



U.S. Department  
of Transportation  
**Federal Aviation  
Administration**

# Policy Statement

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**Subject:** Bonded Repair Size Limits

**Date:** 11/24/14

**Policy No:**

PS-AIR-100-14-130-001

**Initiated By:**

AIR-100

## 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 or pre-cured 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 because there are differences in the definitions of primary structure, secondary structure, and principal structural elements (PSE) when considering the different categories of aircraft (taken from Advisory Circular (AC) 20-107B). For each product category, critical structure applies to those structures that must be shown to meet Title 14, Code of Federal Regulations (14 CFR) 2X.571/573. For example, critical structures for Transport Category Airplanes are PSE.

**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 reliably detected using current industry non-destructive inspection (NDI) techniques. Weak bonds result from poor chemical bonding<sup>1</sup> (AC 20-107B).

Additional definitions of terms are contained in Attachment 1.

## **C. Current Regulatory and Advisory Material**

### **1. Regulations.**

**a.** 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.

**b.** 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 AC 20-107B, Composite Aircraft Structure, Appendix 1.

**2. Guidance.** Policy and advisory materials are 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

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<sup>1</sup> 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).

viable repair option. In the past, bonded repairs on transport airframe structures were generally limited to some critical structures (e.g., control surfaces) and non-critical structures. Service experience shows these past repairs were not always successful, resulting in unexpected repair bond failures. Without a reliable inspection technique to detect weak bonds until related bond failures, the FAA concludes that bonded repair of critical structure is a potential safety threat. The current policy is intended for bonded repairs; however, the safety issues and risk mitigation procedures documented within have been adopted by industry for structural bonding and rework with critical structures.

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, insufficient control of cure temperature (either overheating or under-cure), loss of vacuum or pressure, and use of materials outside of time and temperature or calendar life limits can cause undetectable low bondline strengths. Currently, there are no reliable 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 required 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 or analyses supported by tests that meet the applicable regulatory requirements for fatigue and damage tolerance, static and dynamic strength, material and fabrications specification, statistical material allowables, flutter behavior, 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<sup>2</sup>. 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),

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<sup>2</sup> “Industry and Regulatory Interface in Developing Composite Airframe Certification Guidance”, Cindy Ashforth, Rusty Jones and Larry Ilcewicz, published in the Proceedings for the American Society for Composites 29<sup>th</sup> Technical Conference, September 8-10, 2014.

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). See AC 43-214 for guidance in this area.
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)
  - Statistical material design values, (§ 2x.613)
  - Flutter behavior, (§ 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, e.g., fasteners that exist within the base structure or repair design) of the bond line. Inspection methods, thresholds and intervals must be set considering the repeated load environment, likelihood of load excursions, the specific damage threats, criticality of the structure and the magnitude of the residual strength in the case of a failed repair in accordance with AC 20-107B (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 no larger 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.

Bonded repairs to critical structures must be designed to be damage tolerant in order to preclude catastrophic failure due to fatigue, corrosion, or accidental damage throughout the operational life of the aircraft. Manufacturing defects, which cannot be detected or which are on the threshold of detectability with available inspection methods (i.e., porosity, disbonds and other

anomalies) must be controlled by process 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 and extremely rare, (i.e., weak bonds).

Regardless, the design of the repair still must account for these rare events and they must be 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 no larger 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 defects acceptable by process, but may not be found by inspection. 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 some further discussion 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 must 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. Some specific guidance on the engineering data and procedures, including the information needed for repairs that are not in compliance with the existing Design Approval Holders' Manuals, appears in AC 43-214.

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.

## **F. 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. 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 no larger than a size that maintains 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.

Note: To accommodate special cases and advances in bond repair technology, alternate methods of repair substantiation may be accepted and approved by the managing Aircraft Certification Office (ACO) in coordination with the Design, Manufacturing & Airworthiness Division (AIR-100).



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# Attachment 1

## A. 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<sup>3</sup>.

**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, Volume 1, Chapter 1, Revision F):** The adhesion of one surface to another, with or without the use of an adhesive as a bonding agent.<sup>4</sup>

**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.

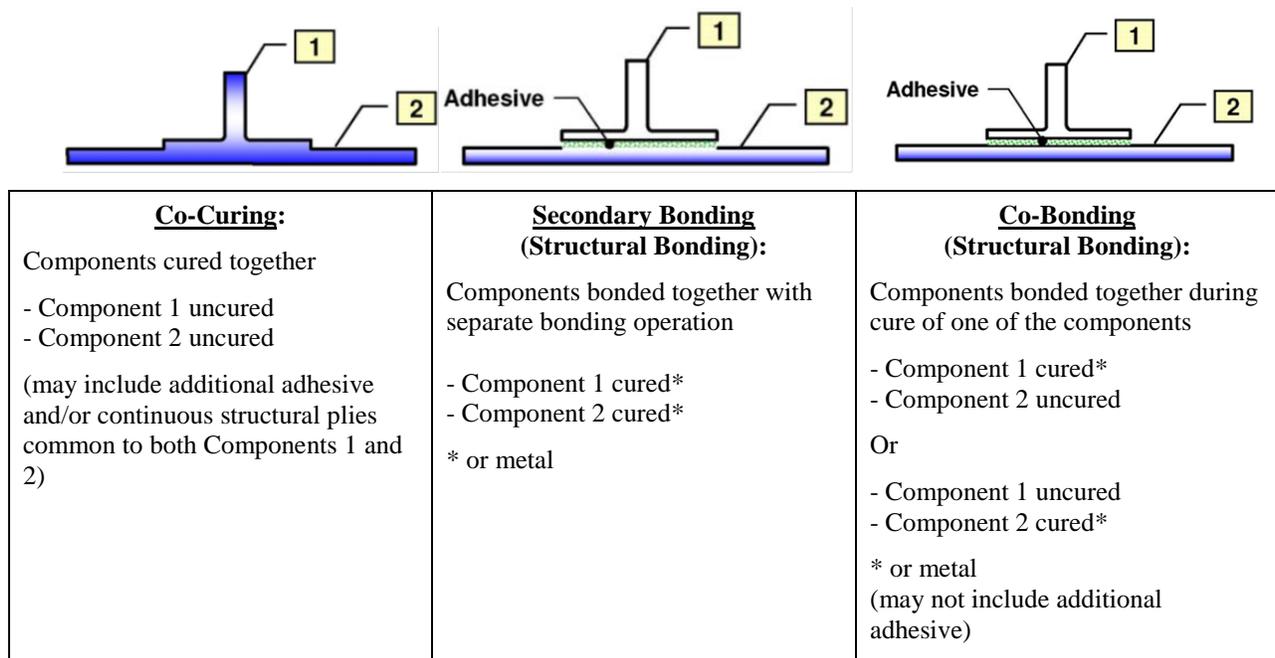
**Cohesive Failure (ASTM D 907-8b):** Rupture of a bonded assembly in which the separation appears visually to be in the adhesive or the adherend.

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<sup>3</sup> Chemical adhesion is the primary goal for structural bonding discussed in this policy

<sup>4</sup> Uncured composite adherends may carry enough matrix material to complete adequate bonding when cured in place to form a bonded repair

## Attachment 1



**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.<sup>5</sup>

**Disbond** (AC 20-107B): An area within a bonded interface between two adherends in which an adhesion failure or separation has occurred.<sup>6</sup> 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.)

**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

<sup>5</sup> “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.

<sup>6</sup> Adhesion failure or separation is usually unintended.

## Attachment 1

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, Volume 1, Chapter 1, Revision 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.<sup>7</sup>

### B. Current Regulatory and Advisory Material

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

#### 1. Regulations.

a. 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:

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<sup>7</sup> 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.

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- § 23.305, § 25.305, § 27.305, and § 29.305 - Strength and deformation.
  - § 23.307, § 25.307, § 27.307, and § 29.307 - Proof of structure.
  - § 23.601 and § 25.601 - General
  - § 27.601 and § 29.601 - Design
  - § 23.603 - Materials and workmanship.
  - § 25.603, § 27.603, and § 29.603 - Materials.
  - § 23.605, § 25.605, § 27.605, and § 29.605 - Fabrication methods.
2. **Guidance.** Guidance may include the AC and policy statements (PS). The guidance listed below is deemed supportive to the purposes of this policy.
- a. Advisory Circulars
- (1) AC 20-107B [Change 1], *Composite Aircraft Structure* [8/2010]
  - (2) AC 21-26A, *Quality Control for the Manufacture of Composite Structures* [7/2010]
  - (3) AC 21-47, *Submittal of Data to an ACO, a DER or an ODA for a Major Repair or a Major Alteration* [9/2010]
  - (4) AC 23-15A [Change 1], *Small Airplane Certification Compliance Program* [12/2003]
  - (5) AC 25.571-1D, *Damage Tolerance and Fatigue Evaluation of Structure* [1/2011]
  - (6) AC 27 MG 8, *Substantiation of Composite Rotorcraft Structure* [4/2006]
  - (7) AC 29 MG 8, *Substantiation of Composite Rotorcraft Structure* [4/2006]
  - (8) AC 43-214, *Repairs and Alterations to Composite and Bonded Aircraft Structure* [4/2013] [Note: AC 145-6 was cancelled.]
- b. Policy Statements
- (1) PS-ACE100-2001-006, *Static Strength Substantiation of Composite Airplane Structure* [12/2001]
  - (2) PS-ACE100-2005-10038, *Bonded Joints and Structures – Technical Issues and Certification Considerations* [9/2005]

### C. 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 may result in less than ultimate load capability in the repaired

## Attachment 1

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.

Many repair manuals developed by industry 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 in accordance with the 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 and additional details in AC 43-214).

The existing industry training materials, such as SAE AIR-5719 (‘Teaching Points for an Awareness Class on ‘Critical Issues in Composite Maintenance and Repair’), 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 structural data is generated to address considerations documented in this policy. Structural data substantiates that specific materials, design details and processes used to define the repair meet appropriate regulations.

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. The OEM documents design, specifications, procedures, tooling and substantiating data that proves the damaged structure can be repaired to its original type certified condition within the *specified repair size limits*. When expanding these size limits *or* using alternate materials, processes, tooling and/or inspection procedures, the larger or alternate repair will generally require additional data that qualifies bonded material and process compatibilities, demonstrates proof of structure, and establishes reliable inspection procedures. As one example of the proof of structure, both damage tolerance and residual strength data would be needed to expand the size limits for a given bonded repair to substantiate structural capability of the larger repair with impact damage and to ensure limit load capability still exists with a failed repair.