

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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Guidelines and Recommendations for the Development of Material Specifications for Carbon Fiber Reinforced Liquid Resin Molded Materials

Executive Summary

1. Introduction.
 - 1.1 Objective.
 - 1.2 Background.
 - 1.3 Related Documents
 - 1.4 Certification Process.
2. Liquid Resin Molding Process and Materials
 - 2.1 Liquid Molding Process
 - 2.2 Liquid Molding Materials
3. Development of Material Controls.
 - 3.1 Industry Material Specification.
 - 3.1.1 Constituent Materials
 - 3.1.2 Cured Part Materials
 - 3.1.3 Qualification
 - 3.2 Part Producer Material Specification.
 - 3.3 Part Producer Responsibilities for Material Use in Structural Design
 - 3.4 Material Qualification Process When Using an Industry Material Specification.
 - 3.5 Material Qualification Process When Using an Part producer Material Specification
4. Qualification Requirements
 - 4.1 Initial Material Qualification
 - 4.1.1 Industry Material Specification
 - 4.1.2 Part Producer Material Specification
 - 4.2 Minimum Level Of Testing
 - 4.3 Equivalency Baseline Enhancement
 - 4.4 Additional Characterization Testing For Specific Design Applications
 - 4.5 Supplier Site Qualification
 - 4.6 Changes To Qualified Materials
 - 4.6.1 Level 0 Changes
 - 4.6.2 Level 1 Changes
 - 4.6.3 Level 2 Changes
 - 4.6.4 Level 3 Changes
 - 4.6.5 Level 4 Changes
5. Recommended LRM Specification Structure
 - 5.1 Recommended Specification Structure
 - 5.2 Sectional Arrangement of Specification
 - 5.2.1 Section 1 – Scope
 - 5.2.2 Section 2 – Applicable Documents
 - 5.2.3 Section 3 –Technical Requirements
 - 5.2.3.1 Section 3.1 – General Material Requirements
 - 5.2.3.2 Section 3.2 – Qualification Requirements
 - 5.2.3.3 Section 3.3 – Process Control Document Requirements

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

- 5.2.4 Section 4 – Quality Assurance
 - 5.2.4.1 Section 4.1 – Responsibility for Inspection
 - 5.2.4.2 Section 4.2 – Classification of Tests and Inspections
 - 5.2.4.3 Section 4.3 – Certification of Conformance
 - 5.2.4.4 Section 4.4 – Statistical Process Control
 - 5.2.4.5 Section 4.5 – Test Methods
 - 5.2.4.6 Section 4.6 – Records
- 5.2.5 Section 5 – Preparation for Delivery
 - 5.2.5.1 Section 5.1 – Material Identification
 - 5.2.5.2 Section 5.2 – Packaging and Preservation
 - 5.2.5.3 Section 5.3 – Packing Requirements
 - 5.2.5.4 Section 5.4 – Shipping Requirements
 - 5.2.5.5 Section 5.5 – Receipt at Procuring Organization
- 5.2.6 Section 6 – Acknowledgement
- 5.2.7 Section 7 – Rejection
- 5.2.8 Section 8 – Notes
 - 5.2.8.1 Section 8.1 – Intended Use
 - 5.2.8.2 Section 8.2 – Definitions
 - 5.2.8.3 Section 8.3 – Ordering Data
 - 5.2.8.4 Section 8.4 – Approved Products
- 6. Guidelines for Sections of a Resin Material Procurement Specification
 - 6.1 Section 1 – Scope
 - 6.2 Section 2 – Applicable Documents
 - 6.3 Section 3 – Technical Requirements
 - 6.3.1 Section 3.1 – General Material Requirements
 - 6.3.2 Section 3.2 – Resin Material Requirements
 - 6.3.3 Section 3.3 – Cured Resin Mechanical Properties
 - 6.3.4 Section 3.4 – Qualification Requirements
 - 6.3.5 Section 3.5 – Process Control Document Requirements
 - 6.4 Section 4 – Quality Assurance
 - 6.4.1 Section 4.1 – Responsibility for Inspection
 - 6.4.2 Section 4.2 – Classification of Tests and Inspections
 - 6.4.2.1 Section 4.2.1 – Qualification Tests
 - 6.4.2.2 Section 4.2.2 – Quality Conformance Tests
 - 6.4.2.3 Section 4.2.3 – Receiving Inspection Tests
 - 6.4.3.4 Section 4.2.4 – Retest
 - 6.4.3.5 Section 4.2.5 – Material Distributors
 - 6.4.3 Section 4.3 – Certification of Conformance
 - 6.4.4 Section 4.4 – Statistical Process Control
 - 6.4.5 Section 4.5 – Test Methods
 - 6.4.6 Section 4.6 – Records
 - 6.5 Section 5 – Preparation for Delivery
 - 6.5.1 Section 5.1 – Material Identification
 - 6.5.2 Section 5.2 – Packaging and Preservation
 - 6.5.3 Section 5.3 – Packing Requirements

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

- 6.5.4 Section 5.4 – Shipping Requirements
- 6.5.5 Section 5.5 – Receipt at Procuring Organization
- 6.6 Section 6 – Acknowledgement
- 6.7 Section 7 – Rejection
- 6.8 Section 8 – Notes
 - 6.8.1 Section 8.1 – Intended Use
 - 6.8.2 Section 8.2 – Definitions
 - 6.8.3 Section 8.3 – Ordering Data
 - 6.8.4 Section 8.4 – Approved Products
- 7. Guidelines for Sections of a Fabric Material Procurement Specification
 - 7.1 Section 1 – Scope
 - 7.2 Section 2 – Applicable Documents
 - 7.3 Section 3 – Technical Requirements
 - 7.3.1 Section 3.1 – General Material Requirements
 - 7.3.1.1 Section 3.1.1 – Carbon Fiber Property Requirements
 - 7.3.1.2 Section 3.1.2 – Fabric Workmanship
 - 7.3.2 Section 3.2 – Qualification Requirements
 - 7.3.3 Section 3.3 – Process Control Document Requirements
 - 7.4 Section 4 – Quality Assurance
 - 7.4.1 Section 4.1 – Responsibility for Inspection
 - 7.4.2 Section 4.2 – Classification of Tests and Inspections
 - 7.4.2.1 Section 4.2.1 – Qualification Tests
 - 7.4.2.2 Section 4.2.2 – Quality Conformance Tests
 - 7.4.2.3 Section 4.2.3 – Receiving Inspection Tests
 - 7.4.2.7 Section 4.2.7 – Material Distributors
 - 7.4.3 Section 4.3 – Certification of Conformance
 - 7.4.4 Section 4.4 – Statistical Process Control
 - 7.4.5 Section 4.5 – Test Methods
 - 7.4.6 Section 4.6 – Records
 - 7.5 Section 5 – Preparation for Delivery
 - 7.5.1 Section 5.1 – Material Identification
 - 7.5.2 Section 5.2 – Packaging and Preservation
 - 7.5.3 Section 5.3 – Packing Requirements
 - 7.5.4 Section 5.4 – Shipping Requirements
 - 7.5.5 Section 5.5 – Receipt at Procuring Organization
 - 7.6 Section 6 – Acknowledgement
 - 7.7 Section 7 – Rejection
 - 7.8 Section 8 – Notes
 - 7.8.1 Section 8.1 – Intended Use
 - 7.8.2 Section 8.2 – Definitions
 - 7.8.3 Section 8.3 – Ordering Data
 - 7.8.4 Section 8.4 – Approved Products
- 8. Guidelines for Sections of a Material Acceptance Specification for Composite Parts
 - 8.1 Section 1 – Scope
 - 8.2 Section 2 – Applicable Documents

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

- 8.3 Section 3 – Technical Requirements
 - 8.3.1 Section 3.1. – Materials
 - 8.3.2 Section 3.2 – Equipment
 - 8.3.3 Section 3.3 – Composite Preparation
 - 8.3.4 Section 3.4 – Composite Mechanical Properties and Testing
 - 8.3.4.1 Section 3.4.1 – Baseline Cure Process
 - 8.3.4.2 Section 3.4.2 – Cured Laminate Physical Properties
 - 8.3.4.3 Section 3.4.3 – Cured Composite Laminate Mechanical Properties
 - 8.3.4.4 Section 3.4.4 – Recommended Laminate Tests
- 8.4 Section 4 – Quality Assurance
 - 8.4.1 Section 4.1 – Responsibility for Inspection
 - 8.4.2 Section 4.2 – Classification of Tests and Inspections
 - 8.4.2.1 Section 4.2.1 – Qualification Tests
 - 8.4.2.2 Section 4.2.2 – Constituent Receiving Inspection Tests
 - 8.4.2.3 Section 4.2.3 – Cured Material Batch Release Tests
 - 8.4.2.4 Section 4.2.4 – Part Acceptance Tests
 - 8.4.2.5 Section 4.2.3 – Retest
 - 8.4.3 Section 4.3 – Statistical Process Control
 - 8.4.4 Section 4.4 – Test Methods
 - 8.4.5 Section 4.5 – Records
- 8.5 Section 5 – Notes
 - 8.5.1 Section 5.1 – Definitions
 - 8.5.3 Section 8.3 – Approved Products

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

LIST OF ACRONYMS

AC	Advisory Circular
ACO	Aircraft Certification Office
AGATE	Advanced General Aviation Transport Experiment
AMS	Aerospace Material Specification
ASTM	American Society for Testing and Materials
CACRC	SAE Commercial Airplane Composite Repair Committee
CFR	Code of Federal Regulations
CTD	Cold Temperature Dry
DAR	Designated Airworthiness Representative
DER	Designated Engineering Representative
DMIR	Designated Manufacturing Inspection Representative
DSC	Differential scanning calorimetry
ETD	Elevated Temperature Dry
ETW	Elevated Temperature Wet
DER	Designated Engineering Representative
DMIR	Designated Manufacturing Inspection Representative
FAA	Federal Aviation Administration
IR	Infrared
HPLC	High-Pressure Liquid Chromatography
KC	Key Characteristics
KPP	Key Process Parameter
MIDO	Manufacturing Inspection District Office
MOL	Material Operational Limit
MRB	Material Review Board
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
PCD	Process Control Document
QA	Quality Assurance
RTD	Room Temperature Dry
RTW	Room Temperature Wet
SACMA	Suppliers of Advanced Composite Materials Association
SAE	Society of Automotive Engineers
SPC	Statistical Process Control
TSO	Technical Standard Order

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EXECUTIVE SUMMARY

A widely acknowledged validation process used within the composite aircraft industry for the substantiation of composite structure is called the building block approach. This approach is a process using analysis and associated tests of increasing structural complexity. The building block approach is integrated with supporting technologies and design considerations. MIL-HDBK-17F, Volume 3, Chapter 4 contains a complete description of the building block approach. A key element supporting the building block approach is material and process specifications.

The material and process specifications are interwoven throughout the certification validation process. Material specifications are used to define the material's attributes and define the qualification characterization tests. Materials used within the building block tests are purchased in accordance with the material specification. The same material specification is used for the procurement of production material. This ensures the delivered materials are of the same quality and performance standards used in the certification and validation process. Process specifications define and control the processes used for the fabrication of materials into structural components. It is widely known that the performance properties of composites are directly affected by the specific process used for their fabrication. It is critical that the test specimens fabricated through the various levels of the building block approach use the same process, which is representative of the one that will be used in the fabrication of production aircraft and rotorcraft.

This report establishes recommendations to guide the development of new and revised composite liquid molding resin and continuous fiber reinforcement material specifications and material acceptance documents. This is intended to advance the work that has been done through previous Federal Aviation Administration and National Aeronautics and Space Administration programs such as the Advanced General Aviation Transport Experiment. These programs have established methodology for developing design allowable data, control of the data, and sharing the resulting database. In the current work, a generalized approach to the development of a shared composite material database is proposed. It is intended to expand on those general aviation methods to allow a broader market to utilize the shared database.

This document recommends guidance and criteria for the development of material specifications and material acceptance documents for liquid resins and continuous carbon fiber reinforcement materials to be used on aircraft structures. Similar recommendations for prepreg tape and fabric materials can be found in "Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs," DOT/FAA/AR-02/109, and "Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Fabric Prepregs," DOT/FAA/AR-03/TBD. The guidelines and recommendations are meant to be a documentation of current knowledge and application of sound engineering principles to the development and implementation of composite material procurement specifications. This document can also be used to develop common industry specifications. This document is limited to recommendations and guidance on the development of material specifications. Guidance on the development of process specifications, instructions and controls for making high quality parts by the liquid molding process can be found in the

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companion report “Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites by Liquid Molding Processes,” DOT/FAA/AR-03/TBD. Additional guidance on the development of process specifications, instructions and controls for making high quality prepreg based laminates by can be found in “Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites,” DOT/FAA/AR-02/110.

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1. INTRODUCTION

1.1 OBJECTIVE

This document recommends guidance and criteria for the development of material procurement specifications for liquid resins and continuous carbon fiber reinforcement materials processed by liquid molding processes into composites to be used on aircraft structures. For purposes of this document liquid molding processes are classified as any process where liquid resin is infused into a dry continuous fiber perform. Examples of the liquid molding process include: Resin Transfer Molding (RTM), Resin Film Infusion (RFI), and Vacuum Assisted Resin Transfer Molding (VARTM). The preform structure may be either a textile fabric, non-crimp fabric, braid, or an assembly of these materials.

These recommendations were prepared by a team of industry experts who have extensive experience with material specifications, part processing, qualification programs, and design allowables. This document is limited to recommendations and guidance on the development of material procurement and acceptance specifications. Additional guidance on the development of process specifications, instructions, and controls for making high-quality composites by the liquid molding processes can be found in the companion report "Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites by Liquid Molding Processes," DOT/FAA/AR-03/TBD. Prior to final publication, a thorough review process was used to gain the insights of other industry, government and academic experts.

The purpose of this report is to establish recommendations to guide the development of composite liquid resins and continuous carbon fiber reinforcement material procurement specifications and material acceptance documents. This is intended to advance the work that has been done through previous Federal Aviation Administration (FAA) and National Aeronautics and Space Administration (NASA) programs such as the Advanced General Aviation Transport Experiment (AGATE). These programs have established methodologies for developing design allowable data, control of the data, and sharing the resulting database. In the current work, a generalized approach to the development of a shared composite material database is proposed. It is intended to expand on those general aviation methods to allow a broader market to use the shared database.

The guidelines and recommendations contained in this document should not be viewed as FAA policy or as the only acceptable method for composite material specifications and qualification procedures. They are meant to be a documentation of current knowledge and application of sound engineering principles to the development and implementation of composite material procurement specifications specific to the liquid resins and continuous fiber reinforcements used in liquid molding processes.

This document can also be used to develop an industry approach so that the following goals can be achieved:

- Greatly reduce the number of material and process specifications for identical composite material systems.
- Develop property databases that uniquely define a given material.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- Establish material batch testing and process monitoring sufficient to minimize variability and preclude property changes over time.
- Reduce costs through common documentation and shared databases of basic material properties.

1.2 BACKGROUND

Steady growth in the use of composites has continued in transport aircraft and rotorcraft. General aviation has emerged recently with the growth of new composite aircraft and composite material applications in primary structures. Several new composite aircraft are undergoing the certification process. Many more aircraft are currently undergoing the design and development processes that take advantage of composite materials for primary structure applications. In addition fabrication processes are being advanced beyond the traditional prepreg material based processes. One such emerging process is the liquid resin molding process. With this growth of liquid resin molding composite applications, certification issues have emerged with respect to the philosophy of quality control and quality assurance methods needed to guarantee a safe and consistent material supply.

The material properties of a composite are manufactured into the structure as part of the fabrication process (process intensive material). Therefore, it is essential that material and process specifications used to produce composite materials contain sufficient information to ensure that critical parameters in the fabrication process are identified to facilitate production and adherence to standards in the final engineered part. Due to the wide variety of composite aircraft structures now emerging for certification, control of the materials is rapidly becoming a vital issue with respect to the overall assurance of safety.

In recent years, the aerospace industry, the National Aeronautics and Space Administration, and the FAA have worked together to develop a cost-effective method of qualifying composite material systems by sharing material qualification databases such as MIL-HDBK-17 and AGATE. By using shared databases, a manufacturer can select an approved composite material system to fabricate parts and validate with a smaller subset of testing for a specific application. For materials to be accepted into these shared databases, the raw materials are required to be manufactured in accordance with a material specification which imposes control of key characteristics (physical, chemical, and mechanical properties) and be processed in accordance with a process specification that controls key characteristics (processing parameters).

1.3 RELATED DOCUMENTS

The following documents provided related information:

DOT/FAA/AR-02/109, Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Unidirectional Prepregs, April 2003

DOT/FAA/AR-02/110, Guidelines and Recommended Criteria for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites, April 2003

DOT/FAA/AR-03/19, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems, TBR. (supercedes DOT/FAA/AR-00/47)

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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DOT/FAA/AR-03/XXX, Guidelines and Recommended Criteria for the Development of a Material Specification for Carbon Fiber/Epoxy Fabric Prepregs, TBD

DOT/FAA/AR-03/XXX, Guidelines and Recommended Criteria for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Liquid Resin Molded, Fiber-Reinforced Polymer Composites, TBD

1.4 CERTIFICATION PROCESS

The objective of the composite aircraft structure certification process is to validate that the design meets the applicable configuration requirements. In this context, the design validation process (to establish by proof) is accomplished through verification (to prove by evidence) and qualification (to define attributes or characteristics) of the materials, processes, and analysis tools. Verification is simply to prove by evidence, usually by test data, that the proposed design is acceptable. Material qualification is the verifying of a materials attributes and characterizations, which are typically determined through testing.

A widely acknowledged validation process used within the composite aircraft industry for the substantiation of composite structure is called the building block approach. This approach uses analysis and associated tests of increasing structural complexity. The building block approach is integrated with supporting technologies and design considerations. Refer to MIL-HDBK-17F, Volume 3, Chapter 4 for a complete description of the building block approach. Key elements supporting the building block approach are the material and process specifications.

The material and process specifications are interwoven throughout the certification and validation process. Material specifications are used to define the material's attributes and to define the qualification characterization tests. Materials used within the building block tests are purchased in accordance with a material specification. The same material specifications are then used for procurement of production material. This ensures the delivered materials are of the same quality and performance standards used in the certification validation process. Process specifications define and control the processes used for the conversion of materials into structural parts. It is widely accepted that the performance properties of composites are directly determined by the specific process used for their fabrication. It is critical that the test specimens fabricated through the various levels of the building block approach use the same process, which is representative of the one that will be used in the fabrication of production aircraft and rotorcraft.

Material qualification is a key element of the validation process, which occurs during the coupon level of the building block approach. It is during qualification that the composite material is fully defined and characterized. Qualification tests are planned and conducted to

- establish key material attributes,
- establish material performance properties, and
- verify material characteristics will work in the intended application.

The objective in defining material attributes is to establish the constituent material property limits. Examples of attributes applicable to LRM processing in which limits are set are more easily explained by segregating those associated with the preform from those associated with the liquid resin. Examples of preform attributes include:

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- fiber properties (linear weight, density, tow count, and mechanical properties).
- ply dimensions, alignment and stacking sequence.
- shaped preform contours.
- de-bulked preform fiber volume.
- Permeability.
- Bulk.

These attributes define the preform material and control its resulting performance properties. Other attributes which are often overlooked are those related to the physical structure of the material, which affects processing characteristics. Example attributes of this type include:

- fiber-sizing level and type.
- quantity of tackifiers and/or binders used.
- Distribution of tackifier or binder through the preform thickness
- compatibility of constituent materials with each other.

Examples of liquid resin attributes include:

- initial mix viscosity (at a defined temperature).
- initial mix heat of reaction (ΔH_{ult}).
- mix chemistry (e.g. ratio of epoxide:amine groups in some epoxy chemistries).

These attributes define the liquid resin material and control its resulting performance properties. Other attributes which are often overlooked are those related to the physical structure of the liquid resin material, which affects processing characteristics. Example attributes of this type include:

- Amount of entrained air or solvent
- Thermal conductivity
- Viscosity as a function of temperature and time at temperature

Performance properties are established through statistically significant amounts of testing. It is imperative that the material's natural variability is captured during material qualification. The objective is not to meet a desired level of performance, but rather, establish the true performance range of the material. Unfortunately, mechanical properties are typically thought of as the only performance properties.

There are other performance-related properties that have a direct bearing on the more familiar mechanical properties, which include handling characteristics, kinetic behavior, rheological behavior, sensitivity to ambient moisture and temperature (out-time effects), effect of freezer storage, and resistance to fluids and solvents. Multiple material batches (typically a minimum of three) are tested to establish the combined material variability. Results obtained from these tests are used to establish tolerance limit values within the constituent material specifications.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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2. LIQUID MOLDING PROCESS AND MATERIALS

2.1 LIQUID RESIN MOLDING PROCESS

The liquid resin molding (LRM) processes differ significantly from prepreg processing in that the reinforcement constituents (fiber) are processed independently from the resin, and generally located on the mold or tooling before the resin is introduced. The reinforcement is sometimes trimmed, formed, and assembled outside the mold and may be referred to as a preform. The preform is generally located on the mold, then infused with liquid resin, and then cured according to the specified cure cycle for the liquid resin. A flow chart for the LRM process is provided in Figure 1.

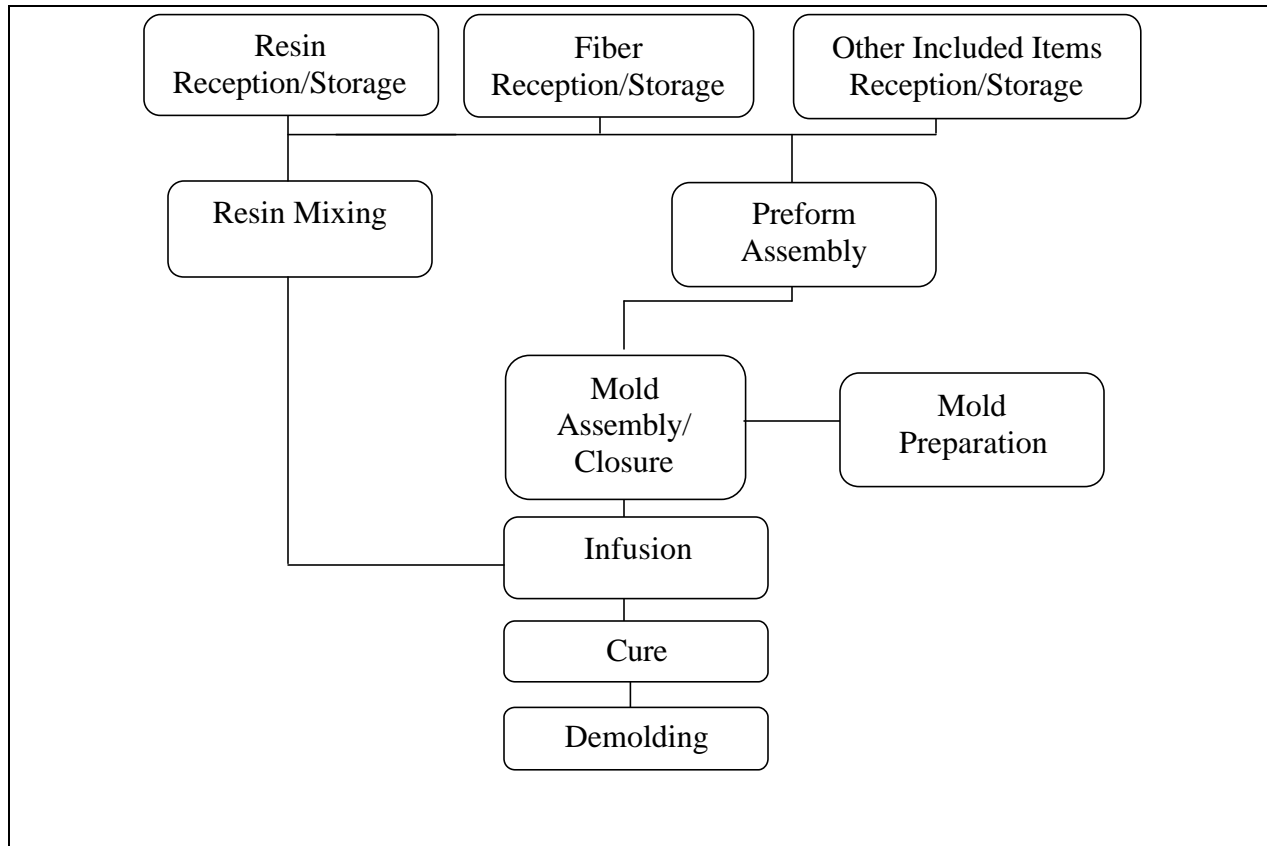


Figure 1 Liquid Resin Molding Process Flow

The various options of reinforcement types, fiber types, and combinations are numerous for the LRM process. Likewise, options for tooling used for LRM processing are numerous. The infusion process may take place in a closed-cavity mold, whereby all surfaces of the final molded part are defined by the surfaces of the rigid tooling, or the tooling may be such that it only defines a portion of the part and the other surfaces are controlled by bagging material of some sort as in a vacuum-bagged prepreg part. These options are illustrated in Figure 2.

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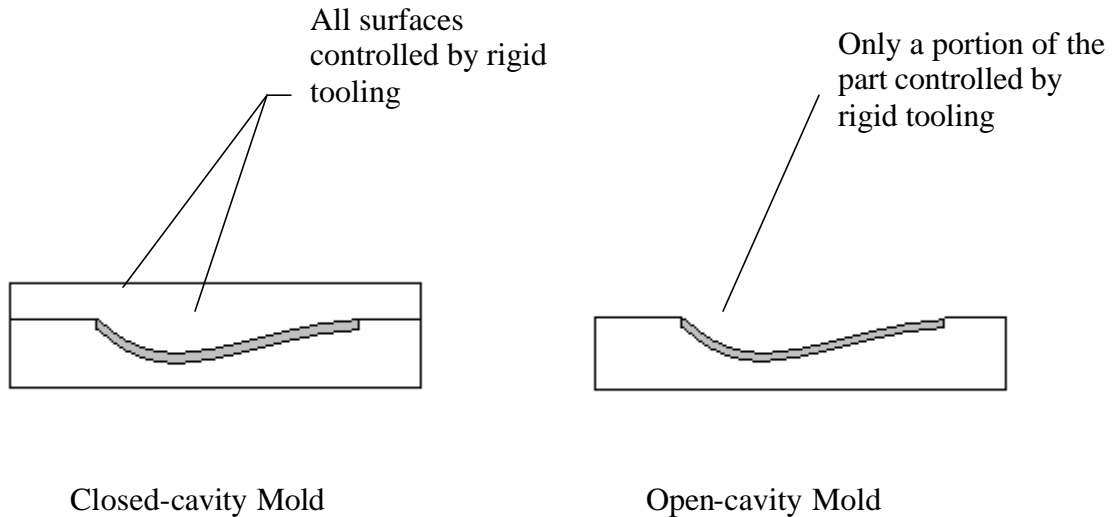


Figure 2 – LRM Mold Options

2.2 LIQUID RESIN MOLDING MATERIALS

In the liquid molding process, as with all composite processes, many materials are used to fabricate components; the matrix and fiber reinforcement are the two major constituent materials. The guidelines contained within this document specifically address polymer resin matrix and continuous carbon fiber reinforcement materials. Materials used by the liquid resin molding process can be divided into categories as follows:

- Reactive resin materials – Reactive materials include the resin, which may be a one-part or two-part system, and tackifiers applied to the carbon fiber reinforcement. Because they undergo polymerization reactions during the cure process they are referred to as reactive materials.
- Non-reactive reinforcement materials – The reinforcing carbon fibers are the non-reactive materials, i.e. they do not polymerize during the cure process. The carbon fibers can be in the form of textile fabrics, braided structure, or non-crimp fabrics. The preforms can be purchased with or without an applied tackifier. The application of a tackifier can change the usually non-reactive material into a reactive material, similar in nature to a prepreg. Tackifiers can be either applied by the preform material supplier or by the part producer just prior to placement into the mold. It is critical that the tackifier be chemically compatible with the matrix resin and fiber sizing.
- Assembled materials – Preforms where the various layers have been assembled together are referred to as assembled materials. A common assembled preform material is the combining of non-crimp fabrics. The non-crimp fabrics are stitched or warp knitted together to form a single preform. Textile fabrics can also be stitched together to form 3D preforms. Other

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material forms assembled into the part include precured laminates, metallic fittings, honeycomb core, and foam core. Materials assembled into the part should be controlled with their own material procurement specification.

- Consumable and ancillary materials – A variety of additional materials are used by the liquid molding process. These materials include: mold release agents, adhesives, bagging films, release films, flow media, damming materials, vacuum bag films, vacuum bag sealants, breather materials, resin distribution materials (such as porous tubes or tightly wound springs), and tapes. While it is not standard practice to control these materials by their own material procurement specifications, consideration should be given to controlling their sources and characteristics via a qualified products list.

With liquid resin molding processes the resin and fiber are typically purchased from different suppliers and are only brought together at the time of part fabrication, making it very difficult for the material suppliers to test the total material system at the composite level. The part fabricator is now required to communicate with a variety of material suppliers and generate individual material procurement specifications for the constituent materials. In addition, a specification is required that combines the matrix resin and reinforcing fiber into the total composite material system. This is the level at which the primary design related properties are evaluated and controlled.

One approach for material control of liquid resin molded parts is the use of material procurement specifications for the constituent materials (resin and reinforcement) in combination with a material acceptance specification for the cured parts, as shown in Figure 3. The constituent materials are tested by the supplier and if applicable by the purchaser (part producer). Depending on the material, the purchaser may or may not elect to test the constituent materials upon receipt. The combined system is then controlled at the cured composite assembly (resin combined with reinforcement) through an acceptance specification by the part producer. It is through this document that the part producer validates the combined composite assembly will yield performance properties equivalent to those developed during qualification, design allowable property and certification development. This same document can define the process for qualifying the material system. This material acceptance document will be very similar in content to a traditional prepreg material specification, with one major difference being that the requirements at the cured part level are levied by the part producer on themselves rather than on a material supplier.

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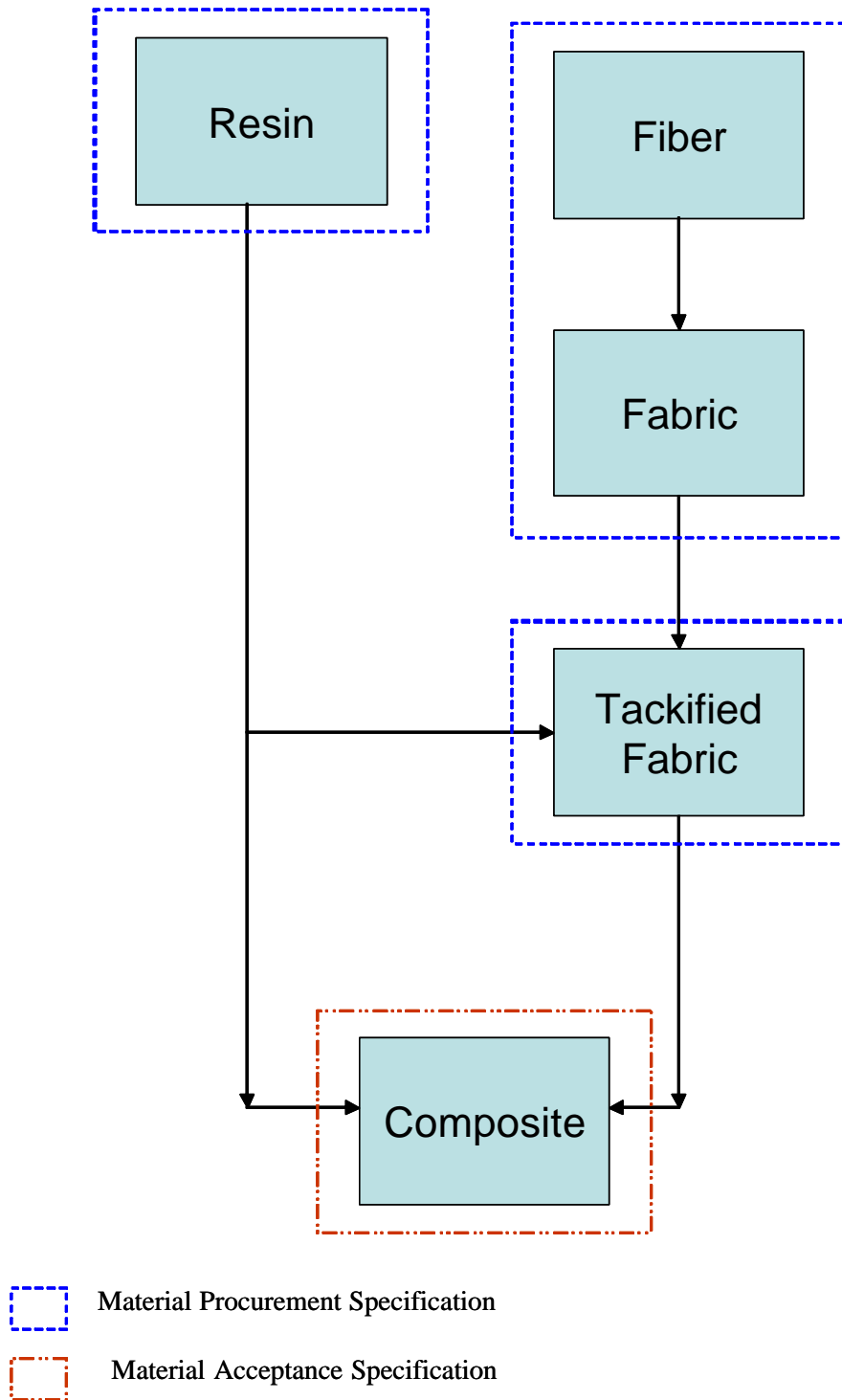


Figure 3 – Liquid Resin Molding Material Procurement and Acceptance Documents

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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3. DEVELOPMENT OF MATERIAL CONTROLS

Before the initiation of a qualification program, the sensitivities of the material to variations in the tolerances set on the material chemical and physical properties and processing should be investigated. This investigation should explore the characteristics of the material as the various limits are reached. These will determine the suitability of control limits in establishing the required reliability for the normal production phase of a qualified composite material.

This investigation can be performed in a structured design of experiments that will give the relative sensitivities to the process variables with minimum testing. These parametric studies should be performed well before the qualification batches are run to allow time for any required adjustment to settle out in the manufacturing process.

The rest of this section outlines the differences between qualification of constituent materials and cured panels to industry standard versus part producer material specifications, the responsibilities of an part producer related to establishing the suitability of a particular material and part fabrication process, and the steps required to establish the material specifications and qualify the materials and cured panels. The following two sections discuss different types of material procurement specifications: (1) industry standard specifications established by an industry committee and (2) specifications established by an individual part producer.

The authors of this document believe that the full benefits of shared material databases can only be achieved through the use of industry standard material specifications. However, it is recognized that there will continue to be cases where part producer material specifications are appropriate or required. This section discusses the qualification steps for both approaches. It is intended that this document apply to both approaches.

3.1 INDUSTRY MATERIAL SPECIFICATIONS.

The recommendations in this document are particularly applicable to material specifications that will be released as industry standards. For liquid resin molding materials, industry standard specifications could be developed for the various constituent materials as well as for the cured part 'material'.

3.1.1 Constituent Materials

The process envisioned for industry standard constituent material specifications would involve the development of an initial material database by the material supplier(s). The material supplier controls the incoming raw materials and processes to produce a consistent product.

3.1.2 Cured Part Material

The process envisioned for an industry standard cured part material specification would involve the development of an initial material database by either a material supplier or an industry consortia. Typically it would be the resin material supplier who would have the interest in and capability for developing the material characterization data. The cured part material specification (referred to as the material acceptance specification in Figure 3) would control the cured part properties and would contain material property acceptance limits which the part producer would be required to meet.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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3.1.3 Qualification

Material qualification is defined as the process of evaluating a material (constituents and cured parts), using a prescribed series of tests, to establish its characteristics as produced by the baseline manufacturing process and using the evaluation results to define material specification requirements. A material qualification is performed initially for a new material; it is repeated in part or in whole when changes to materials or manufacturing processes need to be evaluated, or when a new combination of material constituents is desired. The scope of a previous qualification may also need to be expanded when requirements for additional characteristics are either added to an existing application or result from using the material in a new application. For material characteristics that have never been qualified, a material specification may contain target values in place of requirements; in this case, following qualification, the target values are updated to requirements based on the evaluation results.

The initial material database will result from testing conducted to an FAA-approved and FAA-witnessed test plan and will provide sufficient data to establish the material specification requirements and batch acceptance limits for both the constituent material specifications and the cured material acceptance specification. In this scenario, the material supplier or industry consortia would calculate proposed specification requirements, and bring the material test results along with the proposed specification requirements to an industry committee (such as SAE AMS Committee P, SAE CACRC, MIL-HDBK-17, and ASTM Committee D-30) for development of an industry specification. The committee would review the data, and finding it satisfactory and needed, would approve a development of the specifications. These specifications would uniquely define the material and will include specific property requirements and batch acceptance limits.

With this industry specification approach, the traditional process of qualifying a material to an existing material specification (containing either target requirements or requirements from a previously qualified material) is no longer applicable. The specification requirements will be determined based on the properties of the specific material. It is envisioned that specifications will be issued for any material for which the minimum dataset, process control, and documentation requirements have been met. Part producers desiring multiple material sources for an application can either callout the acceptable materials on the part drawings, on a substitution document, or on an internal specification once they have validated that all of the materials are acceptable for the design(s). However, the materials would be purchased and accepted to the requirements of the industry specifications.

It will be the responsibility of the material supplier (for constituent materials) and part producer (for the cured part 'material') to continually test and evaluate the materials to populate the database on an ongoing basis to ensure that the materials have not changed.

3.2 PART PRODUCER MATERIAL SPECIFICATION.

The traditional approach in the aerospace industry is for each part producer to prepare material and process specifications. After qualification of a material to these specifications, the part producer then purchases the prepreg and manufactures a part. This approach has involved the qualification of a material to an existing material specification (either in draft or released form).

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

In many cases, different materials have been qualified to the same set of specification requirements, even though the properties of the materials may be significantly different. This approach can result in less than desirable levels of control over the properties of the individual materials qualified to the specification. This may then translate into less than optimum control over structure made with these materials.

Since it may be several years before the industry standard specifications are in place, this document includes recommendations for the preparation of part producer material specifications, and the qualification of materials to these specifications, to meet the goals stated in section 1.2.

3.3 PART PRODUCER RESPONSIBILITIES FOR MATERIAL USE IN STRUCTURAL DESIGN.

It is the responsibility of the part producer to qualify the combination of constituent materials and the resulting cured material for use in a particular aircraft or rotorcraft application (see section 4.1 for additional information). This process by the part producer may involve additional tests to characterize the material and validate specific design details. These tests will be conducted to fully populate the certification database and then, on a reduced frequency basis, to ensure that the design allowables remain valid. The part producer is also responsible for validating that alternate materials are acceptable for the application, if this is so desired.

If the part producer decides to use the material property information in previously developed databases in the part producer's certification project, the part producer will need to perform equivalency tests on cured laminates or parts to demonstrate an understanding of the associated material and process specifications. This understanding essentially involves demonstrating that the part producer can produce test panels and specimens that give results that are statistically equivalent to the values in the existing database.

In order to reduce the risk of failing the equivalency demonstration, it is recommended that the equivalency testing first be done using the resin material supplier's baseline infusion and cure process prior to attempting to demonstrate equivalency to an part producer's cure cycle. The part producer has the option of skipping the first step and directly demonstrating the equivalency of their infusion and cure cycle to the baseline database and process. However, the two-step process is recommended, since it is further recommended that the part producer perform the purchaser batch acceptance tests on panels cured using the material supplier's baseline process.

Further, it is the responsibility of the part producer to validate any deviations from the baseline part cure cycle given in the material and process specifications. The part producer's production process must not result in statistically significant changes to design allowables established by using the baseline process. Successful demonstration of equivalency to an existing shared database will allow the part producer to avoid additional material qualification tests and to use the material allowables derived from the shared database. Once an equivalency evaluation is performed by an part producer for one application, it does not have to be repeated by that part producer for follow-on applications that use the same preform architecture, infusion process and cure process.

This document is limited to recommendations and guidance on the development of material procurement specifications and material acceptance documents. Additional guidance on the development of process specifications, instructions and controls for making high quality parts by

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

the liquid molding process can be found in the companion report “Guidelines for the Development of Process Specifications, Instructions, and Controls for the Fabrication of Fiber-Reinforced Polymer Composites by Liquid Molding Processes,” DOT/FAA/AR-03/TBD

3.4 MATERIAL QUALIFICATION PROCESS WHEN USING INDUSTRY MATERIAL SPECIFICATIONS.

The following outlines the process of material qualification, part producer demonstration of equivalency for their part fabrication process, and the on-going material acceptance testing. Details of the industry committee procedures, acceptance limit and allowables calculation procedures, and FAA involvement and procedures for this material qualification process will be defined at a later date.

In this process, it is anticipated that the resin material supplier will:

- develop a new resin material for potential market requirements or want to qualify an old material to an industry specification.
- stabilize the resin material production process through production trials.
- select a baseline fiber preform architecture for which to develop the material characterization database.
- establish and document the baseline infusion and cure process parameters for the material. This process will be used to generate the qualification database.
- perform the minimum qualification tests, as defined in the constituent and cured part material specifications. A minimum of three batches of material will be produced for the manufacture of test panels.
- upon completion of the testing, develop statistical material batch control limits for the constituent and cured materials, and B-basis allowable values.
- provide the test data and specification limits to the industry committees responsible for the industry constituent material procurement specifications, cured material acceptance specification, material processing specification, and database approval.
- make the constituent process control documents (PCDs) available for on-site review by the industry committee and customer personnel who have executed proprietary agreements with the supplier(s).
- the industry committee will review the data and specification values, and if acceptable, will issue appropriate notifications (documents, web announcements, etc.).
- based on marketing requirements, develop a test plan for additional material characterization tests. Perform the tests, calculate material equivalence limits and allowables, and submit the data and calculated values to the industry committee.
- submit the material and accompanying data, material specifications and allowables to a potential part producer.

At this point, the part producer will

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- perform equivalency tests to the cured material acceptance specification, material processing specification, and property database to verify that the user's processes for fabricating test panels and production parts can produce equivalent properties as compared to the industry-approved database.
- compare the results of the equivalency tests to the published material database. If all test data meets the requirements then the part producer can use the material allowables developed from the supplier's database in the design and certification of the part producer's structure.
- if equivalency is not demonstrated, the part producer can either (1) modify their fabrication process and rerun the equivalency test program or (2) perform additional tests to develop design allowables specific to their situation.
- perform additional design verification and certification tests to validate specific configurations and design details of their structure. Upon completion of all certification tests and analyses, the FAA will approve the design, which specifies the materials, for a Type Certificate.

3.5 MATERIAL QUALIFICATION PROCESS WHEN USING PART PRODUCER MATERIAL SPECIFICATIONS.

The following outlines the process of material qualification, part producer demonstration of equivalency for their part fabrication process, and the on-going material acceptance testing. It assumes that the new material will qualify to a material specification written and maintained by an part producer. It also assumes that all qualification and design-related testing will be performed or controlled by the part producer. This material qualification process is consistent with the current FAA procedures for an aircraft certification program.

In this process, it is anticipated that the material supplier(s) will:

- develop new constituent materials for potential market requirements.
- stabilize the constituent material production process through production trials.
- establish and document the baseline infusion and cure process parameters for the materials. This cure process will be recommended to potential part producers.
- submit the material and accompanying data to potential part producers.

At this point the part producer will

- submit a qualification and design allowables test plan and draft constituent and cured material specifications to the FAA.
- perform the qualification and allowables tests, using the part producer's planned production infusion and cure process. A minimum of three batches of material will be used for the manufacture of test panels. Panel fabrication and testing will be witnessed as required.
- upon completion of the testing, calculate proposed material batch acceptance limits for the constituent and cured materials, and B-basis allowables values. Specification limits

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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and allowables will be calculated using procedures documented in DOT/FAA/AR-03/19 and MIL-HDBK-17.

- submit the test data, material specifications, and infusion and cure process documentation to the FAA. The FAA will review the data and specification values, and if acceptable, will approve the use of the material specification and allowables data for the part producer's aircraft certification project.
- perform additional design verification and certification tests to validate specific configurations and design details of their structure. Upon completion of all certification tests and analyses, the FAA will approve the materials and design for a Type Certificate.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

4. QUALIFICATION PLAN

The qualification test plan may be either defined within the material acceptance document or as a separate document (there is no cured laminate level material procurement document when using a liquid resin molding process). Common practice is to use a separate document. The type and number of tests to be performed, acceptance requirements and additional qualification requirements are defined in the qualification plan document. Additional qualification guidelines are listed below.

It is highly recommended that qualification testing be performed at the system level, i.e. a specific resin, tackifier, and fiber preform are tested together as a cured laminate or part. It is not appropriate to perform qualification testing on a resin material and then approve its use with a variety of fiber reinforcement forms without having tested the resin in conjunction with each fiber reinforcement form. Prediction of composite level strength properties from constituent properties is not sufficiently accurate at the present time.

4.1 INITIAL MATERIAL QUALIFICATION

This section should include procedures and requirements for initially characterizing the material to establish the material procurement specification and material acceptance document requirements.

4.1.1 Industry Material Specification

To develop the information needed to qualify a material to an industry specification, tests will be conducted to establish an initial database. The testing can be performed by a material supplier, a part producer, or an industry consortium (suppliers and multiple part producers, e.g., AGATE). The results from the testing are used to establish the initial material specification and batch acceptance limits. The decision on whether the specification becomes industry standard or an part producer proprietary specifications is for the developers of the database to determine.

A request for the initial qualification will be reviewed by the FAA. The organization that will conduct the tests shall submit a test plan, material specifications, and process specifications prior to the actual qualification. Appropriate reviews and inspections should be agreed upon to ensure FAA acceptance of the qualification.

4.1.2 PART PRODUCER MATERIAL SPECIFICATION

For qualification to part producer specifications, the material suppliers and part producer typically will negotiate as to which party will fund and conduct the qualification tests. The part producer will be responsible for submitting a test plan, material specifications, and process specifications to the FAA prior to the actual qualification. The results from the qualification testing are used to establish the initial material specification and batch acceptance limits.

4.2 MINIMUM LEVEL OF TESTING

It is recommended that the initial material database include the minimum required properties listed in sections 6.3.2, 6.3.3, 7.3.1.1, 8.3.4 for the resin, fabric, and cured composite system. At the discretion of the organization(s) developing the database, the test program may include the additional recommended tests listed in 8.3.4 and any additional tests desired by the prospective

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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part producers of the material. It is strongly recommended that fatigue be among the tested properties.

It is strongly recommended that a minimum of three different material batches consisting of a minimum of two different fiber or preform batches, three different resin batches and three different tackifier batches be used for the initial database.

Per the AGATE approach, it is also recommended that composite mechanical property data for each batch be processed using two independent cure cycles. The data from the two processing cycles can be considered separate batches when calculating design allowables from the data.

The statistical procedures given in DOT/FAA/AR-03/19 and MIL-HDBK-17 can be used to calculate the material property equivalency requirements and material batch acceptance limits. When using these procedures, the equivalency requirements should be calculated using an $\alpha = 0.05$, while the batch acceptance limits should be calculated using an $\alpha = 0.01$ (Note: these recommended values for alpha are currently under investigation by the MIL-HDBK-17 Statistics Working Group, which may issue revised recommendations in the future). The equivalency requirements for all tested properties, and the acceptance limits for specified properties shall be listed in the specification. These requirements and acceptance limits are recommended to be established as:

- 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 ply thickness, resin content, areal weight, Tg, etc.
- maximum average values for volatile content, void content, etc.

4.3 EQUIVALENCY BASELINE ENHANCEMENT

Since the initial material qualification testing is typically performed on only three batches of material (containing only three batches of resin and tackifier, and two batches of fiber), and since the qualification batch material is often produced using processes that are not completely representative of full-scale resin and preform production, it is strongly recommended that the material acceptance document contain requirements to test additional structural and other properties on each batch, with the test frequency for these tests reduced once the properties are verified to be stable.

The reasons for recommending this additional testing are:

- The additional data will provide a more robust database (closer estimate of the population means and variability's) for calculating the material batch acceptance and material equivalency requirements. This is expected to result in fewer material batch rejections and fewer failures of follow-on material equivalency programs. It is also expected that there will be a greatly reduced chance of the control specimens in an equivalency test program failing the equivalency requirements.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- Provides an ongoing validation of structural properties, thereby minimizing the chance of surprise changes in material properties.
- A larger database will result, thereby providing the potential for higher allowables.

It is recognized that updating statistical basis values may require significant engineering expense to revisit strength calculations. It should be understood that basis values are not a constant value for samples drawn from a population, but that they have a distribution of values. For instance, two samples drawn from the same population will produce two different basis values; both values are valid in the sense that they represent an estimate of the statistical population distribution. For this reason, it is not practical to continually recalculate basis values as new data points are obtained.

The following testing protocol is recommended:

1. After qualification, the equivalency baseline database (EBD) tests listed in section 8.3.4 should be performed for each cured material production batch. After the 12th batch of production material is tested, the material equivalency and batch acceptance requirements listed in the material acceptance document should be recalculated, and the document revised with the updated values.
2. If there are no significant changes in the requirements from the calculations in step 1, and an SPC analysis of all of the batch data shows that the material is in control, then the EBD testing frequency can be reduced to once every 30 batches or once a year, which ever is more frequent. Normally, the part producer should not have to obtain formal FAA approval for the reduction in EBD testing frequency; the batch data will be reviewed as part of the material acceptance document update described in step 1.
3. Upon accumulation of each additional ten sets of test results (either from the EBD testing or from intervening material equivalency testing), the material equivalency and batch acceptance requirements should be recalculated, and the material acceptance document revised with the updated values. For those properties tested for each batch of material, the data from all batches shall be included in the recalculation.

This testing must be compared to the basis values to assure they are still valid for the new batch and equivalent values.

4.4 ADDITIONAL CHARACTERIZATION TESTING FOR SPECIFIC DESIGN APPLICATIONS

Depending on the intended application for the material, additional tests at the laminate, element, and subcomponent levels may be required to fully characterize the material. This testing would include evaluations of process and configuration variations, such as for cocured sandwich structures. For more discussion of scale-up issues of composite processing see DOT/FAA/AR-03/TBD. These tests could also include evaluations of solvent resistance, impact damage resistance and residual strength, fracture toughness, and bolted and bonded joint strength.

These tests can be performed at the discretion of a material supplier if a common database of properties is desired; otherwise the tests can be left to the individual part producers of the material.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

4.5 SUPPLIER SITE QUALIFICATION

The material manufacturing site should demonstrate to part producers and certification agencies the capability to conduct raw material testing, final product testing, record maintenance, calibrations, and statistical process control. Training programs and records should be in place to assure that personnel are capable of conducting testing, running equipment, and assembling and interpreting test results. Adequate and consistent document control should be demonstrated. Major equipment maintenance and modification records should be available. An appropriate organizational structure should exist to ensure that each major function (i.e., operations and quality assurance) can perform their functions.

4.6 CHANGES TO QUALIFIED MATERIALS

This section should include the procedures and requirements for establishing the equivalency of future material data to the baseline database.

Material equivalency is the process of determining whether two materials or processes are similar enough in their characteristics and properties that they can be used without distinction and without additional evaluation. In this discussion of equivalency, 'material' is defined as the cured part material. Statistical tests are used to determine whether data from the same material processed in two different manners are significantly different. Equivalency is limited to the evaluation of changes in a material's constituents, manufacturing process, or to changes in the fabrication (e.g., resin mixing, infusion and curing) process used with a material. Two materials that meet the same minimum material specification requirements but have statistically different property distributions are not considered equivalent.

DOT/FAA/AR-03/19 provides procedures for evaluating material equivalency. The procedures for material equivalency described in that document are only applicable to specific types of changes and subject to limitations. For details of the changes and conditions, see DOT/FAA/AR-03/19.

The following sections are intended to expand upon the material equivalency guidelines given in DOT/FAA/AR-03/19 by encompassing a greater range of material changes. 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 determine whether there is a statistical difference between the data from the two materials or fabrication processes. For two materials to be truly equivalent, their population means and distributions for every property of interest must be essentially identical. However, in practice, this will almost never be achieved, so engineering judgment will be required when equivalency determinations are necessary.

Since processes and materials undergo continual evolution and change, it is necessary to establish that the material remain true and consistent to the original database and allowables. It is the responsibility of the material supplier to conduct testing to demonstrate that the current material, when processed to the baseline process specification, will generate composite properties statistically equivalent to the properties of the original materials.

Any material changes that result (or can be expected to result) in a change to the material allowables, or to the acceptance limits, shall be considered to be a major change under 14 CFR

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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21.93. The approval of minor and major changes are covered in 14 CFR 21.95 and 21.97, respectively. The following sections describe five levels of material changes and the testing and notification requirements associated with these levels.

4.6.1 Level 0 Changes

These are changes that do not affect the material. Some examples of these changes are typographical error corrections to the specification or process control document (PCD), changes to the names of incoming materials due to company name changes, and use of alternate storage facility locations using identical storage conditions. No notification to the part producers is necessary for these changes.

4.6.2 Level 1 Changes

These changes are minor changes that have been tested internally at the supplier beyond normal batch acceptance testing on the same or similar material, and have been found not to affect the material. Some recommended examples of level 1 changes are

- Alternate vendor for chemically and physically identical raw materials
- Changes to packaging methods and materials

Physical aspects of constituent resin chemicals, such as particulate size and shape, can have a significant effect on the properties of the mixed resin even if the constituents are chemically identical.

Current part producers shall be notified of these changes. A new revision of the applicable material specification is recommended.

4.6.3 Level 2 Changes

Due to the type of change involved, this level is considered major by the FAA. These changes are not subjected to the full equivalency test plan required for a level 3 change. These changes will require that the material supplier or part producer conduct testing to an extent that establishes the requirements listed in the material and process specifications will not change.

Some recommended examples of level 2 changes to constituent materials are:

- Change in feedstock or precursor to resin ingredients
- Change in feedstock or precursor to fiber ingredients
- Second source of chemically and physically similar raw materials
- Changes to test methods that reduce variability
- Modifications to process equipment or processes that do not change key characteristics or key process parameters
- Addition of new similar equipment
- Expansion of existing facilities, including start up of additional production facility machines

Some recommended examples of level 2 changes to cured part materials are:

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- Changes to test methods that reduce variability
- Modifications to tackifier application, infusion or cure process equipment or processes that do not change key characteristics or key process parameters
- Addition of new similar tackifier application, infusion or cure process equipment
- Expansion of existing facilities, including start up of additional production facility machines

The type of change and the testing that demonstrates no significant effect must be documented in the appropriate part of the supplier PCD or part producer material process specification. It is recommended that side-by-side testing of the original material or method and the new material or method be conducted.

Using the material equivalency requirements contained in the specification, the statistical procedures given in DOT/FAA/AR-03/19 can be used to verify that the data from the altered material is equivalent to the baseline database for the material.

A new revision letter for the applicable material specification should be used when this level or higher change is incorporated. Current part producers shall be notified of these changes and approval of the part producers obtained prior to incorporation. Part producer approval is only required for those users receiving material to the new revision of the material specification.

4.6.4 Level 3 Changes

These changes are major changes that are subjected to a full equivalency test program, such as defined in DOT/FAA/AR-03/19. Level 3 major changes are those that have the possibility of changing either the part processing characteristics or the cured lamina properties such that there is a shift away from the average values established for the material. The supplier or part producer should develop and deliver to the part producers a test plan, a description of the change, and the original material and process specifications. Some part producers may require additional tests beyond those given in DOT/FAA/AR-03/19 to address specific critical design issues.

Some recommended examples of level 3 changes to constituent materials are:

- Change in fiber manufacturing process
- Change in fiber size type, size level, finish, or coupling agents
- Change in resin chemical characteristics (e.g., alternate resin ingredient)
- Change in viscosity of major resin components
- Change in manufacturing site for fiber or resin
- Change in resin mixing, mixing equipment, process and key process parameters that change key characteristics, or key process parameters
- Change in viscosity
- Change in nominal number of fibers per tow (small)

Some recommended examples of level 3 changes to cured part materials are:

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- Change in resin mixing, mixing equipment, process and key process parameters that change key characteristics, or key process parameters
- Change in cure cycle (e.g., temperature, dwell time, and pressure)
- Change to/from closed mold from/to open mold process
- Change in preform (small)
- Change in amount of tackifier material (large)

Testing to validate level 3 changes should involve a minimum of three batches of material containing three batches of resin and tackifier, and two batches of fiber. In addition, any other critical properties that are expected to be affected by the change must be included in the test plan.

Using the material equivalency requirement values contained in the specification, the statistical procedures given in DOT/FAA/AR-03/19 can be used to verify that the data from the altered prepreg is equivalent to the baseline database for the material. If equivalency to the original data cannot be confirmed, then the change will not be allowed, or a new material specification designation will be required for the altered material (see level 4 changes below).

A new revision letter for the applicable material specification or material acceptance document should be used when the change is incorporated. Current part producers shall be notified of these changes, and approval by the part producers obtained prior to incorporation. Part producer approval is only required for those users receiving material to the new revision of the process specification.

4.6.5 Level 4 Changes

Level 4 is a major change, where equivalency testing will not suffice for links to a previous material characterization. Level 4 changes require a new product identification (new specification designations) and a new qualification test program. Level 3 or lower material changes that fail to demonstrate equivalency will typically be considered level 4 changes. Some changes will be considered level 4 changes regardless of the results of equivalency results, due their significant potential effect on material properties or on part fabrication processing.

Some recommended examples of level 4 changes are

- Change in resin or tackifier composition
- Change in nominal number of fibers per tow (e.g., 3000 fibers per tow to 6000)
- Change in fiber areal weight (e.g., 145 to 190 gm/m²) that changes cured ply thickness
- Change in fiber type (e.g., T300 to AS4)
- Change in fiber manufacturer (e.g., Toray to Amoco)
- Change in type of fabric weave (e.g., plain weave to eight harness satin)
- Change in preform (large), including fiber architecture, stitching, etc.

Because level 4 changes are considered a new material, existing part producers will not be affected unless they elect to purchase the new material. An part producer who wishes to use the

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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new material must perform sufficient tests to qualify and certify the use of the material in the intended aircraft and rotorcraft application.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

This document is not to be construed as official policy. It is not for use in development for certification of other validation efforts. This is a review document only and is intended to be used by the WSU/FAA designated review team for commentary

5. RECOMMENDED LRM SPECIFICATION STRUCTURE

5.1 RECOMMENDED SPECIFICATION STRUCTURE

Generation of material specifications for the liquid resin molding process is not as simple and straight forward as with traditional prepreg materials. With prepreg materials the resin and fiber are combined at the material supplier and can be processed into laminates by the supplier to validate performance properties through certification tests. The prepreg procurement specification can then control all aspects of the prepreg manufacturing process from receipt of fiber, through resin mixing and filming, to impregnation of the fibers with the resin film, and ending with testing of the total material system by the fabrication and testing of laminates or parts. The prepreg material procurement specification essentially is applicable to a single supplier, i.e., the user (purchaser) communicates with a single source for the total material system.

With liquid resin molding processes the resin and fiber are typically purchased from different suppliers and are only brought together at the time of part fabrication, making it very difficult for the material suppliers to test the total material system at the laminate level. The part fabricator is now required to communicate with a variety of material suppliers and generate individual material procurement specifications for the constituent materials. In addition a specification (referred to as the material acceptance specification in Figure 3) is required that combines the matrix resin and reinforcing fiber into the total laminate or part material system. This is the point at which the primary design related properties are evaluated.

The three major material procurement specification categories are required for LRM are: reactive resins, non-reactive reinforcing fibers and fiber preforms, and combined cured material system. This document provides guidance for the generation of material procurement and acceptance specifications for these three classes of LRM materials.

One approach is the use of material procurement specifications in combination with an acceptance specification. The constituent materials (resin and reinforcement) are controlled through material procurement specifications. The constituent materials are tested individually by the supplier and purchaser. The combined system is then controlled at the cured composite assembly (resin combined with reinforcement) through an acceptance specification by the part producer. It is through this document that the part producer validates the combined composite assembly will yield performance properties equivalent to those developed during qualification and design allowable property development. This same document can define the process for qualifying combination of constituent material to produce the cured parts.

5.2 SECTIONAL ARRANGEMENT OF SPECIFICATION

For consistency and standardization purposes, a general format for composite material specifications should be followed. The following is a recommended format for subjects to be included that follows the standard format of SAE AMS specifications; other formats with the same content are acceptable to the FAA. Please see "Editorial Style Manual for the Preparation of Aerospace Material Specifications (AMS)" prepared by SAE International for additional information on specification structure. Only those subjects applicable to the material should be included in the specification.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- 1.0 *Scope*
- 2.0 *Applicable Documents*
- 3.0 *Technical Requirements*
 - 3.1 *General Material Requirements*
 - 3.1.1 *Formulation or Constituent Materials*
 - 3.1.2 *Product Characteristics*
 - 3.1.3 *Chemical, Electrical, and Mechanical Properties*
 - 3.1.4 *Environment Conditions*
 - 3.1.5 *Stability*
 - 3.1.6 *Environmental, Health, and Safety*
 - 3.1.7 *Identification*
 - 3.1.8 *Workmanship*
 - 3.2 *Qualification Requirements*
 - 3.3 *Process Control Document Requirements*
- 4.0 *Quality Assurance*
 - 4.1 *Responsibility for Inspection*
 - 4.2 *Classification of Tests and Inspections*
 - 4.2.1 *Qualification Tests*
 - 4.2.2 *Quality Conformance Tests*
 - 4.2.3 *Receiving Inspection Tests*
 - 4.2.4 *Sampling*
 - 4.2.5 *Retest*
 - 4.2.6 *Storage Life Extension*
 - 4.2.7 *Material Distributors*
 - 4.3 *Certification of Conformance*
 - 4.4 *Statistical Process Control*
 - 4.5 *Test Methods*
 - 4.6 *Records*
- 5.0 *Preparation for Delivery*
 - 5.1 *Material Identification*
 - 5.2 *Packaging and Preservation*
 - 5.3 *Packing Requirements*
 - 5.4 *Shipping Requirements*
 - 5.5 *Receipt at Procuring Organization*
- 6.0 *Acknowledgement*
- 7.0 *Rejection*
- 8.0 *Notes*
 - 8.1 *Intended Use*
 - 8.2 *Definitions*
 - 8.3 *Ordering Data*
 - 8.4 *Approved Products*

The remainder of this document is structured as follows. Section 6 provides guidelines specific to the LRM resin material procurement specification. Section 7 addresses the reinforcing fibers material procurement specification (for discussion purposes the non-reactive reinforcing fiber

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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will be in the form of a textile fabric). Section 8 addresses the total material system, resin and fiber combined into a cured composite, through an acceptance specification.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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6. GUIDELINES FOR SECTIONS OF A RESIN MATERIAL PROCUREMENT SPECIFICATION

This section provides guidelines specific to a material procurement specification applicable to reactive materials. Reactive materials would include the matrix resin or perform tackifier resin. The guidelines provided in the following subsections are structured around epoxy based resin systems.

6.1 Section 1 – Scope

This section should include a general description of the resin and its area of application to guide the prospective user. General temperature use limits and cure conditions should be stated. If the resin is to be supplied as one-part or two-part system it should be stated within this section of the specification. Those products to be controlled by this specification are required to be listed here.

A classification system can be used to distinguish different resin forms or characteristics.

6.2 Section 2 – Applicable Documents

This section should include appropriate drawings, specifications, standards, and methods that will form a key part of the specification. The material supplier is encouraged to use existing documentation available to the public that was developed or approved by industry organizations. Test methods can come from ASTM and SACMA (CFA). Government-recommended processes and procedures should be referenced and followed, such as DOT/FAA/AR-03/19, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems, and MIL-HDBK-17, Composite Material Handbook. Supplier internal documents, such as special test procedures, should be kept to a minimum. When used, they should be referenced and included in the PCD.

Examples include:

ASTM D 792	Specific Gravity (Relative Density) and Density of Plastics by Displacement
ASTM D 2471-99	Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins
ASTM D 3878-01	Standard Terminology Composite Materials
ASTM D 4065-95	Standard Practice for Determining and Reporting Dynamic Mechanical Properties of Plastics
ASTM D 5229-92 (1998)e1	Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
ASTM D 5279-99	Standard Test Method for Measuring the Dynamic Mechanical Properties of Plastics in Torsion
ASTM D 5418	Standard Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry
ASTM E 168	General Techniques of Infrared Quantitative Analysis

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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ASTM E 1252-98	Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis
ASTM E 1356-98	Standard Test Method for Assignment of the Glass Transition Temperature by Differential Scanning Calorimetry of Differential Thermal Analysis
ASTM E 1640-99	Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis
ASTM E 2041-99	Method of Estimating Kinetic Parameters by Differential Scanning Calorimetry Using Borchardt and Daniels Method
ASTM E 2070-00	Test Method for Kinetic Parameters by Differential Scanning Calorimetry Using Isothermal Methods
ASTM E 4473-95	Standard Practice for Measuring the Cure Behavior of Thermosetting Resins Using Dynamic Mechanical Procedures
SACMA SRM 20R-4R	High-Performance Liquid Chromatography of Thermoset resins
SACMA SRM 25R-94	Onset Temperature and Peak Temperature for Composite System Resins Using Differential Scanning Calorimetry (DSC)

6.3 Section 3 – Technical Requirements

The technical requirements section defines the material's characteristics and attributes required to ensure the material procured to this specification is satisfactory for its intended use. The actual minimum functional, physical, chemical, electrical, and mechanical requirements are to be defined in this section at the required level of detail.

6.3.1 Section 3.1 – General Material Requirements

This section should include requirements that define the specific raw ingredients and processes for producing the resin (many of these requirements may be specified in the PCD, which is referenced by the specification). In the following sections, it is assumed that the resin mixing is conducted with or without solvent.

6.3.2 Section 3.2 – Resin Material Requirements

This section should include requirements that define the specific chemical and physical properties of the resin.

The designation of the resin must be specified and must refer to only one combination of ingredients processed via one mixing regime. The resin composition and mixing process should be defined prior to qualification. Proposed limits of ingredient-weighing accuracy and process times and temperatures should be validated through physical and chemical testing. Mixing process includes premix step(s), final mix step(s), ingredient handling, mixed resin cooling, and mixed resin storage. The limitations of in-process tests must be understood. Current industry practice is to use resin viscosity and gel time as quick methods to validate the resin mixing step. These quick tests typically allow a wide range of acceptable values and may not be an accurate measure of resin consistency. If blending of mixed resin batches is to be allowed, the nature and

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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type of blending should be validated through chemical analysis. Blending of mixed hot melt resins is not preferred unless it can be demonstrated that there is no impact on viscosity and cure kinetics. Process limits defined and validated by the above tests must be documented in the PCD or specification.

Resin components and their manufacturers must be specified in the PCD or specifications. The material supplier should establish material specifications for all raw materials to be used in the resin. If multiple sources of an ingredient are planned, the use of each component must be validated through chemical analysis. Raw ingredients can be blended as long as storage and handling requirements for the raw materials are met. Testing must establish that departures from the raw material manufacturer's recommendations for handling and storage are valid.

Resin requirements that measure key attributes of the final mix or premix(es) shall be identified. In some cases this information may be considered proprietary and controlled in the PCD. These may include gel time, viscosity, degree of advancement, and analytical signature such as Infrared Spectrophotometry (IR) or High-Performance Liquid Chromatography (HPLC) peak ratios. In addition, the resin cure kinetics and rheology should be well characterized. It is valuable to conduct the kinetic and rheological studies on resins made to the limits of ingredient ratios allowed by the mix procedure and weighing errors. For example in epoxy resins, at one extreme, the curative would be at its lowest concentration and the epoxy resin at their highest concentration. At the other extreme, the curative would be at its highest concentration and the epoxies at their lowest. With two-part resins the effect of ratio tolerances must be quantified.

The diffusion and absorption of moisture and environmental fluids in the cured resin should be evaluated via moisture uptake versus time and degree of plasticization which leads to lowering of elastic modulus and glass transition temperature, T_g . The resistance of the cured resin to thermal microcracking over the range of use temperatures and cycles, both as cured neat resin and cured composite, should be assessed.

All of the above-mentioned data should be documented by the material supplier, be made available to potential users of the material, and be made available to the industry committee responsible for the industry specification for the material, if applicable. Table 1 summarizes the resin property data discussed above. None of the tests in Table 1 are recommended for batch acceptance testing.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 1 – RECOMMENDED SET OF NEAT RESIN PHYSICAL AND CHEMICAL PROPERTIES

Resin Property	Test Method
Density	ASTM D 1475 ¹
Viscosity (Brookfield)	ASTM D 2196 ¹
Viscosity (Cure Behavior)	ASTM D 4473
Gel Time	ASTM D 1824 ¹
Cure Kinetics by DSC	ASTM D 3418 ¹
Heat of Reaction Onset Temperature Peak Exotherm Temperature	
Color	ASTN D 1544 ¹
Epoxide Equivalent Weight	ASTM D 1652 ¹
Amine Content	Any agreed method ¹
High-Pressure Liquid Chromatography	Any agreed method ¹
Spectrophotometry (IR)	Any agreed method ¹

1. Acceptance tests.

This section should include definitions and limitations for storage life under specified conditions and handling life under ambient conditions. These requirements should be based on specific test data and experience with similar materials. The material supplier can establish and document the storage life as a function of storage temperature. A portion of the material batches produced for the initial material database development should be placed in an appropriate storage facility. After the desired maximum shelf life is reached, the material should be tested and the results compared to the specification requirements.

It is recommended that a tracking policy be implemented by the material supplier to document storage of material from date of manufacture to arrival on dock at the part producer. Tracking should include resin intermediates and mixed resin.

Any testing to re-establish the acceptance of materials that have been subjected to storage upsets, such as a freezer breakdown, must demonstrate that key cure-related attributes are within the

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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normal range. A distributor should practice the same documentation of storage life and conditions as the material supplier and part producer.

6.3.3 Section 3.3 – Cured Resin Mechanical Properties

It is recommended that the material supplier establish a baseline resin plaque cure cycle to be used to produce neat resin plaques for neat resin mechanical properties. Reasonable tolerances on heat-up rates and time-at-temperature should be established and documented. The cure process shall be capable of producing cured resin plaques of consistent, high quality. This cure cycle should be used for all batch acceptance testing by the material supplier and part producer (if required). It is possible that part-manufacturing processes will use a different cure cycle than the baseline resin plaque cure cycle.

It is recommended that the material specification include, as a minimum, requirements for the cured neat resin physical and mechanical properties listed in Table 2. The limits and test methods for each property shall be documented in the specification.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 2 – RECOMMENDED SET OF CURED RESIN PHYSICAL AND MECHANICAL PROPERTIES

Property	Test Method
Tensile Properties	ASTM D 638 ¹
Strength	
Modulus	
Elongation	
Flexural Properties	ASTM D 790 ¹
Strength	
Modulus	
Elongation	
Compressive Properties	ASTM D 695
Strength	
Modulus	
Shear Strength	ASTM D 732
Fracture Toughness	ASTM D 5045
Glass Transition Temperature (by TMA)	ASTM D 1545 ¹
Coefficient of Thermal Expansion	ASTM E 831
Degradation Temperature	ASTM D 3850
Density	ASTM D 792
Water Absorption	ASTM D 570
Shrinkage	ASTM D 2566

1. Acceptance tests.

All of the above-mentioned data should be documented by the material supplier, be made available to potential users of the material, and be made available to the industry committee responsible for the industry specification for the material, if applicable.

6.3.4 Section 3.4 – Qualification Requirements

Qualification requirements are defined in this section. Refer to Section 4 for additional information.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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6.3.5 Section 3.5 – Process Control Document Requirements

It is strongly recommended that the material supplier establish a Process Control Document (PCD) that documents key aspects of the material fabrication, lists all raw material ingredients, defines key process parameters, and establishes statistical process control (SPC) procedures and requirements. The PCD should be maintained by the material supplier. While the PCD will typically be a proprietary document, it should be made available for review at the supplier's site by material part producers and certification agencies. It should be referenced by the material specification.

The PCD shall contain as a minimum the following information. This information shall be considered proprietary and shall be protected in accordance with disclosure agreements signed by the supplier and procuring organization.

- List the sources and exact raw materials used in the formulation of the resin system (generic and trade names).
- List the physical or chemical properties of each material or material component considered critical.
- List the tests conducted on each raw material at receiving inspection. Note the limits for acceptance or rejection.
- Describe the manufacturing process and in-process controls.
- Provide the tolerances on weight measurements for each manufacturing step. The exact formulation is required and substantiation that the weight tolerances are appropriate for the quantities used is required.
- Provide the order and means of combining the subcomponents and give the time-temperature profile with the control tolerances employed.
- List the tests and control limit requirements on the finished resin system.
- List the tests conducted on the fiber yarn prior to weaving the fabric and note the requirements for acceptance or rejection.
- Define the time-temperature history of the tackifier resin during the application of the tackifier to the fabric and the control tolerances employed.
- Describe acceptance inspection procedures used to evaluate the finished material and state the acceptance/rejection criteria.
- List the tests conducted on the finished material and test control limit requirements employed.
- Describe packaging, storage, and shipping controls.

6.4 Section 4 – Quality Assurance

The Quality Assurance section defines the tests and inspections required to verify the material complies with the technical requirements of the specification. In addition it provides guidance for evaluation of manufacturing changes and provides procedures for determining equivalency

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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6.4.1 Section 4.1 – Responsibility for Inspection

Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all Quality Conformance inspection and test requirements specified herein and the Procuring Organization is responsible for the performance of all Receiving Inspection tests specified herein. The supplier Procuring Organization may use their own facilities or any commercial laboratory acceptable to the purchaser. However, the purchaser reserves the right to perform any or all of the inspections/tests which are deemed necessary to assure that the material furnished conforms to the prescribed requirements.

6.4.2 Section 4.2 – Classification of Tests and Inspections

6.4.2.1 Section 4.2.1 – Qualification Tests

The qualification or preproduction tests performed for material qualification are those tests performed on representative samples of each specific form of material to establish a qualified product in accordance with this specification. Qualification testing shall consist of all requirements and tests specified in Section 4. This testing shall be performed for each type of material.

6.4.2.2 Section 4.2.2 – Quality Conformance Tests

The material supplier must preform material certification (acceptance) testing. The material specification should define the type and frequency of tests to be performed by the supplier.

Certification reports must be prepared for each batch of material. The test report must show that the batch meets all of the uncured and cured material requirements. All records for each batch and the original baseline database shall be kept on permanent file. Records of raw material receiving inspection, in-process materials testing, SPC required by the PCD, and full material batch traceability shall be kept for a minimum period of 10 years unless superceded by other requirements. The supplier quality department will review the certification test results prior to shipment to an part producer. Materials that fail the acceptance criteria can undergo a material review board process.

6.4.2.3 Section 4.2.3 – Receiving Inspection Tests

The part producer (purchaser) quality department shall perform acceptance tests for each batch of material. The material specification should define the testing frequency.

The quality department must review the test results and allow the material to be released to manufacturing only upon satisfactory demonstration that the material meets the specification requirements. The part producer should hold to the same record keeping requirements and retest criteria as the material supplier.

An part producer must conduct the acceptance testing whether the material is bought directly from the manufacturer or through a distributor. The original certification testing conducted by the material manufacturer will be made available by the distributor for a specific batch sold to the part producer.

In cases where the material has demonstrated a high level of SPC control and capability for the material, it may be possible to reduce and/or eliminate the purchase acceptance testing. If

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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material is supplied by a distributor, it is recommended that purchaser testing be maintained as a safeguard against uncontrolled material. It is expected that the FAA will evaluate requests to reduce or eliminate part producer testing on a case-by-case basis (specific FAA policy for reduced testing approvals will be developed in the future). If part producer testing is reduced or eliminated, then provisions for monitoring the thermal exposure history of each shipment of material between the supplier and part producer (including all transit periods and storage periods at a distributor) will be required.

The procuring activity reserves the right to perform additional testing to confirm the supplier's certification data, and to approve incoming material for use in the fabrication of production parts.

6.4.3.4 Section 4.2.4 – Retest

Retest or replacement of test data is allowed only if an abnormality is observed or can be reasonably deduced to have occurred during testing,

- data is a statistical outlier, and
- the test has been conducted on materials that have not been prepared or conditioned properly (e.g., machining errors on laminates).

Note: any testing error should be identified and corrected prior to retest.

If a retest is required, a complete set of replicates for the property should be tested. If the retest results fail the acceptance criteria, the material batch covered by the failed test should be rejected and dispositioned through a material review board (including engineering personnel) process. All part producers of a material batch for which retests were performed must be notified at the time of batch shipment.

6.4.3.5 Section 4.2.5 – Material Distributors

Material distributors, either a facility of the manufacturer or an independent facility, must abide by all requirements of the material specification and the applicable portions of the process specification. The part producer should approve a distributor under their supplier surveillance system as described in their quality control manual. It is recommended that the material manufacturer will also have a role in authorizing distributors for proper control of the material. Material batches should remain traceable to the manufacturer's original batch and test reports. The distributor should provide copies of the original material certification and test reports to the user. The manufacturer's material, batch, and lot identification should be maintained.

A distributor should practice the same documentation of storage life and conditions as the material supplier. The distributor should be able to provide objective evidence of the material storage conditions. All shelf life should be determined from the date of material manufacture (impregnation). Any extension of the shelf life allowed by the material specification should be performed by a source approved by the original manufacturer.

If the product is repackaged, the materials used to repackage should be the same as approved for use by the material manufacturer. When the material is repackaged, it should first be allowed to reach room temperature in the unopened package such that moisture does not condense on the prepreg. The repackaged material should be inspected for visual defects and documented. All out-time accumulated during warming, and repackaging must be subtracted from that specified

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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by the manufacturer and documented for part producers, who assume responsibility after acceptance.

6.4.3 Section 4.3 – Certification of Conformance

The supplier shall furnish with each shipment two copies of a Certification of Conformance including certified test reports, confirming that all the material in the shipment complies with the requirements of this specification. For SPC this should also indicate the values of KPPs agreed between the supplier and fabricator.

6.4.4 Section 4.4 – Statistical Process Control

The quality assurance department should maintain the procedures and requirements for SPC based on key characteristics (KC) and key process parameters (KPP). The KCs are a subset of those properties detailed in the uncured and cured prepreg material requirement tables. KCs should be selected such that they ensure all properties of the material are within acceptable statistical limits. These are usually the set of requirements used for acceptance testing. KPPs are those process parameters that have a significant influence on the KCs. KPPs must be determined prior to qualification and be documented in the PCD. Average values, ranges, limits, and sampling frequency should be established and documented in the PCD.

The procedures used by the quality assurance department to conduct SPC analysis of the KCs and KPPs should be documented in the PCD. The PCD should also include the procedures used to establish and calculate the control limits. It is expected that control charts will be maintained on the KCs and KPPs and will be available for inspection by part producer and FAA personnel. It is strongly recommended that there be an effective program to collect, plot, analyze, and act on KC and KPP data. It is expected that action will be taken when the criteria for nonrandom data trends are met. Action should be taken while the data is still within the upper and lower control limits established during the initial data base generation and subsequent production batches.

If a KC is out of control, the cause of variation should be identified and eliminated, re-establishing statistical control. The supplier's quality assurance department must document all corrective actions affecting the process and monitor if the corrective action has been effective.

Reduced testing may be established based on the capability of the KCs and KPPs. Reduced testing will require approval by the FAA and the part producer(s) prior to being implemented. The reduced testing plan will be documented in the PCD. If KCs are found to be out of control, testing must return to the original level for a period of time until confidence in the control of the material is re-established. The reduced testing may take the form of a reduction of part producer testing or less frequent supplier testing. A prerequisite for reduced testing is adherence to monitoring and action based on control charts.

6.4.5 Section 4.5 – Test Methods

Recommended test methods for each property are given in Chapters 3 through 7 of Volume 1 of MIL-HDBK-17. In general, ASTM Standard Test Methods are recommended. However in most cases, additional test specimen configuration requirements and test procedures will have to be defined to provide sufficient detail to avoid undesired variations. Deviations from industry standard methods must be clearly detailed in the specification. In the event that part producer

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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testing is required by the specification, it is recommended that the material supplier and part producer conduct round-robin test evaluations to reduce test result differences.

It is recommended that all testing be conducted by a laboratory certified to conduct the tests to the specified methods; this certification applies to supplier, part producer, and independent test labs. A certified laboratory follows established policies and procedures such as training of test technicians, written procedures for performing tests, documenting the dimensional accuracy of test fixtures, and tracing calibration to National Institute of Standards and Technology (NIST) standards. The specification should define the requirements and procedures for certifying a test lab. It is recommended that for an industry specification, a national laboratory certification be required for facilities used.

6.4.6 Section 4.6 – Records

The supplier shall retain records of the batch raw ingredients for a minimum of seven years from date of manufacture. Records shall contain date of manufacture, process control tests, certification tests, acceptance tests, and storage conditions.

6.5 Section 5 – Preparation for Delivery

The product must have suitable identification and the packaging and handling during shipping must result in the product being capable of its full handling and working life when received by the part producer.

If repackaged by a distributor, the new packaging must be labeled properly and functionally equivalent to the original packaging and the labeling requirements met. Any decrease in storage life, working life, and handling life must be documented by the distributor and provided to all users.

6.5.1 Section 5.1 – Material Identification

The batch number should be on two labels, one on the container, the other on the outside of the shipping wrapper. The label should also include the material designation, name of manufacturer, specification number, and date of manufacture. The outside label should also clearly define the required material storage conditions.

6.5.2 Section 5.2 – Packaging and Preservation

The material shall be placed into containers appropriate for the protection of the material during shipping and storage. Step-by-step procedures should be given for the packaging of the material.

6.5.3 Section 5.3 – Packing Requirements

The resin should be packaged in containers that meet Federal regulations. Consideration should be given to container material selection to ensure the container material does not act as a catalyst and will allow the resin to be preheated while still in the container.

6.5.4 Section 5.4 – Shipping Requirements

The appropriate shipping and storage temperatures must be established for the material. If freezer temperatures are needed to maintain product quality, time-temperature recording devices

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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should be used to document the temperature exposure history of the shipment. Materials that have exceeded recommended limits will require a disposition process.

6.5.5 Section 5.5 – Receipt at Procuring Organization

Instructions for receipt of the material at the procuring organization are specified in this section.

6.6 Section 6 – Acknowledgement

This section of the specifications should contain the standard phrase:

“A vendor shall mention this specification number and the applicable detail specification number and their revision letters, if any, in all quotations and when acknowledging purchase orders.”

6.7 Section 7 – Rejection

This section should contain the standard phrase:

“Product not conforming to this specification and the applicable detail specification, or to modifications authorized by purchaser, will be subject to rejection. Rejected batches, by a purchaser, should not be rerouted to other purchasers.”

6.8 Section 8 – Notes

This section is reserved for explanatory and other notes.

6.8.1 Section 8.1 – Intended Use

This section shall define the intended use of the material.

6.8.2 Section 8.2 – Definitions

This section should include definitions for terms or abbreviations that are used. The definitions provide clarity between the supplier and the procurer. This is of major importance with respect to material batch definition and many times is not addressed. Material properties, quality, and defects must be defined such that batches made after the original qualification have the same level of quality and properties. Where possible, definitions from industry standards such as MIL-HDBK-17, SAE, and ASTM should be used.

The following resin batch definitions are recommended:

Batch (or Lot) (general) – n, A quantity of material produced essentially at the same time and under the same conditions from a well-defined collection of raw materials. The quantity of material must have minimal variation in properties throughout to be considered a unique batch.

Batch (or Lot) (resin) – n, For a batch of resin, the definition varies depending on the specific mixing process:

- In a batch mixing process a large vessel is charged with the desired types and quantities of raw ingredients. After mixing is complete, the vessel is discharged. The material made from this single-mix process is defined as a single batch of resin.

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- A continuous mixing process for producing resin typically involves incrementally feeding raw ingredients into a mixing device that blends them into a stream of resin. A batch of resin made by this process is defined as a quantity of material formed during one essentially continuous uninterrupted production run under the same process conditions using the same raw ingredients. Since start up and shutdown usually require purging the equipment, a shutdown will signal the end of a specific batch. Material made after start up is defined as a new batch. If a process shutdown does not require purging, an interruption in the process of up to 72 hours is permitted, provided that the production equipment settings are not modified or another material was not produced on the equipment during the interruption.
- In one version of a semi-continuous mixing process, a large vessel is charged with a portion of the raw ingredients (premix). After mixing, the vessel is discharged into several smaller containers, each of which acts as the vessel for subsequent mixing steps. The remaining raw ingredients are added to these smaller vessels and further mixing results in the final resin composition. The premix produced in the large vessel can be considered as a single batch of raw ingredient. The material produced during the final mixing in the small containers can be considered one batch if it is produced from the same raw ingredients batches without an interruption of more than 72 hours without the production of another material in the interval, and until the premix is consumed.
- In another version of a semi-continuous mixing process, small complete mixes of raw ingredients are made without the premix step. A batch of resin then consists of any number of these small mixes if they are made from the same lots of raw ingredients, the production run is not interrupted for more than 72 hours, and there is no other material made in the interval.
- For all mixing processes, blending of raw ingredient lots is permissible if the same blend ratio is found throughout all portions of the resin batch. Traceability must be retained on the ingredient lots that were used. For all mixing processes, a single-resin batch may contain a maximum of three blended lots of each raw chemical ingredient.

The above definitions are generally applicable for use with material acceptance processes, including sampling plans for acceptance testing. For material qualification and allowables test programs, stricter definitions of a batch are often specified in order to control the amount of material variability to be evaluated in the test program. For example, specific resin batches are required to be combined with specific preform batches for evaluation of the combined composite system batch.

6.8.3 Section 8.3 – Ordering Data

Detailed information to be incorporated in purchasing documents shall be contained in this section.

6.8.4 Section 8.4 – Approved Products

A listing of products that have qualified as defined within the specification is provided in this section.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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7. GUIDELINES FOR SECTIONS OF A MATERIAL PROCUREMENT SPECIFICATION FOR FABRIC REINFORCEMENT

7.1 Section 1 – Scope

This section should include a general description of the product and its area of application to guide the prospective user. General temperature use limits and cure conditions should be stated. If the product is to be supplied with various cured ply thickness and product forms, i.e., different fabric weaves, then a system must be defined to distinguish the various types, classes, grades, etc. Those products to be controlled by this specification are required to be listed here.

It is recommended that for part producer material specifications:

- Form—defines the basic material form
- Style—defines the fabric weave style, fiber tow count, and areal weight of the fiber in the prepreg
- Class—defines the specific fiber used in the fabric (fiber type, tow count, size type and content, surface treatment level, manufacturer, facility)

For industry standard specifications, they would specify the form, areal weight, fabric and specific fiber information for each specific fabric material covered.

7.2 Section 2 – Applicable Documents

This section should include appropriate drawings, specifications, standards, and methods that will form a key part of the specification. The material supplier is encouraged to use existing documentation available to the public that was developed or approved by industry organizations. Test methods can come from ASTM and SACMA (CFA). Government-recommended processes and procedures should be referenced and followed, such as DOT/FAA/AR-03/19, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems, and MIL-HDBK-17, Composite Material Handbooks. Supplier internal documents, such as special test procedures, should be kept to a minimum. When used, they should be referenced and included in the PCD.

Examples include:

ASTM D 3544-76 (1996)	Standard Guide for Reporting Test Methods and Results on High Modulus Fibers
ASTM D 3800-99	Standard Test Method for Density of High-Modulus Fibers
ASTM D 3878-01	Standard Terminology Composite Materials
ASTM D 4018-99	Standard Test Methods for Properties of Continuous Filament Carbon and Graphite Fiber Tows
ASTM D 4102-82 (1999)	Standard Test Method for Thermal Oxidative Resistance of Carbon Fibers
ASTM D 6507-00	Standard Practice for Fiber Reinforcement Orientation Codes for Composite Materials

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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ASTM E 1309-00	Standard Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
ASTM E 1434-00	Standard Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
ASTM E 1471-92 (1998)	Standard Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases

7.3 Section 3 – Technical Requirements

The technical requirements section defines the material's characteristics and attributes required to ensure the fabric procured to this specification is satisfactory for its intended use. The actual minimum functional, physical, and mechanical requirements are to be defined in this section at the required level of detail.

7.3.1 Section 3.1 – General Material Requirements

This section should include requirements that define the specific fibers and processes for producing the fabric (many of these requirements may be specified in the PCD, which is referenced by the specification).

7.3.1.1 Section 3.1.1 – Carbon Fiber Property Requirements

This section should include requirements that define the mechanical and physical properties of the fiber. The carbon fiber to be used in the fabric should be purchased to a separate fiber specification that uniquely defines the fiber type, manufacturer, and facility.

The carbon fiber must be capable of meeting the requirements of the composite acceptance specification when woven in accordance with the fabric specification and infused with the specified resin and processed in accordance with the specified cure procedure. If they are separate documents, both the fabric and composite acceptance specifications must define the specific fiber to be used. If multiple fiber sources are to be included in the composite acceptance specification, then each fiber source must correspond to a unique designation (e.g., class) and, in the case of an industry specification, must correspond to a unique designation (Note: two or more facilities owned by the same company producing identical fiber can be considered a single item when it has been established by testing that the two materials are equivalent). It is not acceptable for a specification to refer to the carbon fiber and the fabric by a trade name without specifying the manufacturer and facility that produces the fiber, the fiber specification that controls the fiber, the fabric specification that controls the fabric weaving, and the manufacturer and facility that produces the fabric.

The fiber specification must define the average values and ranges for all critical fiber mechanical and physical properties including tensile strength, tensile modulus, and density. The fabric and prepreg specifications must identify the fiber form, tow count (e.g., 12K flat tow), and twist or no twist. The fiber-sampling plan and test methods for fiber properties and quality must be documented.

The fiber size material, method of size application, and size content are considered to be an integral part of the carbon fiber. The fiber sizing is to be unique and there should be a shelf life

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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requirement if the sizing ages during storage. Changes to the size, application, or content will require equivalency testing or the establishment of a new material designation (see section 3).

The recommended definition of fiber batch is given in section 7.8.2. Fiber batch blending of up to three lots is allowed as long as there is traceability of each fiber batch, and the lots are randomly distributed across the fabric.

Table 3 summarizes the fiber property data discussed above. These tests should be performed by the fiber supplier on each lot of fiber supplied to the fabric weaver. None of the tests in Table 3 are recommended for fabric batch acceptance testing by the fabric supplier or material part producer.

TABLE 3. RECOMMENDED SET OF CARBON FIBER PROPERTIES

Fiber Property	Test Condition	Test Method
Form	N/A	ASTM E1309
Twist	N/A	Any agreed method ¹
Size Content	N/A	ASTM D4018 ¹
Tensile Modulus	RTD	ASTM D4018 ¹
Tensile Strength	RTD	ASTM D4018 ¹
Density	RTD	ASTM D3800 ¹

1. Acceptance tests performed by the fiber supplier.

7.3.1.2 Section 3.1.2 – Fabric Construction and Description

Fabric destined for the LRM processes should be purchased to a fabric specification that defines the manufacturer and facility. The fabric specification should establish the fiber type, tow filament count, sizing type and level, fabric areal weight and the fabric style. Carbon-fiber fabric can include a contrasting glass or aramid fiber tow (tracer) to help in discerning tow alignment. These tracer fibers can be treated to enhance detection by NDI methods. It must be demonstrated that these tracer fibers do not affect the short and long term performance of the cured composite.

Carbon fiber fabrics which contain conductive fibers (aluminum, copper, phosphor bronze, nickel, nickel coated carbon) for lightning protection, EMI shielding or other purposes must be treated in the applicable fabric and prepreg specifications as a separate fabric style from the basic fabric without the conductive fibers. A full set of fabric and composite laminate qualification test data should be obtained on the fabric with the conductive fibers.

Table 4 shows the recommended set of fabric properties.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 4: RECOMMENDED SET OF FABRIC PROPERTIES

Fabric Property	Test Condition	Test Method
Width	RTD	ASTM D 3774
Tracer spacing ¹	RTD	Any agreed method
Alignment ¹	RTD	Any agreed method
Waviness	RTD	Any agreed method
Openess	RTD	Any agreed method
Yarn count/inch ¹	RTD	Any agreed method
Areal weight (g/m ²) ¹	RTD	ASTM D 3776

¹Batch acceptance tests (see section 6.5)

7.3.1.8 Section 3.1.6 – Fabric Workmanship

This section should include limitations on visual defects in the fabric. Criteria for continuous defects, such as yarn alignment, width, tracer alignment, and edge alignment, must be established and documented. In some cases, this information may be considered proprietary and controlled in the PCD. Allowable defect limits can be based on generally accepted industry standards.

Procedures for closing fabric openess, e.g., through the use of rollers, can be used if documented in the PCD. Edge alignment can be corrected by tentering. Where reactive binders with low temperature storage requirements are used procedures must be established to control and document material out-time.

Criteria for discontinuous defects, e.g., puckers, fuzz balls, wrinkles, slubs, crimps, splices, foreign material, incomplete wet out, yarn twists and crossovers, broken yarns, fiber distortion, crushed yarns, and bowed fibers, should be defined in the PCD or specification (see the Glossary for recommended definitions of fabric defects). Where surface defects such as foreign material and fuzz balls can be removed by scraping or picking, these procedures can be used if defined in the PCD or specification.

Procedures for continuous inspection of the fabric shall be defined in the specification or PCD. It is recognized that due to machine limitations only the top surface can be inspected. Should the same defects be detected by the part producer on the bottom of the fabric when the part is being laid up, the same criteria for allowable defect limits and correction should be followed.

The specification should require that each defect outside the allowable limits be identified and marked by a flag positioned at the edge of the material. The type, location, and length of each defect should be recorded for each roll and attached to the roll. Defects can be removed by splicing per documented procedures and by criteria for maximum number and minimum spacing of splices. The splicing technique must be easily identified by the part producer to avoid incorporation of the splice into a part.

Recommended fabric defects and allowable limits are listed in Table 5. See the Glossary for descriptions of various fabric defects.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 5 – RECOMMENDED FABRIC DEFECTS AND ALLOWABLE LIMITS

Subject	Defect	Allowable Limits
Gaps and alignment	a. Warp yarn deviation from a straight line.	0.18 inch wide by 3 feet long max.
	b. Fill deviation from a straight line.	1. 2.0 inches over width of roll max. 2. 1.0 inch in any 21 inch width of roll.
Single yarn defects	Broken filaments, fiber distortions, fuzz balls, and wrinkles.	Defects shall not be greater than three over a distance of 6 lineal feet.
Continuous defects	Multiplicity of defects; e.g., two or more single yarn defects closer than 6 inches, excess binder, binder gaps , , blisters, and foreign materials.	Defects separated by at least 3 lineal feet of each other, excluding selvage.
Tow splices	Spliced on adjacent tows within 0.5 inch of each other.	None
Single and continuous defects	All	10 percent of roll length max.

7.3.2 Section 3.2 – Qualification Requirements

Qualification requirements are defined in this section. Refer to Section 4 for additional information.

7.3.3 Section 3.3 – Process Control Document Requirements

It is strongly recommended that the material supplier establish a Process Control Document (PCD) that documents key aspects of the material fabrication, lists all raw material ingredients, defines key process parameters, and establishes statistical process control (SPC) procedures and requirements. The PCD should be maintained by the material supplier. While the PCD will typically be a proprietary document, it should be made available for review at the supplier’s site by material part producers and certification agencies. It should be referenced by the material specification.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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The PCD shall contain as a minimum the following information. This information shall be considered proprietary and shall be protected in accordance with disclosure agreements signed by the supplier and procuring organization.

- List the sources and exact raw materials used in the formulation of the resin system (generic and trade names).
- List the physical or chemical properties of each material or material component considered critical.
- List the tests conducted on each raw material at receiving inspection. Note the limits for acceptance or rejection.
- Describe the manufacturing process and in-process controls.
- Provide the tolerances on weight measurements for each manufacturing step. The exact formulation is required and substantiation that the weight tolerances are appropriate for the quantities used is required.
- Provide the order and means of combining the subcomponents and give the time-temperature profile with the control tolerances employed.
- List the tests and control limit requirements on the finished resin system.
- List the tests conducted on the fiber yarn prior to weaving the fabric and note the requirements for acceptance or rejection.
- Define the time-temperature history of the tackifier resin during the application of the tackifier to the fabric and the control tolerances employed.
- Describe acceptance inspection procedures used to evaluate the finished material and state the acceptance/rejection criteria.
- List the tests conducted on the finished material and test control limit requirements employed.
- Describe packaging, storage, and shipping controls.

7.4 Section 4 – Quality Assurance

The Quality Assurance section defines the tests and inspections required to verify the material complies with the technical requirements of the specification. In addition it provides guidance for evaluation of manufacturing changes and provides procedures for determining equivalency.

7.4.1 Section 4.1 – Responsibility for Inspection

Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all Quality Conformance inspection and test requirements specified herein and the Procuring Organization is responsible for the performance of all Receiving Inspection tests specified herein. The supplier Procuring Organization may use their own facilities or any commercial laboratory acceptable to the purchaser. However, the purchaser reserves the right to perform any or all of the inspections/tests which are deemed necessary to assure that the material furnished conforms to the prescribed requirements.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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7.4.2 Section 4.2 – Classification of Tests and Inspections

7.4.2.1 Section 4.2.1 – Qualification Tests

The qualification or preproduction tests performed for material qualification are those tests performed on representative samples of each specific form of material to establish a qualified product in accordance with this specification. Qualification testing shall consist of all requirements and tests specified in Section 4. This testing shall be performed for each type of material.

7.4.2.2 Section 4.2.2 – Quality Conformance Tests

The material supplier must perform material certification (acceptance) testing. The material specification should define the type and frequency of tests to be performed by the supplier.

Certification reports must be prepared for each batch of material. The test report must show that the batch meets all of the uncured and cured material requirements. All records for each batch and the original baseline database shall be kept on permanent file. Records of raw material receiving inspection, in-process materials testing, SPC required by the PCD, and full material batch traceability shall be kept for a minimum period of 10 years unless superseded by other requirements. The supplier quality department will review the certification test results prior to shipment to an part producer. Materials that fail the acceptance criteria can undergo a material review board process.

7.4.2.3 Section 4.2.3 – Receiving Inspection Tests

The part producer (purchaser) quality department shall perform acceptance tests for each batch of material. The material specification should define the testing frequency.

The quality department must review the test results and allow the material to be released to manufacturing only upon satisfactory demonstration that the material meets the specification requirements. The part producer should hold to the same record keeping requirements and retest criteria as the material supplier.

An part producer must conduct the acceptance testing whether the material is bought directly from the manufacturer or through a distributor. The original certification testing conducted by the material manufacturer will be made available by the distributor for a specific batch sold to the part producer.

In cases where the material has demonstrated a high level of SPC control and capability for the material, it may be possible to reduce and/or eliminate the purchase acceptance testing. If material is supplied by a distributor, it is recommended that purchaser testing be maintained as a safeguard against uncontrolled material. It is expected that the FAA will evaluate requests to reduce or eliminate part producer testing on a case-by-case basis (specific FAA policy for reduced testing approvals will be developed in the future). part producerpart producerThe procuring activity reserves the right to perform additional testing to confirm the supplier's certification data, and to approve incoming material for use in the fabrication of production parts. Each roll of material shall be examined for appearance, color uniformity, imperfections which would be detrimental for use in the fabrication of parts, and for quality of workmanship.

7.4.2.7 Section 4.2.7 – Material Distributors

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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Material distributors, either a facility of the manufacturer or an independent facility, must abide by all requirements of the material specification and the applicable portions of the process specification. The part producer should approve a distributor under their supplier surveillance system as described in their quality control manual. It is recommended that the material manufacturer will also have a role in authorizing distributors for proper control of the material. Material batches should remain traceable to the manufacturer's original batch and test reports. The distributor should provide copies of the original material certification and test reports to the user. The manufacturer's material, batch, and lot identification should be maintained.

A distributor should practice the same documentation of storage life and conditions as the material supplier. The distributor should be able to provide objective evidence of the material storage conditions. All shelf life should be determined from the date of material manufacture (impregnation). Any extension of the shelf life allowed by the material specification should be performed by a source approved by the original manufacturer.

If the product is repackaged, the materials used to repackage should be the same as approved for use by the material manufacturer.

7.4.3 Section 4.3 – Certification of Conformance

The supplier shall furnish with each shipment two copies of a Certification of Conformance including certified test reports, confirming that all the material in the shipment complies with the requirements of this specification.

7.4.4 Section 4.4 – Statistical Process Control

The quality assurance department should maintain the procedures and requirements for SPC based on key characteristics (KC) and key process parameters (KPP). The KCs are a subset of those properties detailed in the uncured and cured prepreg material requirement tables. KCs should be selected such that they ensure all properties of the material are within acceptable statistical limits. These are usually the set of requirements used for acceptance testing. KPPs are those process parameters that have a significant influence on the KCs. KPPs must be determined prior to qualification and be documented in the PCD. Average values, ranges, limits, and sampling frequency should be established and documented in the PCD.

The procedures used by the quality assurance department to conduct SPC analysis of the KCs and KPPs should be documented in the PCD. The PCD should also include the procedures used to establish and calculate the control limits. It is expected that control charts will be maintained on the KCs and KPPs and will be available for inspection by part producer and FAA personnel. It is strongly recommended that there be an effective program to collect, plot, analyze, and act on KC and KPP data. It is expected that action will be taken when the criteria for nonrandom data trends are met. Action should be taken while the data is still within the upper and lower control limits established during the initial data base generation and subsequent production batches.

If a KC is out of control, the cause of variation should be identified and eliminated, re-establishing statistical control. The supplier's quality assurance department must document all corrective actions affecting the process and monitor if the corrective action has been effective.

Reduced testing may be established based on the capability of the KCs and KPPs. Reduced testing will require approval by the FAA and the part producer(s) prior to being implemented.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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The reduced testing plan will be documented in the PCD. If KCs are found to be out of control, testing must return to the original level for a period of time until confidence in the control of the material is re-established. The reduced testing may take the form of a reduction of part producer testing or less frequent supplier testing. A prerequisite for reduced testing is adherence to monitoring and action based on control charts.

7.4.5 Section 4.5 – Test Methods

Recommended test methods for each property are given in Chapters 3 through 7 of Volume 1 of MIL-HDBK-17. In general, ASTM Standard Test Methods are recommended. However in most cases, additional test specimen configuration requirements and test procedures will have to be defined to provide sufficient detail to avoid undesired variations. Deviations from industry standard methods must be clearly detailed in the specification. In the event that part producer testing is required by the specification, it is recommended that the material supplier and part producer conduct round-robin test evaluations to reduce test result differences.

It is recommended that all testing be conducted by a laboratory certified to conduct the tests to the specified methods; this certification applies to supplier, part producer, and independent test labs. A certified laboratory follows established policies and procedures such as training of test technicians, written procedures for performing tests, documenting the dimensional accuracy of test fixtures, and tracing calibration to National Institute of Standards and Technology (NIST) standards. The specification should define the requirements and procedures for certifying a test lab. It is recommended that for an industry specification, a national laboratory certification be required for facilities used.

7.4.6 Section 4.6 – Records

The supplier shall retain records of the batch raw ingredients for a minimum of seven years from date of manufacture. Records shall contain date of manufacture, process control tests, certification tests, acceptance tests, and storage conditions.

7.5 Section 5 – Preparation for Delivery

The product must have suitable identification and the packaging and handling during shipping must result in the product being capable of its full handling and working life when received by the part producer.

If repackaged by a distributor, the new packaging must be labeled properly and functionally equivalent to the original packaging and the labeling requirements met. Any decrease in storage life, working life, and handling life must be documented by the distributor and provided to all users.

7.5.1 Section 5.1 – Material Identification

The batch number should be on two labels, one on the container, the other on the outside of the shipping wrapper. The label should also include the material designation, name of manufacturer, specification number, and date of manufacture. The outside label should also clearly define the required material storage conditions

7.5.2 Section 5.2 – Packaging and Preservation

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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The material shall be placed into containers appropriate for the protection of the material during shipping and storage. Step-by-step procedures should be given for the packaging of the material.

7.5.3 Section 5.3 – Packing Requirements

The fabric should be packaged in containers that meet Federal regulations. Consideration should be given to container configuration that will not allow the fabric to move during shipment.

7.5.4 Section 5.4 – Shipping Requirements

Any special shipping requirements should be identified in this section.

7.5.5 Section 5.5 – Receipt at Procuring Organization

Instructions for receipt of the material at the procuring organization are specified in this section.

7.6 Section 6 – Acknowledgement

This section of the specifications should contain the standard phrase:

“A vendor shall mention this specification number and the applicable detail specification number and their revision letters, if any, in all quotations and when acknowledging purchase orders.”

7.7 Section 7 – Rejection

This section should contain the standard phrase:

“Product not conforming to this specification and the applicable detail specification, or to modifications authorized by purchaser, will be subject to rejection. Rejected batches, by a purchaser, should not be rerouted to other purchasers.”

7.8 Section 8 – Notes

This section is reserved for explanatory and other notes.

7.8.1 Section 8.1 – Intended Use

This section shall define the intended use of the material.

7.8.2 Section 8.2 – Definitions

This section should include definitions for terms or abbreviations that are used. The definitions provide clarity between the supplier and the procurer. Material properties, quality, and defects must be defined such that batches made after the original qualification have the same level of quality and properties. For example, fabric defects such as fuzz balls, creases, foreign material, fiber alignment, splices, and edge deviation from a straight line should have a specific definition (see Section 11.2 for recommended fabric defect definitions). Where possible, definitions from industry standards such as MIL-HDBK-17, SAE, and ASTM should be used.

The following batch definitions are recommended:

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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Batch (or Lot) (general) – n, A quantity of material produced essentially at the same time and under the same conditions from a well-defined collection of raw materials. The quantity of material must have minimal variation in properties throughout to be considered a unique batch.

Batch (or Lot) (fibers) – n, For fibers, a quantity of material formed during one essentially continuous, uninterrupted production run under the same process conditions using one to three precursor lots. An interruption in the process of up to 72 hours is permitted, provided that the production equipment settings are not modified or another material is not produced on the equipment during the interruption.

Batch (or Lot) (fabric) – n, For fabrics, a quantity of material woven from one to three batches (lots) of fiber. The weaving process can be interrupted for up to 72 hours if the loom settings are not changed and another material is not produced in the interim.

The above definitions are generally applicable for use with material acceptance processes, including sampling plans for acceptance testing. For material qualification and allowables test programs, stricter definitions of a batch are often specified in order to control the amount of material variability to be evaluated in the test program. For instance, a particular batch of fabric may be restricted to a single lot of fiber.

7.8.3 Section 8.3 – Ordering Data

Detailed information to be incorporated in purchasing documents shall be contained in this section.

7.8.4 Section 8.4 – Approved Products

A listing of products that have qualified as defined within the specification is provided in this section.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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8. GUIDELINES FOR SECTIONS OF A CURED MATERIAL ACCEPTANCE SPECIFICATION FOR COMPOSITE PARTS

This section provides guidelines specific to a liquid resin molding acceptance specification applicable to the cured composite material (epoxy resin reinforced with carbon fiber). This document is not a typical material procurement document, rather it defines the qualified constituent materials, and the cured material property requirements that the part producer themselves are required to demonstrate adherence to for each production part. The guidelines contained within this section are specific to cured composite materials in the laminate or part form containing textile fabric as the reinforcement and epoxy resin as the matrix. The reader is referred to Paragraph 5 for additional information on specification structure.

8.1 Section 1 – Scope

This section should include a general description of the product and its area of application to guide the prospective user. General temperature use limits and cure conditions should be stated. A detail description is to be provided for the specific combination of resin and fiber reinforcement applicable to the requirements of this specification. A specific specification designation should include only a single-resin formulation, a single fabric weave style (or specific preform design) and a single, specific fiber (or specific combination of fibers in the preform). A specific designation is defined to be a unique form, type, style, and class. The specification document can include multiple forms, types, styles, and classes (fiber types).

The scope section should also clearly state that the purpose of this document is to provide the performance properties of the combined material system and provide the requirements for the testing and release of the resin and fabric into production usage.

8.2 Section 2 – Applicable Documents

This section should include appropriate drawings, specifications, standards, and methods that will form a key part of the specification. The part producer is encouraged to use existing documentation available to the public that was developed or approved by industry organizations. Test methods can come from ASTM and SACMA (CFA). Government-recommended processes and procedures should be referenced and followed, such as DOT/FAA/AR-03/19, Material Qualification and Equivalency for Polymer Matrix Composite Material Systems, and MIL-HDBK-17, Composite Material Handbook.

Examples include:

ASTM D 792	Specific Gravity (Relative Density) and Density of Plastics by Displacement
ASTM D 2471-99	Standard Test Method for Gel Time and Peak Exothermic Temperature of Reacting Thermosetting Resins
ASTM D 3878-01	Standard Terminology Composite Materials
ASTM D 4065-95	Standard Practice for Determining and Reporting Dynamic Mechanical Properties of Plastics

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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ASTM D 5229-92 (1998)e1	Standard Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
ASTM D 5279-99	Standard Test Method for Measuring the Dynamic Mechanical Properties of Plastics in Torsion
ASTM D 5418	Standard Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry
ASTM E 168	General Techniques of Infrared Quantitative Analysis
ASTM E 1252-98	Practice for General Techniques for Obtaining Infrared Spectra for Qualitative Analysis
ASTM E 1356-98	Standard Test Method for Assignment of the Glass Transition Temperature by Differential Scanning Calorimetry of Differential Thermal Analysis
ASTM E 1640-99	Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis
ASTM E 2041-99	Method of Estimating Kinetic Parameters by Differential Scanning Calorimetry Using Borchardt and Daniels Method
ASTM E 2070-00	Test Method for Kinetic Parameters by Differential Scanning Calorimetry Using Isothermal Methods
ASTM E 4473-95	Standard Practice for Measuring the Cure Behavior of Thermosetting Resins Using Dynamic Mechanical Procedures
SACMA SRM 20R-4R	High-Performance Liquid Chromatography of Thermoset resins
SACMA SRM 25R-94	Onset Temperature and Peak Temperature for Composite System Resins Using Differential Scanning Calorimetry (DSC)

8.3 Section 3 – Technical Requirements

The intent of this section is define the characteristics required of the composite laminate or part. The required materials, equipment, and processing details necessary to ensure a consistently quality material are to be specified.

8.3.1 Section 3.1. – Materials

Two classes of materials are used within this specification: (1) materials being tested and (2) materials used in the fabrication of composite test panels. The LRM materials being tested should be inspected upon receipt by the part producer, in accordance with the applicable material procurement specification. Test methods, types of tests required, sampling requirements, criteria (acceptance value), and retest provisions should be clearly defined. Supplier certification records should be reviewed and maintained with the laminate process instructions. Material that does not meet the established quality requirements should not be processed into test panels.

See DOT/FAA/AR-03/TBD for complete discussion on the materials required to fabricate composite parts by the liquid resin molding process..

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8.3.2 Section 3.2 – Equipment

Equipment guidelines for the preparation of composite parts by the liquid molding process can be found in DOT/FAA/AR-03/TBD.

8.3.3 Section 3.3 – Composite Preparation

Guidelines for the preparation of composite parts by the liquid molding process can be found in DOT/FAA/AR-03/TBD.

8.3.4 Section 3.4 – Composite Mechanical Properties and Testing

This section should include requirements for the cured composite. These requirements should be based on specific data obtained for the material. Whereas for prepreg materials batch acceptance tests are performed on the received prepreg material, with liquid resin molding processes the part producer is responsible for three levels of material acceptance testing:

- Material batch acceptance tests for the constituent materials per the applicable procurement specifications; these are discussed in sections 6 and 7 above.
- Material batch release tests for the combination of resin, tackifier and fiber preform per the material acceptance document; these are discussed below and in section 8.4. These tests termed ‘batch release’ tests to distinguish them from the constituent material batch acceptance tests. They are essentially equivalent to the batch acceptance tests performed on cured laminates for prepreg materials
- Part acceptance or process control tests per the process specification and performed on excess resin, prolongation specimens or traveller panels infused and cured at the same time as the part; these are discussed in section 8.4.

8.3.4.1 Baseline Infusion and Cure Process

It is recommended that the part producer establish a baseline cure cycle to be used to produce panels for the initial material database (for qualification and design allowables) and for material batch release testing. The baseline cure cycle should be selected based on the expected applications and requirements for the material (see DOT/FAA/AR-03/XXX for recommendations on selecting the cure cycle). Reasonable tolerances on heat-up rates and time-at-temperature should be established and documented. The cure process shall be capable of producing cured laminates or parts of consistent, high quality. This cure cycle should be used for all material batch release testing by the part producer. It is possible that part-manufacturing processes will use a different cure cycle than the baseline cure cycle. The part producer must demonstrate that the part cure cycle produces equivalent properties to the material database in order to use the allowables generated by the database for certification of the part (see DOT/FAA/AR-03/19). If the part producer defines an alternate infusion and cure process, they should define additional acceptance testing with that process.

8.3.4.2 Cured Laminate Physical Properties

It is recommended that the specification include, as a minimum, requirements for the cured composite physical properties listed in Table 6. The limits and test methods for each property shall be documented in the specification.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 6 – RECOMMENDED SET OF CURED COMPOSITE PHYSICAL PROPERTIES

Cured Laminate Physical Property	Test Condition	Test Method
Cured Ply Thickness ¹		Any agreed method
Fiber Volume, % by volume ²		ASTM D 3171
Resin Content, % by weight ²		ASTM D 3171
Void Content, % by volume ²		ASTM D 2734
Laminate Density	RTD	ASTM D 792
Glass Transition Temperature, T _g ²	Pre-condition environments: <ul style="list-style-type: none"> • Dry • Wet (saturation under 85% RH environment) 	SACMA SRM 18, ASTM D4065
Equilibrium Moisture Content	Equilibrium under 85% Relative Humidity Environment	ASTM D 5229
Moisture Absorption	Absorption vs Time under Room temperature, 85% Relative Humidity Environment	ASTM D 5229
Thermal Induced Microcracking	Cycles over expected range of usage temperatures; fast heat-up spikes, etc.	Any agreed method

1 - Batch release test.

2 - Equivalency baseline database test.

8.3.4.3 Cured Composite Laminate Mechanical Properties

A minimum set of mechanical property data will be required to adequately characterize the material and to provide a database for future material equivalency evaluations. The tests should be able to detect changes in the fiber, resin, and the response of the material to variations in the cure process. A subset of these tests is required for material release testing for each batch.

In addition to the batch release tests, it is recommended that a second set of tests be run on an ongoing basis to further populate the database, especially for use as a baseline in future equivalency evaluations (see section 4.3). The results from these tests would be used to monitor the material acceptance and equivalency requirements in the specification. They would also assist in detecting material changes or an increase in variability.

The following paragraphs present a series of recommended tests for development of a material property database. It is expected that this database will be developed over time, as the market for the material expands, and specific applications require additional data. The first set of tests represents the minimum tests required to establish a material specification. This test matrix is very similar to the AGATE test matrix in DOT/FAA/AR-03/19 and is intended for applications that have simple layup configurations and do not involve mechanically fastened joints or highly

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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loaded structure. An additional set of open-hole laminate tests is recommended for inclusion in the specifications for materials intended for more general applications.

Further sets of recommended tests for an expanded database are then presented. These tests are optional with regard to inclusion in the material specification, but may be required for the design and certification of an part producer's product. There is a potential for cost savings if these additional tests could be shared amongst several part producers. Therefore, for marketing purposes, a material supplier developing a shared database may elect to perform tests to expand the shared database, either by themselves or in conjunction with one or more part producers. The expanded database could include the tests recommended below, other design specific tests and/or other environmental related tests (e.g., flammability, moisture diffusion, thermal cycling). In each step of the database development, its utility is limited until more data is collected, but the intent is to let market conditions drive the expansion of the database.

It should be understood that, while material specification acceptance values are not the same as B-basis design allowables, they can be derived from the same test data. The calculation methods are different and they are intended for different objectives. Material specification acceptance values are specifically intended for control of material. The values are calculated using statistical procedures that are a function of a selected value for the probability of rejection of a good batch of material. The acceptance values are a function of the database mean and standard deviation, and the batch sample size. Therefore, as data is added to the database, acceptance values will only change if there is a change in the data mean or variation.

Basis values (allowables) are intended to provide a certain level of statistical confidence for design strength calculations. B-basis values are established such that 90% of the population data falls above the basis value, with 95% confidence. Basis values are a function of database mean and standard deviation, and the number of data points in the database.

8.3.4.4 Recommended Laminate Tests

Table 7 lists the specific fabric ply lay-ups for the tests recommended in Tables 8 to 12. To establish a material specification, the tests in Table 8 are recommended as a minimum set for material characterization and qualification of a prepreg fabric material. The additional open hole tests in Table 9 are recommended for materials expected to be used in more general applications that will contain mechanical fastened joints or will be designed with notched laminate properties. The requirements and the test methods for each property shall be documented in the specification.

For fabrics where each warp or fill yarn crosses over more than one of the other direction yarn (e.g., an 8-harness fabric), one surface of the fabric will have more warp fibers (warp surface) and the other surface will have more fill fibers (fill surface). For these fabric materials, the orientation of the fabric relative to which surface is up in the laminate stack can be important to avoid panel warping. For the tests using solid laminates containing only one of 0°, 90° or 45° oriented plies in Tables 7 to 12 below, it is recommended to layup the laminate with all of the fill faces down (if the warp and fill faces are alternated, a condition called warp face nesting can occur, which can lead to panel warping). For the tests using solid laminates containing both 0° and 45° oriented plies in Tables 7 to 12 below, it is recommended to layup the lower half of the laminate with the warp face down, and the upper half of the laminate with the warp face up.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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Process documents and controls for lay-up of test panels and parts should ensure accurate alignment of both the warp and fill fiber directions (it is not sufficient to only align the warp fibers of the fabric). Fiber orientation tolerances (typically $\pm 1^\circ$ for test panels and $\pm 3^\circ$ to $\pm 5^\circ$ for parts) and fiber straightness requirements (such as $\pm 2^\circ$ over a distance of 12 inches for parts) should be specified. Exceptions are often required in areas of highly contoured areas of parts.

All of the tests should be robust in that material variability, rather than test variability, will be evaluated. Recommended test methods for each property are given in MIL-HDBK-17, Volume 1, Chapters 3 through 7. Moisture conditioning should be conducted per the procedures given in MIL-HDBK-17 and ASTM D 5229. The ASTM D6641 (CLC) test method is recommended for compression testing due to its superior performance (reduced variability) and lack of requirement for tabs on the test specimens. It is expected that all industry material specifications to be developed in the near future will require the use of the CLC test method.

Batch release tests are recommended in Table 8 (as noted). These batch release tests are recommended based on the following rationale.

- The room temperature tension test is included to monitor the fiber and fiber-resin interface properties.
- The hot compression test is included to primarily monitor the resin properties.
- The apparent shear strength by short beam test is included to monitor the fiber-resin interface properties.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 7 – PLY LAY-UP SEQUENCES FOR RECOMMENDED COMPOSITE TESTS

<p>In the following lay-up sequences the fabric ply orientations are defined as follows:</p> <p>0 warp fibers in 0° direction, warp face down 0* warp fibers in 0° direction, warp face up 90 warp fibers in 90° direction, warp face down 90* warp fibers in 90° direction, warp face up 45 warp fibers in 45° direction, warp face down 45* warp fibers in 45° direction, warp face up -45 warp fibers in -45° direction, warp face down -45* warp fibers in -45° direction, warp face up</p> <p>// - indicates mid-plane of the lay-up</p>		
Lay-up Name	Ply Lay-up Sequence (starting from toolside)	Recommended Thickness Range for Selecting 'n' (inches)
1. Warp Tension	[0*]n	0.060 to 0.100
2. Warp Compression	[0*]n	0.100 to 0.150
3. Fill Tension	[90*]n	0.060 to 0.100
4. Fill Compression	[90*]n	0.100 to 0.150
5. ±45 Shear	[45/-45/45/-45 // -45*/45*/-45*/45*]	
6. Warp Interlaminar	[0*]n	0.240 to 0.260
7. Quasi Laminate	[(45/0/-45/0)n // (0*/-45*/0*/45*)n]	0.100 to 0.150
8. Soft Laminate	[(45/-45/0/45/-45)n // (-45*/45*/0*/-45*/45*)]	0.100 to 0.150
9. Hard Laminate	[(0/0/45/0/0)n // (0*/0*/45*/0*/0*)]	0.100 to 0.150
10. Warp Sandwich	[0*/0*/ core /0/0] (warp face next to core)	
11. Fill Sandwich	[90*/90*/ core /90/90] (warp face next to core)	
12. Quasi Sandwich	[45*/0*/ core /0/45] (warp face next to core)	
13. Warp Toughness	[0*]n	0.120 to 0.200
14. Quasi CAI	[(45/0/-45/0)n // (0*/-45*/0*/45*)n]	0.140 to 0.200

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 8 – RECOMMENDED MINIMUM SET OF CURED COMPOSITE MECHANICAL PROPERTIES

Layup (see Table 7)	Test Type and Direction	Property	No. of Batches x No. of Panels x No. of Tests/ Batch/Panels			
			Test Temperature/Moisture Condition			
			Lowest Temperature/ Ambient	70°F/ Ambient	Highest Temperature/ Ambient	Highest Temperature/ Wet
1. Warp Tension	0 (Warp) Tension ASTM D 3039	Ultimate Strength and Modulus	3 x 2 x 3	3 x 2 x 3 ²	1 x 2 x 3	
2. Warp Compression	0 (Warp) Compression ASTM D 6641	Ultimate Strength and Modulus	3 x 2 x 3	3 x 2 x 3 ²	1 x 2 x 3	1 x 2 x 3
3. Fill Tension	90 (Fill) Tension ASTM D 3039	Ultimate Strength and Modulus	3 x 2 x 3	3 x 2 x 3 ¹	1 x 2 x 3 ²	3 x 2 x 3
4. Fill Compression	90 (Fill) Compression ASTM D 6641	Ultimate Strength and Modulus	3 x 2 x 3	3 x 2 x 3 ²	1 x 2 x 3 ¹	3 x 2 x 3
5. ±45 Shear	In-plane Shear ASTM D 3518	Ultimate Strength and Modulus	3 x 2 x 3	3 x 2 x 3 ²	3 x 2 x 3	3 x 2 x 3
6. Warp Interlaminar	Short Beam Shear ASTM D 2344	Ultimate Strength		3 x 2 x 3 ¹		

1 – Batch release tests.

2 – Equivalency baseline database tests.

TABLE 9 – RECOMMENDED ADDITIONAL CURED COMPOSITE MECHANICAL PROPERTIES FOR GENERAL APPLICATIONS

Layup (see Table 7)	Test Type and Direction	Property	No. of Batches x No. of Panels x No. of Tests/ Batch/Panels			
			Test Temperature/Moisture Condition			
			Lowest Temperature/ Ambient	70°F/ Ambient	Highest Temperature/ Ambient	Highest Temperature/ Wet
7. Quasi Laminate	Open Hole Tension ² ASTM D 5766	Ultimate Strength	3 x 2 x 3	3 x 2 x 3 ¹	3 x 2 x 3 ¹	3 x 2 x 3
7. Quasi Laminate	Open Hole Compression ² ASTM D 6484	Ultimate Strength		3 x 2 x 3 ¹	3 x 2 x 3 ¹	3 x 2 x 3

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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- 1 – Equivalency baseline database tests .
- 2 – Open-hole test configuration: 0.25-inch hole diameter, 1.5 -inch width

The tests listed in Table 10 are some optional tests for an expanded material database. These tests are intended to provide data for additional material design allowables that are commonly used to design and certify aircraft structures. The recommended test conditions for each test are shown with a checkmark. The number of batches to be tested will depend on the acceptable level of conservatism for the allowable values, on the criticality of the structure for which the data will be used, and on acceptance by the responsible FAA ACO.

Many aircraft applications involve more than solid laminate construction. The tests listed in Table 11 are recommended for honeycomb sandwich panels. The tests are selected as sensitive indicators of any change in the constituent materials. This testing requires that separate specifications exist for the honeycomb and the adhesive used to bond the prepreg to the core.

The optional tests listed in Table 12 are some of those that may be required to show that the material will be suitable for the intended aircraft/rotorcraft application. These include testing of cured laminates after exposure of the laminates to solvents that the part will be subjected to in actual service. Recommended fluids for testing are:

Extended Contact:

- 100 Low-Lead Aviation Fuel
- JP-4 Jet Fuel
- MIL-H-5606 Hydraulic Oil
- MIL-H-83282 Hydraulic Oil
- Engine Lubricating Oil MIL-L-7808
- Engine Lubricating Oil MIL-L-23699

Short Duration Contact:

- Methyl Ethyl Ketone Washing Fluid. ASTM D740
- Polypropylene Glycol Deicer (Type I) MIL-A-8243
- Isopropyl Alcohol Deicing Agent (TT-I-735)

It is recommended that the test laminates be exposed to the above fluids at room temperature conditions, unless the material is expected to be used in an application where fluid exposure occurs for significant time periods at a different temperature. For example, materials intended for use in integral fuel tanks should be exposed to fuel over the expected range of service temperatures for the fuel tank (typically cold to hot conditions). Tests for extended contact fluids should be conditioned by immersion for 500 ±50 hours; tests for short duration contact fluids should be conditioned by immersion for 48 ±4 hours.

The test method to evaluate solvent affect must be sensitive to the expected effect on the laminate. Shear tests are best for detecting the effect of solvent exposure on epoxy resins. The

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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solvent exposure and subsequent testing should be conducted at the temperatures expected during service.

It is recommended that fatigue testing of open-hole specimens be conducted to confirm that the parts will be durable over the expected service life. Post-impact residual strength evaluation for damage tolerance is recommended for primary structure applications. Fatigue testing of impact-damaged specimens may also be required for certification of certain primary structures; however, the detailed recommendations for these tests are beyond the scope of this document. See FAA AC 21-107A for further guidance on these issues.

It is also recommended that any other unique environmental conditions, such as ultraviolet (UV) exposure and other weathering effects that may degrade material properties, be considered. These environmental conditions should be applied for the expected service conditions and life for the material and structural application.

The recommended test conditions for each test are shown with a checkmark in Table 10. The number of batches to be tested will depend on the acceptable level of conservatism for the allowable values, on the criticality of the structure for which the data will be used, and on acceptance by the FAA.

All of the tests shown in Tables 10, 11, and 12 may not be applicable depending on the physical limitations of the material (for instance, impact energy levels may have to be adjusted for different laminate thicknesses and material characteristics).

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 10 – OPTIONAL CURED COMPOSITE MECHANICAL PROPERTIES FOR EXPANDED DATABASE

Layup (see Table 7)	Test Type and Direction	Property	Test Temperature/Moisture Condition			
			Lowest Temperature / Ambient	70°F/ Ambient	Highest Temperature / Ambient	Highest Temperature / Wet
7. Quasi Laminate	Unnotched Tension ASTM D3039	Ultimate Strength	✓	✓		✓
8. Soft Laminate	Unnotched Tension ASTM D3039	Ultimate Strength	✓	✓		✓
9. Hard Laminate	Unnotched Tension ASTM D3039	Ultimate Strength	✓	✓		✓
7. Quasi Laminate	Unnotched Compression	Ultimate Strength		✓	✓	✓
8. Soft Laminate	Unnotched Compression	Ultimate Strength		✓		✓
9. Hard Laminate	Unnotched Compression	Ultimate Strength		✓		✓
9. Hard Laminate	Open Hole Tension ¹ ASTM D5766	Ultimate Strength	✓	✓		✓
8. Soft Laminate	Open Hole Tension ¹ ASTM D5766	Ultimate Strength	✓	✓		✓
9. Hard Laminate	Open Hole Compression ¹ ASTM D6484	Ultimate Strength		✓		✓
8. Soft Laminate	Open hole Compression ¹ ASTM D6484	Ultimate Strength		✓		✓
7. Quasi Laminate	Filled Hole Tension ² ASTM 6742	Ultimate Strength	✓	✓		
9. Hard Laminate	Filled Hole Tension ² ASTM 6742	Ultimate Strength	✓	✓		
8. Soft Laminate	Filled Hole Tension ² ASTM 6742	Ultimate Strength	✓	✓		

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 10 – OPTIONAL CURED LAMINATE MECHANICAL PROPERTIES FOR EXPANDED DATABASE (Continued)

Layup (see Table 7)	Test Type and Direction	Property	Test Temperature/Moisture Condition			
			Lowest Temperature / Ambient	70°F/ Ambient	Highest Temperature / Ambient	Highest Temperature / Wet
7. Quasi Laminate	Filled Hole Compression ² ASTM 6742	Ultimate Strength		✓		✓
9. Hard Laminate	Filled Hole Compression ² ASTM 6742	Ultimate Strength		✓		✓
8. Soft Laminate	Filled Hole Compression ² ASTM 6742	Ultimate Strength		✓		✓
7. Quasi Laminate	Single Shear Bearing ³ ASTM 5961	Ultimate Strength		✓		✓
9. Hard Laminate	Single Shear Bearing ³ ASTM 5961	Ultimate Strength		✓		✓
8. Soft Laminate	Single Shear Bearing ³ ASTM 5961	Ultimate Strength		✓		✓
[0]n	Compression Interlaminar Shear	Ultimate Strength	✓	✓		✓

1 - Open-hole test configuration: 0.25-inch hole diameter, 1.5-inch width

2 - Filled hole test configuration: 0.25-inch hole diameter, 100° tension head countersunk fastener, 1.5-inch width

3 - Single shear bearing configuration: 0.25-inch hole diameter, 1.5-inch width, one protruding head fastener, and stabilization fixture

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 11 – OPTIONAL CURED SANDWICH PANEL MECHANICAL PROPERTIES FOR EXPANDED DATABASE

Layup (see Table 7)	Test Type and Direction	Property	Test Temperature/Moisture Condition			
			Lowest Temperature / Ambient	70°F/ Ambient	Highest Temperature/ Ambient	Highest Temperature/ Wet
10. Warp Sandwich	Sandwich Long Beam Flexure	Ultimate Strength		✓		✓
11. Fill Sandwich	Sandwich Long Beam Flexure	Ultimate Strength		✓		✓
12. Quasi Sandwich	Sandwich Long Beam Flexure	Ultimate Strength		✓		✓
12. Quasi Sandwich	Sandwich Long Beam Flexure, with Open Hole	Ultimate Strength		✓		✓
12. Quasi Sandwich	Sandwich Long Beam Flexure, with 30 in-lb impact	Ultimate Strength		✓		
12. Quasi Sandwich	Sandwich Long Beam Flexure, with 120 in-lb impact	Ultimate Strength		✓		

1 - If the material is designed to be self-adhesive to the core, then these tests should be conducted on cocured panels fabricated without adhesive. If the material requires an adhesive layer for bonding to the core, then the tests can be conducted on either (or both) cocured panels or precured skins secondarily bonded to the core, depending on the anticipated design and fabrication methods to be used with the material.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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TABLE 12 – RECOMMENDED TESTS FOR DURABILITY AND SERVICE LIFE CONFIRMATION

Layup (see Table 7)	Test Type and Direction	Property	Test Temperature/Moisture Condition			
			Lowest Temperature/ Ambient	70°F/ Ambient	Highest Temperature/ Ambient	Highest Temperature/ Wet
5. ±45 Shear Exposure to Solvent A (repeat for each potential exposure fluid)	In-plane Shear ASTM D3518	Ultimate Strength and Modulus		✓		✓
13. Warp Toughness	Mode I Fracture Toughness ASTM D5528	G1c	✓	✓		✓
13. Warp Toughness	Mode II Fracture Toughness	G2c	✓	✓		✓
7. Quasi Laminate	Open Hole Fatigue ¹ , R=-1 (Tension/ Compression)	Fatigue Life ²		✓		✓
8. Soft Laminate	Open Hole Fatigue ¹ , R=-1 (Tension/ Compression)	Fatigue Life ²		✓		✓
9. Hard Laminate	Open Hole Fatigue ¹ , R=-1 (Tension/ Compression)	Fatigue Life ²		✓		✓
14. Quasi CAI	Compression After Impact, 270 in-lbs impact	Ultimate Strength		✓		
14. Quasi CAI	Compression After Impact, 540 in-lbs impact	Ultimate Strength		✓		
14. Quasi CAI	Compression After Impact, 1080 in-lbs impact	Ultimate Strength		✓		

1 - Open-hole test configuration: 0.25-inch hole diameter, 1.5-inch width

2 - Runout for fatigue life tests should be at least 1×10^6 cycles, unless the material is intended for use in severe fatigue environments, in which case the number of cycles for runout should be increased.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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8.4 Section 4 – Quality Assurance

8.4.1 Section 4.1 – Responsibility for Inspection

Since the material acceptance document controls constituent materials assembled, infused and cured at the part producers facility, the producer has the sole responsibility for the qualification, batch release and part acceptance tests specified in this document.

8.4.2 Section 4.2 – Classification of Tests and Inspections

With liquid resin molding processes the part producer is responsible for three levels of material acceptance testing: material batch acceptance tests for the constituent materials, material batch release tests for the combination of resin, tackifier and fiber preform and part acceptance tests. Two approaches for conducting the required tests are diagramed in Figure 4 and discussed in the following subsections.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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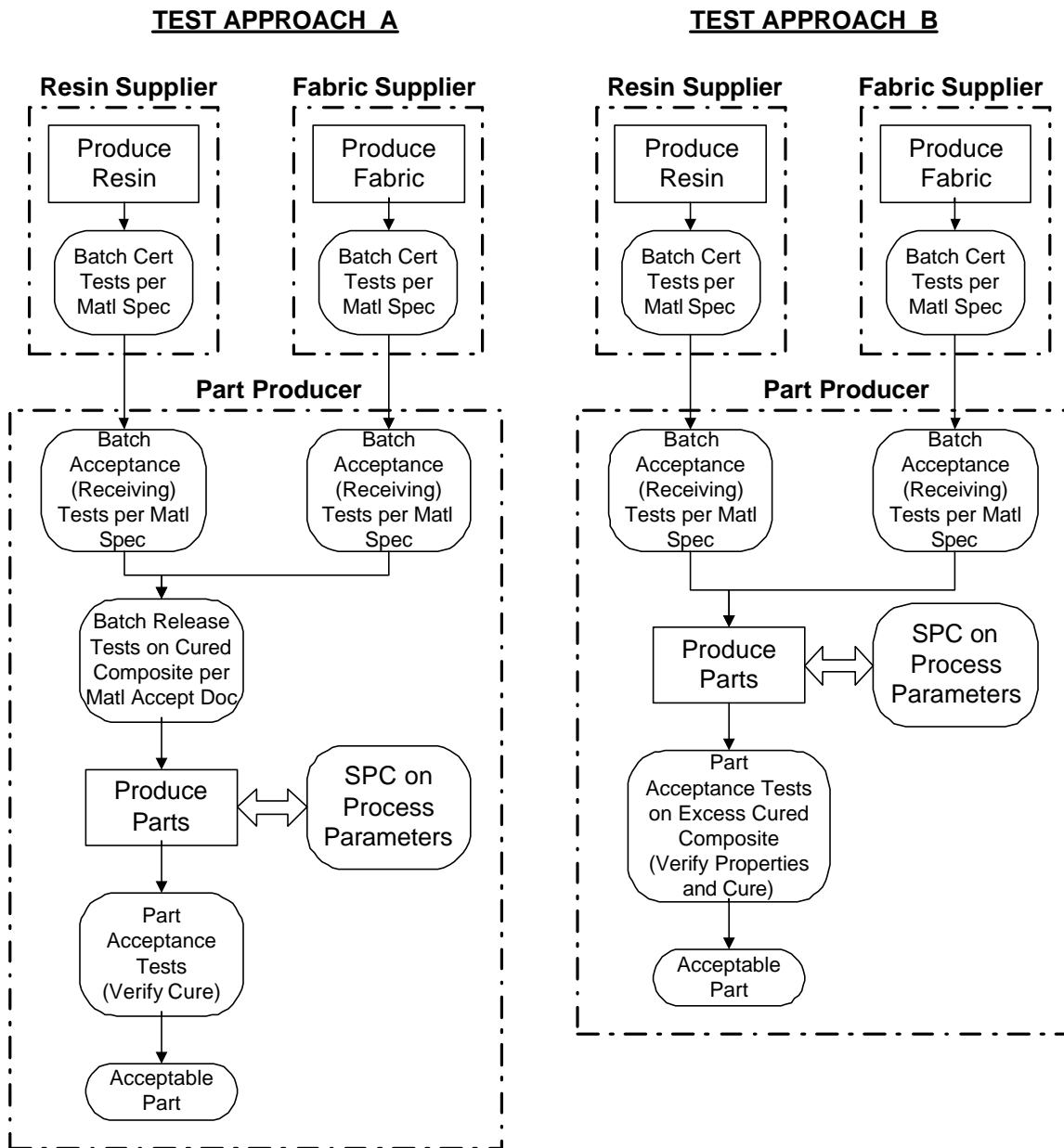


FIGURE 4: LRM MATERIAL AND PART ACCEPTANCE TESTING APPROACHES

8.4.2.1 Section 4.2.1 – Qualification Tests

The qualification or preproduction tests performed for the cured material qualification are those tests performed on representative parts contain each specific form of constituent material to establish a qualified material system in accordance with this specification. Qualification testing shall consist of all requirements and tests specified in Section 3 of the acceptance document

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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(section 8.3 above). This testing shall be performed for each type of material. See section 8.3.4 for further discussion of qualification testing.

8.4.2.2 Section 4.2.2 – Constituent Receiving Inspection Tests

The part producer quality department shall perform the specified acceptance tests defined in the applicable material procurement specification (see sections 6 and 7 of this document) for each batch of material. The material specifications should define the testing frequency.

The quality department must review the test results and allow the material to be released cured material batch release testing only upon satisfactory demonstration that the material meets the specification requirements. The end-user should hold to the same record keeping requirements and retest criteria as the material supplier.

A part producer must conduct the acceptance testing whether the material is bought directly from the manufacturer or through a distributor. The original certification testing conducted by the material manufacturer will be made available by the distributor for a specific batch sold to the part producer.

In cases where the material has demonstrated a high level of SPC control and capability for the material, it may be possible to reduce and/or eliminate the purchase acceptance testing. If material is supplied by a distributor, it is recommended that purchaser testing be maintained as a safeguard against uncontrolled material. It is expected that the FAA will evaluate requests to reduce or eliminate end-user testing on a case-by-case basis (specific FAA policy for reduced testing approvals will be developed in the future). If end-user 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.

The procuring activity reserves the right to perform additional testing to confirm the supplier's certification data, and to approve incoming material for use in the fabrication of production parts. Each roll of material shall be examined for appearance, color uniformity, imperfections which would be detrimental for use in the fabrication of parts, and for quality of workmanship.

8.4.2.3 Section 4.2.3 – Cured Material Batch Release Tests

Once the constituent materials have passed the batch acceptance requirements of the applicable material procurement specification, the part producer must produce test panels and perform tests to demonstrate that the combination of resins, tackifiers and fiber preforms, when combined into a cured composite part, meet the requirements of the material acceptance document. These tests are designated 'batch release' tests since they are intended to provide the data required to release the materials for production use. Recommended mechanical property batch release tests are shown in tables 6 (panel physical properties) and 8 (panel mechanical properties) in section 8.3.4.

Each potential combination of resin batch and fabric batch which will be used in production parts should be tested for the batch release tests. In some cases this could lead to an excessive amount

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of batch release testing. There are two possible approaches for reducing the amount of required tests:

- Demonstrate that there is a very low risk of potential resin/fiber incompatibility. When this is achieved, the batch release testing need only be performed once for each unique batch of resin and fabric.
- Perform the tests designated as batch release tests in Tables 6 and 8 using excess composite material cut from each production part or group of parts infused and cured at the same time

8.4.2.4 Section 4.2.4 – Part Acceptance Tests

If the batch release tests are performed on the combinations of resin and fabric prior to using the material in production, and provided that SPC systems are used to monitor the tackifier application, preform assembly, resin infusion and cure processes, then the part acceptance tests can consist only of tests on excess cured resin (flash, infusion port plugs, etc.) to validate that an acceptable resin cure has been achieved.

If batch release tests on test panels are not performed, then more extensive part acceptance tests will be required. The tests designated as batch release tests in Tables 6 and 8 should be performed on excess material representative of the part. These tests can use excess part material (e.g., prolongation) or test panel material infused and cured along with the part. Successful passage of all of the tests will be required in order to accept the accompanying part.

The choice of which stage of the production process to perform the batch release tests will be driven by part complexity, preform complexity, the specific resin mixing and infusion process, along with test cost and part cost considerations. It should also be noted that later approach (performing release testing at part fabrication) is by far the highest risk approach.

8.4.2.5 Section 4.2.5 – Retest

Retest or replacement of test data is allowed only if an abnormality is observed or can be reasonably deduced to have occurred during testing,

- data is a statistical outlier, and
- the test has been conducted on materials that have not been prepared or conditioned properly (e.g., machining errors on laminates).

Note: any testing error should be identified and corrected prior to retest.

If a retest is required, a complete set of replicates for the property should be tested. If the retest results fail the acceptance criteria, the material batch covered by the failed test should be rejected and dispositioned through a material review board (including engineering personnel) process. All end-users of a material batch for which retests were performed must be notified at the time of batch shipment.

8.4.3 Section 4.3 – Statistical Process Control

The part producer quality assurance department should maintain the procedures and requirements for SPC based on key characteristics (KC) and key process parameters (KPP). The

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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KCs are a subset of those properties detailed in the uncured and cured material requirement tables. KCs should be selected such that they ensure all properties of the material are within acceptable statistical limits. These are usually the set of requirements used for batch release testing. KPPs are those tackifier application, preform assembly, resin infusion and cure process parameters that have a significant influence on the KCs. KPPs must be determined prior to part qualification and be documented in the process specification applicable to the part. Average values, ranges, limits, and sampling frequency should be established and documented in the process specification.

The procedures used by the quality assurance department to conduct SPC analysis of the KCs and KPPs should be documented in the process specification. The process specification should also include the procedures used to establish and calculate the control limits. It is expected that control charts will be maintained on the KCs and KPPs and will be available for inspection by FAA personnel. It is strongly recommended that there be an effective program to collect, plot, analyze, and act on KC and KPP data. It is expected that action will be taken when the criteria for nonrandom data trends are met. Action should be taken while the data is still within the upper and lower control limits established during the initial data base generation and subsequent production batches.

If a KC is out of control, the cause of variation should be identified and eliminated, re-establishing statistical control. The quality assurance department must document all corrective actions affecting the process and monitor if the corrective action has been effective.

Reduced testing may be established based on the capability of the KCs and KPPs. Reduced testing will require approval by the FAA prior to being implemented. The reduced testing plan will be documented in the process specification. If KCs are found to be out of control, testing must return to the original level for a period of time until confidence in the control of the material is re-established. The reduced testing may take the form of a reduction of part level testing by the part producer. A prerequisite for reduced testing is adherence to monitoring and action based on control charts.

8.4.4 Section 4.4 – Test Methods

Recommended test methods for each property are given in Chapters 3 through 7 of Volume 1 of MIL-HDBK-17. In general, ASTM Standard Test Methods are recommended. However in most cases, additional test specimen configuration requirements and test procedures will have to be defined to provide sufficient detail to avoid undesired variations. Deviations from industry standard methods must be clearly detailed in the specification.

It is recommended that all testing be conducted by a laboratory certified to conduct the tests to the specified methods; this certification applies to part producer and independent test labs. A certified laboratory follows established policies and procedures such as training of test technicians, written procedures for performing tests, documenting the dimensional accuracy of test fixtures, and tracing calibration to national standards organization (such as the U. S. National Institute of Standards and Technology (NIST)) standards. The specification should define the requirements and procedures for certifying a test lab. It is recommended that for an industry specification, a national laboratory certification be required for facilities used.

8.4.5 Section 4.5 – Records

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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The supplier and procuring organization shall retain records of the batch raw ingredients for a minimum of seven years from date of manufacture. Records shall contain date of manufacture, process control tests, certification tests, acceptance tests, and storage conditions.

8.5 Section 5 – Notes

8.5.1 Section 5.1 – Definitions

This section should include definitions for terms or abbreviations that are used. The definitions provide clarity between the supplier and the procurer. Material properties, quality, and defects must be defined such that batches made after the original qualification have the same level of quality and properties. For example, fabric prepreg defects such as fuzz balls, creases, foreign material, dry spots, fiber alignment, splices, and edge deviation from a straight line should have a specific definition (see Section 11.2 for recommended fabric defect definitions). Since the ability to be laid up and cured dependably into a part can be affected by the degree of advancement of the resin, storage life, out life, and handling life must be clearly defined. Where possible, definitions from industry standards such as MIL-HDBK-17, SAE, and ASTM should be used.

The following batch definitions are recommended:

Batch (or Lot) (general) – n, A quantity of material produced essentially at the same time and under the same conditions from a well-defined collection of raw materials. The quantity of material must have minimal variation in properties throughout to be considered a unique batch.

Batch (or Lot) (fibers) – n, For fibers, a quantity of material formed during one essentially continuous, uninterrupted production run under the same process conditions using one to three precursor lots. An interruption in the process of up to 72 hours is permitted, provided that the production equipment settings are not modified or another material is not produced on the equipment during the interruption.

Batch (or Lot) (fabric) – n, For fabrics, a quantity of material woven from one to three batches (lots) of fiber. The weaving process can be interrupted for up to 72 hours if the loom settings are not changed and another material is not produced in the interim.

Batch (or Lot) (resin) – n, For a batch of resin, the definition varies depending on the specific mixing process:

- In a batch mixing process a large vessel is charged with the desired types and quantities of raw ingredients. After mixing is complete, the vessel is discharged. The material made from this single-mix process is defined as a single batch of resin.
- A continuous mixing process for producing resin typically involves incrementally feeding raw ingredients into a mixing device that blends them into a stream of resin. A batch of resin made by this process is defined as a quantity of material formed during one essentially continuous uninterrupted production run under the same process conditions using the same raw ingredients. Since start up and shutdown usually require purging the equipment, a shutdown will signal the end of a specific batch. Material made after start up is defined as a new batch. If a process shutdown does not require purging, an interruption in the process of up to 72 hours is permitted, provided that the production

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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equipment settings are not modified or another material was not produced on the equipment during the interruption.

- In one version of a semi-continuous mixing process, a large vessel is charged with a portion of the raw ingredients (premix). After mixing, the vessel is discharged into several smaller containers, each of which acts as the vessel for subsequent mixing steps. The remaining raw ingredients are added to these smaller vessels and further mixing results in the final resin composition. The premix produced in the large vessel can be considered as a single batch of raw ingredient. The material produced during the final mixing in the small containers can be considered one batch if it is produced from the same raw ingredients batches without an interruption of more than 72 hours without the production of another material in the interval, and until the premix is consumed.
- In another version of a semi-continuous mixing process, small complete mixes of raw ingredients are made without the premix step. A batch of resin then consists of any number of these small mixes if they are made from the same lots of raw ingredients, the production run is not interrupted for more than 72 hours, and there is no other material made in the interval.
- For all mixing processes, blending of raw ingredient lots is permissible if the same blend ratio is found throughout all portions of the resin batch. Traceability must be retained on the ingredient lots that were used. For all mixing processes, a single-resin batch may contain a maximum of three blended lots of each raw chemical ingredient.
- Solvated resins typically can be handled and blended easily without the heat history associated with reactive processes. In this case up to five resin lots may be blended, but only if the individual resin lots themselves do not consist of blends of resin lots. Traceability must be maintained as to lot designations and amounts blended.

Batch (or Lot) (specific to lamina, laminates and parts) – n, For laminae, laminates and parts, material made from:

- One batch (lot) of fiber and one batch of resin(s)
- One batch of fabric and one batch of resin(s)

The above definitions are generally applicable for use with material acceptance processes, including sampling plans for acceptance testing. For material qualification and allowables test programs, stricter definitions of a batch are often specified in order to control the amount of material variability to be evaluated in the test program. For instance, a particular batch of LRM composite may be restricted to a single batch of fabric (containing a single lot of fiber) and a single mix of resin.

8.5.3 Section 8.3 – Approved Products

A listing of products that have qualified as defined within the specification is provided in this section.

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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GLOSSARY.

This glossary is a compilation of terms with their definitions used within this report and of general interest. Definitions for this glossary were obtained from a variety of sources, which are noted at the end of the definition. Refer to MIL-HDBK-17 for a more complete listing of terms and their definitions.

GENERAL

bag, v—the process of enclosing the ply layers within a flexible container. See also vacuum bag (ASTM D 5687).

baseplate, n—a flat plate on which a laminate is laid up. See also mold (ASTM D 5687).

braided fabric, n—a cloth constructed by a braiding process (ASTM D 3878).

breather, n—cloth which allows even gas flow over the layup surface. The breather also helps minimize bag punctures by protecting the bag from sharp points (ASTM D 5687).

Discussion: Typically within the bagging layup sequence, the breather material is a mixture of materials. The layer closest to the laminate is a lightweight glass fabric, such as Style 120, in order to minimize mark off on the laminate. The remaining layers are materials selected for their ability to transport gasses under pressure and elevated temperature. Typical materials are heavy weight glasses such as Style 1000 or synthetic non-woven materials.

breather string, n—a glass string connected from the laminate to a breather in the bagging lay-up. It provides a path for gasses to be transferred from the laminate while minimizing matrix flow (ASTM D 5687).

broadgoods, n—prepreg material (fabric or unidirectional) where the width is greater than 24 inches. See also tape.

caul plate, n—a flat plate used to provide a flat surface to the top of the laminate during laminate consolidation or cure (ASTM D 3878).

CFR—Code of Federal Regulations.

cloth, n—a piece of textile fabric containing woven reinforcement without a load transferring matrix (ASTM D 5687).

composite material, n—a substance consisting of two or more materials, insoluble in one another, which are combined to form a useful engineering material possessing certain properties not possessed by the constituents. Composites are subdivided into classes on the basis of the form of the structural constituents; Lamina: Composed of layer or lamina constituents; Particulate: The dispersed phase consists of fibers; Flake: The dispersed phase consists of flat flakes; Skeletal: Composed of a continuous skeletal matrix filled by a second material (ASTM D 3878 and Handbook of Composites).

cure, v—to change the physical properties of a polymer by chemical reaction, which may be by condensation, polymerization, or vulcanization; usually accomplished by the action of heat and catalyst, alone or in combination, with or without pressure (ASTM D 907).

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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cured ply thickness (CPT), n —the theoretical thickness of an individual ply, which is a function of the fiber areal weight, resin content, fiber density, and resin density.

Discussion: cured per ply thickness is determined from the fiber areal weight, fiber volume, and fiber density:

$$CPT = \frac{FAW}{25400 \rho_f FV}$$

Where:

CPT is theoretical cured ply thickness (inches)
 FAW is fiber areal weight (g/m^2)
25400 is a units conversion factor
 ρ_f is the fiber density (g/cc)
 FV is fiber volume (fraction, e.g., 0.61)

Or cured per ply thickness can also be determined from the fiber areal weight, resin content, fiber density, and resin density:

$$CPT = \frac{FAW}{25400} \left[\frac{1}{\rho_f} + \frac{RC}{\rho_r(1-RC)} \right]$$

Where:

CPT is theoretical cured ply thickness (inches)
 FAW is fiber areal weight (g/m^2)
25400 is a units conversion factor
 ρ_f is the fiber density (g/cc)
 ρ_r is the resin density (g/cc)
RC is resin weight content (fraction, e.g., 0.33)

The actual cured ply thickness is determined by measuring the laminate thickness and dividing it by the number of plies (see SACMA SRM 10).

Fiber volume and resin content are related by the fiber and resin densities:

$$FV = \frac{1-RC}{\rho_f} \left[\frac{1}{\frac{1-RC}{\rho_f} + \frac{RC}{\rho_r}} \right]$$

Where:

FV is fiber volume (fraction, e.g., 0.61)

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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ρ_f is the fiber density (g/cc)
 ρ_r is the resin density (g/cc)
RC is resin weight content (fraction, e.g., 0.33)

dam, n—a solid material (such as silicone rubber, steel, or aluminum) used in the lay-up to contain the matrix material within defined boundaries during laminate consolidation (ASTM D 5687).

DAR—Designated Airworthiness Representative. FAA designees authorized to conduct conformity inspections on behalf of the FAA.

debulk, v—process of decreasing voids between lamina before laminate consolidation through use of vacuum or by mechanical means. Lamina can be debulked at ambient or elevated temperature (ASTM D 5687).

degree of cure (α), n—in thermoset polymers, the quantity of heat of reaction of the unreacted resin remaining after a reaction (cure cycle) compared to the total available quantity of heat of reaction expended by the complete reaction (cure) of a reacted resin.

Discussion: The degree of cure of a laminate can be obtained from differential scanning calorimetry (DSC) data. In order to obtain the degree of cure of a laminate, the baseline or total heat of reaction released by the complete curing of the resin (or prepreg) must first be obtained. This total heat of reaction is determined from the DSC curve. It is important to obtain the total heat of reaction from a sample that is of the same resin content as the laminate in question. This is typically accomplished by testing a sample of the prepreg used to fabricate the laminate. The laminate in question is then tested to determine the partial heat of reaction. The DSC heating rate used to determine the baseline heat of reaction and partial heat of reaction must be the same. Typically a heating rate of 10°C per minute is used. The degree of cure is calculated as follows:

$$a = 100 - \left(\frac{\Delta H_p}{\Delta H_T} \times 100 \right)$$

Where:

a is the percent degree of cure (ranges from 0% to 100% with 100% being fully cured)
DH_p is the heat of reaction released by the partially cured sample (laminate in question) expressed in Joules
DH_T is the total heat of reaction released by the uncured resin expressed in Joules (baseline)

Resin formulations commonly used in the aerospace industry rarely reach a degree of cure of 100%. Values of 95% to 98% are common. It should be noted that determining degree of cure by DSC is not considered the most repeatable test and is best limited to research investigations and not used as a production test. Depending on the circumstances,

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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measurement of the glass transition temperature may be the best method to determine if a laminate is fully cured.

DER—Designated Engineering Representative. FAA designees authorized to approve engineering data.

differential scanning calorimetry (DSC), n—a technique in which the temperature difference between the substance and a reference material is measured as a function of temperature while the substance and reference material are subjected to a controlled-temperature program (ASTM E 473).

DMIR—Designated Manufacturing Inspection Representative. FAA designees authorized to conduct conformity inspections on behalf of the FAA.

end, n—in fabric, an individual warp yarn (single or ply) or cord (ASTM D 123).

ETD—Elevated Temperature Dry.

ETW—Elevated Temperature Wet.

FAA—Federal Aviation Administration.

fabric, n—in textiles, a planar structure consisting of yarns or fibers (ASTM D 123).

FEP, n—fluorinated ethylenepropylene.

Discussion: fluorinated ethylenepropylene is a fluorocarbon polymer commonly known by its DuPont trade name Teflon[®] FEP.

fiber, n—in textiles, a generic term for any one of the various types of matter that form the basic elements of a textile and that is characterized by having a length at least 100 times its diameter (ASTM D 123).

fiber areal weight (FAW), n—the weight per area of the fiber reinforcement within a composite, expressed as grams per square meter or ounces per square yard. See also prepreg areal weight.

fiber content, n—the amount of fiber present in a composite expressed either as a percent by weight or percent by volume. This is sometimes stated as a fraction, that is, fiber volume fraction (ASTM D 3878).

fiber volume fraction (FV or V_f), n—see fiber content (ASTM D 3878).

filament, n—a fibrous form of matter with an aspect ratio >10 and an effective diameter <1 mm (ASTM D 3878).

fill, n—in a woven fabric, (1) the yarn running from selvage to selvage at right angles to the warp and (2) fiber inserted by the shuttle during weaving also designated as filling (ASTM D 3878, MIL-HDBK-17, and ASTM D 5687).

fill surface, n—in a woven fabric where each fill yarn crosses over more than one warp yarn, the ply surface that shows the larger area of fill tows with respect to warp tows.

flip/flop, v—the process of alternating plies through an angle orientation of 180° during laminate lay-up. This practice is commonly used if the material of the same width as the laminate has a

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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recurring flaw. The process changes the location of the flaw so that it does not unduly affect the laminate structure (ASTM D 5687).

glass transition, *n*—the reversible change in an amorphous polymer or in amorphous regions of a partially crystalline polymer from (or to) a viscous or rubbery condition to (or from) a hard and relatively brittle one (MIL-HDBK-17).

Discussion: The glass transition generally occurs over a relatively narrow temperature region and is similar to the solidification of a liquid to a glassy state; it is not a phase transition. Not only do hardness and brittleness undergo rapid changes in this temperature region but other properties, such as thermal expansibility and specific heat, also change rapidly. This phenomenon has been called second order transition, rubber transition, and rubbery transition. The word transformation has also been used instead of transition. Where more than one amorphous transition occurs in a polymer, the one associated with segmental motions of the polymer backbone chain or accompanied by the largest change in properties is usually considered to be the glass transition (ASTM D 883).

glass transition temperature (T_g), *n*—the approximate midpoint of the temperature range over which the glass transition takes place (MIL-HDBK-17).

Discussion: The glass transition temperature can be determined readily only by observing the temperature at which a significant change takes place in a specific electrical, mechanical, or other physical property. Moreover, the observed temperature can vary significantly depending on the specific property chosen for observation and on details of the experimental technique (for example, rate of heating and frequency). Three common methods for determining T_g are Thermal Mechanical Analysis, Differential Scanning Calorimetry, or Dynamic Mechanical Analysis.

knit, *v*—a textile process that interlocks, in a specific pattern loop, by means of needles or wires (ASTM D 3878).

knitted fabric, *n*—a cloth constructed by a knitting process (ASTM D 3878).

lamina, *n*—a subunit of a laminate consisting of one or more adjacent plies of the same material with identical orientation (ASTM D 3878).

laminate, *n*—any fiber or fabric-reinforced composite consisting of lamina (plies) with one or more orientations with respect to some reference direction (ASTM D 3878).

laminate coordinate axes, *n*—a set of coordinate axes, usually right-handed Cartesian, used as a reference in describing the directional properties and geometrical structure of the laminate. Usually the *x*-axis and the *y*-axes lie in the plane of the laminate, and the *x*-axis is the reference axis from which ply angle is measured (ASTM D 3878).

laminate principal axis, *n*—the laminate coordinate axis that coincides with the direction of maximum in plane Young's modulus (ASTM D 3878).

lay-up, *n*—(1) the stack of plies in specified sequence and orientation before cure or consolidation; (2) the complete stack of plies, bagging material, and so on before cure or

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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consolidation; and (3) a description of the component materials, geometry, and so on of a laminate (ASTM D 3878).

lay up, v—to stack plies of material in specified sequence and orientation (ASTM D 3878).

lay-up code, n—a designation system for abbreviating the stacking sequence of laminated composites (ASTM D 3878).

mandrel, n—a form, fixture, or male mold used as the base for production of a part in processes such as lay-up or filament winding (ASTM D 3878).

material form, n—the contour, arrangement, and structure of an unconsolidated composite material, especially with regard to the geometry and nature of the reinforcement. Factors considered part of the material form include, but are not limited to, reinforcement length (for discontinuous reinforcements), tow size or count, fabric areal weight, fabric style, reinforcement content, and ply thickness (ASTM D 3878).

matrix, n—the continuous constituent of a composite material, which surrounds or engulfs embedded filler or reinforcement (ASTM D 3878).

matrix content, n—the amount of matrix present in a composite expressed either as a percent by weight or percent by volume. Standard practice is to specify matrix content as weight percent (ASTM D 3878).

MIDO—Manufacturing Inspection District Office for the FAA.

MOL—Material Operational Limit.

mold, n—the support structure that holds the laminate or lay-up during laminate consolidation process (ASTM D 5687).

MRB—Material Review Board.

NIST—National Institute of Standards and Technology.

nondestructive inspection (NDI), v— to identify and measure abnormal conditions within a laminate without degrading or impairing the utility of the laminate.

nonperforated FEP, n—a nonporous fluorinated ethylenepropylene film used as a release film in the bagging lay-up.

Discussion: fluorinated ethylenepropylene is a fluorocarbon polymer commonly known by its DuPont trade name Teflon[®] FEP.

nonperforated TFE, n—a nonporous tetrafluoroethylene film used as a release film in the bagging lay-up (ASTM D 5687).

Discussion: tetrafluoroethylene is a fluorocarbon polymer commonly known by its DuPont trade name Teflon[®] TFE.

nonporous TFE-coated cloth, n—a cloth coated with tetrafluoroethylene used as a release material in the bagging process (ASTM D 5687).

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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nonwoven fabric, n—a cloth constructed by bonding or interlocking, or both (but not interlacing), fiber by any combination of mechanical, chemical, thermal, or solvent means (ASTM D 3878).

panel, n—a uniformly contoured composite laminate, typically flat (ASTM D 5687).

peel ply, n—a cloth with release capabilities, usually used in conjunction with laminates requiring secondary bonding (ASTM D 5687).

perforated FEP, n—a porous fluorinated ethylenepropylene film used in the bagging process that allows gasses or excess matrix materials to escape (flow) from a laminate during consolidation while protecting the laminate from physical bonding to other items such as caul plates.

perforated TFE, n—a porous tetrafluoroethylene film used in the bagging process that allows gasses or excess matrix materials to escape (flow) from a laminate during consolidation while protecting the laminate from physical bonding to other items such as caul plates (ASTM D 5687).

plied yarn, n—a yarn formed by twisting together two or more single yarns in one operation (ASTM D 3878).

ply, n—in laminar composites, the constituent single layer as used in fabricating or occurring within a composite structure (ASTM D 3878).

ply coordinate axes, n—a set of Cartesian coordinates, two of which lie within the plane of the ply, one axis of which is parallel to the principal fiber direction and the other axis perpendicular to the principal fiber direction (the third axis is through the ply's thickness) (ASTM D 3878).

ply count, n—in laminated composite materials, the number of plies or lamina used to construct the composite (ASTM D 3878).

ply orientation, n—the acute angle (theta) including 90° between a reference direction and the ply principal axis. The ply orientation is positive if measured counterclockwise from the reference direction and negative if measured clockwise (ASTM D 3878).

ply principal axis, n—the ply coordinate axis that coincides with the direction of maximum in plane Young's modulus. For balance weave fabric, either warp or fill direction may be chosen (ASTM D 3878).

polymer, n—an organic material composed of molecules characterized by the repetition of one or more types of monomeric units (MIL-HDBK-17).

polymerization, n—a chemical reaction in which the molecules of a monomer(s) are linked together in repeating units to form larger molecules (ASTM D 907).

porosity, n—a condition of trapped pockets of air, gas, or vacuum within a solid material, usually expressed as a percentage of the total nonsolid volume to the total volume (solid plus nonsolid) of a unit quantity of material (MIL-HDBK-17).

porous TFE-coated cloth, n—a porous cloth coated with tetrafluoroethylene used in the bagging process that allows gasses or excess matrix materials to escape (flow) from a laminate during

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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consolidation. It differs from perforated TFE in that it gives a textured surface to the laminate (ASTM D 5687).

prepreg, n—a ready to mold or cure fibrous reinforcement impregnated with a polymeric matrix. Its form may be sheet, tape, or tow. For thermosetting matrices, it has been partially cured to a controlled viscosity called B stage (ASTM D 3878 and MIL-HDBK-17).

prepreg areal weight (PAW), n—the weight per area of the prepreg composite material, expressed as pounds per square foot or the inverse square feet per pound. Used as a conversion factor to convert prepreg area to prepreg weight. See also fiber areal weight.

Discussion: Prepreg areal weight is a function of resin content and fiber areal weight:

$$PAW = \frac{FAW}{1 - RC}$$

Where:

PAW is prepreg areal weight (g/m²)

FAW is fiber areal weight (g/m²)

RC is resin weight content (fraction, e.g., 0.33)

To convert g/m² to lb/ft² multiply by 204.81 x 10⁻⁶.

reinforcement, n—in a composite material, the discrete constituent of a composite material, either fiber or particle, which is contained within the continuous matrix (ASTM D 3878).

resin, n—a solid or pseudo solid organic material, often of high molecular weight, which exhibits a tendency to flow when subjected to stress, usually has a high softening or melting range, and usually fractures conchoidally (ASTM D 3878).

resin content (RC), n—see matrix content (ASTM D 3878).

sealant, n—a high-temperature material used to seal the edges of a vacuum bag to a base plate during consolidation (ASTM D 5687).

selvage, n—the woven edge portion of a fabric parallel to the warp (ASTM D 3878).

single yarn, n—an end in which each filament follows the same twist (ASTM D 3878).

stacking sequence, n—the arrangement of ply orientations and material components in a laminate specified with respect to some reference direction (ASTM D 3878).

staggered, adj—the description of ply placement where the joints are not positioned in the same in-plane location through some specified thickness of the laminate (ASTM D 5687).

tape, n—prepreg material (typically unidirectional material) equal to or less than 24 inches in width. Also see broadgoods.

textile, n—a general term applied to fibers and organized assemblies of fibers with sufficient integrity to retain the organization (ASTM D 3878).

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thermoplastic, n—a plastic that repeatedly can be softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and that in the softened state can be shaped by flow into articles by molding or extrusion for example (ASTM D 883).

thermoset, n—a class of polymers that, when cured using heat, chemical, or other means, changes into a substantially infusible and insoluble material (ASTM D 3878).

tow, n—in fibrous composites, a continuous, ordered assembly of essentially parallel, collimated filaments, normally without twist and of continuous filaments (ASTM D 3878).

tracer yarn, n—in a woven fabric, a yarn woven into the fabric for the purpose of tracing the direction of the warp and fill fibers or tows.

traveler, n—a coupon with the same nominal thickness and, preferably, width as the test specimen, made of the same material, and processed similarly to the specimen except usually without tabs or gages. The traveler is used to measure mass changes during environmental conditioning when it is impractical to measure these changes on the actual specimen (ASTM D 5687).

traveler panel, n—(aka witness panel) a panel that is subjected to the same conditions as a part or group of parts to allow destructive testing to verify processing.

unidirectional, n—any fiber-reinforced composite with all the fibers aligned in a single direction. Both prepreg material and consolidated laminates can be described as being unidirectional.

vacuum bag, n—a low gas permeable material used to enclose and seal the lay-up during a consolidation or debulking cycle (ASTM D 5687).

vacuum couple, n—the mechanical connection that seals the vacuum source to the lay-up during a consolidation or debulking cycle (ASTM D 5687).

vitrification, n—the point during polymerization where the T_g of the polymer rises above the temperature of cure.

void, n—any pocket of enclosed gas or air within a composite (ASTM D 3878).

void content, n—the volume percentage of voids in a composite (ASTM D 3878).

warp, n—(1) the yarn running lengthwise in a woven fabric; (2) a group of yarns in long lengths and approximately parallel, put on beams or warp reels for further textile processing including weaving, knitting, twisting, dyeing, and so forth (ASTM D 3878).

warp surface, n—in a woven fabric where each warp yarn crosses over more than one fill yarn, the ply surface that shows the larger area of warp tows with respect to fill tows (ASTM D 3878).

warp surface nesting, v—process of laying up fabric plies in an alternating pattern where the warp surface is placed up and then for the next ply the warp surface is placed down, thus nesting the plies.

weave, v—interlaces, in a specific pattern, strands or yarns orientated in two or more directions in a planar textile process (ASTM D 3878).

woven fabric, n—a cloth constructed by a weaving process (ASTM D 3878).

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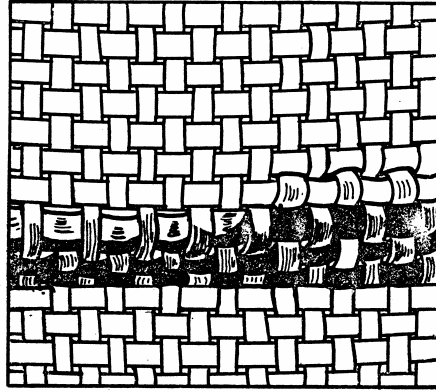
yarn, n—in fibrous composites, a continuous, ordered assembly of essentially parallel, collimated filaments, normally with twist, and either discontinuous or continuous filaments (ASTM D 3878).

Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

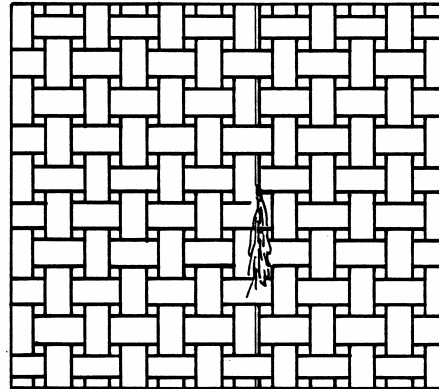
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FABRIC DEFECT DEFINITIONS

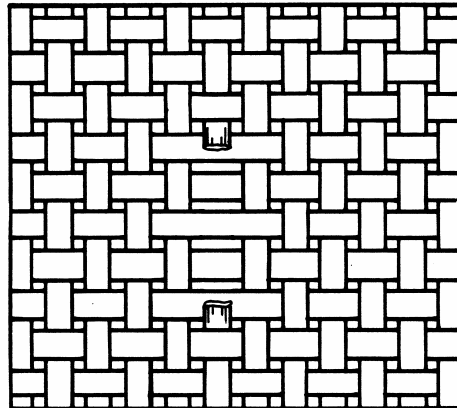
Baggy cloth, n — in a woven fabric, a cloth that will not lie flat on a cutting table (also, crooked cloth, ridgy cloth, wavy cloth).



Broken tracer yarn, n —in a woven fabric, a damaged tracer yarn.



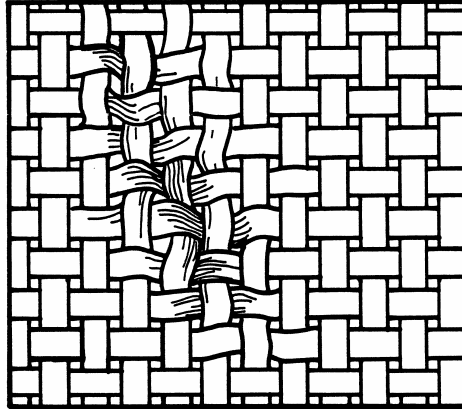
Broken warp or fill, n —in a woven fabric, a single warp or fill tow or yarn which has been severed or broken (also, broken pick, cut pick).



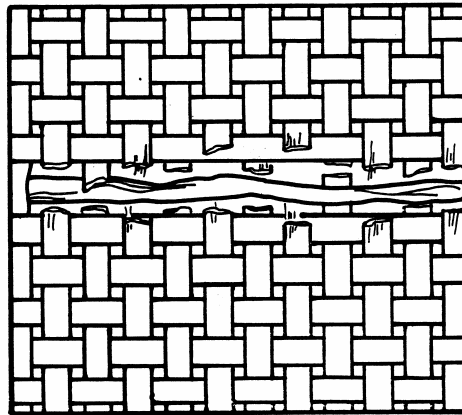
Unofficial Draft of Recommendation for Review Use Only - September 8, 2003

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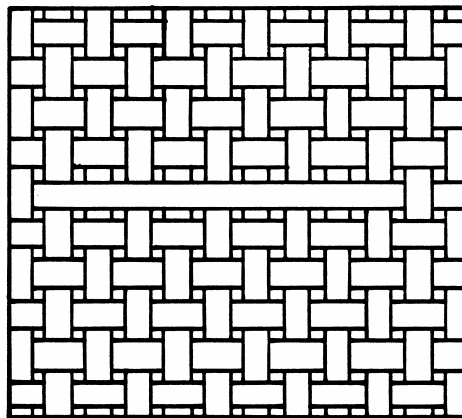
Crease or wrinkle, n —in a woven fabric, a break or line in a fabric usually caused by a sharp fold (also, mill wrincke, wrinkle mark).



Cut or tear, n —in a woven fabric, adjacent yarns or tows which have been cut or broken.



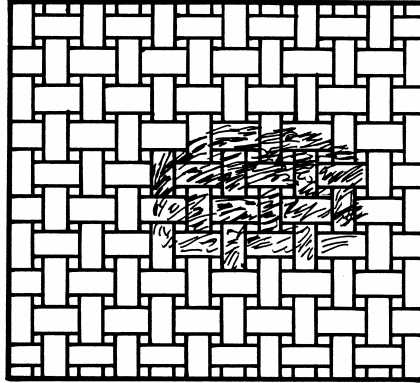
Float, n —in a woven fabric, a place in the fabric where a warp or filling yarn or tow extends unbound over the yarns or tows which it should be interlaced (also, harness skip, overshot, skip).



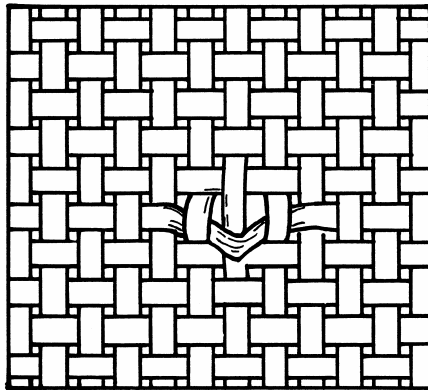
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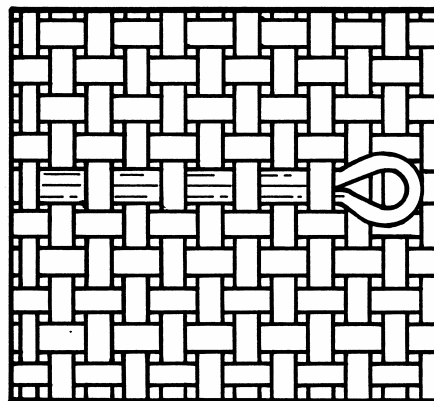
Fuzzball, n —in a woven fabric, loose or frayed fibers that have formed into a ball and are entwined either within the fabric or on the surface (also balling up, lint ball, snow ball).



Hang pick, n —in a woven fabric, a pick (fill yarn) caught on a warp yarn producing a triangular shaped hole in the fabric (also, hung filling yarn, hang shot).



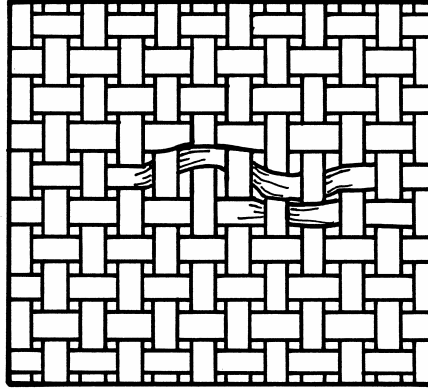
Kink, n —in a woven fabric, a yarn that has doubled back on itself to form a loop in the yarn (also, center loop, curl, snarl, kinky thread, looped yarn).



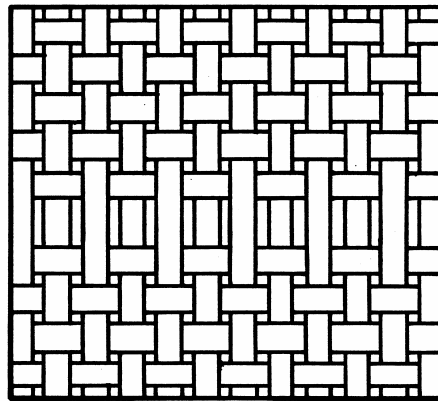
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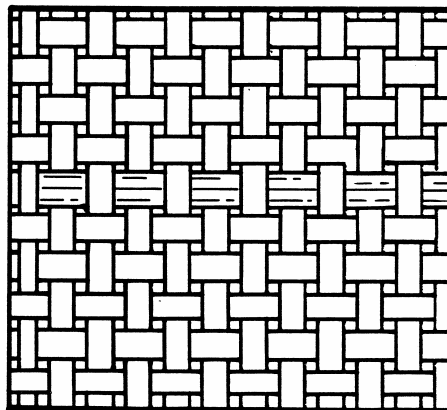
Loose pick, n —in a woven fabric, a filling yarn which is not flush with the surrounding fabric usually caused by insufficient tension (also, loose filling yarn, slack pick, slack filling).



Missing pick, n —in a woven fabric, a filling yarn or tow missing from all or a portion of the width of the fabric (also, missing filling yarn, filling run out).



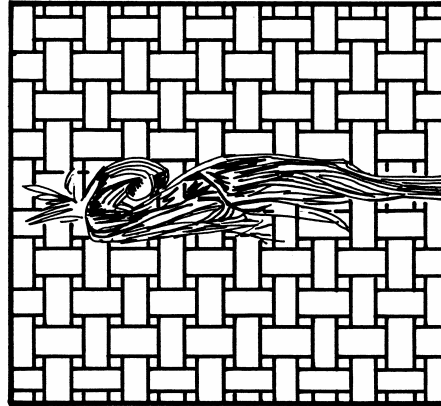
Mispick, n —in a woven fabric, a pick not properly interlaced which causes a break in the weave pattern (also, wrong pick).



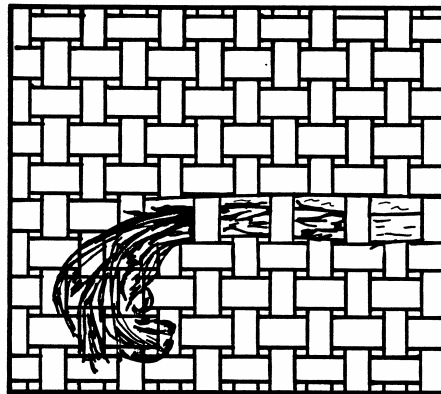
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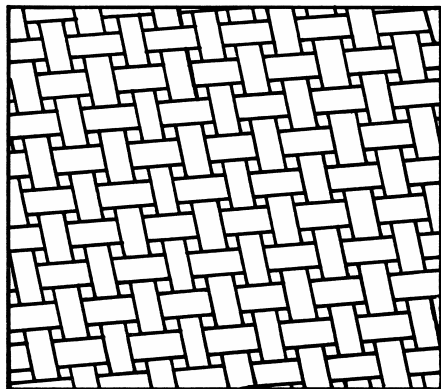
NEP, n —in a woven fabric, one or more fibers occurring in a tangled and unorganized mass (also, bird's nest, fly waste)



Pulled in filling, n —in a woven fabric, an extra filling yarn or tow dragged into the fabric along with a regular filling yarn or tow (also, double pick, dragged in, jerked in, lashed in, whipped in).



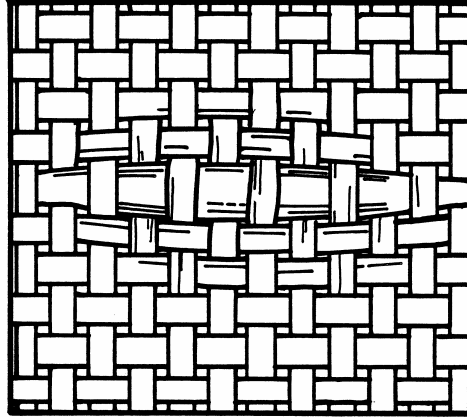
Skewing, n —in a woven fabric, a condition where the warp and fill yarns or tows are not at right angles to each other (also, bias filling).



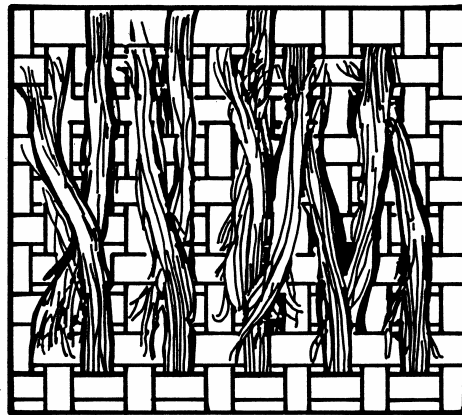
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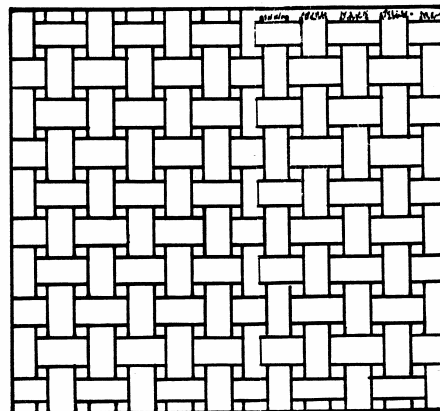
Slub, n —in a woven fabric, an abruptly thickened place in the yarn or tow (also, slug, bunch, lump, piece, slough off).



Smash, n —in a woven fabric, a place in the fabric where a number of warp or fill yarns or tows have been broken (also, break out, slam-off).



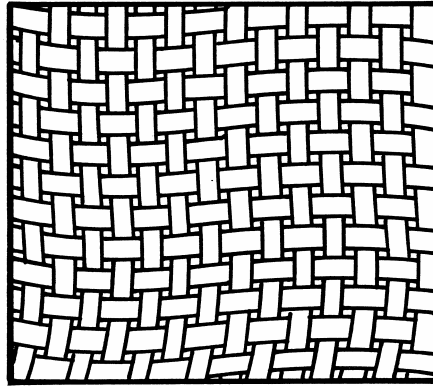
Splice, n —in a woven fabric, a portion of the fabric which has been cut and rejoined.



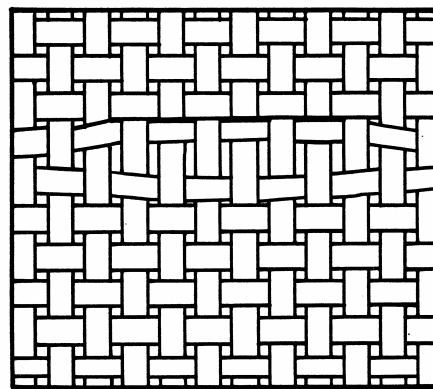
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Waviness, n —in a woven fabric, a condition where the warp or fill yarns or tows are in a sinusoidal or wave pattern (weave distortion).



Weave separation, n —in a woven fabric, an opening between yarns or tows due to improper yarn or tow alignment (also, crack, broken weave, open place, thin spot, shier).



Yarn splice, n —in a woven fabric, a yarn or tow which has been cut or broken and subsequently overlap spliced (also, tow splice).

