CompTest 2004

Bristol, 21-23 September 2004

Mechanical properties balance in novel Z-pinned sandwich panels: out-of-plane shear

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CompTest 2004

Contents

- ► **Introduction**
  Materials: K-Cor™, X-Cor™, Nomex® honeycomb
- ► **Out-of-plane shear**
  Test method
- ► **Experimental results**
- ► **Failure modes**
- ► **X/K-Cor™ Modelling**
  Overview
- ► **X-Cor™ Analytical modelling**
- ► **Design issues**

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X/K-COR™

Foam based lightweight structural cores reinforced with Z-Fiber® rods oriented in a truss pattern

Mechanical properties match and/or exceed high performance honeycombs

MAIN ADVANTAGE

Multi parameter

Pins

- Spatial lay-out
- Properties
- Local reinforcement

Polymeric foam

- Range of mechanical properties and densities
- Special properties *(temperature resistance, noise absorption etc.)*

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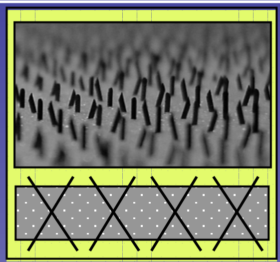
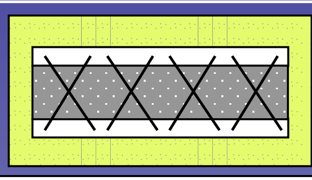
X/K-COR™

X-COR™ preform



Preform laminated between composite skins

X-COR™ sandwich construction

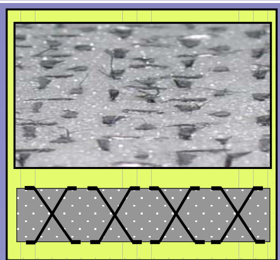


Pins penetrate the facesheet

Skin/core mechanical bond

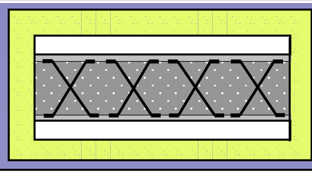
Protruding pins folded back on the core (hot press)

K-COR™ preform



Skins either cocured or secondarily bonded

K-COR™ sandwich construction



Skin/core adhesive bond

Test Materials

CORE TYPE	CORE ATTRIBUTES			
	thickness [mm]	density [kgm^{-3}]	cell face side [mm]	stabiliser
Nomex	12.7	64	3.18	Redux 322

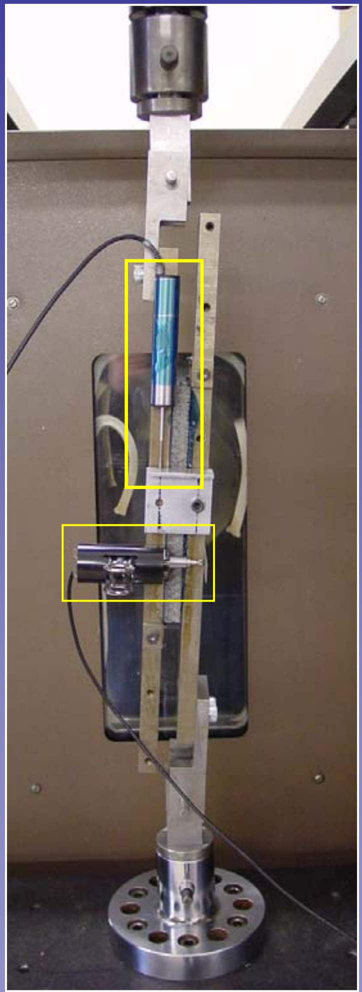
	thickness [mm]	density [kgm^{-3}]	pin Ø / fibre	pin angle θ	foam type	foam density [kgm^{-3}]
X-Cor type 1	12.7	~64	0.51 / T300	22°	Rohacell	32
X-Cor type 1 hollow	12.7	~32	0.51 / T300	22°	---	0
X-Cor type 2	12.7	~64	0.51 / T300	30°	Rohacell	32
K-Cor	12.7	~64	0.51 / T300	30°	Rohacell	32


hollow X-Cor sandwich

SKIN ATTRIBUTES		
resin type/fibre type	plies per skin	skin thickness [mm]
QI 8552/IM7	6	0.75


Nomex honeycomb sandwich

Test method: out-of-plane shear

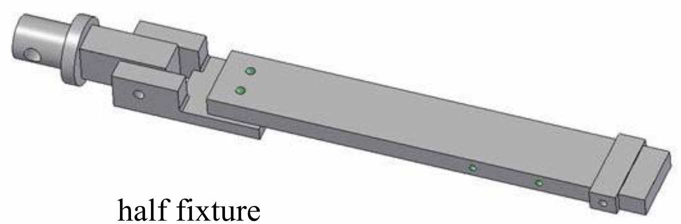


ASTM C273

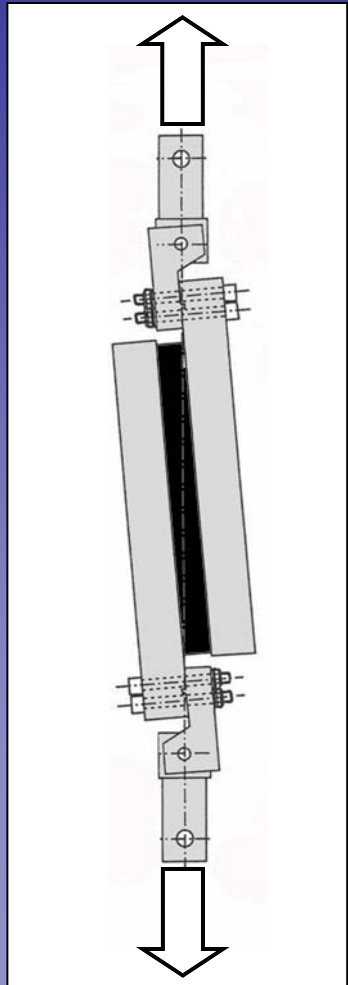
Cross head speed 0.5mm/min

Specimen dimensions: 50mm x 188mm

Longitudinal + transversal LVDT transducers



half fixture



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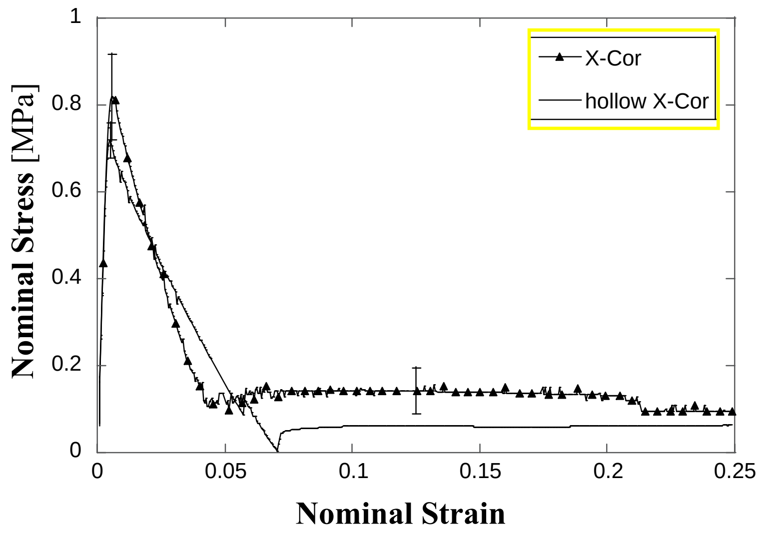
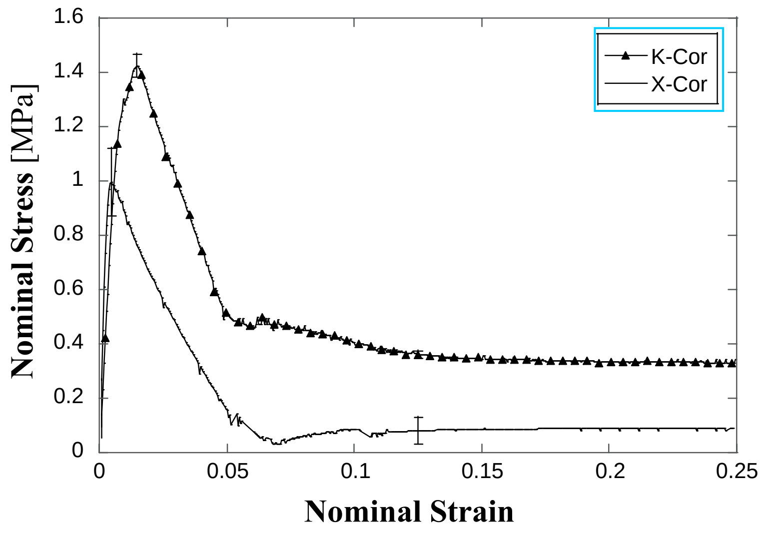
Experimental results

	K-Cor (θ=30°)	X-Cor (θ=22°)	Hollow X-Cor (θ=22°)	X-Cor (θ=30°)	Nomex
strength [MPa]	1.4±0.1	0.8±0.1	0.7±0.1	1.0±0.1	2.3±0.1
modulus [MPa]	193±12	204±34	204±16	372±34	81±4





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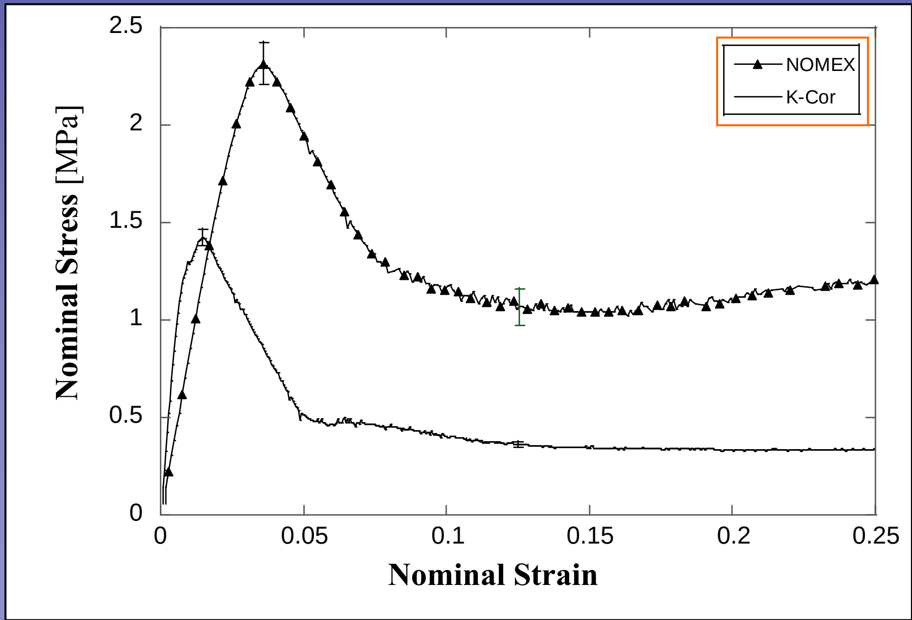
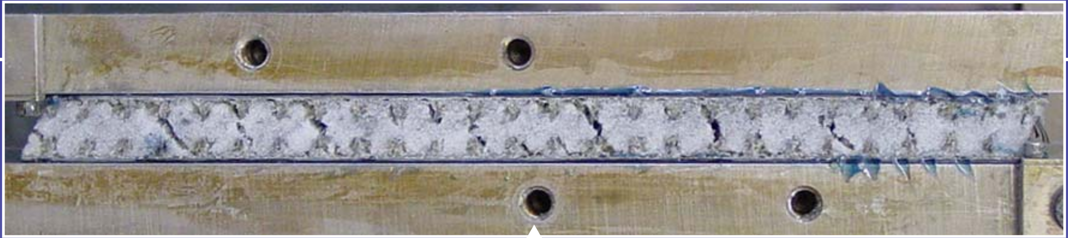


Failure modes

Pinned cores:

failure of skin-core interface



K-COR™

pin debond from skin

pin rotation accompanied by increasing skin separation

X-COR™

pin pull-out from skin

Honeycomb:

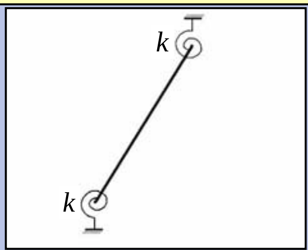
failure determined by buckling of cell walls

NOMEX® honeycomb

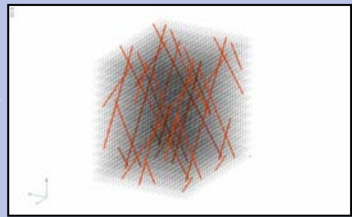
X/K-Cor^{TM} Modelling

MATERIAL OPTIMISATION

Analytical model



FE model Unit Cell



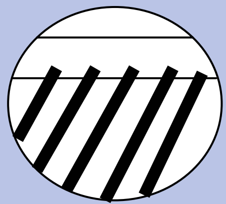
FE determination of macroscopic properties (E_1,E_2 etc.)

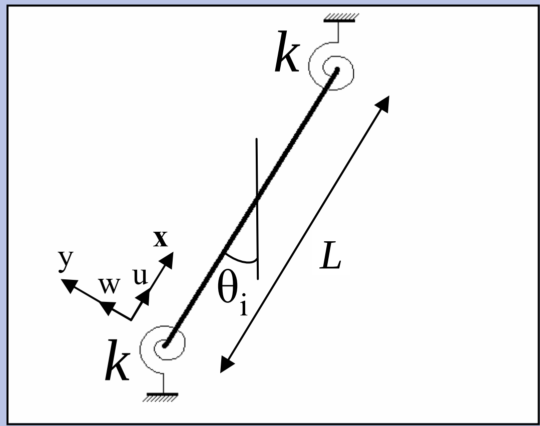
TESTING

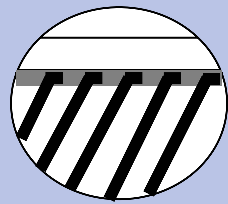
FE model of complex structures with Z-pinned cores

X/K-Cor™ Analytical modelling

Pin: column with torsional springs at ends







X-COR™

k (torsional spring constant of rigidity) depends on combination of:

• <u>resin/pin for X-Cor</u>

• <u>adhesive-film/pin for K-Cor</u>

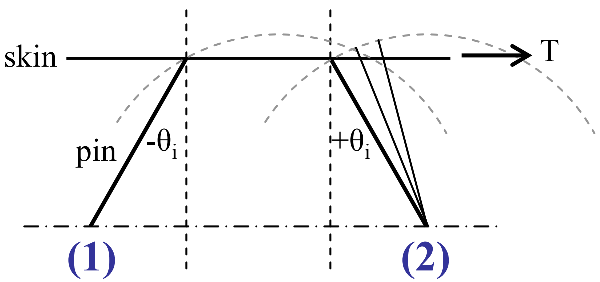
K-COR™

Analytical model development: X-Cor™

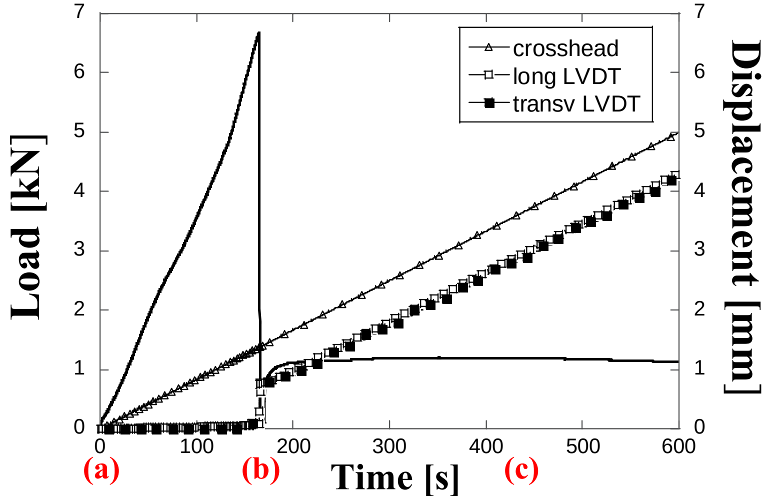
Skin-core interface failure:

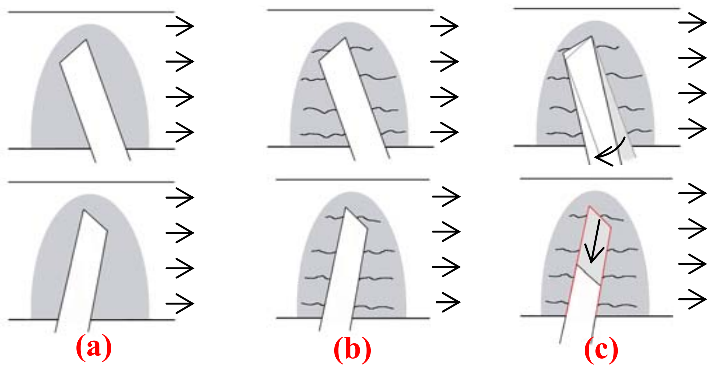
(1) Pin debonding ⟹ pull-out

(2) Matrix cracking at pin tip ⟹ rotation



Transversal opening

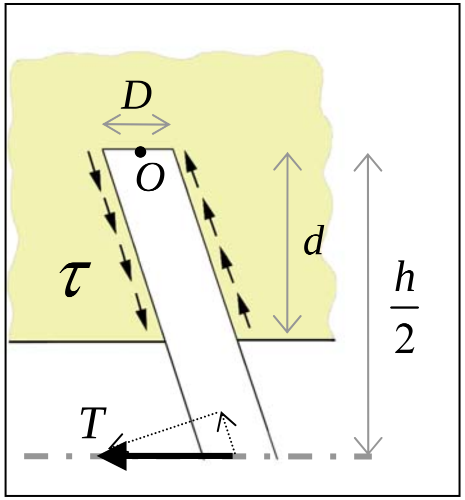




Analytical model development: X-Cor™

Linear elastic phase is determined by matrix shear strength

Critical stress condition at pin tips



At peak load:

$$T_{SPECIMEN,ave} = 7000N$$

$$T_{PIN} \cong 9N$$

$$\tau_{PIN} \cong 90MPa \gg \tau_{RESIN}$$

Qualitative Analysis

(vertical pin)

$$\begin{cases} M_{EXT,O} = T\dfrac{h}{2} \\ M_{INT,O} = \tau\pi dD^2 \end{cases}$$

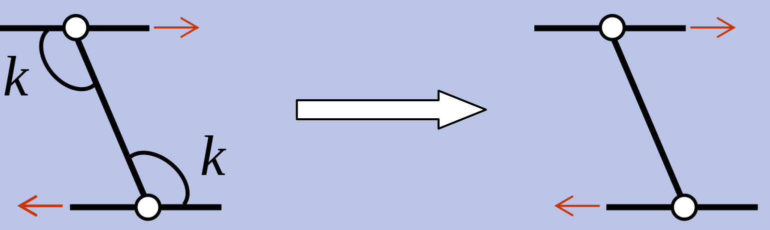
$$\tau = T\frac{h}{\underbrace{2\pi dD^2}_{\text{intensification factor}}}$$

Model considers only pins inserted "against the nap". The component of the force along the pin axis keeps the pin in place, causing the opening of the skins

Analytical model development: X-Cor™

Pins and skins considered as rigid bodies pinned together

Relative rigid motion (rotation)



Linear elastic behaviour

Torsional springs oppose the relative motion until pin-resin interface failure

Post elastic behaviour

Pin simply pinned to skins

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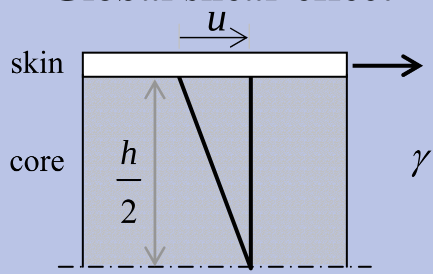
Analytical model: X-Cor™

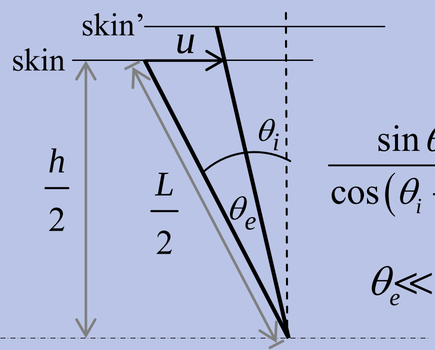
Pin geometry and kinematics considerations

Global shear effect $\Longrightarrow$ core



$$\gamma = \frac{u}{h/2}$$

Local shear effect $\Longrightarrow$ pin



$$\frac{\sin\theta_e}{\cos(\theta_i-\theta_e)} = \gamma\cos\theta_i$$

$$\theta_e \ll 1$$

Pin angle of elastic response

Core shear

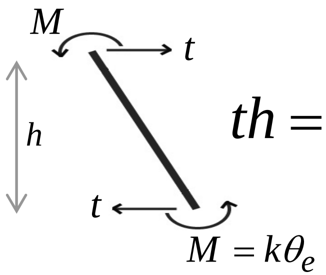
$$\boxed{\theta_e = \theta_e(\gamma)}$$

$$\Downarrow$$

$$\boxed{\theta_e = \frac{\gamma\cos^2\theta_i}{1-\frac{1}{2}\gamma\sin 2\theta_i}}$$

Analytical model: X-Cor™

Single pin equilibrium



$$th = 2k\theta_e$$

Pinned core equilibrium

$$\begin{cases} T = \sum_{i=1}^{N} t_i \\ K = \sum_{i=1}^{N} k_i \end{cases} \qquad Th = 2K\theta_e$$

$$\boxed{\theta_e = \theta_e(\gamma)}$$

For elastic response:

$$\tau = \frac{T}{A} = G\gamma \implies G = G(\gamma)$$

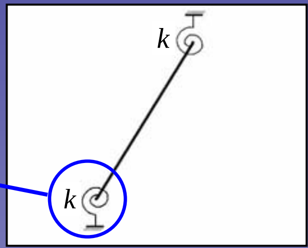
Experimentally: $\gamma \ll 1$

$$\boxed{G \cong \frac{2K}{Ah}\cos^2\theta_i}$$

Analytical model: X-Cor™

Evaluation of pin constant of rigidity *k* for torsional spring in the elastic phase

	nominal insertion angle θ_i	modulus G_{exp} [MPa]	model pin-end k [Nm]
X-Cor type 1	22°	200±34	~43
X-Cor type 2	30°	370 ±34	~83



$\Downarrow$

Pin insertion angle influence on out-of-plane shear elastic behaviour

$$G \cong \frac{2K(\theta_i)}{Ah}\cos^2\theta_i$$

$$\Longrightarrow K = K(\theta_i, \phi_{PIN}, MAT)$$

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Design Issues

Pin related *critical factors* in X/K-Cor mechanical performance

- **Pin areal density and pin lay-out**
  - Isotopic/anisotropic cores, Pin lay-out optimisation
- **Pin end -constraint**
  - **K-Cor=f(θ_i, pin/adhesive material)**
  - **X-Cor=f(θ_i, $Ø_{pin}$, pin/skin material)**
  - For Ø=0.5mm X-Cor foam not necessary

Nomex specimen proved higher shear strength but lower shear stiffness than pinned cores

Pin: column with torsional spring at ends
► found suitable for determining model parameters as input into FEA

Thank you for your attention