CertBond
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WG4: Guided lines for bonded repairs

Author(s): Wiesław Ostachowicz
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Challenges and Considerations in Bonded Repairs:

Surface Preparation
Material Compatibility
Adhesive Selection
Quality Control and Inspection
Environmental Considerations

Advanced Techniques for Monitoring Bonded Repairs:

Guided Ultrasonics
Acoustic Emission (AE)
Digital Shearography
Embedded Sensors
Finite Element Analysis (FEA)

Bonded repairs require careful design and strict processing control to ensure good quality for the specific materials and processes used for a given structure.
Common processing errors, such as high humidity, improper surface preparation, bondline contamination, and insufficient control of cure temperature (either overheating or under-cure), can cause undetectable low bondline strengths.
Also, loss of vacuum or pressure and using materials outside of time, temperature, or calendar life can result in undetectable low bond strengths.
It can be assumed that there are currently no reliable non-destructive inspection (NDE) techniques that would guarantee that the bonded assembly has reached its full strength.
When undertaking the task of glueing structural elements, the adhesive, the base structure, and the surfaces of the repair material must be addressed. In addition, the technical properties of the base material and repair materials should also be considered when justifying the need for glued repair.

There are several hazards to consider in the bonding process. In the case of metals, these are primarily fatigue and corrosion. In the case of a compound threat, it is primarily an impact. In addition, remember to adopt the appropriate tolerance philosophy to fatigue and damage.
When bonding a mixed metal and composite configuration, problems with the hybrid structure may arise, such as galvanic incompatibilities and differences in the coefficient of thermal expansion.

A bonded repair should be designed in such a way that its failure does not become a critical failure mode for the underlying structure.

In the case of the service of glued structures, another problem arises related to weak bonding. This problem results from environmental influences and can unpredictably deteriorate bond strength over time. The effects of exposure to service loads and environmental ageing should also be considered when justifying the need for repairs.
Good repair designs, qualified materials, proven processes, well-trained and experienced personnel, and the existence of an extensive database of structural justifications reduce the risk of disintegration or weak bonds.

The justification for the need for repair following the procedures is provided by previously developed specific data of the repair project. They describe the construction details, materials, and process specifications that must be followed when repairing. In addition, they provide a reasonable degree of certainty that the weld will reach its full strength.
However, experience to date has shown that there have been cases where critical structures with approved bonded repairs had undetected defects that resulted in insufficient weld strength.
Therefore, it is necessary to account for weak bonds in the repair and repair structure's design and substantiation. This results in the necessity to limit the size of bonded repairs such that the considered structure can sustain required regulatory loads in the event of a failed bonded repair.
Data confirming that the structures to be repaired should include tests or analyses that meet the applicable requirements for fatigue and damage tolerance, static and dynamic strength, material specifications and worker ship, and acceptable statistical data.

The information developed for complete bonded repair substantiation is typically unavailable to the maintenance engineering community. Furthermore, significant investment in resources, testing and analyses is needed to demonstrate compliance with the appropriate rules for structural substantiation of a given structure.
In-service bonded repairs are generally performed less frequently than production bonding activities. Very often, such repairs are performed in less established service environments. As a result, the repair is more susceptible to changes in material properties, which may alter the basis for repair substantiation. The result is a lower ultimate load capacity in the repaired condition. As a result, operating conditions and the availability of experts for warranty repairs should be subject to specific regulations. Therefore, there is a need to develop supplementary maintenance documents. Such observations lead to more conservative (more minor) in-service repair limits than those allowed for factory warranty repairs.
The bonded repair should not exceed reasonable dimensional limits. The adhesive repair design and repair instructions should also include descriptions of the facilities, tools, equipment and skills of the technical staff that justify the required criteria necessary for the correct completion of the repair.

In-service repairs in many cases require the use of devices, equipment and tools adapted to work with the assembled part. In these cases, special care should be taken to avoid contamination of the repaired parts of the structure. Thus, the desired laying, bagging and curing conditions must be ensured.

Repair manuals for composite structures usually limit the size of repairs related to the operation of the structure. In general, the size of the repair area depends on the location of the considered part. In addition, the databases and access to operational experience are taken into account. Repairs are carried out in accordance with the instructions that apply to the repaired object. In addition, the choice of repair method should comply with all restrictions. Otherwise, the repair would require special approval justifying deviations from the provisions in the manual. In some cases, by way of exception, new repair processes are established.
In some special cases, additional criteria are required to ensure that the bonded repair size limit is correctly defined.

For instance:

- Before the repair, a comprehensive characterization of the damage is made in order to determine the full extent of the damage. The potential for significant areas of hidden damage should also be considered. These damages are dependent on the configuration of the repaired part and the event causing the damage.

- A bonded repair is one or more repairs made at the same time and under similar processes (on the tested part of the structure). The potential interaction between repairs may be relevant to the residual strength.

- In some cases, repaired components may require a full assessment of fatigue and damage tolerance. When evaluating the adjacent structure in multi-load path design, the effect of a failed composite repair must be considered.

- In the case of repairs to structural components subject to pressure loading, where partial or complete failure of the repair could lead to loss of pressure, rapid decompression should be considered in the assessment.

In exceptional cases, there may be additional considerations in which a repair failure may significantly reduce the safety of the entire structure.

For instance:

When repairing composite fuel tanks where failure could result in fuel leaks.
For bonded repair of composite and metal engine parts, consideration should be given to whether a failed repair could result in damage to the engine components.
Such and similar cases require additional engineering assessment at an early stage of the ongoing processes. Whenever additional data is needed to justify the extension of existing repair size limits, further detailed analysis should be undertaken.
Bonded joints are of interest to manufacturers and users of many structures in aviation, civil engineering, offshore engineering, marine structures and many others. The influence of many environmental factors, such as humidity, temperature, chemical pollution and many others, is critically pointed out. Environmental factors undoubtedly significantly impact the mechanical properties of composite bonded repairs.

In recent years, many significant improvements have been made to improve the environmental resistance of composite structures (including bonded repairs). Among other things, new

technologically advanced composite materials are being produced, curing methods have been improved, manufacturing glued joints have been improved, and bonded repairs have been improved.
Undoubtedly, there is a strong need to improve the repair of composites exposed to environmental factors such as moisture, temperature, etc. The main goal is the need to obtain reliable and repeatable repairs. Below is an overview of some scientific challenges and opportunities to develop more durable and cost-effective composite repair technologies with a short repair cycle.
It turned out that there is no general trend in the influence of moisture and temperature on the glued joint. This technological process depends on many factors, such as temperature, method, adhesive and composite laminate.
Thus, it was determined that there was an urgent need to evaluate the performance of an advanced composite laminate and adhesive material at high and low temperatures and various humidity conditions. Of course, in this case, it is about entirely using the material for glued repair joints. Advanced structural adhesives and composite materials can provide opportunities to increase the strength and long-term durability of bonded repairs.

- The time necessary to fabricate a bonded repair depends mainly on drying the composites before repairing and curing the same repair joints. Of course, this time significantly impacts the related economic aspects. Materials curing at low temperatures in a short cycle should have a higher glass transition temperature. Such material characteristics are of great importance in the case of bonded repairs. Current composite repair practice provides for complete drying of the composite. However, it is not always necessary. Thus, low-temperature curing and incomplete drying help reduce repair time. Of course, this assumption has a significant economic impact.

- Efficiency can be improved by introducing new composite repair processes. Recently, a new vacuum curing method has been implemented, providing good repair quality with low voids. A similar effect can be obtained by the autoclave curing method. This way, co-bonded joints absorb less moisture compared to co-curing standard methods. However, there is a need for further research on this aspect and planning more tests.

- The research focuses on assessing the impact of moisture and temperature on the technical condition of glued joints. These studies still show significant differences in the physical properties of the bonded and adhesive material, the method of processing the material, the temperature of the adhesive curing and the configuration of the samples. Therefore, it is sought to establish preliminary knowledge, primarily concerning curing temperature, glass transition temperature, moisture absorption-desorption limit, swelling, and thermal expansion. In addition, knowledge of the behaviour of the adhesive and composite at the specified temperature and humidity level should be acquired. Above these parameters, the structure will be exposed during the service period for the best-used material to obtain better composite repair joints.

 The influence of moisture and temperature on composite joints was also tested. At the same time, it was found that there is a great need for such research because the combined effect of both parameters is more severe than the individual condition.

 In some cases, the frequency of repairs and maintenance of the composite structure can be reduced. This is possible thanks to the introduction of self-healing materials, as they can improve the structure's durability. It is also sought that the structure bonded with the composite can be easily detached without damaging the structure. Following this process, the items mentioned above can be reused and recycled.

 The criterion of failure of composite glued joints, considering the parameters of humidity and temperature, is the main limitation in the case of a scarf and stepped joints. The finite element method is used to optimize the geometry and material parameters of the repair joint to obtain better performance parameters of the structure.

 The model of cohesive zones successfully considers the environmental problem at adhesive joints. Using this model, connections can be analyzed, considering the influence of moisture and temperature. Long-term sustainability is still a significant concern, as it is difficult to predict the behaviour of joints in the environment accurately.

 The open-face swatch technique has introduced an accelerated ageing process which helps to reduce the exposure time. The open-face approach offers the potential for accurate predictions of long-term joint behaviour using cohesion zone modelling. The said process occurs for any adhesive system that exhibits uneven degradation.

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Definitions

Adherend

A body that is held to another body, usually by an adhesive. A detail or part prepared for bonding.

Adhesion

The state in which two surfaces are held together by interphase forces.

mechanical adhesion, n-adhesion between surfaces in which the adhesive holds the parts together by interlocking action. Specific adhesion, n-adhesion between surfaces which are held together by intermolecular forces of a chemical or physical nature.

Adhesive

A substance capable of holding two materials together by surface attachment. Adhesive can be in film, liquid, or paste form. In this context, the term is used to denote structural adhesives, i.e., those which create attachments capable of transmitting significant structural loads.

Adhesion Failure

Separation of the adhesive-adherend interface due to inadequate bonding.

Bond

The adhesion of one surface to another, with or without the use of an adhesive as a bonding agent.

Bonded Joint\Structure

See Structural Bonding (The term 'Bonded Joint\Structure' has typically been considered to mean Secondary Bonded structure. However, increasing diversity of material forms and processes has broadened the common meaning to include Co-bonding.)

Bonded Repair

A repair means elimination of damage and/or restoration to an airworthy condition following initial release into service by the manufacturer. For the purposes of this Policy, Bonded Repair refers to repairs using Co-bonding or Secondary Bonding, as described in these definitions. This includes repairs that use uncured skins bonded over sandwich core.

Co-bonded Structure

Components bonded together during cure of one of the components.

Co-cured Structure

Uncured components cured together.

Cohesion

The state in which the constituents of a mass of material are held together by chemical and physical forces.

Cohesive Failure

Rupture of a bonded assembly in which the separation appears visually to be in the adhesive or the adherend.

Critical Structure

A load bearing structure/element whose integrity is essential in maintaining the overall flight safety of the aircraft.

<u>Critical Failure Mode</u>
The failure mode most likely to compromise safety.

<u>Cure</u>
To develop the structural properties of an adhesive (or composite resin) by chemical reaction.

<u>Debond</u>
Same as disbond.

<u>Disbond</u>
An area within a bonded interface between two adherends in which an adhesion failure has occurred. It may occur at any time during the life of the substructure and may arise from a wide variety of causes. Also, colloquially, an area of separation between two lamina in the finished laminate (in this case the term “delamination” is normally preferred).

<u>In-Production Repair</u>
Repair completed before initial release of an aircraft or component from production for which design and substantiation has been appropriately supported by the design approval holder.

<u>In-service repair</u>
Repair completed following initial aircraft release from production by TCH (or appropriately approved TCH original component subcontractors).

<u>Primary Structure</u>
The structure which carries flight, ground, or pressurisation loads, and whose failure would reduce the structural integrity of the airplane.

<u>Principal Structural Element</u>
Principal structural elements are those which contribute significantly to carrying flight, ground, and pressurisation loads, and whose failure could result in catastrophic failure of the aeroplane. Principal structural elements include all structure susceptible to fatigue cracking, which could contribute to a catastrophic failure.

<u>Sandwich Constructions</u>
Panels composed of a lightweight core material, such as honeycomb, foamed plastic, etc. to which two relatively thin, dense, high-strength or high-stiffness faces or skins are adherends.

<u>Secondary Bond</u>
The joining together, by the process of adhesive bonding of two or more previously-cured composite parts or metal parts, during which the principal chemical or thermal reaction occurring is the curing of the adhesive itself.

<u>Structural Bonding</u>
A structural joint created by the process of adhesive bonding, comprising of one or more previously-cured composite or metal parts (referred to as adherends). Also, see the definition of “Co-cured Structure”.

<u>Weak Bond</u>
A bond line with mechanical properties lower than expected which cannot be detected reliably using non-destructive inspection (NDI) procedures currently applied by industry. Such situations result from poor chemical bonding.

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