
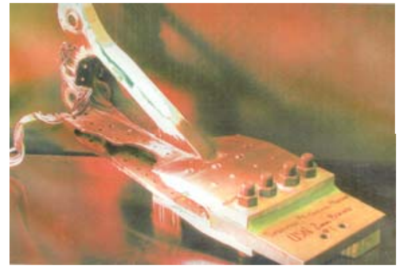


The effect of environmental moisture on the performance and certification of adhesively bonded joints & repairs

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The effect of environmental moisture on the certification of bonded joints

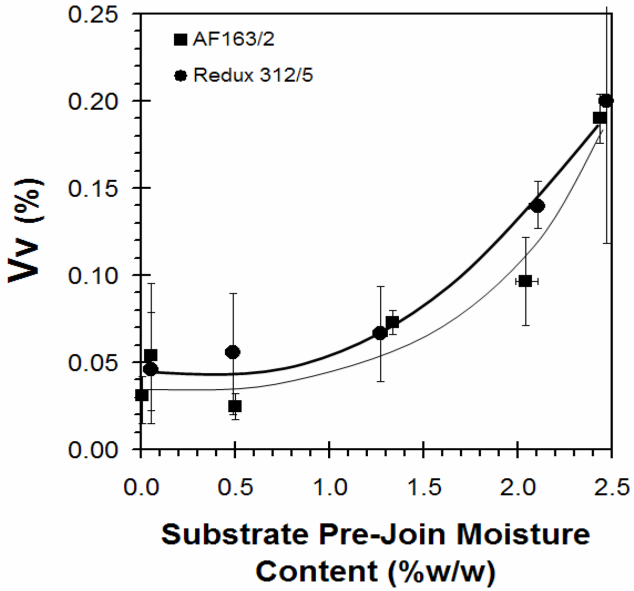
- Initial assumption of discussion is that there currently are appropriate design rules, surface preparation, application quality management and staff training techniques that will produce adhesively bonded joints capable of meeting performance criteria i.e., no arguments that it is possible to make durable bonds.
- The problem is how to demonstrate the airworthiness of these joints for operation throughout their service life – a matter of defining the risk of failure of such a joint/repair.
- This difficulty is caused by possible degradation of joint strength due to exposure to (predominantly) atmospheric moisture. The various mechanisms that cause the degradation can occur before, during and after installation/cure of the joint.
- Anecdotes suggest that short term testing may not detect this degradation and real-time testing impractical – so problem becomes how to determine/manage risk.

Critical question?

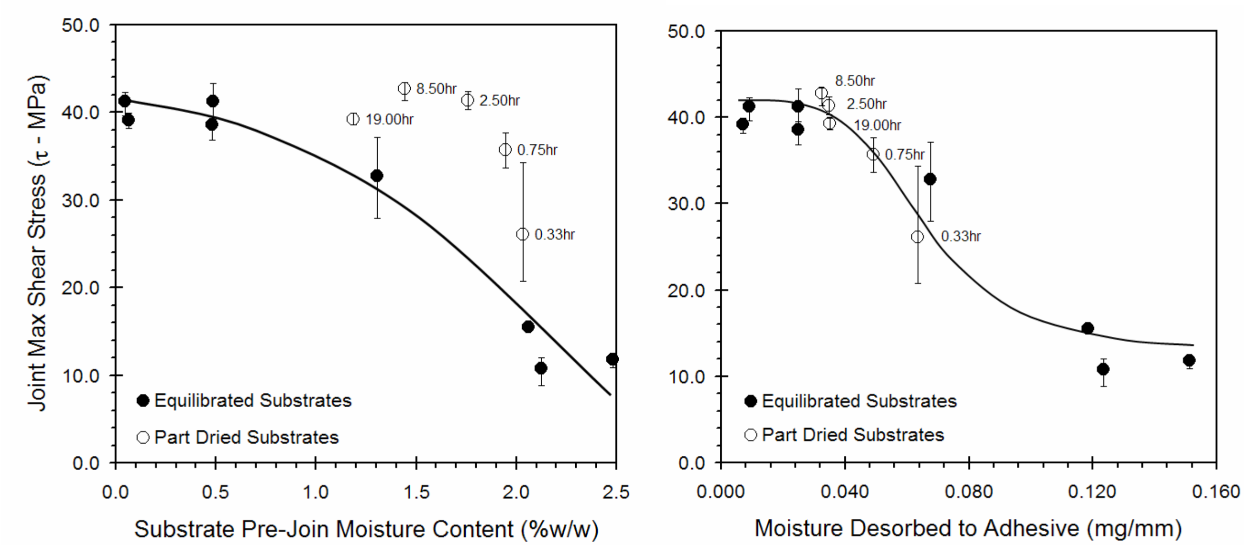
- How do we as designers, regulators, operators and maintainers demonstrate that an installed joint will perform as required throughout the life of the aircraft?
  - Mechanical joints with metallic adherends traditionally adopted fail-safe or safe-life design philosophy.
  - Only relatively recently has the industry moved to a safety by inspection philosophy for metallic structures- made possible by accurate/reliable life prediction techniques and modern NDT techniques.
  - In comparison, adhesively bonded joints are still a long way from being able to adopt either a safe-life or a safety-by-inspection design philosophy (the former due to absence of reliable service data the latter due to the absence of an accurate life prediction technique and NDT method).
  - This leaves a fail-safe approach only achievable through use of alternate load paths.
  - But this is structurally inefficient and/or impractical for repair of structure designed using safe-life or safety-by-inspection philosophies.

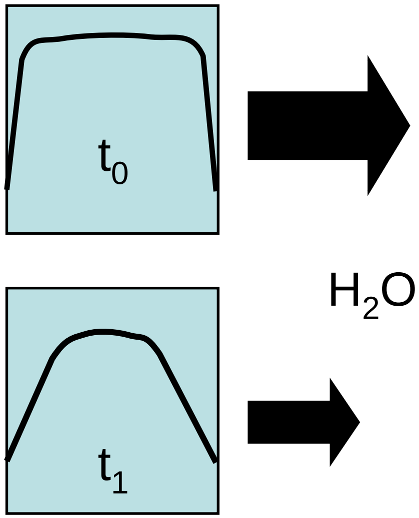
How does environmental moisture affect the performance of an adhesive joint (pre-bond)?

- Environmental effects: Pre-Bond.
  - Adhesives (esp. epoxies) are often hydrophillic i.e. absorb moisture.
  - Absorbed moisture reduces Tg, modulus and (usually) strength.
  - The moisture may be absorbed by adherends/adhesives prior to bonding.
  - In elevated temperature cure joints pre-bond absorbed moisture may affect a bonded-joint by:
    - interfering with surface wetting and consequential development of interfacial bonds at the adherend/adhesive interface,
    - interfering with the cure reaction of the adhesive, and/or
    - causing excessive voiding in the adhesive.
  - These problems generally overcome by thorough drying of adherends and dry storage of adhesives prior to bonding.



Effect of pre-bond adherend moisture on short term joint performance

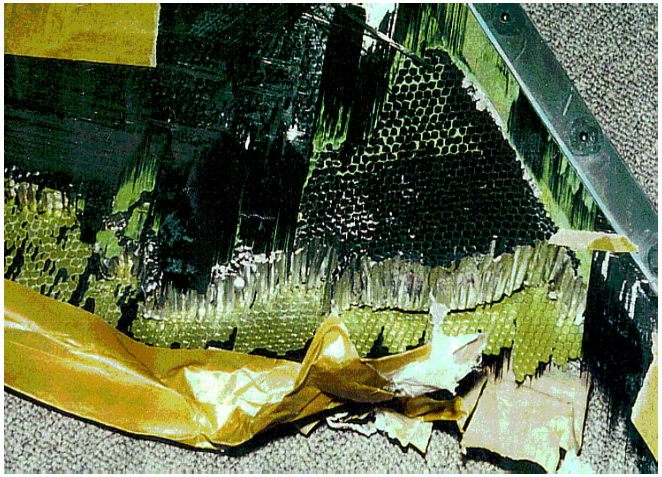




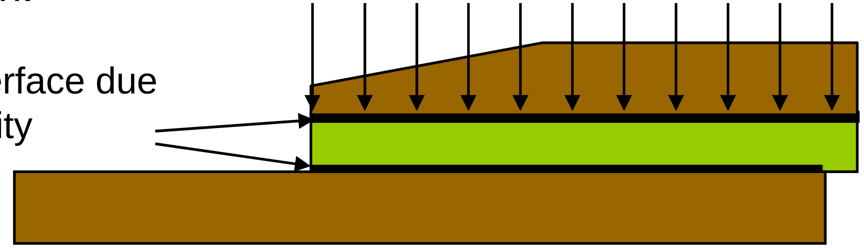
- Typical SRM process requires thorough drying (often >24hrs) prior to bonding.
- This level of drying generally not required – only need to alter the distribution of moisture in the adherends to reduce the level of moisture desorbed to the joint to below a critical level.
- There appears to be a level below which the moisture has a negligible effect on short-term joint strength and void content (approx 0.04 mg/mm for this resin system) – this trend also seen for adhesives less sensitive to moisture (could this be a design/process parameter for adhesives?)

How does environmental moisture affect the performance of an adhesive joint (post-bond)?

- Environmental effects: Post-Bond.
  - Post bonding, moisture will be absorbed into the joint increasing compliance and, significantly, possibly reducing the strength of the interfacial bond between the adhesive and adherend increasing likelihood of LOW STRENGTH INTERFACIAL ADHESION FAILURES
  - The sensitivity of a bond to interfacial degradation can be reduced by good surface preparation but currently not reliably predicted or NDT inspectable. This is the problem for certification.

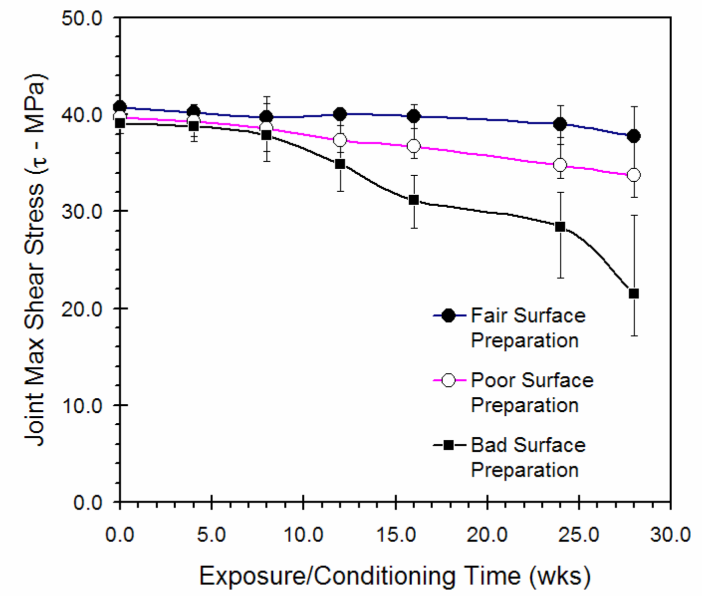


Interfacial Failure on F/A-18 Rudder



Certification difficulties caused by possible time-dependant degradation of bondline

- Hot-wet performance reduction covered in composites by use of knockdown factors.
- In an adhesively bonded joint knockdown factor could be 100% due to degradation over time.
- Safety-by-inspection methodology requires predictive capability for rate of performance degradation.
- Little public work being done – perceived as being difficult with many influencing parameters.
- For certification of a repair/joint for long-term environmental durability:
  - Provide alternative load paths to the adhesive joint (Fail-Safe)
  - Probability based - acceptable level of risk for no environmental durability related failures in a given operational life-time (Safe-Life)
  - Monitor joint performance throughout life to ensure adequate performance (Safety-by-Inspection)



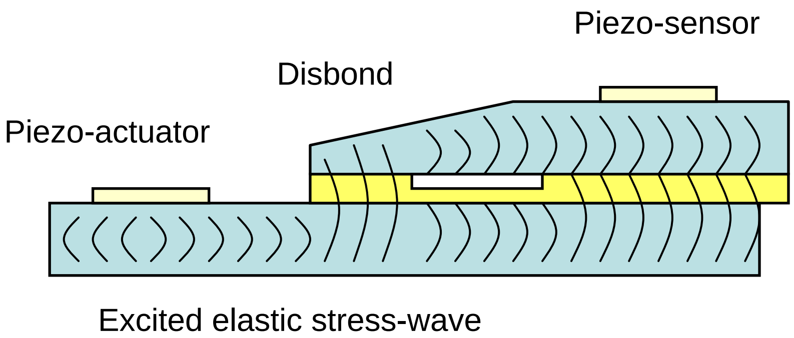
<u>Level of Technical maturity</u>

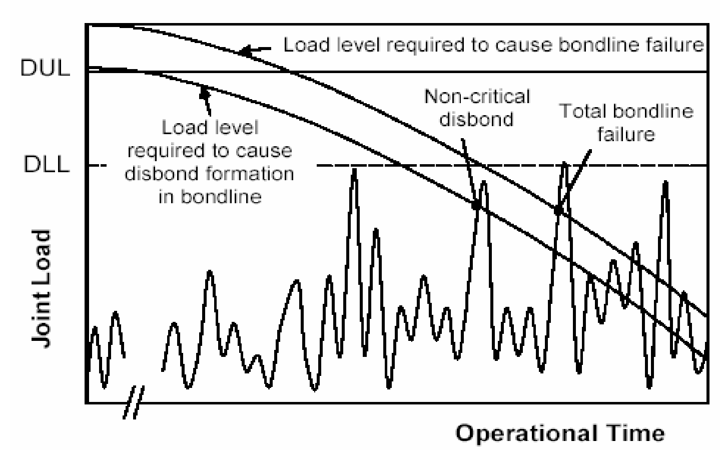
High – Available to industry now

Medium - available in 2-5 yrs if data accessible

Low – 5-10yrs + ???

SMART Health Monitoring solutions





- Current R&D work in this area is in smart patches/repairs that "sense" and warn of their own failing effectiveness and ensure replacement prior to failure.
- Have the advantage of not requiring a degradation prediction capability only looking for a relative reduction in joint performance.
- Existing techniques based on elastic stress waves interactions with the interface but have generally only demonstrated an ability to detect disbonds in the region of sensors – whilst useful this is insufficient for certification purposes.

Summary of possible solutions to certification of bonded joints for environmental degradation

- **Fail-safe** (alternate load path)
  - low risk.
  - limited applicability for repairs and structurally inefficient for new structures.
- **Safe-life** (acceptable level of risk)
  - Statistically identified level of risk.
  - Reliant upon large database of long-term durability tests or equivalent short term tests.
  - Are available tests, i.e., Wedge test, accurate predictors of long term durability for all bonding processes and applications?
  - Does this need to be proven before this methodology is an acceptable certification basis?
  - May prevent adoption of new bonding processes from lack of statistical data.
- **Safety-by-Inspection** (structural health monitoring)
  - Potentially low-risk.
  - Need an inspection technique to reliably assess integrity of the joint.
  - Need to either continually monitor performance or have an accurate understanding of degradation rate to allow selection of appropriate inspection intervals i.e., a degradation rate prediction capability.