A Call for Minimum Standards in Design and Application Technology for Bonded Structural Repairs

By

M.J. Davis, B.Eng. (Mech), M.Eng. (Mech)
Aeromechanical Technologies and Standards
Logistics Systems Agency
Royal Australian Air Force

SUMMARY:

Some approved repairs have little chance of success.

Service lives of many components have been *reduced* by poor repairs.

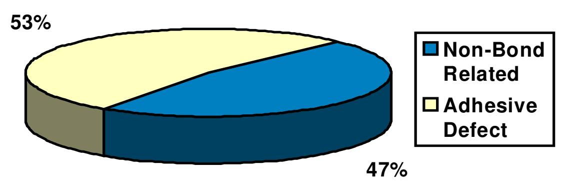
Cost of deficient repairs is significant.

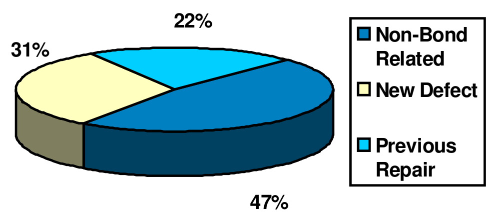
Royal Australian Air Force has developed its own Engineering Standard.

The paper will provide examples of deficient repairs.

If a Standard was applied to Structural Repair Manuals *at the time of delivery* of the aircraft, many of the current deficiencies could be reduced.

CURRENT POSITION: THE NEED FOR A STANDARD





Survey of 367 defect reports. 53% due to defective bonds.

Does not include:

- Obvious impact damage.
- Defects within SRM repair limits.

Deficient durability from original manufacture.

22% were associated with previous repairs.

- Repair patches debonded.
- Subsequent damage (corrosion, core corrosion, skin debonding, fatigue cracking etc.).

These repairs were performed IAW the aircraft SRM.

High repair repeat rate would not be accepted in any other aircraft system.

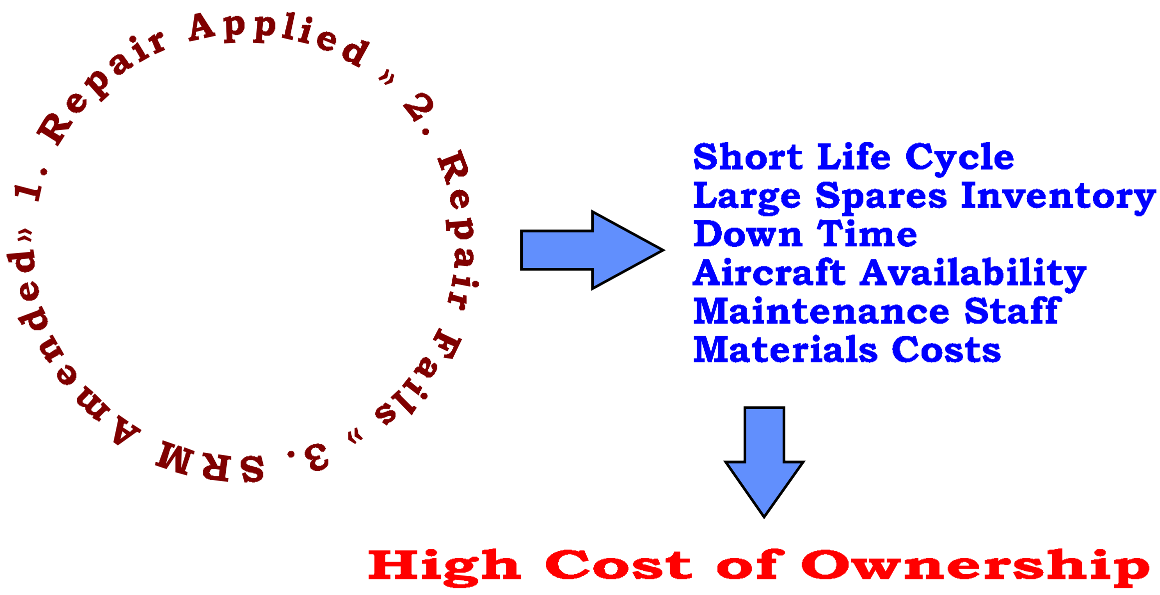
Factor which has greatest impact is the veracity of procedures in the original repair manuals.

- Initial training based on manuals.
- Personnel are obliged to follow approved procedures.

The high repeat repair occurrence is a legacy of the original poor procedures.

Regrettably, poor procedures have been identified in more recent acquisitions. (civil aircraft also?)

CURRENT REPAIR MANAGEMENT CYCLE



This cycle would be unnecessary if correct procedures were specified *at the time of acquisition* of the aircraft.

DEFICIENCIES IN CURRENT REPAIR TECHNOLOGY

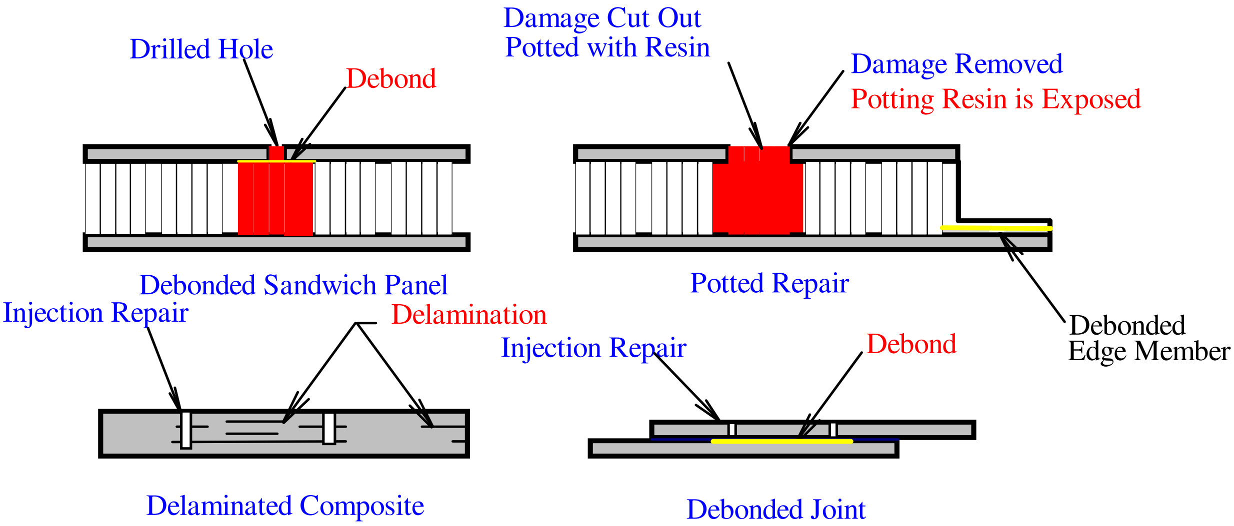
A plethora of examples of low standards in authorised repair manuals.

- Inappropriate repair concepts
- Materials selection.
- Surface preparation.
- Temperature measurement and control
- Sequence of repair procedures.
- Occupational health and safety.

Several examples will be presented which demonstrate poor repair procedures.

(Examples demonstrate the need for a Standard; not to denigrate any specific company or organisation.)

INAPPROPRIATE REPAIR CONCEPTS



- Injection Repairs for Adhesive Debonds.
- Potted Repairs.
- Injection Repairs for Delaminations.

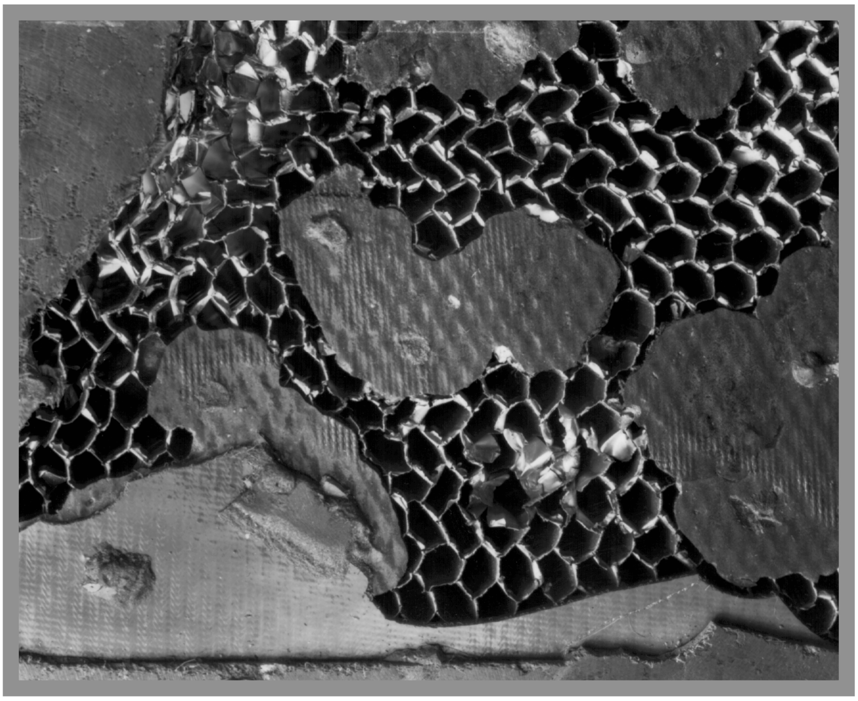
A sample of a panel which had been injection repaired nine times. Not one repair worked.

No NDI method exists which can determine the condition of the bond interface either before or after repair.

- Repair is futile.
- Consequent damage by moisture diffusion, results in corrosion.

OPINION: Whatever validation there was, must be repeated.

Injection repairs can be flight-critical



This “repair” and several others adjacent led to an in-flight failure.

The imprint of the old adhesive release film is visible.

- The original adhesive did not bond at manufacture.
- Injected adhesive did not bond to the old adhesive.

The panel departed the aircraft at speed, destroyed the rudder and leading edge of the vertical stabiliser, damaged one horizontal stabiliser and caused significant fuselage damage.

There was a very high potential for aircraft loss.

THESE REPAIRS MUST BE PROHIBITED.

INJECTION OF COMPOSITE DELAMINATIONS

Validation based on ultrasonic inspection after injection.

NDI can only indicate that the void has been filled. *Try injection resin without hardener.*

High probability that a drilled hole will not connect all delaminations.

Work at DREP [2] has been largely focussed on a specimen with a central hole; all delaminations will break out to the edge.

Fatigue tests at NADC showed that injection repairs to 24 ply composites REDUCED THE FATIGUE LIFE BY A FACTOR OF THREE.

For an eighty ply composite, the reduction in fatigue life was over 26 times.

Clearly, this method must be subjected to utmost scrutiny.

MECHANICAL FASTENERS IN A BONDED REPAIR

Combination of adhesive bonding and mechanical fastening, ("chicken rivets").

Bond transfer length smaller than edge distance for fasteners.

The presence of fasteners in any adhesive bond on thin material is an admission that the repair authority is incapable of specifying reliable bonding processes.

Moisture causes corrosion, bond degradation and cracks will grow outside the patch.

SCARF REPAIRS FOR THIN SECTIONS

Scab repair adhesive has load capacity greater than laminate, why scarf?

SELECTION OF REPAIR MATERIALS

Repair materials usually selected from materials *qualified for construction.*

High processing temperatures and pressures not practical for repair.

Materials should match *repair processes*, rather than manufacturing specifications.

NOTE: 14.7 psi autoclave $\neq$ vacuum.

Vacuum Bagging of Foaming Adhesives.

Under vacuum foaming adhesive drastically over-expands.

Significant in full depth core repairs in sandwich panels.

One repair manual avoids vacuum for foaming adhesive
Result: Poor bond integrity between the face sheet and core.

How can a skin to core disbond be repaired by a process which results in a skin-to-core bond with low integrity?

If a vacuum baggable foaming adhesive were identified, effective repairs could be performed.

NYLON TEAR PLIES

Some SRMs rely on removal of a nylon tear ply as the only surface preparation for bonding.

Despite the manufacturer's claims, release material *is* deposited on the surface as the tear ply is removed. Verified by X-Ray Diffraction.

Nylon peel plies must not be used on the bonding surface of repair patches. *(Should they be used in manufacture?)*

Some manuals specify hand abrasion of peel ply surfaces.

Failure to remove the surface impression by hand abrasion leaves contaminant.

Light grit blast is effective. Confirmed by X-Ray Diffraction.

POST-REPAIR VALIDATION OF ADHESIVE BONDS

Post-repair NDI shows no bond defects, and lap-shear tests pass. Is your bond quality assured? *NO!*

NDI and quality control tests do not assure durability.

Ultrasonic inspection will only indicate the presence of an air gap within the bond.

There is no reliable post-repair NDI method for determining the resistance of the bonds to environmental degradation.

Several destructive tests commonly used to "validate" the acceptability of the repairs.

- Lap shear test (ASTM D1002)
- Boeing Wedge Test (ASTM D3762-79).

No certainty that the specimens and repair have seen the same cure cycle temperatures and pressures.

Given the poor correlation between the specimen and the repair, these tests are meaningless.

SURFACE PREPARATION

The standard of surface preparation for adhesive bonding specified in many SRMs is poor.

There is a common perception that surface preparation is required for bond strength.

A corollary is that lightly loaded structures may not need surface preparation.

In reality, surface preparation is required for bond durability.

There is no adhesive bond which is so lightly loaded that surface preparation is unnecessary.

This deficiency alone contributes to the majority of repair failures.

CORRECT SURFACE PREPARATION PROCEDURES

Surface preparation must follow three basic steps;

- Solvent clean to remove soluble contamination.
- Abrade to expose a fresh chemically active surface.
- Chemically modify the active surface to facilitate the formation of a strong, durable bond.

Surface preparation for adhesive bonding is not just "cleaning".

Bonding relies on chemical reaction with surface.

Durable adhesive bonds are formed on interfaces which are resistant to hydration.

Metallic materials require chemical modification, either by oxide film control or by use of a chemical coupling agent.

All of the above steps must be undertaken for every adhesive bond, and they must follow the above sequence.

Abrasion is not to "rough the surface up"; generates fresh chemically active surface.

The best durability from phosphoric acid anodising, combined with a corrosion inhibiting primer.

Difficult to manage under field conditions.

- * PANTA process (Phosphoric Acid Non Tank Anodise).
- * PACS process, (Phosphoric Acid Contained System)
  - Effectiveness low for surfaces prepared at temperatures above 29.5*C (85*F).
  - No surface preparation is possible over fastener heads.

Coupling agents produce durable bonds.

- Non-acidic.
- Effective on a wide range of materials; will produce an effective bond over the fasteners as well as the surface of the structure.

INCORRECT SURFACE PREPARATION

1. "Scuff sand and solvent clean".

2. Abrasion followed by moisture removal on composite structure.
   - Heater blankets etc. in contact with the surface for a minimum of six hours.

3. Detergent wash prior to application of a coupling agent.
   - Detergent is almost impossible to remove from the surface, and inhibits the chemical reaction.

4. Use of chlorinated solvents for preparation of titanium alloys.
   - Chlorinated hydrocarbons may cause stress corrosion cracking in some titanium alloys.

5. No repair manual controls *Surface Exposure Time*.

6. No solvent clean at all.

7. No abrasion before etching.

Most would not pass a Boeing Wedge Test. (ASTM D3762-79 acceptance limits are absurd.)

HEALTH AND SAFETY

Safety measues must always be compatible with the bonding process.

> "..If rubber gloves are not available, *use a protective skin cream*..." (italics added)

Most hand creams contain agents (including silicones) to overcome de-fatting of skin tissue.

Totally incompatible with bonding processes.

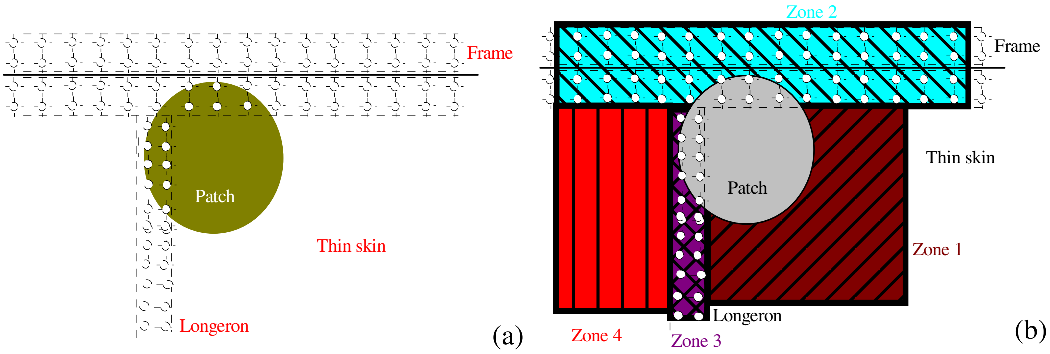
To infer that their use is acceptable, is to guarantee poor bond durability.

TEMPERATURE MEASUREMENT AND CONTROL

Essential to bond integrity, and also to the avoidance of overheating damage.

Influenced by several factors:

- The distribution of heat sources.
- Heat sinks.
- Location and method of installation of temperature sensors.
- How the data provided by sensors is used.



Each zone is heated by its own heat source.

Avoids undercure of the adhesive or overheating of the structure.

TEMPERATURE SENSORS

Temperature sensors perform two functions:

- Control the maximum temperatures to avoid overheat.
- To ensure adequate cure.

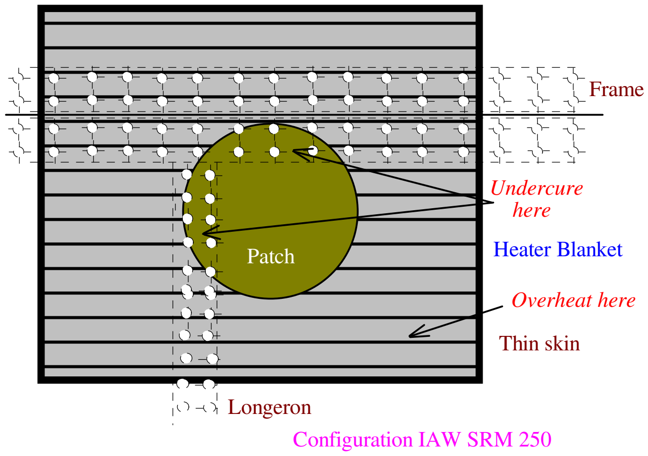
Sensors must be located *on the surface* of the structure such that the *maximum* temperature is measured under *each heated zone*.

Other sensors located *on the surface* of the structure to ensure adhesive cure by measurement of the *coldest* point *around the repair*.

TEMPERATURE CONTROL ERRORS

1. Almost every repair manual relies on a single heater blanket.

- Very high risk of either overheating the structure or undercuring the adhesive.



2. Use of a specific configuration of temperature sensors, (120 degrees apart).

3. Copper sheet over the repair patch to facilitate heat distribution.

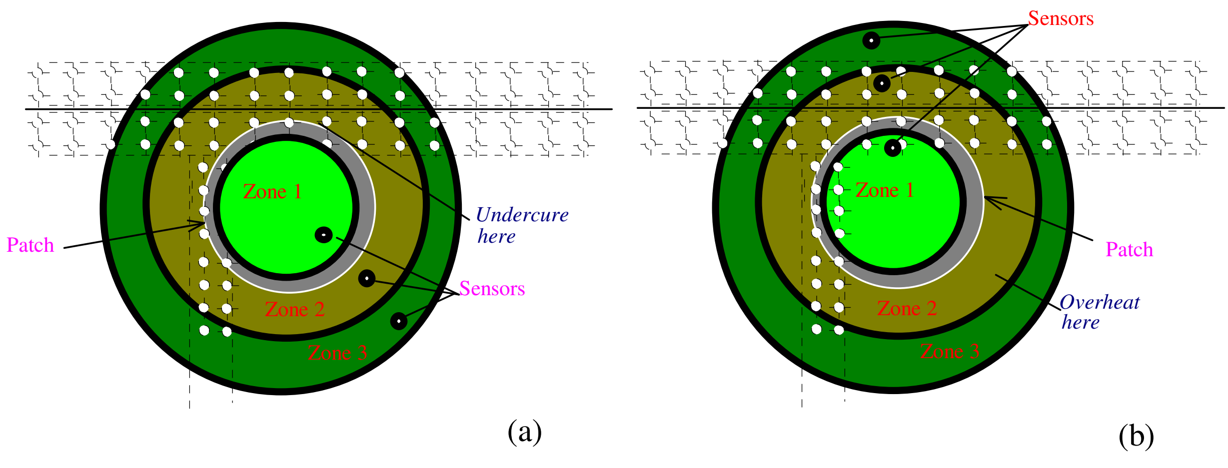
4. One thermocouple located on the copper sheet over the repair.

5. Extra sensors to correct heating problems.

6. Adjust the control system such that the low temperature is forced to increase.

7. Generalised heating such as heat lamps.

8. Multiple zone circular heater blankets.



HOT BONDERS

RAAF has developed HBC 43 a PC based hot bonding unit.

Six controlled outlets capable of supplying 14.4 kW

Sixteen temperature sensors.

All data displayed simultaneously in digital form.

COLOR coding to identify out-of-limits temperatures.

Graphical data presentation is also possible.

Control is zonal. Automatically searches each zone to find the highest temperature for control.

Identifies the coldest location near the repair to evaluate cure.

The system will automatically adjust the cure cycle duration to ensure the adhesive is fully cured.

HOT BONDER DEFICIENCIES

Too few controlled outlets. (Need at least three.)

Too few temperature sensors.

Data presented in two forms (digital and analog).

Limited data presented. Need to switch channels.

Hard copy analog record not the control thermocouple or the lowest temperature.

Over temperature alarm requires a scan of all channels to detect the errant sensor.

One controller started to count the soak time from the time when the controller should have reached the set point, even though the maximum temperature was only 60% of the cure temperature.

REPAIR AUTHORITY

Design authority for repairs is usually the OEM.

OEM knowledge of the structural loads essential for design.

Deficiencies in OEM application procedures for field repairs:

- Repairs have departed aircraft in flight.
- Components destroyed or life reduced by inappropriate repair procedures.
- Repair durability is poor, (22% repeat rate).

OEMs expertise is in aircraft design, fabrication and assembly.

Field procedures are significantly different from those used in production.

Unacceptable to expect the OEM to have definitive expertise in a field in which they have negligible experience.

A STANDARD IS REQUIRED.

Should be set by organisations with competence in field level repairs. viz. knowledgeable *operators*.

QUALITY MANAGEMENT

Adhesive bonding is defined (according to ISO 9001) as a *Special Process*

There is no post-repair inspection procedure which can guarantee successful performance of the process.

Quality is controlled by:

Certification by the technician of compliance with validated processes which have been clearly specified.

Rely on QUALITY MANAGEMENT, rather than assurance testing.

WHAT NEEDS STANDARDISATION ?

1. Repair materials.

2. Processes.
   - Repair fabrication.
   - Surface preparation.
   - Temperature measurement and control.

3. Process validation standards.

4. The form of process specifications.

5. Methods for materials quality before repair.

6. Pre- and post-repair and in-service inspection.

7. Training requirements and measurement of competence.

8. Minimum facilities.

9. Ground support equipment.

CONCLUSIONS:

Procedures in OEM approved SRMs have limited validity.

Deficiencies contribute significantly to the cost of ownership of aircraft components.

A Standard should be established for repair manuals such that validated procedures are provided at the time of introduction of an aircraft type into service.

That Standard must define the requirements for process validation, and the qualifications required for personnel who perform bonded and composite repairs.

Materials should be compatible with the repair method available in the field, rather than selection only of the material used for production.

Any body which undertakes the writing of this Standard must contain capable aircraft operators.

An appeal is also made for regulatory authorities to recognise the role of application technology in bonded and composite repairs, such that processes receive a higher standing, at least equivalent to the current focus on repair design regulations.