|  |  |  |
| --- | --- | --- |
|  | **Policy Statement** | |
| **Subject:**  Bonded Repair Size Limits | **Date:** mm/dd/yy  **Initiated By:**  AIR-100 | Policy No:PS-AIR-20(xxx)-xx-xx |

**A. Summary**

This policy reviews the regulatory basis and establishes the guidance in setting size limits for bonded repair to critical composite (monolithic and sandwich structures) and metallic structure. Bonded repair of critical structure must first be constrained to the sizes allowed by substantiating design data. This policy informs Aircraft Certification Office (ACO) engineers and designees that due to inspection limitations, bonded repair must be further limited to a maximum size whereby limit load residual strength can be demonstrated with a complete or partial failure of the bond within the repair or base structure arresting design features. This policy is not intended for minor repairs.

**B. Definition of Key Terms**

The following definitions apply to this policy statement.

# 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 purpose of this policy, bonded repair refers to repair using co-bonding or secondary bonding; including repair using uncured skins bonded over sandwich core.

# Critical Structure: A load bearing structure/element whose integrity is essential in maintaining the overall flight safety of the aircraft. This definition was adopted for this policy because there are differences in the definitions of primary structure, secondary structure, and principle structural elements (PSE) when considering the different categories of aircraft. For example, PSE are critical structures for Transport Category Airplanes (AC 20-107B).

# Structural Bonding: A structural joint created by the process of adhesive bonding, comprised of one or more previously-cured composite or metal parts (referred to as adherend) (AC 20-107B).

# Weak Bond: A bond line with mechanical properties that is lower than expected which cannot be detected using current industry non-destructive inspection (NDI) techniques. Weak bonds result from poor chemical bonding[[1]](#footnote-2) (AC 20-107B).

Additional definitions of terms are contained in Attachment 1.

**C. Current Regulatory and Advisory Material**

1. **Regulations.**
2. Maintenance rules include the general requirements applicable to various aircraft types and operations, and any additional requirements deemed specific to operating provisions. The general maintenance rules include:

* 14 CFR Part 43 - Maintenance, Preventive Maintenance, Rebuilding, and Alteration.

1. To ensure the safe employment of composites in manufacture and repair of aircraft products, these products need to be in compliance with the airworthiness standards set forth in 14 CFR, which include:

* 14 CFR 21.21 – Issue of type certificate: normal, utility, acrobatic, commuter, and transport category aircraft; manned free balloons; special classes of aircraft; aircraft engines; propellers.
* 14 CFR 23.573 – Damage tolerance and fatigue evaluation of structure.
* 14 CFR 25.571 – Damage tolerance and fatigue evaluation of structure.
* 14 CFR 27.573 – Damage tolerance and fatigue evaluation of composite rotorcraft structures.
* 14 CFR 29.573 - Damage tolerance and fatigue evaluation of composite rotorcraft structures.

A comprehensive list of relevant regulations is contained in Attachment 1 and Advisory Circular (AC) 20-107B, Composite Aircraft Structure, Appendix 1.

1. **Guidance.** Additional policy and advisory materialsare contained in Attachment 1.

**D. Background and Relevant Past Practice**

The continued advancement of bonding in small airplane and rotorcraft structures and recent implementation of bonding as a principal means of fabricating critical structures on transport airplanes (e.g., pressure hull and wing box structure) increases the likelihood of bonding as a viable repair option. In the past, bonded repairs on transport airframe structures were generally limited to control surfaces and non-critical structures. Service experience shows these past repairs were not always successful, resulting in unexpected repair bond failures. Without obvious cause for the bond failures, the FAA concludes that bonded repair of critical structure is a potential safety threat.

Bonded repairs require careful design and processing 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, and bondline contamination can cause undetectable low bondline strengths. There are no currently available non-destructive inspection (NDI) techniques to ensure a bonded assembly has achieved full strength.

FAA approved substantiation data is required to demonstrate compliance with the regulations. The data includes approved material and process specifications that must be followed when installing a repair. Past experience has shown that when repairs are installed in accordance with these specifications there is a reasonable confidence the bondline will achieve full strength. There have been cases where critical structures with approved bonded repairs have contained undetected flaws that have resulted in inadequate strength of the bondline. Therefore, it is necessary to account for weak bonds in the design and substantiation of the repair and repaired structure. This results in the necessity to limit the size of bonded repairs such that the aircraft structure can sustain minimum regulatory loads in the event of a failed bonded repair. The substantiating data that supports proof of structure for the bonded repair must include the tests and supporting analyses that meet existing regulatory requirements for fatigue and damage tolerance, static and dynamic strength, material and fabrications specification, statistical material allowables, flutter protection, and lightning protection.

An industry composite working group met over several years to discuss the technical issues for bonded structural repairs and the best practices needed to show compliance with the regulations. Supplementary background information compiled in these meetings is included in a public reference[[2]](#footnote-3). Attachment 1 documents some of the discussions associated with experience in bonded field repairs and a need to follow approved documentation, while avoiding reverse engineering approaches for specific critical composite structure.

**E. Policy**

Bonded repairs must meet the appropriate airworthiness requirements for the structure they are designed to cover; including material and process qualification, static strength (ultimate load), and fatigue and damage tolerance. Bonded repairs to critical structure should follow the guidance specified in this policy.

Bonded repairs may not require size limits for structure where there is no safety risk in the event of repair failure. In contrast, repair size limits may be restrictive for critical structures addressed by this policy.

The maximum size and other limits of a bonded repair are first constrained by the limitations inherent in the design to be repaired. There may also be repair size limits or other constraints associated with the substantiating data used to meet the appropriate rules. These include:

1. Repair processes that produce a consistently sound structure and critical fabrication processes must be performed under approved process specifications using approved and qualified repair materials. Repair designs must be approved by the FAA, or an appropriately rated designee, and must be performed and inspected by properly trained/qualified individuals with suitable experience (§ 43.3).

2. Repair designs must have structural substantiation based on tests or analyses supported by tests. Per § 21.21, there cannot be any feature or characteristic which makes an aircraft unsafe. The bonded repair must be shown to be capable of withstanding ultimate static loads and be shown to retain the required residual strength, as defined in the applicable 14 CFR parts (i.e., 2x.571/573). The applicable regulations (see appendix) include, but are not limited to;

* Fatigue and damage tolerance, (§§ 23.573, 25.571, 27.573 & 29.573)
* Static and dynamic strength requirements, (§§ 2x.305 & 2x.307)
* Material and fabrications specification requirements, (§§ 2x.603 & 2x.605)
* A requirement for statistical material design values, (§§ 2x.613)
* Flutter protection, and (§§ 2x.629)
* Lightning protection. (§§2x.954 & 2x.981)

3. Data supporting the bonded repair must include inspections that are capable of detecting complete or partial failure (within arresting design features) of the bond line. Inspection methods, thresholds and intervals must be set that consider the specific damage threats, criticality of the structure and the magnitude of the residual strength in the case of a failed repair (i.e., a failed repair which could result in a residual strength near limit load is recommended to be inspected with increased frequency).

All critical structure must have a repair size limit nolarger than a size that allows limit load strength to be achieved with the repair failed or failed within constraints of the arresting design features (in the repair or base structure). This requirement is needed to ensure limit load capability in the event of bonded repair failures such as “weak bonds”, which result from rare processing mistakes or problems. As noted in item 2 from above, bonded repairs must be designed to be damage tolerant in order to preclude catastrophic failure due to fatigue, corrosion, manufacturing defects or accidental damage throughout the operational life of the aircraft. Manufacturing defects, which can be detected with available inspection methods (i.e., porosity, disbonds and other anomalies) must be controlled within inspectable limits and included in the damage tolerance assessment as appropriate. Per item 1 above, the design and process specifications should make manufacturing defects for which inspection methods are not available, (i.e., weak bonds) extremely rare. Regardless, the design of the repair still must account for these rare events and considered in the damage tolerance evaluation. The regulatory considerations for accounting for these rare events may be addressed as follows:

* When complying with 14 CFR 23.573(a)(5)(i), all part 23 critical structure must have a bonded repair size limit nolarger than a size that allows limit load strength [per loads defined in 23.573 (a)(3)] to be achieved with the repair failed or failed within constraints of the arresting design features (in the repair or base structure).
* When complying with 14 CFR 25.571, 27.573 and 29.573, all part 25 PSE and parts 27 and 29 critical structures have a minimum required residual strength of limit load (as defined in the regulations for each type of aircraft) for all assumed detectable damage types. Limiting the bonded repair size to sustain minimum loads with the bond failed or failed within constraints of the arresting design features (in the repair or base structure) is an acceptable approach to address potential weak bonds.

AC 20-107B provides a further description of the bonded structure or repair qualification, quality controls and reliable procedures needed to ensure weak bonds are extremely rare. The bonded repair size limits are first constrained by the data collected in establishing sound fabrication processes and substantiating the design. In addition, the bonded repair may be no larger than needed in demonstrating residual strength for a failed repair. All other approaches applied in establishing bonded repair size limits must have approved substantiating data, inspections or other procedures, as necessary, to prevent catastrophic failure.

Residual strength requirements with the repair failed must be shown by tests or analysis supported by tests. Some structures have limit load capability, even with a very large failed repair. If significant changes in structural stiffness and/or geometry result from the failed repair, analysis for flutter and other aeroelastic instabilities should be performed to ensure the failed repair does not lead to other flight safety issues.

Documentation on all repairs should be added to the maintenance records for the specific part number. This information supports future maintenance damage disposition and repair activities performed on the same part. It also helps ensure the associated data, including repair design and process details, structural substantiation evidence, and inspection procedures, are available to those evaluating airworthiness. Any failed bonded metal or composite repairs should be reported through the normal incident or accident reporting process (e.g., failure, malfunction, or defect reports required by 14 CFR 21.3 or service difficulty reports required by 14 CFR 121.703).

The inspection of bonded repairs, including the specified inspection methods, interval and detection criteria, must be defined based on substantiating tests, analyses, trials, and other safety risk mitigation procedures.

1. **Effect of Policy**

The general policy stated in this document does not constitute a new regulation or create what the courts refer to as a “binding norm.”

Coordination is needed between the policy-issuing office and the responsible implementing office when:

• Using a method of compliance outside of this established policy; or

• Not approving an applicant’s proposal that meets this policy.

**G. Implementation**

This policy discusses compliance methods that should be applied to design approval for major bonded repair and/or alteration projects. The compliance methods apply to those projects with an application date that is on or after the effective date of the policy. If the date of application precedes the effective date of the policy and the methods of compliance have already been coordinated with and approved by the FAA or its designee, the applicant may choose to either follow the previously acceptable methods of compliance or follow the guidance contained in this policy.

**H. Conclusion**

This policy responds to the rapidly increasing trend of using bonded repairs to critical structures on transport aircraft in service. It also supports the large amounts of bonded structure that have existed in numerous critical structures for small airplanes and rotorcraft. It addresses the compliance issues for approval of bonded repair and related size limits that mitigate the risks of: 1) repairs with insufficient data for substantiation and 2) catastrophic structural failure due to a potentially undetectable “weak bond” that may occur in a bonded repair. This policy applies to both critical bonded structures consisting of both composite (monolithic and sandwich structures) and metallic materials.

The size of a bonded repair to critical structure is first constrained to the size limits allowed by substantiating repair design data, including considerations for material & process control, static strength, flutter, fatigue, damage tolerance, lightning protection and other appropriate regulations for the specific critical structure. Due to the fact that post-repair inspection techniques cannot determine the bond strength, a bonded repair must also be designed to avoid potential catastrophic failure. As a result, all critical structure must have a repair size limit nolarger than a size that allows limit load residual strength capability with the repair completely failed, or failed within arresting design features. Residual strength requirements should be shown by tests or analysis supported by tests. Some structure may be shown to have limit load capability, even with a very large failed repair. If significant changes in structural stiffness result from the failed repair, analysis for flutter and other aeroelastic instabilities must be performed to ensure the failed repair does not lead to other flight safety issues.

James D. Seipel

Acting Manager, Design, Manufacturing &

Airworthiness Division,

Aircraft Certification Service

1. **Definition of Key Terms**

These additional definitions may assist the reader in understanding this policy statement.

**Adherend (SAE AIR 4844):** A body that is held to another body, usually by an adhesive.

A detail or part prepared for bonding.

**Adhesion (ASTM D 907-8b):** 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[[3]](#footnote-4).

**Adhesive** (SAE AIR 4844): 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** (CMH-17, Vol.1, Chapter 1 rev.F): The adhesion of one surface to another, with or without the use of an adhesive as a bonding agent.[[4]](#footnote-5)

**Bonded Joint\Structure** (14 CFR 23.573(a)(5)): 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** – see Figure 1.

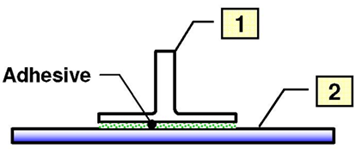
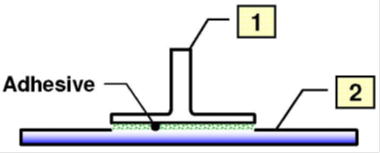
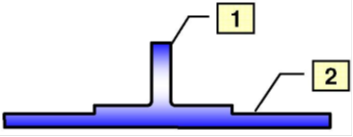
**Co-bonded Structure**: Components bonded together during cure of one of the components.

**Co-cured Structure**: Uncured components cured together. Bonded repairs of co-cured structure are covered by this policy.

**Cohesion** (ASTM 907-8b): The state in which the constituents of a mass of material are held together by chemical and physical forces.

**Cohesive Failure** (ASTM D 907-8b): Rupture of a bonded assembly in which the separation appears visually to be in the adhesive or the adherend.

**Composite Material** (SAE AIR 4844): A combination of two or more materials (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a macro scale. The constituents retain their identities; that is, they do not dissolve or merge completely into one another although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another. (See ISO 472) Composite materials are usually man-made and created to obtain properties that cannot be achieved by any of the components acting alone.



|  |  |  |
| --- | --- | --- |
| **Co-Curing:**  Components cured together  - Component 1 uncured  - Component 2 uncured  (may include additional adhesive and/or continuous structural plies common to both Components 1 and 2) | **Secondary Bonding**  **(Structural Bonding):**  Components bonded together with separate bonding operation  - Component 1 cured\*  - Component 2 cured\*  \* or metal | **Co-Bonding**  **(Structural Bonding):**  Components bonded together during cure of one of the components  - Component 1 cured\*  - Component 2 uncured  Or  - Component 1 uncured  - Component 2 cured\*  \* or metal  (may not include additional adhesive) |

**Figure 1. Fabrication Differences for Co-Curing and Structural Bonding**

(Airbus – Composites Workshop Tokyo 2009, with permission)

**Critical Failure Mode**: The failure mode most likely to compromise safety.

**Cure** (modified ASTM D 907-8b): To develop the structural properties of an adhesive (or composite resin) by chemical reaction.

**Debond** (AC 20-107B): Same as disbond.[[5]](#footnote-6)

**Disbond** (AC 20-107B): An area within a bonded interface between two adherends in which an adhesion failure or separation has occurred.[[6]](#footnote-7) 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.)

**Initial Damage Mode**: The first damage mode in the failure sequence, which may, or may not, be the same as the **Critical Failure Mode**.

**Interim Damage Mode**: Any damage mode(s), which may exist between **Initial Damage Mode** and **Critical Failure Modes**.

**Primary Structure** (AC 20-107B)**:** The structure which carries flight, ground, or pressurization loads, and whose failure would reduce the structural integrity of the airplane.

**Principal Structural Element (PSE)** (AC 25.571-1D):An element that contributes significantly to the carrying of flight, ground, or pressurization loads, and whose integrity is essential in maintaining the overall structural integrity of the airplane. Principal structural elements include all structure susceptible to fatigue cracking, which could contribute to a catastrophic failure.

**Sandwich Constructions** (SAE AIR 4844): 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. (See CMH-17 Volume 6.)

**Secondary Bond** (CMH-17 Vol.1 Chapter 1 rev. F): The joining together, by the process of adhesive bonding of two or more already-cured composite parts or metal parts, during which the only chemical or thermal reaction occurring is the curing of the adhesive itself.[[7]](#footnote-8)

1. **Current Regulatory and Advisory Material**

This section provides additional details on relevant regulations and advisory materials related to this policy.

1. **Regulations.**
2. Typically, the maintenance related rules would include the general requirements that may apply to various aircraft types and operations, and any additional requirements that may be deemed specific to operating provisions. The general maintenance rules may include:

* 14 CFR Part 43 - Maintenance, Preventive Maintenance, Rebuilding, and Alteration.
* 14 CFR Part 65 [Certification: Airman other than Flight Crewmembers]:
  + Subpart D – Mechanics.
  + Subpart E – Repairmen.
* 14 CFR Part 145 - Repair Stations.

b. To ensure the safe employment of composites in manufacturing and repairing of aircraft products, these products need to be in compliance with the airworthiness standards set forth in 14 CFR. These airworthiness standards may include:

A list of applicable regulations deemed relevant in general is also presented in AC 20-107B, Composite Aircraft Structure, Appendix 1.

For the specific purpose of this policy, the applicable regulations may include:

* Sections 23.305, 25.305, 27.305, and 29.305 - Strength and deformation.
* Sections 23.307, 25.307, 27.307, and 29.307 - Proof of structure.
* Section 23.601 and 25.601 - General
* Section 27.601 and 29.601 - Design
* Section 23.603 - Materials and workmanship.
* Sections 25.603, 27.603, and 29.603 - Materials.
* Sections 23.605, 25.605, 27.605, and 29.605 - Fabrication methods.

1. **Guidance.** Guidance may include the AC and policy statements (PS). The guidance listed below is deemed supportive to the purposes of this policy.
2. Advisory Circulars
3. AC 20-107B [Change 1], *Composite Aircraft Structure* [8/2010]
4. AC 21-26A, Quality Control for the Manufacture of Composite Structures [7/2010]
5. AC 21-47, Submittal of Data to an ACO, a DER or an ODA for a Major Repair or a Major Alteration [9/2010]
6. AC 23-15A [Change 1], Small Airplane Certification Compliance Program [12/2003]
7. AC 25.571-1D, Damage Tolerance and Fatigue Evaluation of Structure [1/2011]
8. AC 27 MG 8, Substantiation of Composite Rotorcraft Structure [4/2006]
9. AC 29 MG 8, Substantiation of Composite Rotorcraft Structure [4/2006]
10. AC 43-214, Repairs and Alterations to Composite and Bonded Aircraft Structure [4/2013] [Note: AC 145-6 was cancelled.]
11. Policy Statements
12. PS-ACE100-2001-006, Static Strength Substantiation of Composite Airplane Structure [12/2001]
13. PS-ACE100-2005-10038, Bonded Joints and Structures – Technical Issues and Certification Considerations [9/2005]
14. **Additional Background and Relevant Past Practice**

In-service bonded repairs are typically performed less frequently than production bonding activities and often occur in less stabilized service environments. As a result, an in-service bonded repair is more likely to have material property variation, which may alter the basis for repair substantiation and result in less than ultimate load capability in the repaired condition. Therefore, consideration of field conditions and the use of experts in bonded in-service repairs have been used by industry to develop the supporting maintenance documents. The result of such considerations may yield more conservative (smaller) repair size limits for repairs performed in the field than may be allowed with bonded factory repairs.

Industry repair manuals typically state that the bonded repair should not exceed substantiated size limits. The bonded repair design and fabrication instructions also outline the facilities, tooling, equipment, and technician skills required to complete the repair. This documentation also describes the conditions, equipment, and tools adopted to mate with the assembled part when field repairs are performed on the airplane. Special notes are also added to describe the care that must be taken to avoid contamination and to maintain the desired layup, bagging, and cure conditions.

The Original Equipment Manufacturer (OEM) Structural Repair Manual (SRM) typically limits bonded repair size, often as a function of part location, based on their internal databases and access to field experiences. Bonded repairs performed per an aircraft SRM are expected to comply with all the processing details and limitations. The bonded repair would otherwise require a specific approval substantiating deviations or new processes (see details outlined in this policy).

The existing industry training materials note that reverse engineering practices will generally not equip the designer with a full understanding of the knowledge basis that is necessary to expand repair size limits defined in the SRM. This has been done to discourage the premise that structural substantiation has been achieved for the “reversed-engineered” design or that a safe product will result, unless additional data is generated to address considerations documented in this policy.

It has been argued that a part can be remanufactured well beyond published repair size limits using OEM specified materials, processes, tooling, and structural details without additional data since it is substantiated by the original type certification. Unless receiving assistance from the OEM, it is unlikely that this can be accomplished without further substantiating data development.

1. Poor chemical bonding is due to several contributing factors (e.g., material incompatibility, pre-bond surface contamination, use of out-of-date materials, and environmental degradation of the adherends). [↑](#footnote-ref-2)
2. “Industry and Regulatory Interface in Developing Composite Airframe Guidance and Policy”, Cindy Ashforth, Rusty Jones and Larry Ilcewicz, to be published in the Proceedings for the American Society for Composites 29th Technical Conference, September 8-10, 2014. [↑](#footnote-ref-3)
3. Chemical adhesion is the primary goal for structural bonding discussed in this policy [↑](#footnote-ref-4)
4. Uncured composite adherends may carry enough matrix material to complete adequate bonding when cured in place to form a bonded repair [↑](#footnote-ref-5)
5. “Debond” and “disbond” are used interchangeably throughout literature. The term “debond” may also apply to the process of deliberately separating joints, e.g., using heat guns, freezing etc., for the purposes of disassembly for access, repair etc. [↑](#footnote-ref-6)
6. Adhesion failure or separation is usually unintended. [↑](#footnote-ref-7)
7. The word ‘Secondary’, historically used within the term ‘Secondary Bonding’, has been mistakenly considered to imply a lesser significance, e.g., in the sense of Secondary structure etc. For this reason, the intention of the FAA and other Civil Aviation Authorities (CAAs) is to avoid using this term in regulatory text. When used, the understanding of the term Secondary Bond should be clarified with the user. [↑](#footnote-ref-8)