INTRODUCTION TO REPAIR OF COMPOSITE STUCTURES

CO-HOSTED BY:

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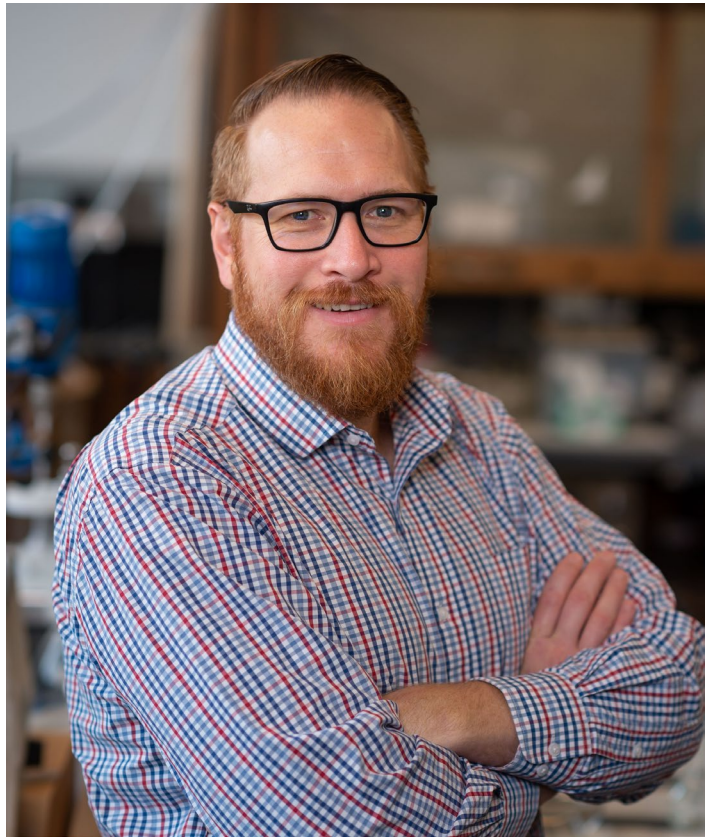
YOUR HOST



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- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Over 15 years experience in industry and academia working on polymer matrix composites in aerospace, automotive, marine, energy, recreation and others
- Experience working with over 150 companies from SME to major international corporations
- Expertise in liquid composite moulding and thermal management

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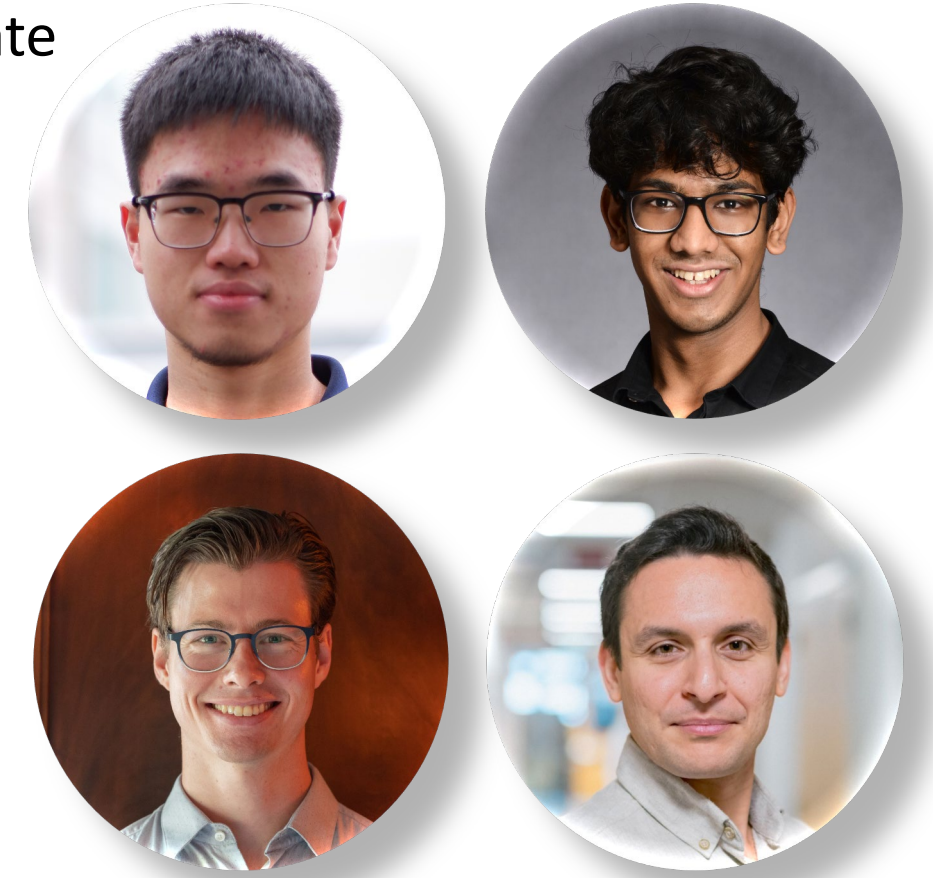
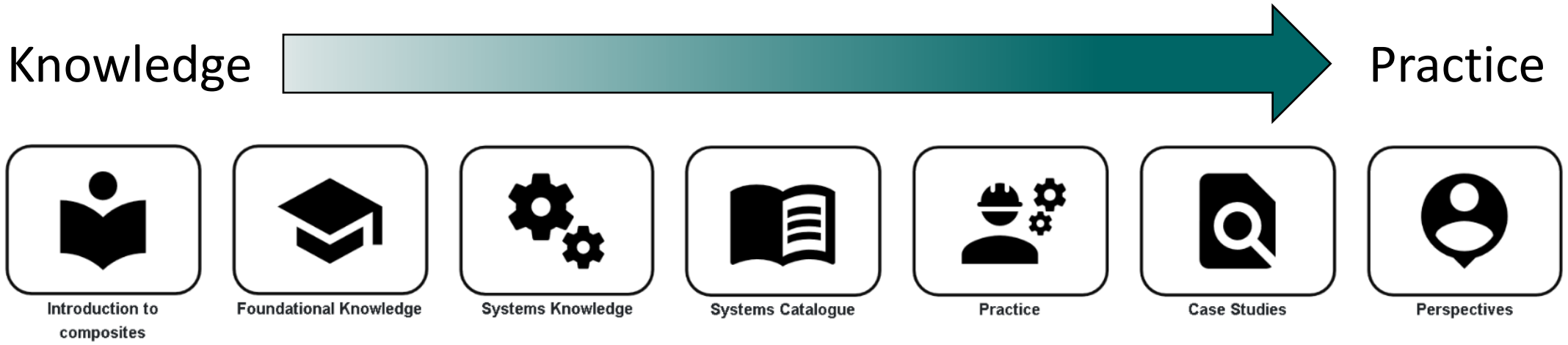


KNOWLEDGE IN PRACTICE CENTRE (KPC)

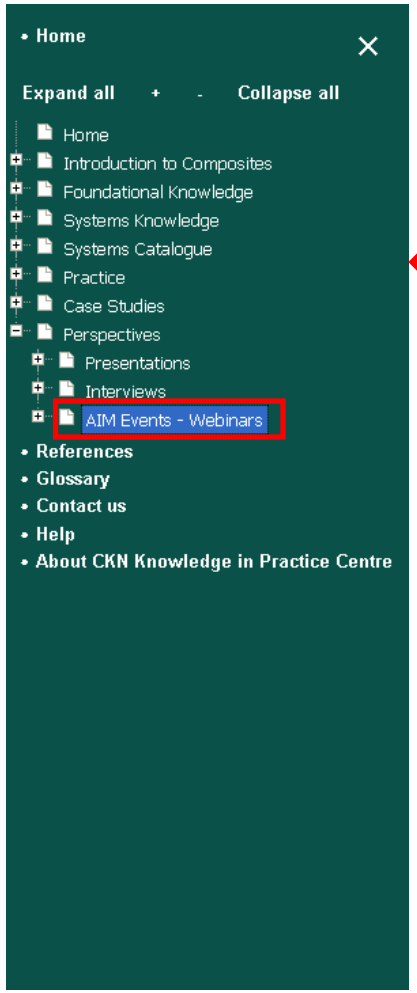
- A freely available online resource for composite materials engineering:

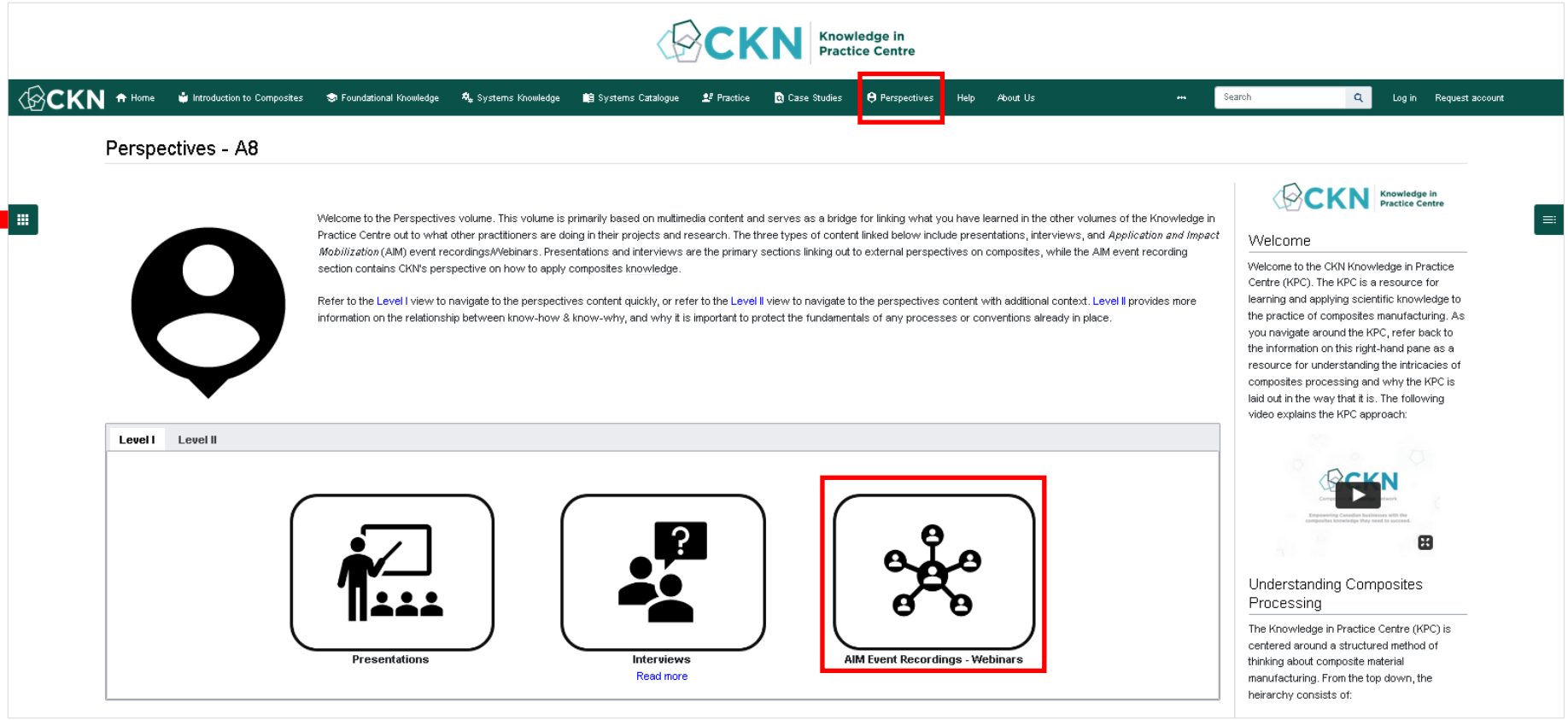
compositeskn.org/KPC

- 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/A365

TODAY'S TOPIC:

INTRODUCTION TO REPAIR OF COMPOSITE STRUCTURES

OUTLINE

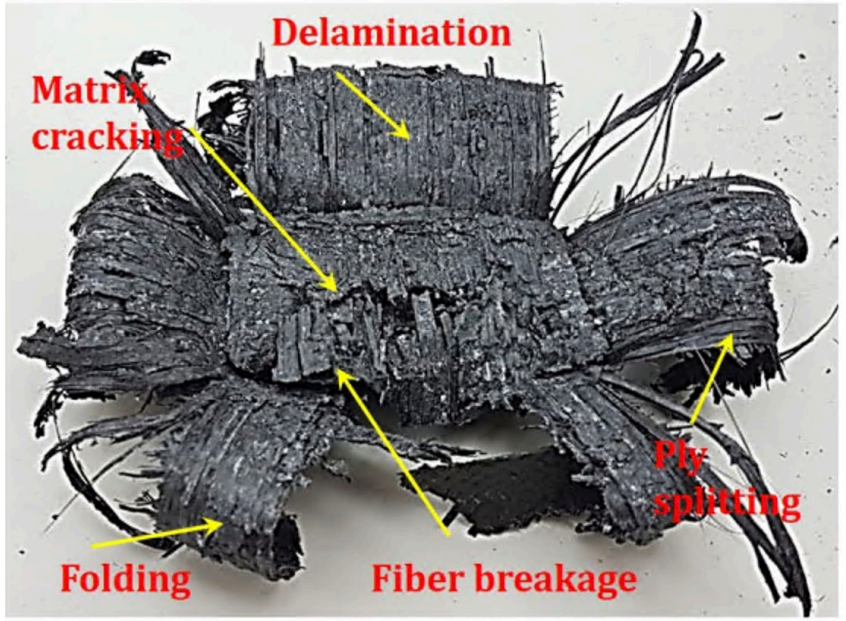
- Types of damage in composites
- Classification of damage
- Repair vs. replace
- Repair workflow
- Damage assessment
- Repair types and methods
- Defects
- Validation and certification

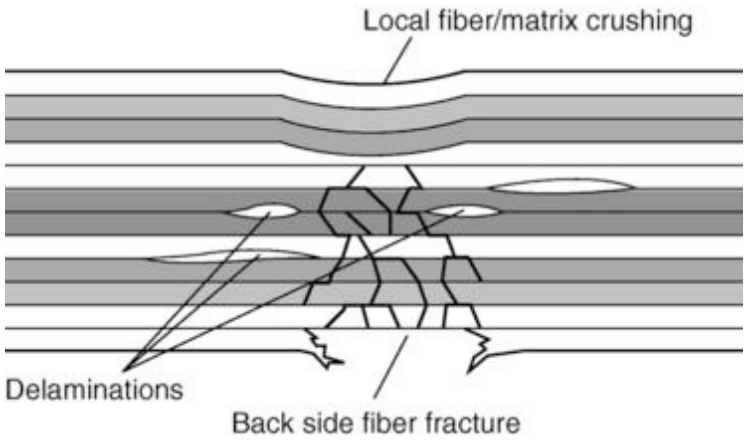
TYPES OF DAMAGE IN A COMPOSITE

- Damage of composite materials is complex
- Generalized damage types[1]:
  - Surface scratch
  - Matrix cracking
  - Fiber fracture
  - Delamination
    - Surface
    - Edge
    - Deep

- More info on damage:
  - Failure of Composites AIM Event Webinar: https://compositeskn.org/KPC/A129

[1]

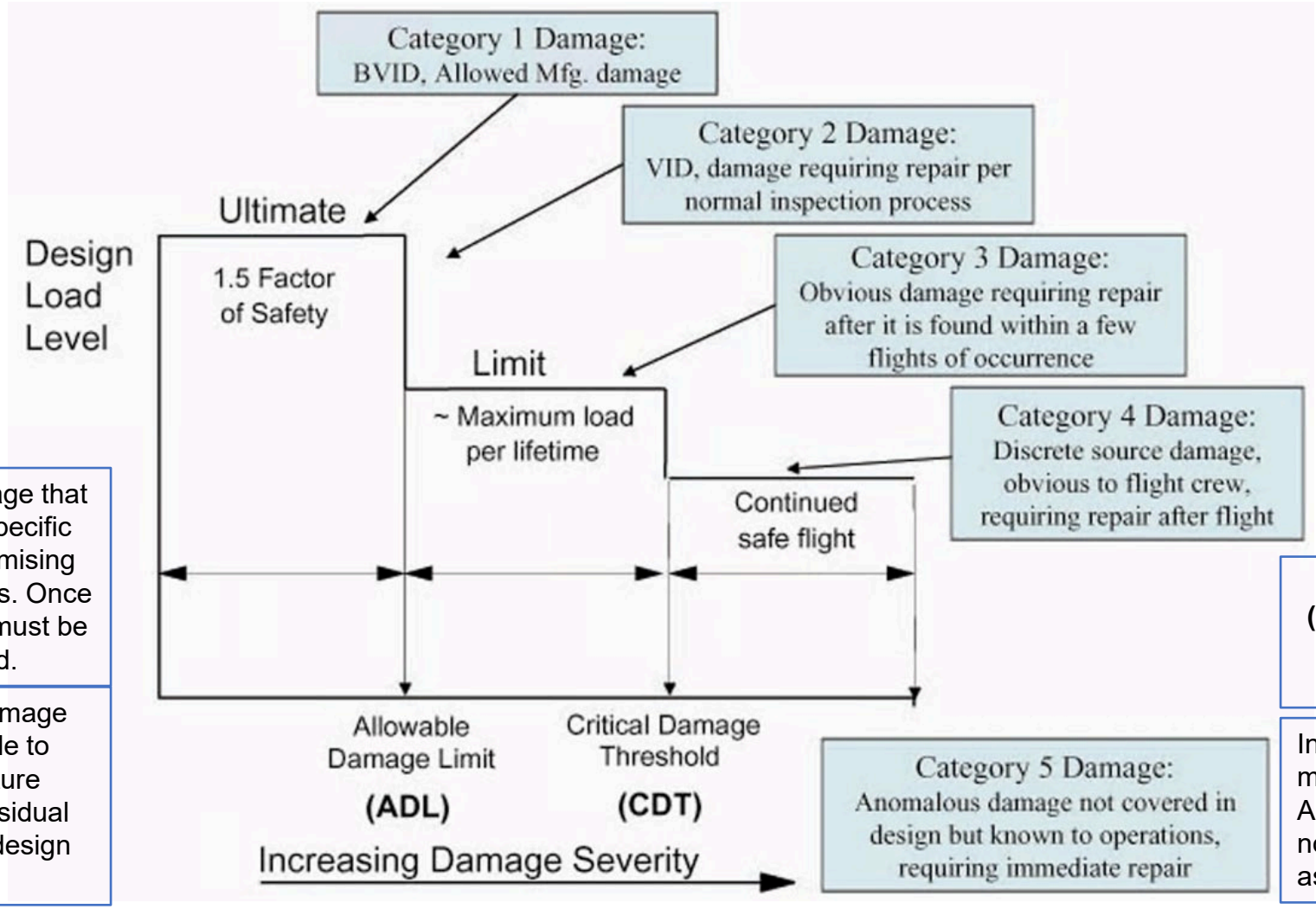




Medium-energy impact damage [2]

[1] Sebaey, Tamer A. "Effect of exposure temperature on the crashworthiness of carbon/epoxy composite rectangular tubes under quasi-static compression." Polymers 12.9 (2020): 2028.
[2] ASM Handbook Vol 21 Repair Applications, Quality Control, and Inspection

REGULATORY DAMAGE CATEGORIES (AVIATION)



(ADL): The level of damage that can be sustained at a specific location without compromising load-bearing requirements. Once exceeded, the structure must be repaired or replaced.

(CDT): "The state of damage that must be detectable to ensure that the structure possesses adequate residual strength to sustain the design limit loads" [1]

Repairable Damage Limit (RDL): the level of damage that can be repaired (has to be replaced after reaching RDL)

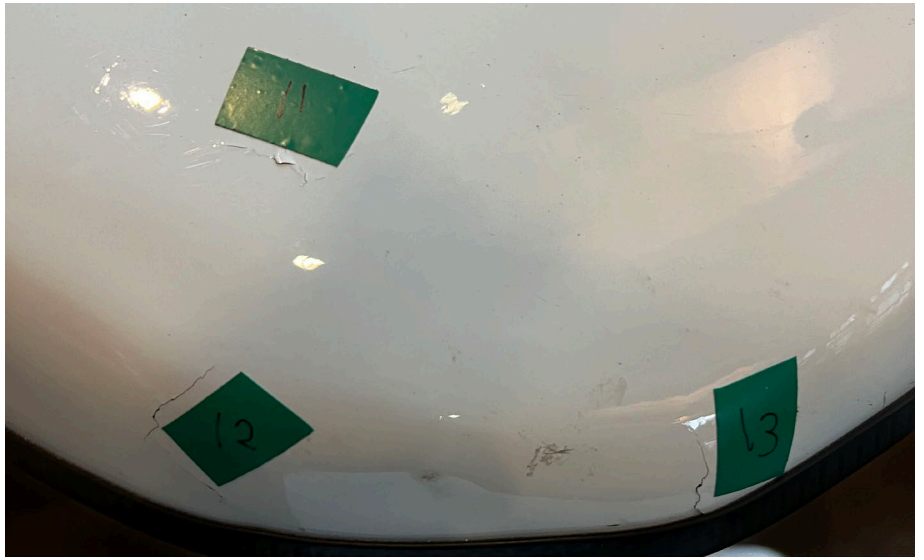
In civil aviation, structural repair manuals (SRMs) usually contain ADL, CDT, and RDL. Damages not addressed in SRMs are to be assessed by aircraft OEM.

Categories of damage defined in FAA AC No: 20-107B

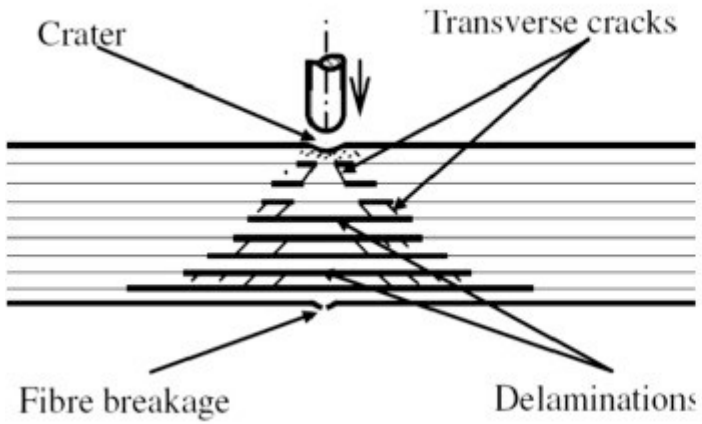
[1] Harris, C. E., Starnes, J. H., & Shuart, M. J. (2003). *Advanced Durability and Damage Tolerance Design and Analysis Methods for Composite Structures: Lessons Learned from NASA Technology Development Programs* (L–18297). https://ntrs.nasa.gov/citations/20030059016

BARELY VISIBLE IMPACT DAMAGE (BVID)

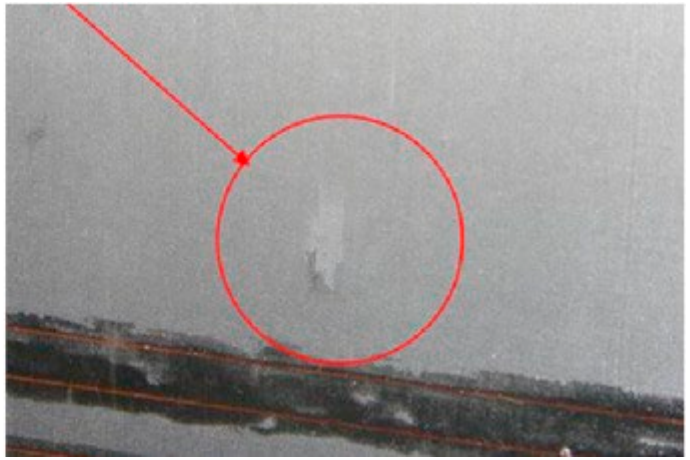
- Usually result of low velocity impacts (e.g. dropped tools, debris)
- Hard to notice by visual inspection, but may be extensive under the surface

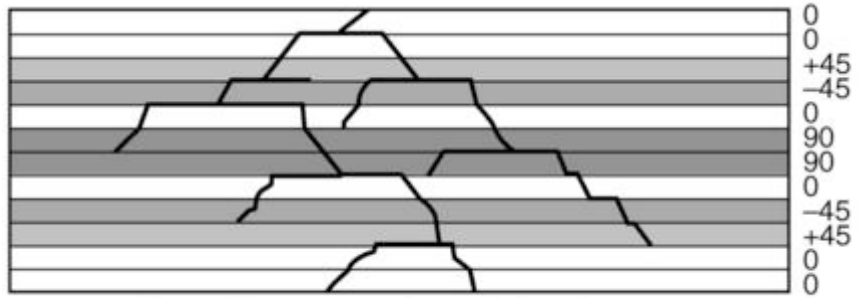


BVID can appear as small cracks on the surface
(courtesy of UBC Supermileage)



[1]





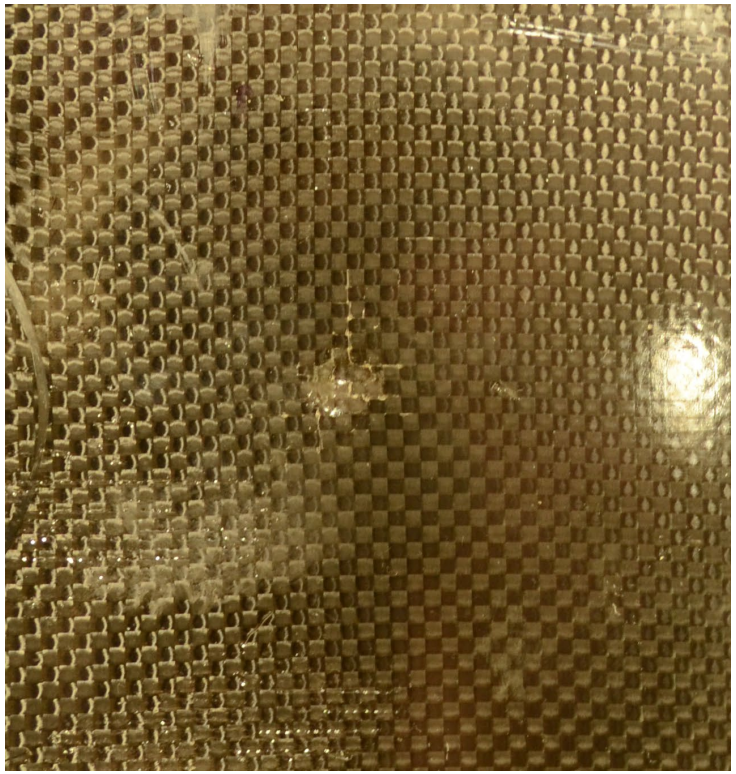
Pyramid pattern matrix crack from impact

[2]

[1] Giurgiutiu, V. (2018). 7.19 Smart Materials and Health Monitoring of Composites. In P. W. R. Beaumont & C. H. Zweben (Eds.), *Comprehensive Composite Materials II* (pp. 364–381).
[2] ASM Handbook Vol 21 Repair Applications, Quality Control, and Inspection

BARELY VISIBLE IMPACT DAMAGE (BVID)

GFRP Sample

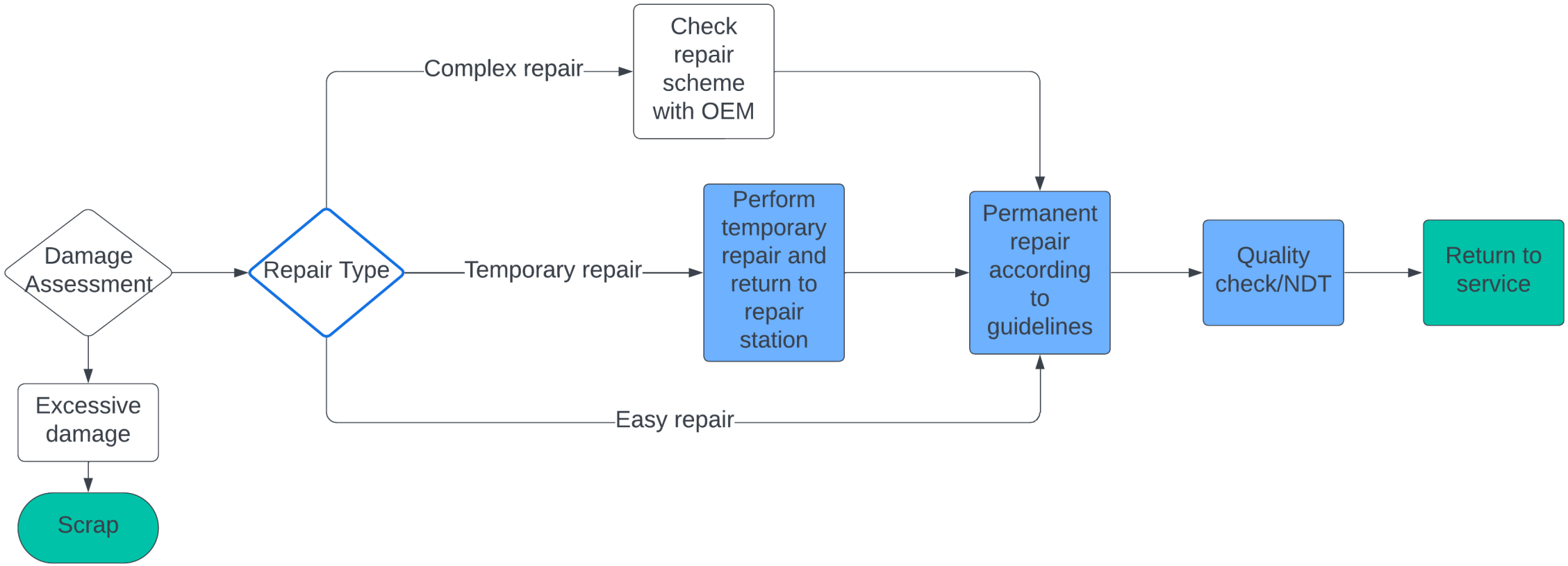


CFRP Sample

REPAIR VS REPLACEMENT

- Possible reasons for repair:
  - Repairs may be more economical/available than replacements
  - Lead times may make repairs more appropriate than replacement
- Possible reasons for replacement:
  - Lack of inspection capabilities to ensure repair quality
  - Lack of personnel/equipment to repair
  - Repair would be too complex/time-consuming
- Facility/personnel may affect the assessment/repair capabilities
  - Field vs repair station vs manufacturer facility
  - Field repairs might be temporary before a more permanent solution

EXAMPLE REPAIR WORKFLOW[1]

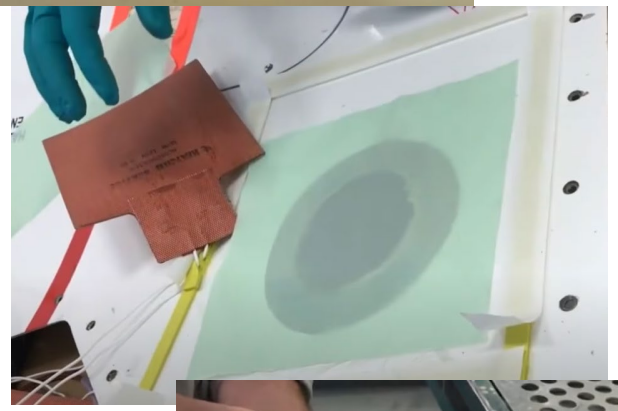


[1] Adopted from https://www.hexcel.com/user_area/content_media/raw/Composite_Repair.pdf

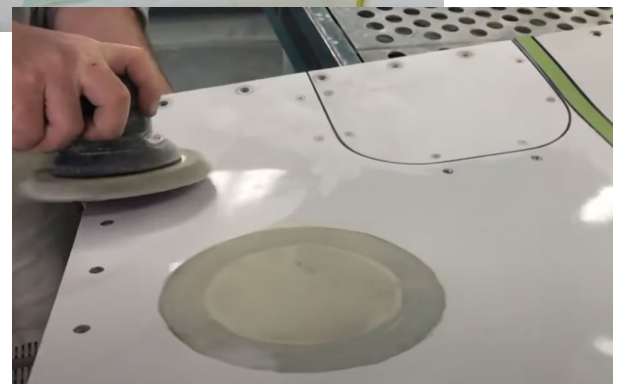
STEPS OF REPAIR

- A repair typically follows these steps:
  - Damage assessment
  - Damage removal and surface preparatio
  - Perform repair
  - Restore surface finish
  - Repair validation and certification
- Note: repairs are specific to the damaged structure and determined on a case-by-case basis

Damage removal



Complete repair



Surface restoration

https://www.youtube.com/watch?v=qqVwszm4Eq8

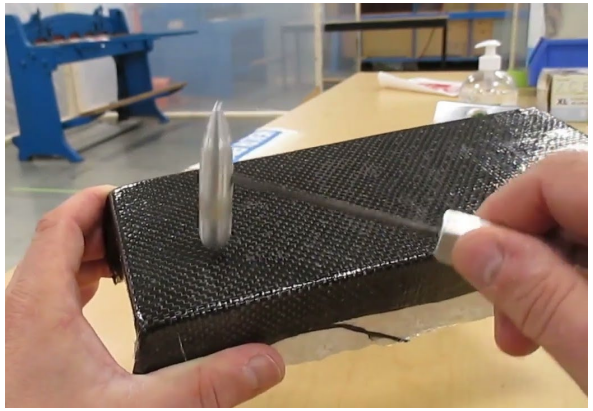
DAMAGE ASSESSMENT

- Non-Destructive Inspection (NDI) is typically used
- Need to identify both internal and external damages

- Factors to consider when choosing testing method[1]:
  - Time required
  - Result accuracy
  - Accessibility of part
  - Type of damage you're looking for
  - Efficiency
  - Cost
  - Safety

[1]: https://www.sciencedirect.com/science/article/pii/S2452321616000093

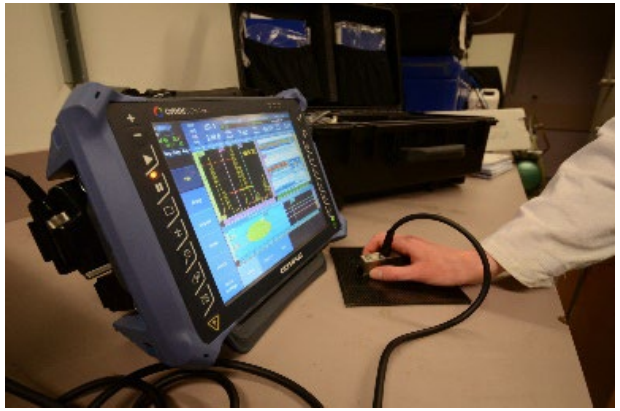
NON-DESTRUCTIVE INSPECTION – METHODS


[1]

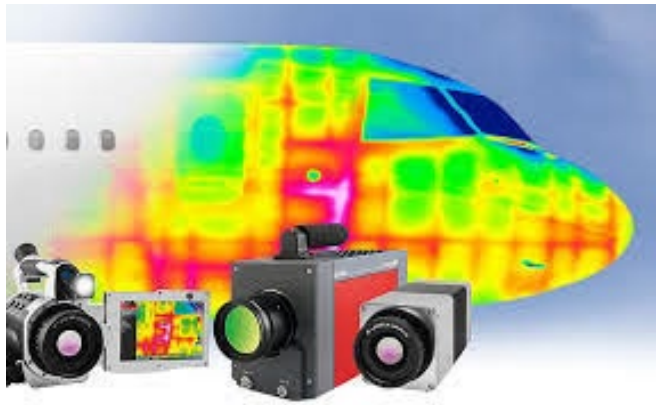
Tap


[2]

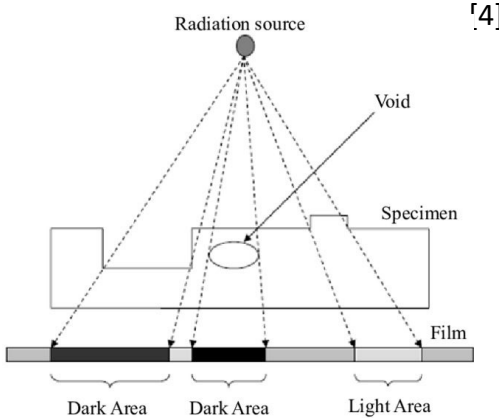
Visual



Ultrasound


[3]

Thermography



[4]

Radiography

Join us on May 29th for AIM Event

Non-Destructive Inspection!

Posted on A366

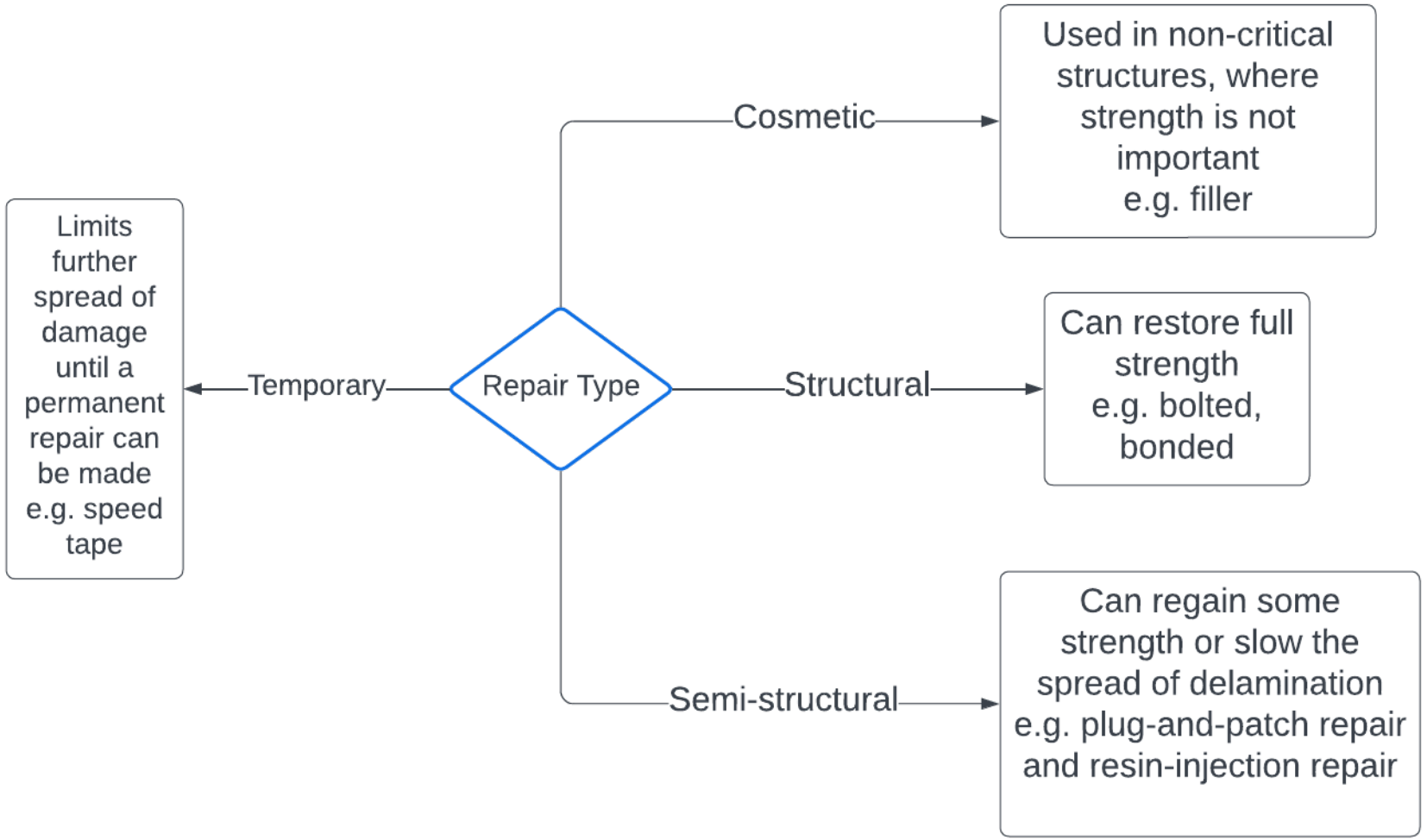
[1]: https://www.youtube.com/watch?v=VgrMJK9DZLY
[2]: https://datumlimited.com/services/advanced-composite-manufacturing/
[3]: https://www.infratec-infrared.com/press/press-releases/details/2015-11-17-non-destructive-testing-of-cfrp-components/
[4]: https://www.researchgate.net/publication/276492796_Higher-Order_Statistics_for_Automatic_Weld_Defect_Detection

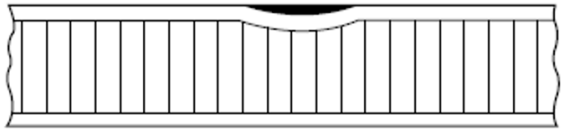
GOALS/REQUIREMENTS OF REPAIR[1]

- Fundamentally the goal of the repair is to restore the original design requirements of the part being repaired
  - Part stiffness
    - Deflection and stability requirements
  - Strength and stability
    - Stress concentrations might be created due to load path changes caused by the repair
  - Durability
    - Fatigue loadings on bonded/bolted joints
  - Damage tolerance
    - Capability of repair to tolerate a level of impact damage
  - Surface smoothness
  - Operating environment
    - Operating temperature and conditions (hot/wet) would influence material selection

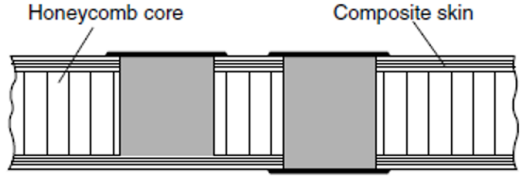
[1] CMH-17

OVERVIEW OF REPAIR TYPES[1]





Cosmetic repair using superficial nonstructural filler



Semi-structural plug-and-patch repair

ASM Handbook, Volume 21: Composites, Repair Applications, Quality Control, and Inspection, pp. 893-898

REPAIR MATERIALS

- Typically, the damaged parts are repaired using like-for-like materials recommended by the original equipment manufacturer (OEM)
- The same material weave and weight should be used for repairs as was used for the original part
- Materials with lower curing temperatures are typically desired as they reduce the temperature other parts are exposed to
- Assumptions should not be made
  - If a technical procedure does not provide a preferred resin type, consultation with the original part manufacturer and material experts is recommended

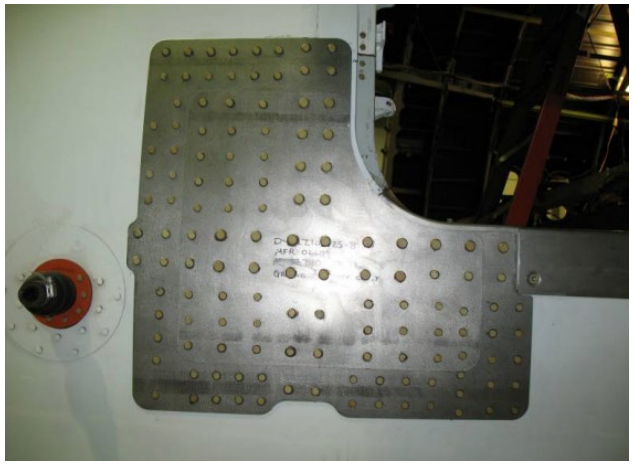
ASM Handbook, Volume 21: Composites, Repair Applications, Quality Control, and Inspection, pp. 893-898

REPAIR METHODS

- Methods for composite laminate repairs can be generalized into three categories:
  - Bonded repairs
    - Stepped repair
    - Scarfed/tapered repair
  - Bolted repairs
  - Resin injection/infusion repairs

Bonded repair of aft fuselage skin of a small aircraft [1]

Injection repair

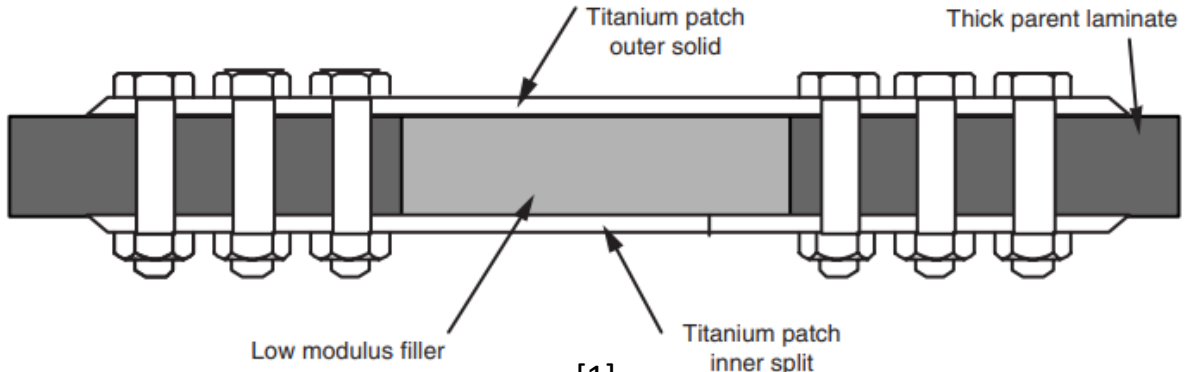


Bolted repair on an aircraft [2]

[1] https://www.mansbergeraircraft.com/mansberger%20aircraft%20composite%20repair%20gallery%206500v.html
[2] https://faa.niar.wichita.edu/Portals/0/2009%20CACRC%20Meeting/31_Boeing(Berner).pdf?ver=vq4LaQfQ1HW3rR68ztTXJw%3d%3d

REPAIR METHODS – BOLTED REPAIR

- Generally easy and quick, does not require the highly developed skills needed for flush repairs
- Damaged section is usually machined away completely through and replaced with a plug
- A low-modulus plug/filler is used to restrict the load into the filled hole
- Metal or pre-cured composite patches are mechanically fastened to parent structure
- Can be used in heavily loaded solid laminates, generally reserved for thicker laminates (>2.5 mm)
- Not aerodynamically smooth
- Titanium alloy fasteners are often used for carbon fiber laminates
- Can be less time-consuming/easier than bonded repairs



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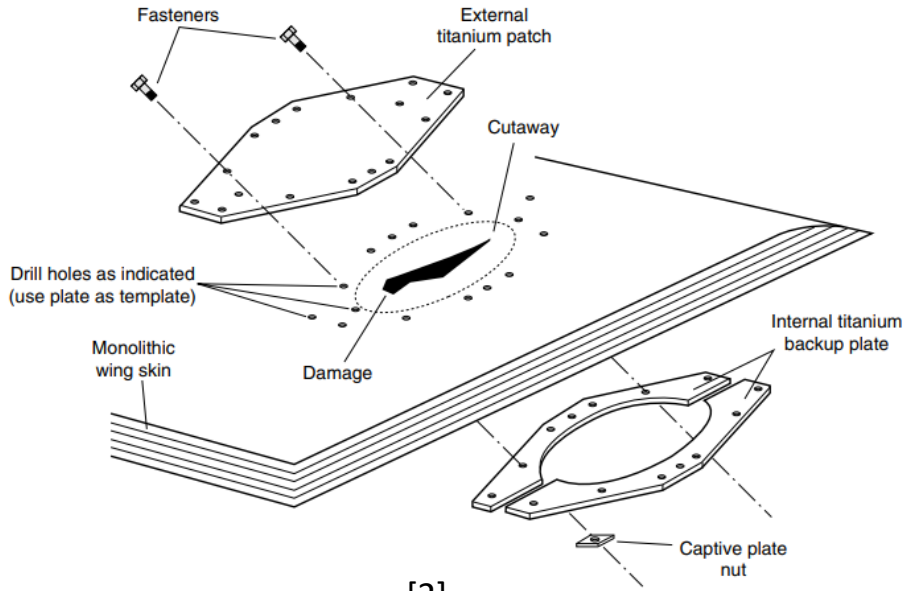
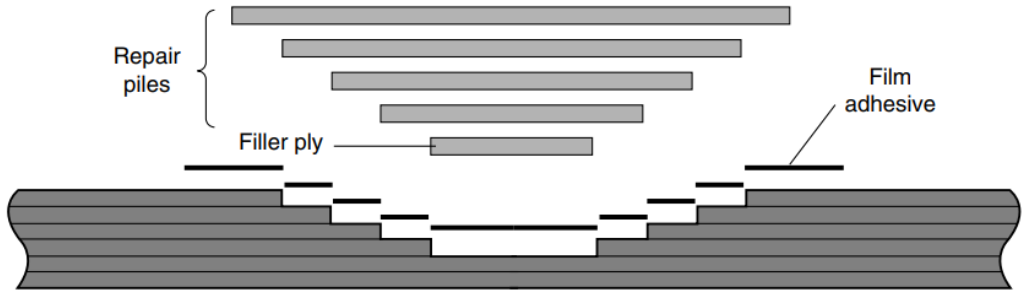


[2]

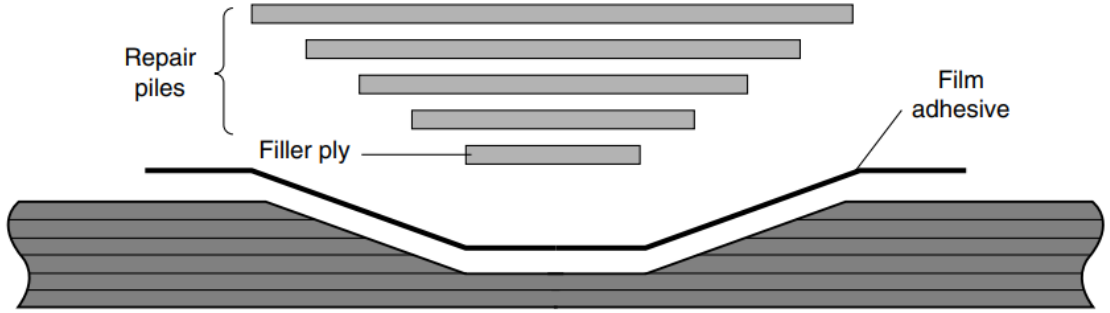
[1] ASM Handbook Vol 21 Repair Engineering and Design Considerations
[2] ASM Handbook Vol 21 Repair Applications, Quality Control, and Inspection

REPAIR METHODS – BONDED REPAIR

- Stepped repair:
  - Area around the damage is machined away in “steps” of plies to provide space for the repair plies
  - Difficult to achieve for curved surfaces
  - Easy to damage underlying plies during machining
- Tapered/scarf repair:
  - Area around the damage is removed at an angle
  - Repair plies/adhesive fills in the space
  - Typical scarf distance is 20-120 times the thickness of the laminate



Stepped repair

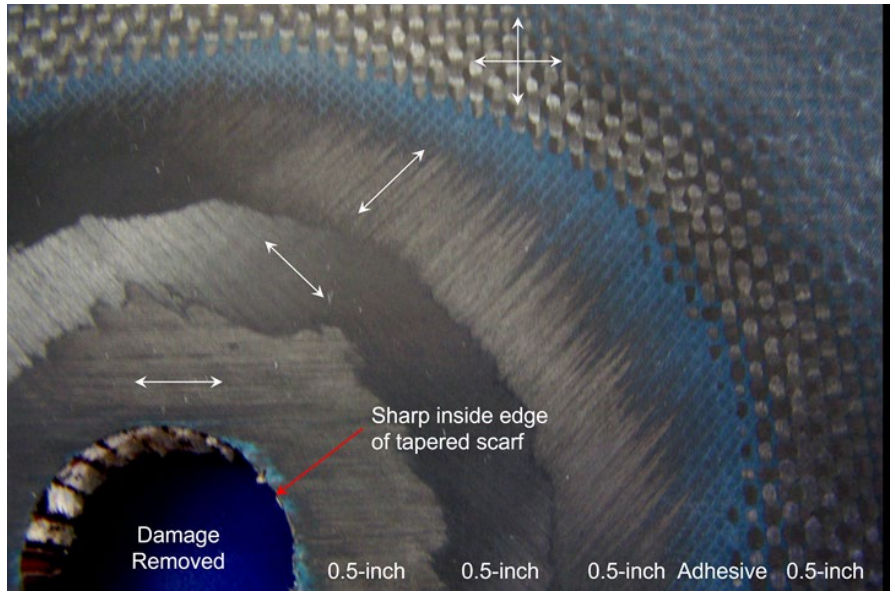


Scarf repair

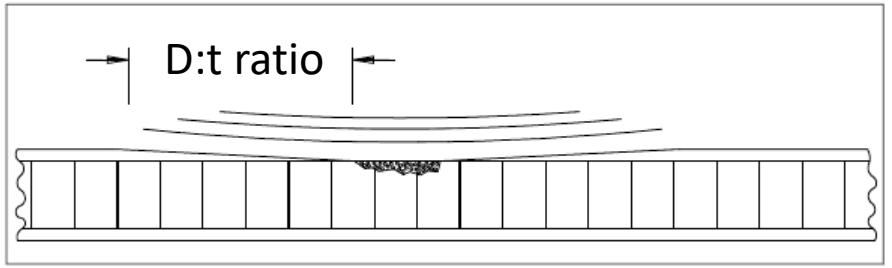
ASM Handbook Vol 21 Repair Applications, Quality Control, and Inspection

SCARFED DAMAGE REMOVAL

- Cut out the damage to a circle or oval with a rotary tool
  - If damage is small, sanding out the damage may suffice.
- Damaged core should be removed
- Sand a diagonal pattern (scarf) out from the removed damage.
  - Scarf angle is expressed in distance to thickness ratio, and is typically anywhere from 20:1 to 120:1
  - Sometimes also expressed as a per ply, ie, 0.5 inch per ply
  - Objective is to have a smooth surface without gauges and divots
- Sanded area should come to a sharp point, not a step at the end, which can cause stress concentrations



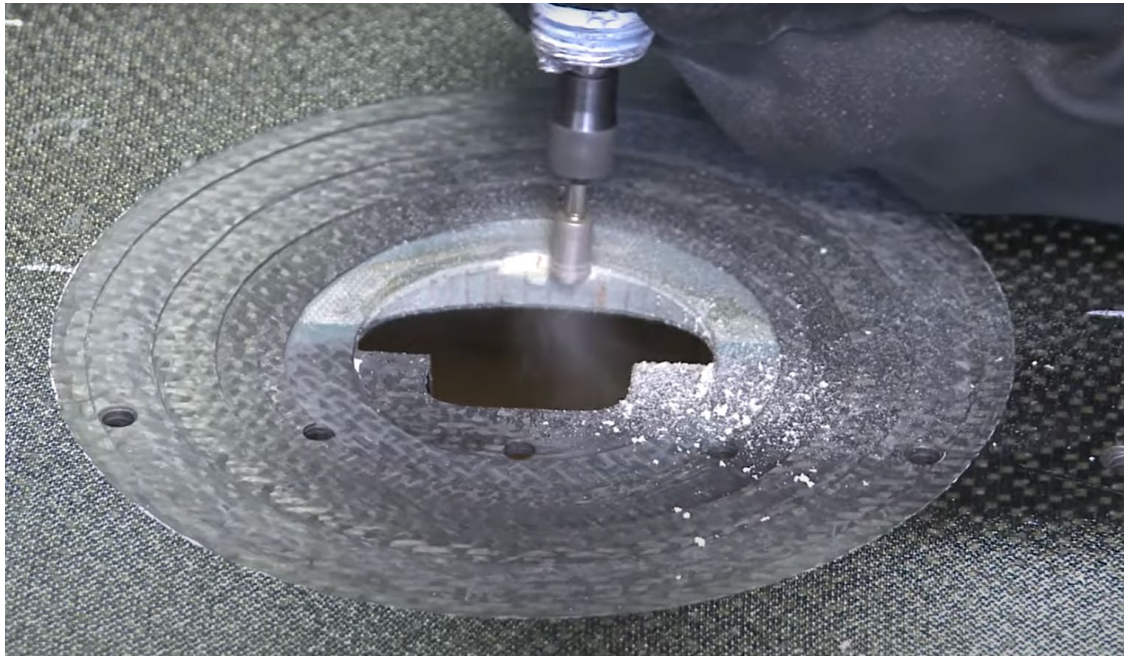
[1]



[2]

[1] https://www.compositesworld.com/articles/a-second-look-at-cobonded-tapered-scarf-repairs-for-composite-structures
[2] Maintenance manuals and illustrated parts catalogue, Extra EA-400, standard practices and structures

STEPPED DAMAGE REMOVAL



[1]

[2]

[1] https://www.youtube.com/watch?v=O06_PPc2WNo
[2] https://www.youtube.com/watch?v=yPP41LFXiLs

SURFACE PREPARATION

- Vacuum out any dust from cutting and scarfing
- Ensure the part is fully dry, placing it in an oven to dry may be recommended
- Clean the repair area and around with isopropanol or acetone
- Sand patch area with 180-240 grit sand paper
- Clean with a lint free cloth using isopropanol or acetone

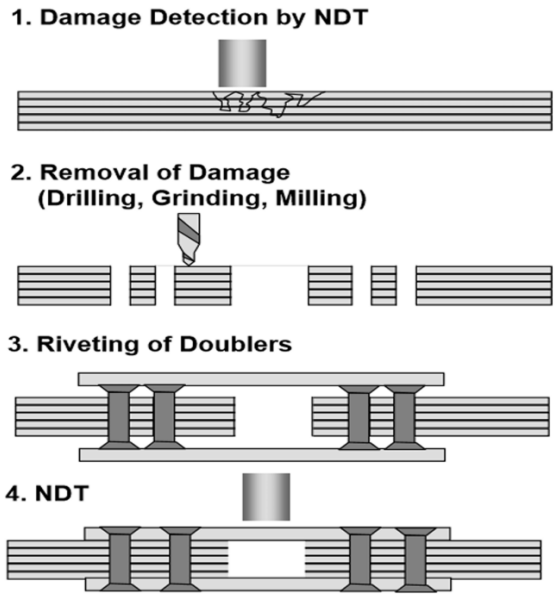
[1]

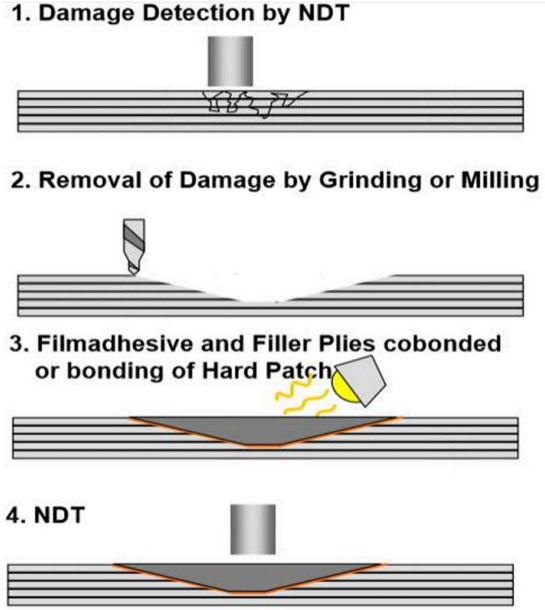
1. Clean 2. Abrade 3. Degrease

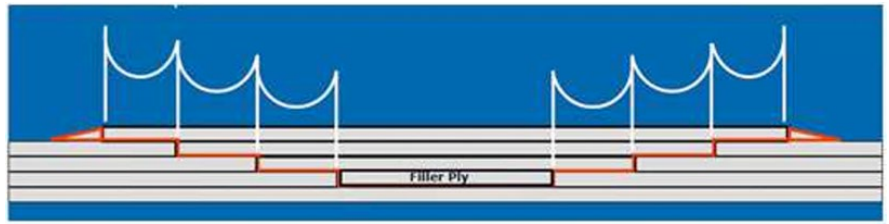
[1] https://images1.mcmaster.com/mvC/contents/gfx/small/b05-about-structural-adhesives-clean-abrade-degrease-rgb-digitals%202.png?ver=1535536311

STRUCTURAL REPAIR - COMPARISON

Bolted	Bonded	
	Scarfed	Stepped
• Fast application • Minimum skin thickness is necessary • Changes the aerodynamics shape	• Loads are transferred directly through the edges of the repair plies • Uniform shear distribution through a tapered scarf joint	• Loads are distributed through repair via a lap joint into the underlying layers • Peak stress concentration at edges of each step • Complex and time consuming • Feasible on flat geometries • Larger bonding surface



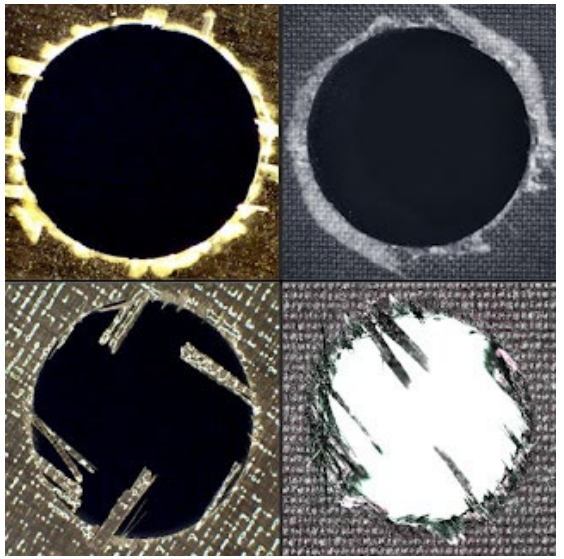




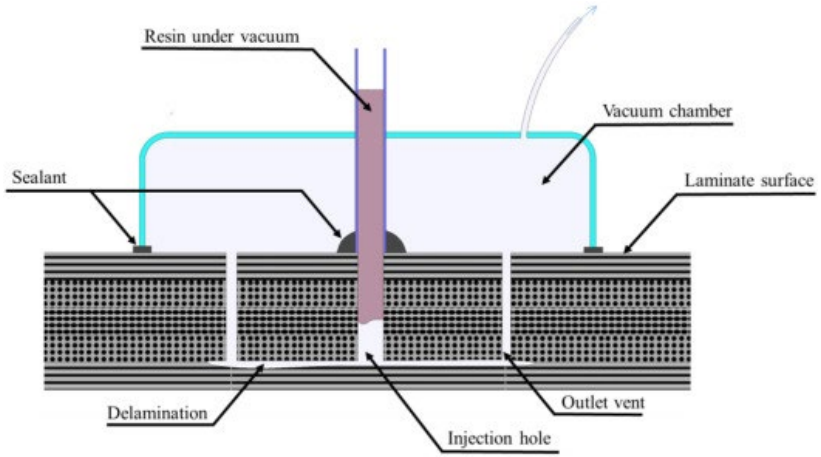
Figures from COMPOSITE STRUCTURES: ESSENTIAL OF REPAIR METHODS. Marco Barile, http://www.aeropolis.it/workshop2016/seminario16aprile2016/presentazioni/FedericoII/Metodi-di-Riparazione-Materiali-Compositi_Barile-dep.pdf

REPAIR METHODS – INJECTION REPAIR

- For repair of delamination in semi-structural applications
- Common in repair of splinters and minor edge delaminations from machining
- Low-viscosity resin is injected by a syringe with/without vacuum until it seeps out from an outlet
- Outlet vent is needed except with edge delaminations



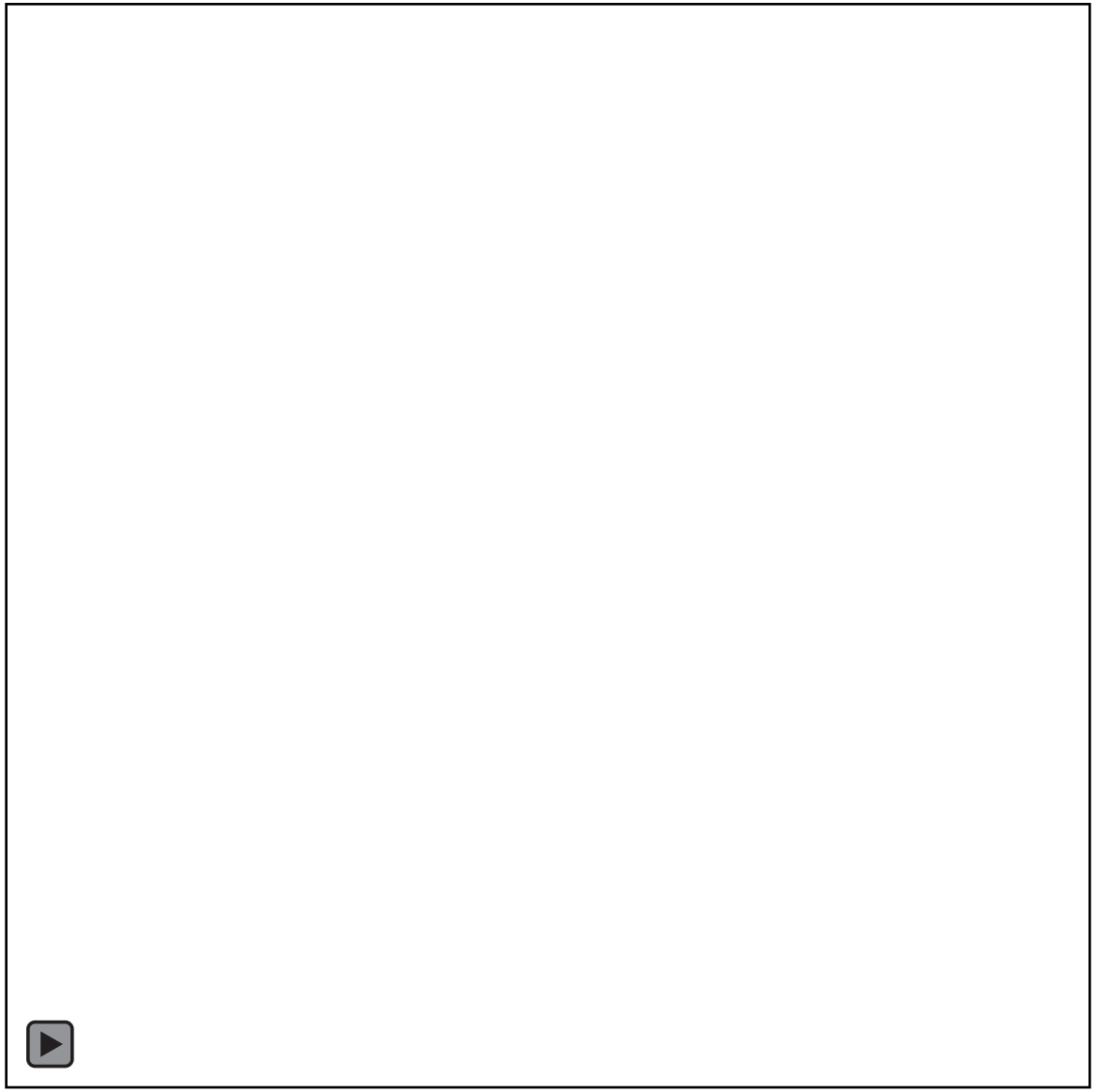
Delamination and splintering around drilled holes [1]



Injection repair under vacuum[2]

[1] https://deschner.blogspot.com/2018/12/how-to-prevent-delamination-while.html
[2] Omairey, S., Jayasree, N., & Kazilas, M. (2022). 9 - Injection repair of advanced composites: A prospective method for delamination damage repair. *Sustainable Biopolymer Composites* (pp. 183–211).

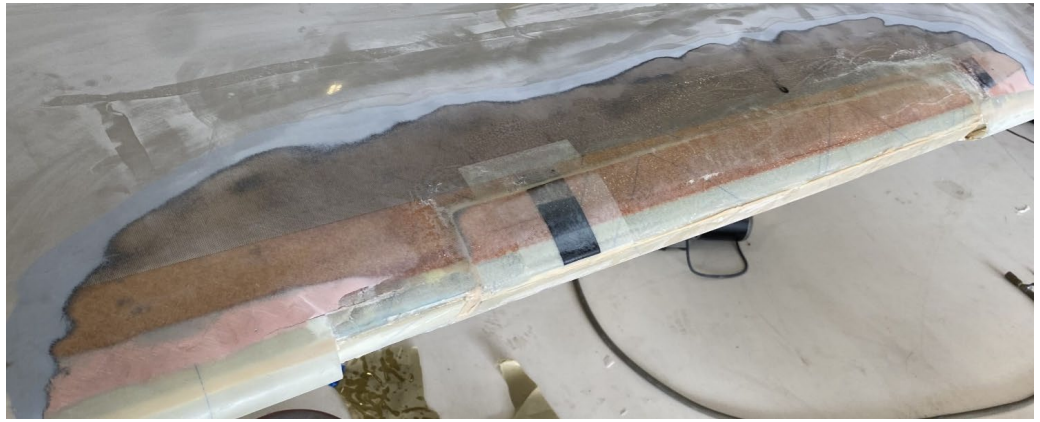
INJECTION REPAIR - EXAMPLE



Courtesy of UBC Supermileage

SURFACE FINISH RESTORATION

- After repair, restoring surface finish is important for:[1]
  - Cosmetic appeal
  - Performance needs
  - Protection from UV degradation
  - Protection from weather
  - Abrasion and wear resistance
- Paint, gel coats, surface veils and adhesives are common options[3]



Before-After Surface Finishing[2]

[1]: https://discovercomposites.com/what-are-composites/materials/surface-finishes/index.html#
[2]: https://www.appliedcomposites.com/mro/
[3]: https://compositeslab.com/composite-materials/surface-finishes/index.html#:~:text=FRP%20composites%20can%20accept%20a,sand%20added%20for%20additional%20protection.

REPAIR VALIDATION AND CERTIFICATION

- Quality assurance should be done by appropriate NDI methods
  - At the least, a visual inspection of adhesive fillet flow and an acoustic-hammer tap test should be done to indicate gross defects
- Destructive testing of sample coupons or bars may also be used for repair validation and quality assurance
- The repair and parent structure are typically monitored for ongoing validation
- Many companies develop their own certification procedures to ensure structural worthiness as requirements change based on a part's application

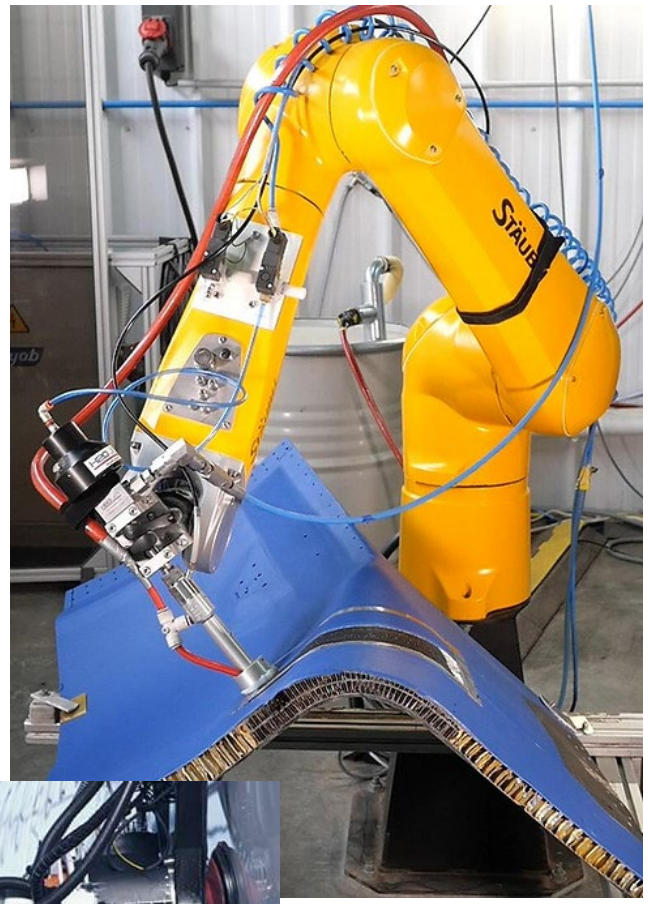
ASM Handbook, Volume 21: Composites, Repair Engineering and Design Considerations, pp. 888-889
NCN Best Practice Guide, Repair of Fibre Reinforced Polymer Structures, p. 7

DEFECTS IN REPAIR

- During the repair process, flaws and defects can occur, compromising the performance of the material
- Such imperfections typically only be identified through comprehensive non-destructive inspection after completion
- The types of defects include:
  - **Cracks**: resin-rich area, high temperature during exotherm
  - **Porosity**: entrapped air, foreign matter
  - **Disbond**: poor adhesion of resin, insufficient surface preparation
  - **Delamination**: moisture, poor mixing, improper cure, poor surface preparation
  - **Undercure**: poor mixing, bad cure cycle, or temperature control
- For more info on defects: https://compositeskn.org/KPC/A130

AUTOMATION OF REPAIR

- Several companies offer automated repair solutions for aerospace and energy sectors
- Can assist with repair of difficult-to-reach areas
  - Vertical/upside down surfaces
  - Wind turbines
- Automated machining allows for variable scarf angles, which can reduce the size of repair
- Some solutions are portable, which allows for field repairs that were previously not available
  - May eliminate need for disassembly

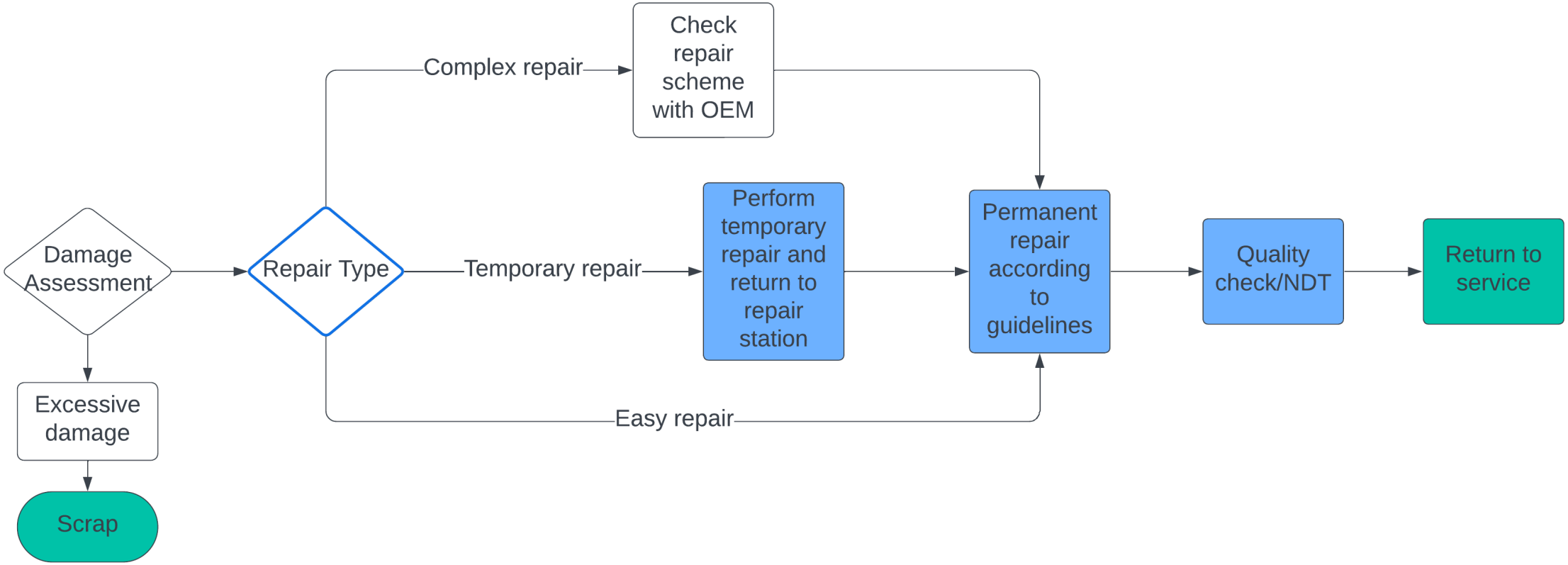


[2]

[1]

[1] Lufthansa Technik
[2] Bayab Industries

CONCLUSION



Thank you for joining us!

Keep an eye out for upcoming AIM events:

Non-destructive Testing of Composites
May 29th, 2024
https://compositeskn.org/KPC/A366

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

https://compositeskn.org/KPC

Today's Webinar will be posted at:
https://compositeskn.org/KPC/365