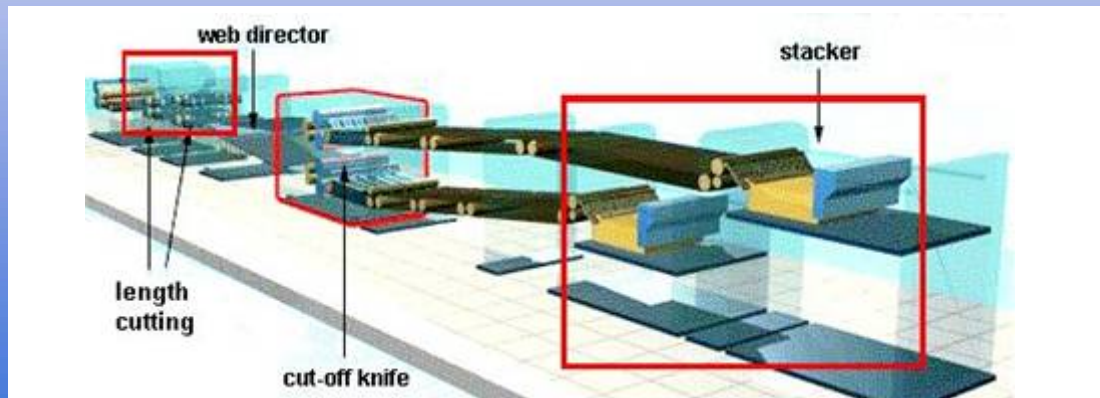
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Processes from Packaging Industry

Corrugated cardboard production



Corrugated cardboard
(Cost ≈ 0.2 Eur/m²)



Cost efficient
in-line production
with cutting and
stacking

- Very low cost are possible because sandwich core and panel are produced from one continuous material web by successive in-line operations

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Cost Efficient Processes

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New strategy for honeycomb core production

Folded Honeycomb Concept

- Honeycombs produced from a continuous web by successive in-line operations

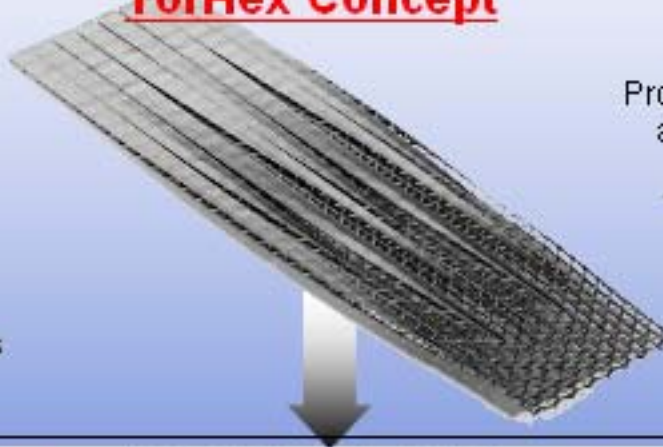
From Aerospace Industry



Internal structure and properties

- ⇒ Excellent mechanical properties
- ⇒ Very low weight

TorHex Concept



From Packaging Industry

Production principle and technology



- ⇒ Automated production
- ⇒ Low production costs



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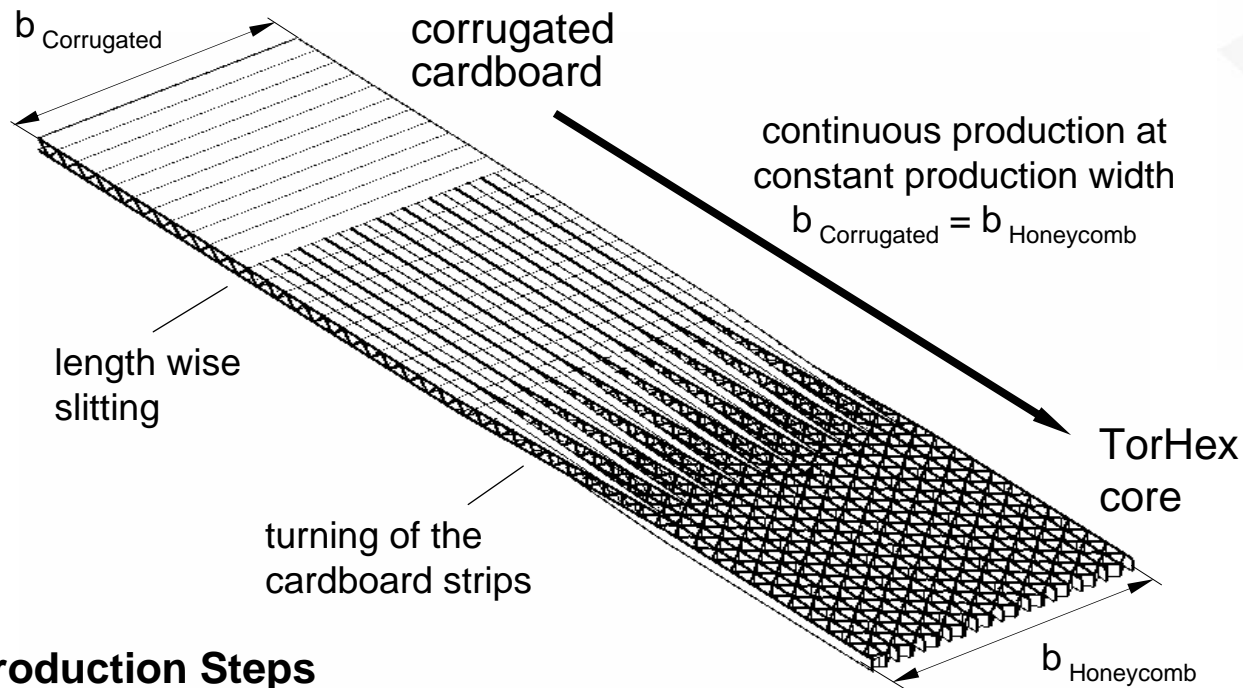


TorHex Folded Honeycomb from Corrugated Board

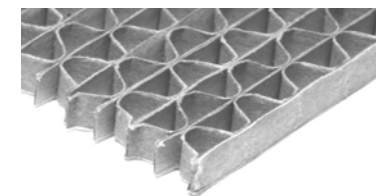
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Folded Honeycomb TorHex

Folded Honeycomb from Corrugated Cardboard



TorHex core sample showing the production process



5 mm high TorHex core from corrugated board

Production Steps

- **Corrugation:** Cell wall corrugation by a corrugator (packaging industry)
- **Length wise slitting:** Slitting of the board from above and below
- **Turning/Folding:** Turning of the connected cardboard strips (90°)
- **Skin lamination:** In-line lamination of the skins onto the core is possible

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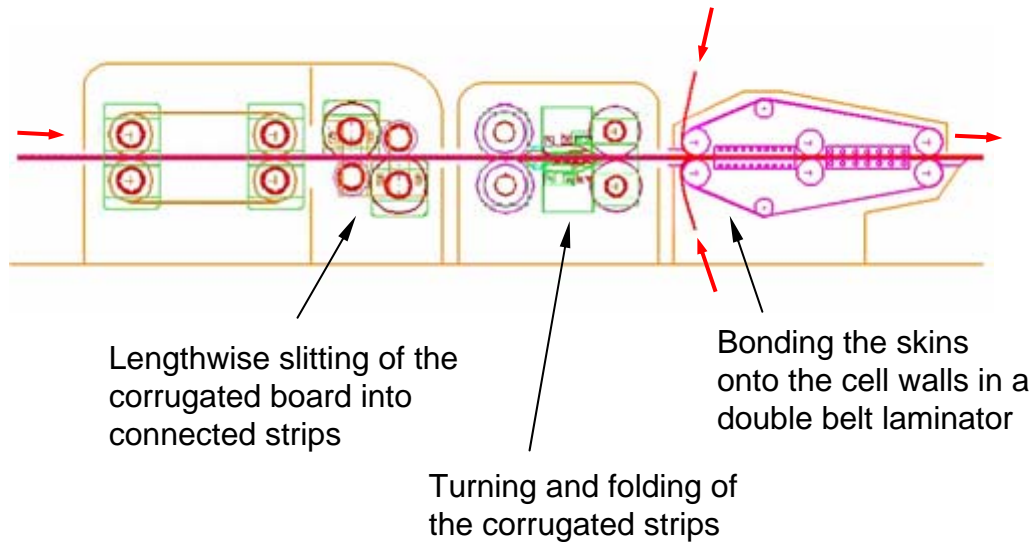


TorHex Folded Honeycomb from Corrugated Board

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TorHex Production Line

TorHex Panel Production Line



- Automated production at high speeds is possible and will lead to a high productivity and low costs
- Development by packaging industry will enable efficient machine development (> 100 m/min)



TorHex lab-scale production line (slitting and turning unit)

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TorHex Prototype Production Unit



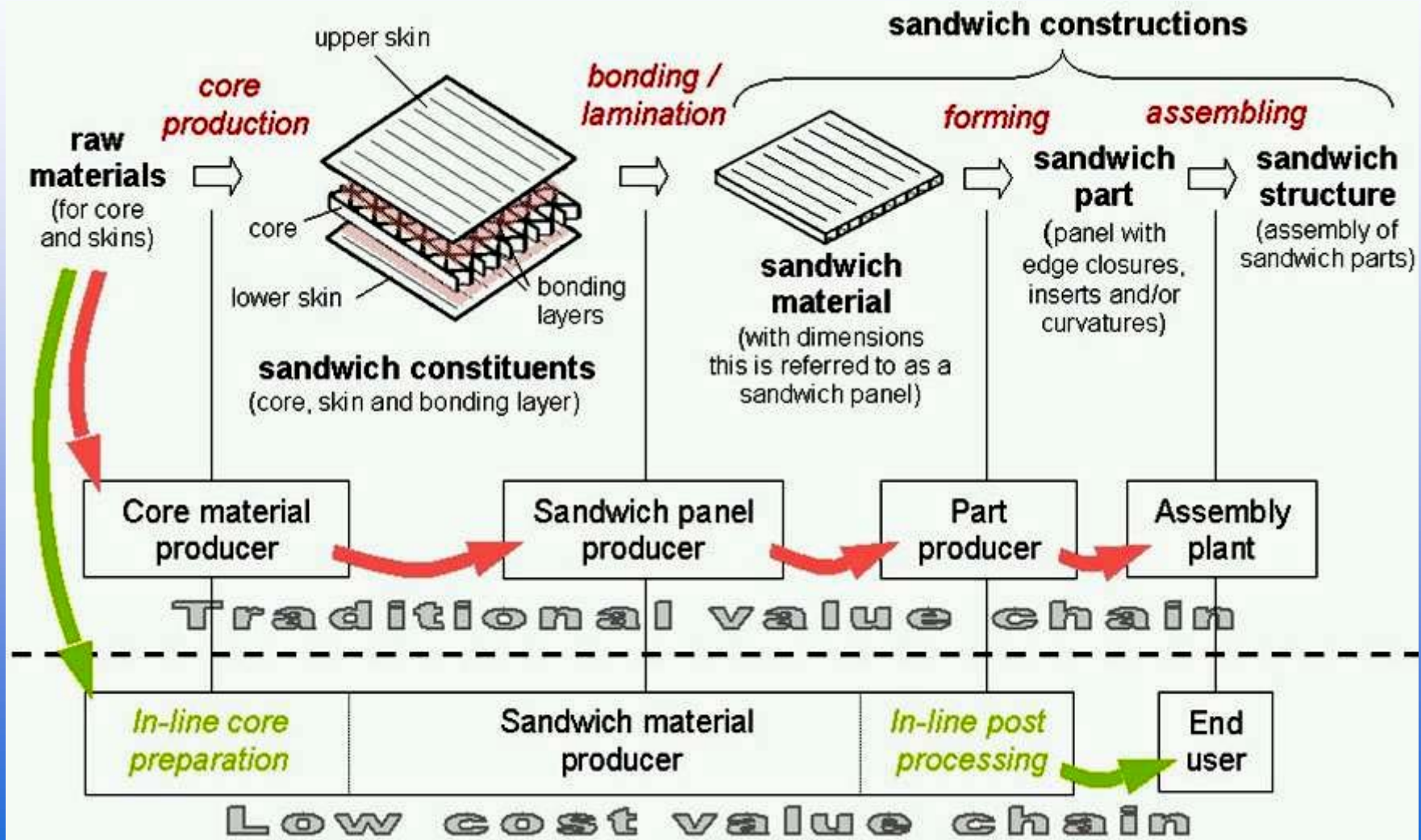
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Sandwich Part - Value Chain



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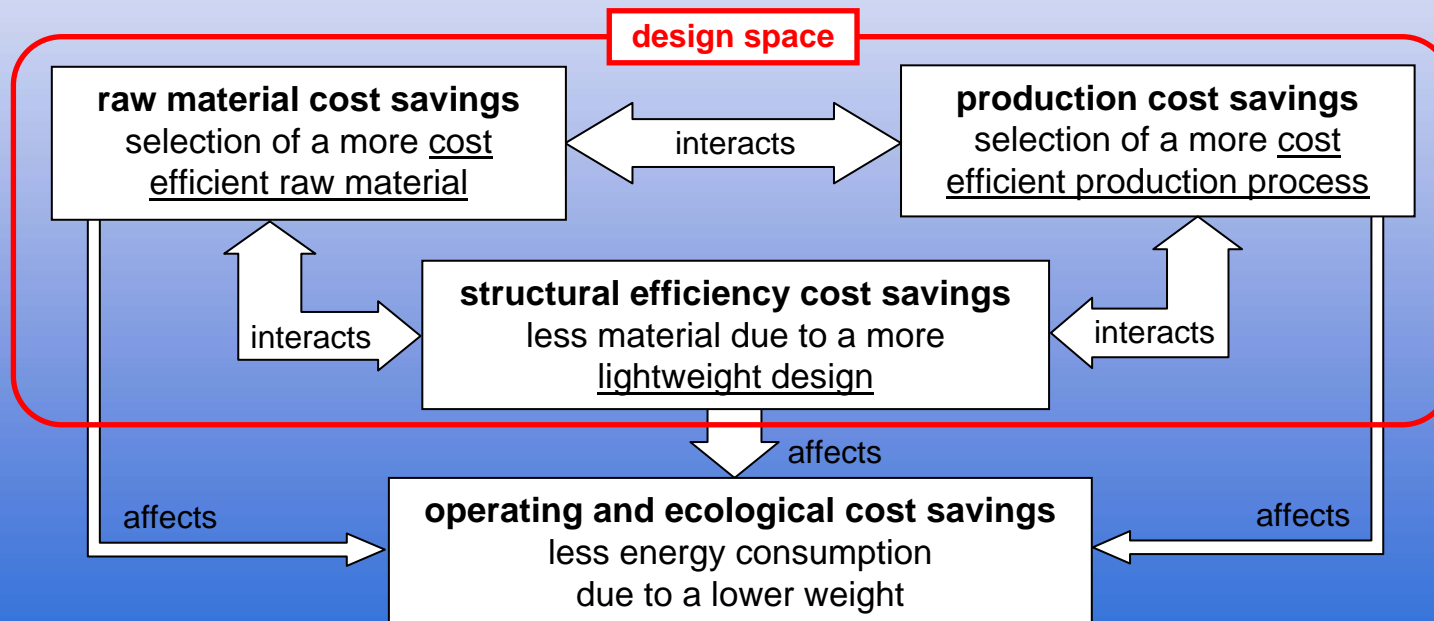
Performance per Cost

Economical advantage of lightweight constructions

For structural parts : $\frac{\text{performance}}{\text{costs}} \approx \frac{\text{structural performance}}{\text{material costs} + \text{production costs} + \text{operating costs} + \text{ecological costs}}$

affected by weight (pointing to operating costs + ecological costs)

Potential economical advantages of sandwich constructions:



➔ Complex interactions require to consider cost of material, weight and production

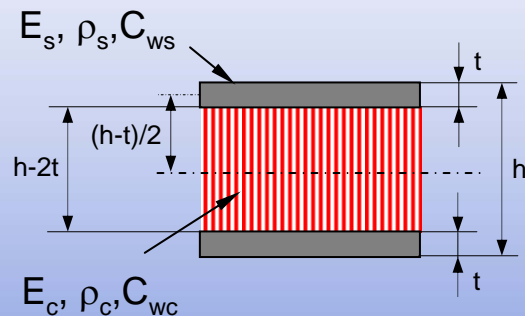
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Effect of Sandwich Construction

Sandwich constructions: Definitions and effect of the sandwich thickness

- Geometrical definitions
(symmetrical sandwich materials)



Only two geometrical variables:

t : skin thickness

h : sandwich thickness

core thickness: $h-2t$

distance skins-neutral axis: $(h-t)/2$

Sandwich effect on bending stiffness weight and cost	$h_1 = 2 t_1$	$h = 2 h_1$ $t = 0.5 t_1$	$h = 2.4 h_1$ $t = 0.06 t_1$
Relative thickness	1	2	2.4
thickness ratio t/h	0.5	0.125	0.0125
Relative bending stiffness	1	4.625	1
Relative weight (core density 20 times lower)	1	0.575	0.177
Relative cost with expensive core (equal cost per volume)	1	2	2.4
Relative cost with low cost core (20 times lower cost per vol.)	1	0.575	0.177

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Sandwich Materials Selection Chart (weight)

Sandwich materials selection chart (modulus versus density)

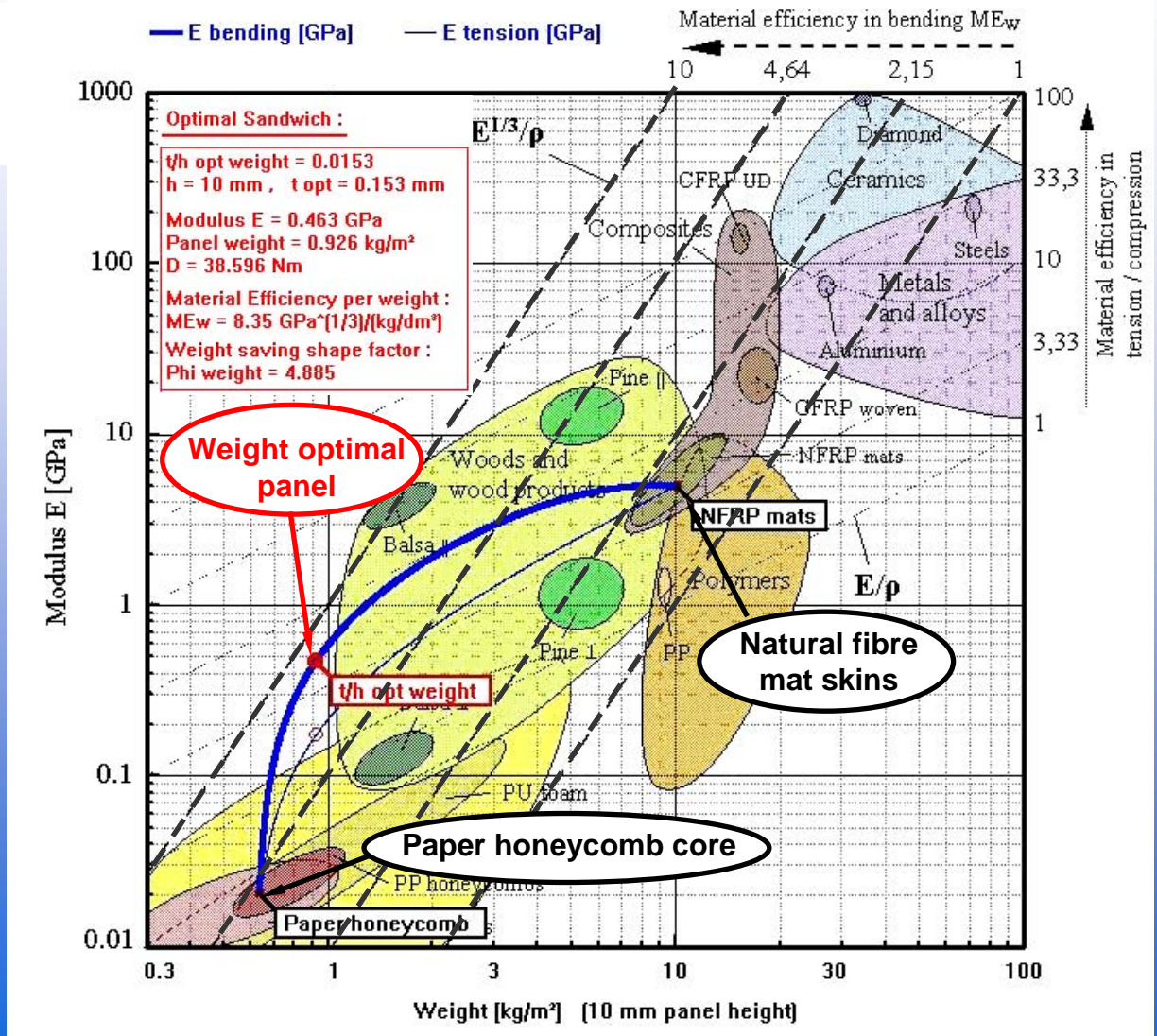
Material efficiency in bending:

$$E^{1/3}/\rho \text{ [GPa}^{1/3}/(\text{kg}/\text{dm}^3)]$$

Sandwich material combinations in function of thickness ratio t/h

Example:

Natural fibre mat skins on paper honeycomb core

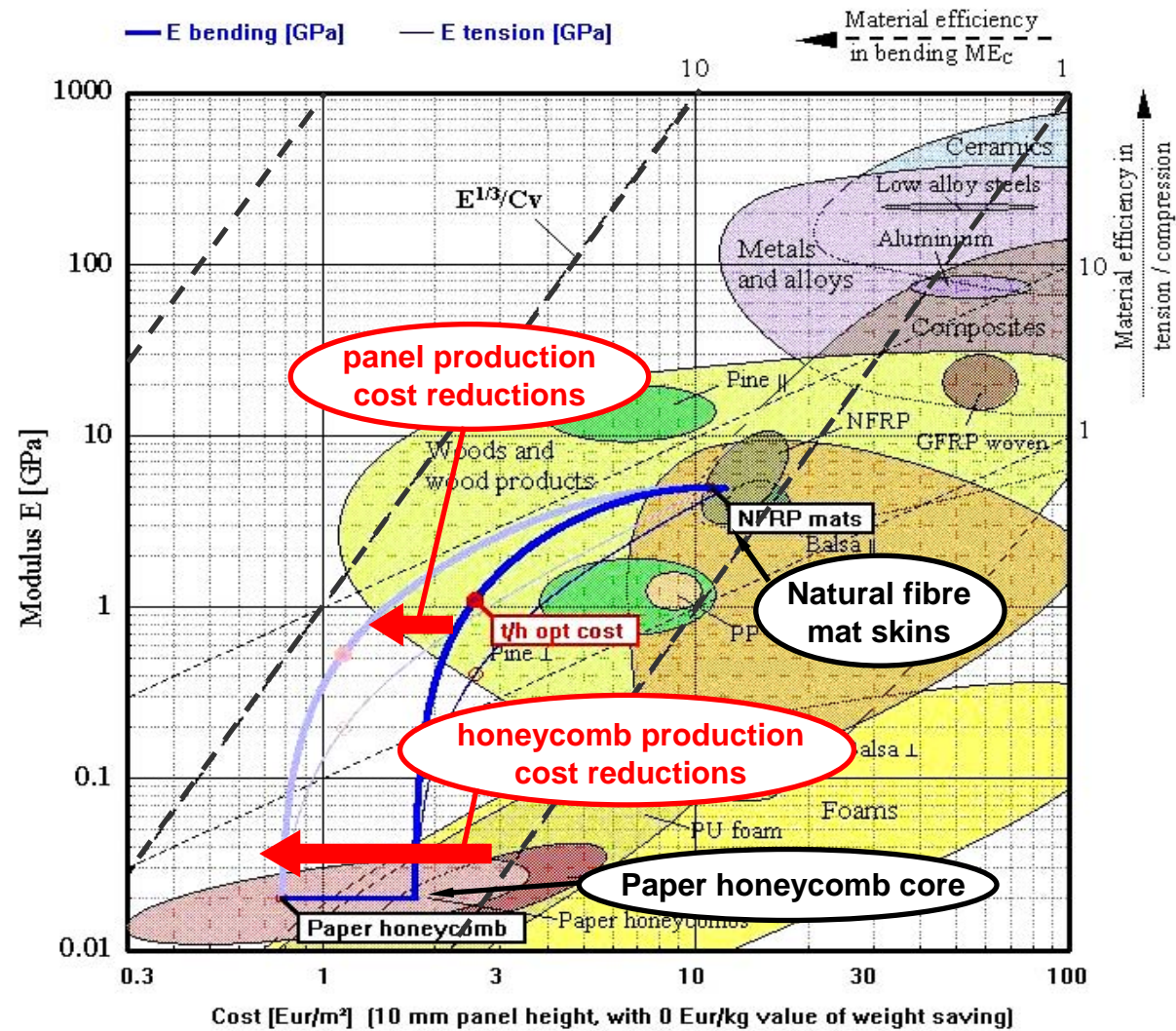


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Sandwich Materials Selection Chart (cost)

Sandwich materials selection chart (modulus versus cost)



Skin material :

NFRP mats

Modulus $E_s = 5$ GPa
Density $\rho_{hos} = 1$ kg/dm³
Cost $C_{ws} = 1.1$ Eur/kg

Core material :

Paper honeycomb

Modulus $E_c = 0.02$ GPa
Shear not included
Density $\rho_{hoc} = 0.064$ kg/dm³
Cost $C_{wc} = 1.25$ Eur/kg

Optimal sandwich :

t/h opt cost = 0.0389
 $h = 10$ mm , t opt = 0.389 mm
Modulus $E = 1.095$ GPa
Panel cost = 2.594 Eur/m²
 $D = 91.275$ Nm
Material Efficiency per cost :
 $ME_c = 3.973$ GPa^{1/3}/(Eur/dm²)
Cost saving shape factor :
 Φ cost = 2.556

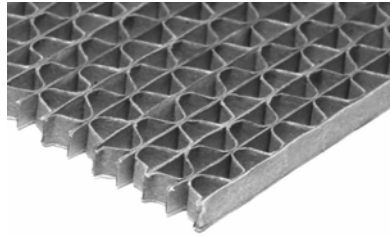
Value of weight saving
 $C_{wv} = 0$ Eur/kg
Sandwich production cost
 $Cap = 1$ Eur/m²

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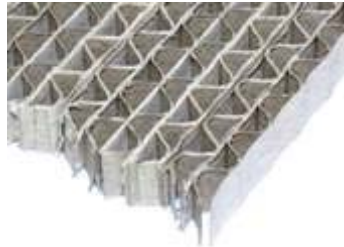


Natural Fibre Sandwich Panels

Continuously produced TorHex paper honeycomb cores



5 mm A-Flute core



10 mm AA-Flute core

+

25 g/m² EAA adhesive film
(ethylene acrylic acid copolymer,
Integral from DOW)

Continuously laminated natural fibre sandwich panels



100 g/m² PP/ hemp fibre mat skins



430 g/m² PP/ natural fiber mix
(flax, kenaf, hemp) mat skins



600 g/m² PP/ flax fiber mat skins

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TorHex Folded Honeycomb from Corrugated Board

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Natural Fibre Sandwich Panels

Panel examples for automotive and furniture applications



5 mm and 10 mm TorHex panels with natural fibre /PP skins



TorHex panels with wood veneer and MDF skins for furniture applications

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Natural Fibre Sandwich Panels

Part examples for automotive applications



TorHex PP/natural fibre Golf 4 headliner



TorHex PP/natural fibre door panel



Closed edge detail

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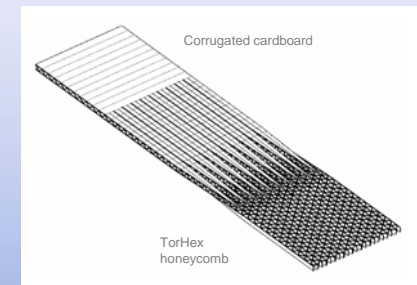
Conclusions

TorHex folded honeycomb material concept offers

- a process to produce paper honeycomb cores from one single corrugated board

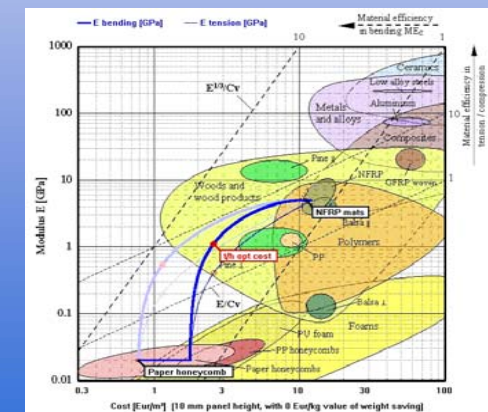
The production process enables

- fast and automated production for very cost efficient honeycomb core panels
- natural fibre sandwich panels with a core from recycled material
- are suitable for many applications in the automotive and furniture industry



Sandwich material selection charts

- allow a graphical comparison of compare sandwich material combinations based of their bending modulus, density and cost
- enable to determine the weight and cost advantage of sandwich material combinations



To expect in the near future

- industrial scale in-line panel production line
- many natural fibre sandwich part with low cost honeycomb cores

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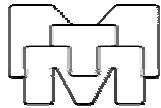


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