

The honeycomb sandwich construction is one of the most valued structural engineering innovations developed by the composites industry.

Used extensively in aerospace and many other industries, the honeycomb sandwich provides the following key benefits over conventional materials:

- Very low weight
- High stiffness
- Durability
- Production cost savings

Hexcel began developing honeycomb over 40 years ago, and now supplies a range of high performance honeycombs, prepregs and Redux® film adhesives - all ideally suited to the manufacture of honeycomb sandwich constructions. Hexcel is also the leading supplier of lightweight honeycomb sandwich panels.

This guide explains how to design and manufacture honeycomb sandwich panels, from materials selection and analysis of mechanical properties, through to production methods, and includes basic sample calculations for simple constructions.

More complex calculations may require computer modelling which, although mentioned briefly, is beyond the scope of this publication.

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BENEFITS OF HONEYCOMB SANDWICH CONSTRUCTIONS

The facing skins of a sandwich panel can be compared to the flanges of an I-beam, as they carry the bending stresses to which the beam is subjected. With one facing skin in compression, the other is in tension. Similarly the honeycomb core corresponds to the web of the I-beam. The core resists the shear loads, increases the stiffness of the structure by

holding the facing skins apart, and improving on the I-beam, it gives continuous support to the flanges or facing skins to produce a uniformly stiffened panel. The core-to-skin adhesive rigidly joins the sandwich components and allows them to act as one unit with a high torsional and bending rigidity.

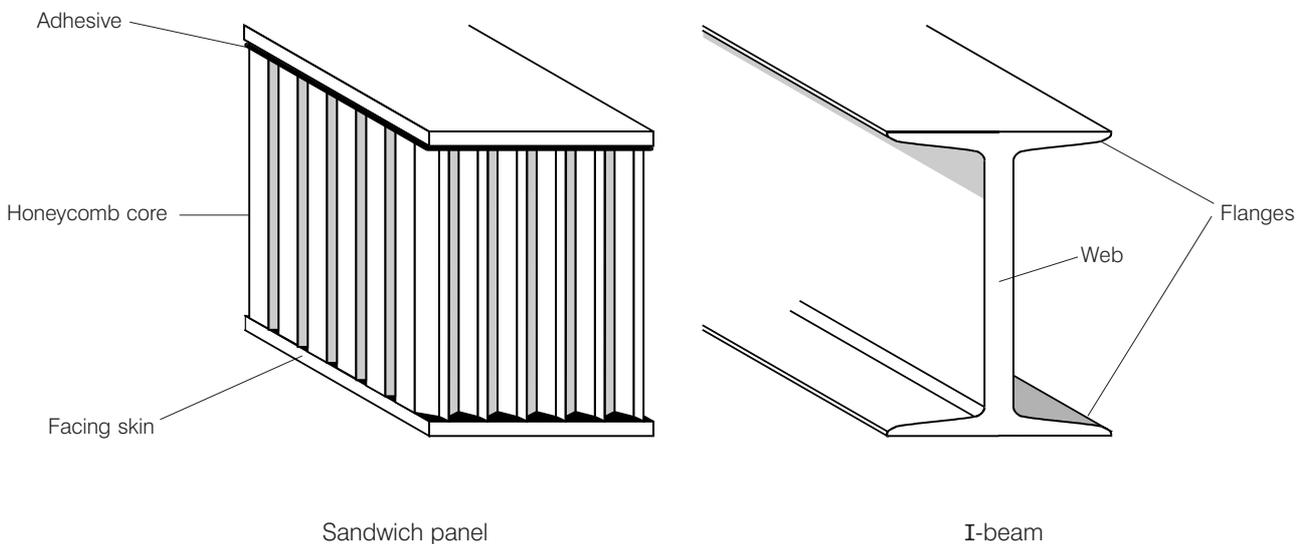


Figure 1 shows the construction of a sandwich panel compared to an I beam.

	Solid Material	Core Thickness t	Core Thickness $3t$
Stiffness	1.0	7.0	37.0
Flexural Strength	1.0	3.5	9.2
Weight	1.0	1.03	1.06

Figure 2 shows the relative stiffness and weight of sandwich panels compared to solid panels.

MATERIALS SELECTION

Honeycomb Sandwich Materials

The honeycomb sandwich construction can comprise an unlimited variety of materials and panel configurations. The composite structure provides great versatility as a wide range of core and facing material combinations can be selected. The following criteria should be considered in the routine selection of core, facing, and adhesive.

Structural Considerations

Strength:

Honeycomb cores and some facing materials are directional with regard to mechanical properties and care must be taken to ensure that the materials are orientated in the panel to take the best advantage of this attribute.

Stiffness:

Sandwich structures are frequently used to maximise stiffness at very low weights. Because of the relatively low shear modulus of most core materials, however, the deflection calculations must allow for shear deflection of the structure in addition to the bending deflections usually considered.

Adhesive Performance:

The adhesive must rigidly attach the facings to the core material in order for loads to be transmitted from one facing to the other. Suitable adhesives include high modulus, high strength materials available as liquids, pastes or dry films. As a general rule, a low peel-strength, or relatively brittle adhesive should never be used with very light sandwich structures which may be subjected to abuse or damage in storage, handling or service.

Economic Considerations:

Composite sandwich panels can provide a cost effective solution. Value analysis should include assessment of production and assembly costs; and installation costs including supporting structure.

Environmental Considerations

Temperature:

As in any materials system the thermal environment will play an important role in the selection of materials.

All systems are basically operational at Room Temperature and materials are readily available to give performance up from -55°C to 170°C.

Material selection should also take account of available manufacturing facilities, especially cure temperature capability.

Flammability:

Materials used in bonded sandwich construction are usually classified into three categories:

- 1) Non-burning - which means that the product will not burn.
- 2) Self-extinguishing - which means that the material will burn while held in a flame but will extinguish when the flame is removed.

- 3) Flammable. Flammable materials are sometimes further defined by determining the flame spread rate under specified conditions.

Heat Transfer:

The transfer of heat through a sandwich panel is dependent upon the basic principles of convection, conduction and radiation. Metallic cores with metallic facings maximise heat flow characteristics.

Moisture/Humidity:

Some core and facing materials offer excellent resistance to degradation due to moisture and humidity.

Adhesive Solvents and Outgassing:

Some adhesives give off gases or solvent vapours during cure which can interact with resin systems in some non-metallic cores, or with the node adhesive in some metallic honeycombs. The entire bonding process must be checked to ensure that no reduction in mechanical properties has occurred due to incompatibility of the materials or process actually used. All of Hexcel's Redux® film adhesives are compatible with this type of construction.

Honeycomb Materials

HexWeb honeycomb is available in a wide range of materials including:-

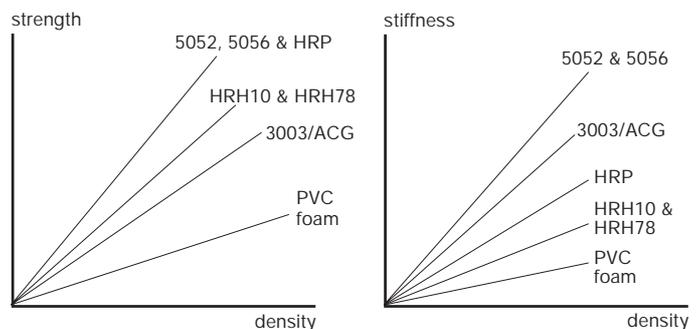
Aluminium, Nomex (Aramid), Korex, Kevlar, Fibreglass, Carbon.

For details please consult The HexWeb Honeycomb Selector Guide and the HexWeb Honeycomb Attributes and Properties Manual.

Selected mechanical properties for Aluminium and Nomex honeycombs are shown in Appendix I.

Mechanical Performance

Honeycomb strength and stiffness (compression and shear) is proportional to density. Relative performance of the material types is shown in comparison to PVC foam.



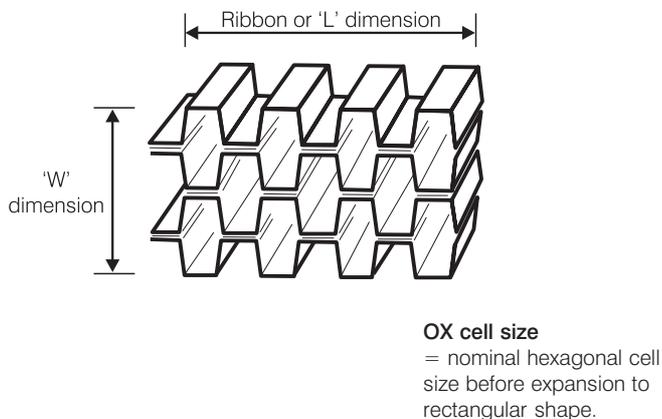
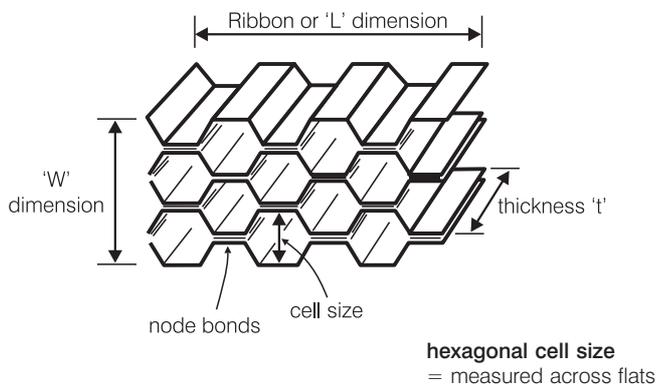
Key: Aluminium - 3003/ACG; 5052; 5056
Nomex - HRH10; HRH78;
Fibreglass - HRP

Cell Size

A large cell size is the lower cost option, but in combination with thin skins may result in telegraphing, i.e. a 'dimpled' outer surface of the sandwich. A small cell size will give an improved surface appearance, and provides a greater bonding area, but at higher cost.

Cell Shape

Normally supplied with hexagonal cell shapes, a few honeycomb types can be supplied with rectangular cell shapes (W:L approximately 2:1), and designated OX.



Hexagonal cells give minimum density for a given amount of material.

Rectangular cells give easier forming in the W direction (with less anticlastic curvature than is exhibited by hexagonal cell honeycomb).

Skin Materials

The table in Appendix II shows properties of typical facing materials for sandwich panel construction.

Skin considerations include the weight targets, possible abuses and local (denting) loads, corrosion or decorative constraints, and costs.

Facing material thickness directly affects both the skin stress and panel deflection.

Hexcel Composites offers a wide range of prepreg materials. Refer to the Prepreg Matrix Selector Guide to identify systems most likely to suit your application, where fibre reinforced composites are thought appropriate.

Adhesive Materials

For honeycomb sandwich bonding, the following criteria are important:

1. Fillet Forming

To achieve a good attachment to an open cell core such as honeycomb, the adhesive should flow sufficiently to form a fillet without running away from the skin to core joint.

2. Bond Line Control

Every endeavour should be made to ensure intimate contact between the parts during bonding, as the adhesive needs to fill any gaps between the bonding surfaces.

Adhesives are often supplied supported by a carrier cloth, for the purpose of helping them to remain in place where the parts are squeezed particularly tightly together.

Hexcel Composites offers a wide range of film adhesives. Refer to the REDUX® Film Adhesive Selector Guide to identify the most suitable material for your application.

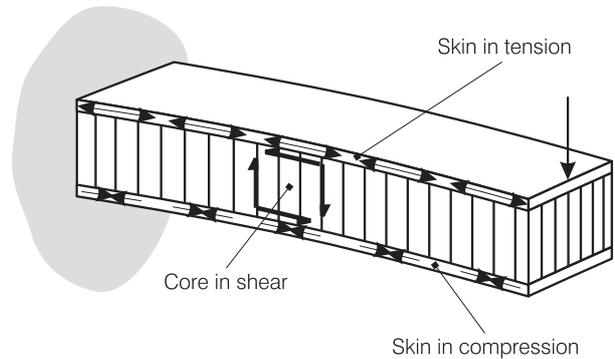
SANDWICH DESIGN

How a Sandwich Beam Works

Loads

Consider a cantilever beam with a load applied at the free end. The applied load creates a bending moment which is a maximum at the fixed end, and a shear force along the length of the beam.

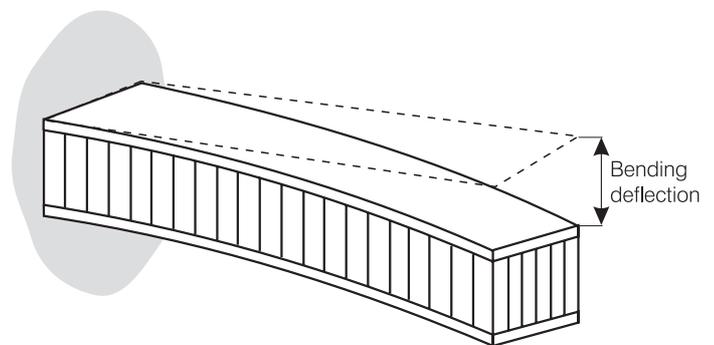
In a sandwich panel these forces create tension in the upper skin and compression in the lower skin. The core spaces the facing skins and transfers shear between them to make the composite panel work as a homogeneous structure.



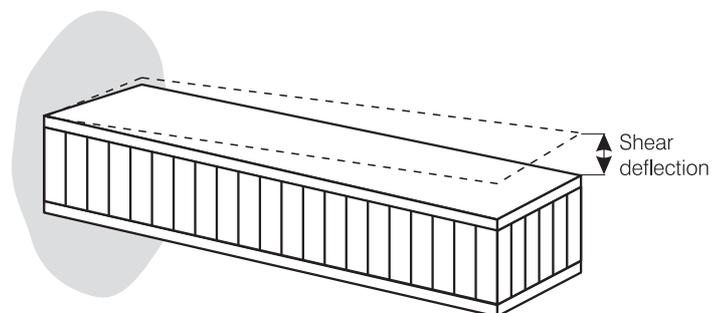
Deflections

The deflection of a sandwich panel is made up from bending and shear components.

The bending deflection is dependant on the relative tensile and compressive moduli of the skin materials.



The shear deflection is dependant on the shear modulus of the core.



Total Deflection = Bending Deflection + Shear Deflection.

Under different sets of applied loads and supporting conditions, the material stresses and deflections can be calculated as shown on page 9 onwards.

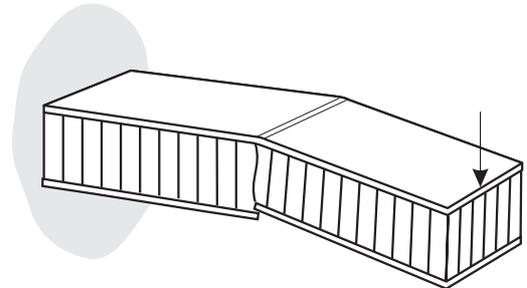
Failure modes

Designers of sandwich panels must ensure that all potential failure modes are considered in their analysis. A summary of the key failure modes is shown below:

1. Strength

The skin and core materials should be able to withstand the tensile, compressive and shear stresses induced by the design load.

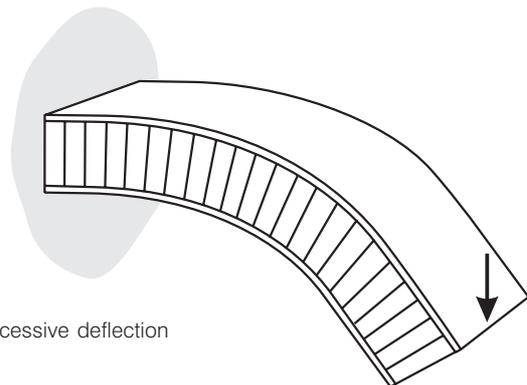
The skin to core adhesive must be capable of transferring the shear stresses between skin and core.



Skin compression failure

2. Stiffness

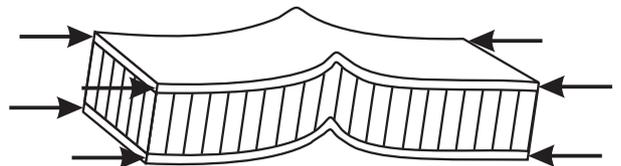
The sandwich panel should have sufficient bending and shear stiffness to prevent excessive deflection.



Excessive deflection

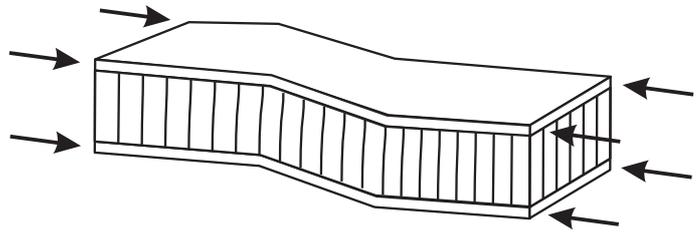
3. Panel buckling

The core thickness and shear modulus must be adequate to prevent the panel from buckling under end compression loads.



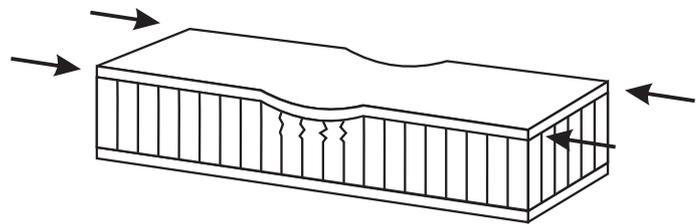
4. Shear crimping

The core thickness and shear modulus must be adequate to prevent the core from prematurely failing in shear under end compression loads.



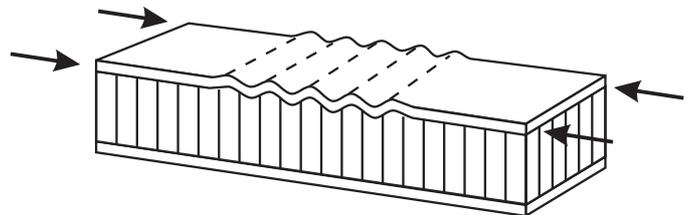
5. Skin wrinkling

The compressive modulus of the facing skin and the core compression strength must both be high enough to prevent a skin wrinkling failure.



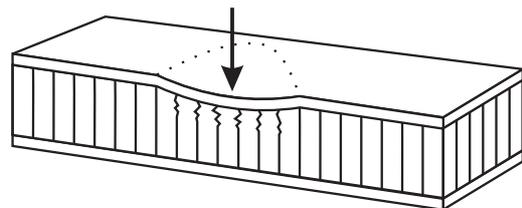
6. Intra cell buckling

For a given skin material, the core cell size must be small enough to prevent intra cell buckling.



7. Local compression

The core compressive strength must be adequate to resist local loads on the panel surface.



DESIGN GUIDELINES FOR A HONEYCOMB SANDWICH PANEL

1. Define loading conditions

e.g. Point loading, uniform distributed load, end loads.

Care should be taken to consider all possible loading conditions. For example, see table page 11, or refer to an appropriate 'Industry Standard' for guidance.

2. Define panel type

e.g. Cantilever, simply supported.

This is determined by the type and extent of the panel supports. Fully built in support conditions should only be considered when the supporting structure has adequate stiffness to resist deflection under the applied loads.

3. Define physical/space constraints

This should include an assessment of the requirements including:

- deflection limit
- thickness limit
- weight limit
- factor of safety

Preliminary materials selection should be based on the above criteria in conjunction with the features considered on pages 4 - 5 (and appendices I and II).

4. Preliminary calculations

- Make an assumption about skin material, skin thickness and panel thickness. Ignore the core material at this stage.
- Calculate stiffness.
- Calculate deflection (ignoring shear deflection).
- Calculate facing skin stress.
- Calculate core shear stress.

5. Optimise design

- Modify skin thickness, skin material and panel thickness to achieve acceptable performance.
- Select suitable core to withstand shear stress.

6. Detailed calculations

- Calculate **stiffness**.
- Calculate **deflection**, including shear deflection.
- Calculate **facing skin stress**.
- Calculate **core shear stress**.
- Check for **panel buckling** - where applicable
- Check for **shear crimping**.
- Check for **skin wrinkling**.
- Check for **intracell buckling**.
- Check for **local compression** loads on core.

NB.

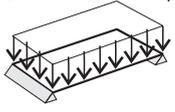
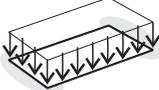
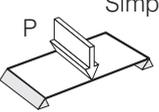
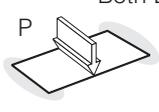
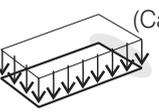
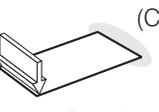
The formulae used for the sample problems that follow on pages 12 to 19, use simplified terms and give an order of magnitude appreciation.

See also Summary of Formulae in Appendix III.

NOMENCLATURE

- a = Panel length
- A = Area of applied load
- b = Beam width
- D = Panel bending stiffness
- E_c = Compression modulus of core
- E_f = Modulus of elasticity of facing skin
- F = Maximum shear force
- G_c = Core shear modulus - in direction of applied load
- G_L = Core shear modulus - Ribbon direction
- G_w = Core shear modulus - Transverse direction
- h = Distance between facing skin centres
- k_b = Beam - bending deflection coefficient
- k_s = Beam - shear deflection coefficient
- K_1 = Panel parameter (used for simply supported plate)
- K_2 = Panel parameter (used for simply supported plate)
- K_3 = Panel parameter (used for simply supported plate)
- l = Beam span
- M = Maximum bending moment
- P = Applied load
- P_b = Critical buckling load
- q = Uniformly distributed load
- R = Ratio G_L/G_w
- s = Cell size
- S = Panel shear stiffness
- t_c = Thickness of core
- t_f = Thickness of facing skin
- V = Panel parameter (used for simply supported plate)
- δ = Calculated deflection
- σ_c = Core compressive stress
- σ_{CR} = Critical facing skin stress
- σ_f = Calculated facing skin stress
- τ_c = Shear stress in core
- μ = Poissons Ratio of face material
- λ = Bending correction factor for Poissons Ratio effect

Summary of beam coefficients

BEAM TYPE	MAXIMUM SHEAR FORCE F	MAXIMUM BENDING MOMENT M	BENDING DEFLECTION COEFFICIENT k_b	SHEAR DEFLECTION COEFFICIENT k_s
$P = q l / b$ Simple Support  Uniform Load Distribution	$\frac{P}{2}$	$\frac{Pl}{8}$	$\frac{5}{384}$	$\frac{1}{8}$
$P = q l / b$ Both Ends Fixed  Uniform Load Distribution	$\frac{P}{2}$	$\frac{Pl}{12}$	$\frac{1}{384}$	$\frac{1}{8}$
 Central Load	$\frac{P}{2}$	$\frac{Pl}{4}$	$\frac{1}{48}$	$\frac{1}{4}$
 Central Load	$\frac{P}{2}$	$\frac{Pl}{8}$	$\frac{1}{192}$	$\frac{1}{4}$
$P = q l / b$ One End Fixed (Cantilever)  Uniform Load Distribution	P	$\frac{Pl}{2}$	$\frac{1}{8}$	$\frac{1}{2}$
 Load One End	P	$\frac{Pl}{3}$	$\frac{1}{3}$	1
$P = \frac{q l / b}{2}$ One End Fixed (Cantilever)  Triangular Load Distribution	P	$\frac{Pl}{3}$	$\frac{1}{15}$	$\frac{1}{3}$

SAMPLE PROBLEMS BASED ON A STANDARD HEXLITE 220 PANEL

Configuration and Data:

Facing Skins Aluminium 5251 H24

Thickness t_1 and t_2 = 0.50mm

and from Appendix II

Yield Strength = 150 MPa

E_f Modulus = 70 GPa

Poissins Ratio μ = 0.33

Core 5.2 - 1/4 - 3003

Thickness t_c = 25.4 mm

and from Appendix I

E_c Modulus = 1000 MPa

Longitudinal shear = 2.4 MPa

G_L Modulus = 440 MPa

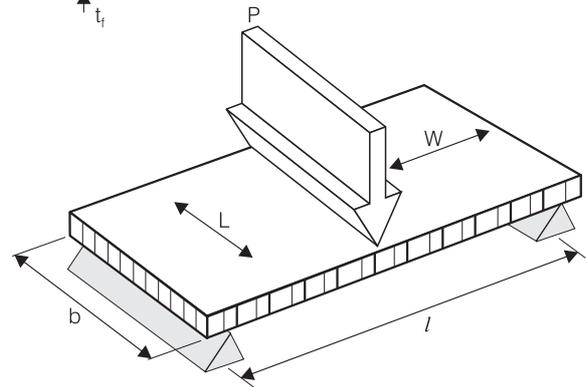
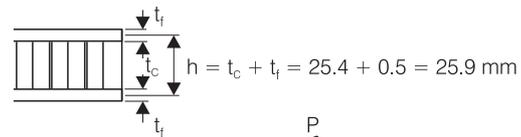
Transverse shear = 1.5 MPa

G_w Modulus = 220 MPa

Stabilized Compression = 4.6 MPa

Simply Supported Beam

- taking a beam as being defined as having width (b) less than $1/3$ of span (l)



Considering a centre point loaded beam with $b = 0.5$ m and $l = 2$ m and $P = 1500$ N

Beam

Bending Stiffness

$$D = \frac{E_f t_f h^2 b}{2}$$

Where $h = t_f + t_c$

Shear Stiffness

$$S = b h G_c$$

$$D = \frac{(70 \times 10^9) (0.5 \times 10^{-3}) (25.9 \times 10^{-3})^2 (0.5)}{2}$$

$$D = 5869.6 \text{ Nm}^2$$

As the core shear here will be taken by the weaker transverse direction - take $G_c = G_w$ shear modulus

$$S = (0.5) (25.9 \times 10^{-3}) (220 \times 10^6)$$

$$S = 2849 \times 10^3 \text{ N}$$

Beam continued

Deflection

$$\delta = \frac{k_b Pl^3}{D} + \frac{k_s Pl}{S}$$

Where k_b and k_s are deflection coefficients from page 11.

If doing preliminary calculations, just work out the bending deflection.

If optimising design, calculate for both bending and shear components (as shown opposite).

Facing Stress

$$\sigma_f = \frac{M}{h t_f b}$$

Where M is Maximum Bending Moment expression from page 11

and $h = t_f + t_c$

Core Stress

$$\tau_c = \frac{F}{hb}$$

Where F is Maximum Shear Force expression from page 11

$$\delta = \frac{1}{48} \times \frac{1500 \times 2^3}{5869.6} + \frac{1}{4} \times \frac{1500 \times 2}{2849 \times 10^3}$$

$$\delta = 0.04259\text{m} + 0.000263\text{m}$$

$$\text{Total} = \text{approx } 43\text{mm}$$

If excessive, then the most efficient way to reduce deflection is to increase core thickness, and thus increase the skin separation and the value of h.

$$M = \frac{Pl}{4} = \frac{1500 \times 2}{4} = 750 \text{ Nm}$$

$$\sigma_f = \frac{750}{(25.9 \times 10^{-3})(0.5 \times 10^{-3})(0.5)}$$

$$\sigma_f = 115.8 \text{ MPa}$$

So calculated stress is less than face material typical yield strength of 150 MPa, thus giving a factor of safety.

$$F = \frac{P}{2} = \frac{1500}{2} = 750\text{N}$$

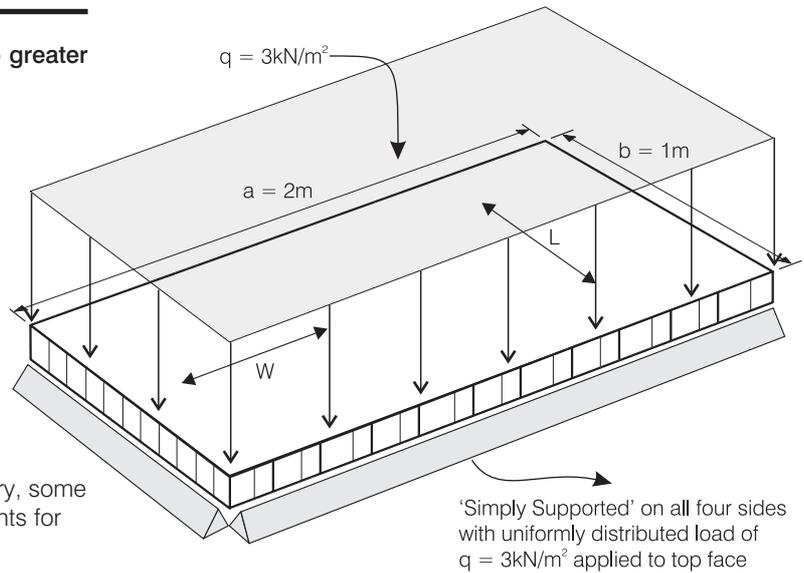
$$\tau = \frac{750}{(25.9 \times 10^{-3})(0.5)}$$

$$\tau = 0.06 \text{ MPa}$$

So calculated shear is considerably less than core material typical plate shear in the transverse (W) direction of 1.5 MPa, giving a factor of safety, which could allow core density to be reduced.

Simply Supported Plate

- taking a plate as being defined as having width (b) greater than 1/3 of length (a)



Because plate theory is more involved than beam theory, some 'charts' have been provided to give multipliers/coefficients for use with plates simply supported on all four sides.

A further term (λ) is also introduced, to take account of the Poisson's Ratio of the face skin materials. For the plate set up shown, λ is taken as $1 - \mu^2$.

NB. For the earlier beams, and the end load conditioning to follow, λ is assumed to be 1, as any affect from Poisson's Ration is small due to the relative narrowness of beams.

Plate

Determine Plate Coefficient

$$\frac{b}{a} = R = \frac{G_L}{G_W}$$

$$V = \frac{\pi^2 E_f t_f h}{2b^2 G_W \lambda}$$

From Fig.1 (page 16) $K_1 = 0.0107$
 From Fig.2 (page 17) $K_2 = 0.102$

and for shorter span length b

From Fig.3 (page 17) $K_3 = 0.36$

Deflection

$$\delta = \frac{2K_1 q b^4 \lambda}{E_f t_f h^2}$$

$$\frac{1000}{2000} = 0.5$$

$$\frac{440}{220} = 2$$

Use $R = 2.5$ in Figs. on pages 16 & 17

$$V = \frac{\pi^2 (70 \times 10^9) (0.5 \times 10^{-3}) (25.9 \times 10^{-3})}{(2) (1^2) (220 \times 10^6) (1 - 0.33^2)} = 0.023$$

Take $V = 0$ in Figs. on pages 16 & 17

$$\delta = \frac{(2) (0.0107) (3 \times 10^3) (1^4) (1 - 0.33^2)}{(70 \times 10^9) (0.5 \times 10^{-3}) (25.9 \times 10^{-3})^2}$$

$$\delta = 0.0024\text{m} = 2.4\text{mm}$$

Plate continued

Facing Stress

$$\sigma_f = \frac{K_2 q b^2}{ht}$$

$$\sigma_f = \frac{(0.102) (3 \times 10^3) (1^2)}{(25.9 \times 10^{-3}) (0.5 \times 10^{-3})}$$

$$\sigma_f = 23.6 \text{ MPa}$$

So calculated stress is considerably less than skin material typical yield strength of 150 MPa, thus giving a factor of safety.

Core Shear

$$\tau_c = \frac{K_3 q b}{h}$$

$$\tau_c = \frac{(0.36) (3 \times 10^3) (1)}{(25.9 \times 10^{-3})}$$

$$\tau_c = 0.042 \text{ MPa}$$

So calculated core shear is considerably less than typical core material shear value of 1.5 MPa, thus giving a factor of safety.

Local Compression

$$\sigma_c = \frac{P}{A} = \frac{q \times A}{A}$$

$$\sigma_c = \frac{(3 \times 10^3) (2 \times 1)}{(2 \times 1)}$$

$$\sigma_c = 0.003 \text{ MPa}$$

So local compression would not be an issue, being very small in comparison to typical core compression strength of 4.6 MPa.

Charts providing coefficients for plates simply supported on all four sides

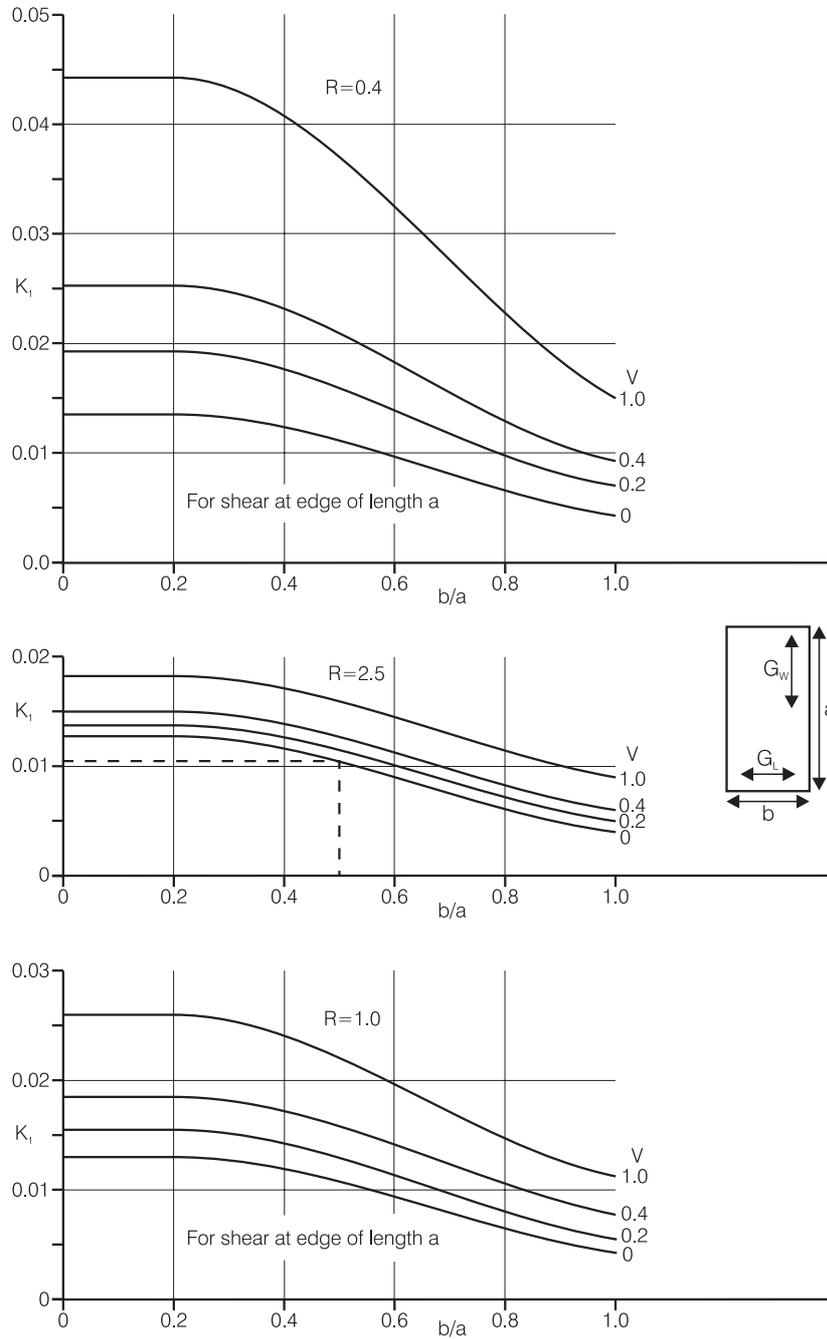


Figure 1 - K_1 for determining maximum deflection δ

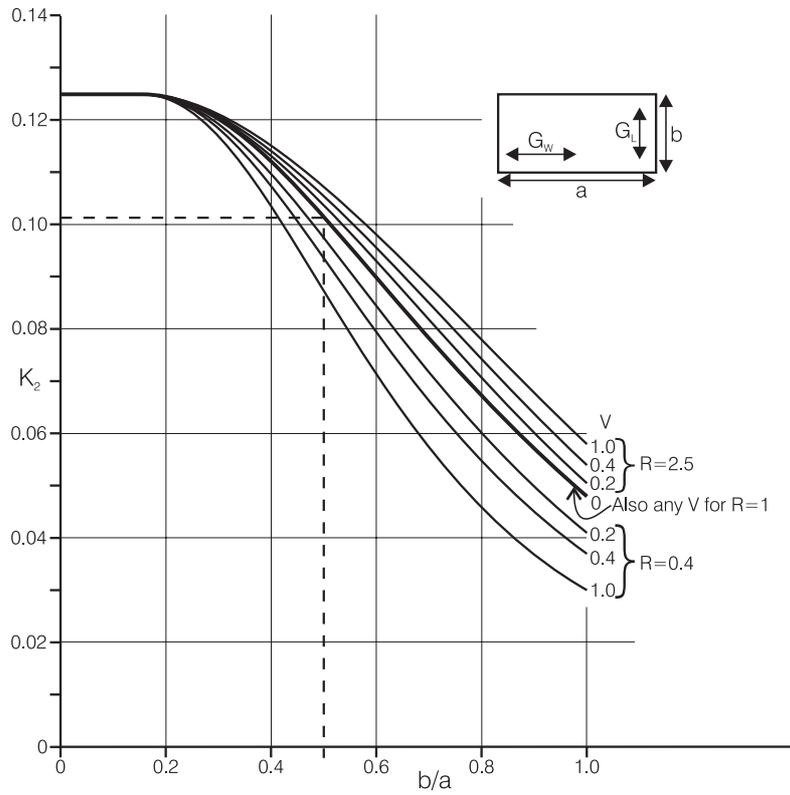


Figure 2 - K_2 for determining facing stress σ

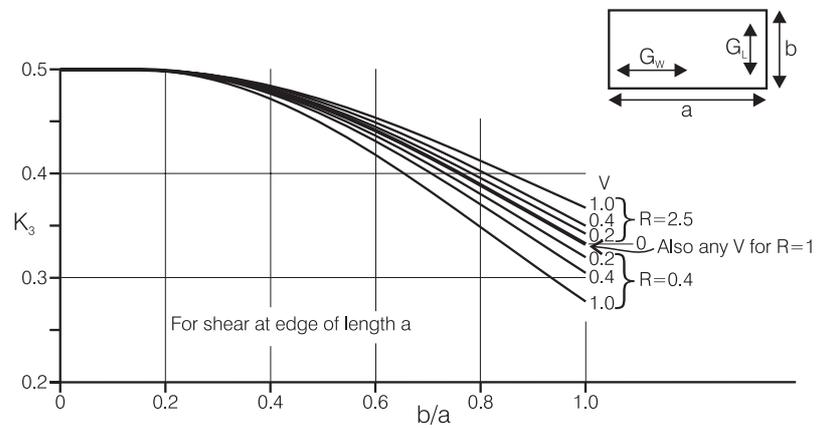
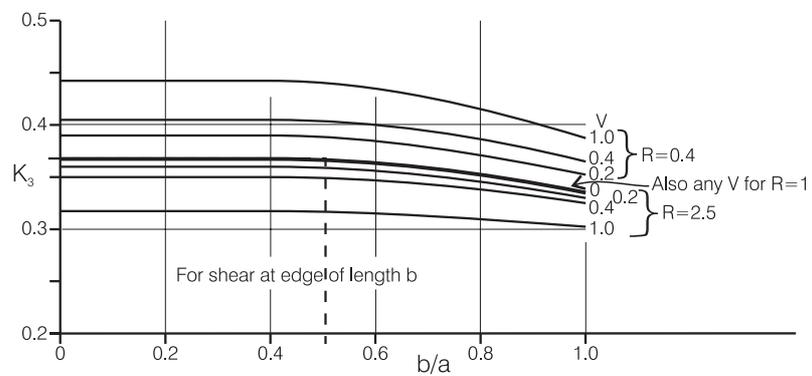
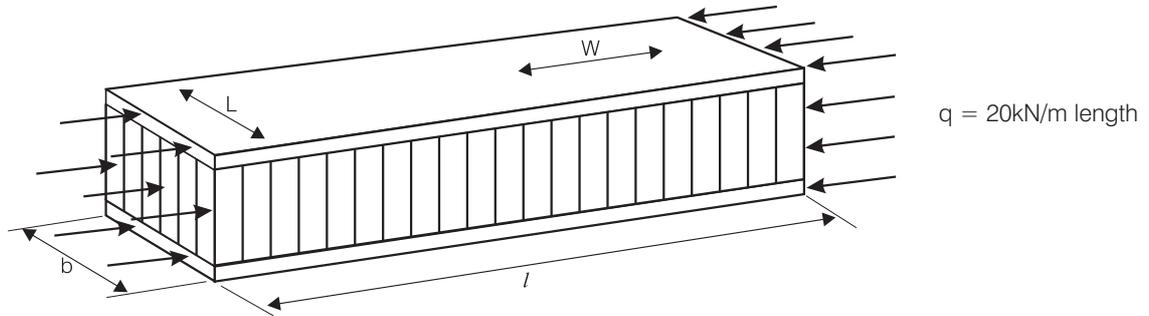


Figure 3 - K_3 for determining maximum core shear stress t_c

END LOAD CONDITIONS

Considering a uniformly distributed end load of $q = 20\text{kN/m}$ length and with $b = 0.5\text{m}$ and $l = 2\text{m}$.



End Loading

Facing Stress

$$\sigma_f = \frac{P}{2 t_f b}$$

assuming end load is taken by both skins, and applied load $P = q \times b$

Panel Buckling

$$P_b = \frac{\pi^2 D}{\frac{l^2}{G_c h b} + \pi^2 D}$$

Taking D from the beam calculation example.

$$\sigma_f = \frac{(20 \times 10^3) (0.5)}{(2) (0.5 \times 10^{-3}) (0.5)}$$

$$\sigma_f = 20 \text{ MPa}$$

This is safe, as it is considerably less than skin material typical yield strength of 150 MPa.

Considering the core shear to be in the weaker transverse direction

So $G_c = G_w$ shear modulus

Then

$$P_b = \frac{\pi^2 (5869.6)}{\frac{(2)^2 + \pi^2 (5869.6)}{(220 \times 10^6) (25.9 \times 10^{-3}) (0.5)}}$$

$$P_b = 14,413 \text{ N}$$

So calculated load at which critical buckling would occur is greater than the end load being applied (P) of 10,000 N, thus giving a factor of safety.

End Loading continued

Shear Crimping

$$P_b = t_c G_c b$$

Taking G_c as G_w

$$P_b = (25.4 \times 10^{-3}) (220 \times 10^6) (0.5)$$

$$P_b = 2.79 \text{ MN}$$

So the calculated load at which shear crimping would occur, is considerably greater than the end load being applied (P) of 10,000 N, thus giving a factor of safety.

Skin Wrinkling

$$\sigma_{CR} = 0.5 [G_c E_c E_f]^{1/3}$$

Taking G_c as G_w

$$\sigma_{CR} = 0.5 [(220 \times 10^6) (1000 \times 10^6) (70 \times 10^9)]^{1/3}$$

$$\sigma_{CR} = 1244 \text{ MPa}$$

So the stress level at which skin wrinkling would occur, is well beyond the skin material typical yield strength of 150 MPa; so skin stress is more critical than skin wrinkling.

Intracell Buckling

$$\sigma_{CR} = 2 E_f \left[\frac{t_f}{s} \right]^2$$

NB: s = cell size

$$\sigma_{CR} = 2 (70 \times 10^9) \left[\frac{(0.5 \times 10^{-3})}{(6.4 \times 10^{-3})} \right]^2$$

$$\sigma_{CR} = 854 \text{ MPa}$$

So stress level at which intracell buckling would occur is well beyond the skin material typical yield strength of 150 MPa; so skin stress is more critical than intracell buckling.

COMPUTER MODELLING OF HONEYCOMB SANDWICH PANELS

For a more sophisticated analysis of a structure, considering the sandwich panel to be subjected to a combination of forces, a technique such as Finite Element Analysis (FEA) might be used.

In general terms, the shear forces normal to the panel will be carried by the honeycomb core. Bending moments and in-plane forces on the panel will be carried as membrane forces in the facing skins.

For many practical cases, where the span of the panel is large compared to its thickness, the shear deflection will be negligible. In these cases, it may be possible to obtain reasonable results by modelling the structure using composite shell elements. It should be noted that the in-plane stiffness of the honeycomb is negligible compared to that of the facing skins.

Where a more detailed model is required it is possible to model the honeycomb core using solid 3D elements. Attempts to model the individual cells of the honeycomb should be avoided for normal engineering analyses.

When defining the properties of honeycomb core the following points should be taken into consideration:-

$$E_x \approx E_y \approx 0$$

A very small value may be necessary to avoid singularity.

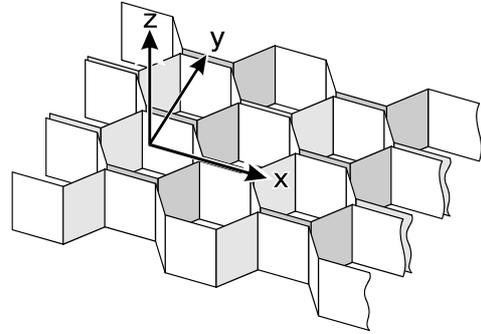
$$\mu_{xy} \approx \mu_{xz} \approx \mu_{yz} \approx 0$$

$$G_{xy} \approx 0$$

$$G_{xz} = G_L = \text{shear modulus in ribbon direction}$$

$$G_{yz} = G_W = \text{shear modulus in transverse direction}$$

$$E_z = E_c = \text{compressive modulus of core material}$$



Before analysing a large structure the modelling technique should be checked by modelling a simple panel with known results.

The above simplistic approach has proven to give reasonable engineering solutions for practical applications.

The actual force/stress distribution within a honeycomb sandwich structure is a complex subject, and is beyond the scope of this publication.

MANUFACTURE

Basic Honeycomb Sandwich Production Methods

Honeycomb sandwich components may be produced using three alternative well-established methods:-

Heated Press, generally used for the production of flat board or simple preformed panels.

Vacuum Bag Processing, used for curved and complex form panels.

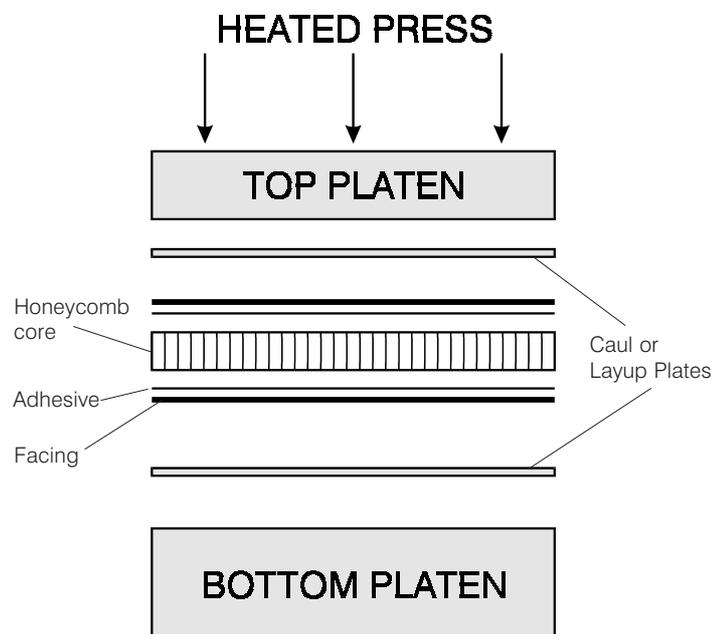
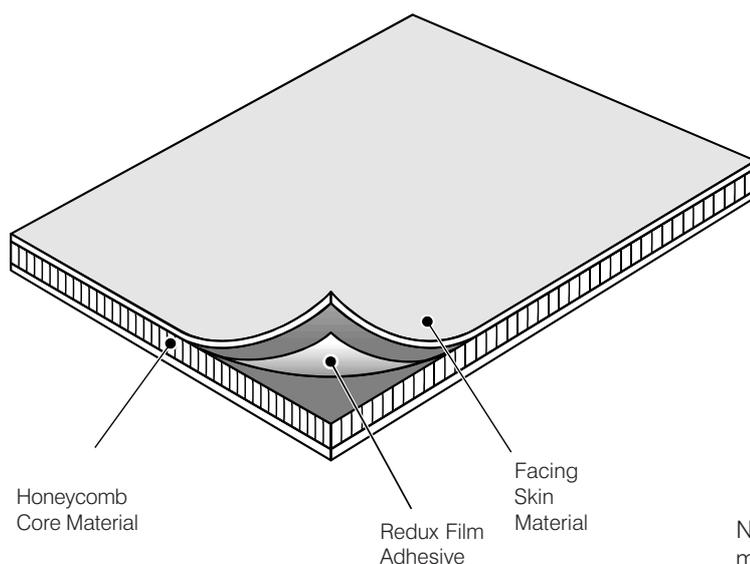
Matched Mould Processing, used generally for batch production of finished panels.

Heated Press

Ideally the panels should be assembled ready for curing as a single shot process. This method is suitable for metallic and prepreg (pre-impregnated) facing skins. Alternatively prepreg facing skin materials may be pre-cured by using a press, and subsequently bonding with a film adhesive layer.

Hexcel's Redux® range of film adhesives is well suited for these production methods.

Integrally bonded items such as extruded bar sections and inserts may be included and located by the honeycomb core or with simple tooling.

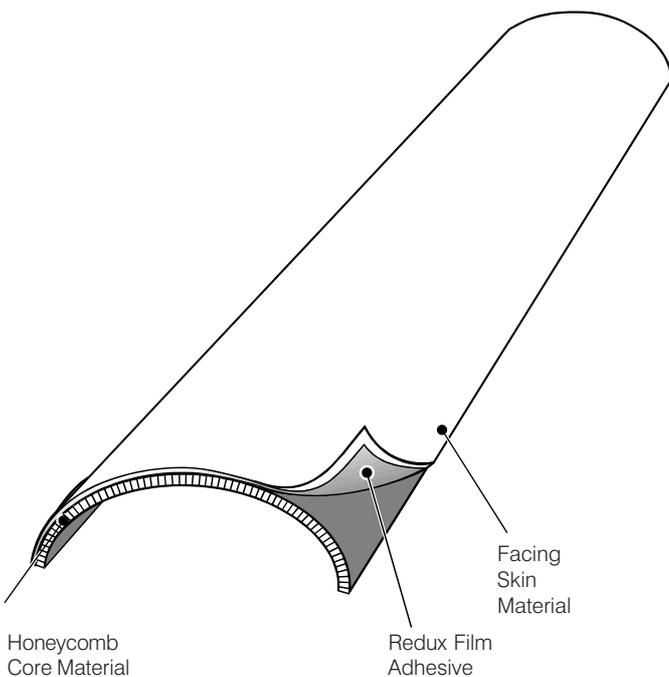
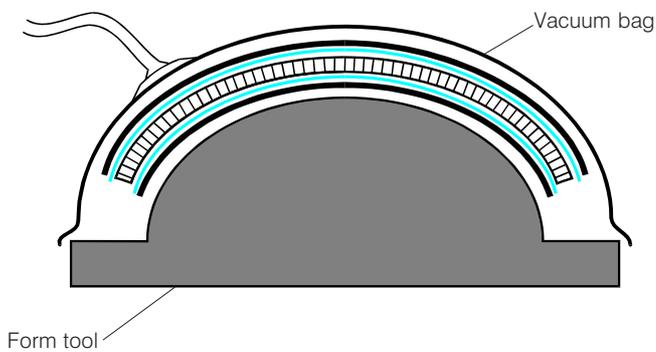


NB. Some further information related to production methods, may be found in Hexcel Composites publications: "Redux Bonding Technology" Ref: RGU 034b and "Prepreg Technology" Ref: FGU 017 available on request or via www.hexcelcomposites.com

Vacuum Bag Processing

The component should be assembled for cure as a single shot process, the necessary consolidation is obtained using a vacuum. This can be cured in an oven, and additional pressure can be applied if an autoclave is used.

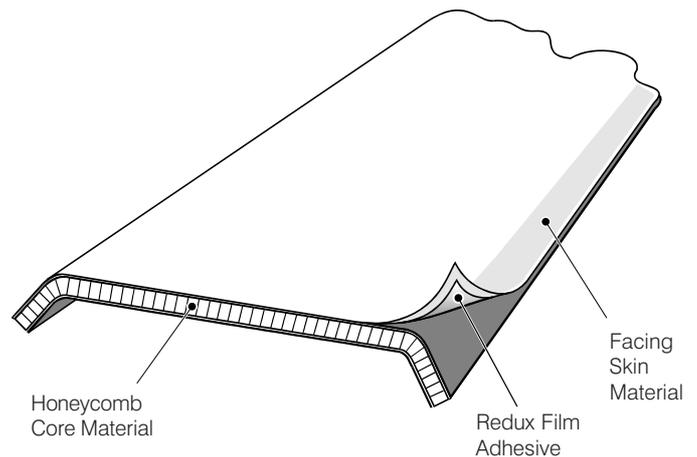
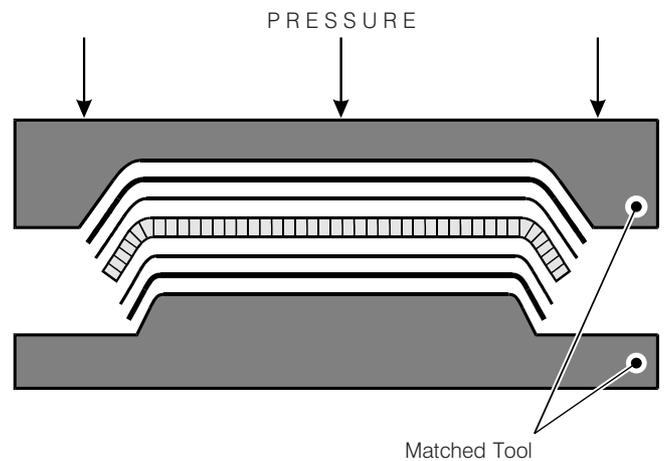
This method is suitable for items with prepreg or preformed composite or metallic facing skins. When flexible or formed honeycomb core and film adhesives are used complex items may be produced.



Match Mould Processing

This method is most suited to the single shot cure process where a key objective is to achieve production items with high levels of tolerance and surface finish. The heat and pressure cure cycle in this case is applied using a variety of methods. Typical methods are the use of heated tools with external mechanical pressure or non heated tools placed in a press or oven to achieve the full cycle.

Using a room temperature curing adhesive cold bonding may be considered if the sandwich construction is too large to be processed using the above methods, or if heating equipment is unavailable.



Advice on special methods and applications, plus information on equipment and suppliers can be obtained from Hexcel Composites on request.

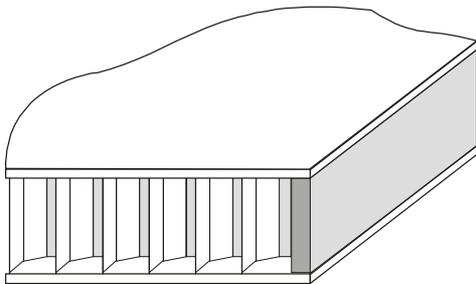
Sandwich Panel Edge Closure Design

When designing of sandwich panels it may be necessary to consider methods of closing or sealing the edges. Exposed edge areas are a potential weakness in the design as they may be susceptible to local impact or environmental damage.

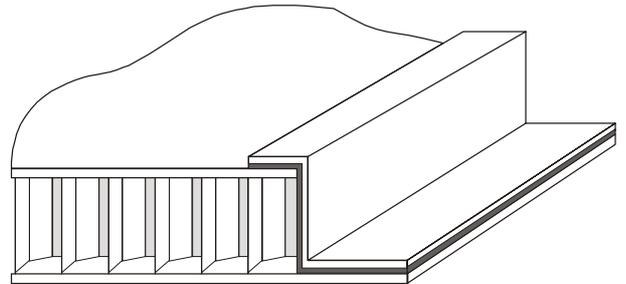
Edge closures may also provide local reinforcements, attachment points, or simply meet aesthetic requirements.

Illustrated are a number of methods commonly used to close sandwich boards:

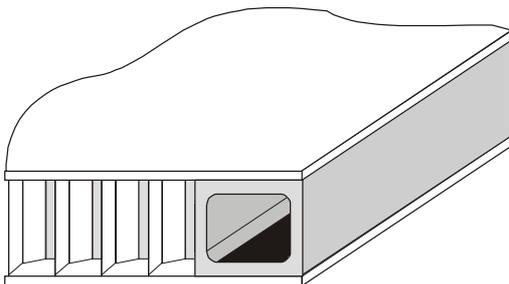
Further information on edge closure, board joining, fabrication and finishing methods is available in the Hexcel Composites publication "Sandwich Board Fabrication Technology" Ref: LTU 018, available on request.



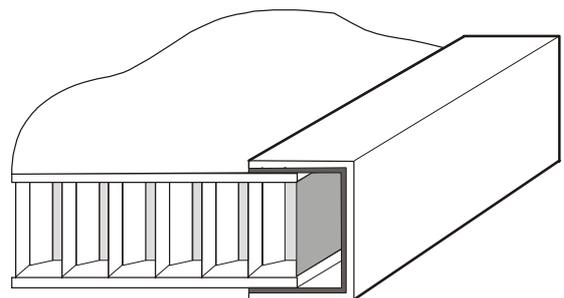
Panel closed with edge filler.



Bonded 'Z' section



Box extrusion



Bonded 'U' section

SAFETY

Handling Precautions

When fabricating from honeycomb sandwich board materials it is advisable to wear disposable clean cotton gloves throughout the entire operation. This helps to keep the panel clean, and affords protection for the operator's hands.

Glass fibre dust is an irritant. Avoid breathing the dust generated by cutting operations, and do not rub the eyes with hands which may be contaminated with the dust.

The usual precautions should be observed while working with synthetic resins.

Product Safety Data Sheets have been prepared for all Hexcel Composites products and are available to company safety officers on request.

The information contained herein is believed to be the best available at the time of printing but is given without acceptance of liability, whether expressed or implied, for loss or damage attributable to reliance thereon. Users should make their own assessment of the technology's suitability for their own conditions of use and, before making any commitment with regard to the information given, should check that it has not been superseded.

APPENDIX I

Mechanical Properties of Honeycomb Materials - Typical Values at Room Temperature

PRODUCT CONSTRUCTION		COMPRESSION		PLATE SHEAR			
Density	Cell Size*	Stabilized		L Direction		W Direction	
kg/m ³ (lb/ft ³)	mm (in)	Strength MPa	Modulus MPa	Strength MPa	Modulus MPa	Strength MPa	Modulus MPa
3003 Aluminium							
29 (1.8)	19 (3/4)	0.9	165	0.65	110	0.4	55
37 (2.3)	9 (3/8)	1.4	240	0.8	190	0.45	90
42 (2.6)	13 (1/2)	1.5	275	0.9	220	0.5	100
54 (3.4)	6 (1/4)	2.5	540	1.4	260	0.85	130
59 (3.7)	9 (3/8)	2.6	630	1.45	280	0.9	140
83 (5.2)	6 (1/4)	4.6	1000	2.4	440	1.5	220
5052 Aluminium							
37 (2.3)	6 (1/4)	1.35	310	0.96	220	0.58	112
50 (3.1)	5 (3/16)	2.3	517	1.45	310	0.9	152
54 (3.4)	6 (1/4)	2.6	620	1.6	345	1.1	166
72 (4.5)	3 (1/8)	4.2	1034	2.3	483	1.5	214
83 (5.2)	6 (1/4)	5.2	1310	2.8	565	1.8	245
127 (7.9)	6 (1/4)	10.0	2345	4.8	896	2.9	364
130 (8.1)	3 (1/8)	11.0	2414	5.0	930	3.0	372
5056 Aluminium							
37 (2.3)	6 (1/4)	1.8	400	1.2	220	0.7	103
50 (3.1)	3 (1/8)	2.4	669	1.7	310	1.1	138
50 (3.1)	5 (3/16)	2.8	669	1.8	310	1	138
72 (4.5)	3 (1/8)	4.7	1275	3.0	483	1.7	193
HRH10 Nomex (Aramid)							
29 (1.8)	3 (1/8)	0.9	60	0.5	25	0.35	17.0
32 (2.0)	5 (3/16)	1.2	75	0.7	29	0.4	19.0
32 (2.0)	13 (1/2)	1.0	75	0.75	30	0.35	19.0
48 (3.0)	3 (1/8)	2.4	138	1.25	40	0.73	25.0
48 (3.0)	5 (3/16)	2.4	140	1.2	40	0.7	25.0
64 (4.0)	3 (1/8)	3.9	190	2.0	63	1.0	35.0
64 (4.0)	6 (1/4)	5.0	190	1.55	55	0.86	33.0
80 (5.0)	3 (1/8)	5.3	250	2.25	72	1.2	40.0
96 (6.0)	3 (1/8)	7.7	400	2.6	85	1.5	50.0
123 (7.9)	3 (1/8)	11.5	500	3.0	100	1.9	60.0
144 (9.0)	3 (1/8)	15.0	600	3.5	115	1.9	69.0
29 (1.8)	5 OX (3/16)	1.0	50	0.4	14	0.4	21.0
48 (3.0)	5 OX (3/16)	2.9	120	0.8	20	0.85	35.0
HRH78	Typical mechanical properties are similar to HRH10, however, the aramid sheet manufacturing tolerances are wider therefore minimum values may be reduced.						

Other foil thicknesses and cell size are available: see specific data sheet or Selector Guide, obtainable from Hexcel Composites on request.
 *Please note that the exact cell sizes for HexWeb core are the imperial measurements. The metric values are provided for reference only.

APPENDIX II

Properties of typical facing materials for sandwich panel construction.

FACING MATERIAL	TYPICAL STRENGTH Tension/Compression MPa	MODULUS OF ELASTICITY Tension/Compression GPa	POISSON'S RATIO μ	TYPICAL CURED PLY THICKNESS mm	TYPICAL WEIGHT PER PLY kg/m ²
Epoxy UD CARBON tape (0°) 60% volume fraction	2000 / 1300	130 / 115	0.25	0.125	0.19
Epoxy UD GLASS tape (0°) 55% volume fraction	1100 / 900	43 / 42	0.28	0.125	0.25
Epoxy WOVEN CARBON (G793-5HS) 55% volume fraction	800 / 700	70 / 60	0.05	0.30	0.45
Epoxy WOVEN ARAMID (285K-4HS) 60% volume fraction	500 / 150	30 / 31	0.20	0.20	0.27
Epoxy WOVEN GLASS (7781-8HS) 50% volume fraction	600 / 550	20 / 17	0.13	0.25	0.47
Phenolic WOVEN GLASS (7781-8HS) 55% volume fraction	400 / 360	20 / 17	0.13	0.25	0.47
ALUMINIUM Alloy 2024 T3 5251 H24 6061 T6	Av. Yield 270 150 240	Av. 70	0.33	0.50	1.35
STEEL carbon 1006 1017	Av. Yield 285 340	Av. 205	0.30	0.5	4.15
Exterior PLYWOOD Fir	30 / 35	Av. 9	0.1	12.7	6.3
Tempered HARDWOOD Teak	110 / 40	Av. 12	0.1	12.7	8.5

APPENDIX III

Summary of Formulae

BEAM (pages 12 to 13)

$$\text{Bending Stiffness} = D = \frac{E_f t_f h^2 b}{2} \quad \text{where } h = t_f + t_c$$

$$\text{Shear Stiffness} = S = bhG_c \quad \text{where } G_c = G_L \text{ or } G_w$$

$$\text{Deflection} = \delta = \frac{K_b Pl^3}{D} \quad (\text{bending}) + \frac{K_s Pl}{S} \quad (\text{shear})$$

$$\text{Facing Stress} = \sigma_f = \frac{M}{h t_f b} \quad \text{where } M \text{ is from page 11}$$

$$\text{Core Stress} = \tau_c = \frac{F}{h b} \quad \text{where } F \text{ is from page 11}$$

PLATE (pages 14 to 17)

$$\text{Plate Coefficient} = \text{i) } \frac{b}{a}; \quad \text{ii) } R = \frac{G_L}{G_w}; \quad \text{iii) } V = \frac{\pi^2 E_f t_f h}{2b^2 G_w \lambda}$$

$$\text{Deflection} = \delta = \frac{2K_1 q b^4 \lambda}{E_f t_f h^2}$$

$$\text{Facing Stress} = \sigma_f = \frac{K_2 q b^2}{h t}$$

$$\text{Core Shear} = \tau_c = \frac{K_3 q b}{h}$$

$$\text{Local Compression} = \sigma_c = \frac{P}{A} = \frac{q x A}{A} \quad (\text{NB: also applicable to Beams})$$

END LOADING (pages 18 to 19)

$$\text{Facing Stress} = \sigma_f = \frac{P}{2 t_f b} \quad \text{where } P = q x b \text{ if applicable}$$

$$\text{Panel Buckling} = P_b = \frac{\pi^2 D}{l^2 + \frac{\pi^2 D}{G_c h b}} \quad \text{where } D \text{ is as per beam}$$

$$\text{Shear Crimping} = P_b = t_c G_c b$$

$$\text{Skin Wrinkling} = \sigma_{CR} = 0.5 [G_c E_c E_f]^{1/3}$$

$$\text{Intra Cell Buckling} = \sigma_{CR} = 2 E_f \left[\frac{t_f}{S} \right]^2$$

The above formulae assume symmetrical items, with thin facings of the same skin material and thickness, and core relatively much less stiff than skins.

Further reading:

ZENKERT, D. - *An Introduction to Sandwich Construction*
Emas Publishing, London (1997)

BITZER, T. - *Honeycomb Technology*
Chapman & Hall, London (1997)