Kissing Bonds in Adhesive Joints: Experimental Investigations and Numerical Predictions

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Objectives

1. Producing reliable and repeatable kissing bonds

2. Detailed understanding of their surface chemistry and morphology

3. Failure mechanics of kissing bonds

4. Numerical modelling of kissing bonds

5. Assess the feasibility of developing an industrially useful instrument for the NDE of adhesive joints
Definition of Kissing Bonds

“Kissing bonds” or “Zero-volume disbonds” are interfacial defect which show no sign of separation at the interface

Two types of kissing bonds†

1. **Dry contact kissing bonds** - adherend and adhesive are in contact (solid-solid contact) resulting from a disbond subjected to some form of compressive loading

2. **Liquid layer kissing bonds** - surface contamination with a thin liquid layer

Possible Criteria of Kissing Bonds

- The surfaces created are not entirely traction-free (interface weakness)
- Lap shear strength < 20% nominal strength
- Adhesive failure dominates – mostly at the interface
- Unable to detect using conventional ultrasonic methods

†† Marty, N.P., Desai, N. and Andersson, J. (2002) NDT of kissing bonds in aeronautical structures 16th World Conference for NDT
Producing Kissing Bonds

- Surface contamination using **PTFE spray lubricant** and **PTFE release film**

  - Hardened steel adherends
    - *(The surfaces have been degreased and grit blasted)*
  - PTFE spray lubricant or 25 μm PTFE release film
    - *(25% contaminated area)*
  - Nylon carrier film adhesive
    - *(Redux® 319A)*
Producing Kissing Bonds

- Electrically disbonding adhesive, ElectRelease™

Conditions:
- 10 Volts DC for 25 mins at room temperature
- Adhesive thickness ~ 0.2-0.3 mm
- Bonded area = 12.7x25.4 mm²
Surface Morphology and Chemistry

- PTFE spray lubricant

Difficult to detect this contaminant on the cross section samples due to
- PTFE spray consists of around 1% PTFE particles unevenly dispersed in a volatile organic solvent (chloromethane or methyl chloroform)
- PTFE spray tends to migrate from the interface into the adhesive at curing temperature (175 °C)
- No Fluorine was found however small amount of Chlorine can be detected using EDS
Surface Morphology and Chemistry

- Electrically disbonding adhesive (ElectRelease™)

- Change along the steel anode /ElectRelease™ interface due to electrochemical reactions
- The gap increases by almost 1 µm
- Some adhesion (mechanical interlocking??) remains despite the visible opening along the interface
- The joint remains intact
X-ray line scan across steel/ElectRelease™ interface

- Before electric field
X-ray line scan across steel/ElectRelease™ interface

- After electric field

![ElectRelease™ interface](image1.png)

![Graphs showing elements](graphs.png)
Effect of Electric Field

• Same specimen at identical position analysed

• Significant loss of carbon and oxygen at anodic steel/ElectRelease™ interface as the interface is opening

• Small reduction of phosphorus and silicon at anode steel/ElectRelease™ interface

• More iron (under the examined surface) detected as the adhesive opening up
Numerical Simulation of Kissing Bonds

- 3D simulations with geometric nonlinearity

- Eight-node cohesive elements with zero thickness (cohesive zone) were used to simulate the failure at nylon/epoxy interfaces.

- In case of the contaminant, unshared nodes were simulated in the middle. The surrounded area was modelled using the cohesive zone.

- In case of ElectRelease™, the weakened interfaces have been modelled using the measured interfacial fracture toughness (Gc) taken into account the adhesion loss.
Numerical Simulation of Kissing Bonds

Linear softening constitutive equation of the cohesive zone:

- Initial stiffness or penalty stiffness before damage initiation to prevent additional deformation; calculated from measured bondline stiffness
- Interfacial normal and shear traction ($\sigma_c$, $\tau_c$) to determine the damage initiation; derived from measured joint strength
- Interfacial fracture toughness ($G_c$) under BK criterion to determine damage evolution; derived from peel tests

Material models for the adherend and adhesive:

- Hardened steel was modelled using elastic-plastic models derived from tensile tests
- Epoxy region in Redux® 319A adhesive was modelled using exponent Drucker-Prager criterion deduced in previous work
- Nylon cloth was modelled using typical elastic properties

††† Guild, F.J.
Failure Mechanics of Kissing Bonds

- Double-lap joint (DLJ) configurations

All dimensions are in mm and not to scale
Comparison of joint strength: contaminants

- Gauge steel results affected by yield of adherends
- No reduction in failure strength when using PTFE spray even though there is a trace of the PTFE spray confirmed by FESEM with EDS, FTIR and Raman
- Reduction in failure strength when using PTFE release film
- Good agreement with FEA for PTFE release film BUT close to real nature of kissing bonds???
Edge view of failed non-contaminated joint

- Cracks initiated at A and B and propagated at the lower and upper epoxy/nylon interface

- Bending of nylon cloth observed where the two crack paths met

- Good correlation between FEA and experimental
Edge view of failed contaminated joint (PTFE release film)

- Initial cracks initiated from the edge of the contaminant at the upper epoxy/steel interface and then propagated into the upper epoxy/nylon interface via transverse crack

- Nylon carrier cloth may interfere with failure mechanism

- Good correlation between FEA and experimental
Mode of Failure: DLJ with PTFE Release Film

- **Without contaminant**
  - Cohesive failure found at the nylon/epoxy interfaces

- **With contaminant**
  - Adhesive failure found only at the position of the release film
Comparison of load vs local strain

- On the outer adherend at the middle of overlap above the contaminant
- On the inner adhered adjacent to the overlap

- Same initial stiffness between non-contaminated and contaminated joint despite different interfacial stiffness (25% reduction in bonded area for contaminated joint)
- Non-linearity becomes more evident after 0.0007 strain
- Reliable boundary conditions used as confirmed by local strain on the inner adherend
Comparison of joint strength: ElectRelease™

- Approximately 37% reduction in failure load was found after the application of 10 volts DC for 25 mins.
- The joint strength varies greatly with the amount of applied voltage, time, adhesive bondline thickness, type of adherend and surface treatment.
- FEA models associated with loss in fracture energy due to the application of electric field is being developed.
Mode of Failure: DLJ with ElectRelease™

- **Without electric field**

  - Cohesive failure dominates

- **With electric field**

  - Adhesive failure dominates
Conclusions and Future work

- Good understanding of weak bonds has been obtained using PTFE release film and ElectRelease™ but the release film may not represent real nature of kissing bonds.

- Other contaminants e.g. Frekote® 800-NC and salt water (sweat) will be investigated.

- Reduction in joint strength for both PTFE release film and ElectRelease™.

- Same failure mechanisms for non-contaminated and contaminated joints with PTFE release film (at the lower fracture toughness interfaces between nylon cloth and epoxy) due to the interference of the carrier.

- DLJ made with Redux® 319 adhesive (without carrier) has been investigated.

- Same initial in-plane stiffness between non-contaminated and contaminated joints despite different interfacial stiffness.

- Potential ultrasonic methods which interrogate the out-of-plane stress-strain characteristics with respect to the bond interface may be capable of detecting kissing bonds.

- FEA results deliver comprehensive understanding of failure mechanisms associated with kissing bonds.
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