AE 737: Mechanics of Damage Tolerance

Lecture 25 - Non-destructive Testing, Composites

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schedule

- 3 May - NDE, Fracture in Composites
- 5 May - Class Canceled
- 9 May - Final Projects Due

outline

- NDT
- structural health monitoring
- composites
- corrosion
- aging

NDT

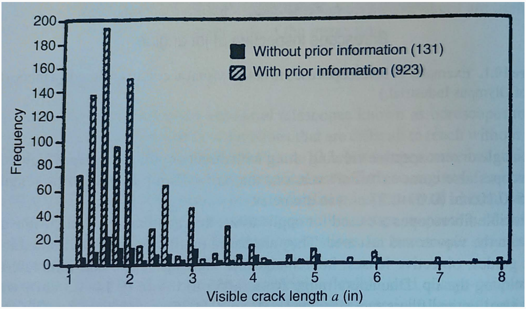
non-destructive testing methods

- Visual Methods
- Radiographic Inspection
- Ultrasonic Inspection
- Eddy Current Inspection
- Magnetic Particle
- Other Methods

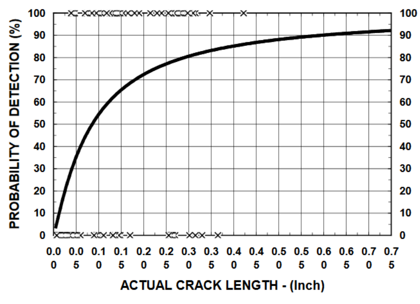
visual inspection

- Accounts for about 80% of all cracks detected in industry
- Visual inspection can be assisted with borescopes or liquid penetrant
- In practice many cracks can be missed during visual inspection

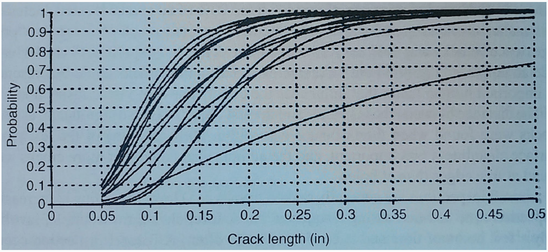
Japanese study



microscope study



faa study



faa study

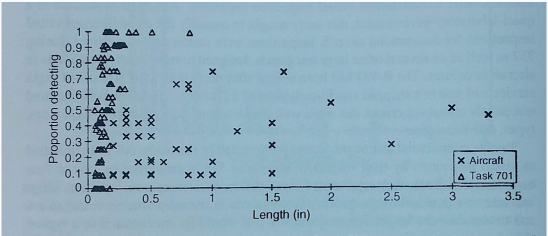
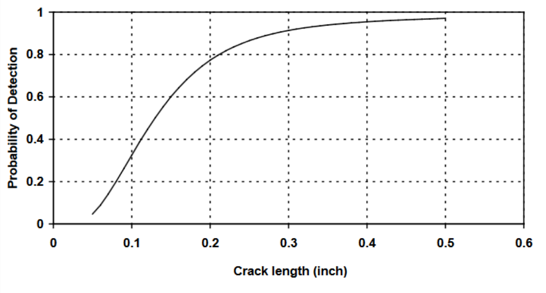


Figure 10.4. Comparison of visual detection rates for B-737 aircraft and a large test panel Task 701 [1].

faa study



liquid penetrants

- Can be visual dye or fluorescent dye (viewed under black light)
- Penetrant is applied to surface
- Developer then enhances visibility of penetrant (blooming effect)
- Can detect cracks as small as 0.05 inches

disadvantages of liquid penetrants

- Can only detect surface anomalies
- Surface must be fairly smooth
- Chemical compatibility of penetrant and structure
- relatively slow (surface prep, application, inspection)

borescopes

radiographic inspection

- X-rays (most common), Gamma rays can also be used
- Easist to detect when major flaw dimension is parallel to X-ray beam

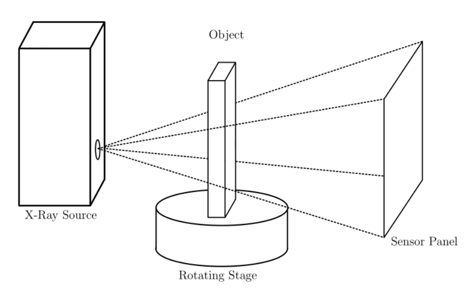
radiographic

- Three main types
    1. Film radiography - image stored on film for later viewing
    2. Real time radiography - image viewed and manipulated in real time
    3. Computed Tomography (CT) - 3D X-rays computed from multiple sections

radiographic inspection

- Size of crack that can be detected depends on scan resolution
- Trade-off betwen total image size and resolution
- Can detect internal flaws
- However, the exact location of an internal flaw is difficult to obtain
- Need access to both sides of structure

ct scan



ultrasonic inspection

- High frequency sound waves
- Can determine presence of flaw and its location through thickness
- Best detects flaws with major axis perpendicular to sound beam
- Immersion testing is often used to facilitate ultrasonic inspection

ultrasonic inspection

- Difficult to use with large parts
- Need access to place probe on one surface
- Need couplant with rough surfaces
- Will not detect “tight” cracks

eddy current inspection

- Generates small electrical currents using an electromagnet
- Can only be used in materials that are electrical conductors
- Otherwise more broadly applicable than Radiography and ultrasonic
- More sensitive to flaws perpendicular to current flow direction (similar to ultrasonic)

magnetic particle

- limited to ferromagnetic materials
- better for small parts (need to generate large electric current for large materials)
- some objects will need to be demagnetized after test
- surface/near surface defects

acoustic emissions

- accelerometers at multiple sources can measure response to acoustic emission
- response will vary between pristine and un-damaged material
- cannot always detect location of damage

thermal inspection

- flaws will also alter thermal conductivity
- thermal source with infrared camera can detect flaws

structural health monitoring

continuous monitoring

- Inspections for damage are often performed at regular intervals
- What if there was damage caused by an unexpected overload between inspection intervals?
- A lot of research is being done to efficiently and continuously monitor critical structure's health

structural health monitoring

- Structural health monitoring often uses accelerometers, strain gauges, together with data processing
- Detailed record of load history can also be used to infer damage and trigger an inspection

active research

- Much active research is ongoing in this field
- Some highlights from the Journal *Structural Health Monitoring* include
  - crack identification using consumer-grade images and neural networks
  - wave excitation and damping in composites
  - wireless fatigue crack sensor (gets energy from vibration)
  - optimization of sensor placement

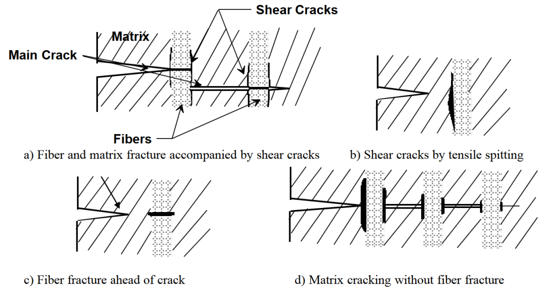
failure modes

- Because composite materials are heterogeneous there are several failure modes to consider
  - Fiber breakage
  - Matrix cracking
  - Fiber-matrix de-bonding
  - Ply delamination

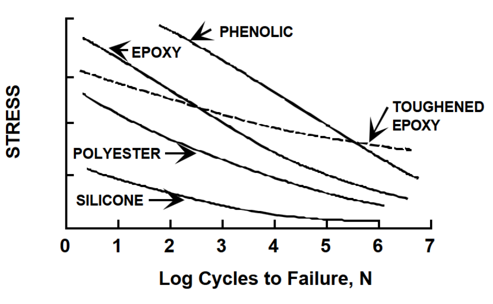
fatigue in composites

- In metals, cracks are most likely to form near the surface or a stress concentration (hole, notch, etc.)
- In composites, internal variability and voids can give rise to sub-surface cracks
- The ideal combination for fatigue performance is a very stiff fiber (reduces strain in the matrix) and a very tough matrix

cracks in a composite



effect of matrix



Various matrix materials' fatigue performance with E-Glass

fiber orientation

- It is intuitive that in tensile fatigue, a composite with fibers aligned in the direction of tension will have the best performance
- At high-cycle fatigue, however, a slight mis-orientation can improve fatigue performance
- Straight roving also has better fatigue performance than woven roving

orientation

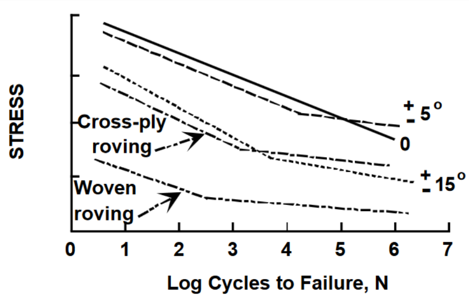


Figure 1: Effect of fiber orientation and roving on fatigue life

free edge effects

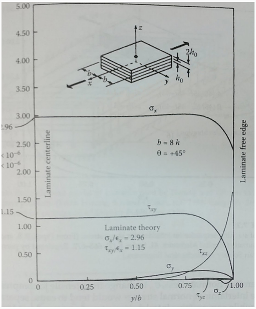
- In practice, composites are often over-designed for in-plane loading
- Problems occur during un-expected out-of-plane loading
- This can occur near the free edge of a laminate

free edge effects

- Composite laminate theory was developed under an assumption of plane stress
- This is fairly accurate sufficiently far away from geometric discontinuities, such as free edges
- At a free edge, in-plane shear stresses must be zero
- To satisfy equilibrium the out-of-plane shear stress increases to match

$$\sigma_{11,1} + \sigma_{12,2} + \sigma_{13,3} = 0$$

free edge effects



stacking sequence

- The free edge effect is proportional to the effective lamina thickness
- It can be minimized by not stacking layers of the same orientation directly on top of each other
- There is also a normal stress in σ_z that develops
- This normal stress can be either tensile or compressive depending on the stacking sequence

interlaminar strengthening

- There are several techniques to improve the inter-laminar performance of composites near the free edge
- Stitching
- Braiding
- Z-Pinning
- Edge Cap
- Toughened inter-laminar adhesive sheet

open hole compression

- One of the first tests of a composite's damage tolerance is known as open hole compression
- A specimen is drilled with a hole and then put in a fixture which prevents buckling under compression
- open hole test[1]
- Meant to give a measure of a composite after being "damaged" by a hole
- While a hole is a very repeatable form of damage, it is not representative of all damage

[1] https://www.youtube.com/watch?v=u1gHxCt-qv0

compression after impact

- Another test was developed to measure the strength of a composite after undergoing impact damage
- Various levels of impact damage can be applied, but most commonly "barely visible impact damage" is used
- After impacting the specimen, it is tested in a compression fixture to prevent buckling
- impact[2]

[2] https://www.youtube.com/watch?v=ygjtNMbmqAM

ceramic matrix composites

- Ceramics are very strong and stiff, with very good performance at elevated temperature
- They are very weak in tension, however, and are very susceptible to damage
- Adding ceramic fibers helps to
  - Reduce stress in the matrix, increase the stress required to propagate crack
  - When cracks do form, the cracks bridge without fracture

corrosion

corrosion

- Corrosion can be difficult to accelerate in a lab (like fatigue), and so is not as well-understood
- There are several general categories of corrosion
- General corrosion - occurs equally and globally
- Localized corrosion - occurs at specific locations
- Metallurgically influenced corrosion - grain boundaries, dealloying
- Mechanically assisted degradation
- Environmentally induced cracking

general corrosion

- Atmospheric corrosion
- Galvanic corrosion (dissimilar metals in contact)

localized corrosion

- Similar to general corrosion, but localized
- Can accelerate the development of fatigue cracks
- Pitting

metallurgical corrosion

- Different concentrations of alloy constituents at grain boundaries
- Galvanic corrosion at a grain boundary could be possible
- Exfoliation is a form of this that can occur in aluminum alloys with elongated grains parallel to the surface
- Fasteners with dissimilar materials can also cause metallurgical corrosion

mechanically assisted degradation

- Chemical effects combined with mechanical stress
- Fretting corrosion (abrasive corrosion particles, like oxides, trapped can lead to more corrosion)
- Corrosion fatigue

environmentally induced cracking

- stress corrosion cracking
- hydrogen damage, embrittlement

aging

aging

- Aging is a term often used to describe the degradation of polymers
- Most polymers are not "pure" but contain some fraction of additives to modify the properties
- Commonly they will have a "plasticizer" which lowers the glass transition temperature
- As these plasticizers degrade, the polymer becomes more brittle