Introduction to Sandwich Structures: Materials and Processing

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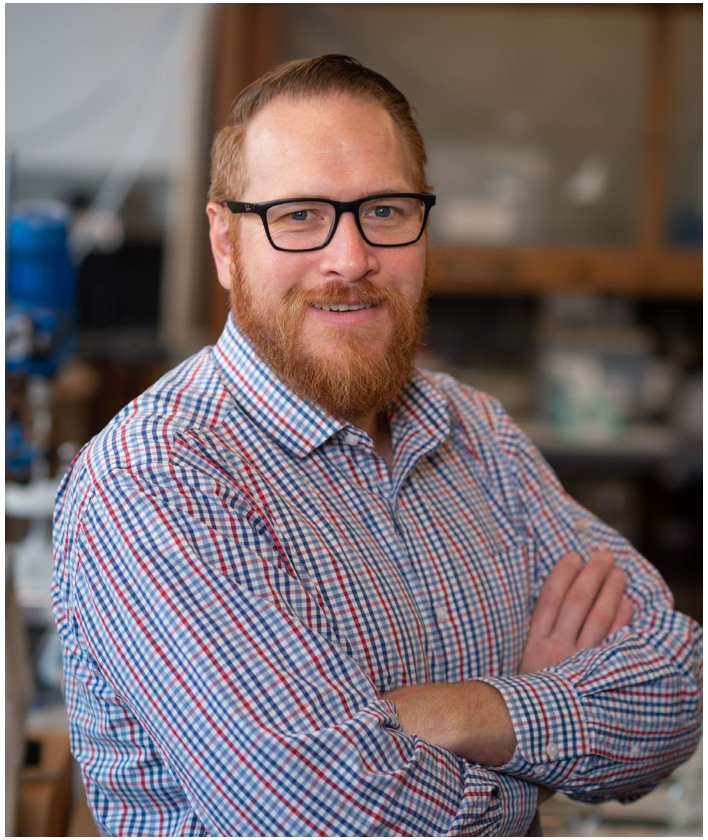

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YOUR HOSTS

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- Expertise in manufacturing and processing of composite materials; process induced deformation
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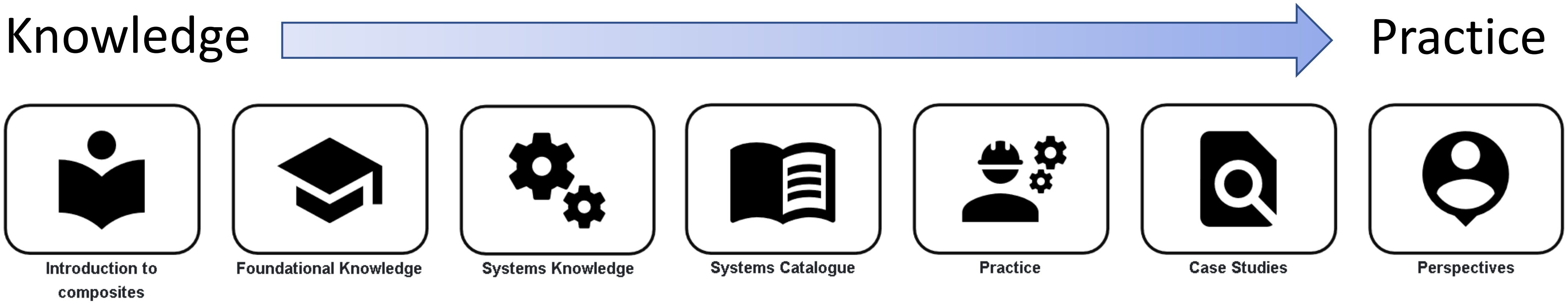
KNOWLEDGE IN PRACTICE CENTRE (KPC)

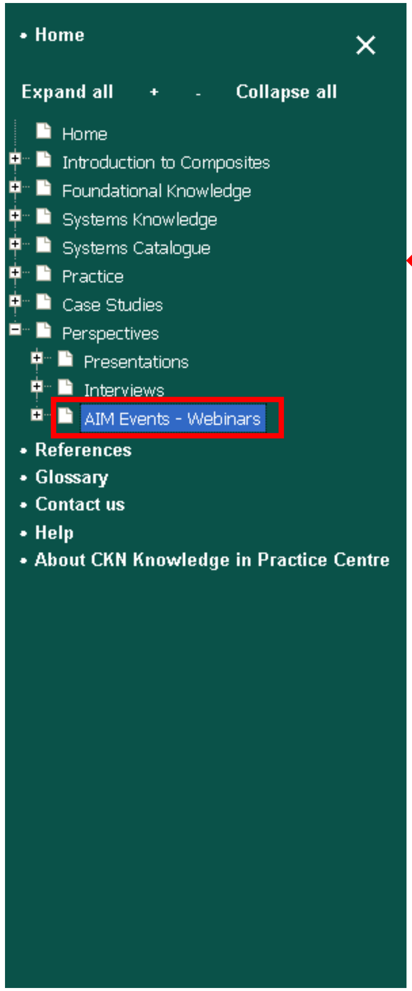
- A freely available online resource for composite materials engineering:

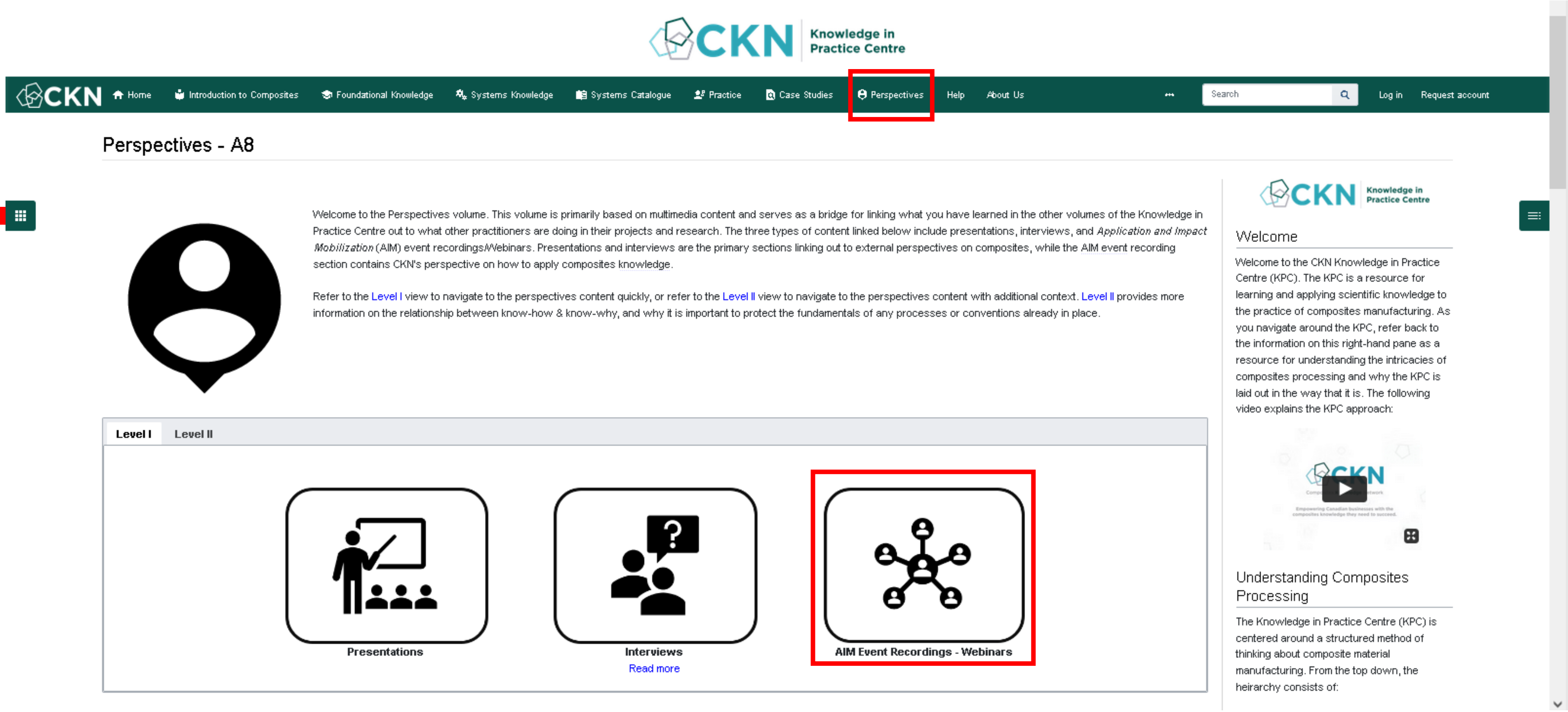
compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



PAST WEBINAR RECORDINGS AVAILABLE





Today's Webinar will be posted at:

https://compositeskn.org/KPC/A327

HOSTED BY: CKN Composites Knowledge Network

https://compositeskn.org/KPC/A115

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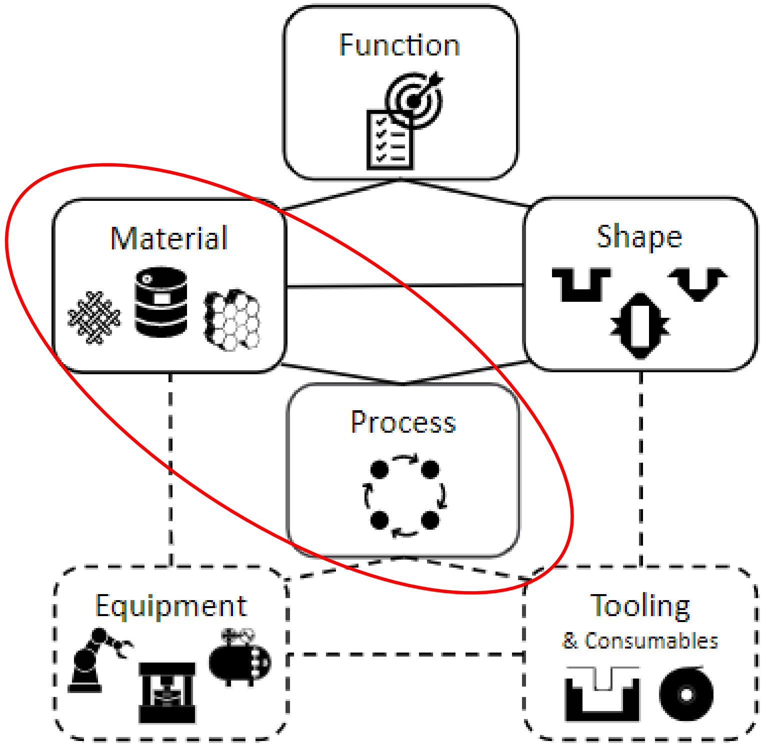
TODAY'S TOPIC:

Introduction to Sandwich Structures: Materials and Processing

OUTLINE

- Introduction and learning objectives
- Sandwich panel application
- Materials
  - Core materials
  - Face sheet materials
  - Adhesive
- Manufacturing
  - Processing pressure
  - Potting and closeouts
  - Thermal management
  - Material deposition and consolidation management
- Manufacturing outcomes and quality management
  - Face sheet dimpling
  - Core crush
  - Other manufacturing outcomes



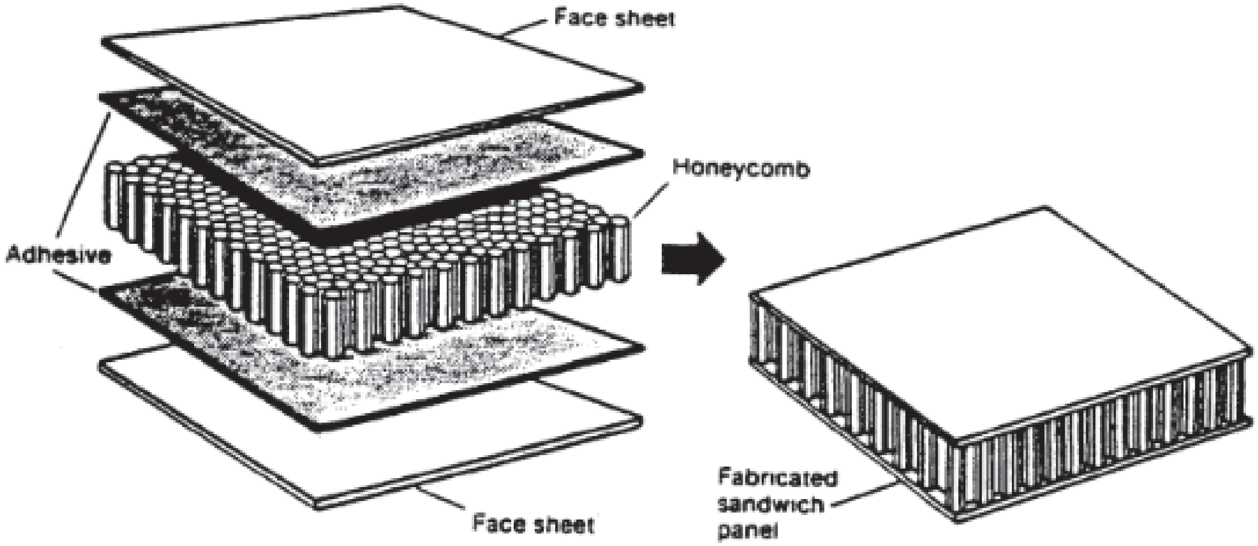
INTRODUCTION

- Learning objectives:
  - Understand fundamentals of sandwich panels
  - Understand the materials, material selection and design considerations of sandwich panels
  - Understand manufacturing processes for sandwich panels
  - Understand common manufacturing outcomes and defects of sandwich panels

Source: CRN, CKN

INTRODUCTION

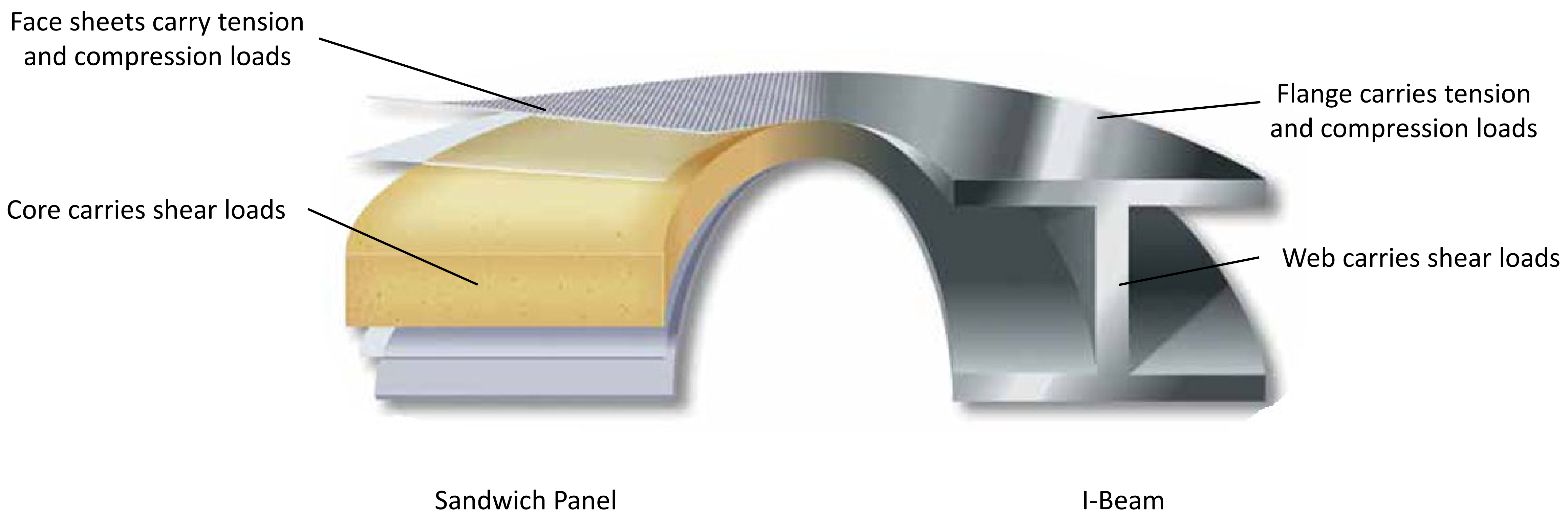
- What is a sandwich panel?
  - Sandwich panels are typically constructed from a core material bonded between two thin, high strength face-sheets via adhesives
  - Core carries the shear loads while spacing the high strength material away from the neutral axis, where the tensile or compressive loads are high



Bitzer, T. (1997). Honeycomb Technology Materials, Design, Manufacturing, Applications and Testing. 1997 Springer Science+Business Media Dordrecht. https://doi.org/10.1007/978-94-011-5856-5

INTRODUCTION

- I-Beam analogy



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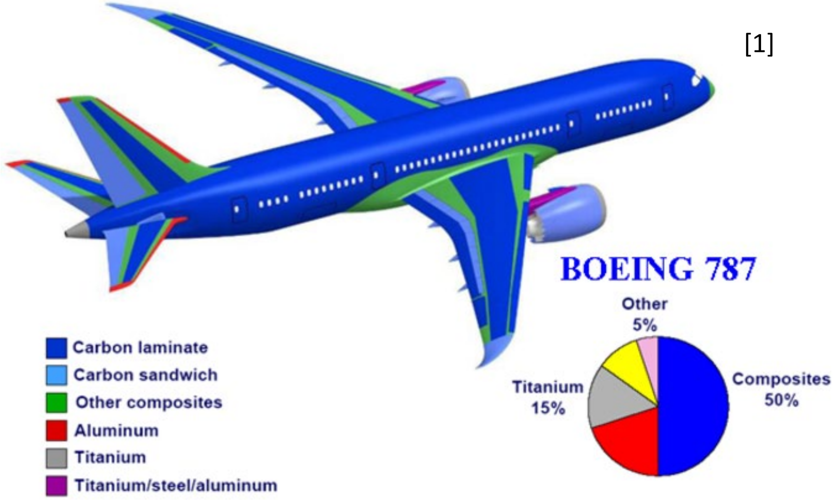
INTRODUCTION

- Applications:
  - Marine
  - Wind energy
  - Aerospace – control surfaces, engineer covers, galleys, lavatories, bulkheads, partitions, storage compartments, and crew rests [1]
  - Automotive transportation
  - Building and construction (insulating, stiff, light weight)
  - Medical – X-ray imaging
  - Sports equipment (skis, snowboards, surf boards)
  - Etc

[2]

[2]

[1]



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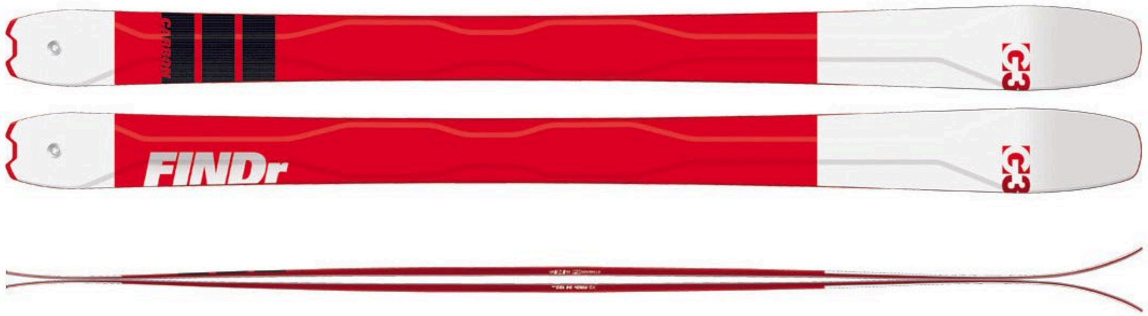
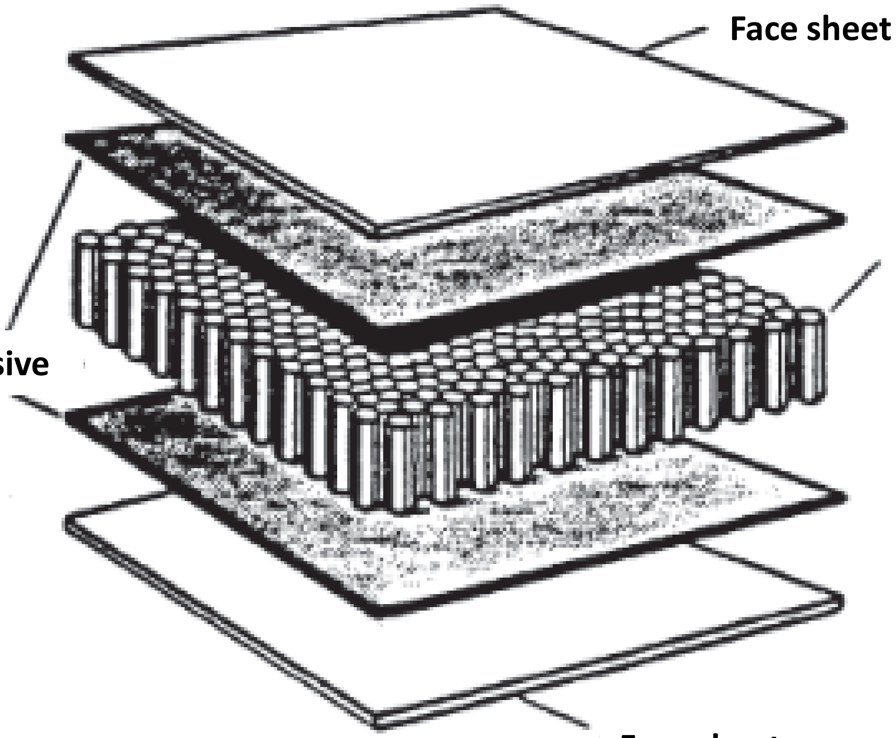


[1] https://showaaircraftusa.com/page/honeycomb-panels
[2] https://www.compositesworld.com/articles/core-for-composites-winds-of-change
[3] https://genuineguidegear.com/products/findr-102

ANATOMY OF A SANDWICH STRUCTURE

- What do we look for in:
  - Face sheet (skin)
    - High modulus of elasticity
    - High strength
    - Low density
  - Core
    - Low density
    - High modulus (elastic and shear)
    - High compressive strength
    - Others
      - Moisture resistance
      - EMI shielding
      - Thermal resistance
      - Chemical resistance
      - Etc.

[1]



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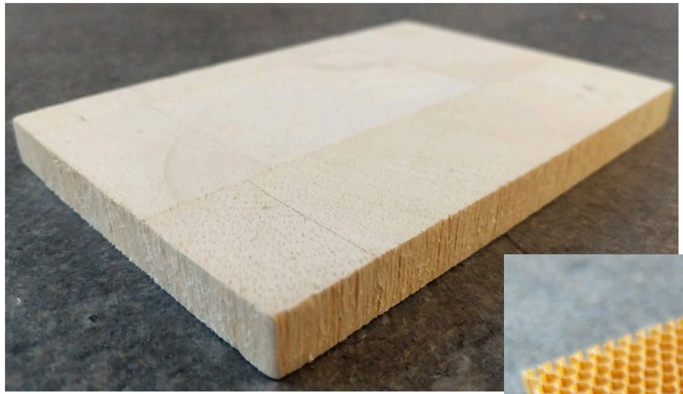
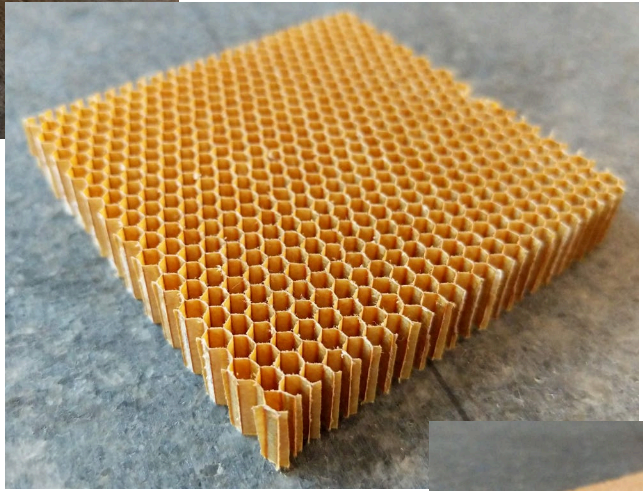
MATERIALS OF SANDWICH STRUCTURE

- Core materials
  - Honeycomb
    - Nomex (aramid)
    - Aluminum
    - Others
  - Foam
  - Wood

- Face sheet materials
  - CFRP
  - GFRP
  - Aluminum
  - Others

- Adhesive
  - Film
    - Supported
    - Unsupported
  - Bulk





Source: CRN, CKN

CORE MATERIAL – WOOD

- Common wood materials include balsa, mahogany, spruce, poplar
- End-grain balsa cut transversely to its grain direction, and re-joined (by adhesive) side by side such that the grain direction is perpendicular to the core surface (0.1 to 0.3 g/cm^3)
  - Advantage:
    - High compression and shear strength
    - Good fatigue performance
    - Easy to machine
    - Faces sheets can also be directly laminated onto the core without using adhesives
    - Low density
    - Low cost
  - Disadvantage:
    - Low conformability
    - High variability in properties (since the core is made from smaller blocks bonded together)
    - High moisture sensitivity, which can lead to rot

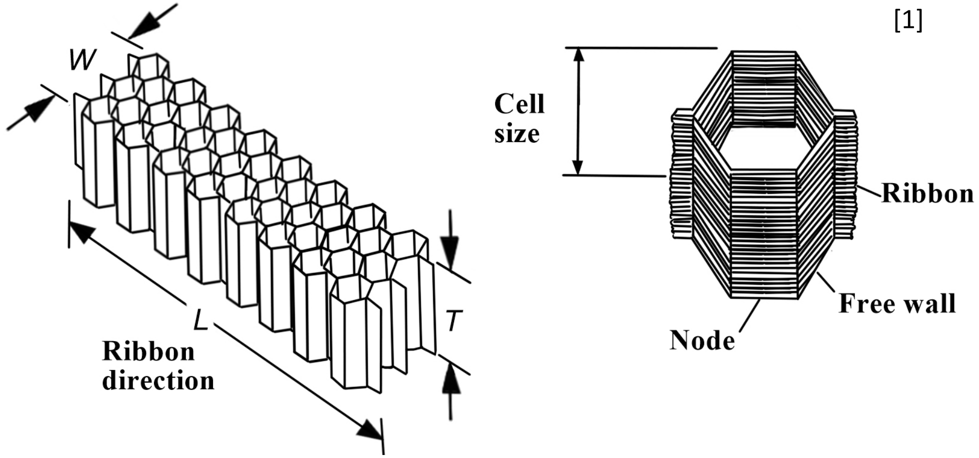
Source: CRN, CKN

- Flexible sheet forms exist, where the small blocks are held by a fabric scrim backing

Source: CRN, CKN

CORE MATERIAL – HONEYCOMB

- Honeycomb is an array of open cells made from thin sheets of material attached to each other
- Commonly used in aerospace:
  - Secondary structures, control surfaces, engine cowling, non-structural body panels and interior applications
- Honeycomb can be made from a wide range of metallic (aluminum, stainless steel) or nonmetallic (Nomex, aramid, polypropylene, polycarbonate, thermoplastic etc.) materials
- Advantage
  - High to extreme performance may be achieved while being light weight
  - Specific properties such as energy absorption and EMI/RFI shielding
  - High fatigue resistance
  - Wide range of weight, material and properties for different requirements
- Disadvantage
  - High cost
  - Complicated to manufacture
  - Prone to moisture ingression
  - Repairability issues



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[1] Adopted from Bitzer, T. (1997). Honeycomb Technology Materials, Design, Manufacturing, Applications and Testing. 1997 Springer Science+Business Media Dordrecht. https://doi.org/10.1007/978-94-011-5856-5 Recreated by CKN

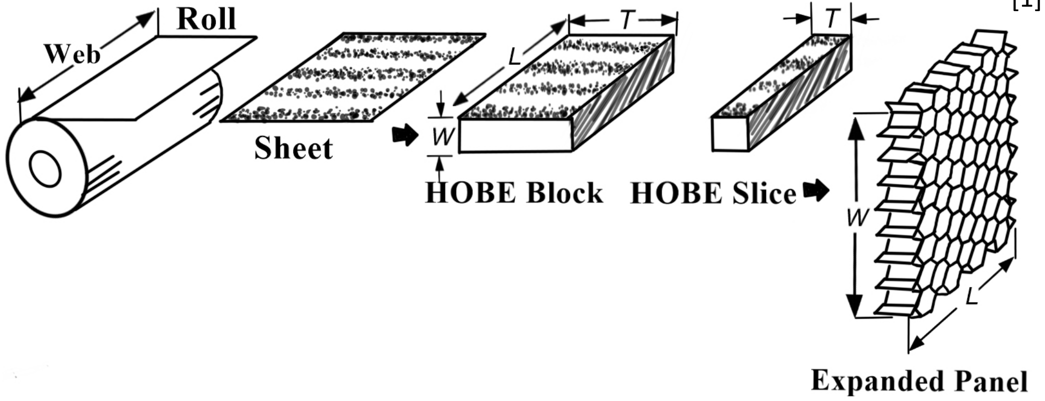
CORE MATERIAL – HONEYCOMB

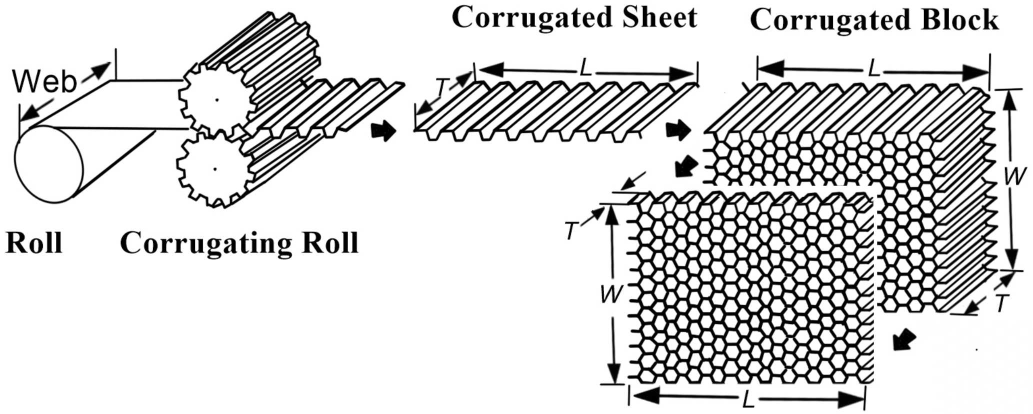
- Honeycomb manufacturing process

- Expansion
  - Metallic honeycomb deform plastically when being expanded
  - Non-metallic honeycomb are repeated dipped in liquid resin (typically phenolic or polyimide) to achieve desired density and maintain the expanded shape
  - Expanded honeycomb often lower density and more economical

- Corrugated
  - Only light pressure can be applied during bonding and curing, resulting in much thicker adhesives
  - More expensive and time consuming to make compared to expansion

[1]





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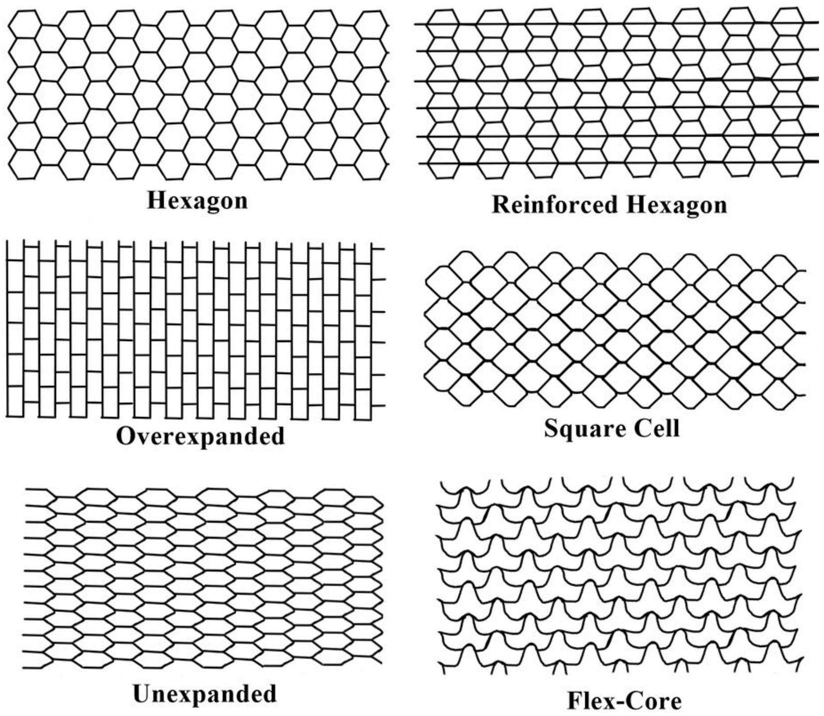
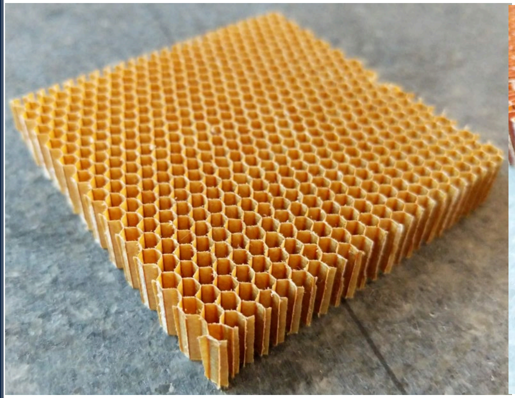
CORE MATERIAL – HONEYCOMB

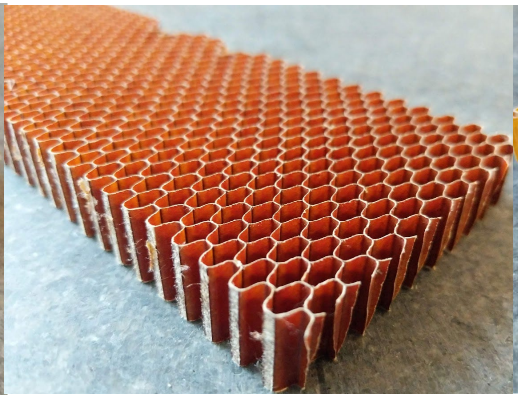
- Honeycomb cell configurations
  - Different cell shapes and configurations can result in different mechanical properties and handling characteristics of the honeycomb
  - Over-expanded core has lower bending stiffness in the L direction compared to the standard hexagon cell, making it easier to conform to curvatures in the L direction. The shear strength and modulus in L direction is lower and in W direction is higher compared to standard hexagon cell shape

[1]

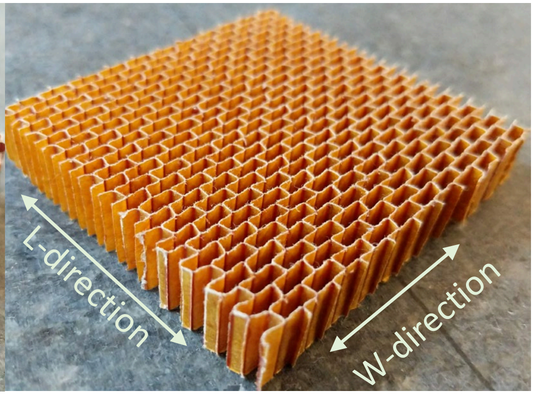




Hexagon



Partially over-expanded



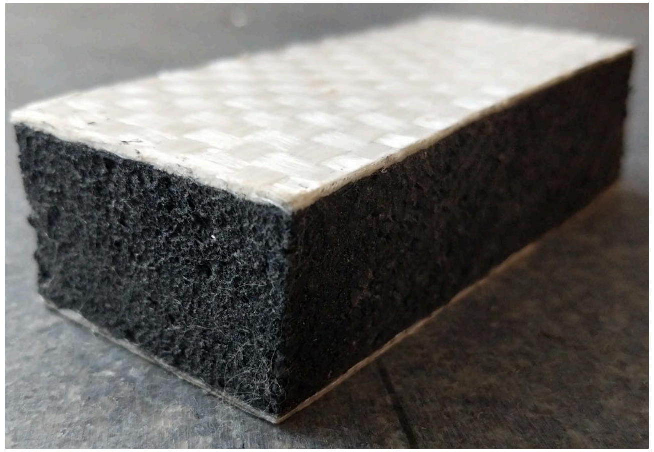
Over-expanded

Source: CRN, CKN

[1] Adopted from Bitzer, T. (1997). Honeycomb Technology Materials, Design, Manufacturing, Applications and Testing. 1997 Springer Science+Business Media Dordrecht. https://doi.org/10.1007/978-94-011-5856-5 Recreated by CKN

CORE MATERIAL – FOAM

- Almost all polymer (uncross-linked thermoplastic and cross-linked thermoset) can be made into a foam with proper foaming or blowing agents
- Thermoset generally has better mechanical properties while thermoplastic foams are more formable
- Thermoset foams can also be lightly cross-linked to achiever higher formability
- Density can range from 0.032 – 0.64 g/cm^3
- Wide variety to choose from, designers should understand the implications of these foam parameters when selecting foams to fulfill the functions and requirements of the to-be-designed product
- Performance considerations:
  - Weight/density
  - Mechanical performance
  - Thermal performance
  - Specialized performance
  - Manufacturability
  - Cost



Source: CRN, CKN

CORE MATERIAL – FOAM

- Advantage:
  - Less local density variations and less moisture absorption compared to wood
  - Can be formed into complex geometries while having uniform properties
  - Easy to machine
  - More economical compared to honeycomb
  - Acoustic or heat insulation and damping
- Disadvantage:
  - Generally lower mechanical properties (compression and shear) compared to honeycombs of the equivalent density
  - Can be less resistant to heat compared to honeycomb
  - Potential core deformation depending on the foam material, density and sandwich manufacturing process (especially pressure)

Source: CRN, CKN

CORE MATERIAL – FOAM

- Foam manufacturing processes
  - Foam-in-place, two-part liquids are mixed and poured into a mould
  - Pre-expanded block, produced by mixing the liquid polymer with the proper foaming or blowing agents (physical or chemical)
    - Physical blowing agents are gases mixed into the foam material that expands while being heated

Source: CRN, CKN

CORE MATERIAL – FOAM

- Foam core structure – Open-cell vs Closed-cell
  - The cells of the foam core can be interconnected (open-cell) or closed and discrete (closed-cell)
  - Closed-cell foams generally have higher density and better mechanical properties than open-cell foams
  - In general, the higher the foam density the higher percentage of closed cells

Open-cell	Closed-cell
• Softer and more springy (returns to original shape once deformed) • Breathable, allows air or other fluids to pass through • Good for sound absorption/insulation	• Denser • Higher mechanical properties • Less permeable

https://image.shutterstock.com/image-photo/white-piece-styrofoam-260nw-1126920257.jpg
https://da.lowes.ca/webassets/images/731906_05497982_001_l.jpg

CORE MATERIAL – FOAM

Common polymer foam materials

- Polystyrene
  - Lightweight
  - Low cost
  - Relatively low mechanical properties, used for non-structural applications
  - Cannot be used with polyester resin (styrene dissolves the core)
- Polyurethane (PU)
  - Moderate mechanical properties
  - Prone to core-to-face sheet delaminate with age
  - Some can be used up to 135 °C and 180 °C, enabling curing with prepregs in oven or autoclave

Source: CRN, CKN

CORE MATERIAL – FOAM

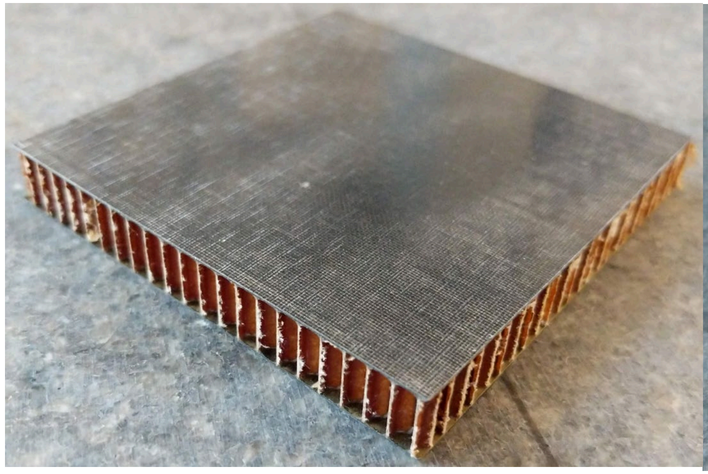
Common polymer foam materials

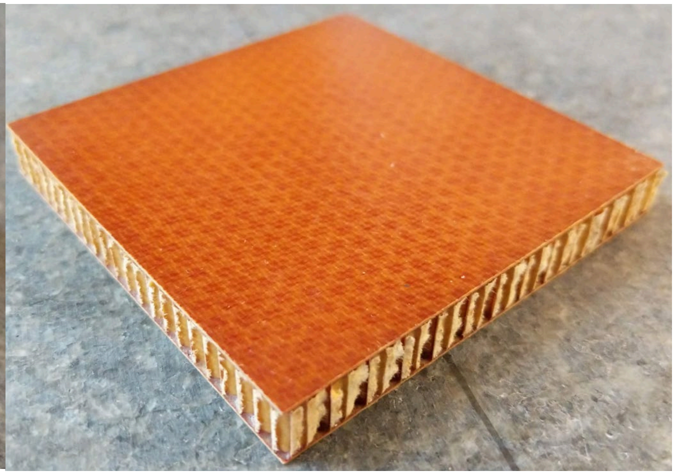
- Polyvinyl chloride (PVC)
  - Most widely used foam core materials for sandwich panels
  - Density range from 0.03-0.42 g/cm^3
  - Available in uncross-linked thermoplastic and cross-linked thermoset form with wide range of properties
- Polymethylmethacrylimide (PMIs)
  - Lightly cross-linked closed-cell foams that have very good mechanical properties
  - Can be processed at very high temperatures (205°C/400°F)
  - Density can range from 0.032-0.30 g/cm^3
  - Can also be thermoformed. Typically expensive and only used for high performance applications such as ovens or autoclaves cured sandwich panels with pre-pregs

Source: CRN, CKN

FACE SHEET MATERIAL

- The same composite material used to manufacture monolithic laminates can generally be used as sandwich face sheets
  - Surface finish and mechanical properties (especially compression) may differ from a solid laminate depending on core, adhesive and process
  - Prototyping is advised to obtain properties – machine away core, test the face sheet
- Pre-preg with excess resin can be used without adhesive in some non-critical applications

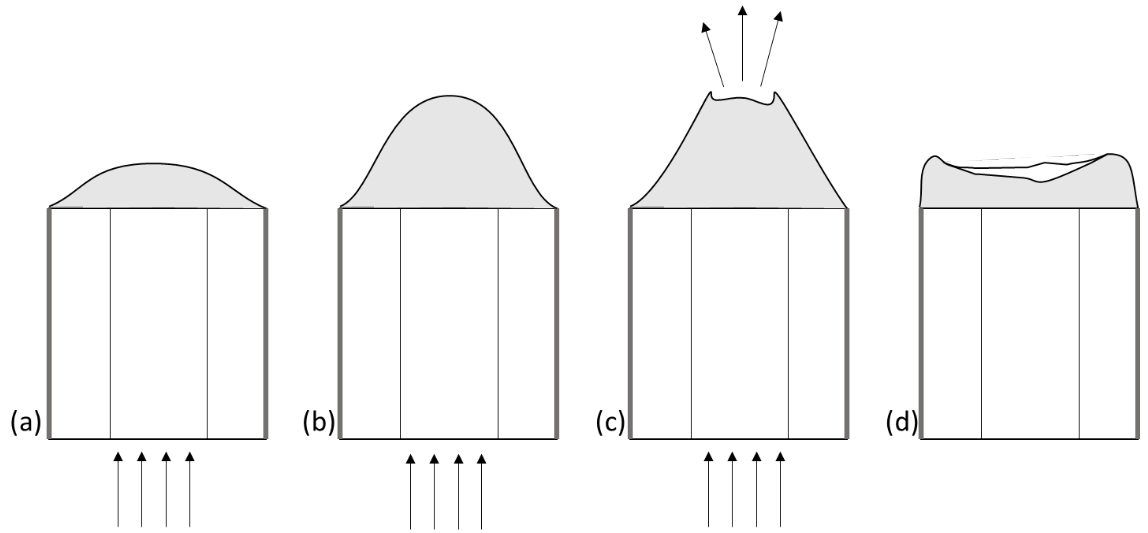




Source: CRN, CKN

ADHESIVES

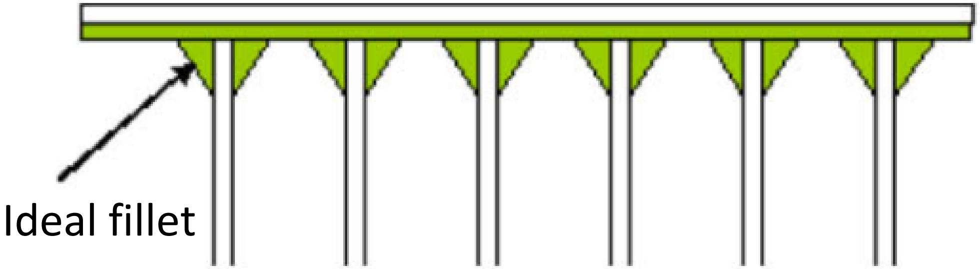
- Typically thermoset films with uncured thickness of 0.075 mm to 0.38 mm
- Supported adhesive films
  - Loosely woven polyester, glass or nylon carrier or scrim for easy handling and control of the bond-line thickness
  - The carrier or scrim can be either embedded in the film adhesive or on the surface
  - Provide a surface for face sheet push against during cure
- Unsupported adhesive films
  - Extremely lightweight
  - Reticulation
    - Efficient adhesive deposition

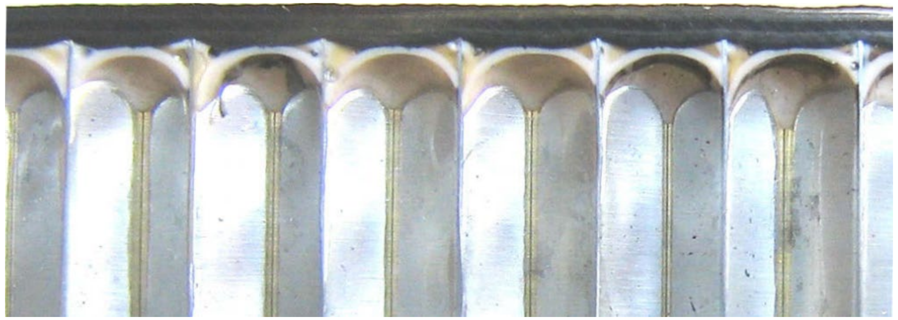


Source: KPC

ADHESIVES

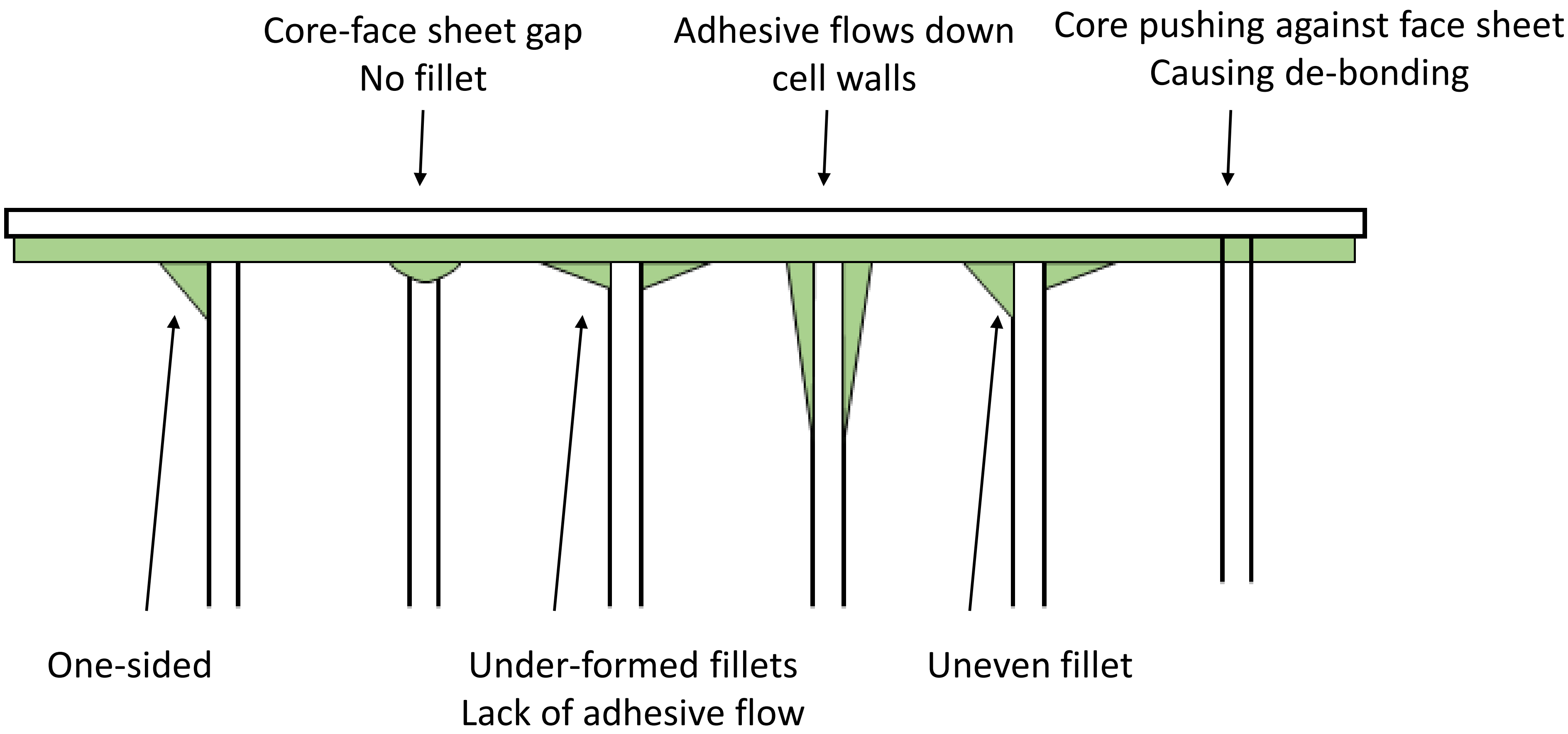
- Adhesive for honeycomb cores
  - Need to form fillets at the cell wall-to-face sheet interface
  - Flow behavior (rheology), surface tension and viscosity are precisely controlled
- Moisture absorption – decrease bond strength, de-bonding/blisters due to evaporation
- Outgassing – Blisters, honeycomb cell split/rupture
- Evaluate using higher strength cores or less bonding area to further stress the bond under critical conditions
- Flatwise tension, climbing drum peel are commonly used for the bond out-of-plane and peeling strength evaluation





Fabrication of Sandwich Structures (materials and processes). (n.d.). In *Composite Materials Handbook -17 (CMH-17)* (Vol. 6, pp. 1–39).

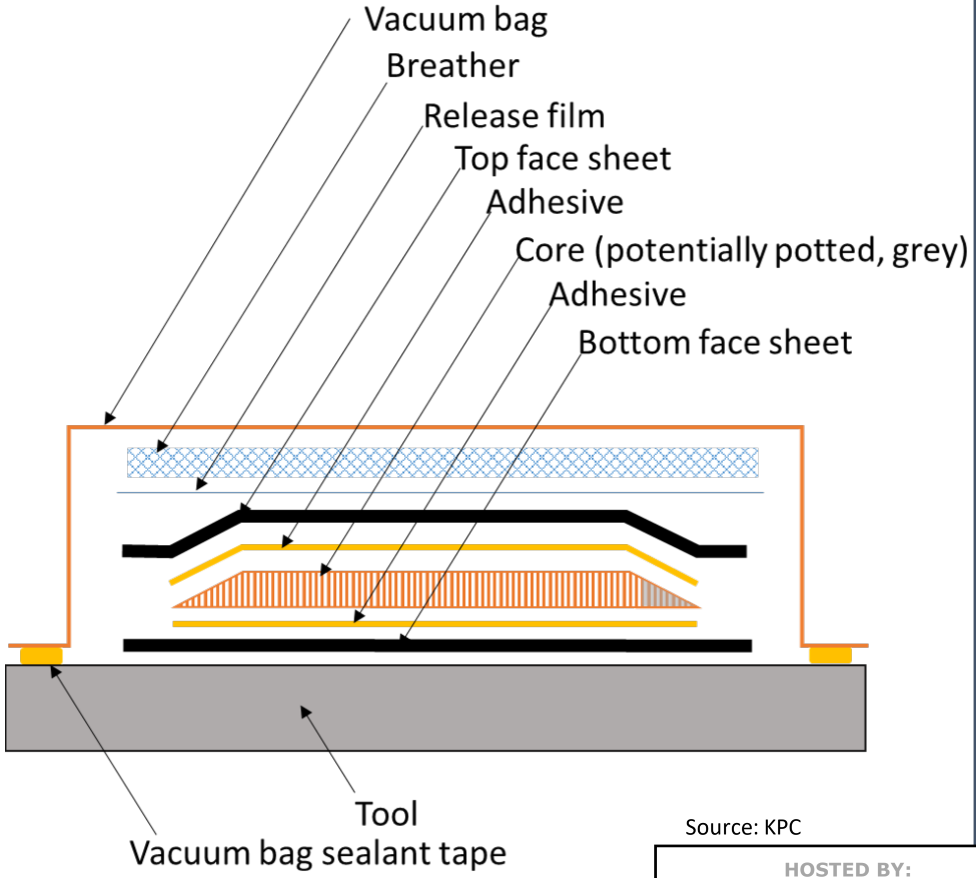
ADHESIVES



Source: CRN, CKN. Recreated from: Fabrication of Sandwich Structures (materials and processes). (n.d.). In *Composite Materials Handbook -17 (CMH-17)* (Vol. 6, pp. 1–39).

MANUFACTURING OF SANDWICH PANELS

- Common methods for making sandwich panels:
  - ***Co-curing:*** both face sheets cure at the same time as the adhesive (1 cure cycle)
  - ***Co-bonding:*** bonding one precured face sheet to the core while the other face sheet cured and bonded to the core and the same time (2 cure cycles)
  - ***Secondary bonding:*** bonding on of more precured composite face sheets to the core using adhesive. Also applies when adhesive bonding aluminum face sheets to aluminum honeycomb core (3 cure cycles)
  - ***Liquid molding processes:*** resin transfer moulding (RTM), vacuum assisted resin transfer moulding (VARTM, infusion)
  - ***Other:*** wet layup, continuous lamination, compression moulding, filament winding



Source: KPC

MANUFACTURING OF SANDWICH PANELS

- **Processing pressure**
  - Usually range from 100 to 350 kPa (15 to 50 psi)
  - 300 kPa for Nomex honeycomb core, especially if the core has ramps
  - Depending on the core material and geometry, even vacuum pressure can cause core movement and deformation
  - Designer can limit the vacuum pressure (to 8-10 inches of Hg for example) in those case

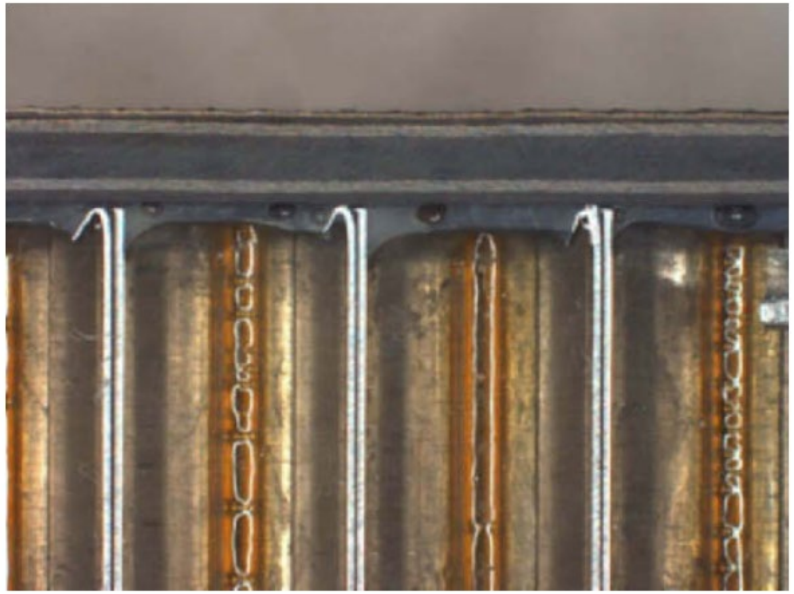
(A) Sandwich panel after layup, before cure. (B) Same panel after cure [1]

[1] Pawson, D. J. (2019). *Core movement during processing of sandwich panels*. The University of British Columbia. https://doi.org/10.33599/nasampe/s.19.1569

MANUFACTURING OF SANDWICH PANELS

- **Processing pressure - Special consideration during co-curing**
  - Pressure in honeycomb cells is low (a few psi or ~0). As face sheet droop into the cells, resin pressure in face sheet and adhesive is low. Can cause porosity and low levels of consolidation
  - For the same reason, honeycomb sandwich panels in autoclave are more sensitive to bag leaks than solid laminate. The autoclave pressure entering a honeycomb cell can literally blow the core apart

Co-bonded [1]



Secondary-bonded [1]

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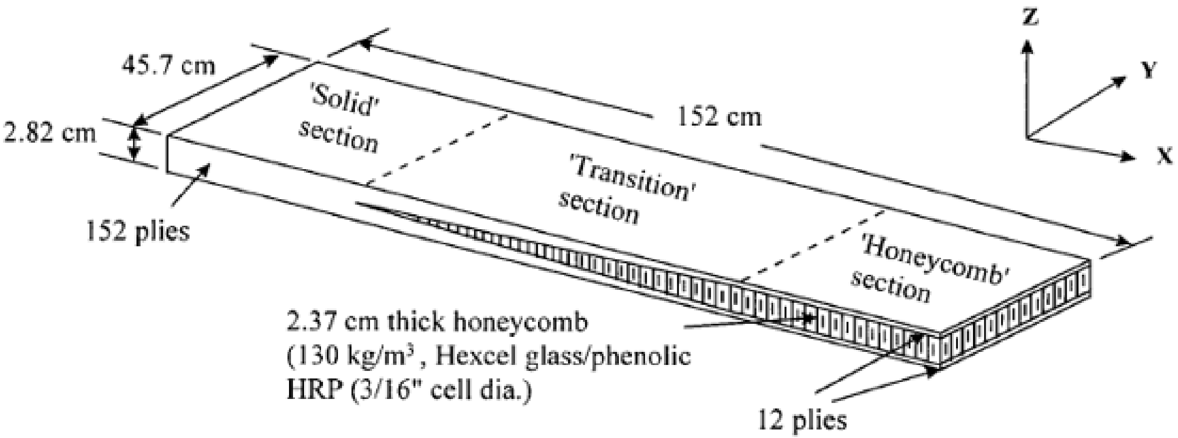
MANUFACTURING OF SANDWICH PANELS

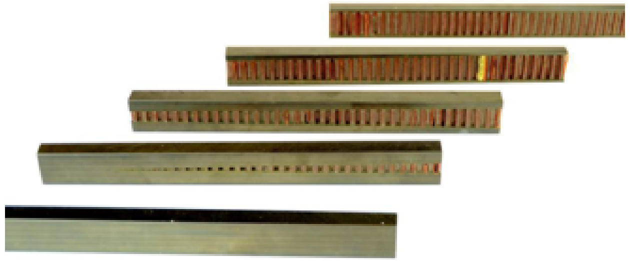
- Potting
  - Honeycomb cells can be selectively filled and reinforced with foam or other materials for the following reasons:
    - local reinforcement for assembly with fasteners
    - prevent core crush
    - locally increase surface area for bonding
    - stabilize the honeycomb cell walls for machining
    - achieve thermal and acoustic insulation properties
- Closeouts
  - Sandwich panels require special closeouts at the edges to prevent potential water ingression. Various types of closeouts and their tradeoffs add to the complexity of honeycomb sandwich panel design and manufacturing

Source: CRN, CKN

MANUFACTURING OF SANDWICH PANELS

- Thermal management for sandwich panels
  - Cores typically insulate the tool side and bag side face sheets to some extend due to their low thermal conductivity. Hence it complicates the system level problem involving the material, shape, tooling and equipment during the thermal transformation step.



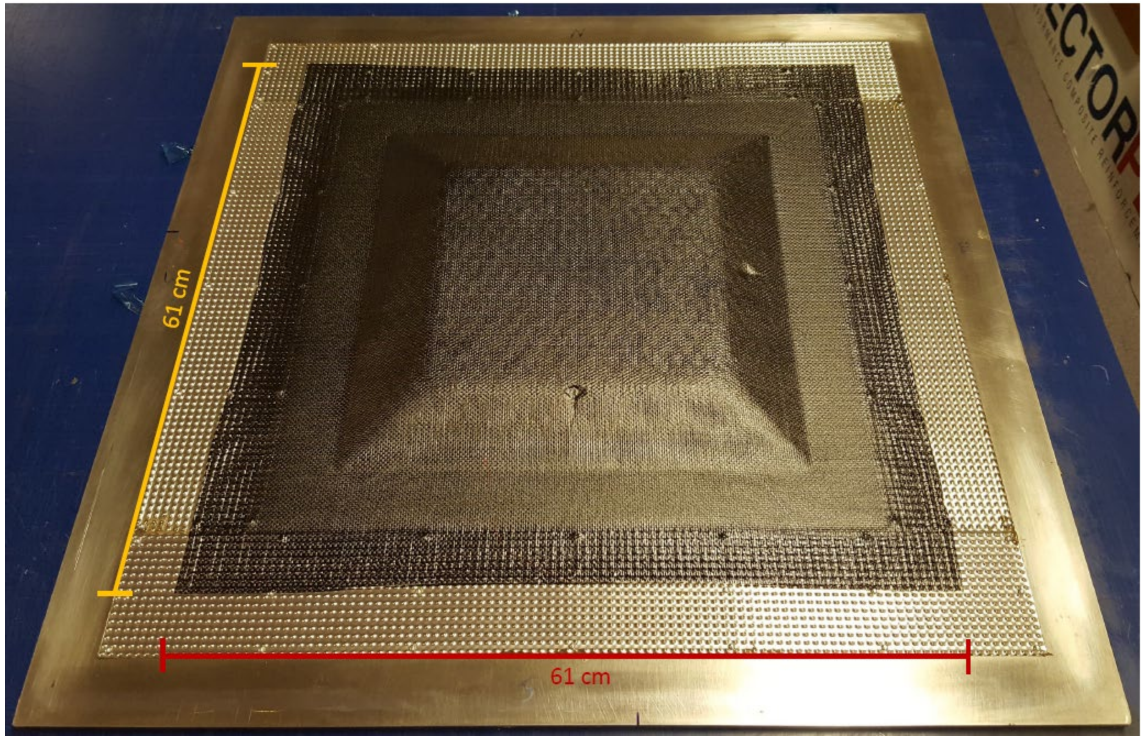


Source: CRN, CKN

MANUFACTURING OF SANDWICH PANELS

- Material deposition and consolidation management
  - Core positioning during deposition:
    - Using features in the core or on the tool
    - Laser projection
    - Templates
  - Maintaining core position during consolidation and thermal transformation (more on core crush)
    - Relying on core or tool features
    - Strict process control (temperature and pressure)
    - Mechanical grit strips (tie-downs)

[1]



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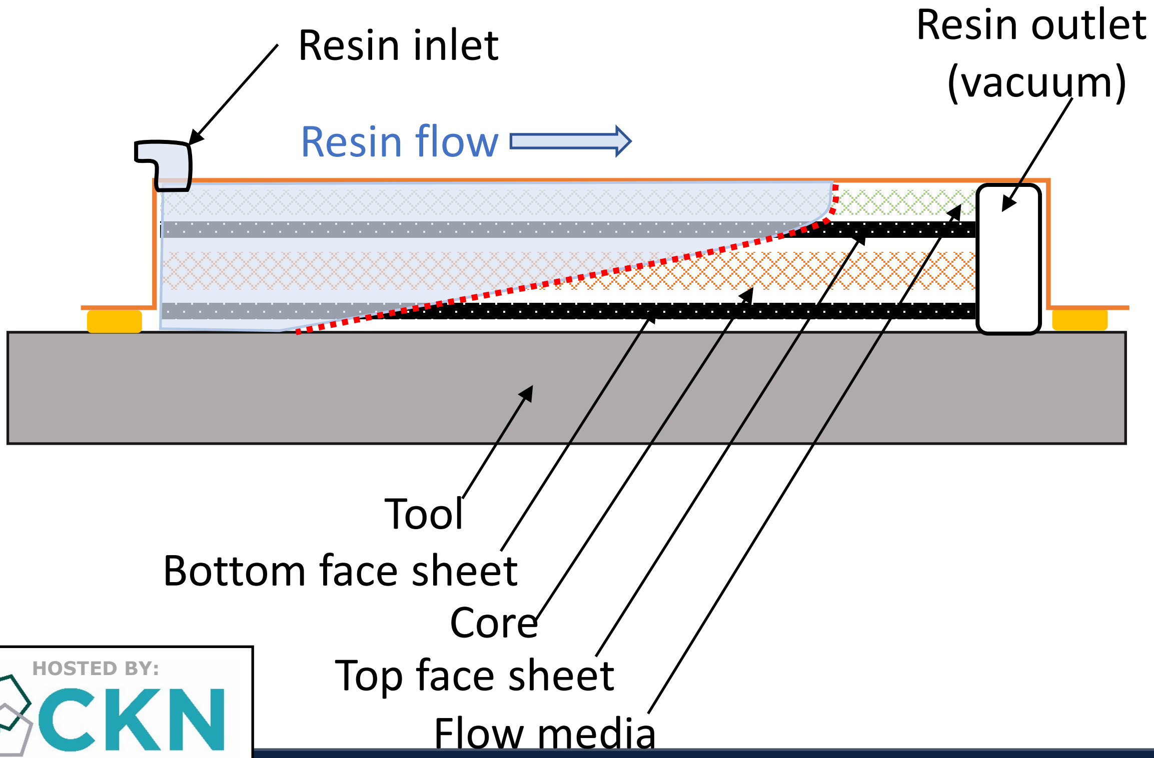
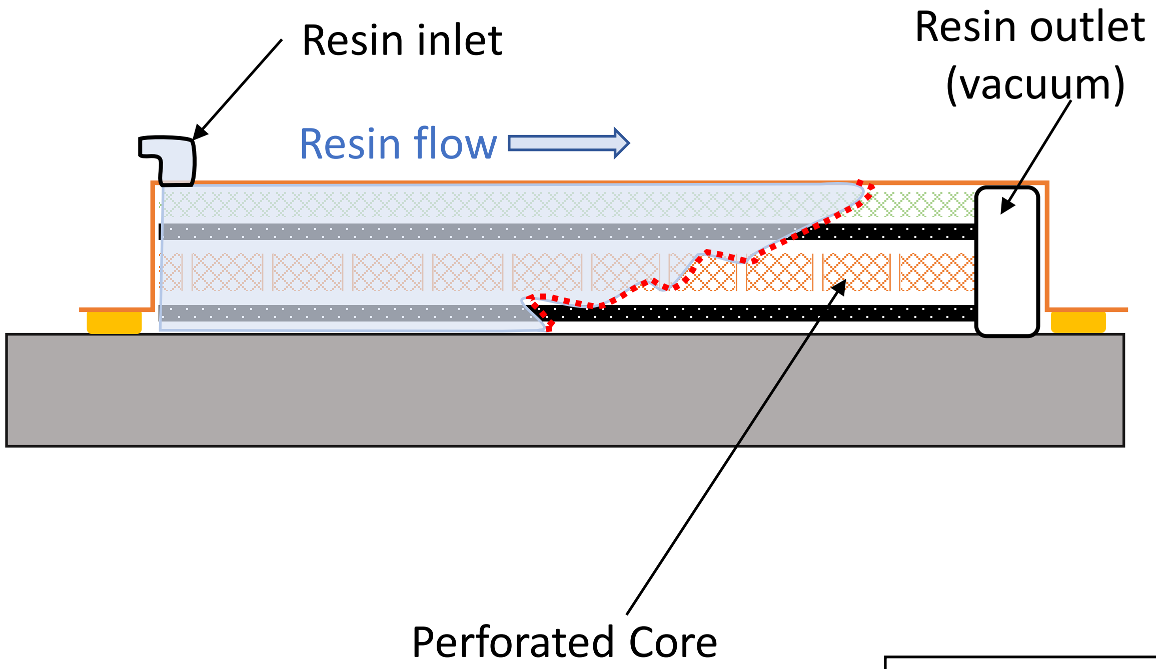
MANUFACTURING OF SANDWICH PANELS

Core and matrix deposition during liquid molding processes

- Allow for sufficient resin flow on either side of the core
- Core can be scored/channeled to create resin pathways
- Perforated cores can allow resin travel from one side to the other





MANUFACTURING OF SANDWICH PANELS

- Examples
  - Foam/CFRP infused C-channel beams
  - Telescope in Penticton

MANUFACTURING OF SANDWICH PANELS

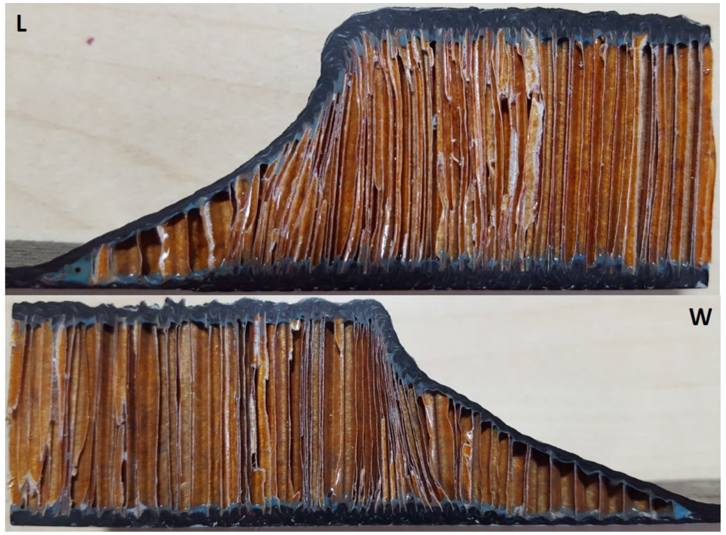
- Manufacturing outcomes – face sheet dimpling
  - Common during co-curing honeycomb sandwich panels
  - Honeycomb pattern telegraph to the face sheet on either the bag side or the tool side
  - The thinner the face sheets and larger the honeycomb cell size, more likely to happen
  - The dimpled face sheet may also exhibit resin starvation and increased surfaced porosity (especially on the tool side)

Source: CRN, CKN

MANUFACTURING OF SANDWICH PANELS

- Manufacturing outcomes – Core crush
  - Sensitive to process conditions (temperature & pressure)
  - Tie-downs are effective
  - Steeper ramp angles increase core deformation
  - Deformation might be different, but also coupled, in the ribbon and non-ribbon direction

[1]



[1] Pawson, D. J. (2019). *Core movement during processing of sandwich panels*. The University of British Columbia. https://doi.org/10.33599/nasampe/s.19.1569

Manufacturing of Sandwich panels

- Other manufacturing outcomes

		Material	shape	tool	equipment		Fill	Do we care about this parameter in the factory cell/ Can the factory cell affect or change the parameter value					
							X	Actively measure, checking					
	Parameter of any process	Receving	Testing	Storage	Material deposition	Thermal Transformation	Demolding	Trimming and machining	Inspection	Assembly	Coating	Package and shipping	Service
MDCM	Resin distribution		X						X				
	Areal weight		X										
	Tack		X		X								
	Drape		X		X								
	IR		X		X								
	Cured ply thickness		X						X				
	Fiber mechnical properties		X										
	Tow mechanical properties		X										
	Ply mechanical properties		X										
	Core properties		X						X				X
	Fiber alignment		X		X				X				
	Resin mixing ratio				X								
	Resin viscosity		X		X	X							
	Contamination		X		X			X	X	X			X
	Wrinkles		X		X				X				
	Ply laps				X				X				
	Ply gaps				X				X				
	Voids								X				
	Fiber volume fraction								X				
	Bleeding						X						
	Consumables						X		X				
	Knit-lines								X				
	Consolidation: final thickness								X				
	Bridging								X				
	Core movement						X		X				
	Core crush						X		X				
	Geometry								X				X
RSDM	Micro-cracks								X				
	Delamination								X				
	Disbonding								X				
	Deformation: spring-in; warpage								X	X			
	Thermal strains												
	Tool CTE												
	Cure shrinkage												
	Crystallization shrinkage												

Source: KPC

Thank you for joining us!

Keep an eye out for announcements on the next AIM events:
Held on the last Wednesday of the month

And don't forget to visit the KPC for more information:

https://compositeskn.org/KPC

Questions?

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A327