CMH-17
COMPOSITE MATERIALS HANDBOOK

Manufacture and Maintenance of Sandwich Structure

One Materials & Process Perspective

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Sandwich Core Bonding V6 Ch5

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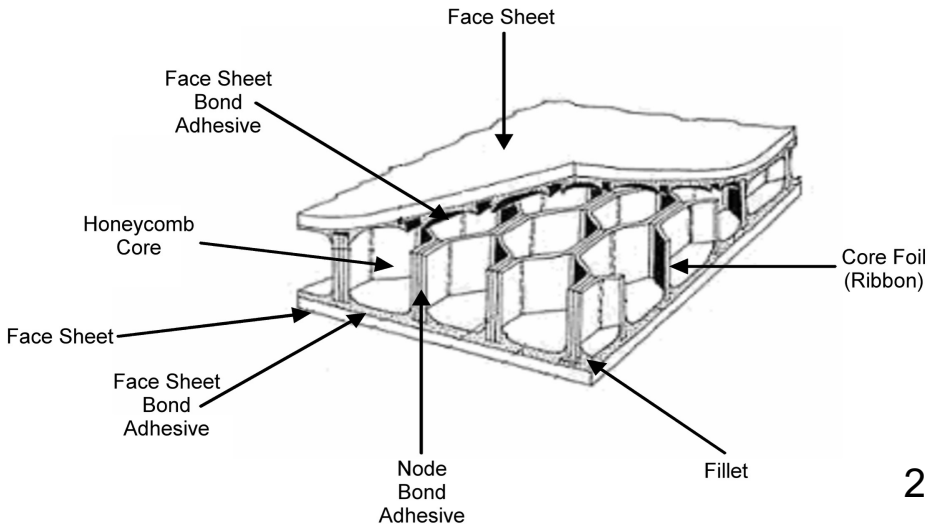
- Most composite structures benefit from bonding – sandwich structure demands it (inherent part of construction)
- At same time, it is the bonded structure type most likely to experience substrate failure first (in the lightweight core), rather than the adhesive (hopefully cohesion not adhesion), or other substrate (if laminate, usually interply) another weird sandwich characteristic came up yesterday – addressed at end
- Attempting to achieve the stiffness to weight advantages that sandwich structure can offer without taking their processing differences into account can result in problems in manufacturing and service, and ultimately increased costs
- "I want to validate the structure with the same design/analysis/inspection/ quality/material variability numbers, just not all the same processes and/or materials" – This is nonsense



Sandwich Structure Manufacturing

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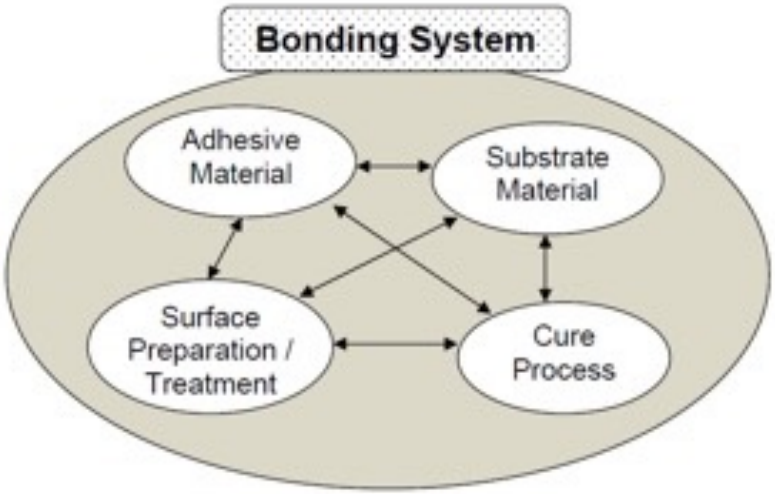
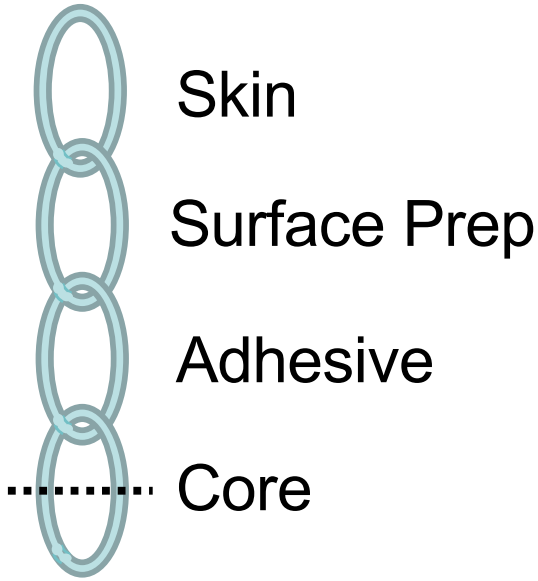
- Sandwich structure has problems when its processing doesn't produce the desired/needed/expected configuration or resulting performance
  - Detectable (& detected) before fielding – mostly a cost issue
  - Not detectable (or successfully detected) before fielding (or damaged in service) – now potentially also a safety issue



Qualified Bonded Systems Approach to Certified Bonded Structure,
Dr. Kay Y. Blohowiak et al, STO-MP-AVT-266



Sandwich Bonding - Process Emphasis

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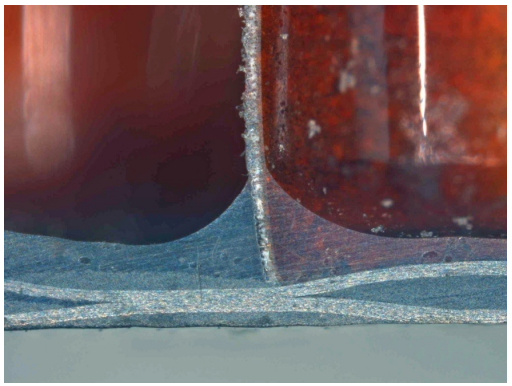
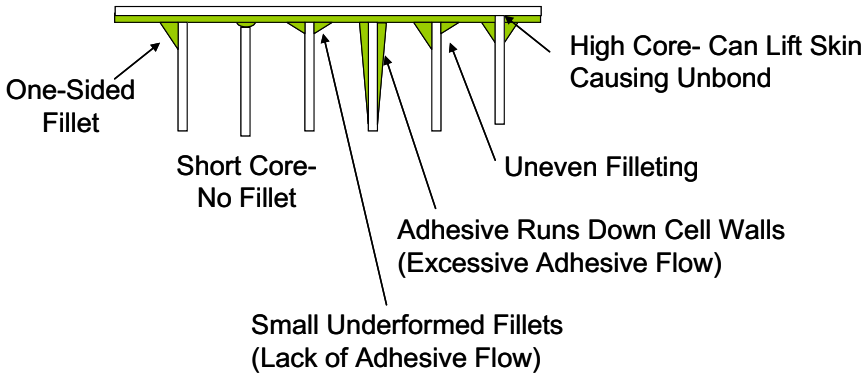
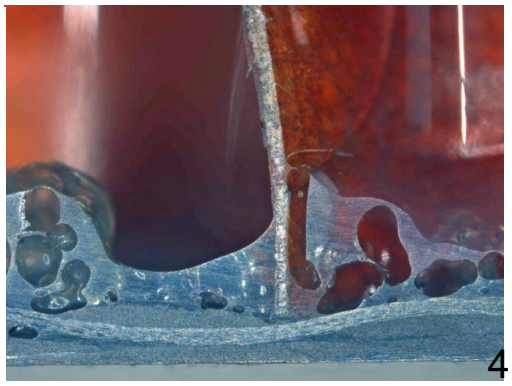
- Honeycomb core bonding – almost all fillet!
  important, yet can only observe in cross section (destructively)
- Since mostly fillets, and very little direct contact with most of adhesive volume, only indirect bond control. So “self-adhesive” prepreg is a tough act
- Materials, design, cure & fabrication processes determine bond quality (e.g., core drying to prevent voids, may need to develop core specific cure cycles)
- With mostly air on one side, what pressure does the adhesive (much less a cobonding skin) really experience during cure? Fillet formation is not a given
- Due to very specific demands, otherwise great adhesives might falter w/ core
- Foaming adhesive bond/splice also must be as good/strong as the core voids!
- Few valid excuses for bond failures outside of relatively low strength core?

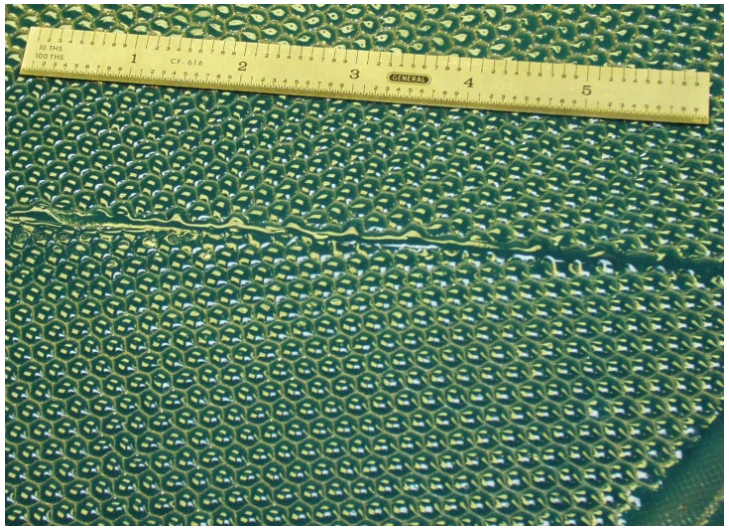






Impression Check – Fitup

- Trying to create 7-thousandths of an inch thick ribbon of adhesive
- Film adhesive can't bridge, expand into excessive gaps or leap across
- Commonly used to check fitup for adequate bonding pressure
- Can buy "Verifilm" product, or place your adhesive between release surfaces
- Verifilm thicknesses may trend with, but not directly correspond to, Bondline Thicknesses (BLTs) measured by cross-section cuts (gold standard)
- Large shifts in bond quality can occur between faying surface interface gaps which can (just barely) be filled by the volume of adhesive applied and gaps that can't dramatic change in cure pressure from tiny change in stackup dimensions from tolerances



Sandwich Failure Modes

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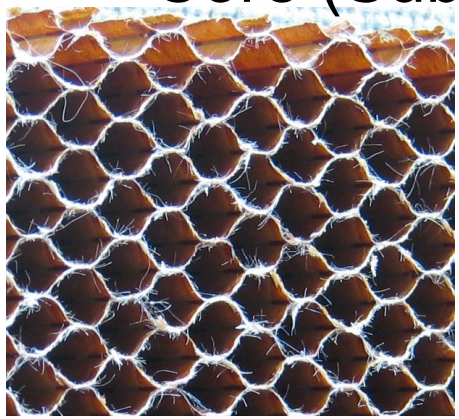
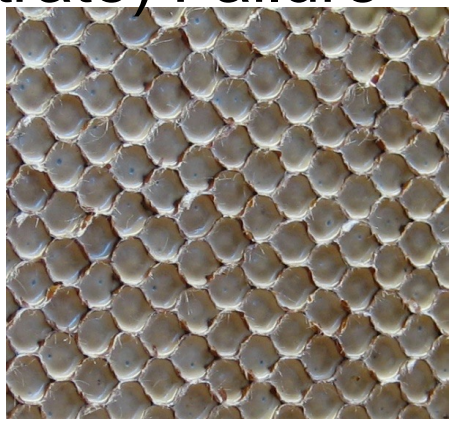
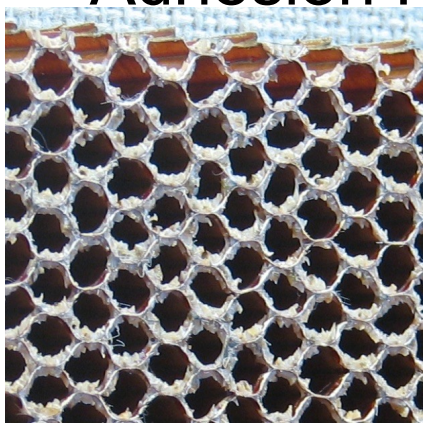
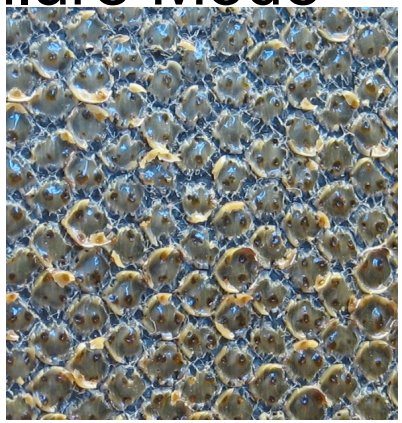
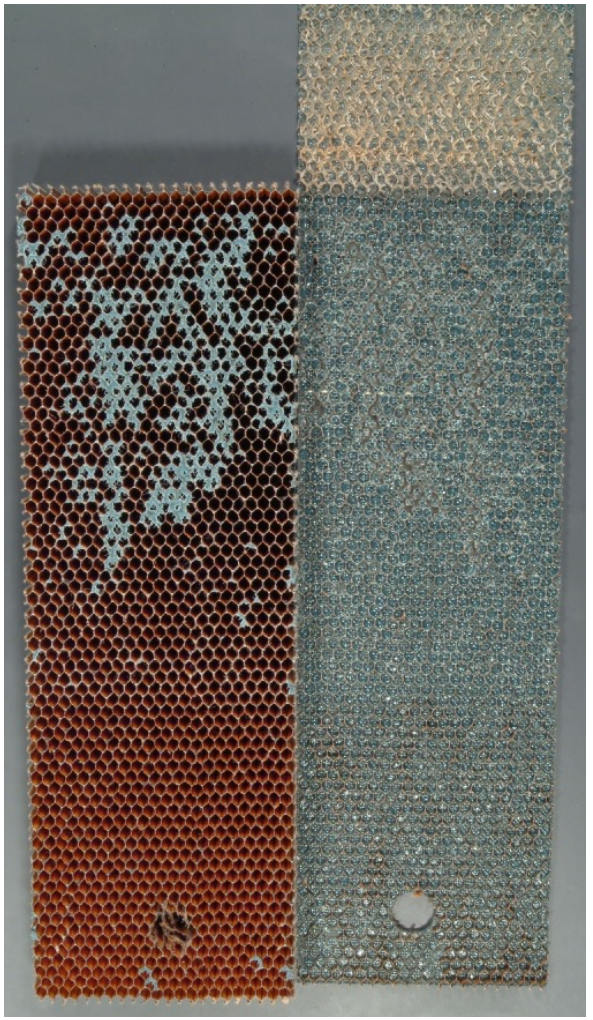
- Bond must be as good/strong as the core (which is 90+% air?)

Core (Substrate) Failure

Adhesion Failure Mode



Core Surface Preparation (Not?)

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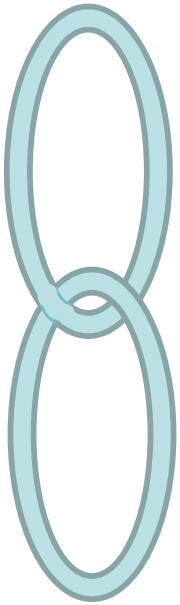
- Most popular – maintain in as-manufactured, uncontaminated, dry condition (by packaging in sealed, moisture-proof film with desiccant)
- Watch out for lower MW unreacted core resin components migrating to surface over time (encouraged with solvent and/or heat exposure cycling?)
  self contaminating
- Cleaning core today is difficult, and not very effective (vapor degrease is hard to still reproduce in an environmentally responsible manner)
- Best to just keep it clean (always good advice!)
- This works if (and only if) we never contaminated the core materials and kept it clean and dry the entire time
- Again, this is usually good enough, because bond just has to be stronger than the core (90+% air?)
- Even if dry core immediately before installation (it's very hygroscopic), any assy delay may have cure effects
- "Wet" core may be a worst case for adhesive pre- and mid-cure moisture exposure altering cure chemistry, in addition to physical quality issues like voids, porosity



“Cocured” Skins – Reduced Resin Pressure

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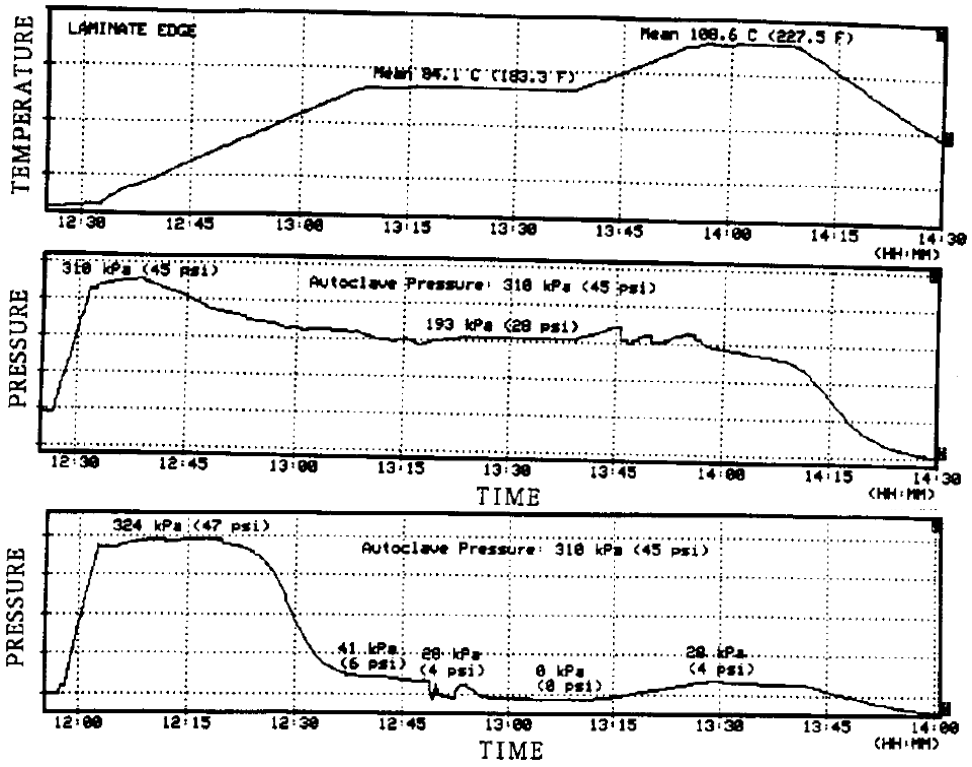
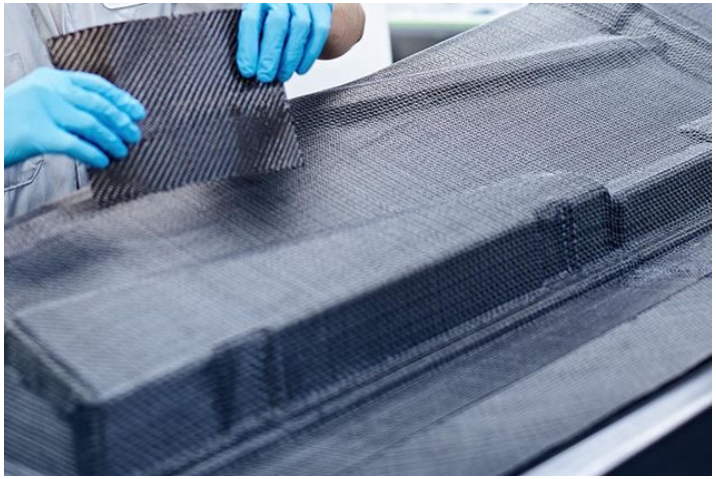
- During sandwich structure skin bonding, what is pushing back again cure vessel applied pressure on skin? Especially critical when curing skins at same time as bonding to core agree that’s cobonding?
- Honeycomb core is +90% air, so very little physical support from core
- Skins during cobond can experience very low resin pressure shows in quality





https://www.rampf-group.com/en-cn/company/rampf-core-competencies/composite-solutions/

Core Crush – Balance of Forces

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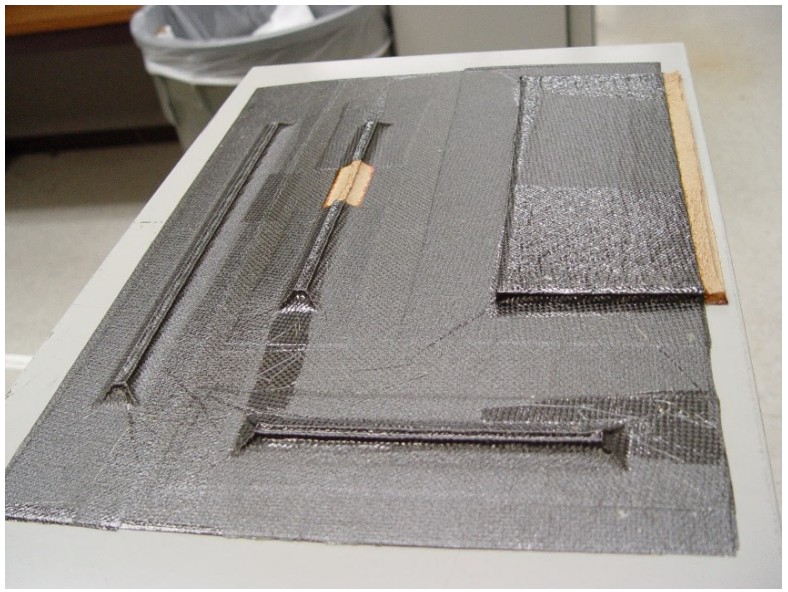
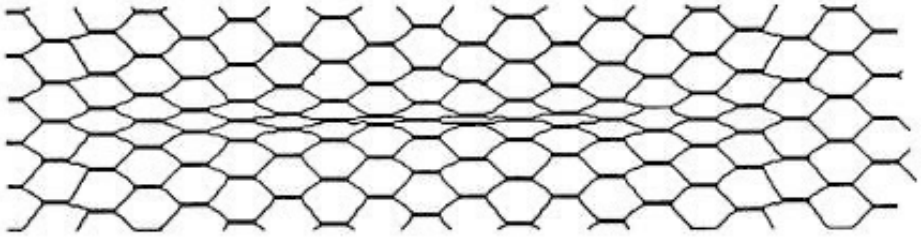
- Actual "crushing" is the least of problems – more core displacement? Core shift? (Slot?) Collapse? Condensing! elastic v deform
- Bonding is (at least potentially) part of the "core crush" picture
- Friction plays a role btwn plies, diff weaves, twist
- A melting layer of film adhesive can be remarkably "slippery" tack strips
- When the skins are precured, only real inelastic "crush" can happen

but not discussed this way





Sandwich Bond Mfr Advantages

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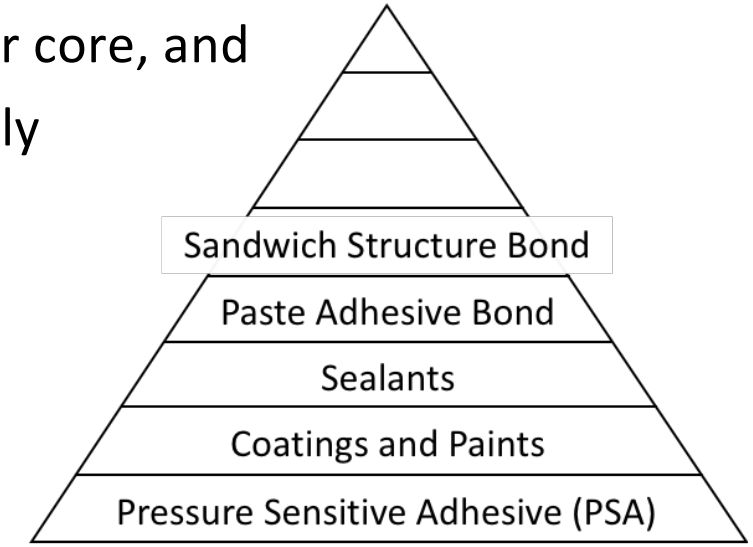
- While there are no (few?) excuses for an adhesion failure mode with sandwich composite structures…
- Commonly no real surface preparation for bond just keep clean & dry, more later
- Sandwich construction is one of the few areas where bond system constituents can be characterized more directly & aggressively
- Adhesive intended for sandwich (or even composite) bonding - qualification, receiving inspection & in-process testing:
  - Test (bond system) at least with heavier core, and
  - Some non-core coupons may be partially or entirely metal-to-metal to stress the adhesive higher than the composite interlaminar strength or core ever could



Maintenance M&P Issues

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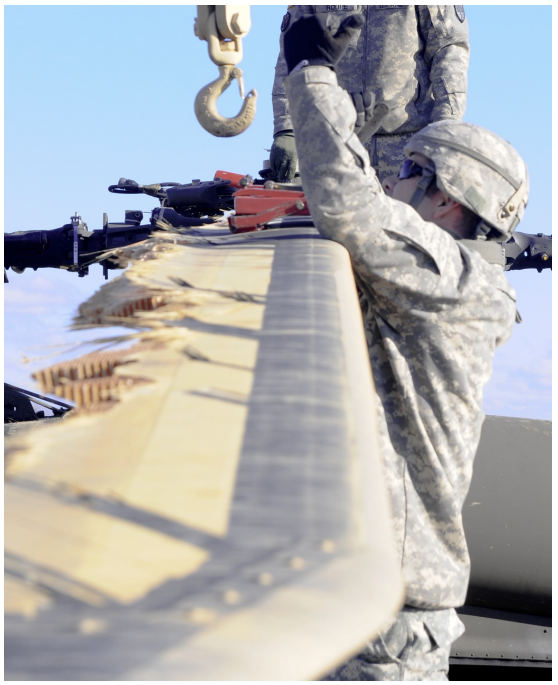
- Early aerospace applications of composites fielded in 70-80s with little (or no) supportability challenged maintenance
- Successful application of SW structure means operator gets weight and other advantages, and can cost effectively support field use
- Composite and Bonded structure maintenance tasks
  - Identify “potential” presence of damage
  - Confirm, characterize and bound damage
  - Disposition (Allowed, Repair, Replace)
  - Verification of completed repair



Identify Presence of Damage

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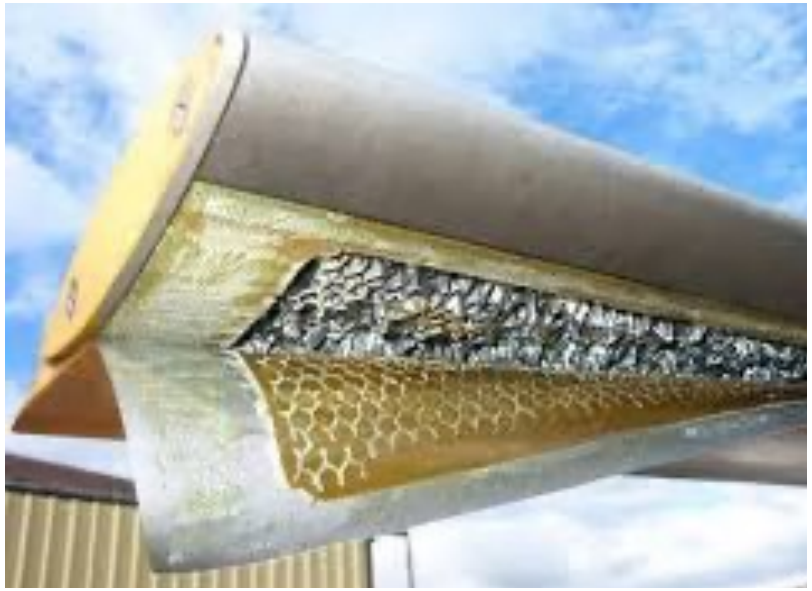
- This field support issue starts with design
- Damage that matters should be visible under normal operating conditions - Barely Visible Impact Damage clearly
- Little instruction or training should be necessary to flag potential damage Do not discount the power of visual inspection
- Walkaround, followed up with spot/side lighting? Slight magnification?
- How many times could it be reasonably be missed: on average, ever?



Characterize and Bound Damage

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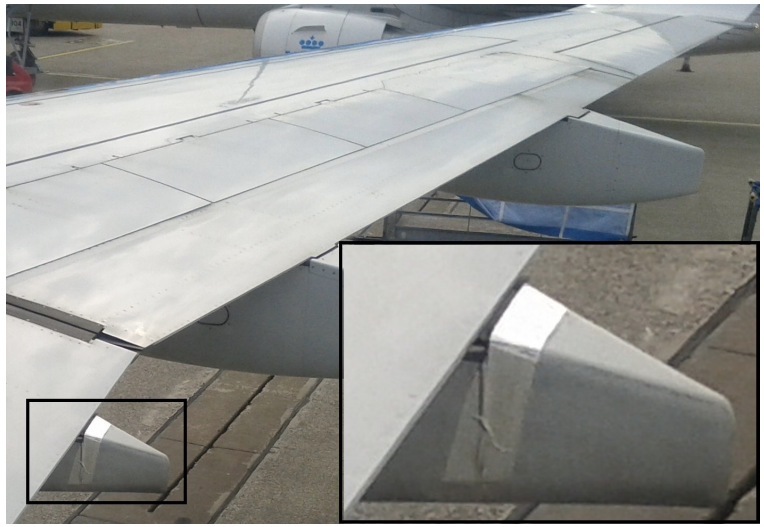
- Same visual inspection used to identify presence of potential damage rarely sufficient to confirm/characterize/bound
- Tap test can give useful feedback; often not (rarely?) actionable info alone
- Everything else is instrumented (UT, resonance, Xray, -ographies)
  - Documented inspection procedures and accept/reject criteria
  - Level I NDI inspectors have hundreds of hours of training and experience to perform documented procedures with clearly defined criteria
  - Procedures developed by NDI Level IIIs have thousands of hours of training and experience
  - Criteria developed in collaboration with Design, Stress, M&P and others
- Many conditions too rare to already have established procedures and criteria - assessor
- Need to field with established procedures/ criteria for most likely 60-80% of occurrences to free up time for the exceptional cases

Disposition - Allowed

- Allowable or acceptable conditions (Use as Is)
  need documented criteria or they get moved to repair or replace
- Allowable criteria often only one step above initial visual observation, perhaps use slight magnification, a scale, and/or (side?) light
- Document “allowed” conditions to avoid repeated discovery and disposition of same artifact
  - May require reinspection –
    one time or recurring
  - Accommodation may be temporary, to prevent further damage, and/or cosmetic



Disposition - Replace

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- Avoid accepting replace plan with no further investigation
- Example: Maybe a door and only need to remove the hinge pin(s) – okay, looks like a good candidate
- But maybe the damaged composite or bonded part is so integrated with electrical and hydraulic lines that remove and replace would cost 10-100x what a repair would cost
- Even if a good remove and replace candidate, what are the (real) life cycle costs of manufacturing, storing, & transporting spares, AoG while acquiring spare, and only then installing a replacement, over the lifetime of the airframe?
- Even remove and replace may require significant training, experience or resources

Repair Challenges

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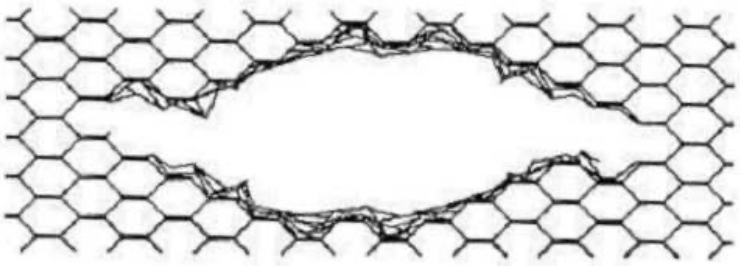
- Instrumented inspections may still not give you all the info you need to do a repair well, like:
  - How far does moisture extend through core surrounding detected “damage”?
  - Are composite substrates intended for bonded repair covered (or saturated) with contamination (e.g., fuel, hydraulic fluid, deicing)? difficult to remediate
- Existing fielded part core & replacement core detail moisture issues
  - Pre-bond moisture absorption can significantly affect adhesive properties (wet core effects, absorption by adhesive, physical and chemical/mechanical effects)
  - Even if core detail dried immediately before installation, any assembly delay (or field storage) may have moisture cure effects (non-metallic core very hygroscopic)
- Repair attempt can create more damage than was originally found (e.g., wet core turning to blown core during cure cycle)
  Steam pressure of moisture in core, fluid or absorbed



Paste Adhesive (2-part)

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- Sandwich structures usually incorporate paste adhesive in manufacture for inserts, edge fill/closeouts, hard points
- Using scrims with paste for bondline control is a process challenge
- Paste adhesive exhibits continually changing viscosity during application and cure
- Paste adhesive can be (and is) applied to what would otherwise be higher level bonding, but more difficult material application and control increases level of difficulty (and necessary skills) considerably

Laminating Resin (2-part)

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- Wet layup of composite repairs
- Application to vertical or overhead surfaces can be challenging
- “Certain amine-cured epoxy paste adhesives can be adversely affected by “amine blush” when exposed to the air (carbon dioxide) in low-temperature, high-humidity conditions and must have their surfaces physically disturbed prior to mating of adherends to prevent reduced bond strength.” Mazza

Foaming Adhesive

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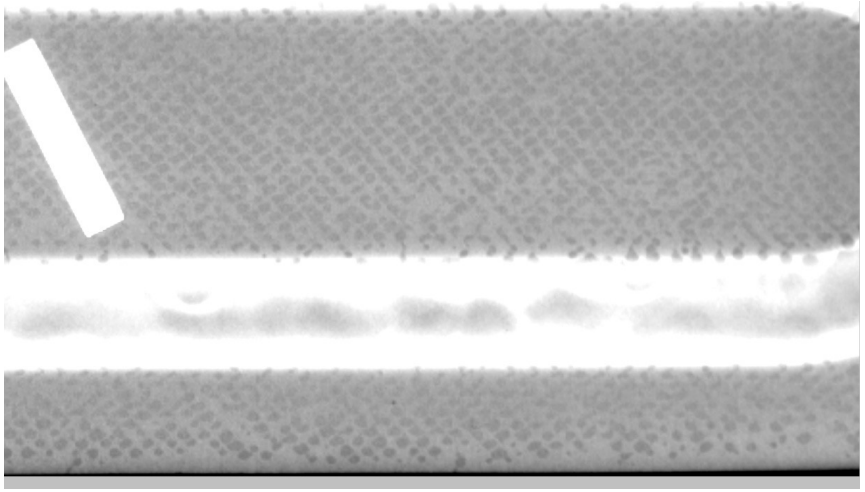
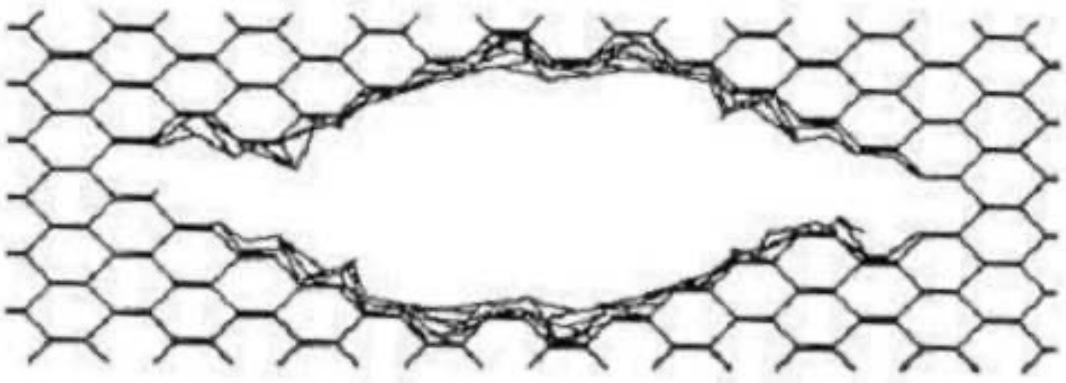
- Used to splice (and repair) core
- Less demanding than paste adhesive bond, so product is made lighter
- Bonds to cell walls
- Needs porosity inspection criteria – “There are voids in my foaming adhesive!”
- Repair may substitute paste adhesive – heavier but easier to deal with in field



Quick Aside - Heat Guns

- Potential for causing tremendous damage, quickly, unintentionally, & perhaps un-inspectable, especially for sandwich structure
- Sight in any ~~bond~~ room should demand immediate attention handful of operators allowed, 200°F ctl
  - Temperature controls? 1000°F will be abused, never prod
  - Operator training & experience?
  - Valid application? Documentation?



https://commons.wikimedia.org/wiki/File:553_CMMXS_160725-F-VV898-018.jpg

Sandwich Repair Challenges

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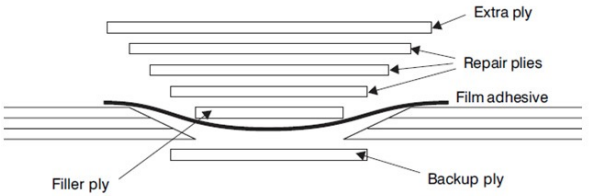
- Identical manufacturing requirements and criteria, but …
  - Substrates soaked in contaminants for years?
  - Limited environmental controls (or none)
  - Reduced or incomplete training, if any
  - Poorer material handling & storage, extended storage periods
  - Few good surface preparation options
  - Crude cure cycle control (especially pressure)
    Kaman blade fixture
  - Difficult tooling, NDI/quality options
    great people doing best they can with tools and resources (not) provided
- Too much repair happens because the damaged part is too expensive to scrap, and/or too time consuming to replace, not because it's the preferred approach
- Repair increases the difficulty level for every process step
- Repair feedback rarely gets back to people who need to hear it



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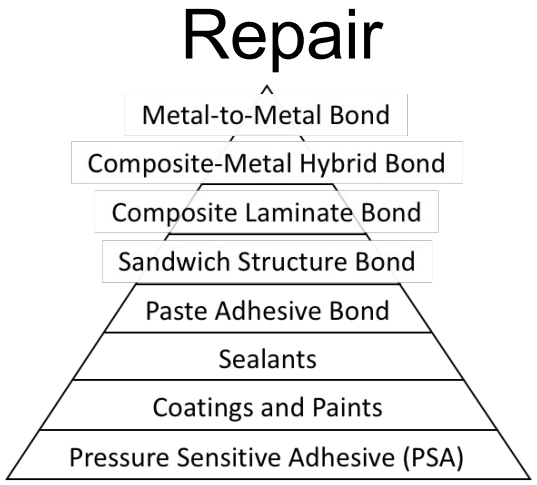

Process and Configuration Drift

- We do a very good job with original qualification & dealing w the entire bond system, although that process can be expensive, and the potential for (budget and schedule shredding) surprises remains. Just means that we successfully rooted out critical issues
- Opinion: only very rarely are (sandwich) bonded structure field failures for the originally qualified structures with absolutely no changes
- I would very much like to hear more about any ~~bonded~~ sandwich structure field failures for structures with no changes (intentional or not) since qualification

Sandwich Breakthroughs Yesterday

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- #1 When adhesive cures against aramid core, the process is "not cocure" (also true for already solid foam cores?)
- The aramid core is already a solid substrate which cannot dissolve or encapsulate any appreciable amount of (liquid) contaminant (like a layer a curing prepreg might) – BUT… weirdly
- #2 Aramid core does not routinely require surface preparation for bonding, only (ideally) "do no harm"
- Restating "Do No Harm" - If the as manufactured aramid core is not subsequently contaminated (including excessive moisture), then no actual surface preparation processing for bonding is required (?!) also true already solid foam core? Preserving isn't preparation
- What other substrate do we (structurally) bond to that routinely requires NO surface preparation for bonding? Best practice - unseal and immediately layup "clean core"?
- #3? When a prepreg skin cures against a layer of film adhesive which is at the same time curing against an (also curing) layer of syntactic foam core, that core cure process is "definitely cocure" (True? Accepted by the room?)
- The rest of Steve Ward's "Dirty Baker's Dozen" of core cure process variations are something in-between the above and "cobond" (?) not to be resolved today

Maybe Related to Core “Do No Harm”

- Core cutting (or other abrasive shaping) creates numerous particulates; problematic for a “clean room” used for bonding or even laminating (CCA, CFAB room)
- Usually necessitates that the core forming process be moved to a “dirty” clean room others – abrasive surf prep, bond primer application room
- A “dirty” clean room does not mean all (other, potential) contaminants are allowed free reign – only the one contaminant (e.g., core dust) the “dirty” clean room is designed to accommodate and then remediate
- Turning smart people in a room telling their stories into knowledge!

TG2 - Fabrication of SW Structure

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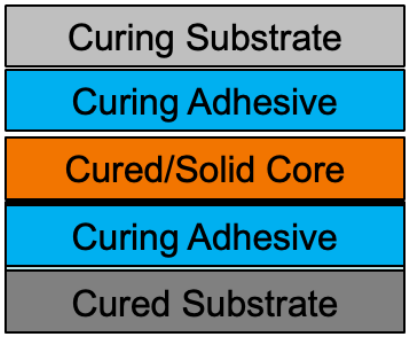
- V6 Chapters 4 and 5 primarily M&P Content
  - Materials (cores, face sheets, adhesives, surfaces and sealing)
  - Processes (core, adh, face sheet cocure vs. precure & resin pressure)
  - Honeycomb Core Crush (cure cycles, physics, stabilization, material characteristics, QC incl NDI)
- Cocure/cobond => 13 variants (skin-3, core cure-2, adh-3)
  - Describing final assembly configuration, or each cure?
  - If bonding is more challenging than laminating, then info about bonding (cobond) more critical (cocure)
- Core crush mostly about friction (weave, matrix, adh, core)
  - Elastic (displacement?) v Inelastic (crush?)
  - Forces on core detail (areas, angles, pressure)
- QC (specs, testing, NDI, SPC, chg mgmt.) – New NDI content



"Cobonded"?