U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: Acceptance Guidance on Material Procurement and Process Specifications for Polymer Matrix Composite Systems

Date: 9/19/03
Initiated By: ACE-100

AC No: 23-20
Change:

CONTENTS

1. PURPOSE.

a. This advisory circular (AC) provides information and guidance concerning an acceptable means, but not the only means, of compliance with Title 14 of the Code of Federal Regulations (14 CFR) part 23. It is applicable to the material and process specifications, or other documents, used to ensure sufficient control of composite prepreg materials in normal, utility, acrobatic, and commuter category airplanes. Material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation.

b. This AC has been developed with the help of industry to ensure adequate composite material control and to promote standardization of material and process specifications. It presents the procedural requirements and technical information from a regulatory perspective. Readers interested in engineering guidelines and recommended criteria should refer to the DOT/FAA Technical Reports provided under the Supporting References in paragraph 3.

c. This AC is issued for guidance purposes and to outline a method of compliance with applicable airworthiness requirements. Because the method of compliance presented in this AC is not mandatory, the terms "should" and "must" used in this AC apply only to an applicant who chooses to follow this particular method.

2. RELATED REGULATIONS AND GUIDANCE DOCUMENTS.

a. Regulations. This AC provides guidance for showing compliance with 14 CFR part 23 requirements relating to material control. The regulations that are directly related to this AC include the following:

- Section 23.601 General
- Section 23.603 Materials and workmanship
- Section 23.605 Fabrication and methods
- Section 23.613 Material strength properties and design values

(1) Section 23.605 requires that "the methods of fabrication used must produce consistently sound structure." Furthermore, "if a fabrication process requires close control to reach this objective, the process must be performed under an approved process specification." This rule mandates that each new aircraft fabrication method be substantiated by a test program.

(2) Section 23.613 contains specific requirements for material strength properties and design values. The requirements that are particularly relevant to this AC include the following:

- "Material strength properties must be based on enough tests of material meeting specifications to establish design values on a statistical basis." [§ 23.613(a)]
- "Design values must be chosen to minimize the probability of structural failure due to material variability." [§ 23.613(b)]

- "The effect of temperature on allowable stresses used for design in an essential component or structure must be considered where thermal effects are significant under normal operating conditions." [§ 23.613(c)] Section 23.603(a)(3) prescribes similar requirements.

(3) This AC focuses on ensuring the control of composite material systems. It closely ties to a policy statement titled "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems" issued by the Small Airplane Directorate.

b. Advisory Circulars. Obtain the ACs listed below from the U.S. Department of Transportation, Subsequent Distribution Office, Ardmore East Business Center, 3341 Q 75th Avenue, Landover, MD 20785. The following two Federal Aviation Administration (FAA) ACs present recommendations for showing compliance with FAA regulations associated with composite materials:

- AC 20-107A Composite Aircraft Structure
- AC 21-26 Quality Control for the Manufacture of Composite Structures

(1) AC 20-107A sets forth an acceptable means, but not the only means, of showing compliance with the provisions of 14 CFR parts 23, 25, 27, and 29 regarding airworthiness type certification requirements for composite aircraft structures. Paragraphs 5 and 6 of AC 20-107A contain valuable guidance relevant to this AC, including the following:

- Material design values, or allowables, which have a high degree of confidence based on experimental evidence, in the appropriate critical environmental exposures expected in service.
- Material and processing variability considerations in deriving proper allowables or design values for use in analysis, and in the analysis of the results of supporting tests.

(2) AC 20-107A also presents guidance on associated quality control and production specifications. It states that specifications covering material, material processing, and fabrication procedures should be developed to ensure a basis for fabricating reproducible and reliable structure.

(3) AC 21-26 provides guidance on 14 CFR part 21 regarding quality control systems for the manufacture of composite structures involving fiber reinforced materials. It also provides guidance on the essential features of quality control systems for composites.

(4) Paragraph 5 of AC 21-26 recognizes that the material properties of a composite structure are manufactured into the structure as part of the fabrication process. Material and process specifications used to produce composite structures must contain sufficient information to ensure that critical parameters in the fabrication process are controlled in production. It also provides information on elements that are to be contained in a typical material and process specification. Furthermore, paragraphs 7 and 8 of AC 21-26 provide an additional description of the requirements relating to both aspects of material and manufacturing controls.

c. Policy Statements. The Small Airplane Directorate issued two policy statements that contain information that ties or closely pertains to the contents of this AC. They are the following:

- “Material Qualification and Equivalency for Polymer Matrix Composite Material Systems" [PS-ACE100-2002-006, September 2003]
- "Static Strength Substantiation of Composite Airplane Structure" [PS-ACE100-2001-006, December 2001]

(1) The first policy statement presents some of the procedures and technical requirements associated with elements of material qualification, equivalency, and continuous quality control. Technical details are referred to in the FAA Technical Reports (DOT/FAA/AR-00/47 in 2001 and DOT/FAA/AR-03/19 in 2003, see paragraph 3a of this AC).

(2) The policy statement on "Static Strength Substantiation" addresses the composite structural substantiation. It includes higher levels of evaluation to substantiate design-specific detail at structural scales.

(3) The two policy statements listed above discuss the connection/application of the base material database established by the qualification testing for fulfilling the higher-level structural substantiation.

3. SUPPORTING REFERENCES.

a. DOT/FAA Technical Reports. The following technical reports are published by the FAA Technical Center and are available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. They are also available at the FAA William J. Hughes Technical Center's Full-Text Technical Reports page: actlibrary.tc.faa.gov in Adobe Acrobat portable document format (PDF).

- “Material Qualification and Equivalency for Polymer Matrix Composite Material Systems" [DOT/FAA/AR-00/47, April 2001]
- “Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs" [DOT/FAA/AR-02/109, March 2003]
- “Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites" [DOT/FAA/AR-02/110, March 2003]
- “Material Qualification and Equivalency for Polymer Matrix Composite Material Systems: Updated Procedure" [DOT/FAA/AR-03/19, September 2003]

(1) The Technical Report on material qualification and equivalency (MQ&E) presents details developed under the Advanced General Aviation Transport Experiments (AGATE) program. This method enables an airframe manufacturer to qualify composite material systems by sample testing to share a central material qualification database.

(2) The information contained in the other two technical reports provides guidelines for material and process control, which is a logical advancement of the AGATE method. The FAA and National Aeronautics and Space Administration (NASA) worked jointly with industry experts to collect inputs on key properties that need to be controlled to ensure stable composite materials. The criteria/guidance presented in these two reports, which are applicable to part 23 products, form the core contents of this AC.

b. Industry Standards. MIL-HDBK-17 (current version) has been developed with the help of industry and is maintained as a joint effort of the Department of Defense (DOD) and the FAA. (At the time that this AC was first released, Version F of MIL-HDBK-17 was current.) The handbook provides guidance for developing base material properties (allowables) and the design values acceptable to the FAA. Valuable information closely related to this AC is contained under Chapter 2 in Volume 1 of this handbook (i.e., Guidelines for Property Testing of Composites). MIL-HDBK-17 can also serve as a reference for most of the terminology used in this document. MIL-HDBK-17 can be obtained from the Department of Defense Single Stock Point (DODSSP), 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111. This handbook can also be purchased through ASTM International's website at "www.astm.org" [note: search using keyword "MIL-17"].

(1) The material and process specifications normally refer to industry test methods or standards such as American Society for Testing and Materials (ASTM International). These standards are available through ASTM at either their Internet site address, which is "www.astm.org", or their mailing address: ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, Pennsylvania 19428-2959.

(2) Consistent and repeatable industry engineering practices would help assure compliance with the requirements for material control. The purpose of building on the current FAA/NASA effort is to standardize these specifications with MIL-HDBK-17, ASTM International, and Society of Automotive Engineering (SAE International) Aerospace Materials Specifications (AMS) Committee P-17.

4. BACKGROUND.

a. Scope. The guidance in this document pertains to prepreg materials, but many of the basic concepts are generic for composite material control. It was derived from certification experiences with the help of industry groups, which represent composite material suppliers and manufacturers for small airplanes (part 23), transport airplanes (part 25), and rotorcraft (parts 27 and 29) product categories. Future efforts to continue development of reliable industry standards for the control and testing of composite materials are needed. The FAA supports international initiatives in this area.

b. Historical Perspectives. Composite materials have not achieved the same level of standardization as metallic materials. This includes a general lack of industry material and process specifications and shared databases for basic properties, as well as test standards that continue to evolve. Composite manufacturers must face these issues as they establish the necessary base material control to ensure repeatable production of their aircraft product. Such control must be achieved in the quality assurance procedures developed by each user and their selected material suppliers.

(1) In the decades since the introduction of advanced composite materials for use in aircraft, the cost associated with material control has been a significant burden to the industry. The cost burden begins with the need to conduct qualification testing for each material system to be used by an airframe manufacturer. The cost may be further escalated by instabilities originating from the sources associated with material supply. Examples of instabilities may include changes in material and/or process from the supplier end and, on a larger scale, the reshaping of the supplier industry as new users and markets evolve.

(2) Traditionally, each manufacturer conducted extensive qualification testing to develop the base material properties and allowable strengths, which are part of their aircraft design data. The practice of qualification, when performed by each manufacturer for an identical material system, represents a duplication of effort. The same can be stated for development of those portions of the composite material and process specifications used to control the source of raw materials.

c. Shared Databases. In recent years, NASA, the FAA, and industry worked together through the AGATE program to develop a cost-effective method of qualifying composite material systems and sharing a central material qualification database. This method is built on existing sections of MIL-HDBK-17, and it allows credit for FAA approved materials testing performed by third parties such as material suppliers.

(1) To use an approved composite material system, airframe manufacturers need to perform a smaller subset of testing (i.e., equivalency) to substantiate their control of material and fabrication processes tailored to a specific application. Throughout its development, the FAA closely participated in the AGATE program to ensure that this method is in compliance with the applicable airworthiness regulations. Use of the shared database presents not only a significant cost saving opportunity for airframe manufacturers, it also provides the stability needed in the material suppliers environment.

(2) Two FAA Technical Reports [DOT/FAA/AR-00/47 and DOT/FAA/AR-03/19] have been published to present the technical details of the AGATE method. Based on this AGATE method, the Small Airplane Directorate issued a policy statement titled "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems." This policy statement presents both the procedure and the technical requirements associated with this method. Since the proposed version was issued, in May 2000, several workshops and presentations have been conducted for audiences representing the authorities and the industries, both domestic and foreign. The AGATE method made a big step in achieving the objective of stabilizing the composite materials, while enhancing efficacy both in terms of cost and cycle time.

d. Material Qualification & Equivalency (MQ&E). A review of the AGATE method provides a clear purpose for material qualification and equivalency. Material qualification is a process of establishing the database to control an "original" material system. The qualification method documented by AGATE presents guidelines for base material properties with several purposes:

- To solidify and finalize material and process specifications, including specific acceptance criteria for sampling relative to the qualification database;
- To quantify base material variability; and
- To provide a central database of material properties for stable processes.

(1) Material equivalency is a process to substantiate material properties. (See paragraph 5d of this AC for expanded discussion.) This is achieved by test sampling and passing the acceptance criteria, which were derived from a larger population of material data. The equivalency method documented by AGATE presents guidelines for engineering practices with several purposes:

- To share and make use of the central database by a new user (i.e., original material qualification);
- To continue surveillance of material and process;
- To show that minor changes to material and processes do not affect base material properties; and
- To make final adjustment on material and process specifications for specific application, and demonstrate that it has minor effect on base material properties.

(2) The AGATE MQ&E protocol for shared databases provides a basis in consistent engineering practices for composite material control. Following this basis, fundamental requirements for material control should include the following:

- Qualification database should be the statistical basis for equivalency (for new users and changes) and quality control acceptance requirements;
- Documentation and databases should exist for each unique material; and
- Property drift should be minimized.

e. Material Control. The FAA and NASA performed efforts, which go beyond AGATE, in composite material control. The primary purpose of these expanded efforts was to establish the guidance for developing composite material and process specifications. Shared composite databases and specifications throughout industry would improve the efficiency of material suppliers, end-users, and regulators.

(1) The FAA/NASA work was administered through the FAA Technical Center and Airworthiness Assurance Center of Excellence (AACE) at Wichita State University (WSU). Industry experts that have extensive experience with material specifications, part processing, qualification programs, and design allowables were invited to participate. They worked together in drafting detailed guidelines for material control. This task covers product categories of small airplanes (part 23), transport airplanes (part 25), and rotorcraft (parts 27 and 29). In August 2002, a workshop was conducted in Chicago that provided a forum for experts, both from government and industry, to discuss the most efficient ways to achieve composite material control.

(2) The inputs generated through the FAA/NASA/industry joint effort have been compiled and published in two DOT/FAA Technical Reports. This effort was driven by the following goals:

- Greatly reduce the number of material and process specifications for identical composite material systems;
- Develop property databases that uniquely define a given material;
- Establish material batch testing and process monitoring sufficient to minimize variability and preclude property changes over time; and
- Reduce costs through common documentation and shared databases of basic material properties.

f. Importance to Structural Substantiation. Analysis and base material data alone is generally not adequate for substantiation of composite structural designs. The "building-block approach" is typically used to fulfill the certification requirement. While details of the "building-block approach" appear in MIL-HDBK-17, the portion that pertains to part 23 certification has been discussed in two policy statements issued by the Small Airplane Directorate.

(1) The AGATE method is typically used to develop the design database and meet certification requirements at the lower level of structural complexity (i.e., coupon tests). The material qualification testing provides a means for quantitative assessment of the variability of key base material properties, leading to various statistics that are used to establish material acceptance, equivalence, quality control, and design basis.

(2) Structural certification is used to ensure acceptable materials and repeatable manufacturing processes are used for all parts that are integrated into the production. The material and process controls are essential prerequisites for a repeatable and safe product. Material and process specifications are interwoven throughout the certification process. Material specifications define the material's attributes and define the qualification tests. Subsequently, materials used for production are purchased under the material specification.

(3) Aircraft manufacturers use the material specification to ensure that the delivered aircraft consists of materials that are of the same quality and performance standards achieved in the certification process. Process specifications define and control the processes used to convert materials into structural components. The base material properties of composite laminates are directly determined by the specific processes used for their fabrication. Quality control procedures, which often make use of the lower levels of building block tests, ensure the material used to fabricate production aircraft parts remains invariant.

(4) Building on the base material database, tests at higher levels of the scale (i.e., structural laminate, element and sub-component) are typically needed to fulfill the remaining parts of the structural substantiation requirement. Structural laminate data may be shared between applications and can become part of a central database. As the program moves closer to application-specific design detail, data sharing typically becomes more difficult.

5. MATERIAL SPECIFICATION.

a. Overview.

- The qualification of databases and specifications are recognized as the prerequisites to ensure a stable raw material source for aircraft products. Detailed background and policy for material qualification, shared databases, and equivalency testing of polymer matrix composites have been published.
- A recent joint FAA/NASA effort defined criteria and guidelines for the related specifications for effective material control. These criteria and guidelines have been published in two FAA Technical Reports. One report focuses on material specification [i.e., DOT/FAA/AR-02/109], and the other one focuses on related process instructions and controls [i.e., DOT/FAA/AR-02/110]. This paragraph gives regulatory guidance on the former.
- Composite material and process specifications are closely interrelated. A material specification typically defines the composite material and its qualification tests. Many of the tests require specimens fabricated using the process specification. Once qualification is completed, requirements in the material specification are finalized. The material specification is used to procure the production material and maintain levels of quality attained at certification.

(1) Standard Specification Format.

(a) The FAA Technical Report [DOT/FAA/AR-02/109] contains the essential criteria and guidelines to develop a material specification. This guidance is applicable to polymer matrix material systems. It also contains some technical details that only apply to a particular material form (unidirectional prepregs).

(b) A standard format for the outline of a material specification can be found in the FAA Technical Report [DOT/FAA/AR-02/109]. This format was derived from SAE International recommendations. As a result, format information contained in the FAA report may be superseded by future changes in the SAE International recommended format.

(c) Initial sections of a material specification typically provide general information, which is essential to users of the specification. The remaining sections contain the engineering criteria and guidelines. The particular order and names for sections in a given material specification may differ from industry standards; however, similar content should be included in material or other specifications and related documents used to control materials.

(2) General Information. The general information essential for a material specification includes the following:

(a) Describe all materials controlled by a specification in the front of the document. This should include details that define the materials (e.g., form, resin content, cured ply thickness, fiber, areal weight, and fiber type) and cure conditions needed for processing, as well as a general description of applications and environmental use limits.

(b) List (usually near the front) all references applicable to the specification. These may include drawings, specifications, standards, company-specific test procedures and methods used in following the specification. Standard methods and procedures available to the public and developed or approved by industry organizations are desirable, but they are not required.

(c) Provide definitions for terms or abbreviations that need to be understood to follow the specification. Any terms essential to raw material control (e.g., prepreg allowed defect levels) and processing (e.g., storage life and out life) need to be clearly defined with no room for interpretation. Where possible, use definitions from industry standards.

b. Material Requirements. The requirements used to control materials need to be well documented. Some requirements will only appear in documents that are proprietary to suppliers while other requirements are also documented in the material specification.

(1) Process Control Document.

(a) The material supplier establishes a process control document (PCD) or equivalent, which contains a description of all the critical details that are used to ensure repeatable raw material fabrication. Usually, a PCD is proprietary to the material supplier, who is responsible for its maintenance. The PCD is referenced by the material specification. The PCD contains more details on raw material processes than potential users need to know; however, customers usually review the information to assess material quality assurance.

(b) The PCD lists all critical raw material ingredients and the associated suppliers. All resin components and their manufacturers are listed, including multiple sources. The resin component specifications, quality sampling plan, and test methods for properties are referenced in the PCD. The fiber specification, quality sampling plan, and test methods for fiber properties are also referenced in the PCD. Backing paper and film is controlled like any other critical raw material.

(c) The PCD defines key process parameters and establishes statistical process control (SPC) procedures. The PCD will contain the requirements for ingredients (fiber, resin, and material form), uncured prepreg, and cured prepreg. The process limits, requirements, and continuous inspection procedures are given in the PCD and/or specification. Internal documents such as company-specific test procedures that are used for material control are referenced in the specification and included in the PCD.

(2) Prepreg Ingredient and Process Requirements.

(a) The material specification includes requirements that define specific raw constituents (i.e., resin and fiber). There is only one resin formulation and a single fiber class (i.e., specific fiber type, manufacturer, and facility) associated with the unique set of requirements. A designation that represents one combination of ingredients and a single mixing process is given to the resin. Multiple sources of the same resin ingredient must be validated through chemical and physical evaluations. Fiber used in the prepreg is purchased to a separate fiber material specification. If multiple fiber sources are included in the specification, then the specific prepreg materials that use each fiber type should have a unique specification, prepreg designation (i.e., class), and associated prepreg requirements. The fiber sizing, process to add sizing, and sizing content are considered to be an integral part of the fiber.

(b) Resin composition and all steps in the mixing process need to be defined before qualification. This includes tolerance limits that are validated by chemical and physical testing. Resin ingredients can be blended as long as individual storage and handling requirements are met. Chemical and physical testing is used to validate any blending of mixed resin batches. The goal is to ensure that all variations in the resin composition and mixing process steps, which are within specified limits, yield repeatable resin to produce a consistent prepreg.

(c) Details for resin mixing steps are defined in the PCD with specific requirements that control these processes. Key attributes of the final mix or any pre-mixes are documented as requirements. These include gel time, viscosity, and a chemical analytical signature. The resin cure kinetics and rheology are also well characterized for limits allowed within the mixing processes. A summary of the resin property data, which can be used as requirements to control the resin processes, is given in DOT/FAA/AR-02/109. This table also gives some cured resin properties (moisture diffusion and resistance to thermal micro cracking), which may be of interest to users.

(d) Fiber requirements are documented. The material specification includes requirements that define the specific mechanical and physical properties of the fiber, including tensile strength, tensile modulus, and density. The specification also identifies the fiber form and tow count. Key fiber properties are listed in DOT/FAA/AR-02/109.

(e) Fiber storage and handling instructions normally appear in the PCD. A shelf life requirement for the fiber sizing is recognized in the processes if the sizing ages during storage. Fiber batch blending is allowed in production, providing each fiber batch can be traced.

(f) The material specification includes requirements that define the processes for producing the prepreg. Details of the resin filming and prepreg processes are documented in the PCD. Process conditions have maximum and minimum limits that are monitored with the SPC procedures. Resin filming process limits maintain the chemical signature while ensuring film quality (e.g., film thickness and visual characteristics). The prepreg process achieves a consistent thickness while controlling resin advancement, degree of impregnation, handling characteristics, defects, and fiber/resin distribution.

(g) Proof is needed that prepreg manufactured at the minimum and maximum limits of allowed thermal history could still be processed within limits of the recommended baseline cure cycle. This effort is needed to ensure an acceptable baseline cure cycle for cured prepreg requirements (see paragraph 5b(4) of this AC). Cured prepreg mechanical property tests in a hot/wet condition and an assessment of the degree of cure provide the necessary validation.

(3) Uncured Prepreg Requirements.

(a) The material specification includes requirements for uncured prepreg physical and chemical properties. A summary of the uncured prepreg property data, which can help establish requirements to control the processes, is given in a table in the DOT/FAA/AR-02/109. Testing should be conducted on prepreg made to the upper and lower limits of the resin mixing, filming, and prepreg processes to help define the requirements. Testing to establish requirements also considers variability for samples taken from different locations within a spool of material.

(b) The material specification includes limitations and correction procedures for visual defects in the prepreg. Criteria for continuous defects that occur during prepreg production (e.g., gaps and fiber alignment) must be established and documented. Criteria for discontinuous defects (e.g., fuzz balls, splices, and foreign material) should also be defined. All procedures for defect removal or identification should be documented. The procedures for continuous inspection of the prepreg should be defined. When the user detects defects after removing the release paper when a part is being laid up, the same criteria for allowable defect limits and correction are followed.

(c) The material specification includes definitions and limitations for storage life, handling life, and out life. These requirements are based on either test data or experience, or both, with materials having similar chemical makeup. The supplier documents the storage/out life of a material from the date of manufacture until it arrives at the purchaser. This tracking includes resin intermediates, mixed resin, and film before prepreg process steps.

(d) Width and length tolerances for spools of prepreg material need to be defined. The roll size, weight, width, and core type should be specified in either a purchasing document or the material specification. The specification has a procedure to identify, mark, and document all prepreg defects that are outside the allowable limits. Similarly, splices to remove defects are identified, marked, and documented for the user. The out time, time accumulated to disposition and remove defects, is recorded and used to adjust the remaining out life.

(4) Cured Prepreg Property Requirements.

(a) The material specification includes requirements for the cured prepreg in a laminate form. These requirements are based on specific data obtained for the material during qualification. The associated laminate process steps and a baseline cure cycle are defined for this purpose and documented in a corresponding process specification or other instructions. The cure process should consistently produce cured laminates of high quality. This cure cycle is used for all qualification and batch acceptance testing.

(b) The material specification includes requirements for cured laminate physical and mechanical properties. These requirements are based on qualification testing to characterize the material in a cured state. The goal is to provide a representative database, which is the basis for criteria applied in material acceptance and equivalency sampling. The limits and test methods for each property are documented in the specification. Perform some subset of the qualification tests for each batch as a part of the continuous quality control process. Batch sampling should be able to identify possible variations in properties as a function of location in prepreg rolls.

(c) Discussions and tables in the DOT/FAA/AR-02/109 recommend a minimum set of cured laminate physical and mechanical property tests to establish the material specification. This test matrix is similar to the AGATE test matrix in DOT/FAA/AR-00/47 and DOT/FAA/AR-03/19. (The primary difference relates to a recommended change in laminate lay-up in DOT/FAA/AR-02/109, which allows a less operator sensitive test for determining consistent longitudinal tension and compression strength data.)

(d) The physical properties include fundamental material characteristics such as cured ply thickness, laminate density, and constituent volume fractions, which are controlled to ensure a repeatable product. The void content and glass transition temperature tests provide additional confidence that the prepreg material is under control. Mechanical tests are able to detect changes in the fiber, resin, fiber/resin interface, and the response of the prepreg to the baseline cure process. They include base material moduli and strength tests for fiber and matrix-dominated properties. A combination of tension, compression, and shear tests for a range of environmental conditions provide a minimum set for qualification purposes.

(e) Discussions and tables in the DOT/FAA/AR-02/109 recommend additional tests be run at some frequency to keep the test methodology current and to further populate the database. Some of these tests are used periodically to update the material acceptance and equivalency requirements in the specification to better represent the population. Others are used to expand the utility of the database for multiple applications. For example, additional laminate test data is recommended for layups and details (e.g., open hole, filled hole, and pin bearing), which are characteristic of design. Other test recommendations help characterize solvent sensitivity, laminate sandwich panels, interlaminar fracture toughness, laminate fatigue, post-impact residual strength, flammability, moisture diffusion, and thermal cycling. These additional tests are optional for inclusion in the material specification, but they may be required for the design and certification of an end-user's product. As a result, there is a potential for cost savings if the additional tests are shared among several end users.

c. Material Characterization.

(1) The material specification includes qualification procedures and methods to initially characterize the material. Tests must be conducted to create an initial database. A material supplier, an end user, or an industry consortium (a supplier and multiple users, e.g., AGATE) can perform the testing. The results from the testing are used to establish the initial material specification requirements and batch acceptance limits. The decision on whether the specification becomes an industry standard or an end-user proprietary specification is for the developers of the database to determine.

(2) The FAA reviews a request for the initial qualification. The organization that will conduct the tests submits a test plan, a material specification, and a process specification before the actual qualification. The material specification submitted for initial review will be without those final requirements, which depend on qualification test databases. Any parties interested in

FAA support must have clear evidence of potential applications that will request certification. The initial request should be made to the geographically responsible Aircraft Certification Office (ACO). That office will then contact the Small Airplane Directorate to determine the most appropriate office to work on the qualification.

(3) The initial qualification database includes uncured prepreg and cured laminate properties that provide a baseline in key composite characteristics, which provide reliable measures that the material is under control. This includes a balanced combination of chemical, physical, and mechanical property tests that are sensitive to any significant changes in fiber, resin, fiber/resin interface and response of the prepreg to the baseline cure process. Minimum recommendations given in the DOT/FAA/AR-02/109 may be used as a guide.

(4) A minimum of three different material batches, consisting of a minimum of two different fiber batches and three different resin batches, is used for the initial database. Laminates for mechanical property data for each batch are processed using a minimum of two independent cure cycles. Allowed limits in thermal history of prepreg material and accepted variations in the baseline cure cycle are considered in developing the qualification database. The data from each processing cycle can be considered a separate batch in following the statistical procedures given in DOT/FAA/AR-00/47, DOT/FAA/AR-03/19, and/or MIL-HDBK-17.

(5) The material property equivalency requirements and material batch acceptance limits may also use DOT/FAA/AR-00/47, DOT/FAA/AR-03/19, and/or MIL-HDBK-17. These documents recommend sample size and statistical parameters, which are discussed in the FAA material qualification and equivalency policy statement. Equivalency requirements for all tested properties, and acceptance limits for specified properties, are listed in the specification. In DOT/FAA/AR-02/109, the requirements and acceptance limits were recommended for the following:

- Maximum average, minimum average, and minimum individual values for all strength properties;
- Maximum and minimum average values for all stiffness properties;
- Maximum and minimum average values for cured laminate physical properties; and
- Maximum average values for uncured prepreg properties.

(6) Although initial qualification tests can be completed with as few as three batches of prepreg, some additional testing to expand this database may help establish a more robust basis. This is particularly important if the material is relatively new and the variation in initial qualification batches is not fully representative of full-scale prepreg production. Without a mechanism in the specification to recalculate material equivalency and batch acceptance limits based on more data, failures of material equivalency programs and batch rejections are possible. If undesirable changes are occurring to the material and reducing key properties over time, periodic property testing will provide a safety benefit.

(7) DOT/FAA/AR-02/109 provides some recommendations for periodic property testing to expand the qualification basis. These procedures can be added to the material specification.

The material equivalency and batch acceptance limits may be recalculated to update the material specification periodically. For those properties tested for each batch of material, the data from all batches is included in the recalculation. The frequency of periodic property tests decreases over time as an accurate basis is achieved.

(8) In expanding a shared database from base material characterization to include additional data at material, laminate, and higher levels, some of the same engineering protocol remains valid. In particular, statistical parameters and acceptance criteria can be derived for each property or design value of interest. These engineering processes are then applied in equivalency sampling tests to demonstrate that new users can produce the material to that level of property or design value. If successful, the new user can share the expanded database. The keeper of a shared database has freedom to decide what properties should be added over time. In practice, additional laminates considered for an expanded database are characteristic of those typically used in product design.

d. Changes to Qualified Materials.

(1) Maintain consistent raw materials and processes to ensure repeatable aircraft product manufacturing. However, it is inevitable that some changes will occur throughout a production run due to economics or issues outside the control of suppliers and users. Since prepreg materials and processes will likely undergo continual evolution, establish procedures to evaluate the effects of changes.

(2) The material specification includes the procedures and associated requirements to deal with change, including the specific means to establish the equivalency of future material data to the baseline database. Material equivalency is the procedure of determining whether changes in the materials or processes yield enough similarity in the key characteristics and properties of a prepreg material that they can be used without distinction and without additional evaluation. Note that two materials that meet the same minimum requirements, but have statistically different mean properties, are not considered "equivalent." MIL-HDBK-17, Volume 1, Section 8.4.1 ("Tests for Determining Equivalency Between an Existing Database and a New Dataset for the Same Material") gives statistical procedures that can be used to establish equivalency criteria for inclusion in a material specification. Another source for information in this area can be found in DOT/FAA/AR-00/47 and DOT/FAA/AR-03/19.

(3) Any material changes that result (or can be expected to result) in a change to the material allowables, or to the acceptance limits, are considered to be a major processing change. Equivalency is used to evaluate all changes in a material's constituents, manufacturing process, or to changes in the fabrication (e.g., curing) process that could potentially require a new material qualification and associated designation. When such potential exists, the equivalency procedures are applied to determine whether a new qualification database is needed to accommodate such change.

(4) DOT/FAA/AR-02/109 provides recommendations for the procedures to evaluate five levels of material changes, which range from minor to major. These recommendations are based on experience and engineering judgment, with additional data collected at higher levels of change to add confidence that the change does not require a new material or process designation. The discussions give examples, as well as the testing and notification guidelines associated with each level of change. The lower levels of change, which are considered minor, may be evaluated without a full set of equivalency tests. Higher levels of change require an equivalency demonstration and associated updates to the material specification and PCD.

(5) Discussions on the highest level of change in DOT/FAA/AR-02/109 suggest that certain material or process modifications should automatically trigger the development of a new qualification, material designation, and associated specifications. These include changes in resin composition, fiber areal weight, fiber type, and fabric weaves.

e. Quality Assurance. The PCD and material specification establish quality assurance procedures that evaluate requirements. The latter defines the batch-sampling plan for material acceptance and establishes testing responsibilities of the material supplier and purchaser. Key characteristics will be monitored using SPC at the material supplier. "Material acceptance" is the process of determining, by test and/or inspection, whether a specific batch of material meets the requirements of the applicable procurement specification. ("Material acceptance" is also called "quality conformance" in specifications that conform to MIL-STD-490/961 practices.) A subset of the material qualification tests are selected and designated as "acceptance tests." These tests measure key material/process characteristics that are sensitive to a potential change in the material. As discussed previously, statistical methods are used to determine the associated material specification requirements using the qualification data and subsequent production batch data.

(1) Statistical Process Control (SPC).

(a) Modern production practices emphasize SPC tools, which use acceptance testing data and process control tests, to monitor production trends and make real-time process corrections. Each supplier's site for prepreg manufacturing is qualified by demonstrating the capability to conduct raw material testing, final product testing, maintenance, calibrations, and the continuing practice of SPC methods. Training programs and records help to ensure that personnel are able to perform and document these tasks. Major equipment maintenance and modification records are available. Appropriate organizational structure exists for each major function (i.e., operations and quality assurance) to ensure consistent production practices.

(b) The quality assurance department, at the material supplier, maintains the procedures and requirements for SPC based on key characteristics (KC) and key process parameters (KPP). The KCs are those uncured and cured prepreg material properties that are given as requirements. The KPPs are those process parameters that have a significant influence on the KCs. The KPPs are determined before qualification and documented in the PCD. Average values, ranges, limits, and sampling frequency are established and documented in the PCD. Procedures used to conduct SPC analysis of the KCs and KPPs are also documented in the PCD. Control charts are maintained on the KCs.

(c) A corrective action is taken whenever the criteria for non-random data trends are met, while the data is still within the upper and lower control limits given in the PCD. If a KC is out of control, the cause of variation is identified and eliminated to re-establish statistical control. The supplier's quality assurance department documents all corrective actions affecting the process and monitors whether the corrective action has been effective.

(d) A plan for reduced testing, which is based on the capability of the KCs and KPPs, may be established and documented. The reduced testing may take the form of a reduction of purchaser testing. Reduced testing will require approval by the FAA and the purchaser(s) before being implemented. If KCs are found to be out of control, testing will return to the original level until confidence in the control of the material is re-established.

(2) Product Certification.

(a) The specification defines the material acceptance testing to be performed by the material supplier and the end user (purchaser). The material supplier performs the material acceptance testing that is identified in the material specification and PCD. Conformance reports are prepared for each prepreg batch to document that the uncured and cured prepreg requirements have been met. The supplier quality department will review these documents before shipment to a purchaser along with the material. All records for each prepreg batch and the original baseline database are kept on permanent file. Records of quality assurance and full prepreg batch traceability are kept for a minimum of 10 years or as required under the applicable production rules.

(b) Materials that fail quality assessment tests undergo a review process. The retest or replacement of test data is allowed if statistical criteria are met to identify data outliers and a physical reason for the outlier is determined. It may also be acceptable if test abnormalities or testing errors can be reasonably deduced, providing steps are taken to eliminate potential future problems. Engineering guidelines in this area are provided in MIL-HDBK-17, DOT/FAA/AR-00/47 and DOT/FAA/AR-03/19.

(c) The purchaser's quality department performs the acceptance testing identified in the material specification on each prepreg batch received directly from the manufacturer or through a distributor. The quality department must review the test results and allow the prepreg to be released to manufacturing only if the material meets the specification requirements. If an approved system, which controls the material, is in place to release material pending testing, that system may be used. The purchaser holds to the same record keeping requirements and retest criteria as the material supplier. The original conformance reports created by the prepreg manufacturer will be made available by the distributor for a specific batch sold to the end user.

(d) In cases where the SPC has demonstrated a high level of control and capability for the material, it may be possible to either reduce or eliminate the purchase acceptance testing. The FAA ACO will evaluate requests for reduced purchaser testing on a case-by-case basis. If purchaser testing is reduced or eliminated, then provisions for monitoring the thermal exposure history of each shipment of material between the supplier and end-user (including all transit periods and storage periods at a distributor) will be required.

f. Material Test Methods. The material specification and PCD will clearly reference or document all test methods required for material control. Chapters 3 through 7 in Volume 1 of the MIL-HDBK-17 give recommended composite test methods. When available, international standards (e.g., ASTM International) are preferred. The ASTM International standards designed specifically for advanced composites come from Committee D30. Options in standards (e.g., specimen width) are controlled and any deviations from industry standard methods must be clearly detailed in the specification or PCD. We recommend that the material supplier and purchaser conduct round-robin test evaluations to reduce test differences for methods required by the specification. All laboratories involved in testing are certified to the specified methods. For an industry material specification, we recommend that a third-party organization be used to certify the test laboratories.

g. Test Panel Fabrication. The fabrication processes used to produce test panels for the initial qualification database and subsequent quality assurance tests are clearly defined in the material and process specifications. This includes laminate layup, bagging, cure, quality inspections, and test specimen machining. The material suppliers and end users must be able to perform the baseline cure process on a routine basis. Process aids such as vacuum bag material, vacuum sealant, breathers, caul plates, and edge dams are defined in the PCD and process specification.

h. Packaging and Shipping Requirements.

(1) The prepreg release film or paper used for a material are easily removable, non-contaminating, and controlled by the PCD. Changes to a different release paper include a demonstration that no contaminants are transferred from the paper to the product.

(2) The material product has suitable identification in packages used for shipping. The packaging and handling during shipping are controlled such that the purchaser realizes the material full handling and out life capability when received. If repackaged by a distributor, the new packaging is labeled properly and functionally equivalent to the original packaging. Any decrease in storage life, out life, and handling life are documented by the distributor and provided to all users.

(3) Material identification provides the batch number and roll number on two labels, one inside the core, and the other outside the shipping wrapper. These labels also include the material designation, name of manufacturer, specification number, and date of manufacture.

(4) The prepreg packaging has a core that adequately supports the weight of the roll without deformation. The roll is in a sealed bag that prevents the ingress of moisture and contaminants. Additional packaging, such as a box, may be needed to ensure that the bag is not torn during shipment.

(5) The shipping and storage temperatures are established and documented in the material specification. If freezer temperatures are needed to maintain product quality, recording devices should be used to track the temperature exposure history during shipment. Provisions are needed in the material specification for the disposition of rolls that have exceeded recommended time-temperature limits or are received with damaged packaging.

i. Use of a Distributor in the Supply Chain.

(1) When using a distributor, either a facility of the manufacturer or an independent facility, the distributor abides by all requirements of the material specification and the applicable portions of the process specification. The end user approves the distributor under their supplier surveillance system as described in the quality control manual. The material manufacturer will also have a role in authorizing distributors for proper control of the composite material. Material lots remain traceable to the manufacturer's original batch and test reports. The distributor provides copies of the original material certification and test reports for the user. The manufacturer's material, batch and lot identification are maintained.

(2) A distributor practices the same documentation of storage life and conditions as the material supplier. The distributor provides objective evidence of the material storage conditions. All shelf life is determined from the date of material production. Any extension of the shelf life allowed by the material specification is performed by a source approved by the original manufacturer.

(3) If the product is repackaged, the materials used to repackage it are approved for use by the manufacturer. When the material is repackaged, it will first be allowed to reach room temperature in the unopened package so moisture does not condense on the prepreg. The repackaged material is inspected for visual defects and documented. All out life accumulated during warming, respooling, and repackaging is subtracted from that specified by the manufacturer and documented for the user, who assumes responsibility after acceptance.

6. PROCESS SPECIFICATION.

a. Overview.

- The material and process specifications are interwoven. The material specification is used to ensure that the delivered aircraft contains materials that meet the same quality and performance standards as those achieved in the certification process. The process specification controls the processes used to convert materials into structural components. The specific processes used for fabrication directly determine the performance properties of composite laminates. The current paragraph gives the regulatory policy for a process specification, with an emphasis on instructions and controls for the processes used in fabricating the test panels important to the quality assurance of prepreg materials. (The terminology "process specification" will be used throughout this AC for the instructions and controls used in test panel fabrication. However, only part of a process specification contains such information, which may alternatively appear in other documentation.)
- The objective of process specifications is to document any regulatory and engineering requirements or procedures that are communicated to organizations involved in the fabrication process. For example, the process specification relates to the fabrication

of high quality and consistent composite laminates. Considering the complexity of associated process steps, the specification is clear and complete to meet the objective.

- A process specification is needed to ensure that the fabrication process, which is used for test panels during certification, is stable and consistent. The consistency includes control of thickness, layup, and cured characteristics. While the test panel process is repeatable, it also captures the variations found in the component fabrication process and, therefore, provides an acceptable baseline for future equivalency exercises. As discussed in paragraph 5d of this AC, equivalency tests are used to judge whether production changes are minor or major. Another function of the process specification is to require complete documentation of the process parameters used to fabricate a specific set of test panels so that traceable records exist whenever questions arise.
- Although the current discussion is focused on those parts of a process specification that are important to test panel fabrication, there are significant manufacturing scaling issues for composite airframe structures. These scaling issues can be important to material and process development that includes the procedures for control of raw materials. Some scaled manufacturing demonstrations should be performed at the same time as base material and process specification development so the appropriate controls are defined to ensure producible airframe structures.

(1) Standard Specification Format.

(a) The FAA Technical Report [DOT/FAA/AR-02/110] has compiled the criteria and guidelines that are deemed essential to develop a process specification. This guidance is only applicable to polymer matrix material systems. A standard format for the outline of a process specification can be found in the FAA Technical Report [DOT/FAA/AR-02/110]. This format was derived from SAE International recommendations. As a result, format information contained in the FAA report may be superseded by future change in the SAE International recommended format.

(b) The initial sections of a process specification typically provide general information that is essential to users of the specification. The remaining sections contain the processing instructions, engineering controls, and guidelines. The particular order and names for sections in a given process specification may differ from industry standards; however, similar content is included in process specifications or other related documents used to control composite processes.

(2) General Information. The general information essential for a process specification includes the following:

(a) Describe the purpose or application of the specification in the front of the document. For example, the purpose would be to give requirements and procedures for the fabrication and inspection of composite laminates. Such a specification would be used to qualify new materials, perform material quality assurance, or establish mechanical property equivalency.

(b) List (usually near the front) all supporting documents, reports, specifications, or standards referenced within the process specification. Also, specify sources for the documents.

(c) Provide definitions, abbreviations, and other relevant information that need to be understood to follow the specification. Wherever possible, use definitions from industry standards.

b. Fabrication Requirements.

(1) Personnel. Technicians are "qualified" for each of the major fabrication processes (layup, bagging, cure, Nondestructive Inspection (NDI), testing, machining) that they perform.

(2) Required Materials.

(a) List all materials (and their sources) required for the fabrication procedures in the process specification. The listing includes both consumable and structural materials. Upon receipt, prepreg materials are inspected per the material specification before use. Verifications exist to ensure that all materials that come in contact with composite prepreg would not cause contamination. Any foreign objects that could potentially become part of the laminate are verified detectable by cured laminate inspection procedures.

(b) Document the total shelf life and out time of prepreg materials up to the time of panel cure. The time limit within which the material will produce quality laminates is a requirement. Throughout this time, the prepreg material storage conditions and working environment (temperature and relative humidity) are controlled per specification requirements. Maintain complete records to ensure fiber, resin, prepreg, and cured laminates are traceable.

(3) Required Equipment, Facilities and Tooling.

(a) All equipment needed to perform the fabrication procedures, which are documented in the process specification, are listed with vendor sources. Define calibration and certification requirements for all equipment (e.g., ovens, autoclaves and process monitoring gauges).

(b) Perform laminate layup in a clean and controlled environment. The temperature and relative humidity of the layup room are maintained within limits of the out time requirements. Layup areas are cleaned and inspected regularly. Mold releases or other materials that could cause contamination are not allowed into the layup room. Any process steps that generate dirt, dust or other debris are also not allowed in the room (e.g., sanding or machining). A positive pressure, filtered ventilation system in the layup room is recommended.

(c) All tools used in fabrication are clearly identified and documented in the process specification. Cure tools are designed and validated to yield required panel geometry for the specified process conditions. Tool handling, storage, and maintenance requirements need to be defined to protect tools over time. Any tooling aids to facilitate accurate ply layup and to maintain laminate panel orientation in subsequent process steps are specified. Irons or heat guns used to facilitate ply layup are calibrated to control ply temperature during ply layup.

(4) Required Procedures.

(a) All procedures required to fabricate quality laminates need to be adequately detailed in the process specification to ensure consistency. Create documentation for each panel fabricated, starting with planning instructions and including records of specific materials and actual process parameters used for each fabrication step. Assign an identification number or code to each panel so it is traceable to the associated records. The process specification will have fabrication details for tool preparation, material handling, laminate layup, cure cycle, panel identification, inspection, and machining.

(b) The process specification details the steps needed for tool and raw material preparation. The former includes inspections that verify the tools were properly cleaned and in good working condition. Give procedures for mold release application. Material preparation process steps will start with identification of the specific materials to be used and a review of their associated records. To prevent moisture condensation, specify the procedure to warm frozen prepreg before opening storage containers. To avoid ply damage and contamination, detail prepreg cutting and handling procedures.

(c) In the process specification, detail instructions for laminate layup and panel bagging. Each ply must be accurately oriented and inspected for defects during layup. Debulk groups of plies in a layup sequence with vacuum pressure per specified instructions. Identify and apply specific bagging materials, tooling aids, and thermocouples for cure monitoring according to the detailed steps in the specification.

(d) The process specification includes details for fabricating a panel to the applicable cure cycle. Before cure, perform a leak check on the vacuum bag and take corrective action as needed. The cure cycle should define heat-up rate, temperature range, time, vacuum, pressure, and cool down rate. Develop procedures to monitor cure time and temperature. Keep records of temperature, vacuum, and pressure for the complete cure cycle.

(e) Document step-by-step procedures for inspections and test measurements used to ensure the quality of cured panels in the process specification, along with associated engineering requirements. These procedures, which need to be performed before panel machining, are best started with a review of process records to ensure that panels are fabricated in compliance with requirements. Subsequent efforts determine laminate thickness, layup, panel flatness, surface defects, completeness of cure, and void content. Use nondestructive inspections, which are tied to standards for laminate defects, to detect any embedded flaws that cannot be measured visually. FAA Technical Report [DOT/FAA/AR-02/110] gives some recommendations on details for the inspections and test measurements, which can be used for the quality assessment of cured laminate panels.

(f) The process specification provides details on machining cured panels. Develop machining diagrams to cut test specimens for each panel and include in the detail processing instructions. Lines drawn on the laminate surface may be used to aid the process. Instructions in the specification should identify the type of machining equipment needed, as well as cutting tool type, speeds, and feed rates. After machining, specimens are inspected for damaged edges and measured for dimensional accuracy per requirements.

c. Quality Assurance.

(1) In the process specification, include quality assurance procedures to monitor the fabrication processes as well as the necessary materials, equipment, facilities, and tooling. Each examination, inspection, or testing task performed for quality assurance is defined with a direct link to the fabrication requirements discussed in paragraph 6b of this AC. Organizations or personnel responsible for quality assurance are properly trained and identified in the specification. Specify process documentation procedures, archive time limits, and test methods. These requirements may be detailed in the quality manual.

(2) Quality assurance inspections are needed for material records that are compared against requirements before panel cure. These include verification of: (1) storage life, (2) total out life, (3) acceptance test results, (4) use of approved consumable materials, (5) batch numbers, (6) panel fabrication, (7) specimen preparation, and (8) testing procedures.

(3) Periodic quality assurance inspections are needed to verify equipment, facilities, and tooling requirements. This includes the measurements and calibrations needed to control equipment. The layup room temperature, relative humidity, and cleaning schedule need to be verified through measurements and records. Tools and their storage conditions are inspected. Take surveys on cure tools to ensure uniform heating during the cure cycle.

7. SUMMARY.

a. This AC has been developed based on FAA and NASA joint efforts that are beyond the AGATE shared database methodology. This AC also establishes the guidance for developing composite material and process specifications that ensures adequate material controls. This AC presents the procedure requirements and technical requirements from regulatory perspectives. Details on technical guidelines can be referred to in the DOT/FAA Technical Reports listed.

b. Structural certification ensures that acceptable materials and repeatable manufacturing processes are used for all parts that are integrated into the production. Material and process controls are essential prerequisites for a repeatable and safe product. The material and process specifications are interwoven throughout the certification process. Material specifications define the material’s attributes and the qualification tests. Process specifications define and control the processes used for conversion of materials into structural components.

c. The essential contents that need to be documented in material and process specifications are presented with a focus on base material control. These include the engineering criteria and guidelines that ensure a repeatable raw material source. For the material specification, the engineering criteria/guidelines are presented in terms of material requirements, material characterization, changes to qualified materials, quality assurance, test methods, test panel fabrication, and packaging and shipping. For the process specification, the engineering criteria/guidelines are presented for test panel fabrication in terms of requirements (including personnel, materials, equipment, facilities, tooling, and procedures) and quality assurance (including responsibility for inspection, documentation, and test methods).

8. FUTURE STANDARDIZATION.

a. Consistent and repeatable industry engineering practices would benefit the compliance with requirements for material control. Shared composite databases and specifications throughout industry would enhance the efficiency of material suppliers, end-users, and regulators. We are building on the current FAA/NASA effort to pursue standardization of these specifications with organizations, including MIL-HDBK-17, the SAE International AMS Committee P-17, and ASTM International.

b. The material contained in this document provides guidance for the current industry and is valid for the future standardization efforts in material control. Progress in standardization can be tracked at MIL-HDBK-17 meetings (or via the website of "www.mil17.org") as part of active FAA initiatives to work with industry to ensure safe and consistent use of composites.

Michael Gallagher
Manager, Small Airplane Directorate
Aircraft Certification Service