Robust Sandwich Structure Design

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EASA Headquarters, Cologne, Germany, October 18-20, 2016

Overview

Objective – Purpose of Presentation

CMH-17 Volume 6 Relevant Sections

- Chapter 4 Design and Certification
- Chapter 5 Fabrication of Sandwich Structures (M&P)
- Chapter 2 Environmental Effects

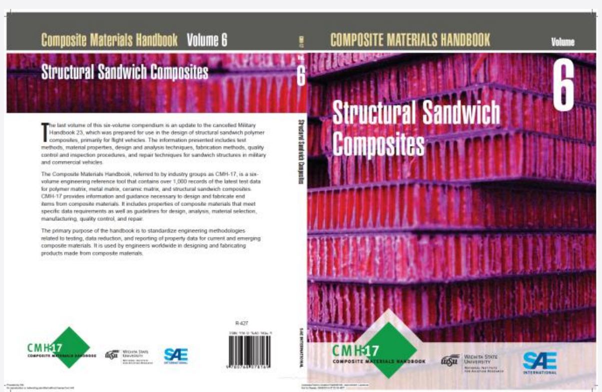
Industry Experience – Lessons Learned

Good Design Practice

Summary

Objective

The purpose of this presentation is to highlight relevant sections of CMH-17 Volume 6 *Sandwich Structures*, along with examples of industry experience to help seed discussion regarding development of guidance for such configurations.



CMH-17 Vol 6 Relevant Sections

Chapter 4 covers the sandwich-unique failure modes and considerations as follows:

4.2 DESIGN AND CERTIFICATION

4.2.1 Basic design principles

The basic design concept for sandwich structures is to space strong, thin face sheets far enough apart to achieve a high ratio of bending stiffness to weight. The lightweight core between the face sheets must provide the required strength to resist the design shear, compression, and tension loads, while also being stiff enough to stabilize the face sheets in the desired configuration. The face sheets and core are joined through a bonding medium (i.e., adhesive, welding, or brazing), which must be capable of supporting and transferring all design loads.

Design of sandwich structures generally proceeds along the same basis as for composite laminate structures, but several failure modes and design issues specific to sandwich construction must be considered. Some of the more important issues specific to sandwich design are:

- Core shear
- Core crushing
- Core buckling
- Face sheet dimpling
- Face sheet wrinkling
- Face sheet buckling
- Strength of core-to-face sheet attachment
- Hardpoints (inserts and attachment points)
- Ramps (areas of transition from sandwich to solid laminate)

While the rest of this chapter provides detailed methods to address these and other sandwich-specific design issues, the basic principles for successful sandwich design can be summarized as follows:

1. Sandwich face sheets should be thick enough and strong enough to withstand design stresses under chosen design loads.
2. The core should be thick enough and/or dense enough to have sufficient shear rigidity and strength so that overall sandwich buckling, excessive deflection, and shear failure do not occur under design loads.

…several design issues specific to sandwich construction must be considered.

CMH-17 Vol 6 Relevant Sections

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Volume 6, Chapter 4 Design and Analysis of Sandwich Structures

3. The face sheet and core should be stiff enough, and the sandwich should have great enough flatwise tensile and compressive strength, so that wrinkling of either face sheet will not occur under design loads.
4. If dimpling of the face sheets is not permissible and the core is a coarse cellular material (e.g., honeycomb) or of corrugated material, the cell size or corrugation spacing should be small enough so that dimpling of either face sheet into the core spaces will not occur under design loads.
5. The attachment between the core and the face sheets should be strong enough to withstand the chosen design loads. This is typically accomplished by an adhesive layer, but other options include welding or brazing of metallic core and face sheets, or self-adhesive composite face sheet material. The materials and fabrication processes should be selected so that the core, rather than the bond, is the weak link.

The choice of materials, methods of sandwich assembly, and material properties used for design must also be compatible with the expected service conditions. For example, face sheet to core bonding must have sufficient flatwise tensile and shear strength to develop the required sandwich strength in the expected service environment. Included in the service environment are effects of temperature, moisture, corrosive atmosphere or fluids, fatigue, creep and any other condition that may affect material properties.

Another major service issue that must be addressed during design is impact damage. Lightweight sandwich structures have been found to be susceptible to impact damage, and some types of impacts may leave significant damage that is not visible on the surface, so the degraded state of the structure is not apparent to the user. Design of the structure must take this into account through choice of materials, redundant load paths, etc.

Certain additional characteristics, such as thermal conductivity, resistance to surface abrasion, dimensional stability, permeability, and electrical properties of sandwich materials should also be considered in developing a sandwich design for the intended purpose.

Environmental effects, impact damage and redundant load path considerations

Sandwich Failure Modes from Vol 6

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4.4 SANDWICH PANEL FAILURE MODES

Sandwich panels can fail in several ways, each mode giving one constraint on the load bearing capacity of the sandwich. Depending on the geometry of the panel and the loading, different failure modes become more critical and set limits on the performance of the structure. Failure of the sandwich may be driven by the strength of the face sheet, core, or adhesive, by a local instability mode such as face sheet wrinkling or dimpling, or by general instability such as general buckling or shear crimping. These failure modes are illustrated in Figure 4.4(a) and are briefly described as follows:

Face sheet failure occurs when one or both of the face sheets fails by yielding or fracture. The criterion for failure is that the face sheet material exceeds its allowable stress or strain.

Core shear failure occurs when the core fails in shear, usually resulting in cracks inclined at 45 degrees to the midplane. The core material is mainly subjected to shear since it carries almost the entire transverse load, and very little in-plane load. Honeycomb core may fail by cell wall buckling, which may not be visible after load is removed.

Core crushing is when the face sheets move towards each other under the influence of bending or through-thickness loads. This failure mode occurs when the core has insufficient compressive strength.

Core tensile failure occurs when the core has insufficient flatwise tensile strength.

Face sheet-to-core debonding occurs when the face sheet-to-core bond has insufficient shear, peel, or tensile strength.

Local indentation occurs at concentrated loads, such as fittings, corners, and joints. When point loads are applied, the face sheet acts as a plate on an elastic foundation. The loaded face sheet bends independently of the opposite face sheet, and if the stress induced in the core exceeds the core's compressive strength, the core will fail. This failure mode may be avoided by spreading the load over a sufficiently large area.

Face sheet wrinkling is a local instability characterized by buckling of the face sheet, often accompanied by core crushing, core tearing, or face sheet-to-core debonding. This failure is most prevalent with thin face sheets and low density core. One or both face sheets may wrinkle, depending on the loading, materials, and thickness of core and face sheets. Figure 4.4(a) shows the cases where both face sheets are wrinkling, in the symmetric and antisymmetric modes.

Face sheet dimpling*, also known as* ***intracell buckling****,* is a local instability characterized by the buckling of a face sheet into or out of the confines of a single cell. This failure can occur when the face sheets are thin and cell size is large.

General buckling of a sandwich panel resembles the classical buckling of plates or columns. The face sheets and core remain intact in this type of failure.

Shear crimping is an instability that can occur if the wavelength of each buckle is of the same order as the cell size. The crimping phenomenon is characterized by a local core shear failure and the lateral dislocation of the face sheets. Since the wavelengths are so short, shear crimping appears to be a local instability failure, but it is really a form of general instability. This failure mode can occur when the core shear modulus is low.

Each of these failure modes is discussed in more detail in Section 4.6.

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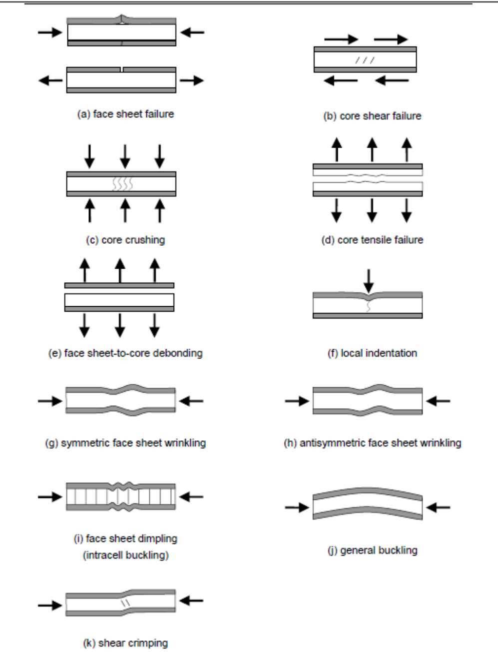


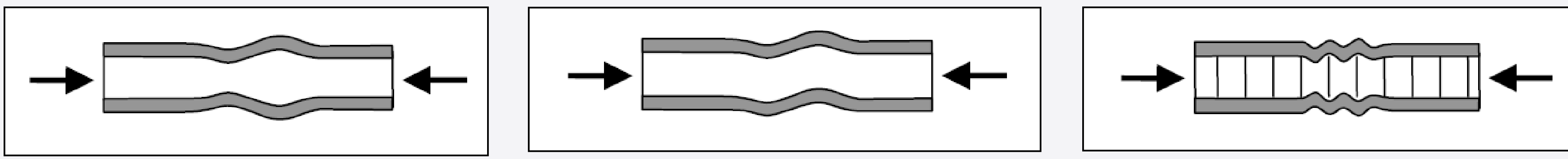
FIGURE 4.4(a). *Sandwich failure modes.*

Section devoted to sandwich unique failure modes

Likely Key Damage Modes for Thin Face Sheets

Need to check for Wrinkling and Dimpling!

– Can be critical for thin face sheets and low density (weak and soft) core material



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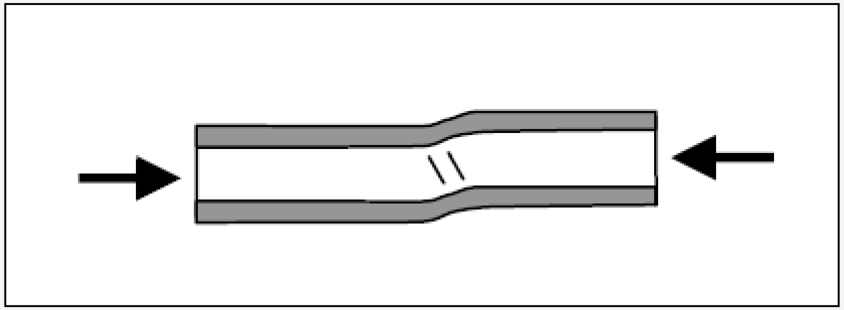
<u>Local</u> instability failure modes typical of <u>thin face sheet</u> sandwich panels

Likely Key Damage Modes for Thick Face Sheets

Need to check for Shear Crimping!

– Can be critical for <u>thick face sheets</u> and low shear modulus core material



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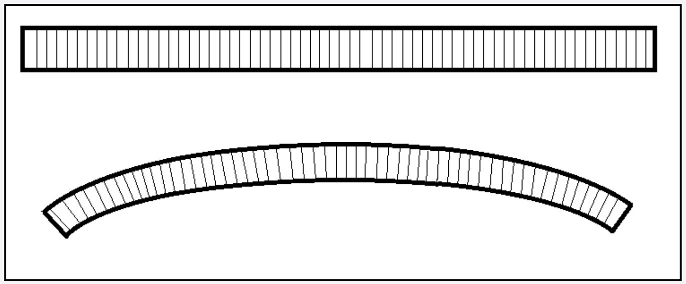
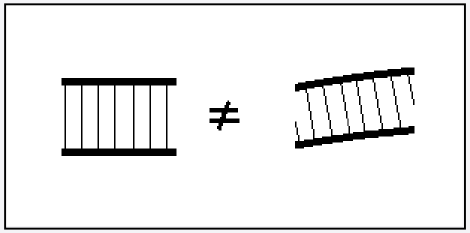
<u>Global</u> instability failure modes typical of <u>thick face sheet</u> sandwich panels

Chapter 5 addresses manufacturing effects on Sandwich Panels as follows:





5.3.1.3 Forming

Metallic honeycomb can be mechanically formed using a brake or rolls. The core surfaces may need to be protected from direct contact with the rollers using a thin sheet.

Some forming for nonmetallic core, such as introducing a complex contour, may be performed by heat forming core that is flexible enough to avoid being damaged by the process. The higher the density of the core, the thinner the sheet of core must be to avoid damage.

Nonmetallic honeycomb core material is commonly heat-formed as described below, where the nominal density does not exceed 6.0 pounds per cubic foot (96 kg/m^3) and the thickness is one inch (25 mm) or less. Additional flexibility for thicker or heavier core sections may be obtained by forming "green" (partially cured) core. Depending on the processing temperature and degree of curvature used, heat-forming may alter the mechanical properties of the core; testing may be required to determine this effect.

<u>Shaped core properties may be significantly different from flat core.</u>

Chapter 2 also addresses environmental effects on Sandwich Panels as follows:

2.6.3 Environmental effects

Environmental conditions, including temperature, moisture and fluids, can affect the strength and stiffness of a sandwich panel. The effects of environment on polymer composite materials are discussed elsewhere in CMH-17, including general discussion in Volume 3 Sections 2.2.4 and 3.4.3, and discussion of testing in Volume 1 Sections 2.2.7 and 6.5. These same effects will be seen when the material is used as a sandwich panel face sheet. The core will also be affected by the same environmental conditions, as will the core-to-face sheet bond. In general, high temperature, moisture, and fluids all degrade the sandwich properties.

Common problems with sandwich structures subjected to temperature and moisture/fluids are those associated with poor core sealing and porous or easily damaged face sheets. Face sheets that have been damaged can provide moisture paths to the core, which then may become degraded. Sandwich panels that are well sealed and with face sheets that are durable and nonporous are typically affected only slightly by environment, similar to the effects on laminate structure.

Repairs of sandwich panels may introduce new intrusion paths for moisture.

Industry Lessons Learned

The following slides provide some examples and lessons learned from industry experience…

Industry Lessons Learned

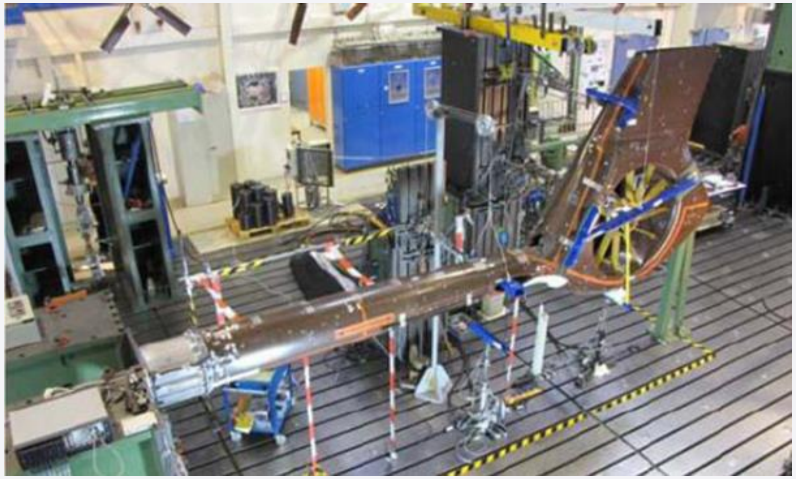
- Hawker 4000 Fuselage Unexpected Failure Mode during Certification Testing
- Post Test Analysis Summary:

Core Shear M.S. = -0.41
Crimping M.S. = -0.60
Dimpling M.S. > 5.00
Compression Wrinkling M.S. = -0.63
Principal Wrinkling M.S. = -0.64
Laminate Fiber M.S. = -0.17
Laminate Transverse M.S. = -0.19
Laminate Shear M.S. = 1.96
Global Stability M.S. = -0.62

Additional Certification Testing and Analyses were Required to Address Failure

Industry Lessons Learned (cont'd)

- Eurocopter presented testing and analyses for composite tail boom structure at a recent CMH-17 meeting
- The discussion was associated with 'lessons learned' in the development (early cert!) Building Block pyramid testing highlighting the importance of understanding shear crimping and the face sheet wrinkling modes (wrt bending, not just compression) for their configuration.
- There was also a thermal contribution to this discussion.



Highlighted sections from Bruhn regarding sandwich unique failure modes

Good Design Practice - GA Composite Fuselage

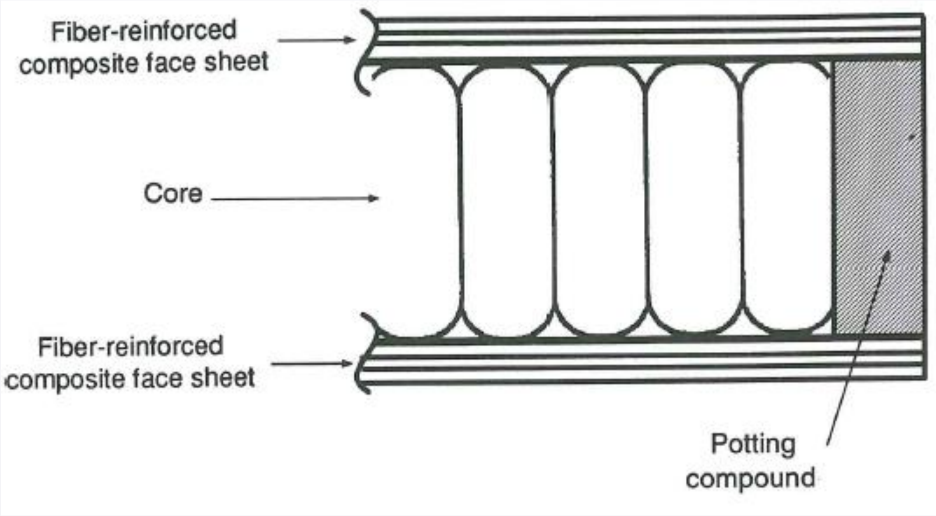
- Arresting Features for Sandwich Panels accomplished by ramping core to edge band configuration of solid laminate for Frame, Longeron and Keel Elements attachment.
- Design cabin to withstand Limit Load with one panel failed and demonstrate arrestment of damage at closeout/attachment to other elements.
- Penetrations best accomplished through solid laminate areas (required core potting and sealing adds significant weight otherwise).

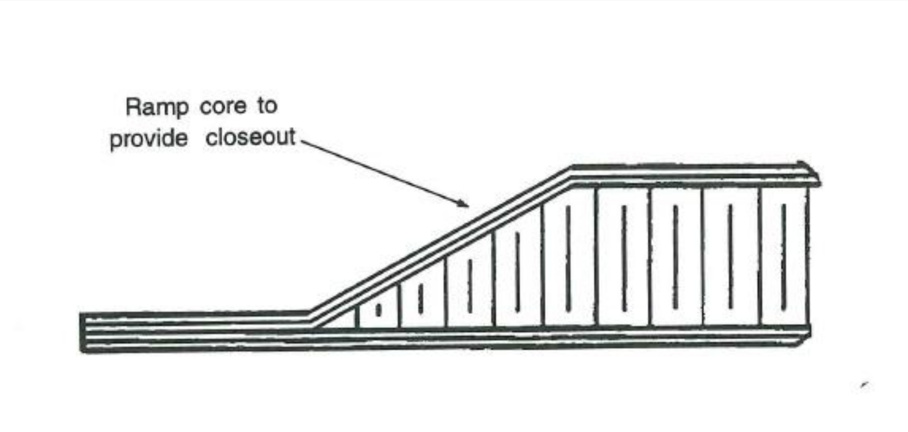
Solid laminate between panels as arresting features. Note redundant fasteners.

Good Design Practice – Sandwich Closeout

- Problem: Square-edged closeout of sandwich panel using potting compound, sealant and/or edge-wrapping with fiberglass have proven inadequate to various degrees.
- Repairs that involve full-depth core replacement are difficult because there is no core to face sheet bond assurance.
- Face sheets must be removed and rebonded for deep contamination.

- Preferred Alternative: Avoid square-edged sandwich closeout.
- Ramped core closeouts provide superior durability.



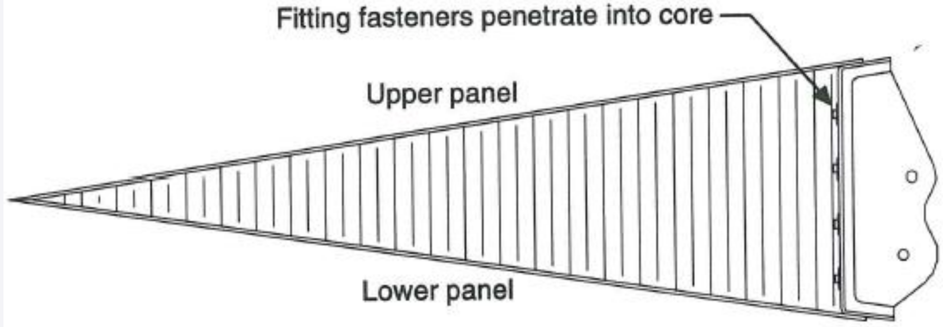


Ref. SAE AE-27, "Design of Durable, Repairable, and Maintainable Aircraft Composites"

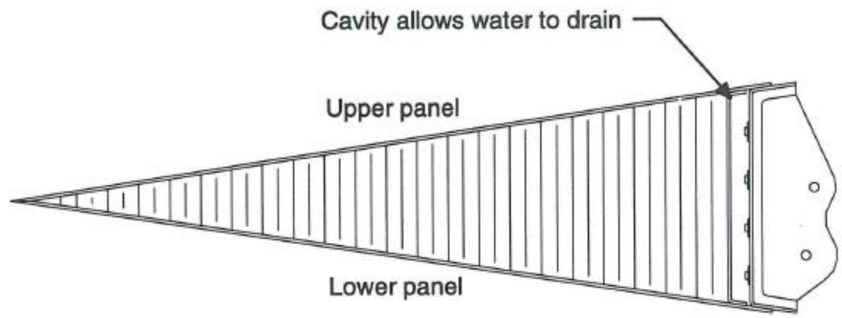
Ramped core closeouts provide a more robust design.

Good Design Practice – Full-Depth Sandwich

- Problem: Fluid ingress is a common problem when full depth core is bonded to face sheets and a "C" channel front spar. Fittings are fastened by penetrations through the "C" channel and provide leak paths into the core. Sealant has been shown to be ineffective as moisture finds its way into the core.



- Preferred Alternative: Avoid fastener penetrations into core areas.
- Terminate and closeout the core locally and provide a cavity to allow drainage of any moisture.



Ref. SAE AE-27, "Design of Durable, Repairable, and Maintainable Aircraft Composites"

Minimize or eliminate penetrations into core areas.

Summary

- CMH-17 Volume 6 addresses sandwich-unique considerations for design and certification
- Industry experience has provided more in-depth understanding of phenomena, cause and effect
- Feedback and assistance from industry and academia (R&D) will be applied to updated documentation and guidance