U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

CONSOLIDATED REPRINT
This consolidated reprint incorporates Change 1

Subject: QUALITY CONTROL FOR THE MANUFACTURE OF COMPOSITE STRUCTURES

Date: 6/26/89
Initiated by: AIR-200

AC No: 21-26
Change:

1. PURPOSE. This advisory circular (AC) provides information and guidance concerning an acceptable means, but not the only means, of demonstrating compliance with the requirements of Federal Aviation Regulations (FAR) Part 21, Certification Procedures for Products and Parts, regarding quality control (QC) systems for the manufacture of composite structures involving fiber reinforced materials, e.g., carbon (graphite), boron, aramid (Kevlar), and glass reinforced polymeric materials. This AC also provides guidance regarding the essential features of QC systems for composites as mentioned in AC 20-107, Composite Aircraft Structure. Consideration will be given to any other method of compliance the applicant elects to present to the Federal Aviation Administration (FAA).

2. RELATED FAR SECTIONS. Sections 21.125, 21.143, 21.303, and 21.605.

3. RELATED REFERENCE MATERIAL.

a AC 21-1, Production Certificates.

b. AC 21-6, Production Under Type Certificate Only.

c. AC 21-303.1, Certification Procedures for Products and Parts.

d. AC 20-107, Composite Aircraft Structure.

4. DEFINITIONS. Appendix 1 contains a list of terms commonly used in the manufacture of composite structures.

5. QUALITY CONTROL SYSTEM. A QC system that is established for composite fabrication should be basically similar to any other QC system that has been established to meet the requirements of FAR Part 21. For example, the QC system should include procedures that ensure the quality of incoming materials, control of in-process manufacturing methods, and testing performed to evaluate the end product for conformity to design requirements. The QC system should include standards to be used for nondestructive and destructive tests, visual inspection techniques during the fabrication process, and product final acceptance. The standards used to determine the acceptance or rejection of manufacturing-induced defects and damage should take into account the process and inspection capability. These standards should be based on approved data developed as a result of proof of structure evaluations conducted in accordance with referenced AC 20-107 and applicable FAR airworthiness standards. This AC addresses those areas of a QC system that may require further expansion to accommodate composite fabrication.

6. MATERIAL AND PROCESS SPECIFICATIONS. Unlike parts which use metallic materials in the manufacturing process, the material properties of a composite structure are manufactured into the structure as part of the fabrication process. Therefore, it is essential that material and process specifications used to produce composite structures, contain sufficient information to ensure that critical parameters in the fabrication process are identified to facilitate production and final inspection. Typical material and process specifications, respectively, should contain the following information:

a. Basic fiber, matrix and cured component properties, and required testing including type, number, and frequency of tests.

b. Conditions and requirements during the manufacturing process including fabrication method, specific tooling, environmental conditions, significant parameters during the cure cycle, inspection criteria at each operation, and storage and handling conditions throughout the process.

7. MATERIALS. The FAA requires that all drawings submitted for type design approval contain sufficient information or references to material specifications or other such data that clearly identify the materials and processes that are necessary to ensure production of like articles. When materials for a composite structure are produced in accordance with a proprietary process, or the composition of the materials is proprietary, the production approval holder or applicant may prefer to exclude this proprietary data from the type design submitted to the FAA. In these instances, the applicable type design drawings should refer to a specification which contains this proprietary information so that complete traceability to material composition is possible. These specifications will then be made available to the FAA for review and approval under an arrangement between the FAA and the production approval holder or applicant which will protect the proprietary nature of the product. Under FAR sections 21.33 and 21.157 (Inspection and tests), the FAA is authorized to review such data upon request. The following are recommendations regarding QC procedures, chemical characterization, testing techniques, and supplier control of purchased materials:

a. The production approval holder or applicant should have an incoming material acceptance plan that ensures conformity and uniformity of purchased composite materials to specifications identified in the approved type design. Copies of supplier laboratory test reports showing actual test results should accompany each batch of material received for review and approval; however, a material supplier's test report alone should not be considered adequate documentation to substantiate that materials satisfy all specification requirements. Samples of these materials should be taken on a batch-to-batch basis and tested to engineering and manufacturing requirements for conformity of physical, chemical, mechanical, and processing properties to verify the accuracy of suppliers' laboratory reports. Sample testing could be accomplished by the production approval holder or applicant at its production facilities or by an independent laboratory approved for such testing under the production approval holder's or applicant's QC system. Such testing may be decreased once confidence in the quality of products from a particular source has been established by the production approval holder.

b. Resin matrix systems: The production approval holder or applicant should require chemical characterization tests of the matrix material. A typical material specification sets upper and lower limits on the amount of reactive functional group per unit of material, as well as other design requirements such as viscosity, color, and moisture content. The characterization tests should identify and measure the amounts of individual constituents of the resin system such as the basic epoxide, curing agent, accelerator, hardener, etc., and the reacted constituents caused by resin mixing, storage, fiber impregnation, etc.

c. It is recommended that tests such as High Performance Liquid Chromatography (HPLC), Fourier Transform Infrared Spectroscopy (FTIS) and Gelation Permeation Characterization (GPC) for chemical characterization, and
* Differential Scanning Calorimeter (DSC) and Dynamic Rheological Analysis for thermal analysis and viscosity/flow/tack/gelation characteristics or their * equivalent be conducted, and resulting traces compared to the standards specified in the material specification. Experience has shown that one method of testing a particular sample may yield the same "fingerprint" as an acceptable sample within specification limits, yet the sample is rejectable when tested using another method. Therefore, it is likely that more than one type of characterization test may be necessary, since all chemical ingredients affecting a given composite's performance may not be quantifiable by a single test method. Accordingly, the production approval holder's or applicant's material specification must define the combinations of acceptable test techniques and test results which adequately demonstrate the material's conformity and process capability. Techniques for chemical characterization are not universal but are strongly dependent upon the resin formulation. Therefore, test methods adapted to each material should be developed considering the sensitivity of the method to detect deviations in formulation.

d. Reinforcement Fibers: The production approval holder or applicant should establish procedures in coordination with its material suppliers to control the quality of incoming fibrous materials such as roving, tow, and woven fabric. Testing for mechanical properties is the primary method used for fiber characterization. This method is also used to qualify or screen continuous filaments since tensile strength and modulus are sensitive indicators of change in composite material mechanical response. In addition, a means should be developed to control the quality of fiber surface treatment, sizing, etc.

e. Preimpregnated Material (Prepreg): In applications where prepreg tape, fabric, or roving are primary materials of composite structures, it is necessary to test for the chemical, physical, and mechanical fiber and matrix dominated properties identified in the applicable prepreg material specification. Quality control procedures previously described for resins and fibers may be used to control the quality of incoming prepreg materials. Chemical characterization should be performed on resin extracted from the prepeg material to be used for production, where applicable.

f. Adhesives: The QC procedures recommended for structural adhesives are similar to those for resin matrix systems; that is, the procedures should provide assurance that each incoming batch conforms to the chemical, physical, and mechanical properties identified in the material specification.

8. MANUFACTURING CONTROLS. The manufacture of acceptable and reliable composite structures is dependent on the type of process controls employed during the fabrication cycle. If all pertinent process variables are adequately controlled, there is added assurance that the parts and structures produced will be acceptable. Quality control should, therefore, establish and implement a plan which verifies that: (1) the parameters affecting material integrity and process capability are operating under controlled conditions; and (2) individual items, batches, or lots conform to specified quality standards. To ensure that QC objectives have been met, process procedures should clearly define specific materials, tooling, equipment, cure cycle parameters, quality standards, operator qualifications, storage and handling requirements, traceability records, and any other special requirements.

a. General: The following are manufacturing process controls that should be included in a manufacturer's QC system:

(1) The production approval holder or applicant should develop integrated quality and production control procedures for operations that define product configuration, selection of materials, tooling and facility equipment, calibration, sequence of fabrication operations, critical in-process parameters and processing tolerances, and conformity to quality standards.

(2) Environmental parameters (temperature, humidity, chemical contamination) should be defined and controlled, as required, where composite parts and structures will be produced; in particular, cutting, layup, and bonding areas.

(a) Unless otherwise validated for the material system in use, the area should be temperature and humidity controlled such that the minimum temperature is 65 degrees F with a corresponding relative humidity not greater than 63 percent and the maximum temperature is 75 degrees F with a corresponding relative humidity not greater than 46 percent. The temperature and relative humidity values between the minimum and maximum acceptable values listed above should form a straight line relationship. Procedures for QC to verify and record temperature and humidity conditions should be established to ensure environmental stability.

(b) Contamination restrictions in environmentally controlled areas should prohibit the use of uncontrolled sprays, exposure to dust, handling contamination, fumes, oily vapors, and the presence of other particulate or chemical matter which may adversely affect the manufacturing process, e.g., release agents or material containing uncured silicon should not be permitted. Also, conditions under which operators may handle materials should be defined.

(c) Layup and clean room air filtration and pressurization systems should be capable of providing a slight positive overpressure.

(3) The production approval holder or applicant should establish a program to train and/or qualify operators, as appropriate. This program should measure operator performance to production standards and provide for requalification as necessary.

(4) Prior to the start of production, manufacturing processes should be qualified by demonstrating that the combination of materials, tooling, equipment, procedures, and other controls making up the process will produce parts having consistent material properties that conform to design requirements. As part of the process qualification, destructive and/or nondestructive inspection (NDI) of appropriate tool proofing specimens should be conducted to determine conformity to specified design requirements. Destructive tests of specimens verify conformity to the specified physical and mechanical properties. Nondestructive inspection of specimens verify that discrepancies caused by fabrication procedures remain within allowable limits.

(5) Once the manufacturing process has been established it should not be changed unless a comparability study and necessary testing of differences has been completed. In addition, processes should be reviewed and requalified if necessary, whenever any significant changes are made to the process such as sources of material, cure cycle, equipment controls, or autoclave loading patterns and tool design changes. Process capability should be demonstrated by inspection and testing as necessary to determine conformity to design requirements.

(6) In order to control adhesives and matrix formulation when resin is mixed during part manufacture, documented procedures should be employed to cover the identity of required constituents, respective quantities, and mixing methods and techniques. Tests should be performed on each resin mix to ensure conformity to specification requirements and should including sampling methods for chemical testing. The mixing process performed under these procedures should ensure that the sequence of additions and mixing techniques are followed, proper chemical reactions are achieved, aeration of the mix is prevented, and the mixing equipment is properly cleaned.

(7) After initial process qualification, testing (process control panels, etc,) for conformity to design requirements should continue on an appropriate frequency to ensure that the manufacturing process, materials, and associated tooling continue to operate in a state of control and produce conforming parts.

(8) For accepting or rejecting cured structures, NDI equipment and procedures should be used to evaluate specified material defects resulting from fabrication and assembly operations. The NDI technique used for inspection should have the sensitivity to detect maximum allowable discrepancy type and size in the part.

(9) Specifications used by QC should define allowable limits for each discrepancy such as: adhesive voids, porosity, delaminations, damaged core, core node bond separations, potting cracks, short core, lack of adhesive, etc.

b. Fabrication of Parts: The following are manufacturing controls unique to laminate and wet layup, filament winding, and pultrusion that a QC system should include:

(1) Laminate Layup.

(a) Standards and methods should be established to ensure proper orientation, stacking, and nesting of the plies during layup operations. The programs that control tape head and table motions, and tape feed and tape stacking, should be approved by QC. Standards should be established for such in-process variables as tape orientation, gaps, and overlap.

(b) For automatic and hand layup methods, controls should be established for in-process variables that affect the cured laminate quality: e.g., resin content, ply compaction, laminate density, porosity, which may result from debulking, pre-bleeding, and bagging operations.

(2) Wet Layup.

(a) Procedures should be established to ensure correct material selection, orientation and stacking, or nesting of the plies during wet layup operations.

(b) Procedures should be established to control in-process variables such as resin content, aeration and air pockets.

(3) Filament Winding.

(a) Preimpregnated filaments for dry winding should be stored and handled according to procedures similar to those for other prepreg materials to ensure that the material's original properties have been maintained, especially material flow and tack to ensure proper bonding for subsequent winding operations.

(b) Procedures should be established to ensure that the working life of the resin system exceeds the anticipated winding time and to ensure that gelation does not take place before completion of winding.

(c) Standards and methods should be established to control machine-dominant parameters such as feed rate, feeder arm and mandrel motions, mandrel dwell angle, number of circuits per pattern, total number of circuits for complete coverage, number of plies per layer, winding angle, fiber tension and alignment, band-width, and fiber/resin ratio.

(d) Procedures should be established to control process variables during the winding operation such as resin viscosity, fiber wetting, fiber tension, fiber band-width and alignment, air entrapment, degree of compaction, and fiber damage.

(4) Pultrusion.

(a) Procedures should be established to control pultrusion start-up, steady state, and shutdown operations including disposition of material produced during start-up and shutdown operations.

(b) Process procedures should define limits for important process parameters that determine product quality such as line speed, die temperature profile for the particular operating conditions and resin system, clamping pull-through lead, resin temperature, die input temperature, material orientation for preform operation, and material tension.

c. Assembly of Components: The following are manufacturing controls unique to the assembly of fabricated composite parts and structures that a manufacture's QC system should include:

(1) Sandwich Construction.

(a) Core material should be inspected for cell damage, crush, correct length and thickness, and should be properly cleaned and protected against contamination.

(b) Cured laminates should be inspected for dimensional conformity. Faying surfaces should be properly cleaned and protected from contamination before subsequent assembly and bonding operations.

(c) Uncured laminates used for subsequent co-curing operations should be properly protected and stored to prevent contamination and to retard chemical advancement.

(d) Procedures should be established to control those critical parameters of the assembly process that affect the integrity and uniformity of the end item such as: bondline thickness, bondline pressure and temperature distribution, and part "floating" within the tooling when the resin or adhesive is in the liquid state during cure cycle (bagging and tooling requirements).

(e) The performance of the sandwich construction process should be evaluated for each autoclave or oven load by testing specimens of the sandwich construction. Test specimens should be made from specially prepared panels that have been fabricated from the same materials, and using the same production methods, environmental working conditions, and cure cycle as the production parts they represent. When co-curing of laminates is required to fabricate an assembly, a solid laminate process control panel should also be prepared for specimen testing. Cutouts or cutoffs from production parts may also be used providing they are representative of the production part configuration.

(2) Curing Process.

(a) Procedures should be developed to control the critical parameters of the process, namely chemical reactions of the resin and

consolidation of the plies to achieve manufacturing consistency and quality parts which are of uniform consolidation, within void tolerances, and of correct fiber volume.

(b) Procedures should identify the equipment and materials which will be used to bag the uncured laminate or sandwich construction. This will ensure the proper control of resin flow, volatile content, and ply consolidation during the cure cycle since such materials (e.g., peel plies) may alter properties of the structure.

(c) Procedures should define the relationship of the variables (time, temperature, pressure) in the cure cycle (and post-cure cycles) which control compaction and consolidation and cure reaction. These controls should include the acceptable limits of variables during the cure cycle and action to be taken when such limits are exceeded; e.g., submit cured parts to QC (MRB) for evaluation and disposition.

(d) Procedures should be established to ensure that, when the autoclave or oven is loaded with uncured parts having different configurations, materials, bagging configurations, and tooling heat-up characteristics, each part is properly cured.

(e) Procedures should describe actions to be taken when heating, cooling, vacuum, or pressure interruptions are experienced during autoclave/oven cure; e.g., submit to QC (MRB) for disposition.

(f) The performance of the curing process should be evaluated for each autoclave or oven load by testing specimens representative of the composite structure. Test specimens should be fabricated from the same materials, and using the same production methods, environmental working conditions, and cure cycle as the production parts they represent. Cutouts or cutoffs from production parts may also be used provided that they are representative of the production part configuration. The use of validated direct-cure monitoring techniques may also be used if found directly applicable.

(3) Secondary Bonding.

(a) Cleaning procedures for surfaces to be bonded together should specify the chemicals and abrasive to be used on faying surfaces. Standards for determining properly cleaned surfaces and methods for protecting clean surfaces from contamination (including peel plies) should be available at the place of fabrication.

(b) Quality control standards should establish adhesive bondline thickness and pressure to be applied along the bondline during the cure cycle.

(c) Tool proofing procedures should demonstrate the capability of the tooling to maintain correct bondline thickness, equal pressure distribution along the bondline, and properly cured adhesive.

(d) Before the application of adhesives, the production parts should be preassembled and inspected in the tooling to determine that the expected bondline thickness and pressure distribution on the bondline will be within design limits. Shims required to fill bonding gaps should only be used in accordance with an approved QC procedure.

(f) Methods for applying adhesive films should preclude the formation of defects such as voids due to air entrapment, bridging, and gaps between adjacent films.

(g) Standards for the application of adhesives (e.g., pastes) should require a complete and even coating of adhesive with wetting of surfaces and exclusion of air in the adhesive.

(h) Controls for high temperature curing adhesives should be recorded and should include heat-up and cool-down rates, cure time and temperature, vacuum, and pressure parameters.

(i) Controls for room temperature curing of adhesives should specify:

1. Minimum and maximum time between mixing of adhesive and mating, clamping, or tooling of parts into final configuration.

2. Minimum time at particular temperatures to achieve adequate handling strength for subsequent processing, and the conditions (time and temperature) for achieving full cure.

(j) The conditions under which bonded structures may be subjected to a subsequent curing operation should specify:

1. Maximum allowable temperature.

2. Maximum number of subsequent curing cycles.

3. Procedures to prevent bond line separation, blistering, delaminations, etc., of the structure when subsequent curing temperatures approach that of the previous cure temperature.

(4) Other Molding Methods. For techniques such as resin injection, compression, and transfer molding processes, specifications should define the limits for all critical process parameters that determine product quality. Such parameters are, for example, resin mix, feed-rate and temperature, mold temperature, and back pressure or vacuum. In addition, molding process specifications should identify the timing and sequence of automatic operations. These critical parameters should be defined in the process specification and identified in the associated operation sheets.

9. FINAL ACCEPTANCE.

a. Final acceptance procedures and quality control standards should provide added assurance that the completed structure meets its functional and design requirements.

b. Final acceptance records should provide evidence that the following significant production and QC activities, specifically designed to assure the quality of composite structures, have been completed:

(1) Incoming material acceptance.

(2) In-process fabrication and assembly controls.

(3) Maintenance of tooling and facility equipment.

(4) Calibration of inspection and laboratory test equipment.

(5) Inspection acceptance of functional characteristics at detail and assembly levels.

(6) Nondestructive inspection acceptance.

(7) Configuration control.

(8) Material Review Board disposition.

c. Nondestructive Inspection (NDI). There are several NDI techniques used in detecting discrepancies in composite structures; however, the most commonly used techniques are visual, audio sonic (coin tapping), radiography, ultrasonics, and mechanical impedance testing.

(1) Visual. Visual inspection is the most widely used NDI method. Discrepancies that can usually be observed include: Discoloration (due to overheating), foreign matter, crazing, cracks, scratches, blisters, dents, orange peeling, pitting, air bubbles, porosity, resin rich and resin poor areas, and surface wrinkles. Reflected light is used for observing surface irregularities and other defects, while transmitted light (assuming both surfaces are accessible and the material is translucent) helps to reveal discrepancies within the specimen.

(2) Audio Sonic. Sonic testing makes use of frequencies in the audible range, from about 10 Hz. to 20 Hz. "Coin tapping" is a common technique used for detecting delaminations. When tapping any area, a coin or other suitable object may be used. When this technique is used, a clear, sharp, ringing sound is indicative of a well-bonded solid structure, while a dull sound or thud indicates a delamination. Automated sonic devices that produce a consistent tapping rate and force are available and can be used for this test.

(3) Radiography. Radiography is generally used in composite fabrication for the detection of bondline defects. In addition, radiography may also be used to inspect for the presence of foreign material, adhesive voids, location of internal parts, honeycomb core defects, mislocated or misdrilled holes, poor fit-up, thick bonds, fiber discontinuities, poor tape layup, or lack of adhesive fillets. In the case of carbon/epoxy,

glass/epoxy, and aramid (kevlar)/epoxy, the resolution differences are low and defect detection becomes difficult due to the low contrast in the film. Radiography is usually performed through the thickness of the product for detection of anomalies.

(4) Ultrasonic. In this technique, the attenuation of sound wave energy is used for flaw detection. Two methods of ultrasonic techniques are available: through transmission, and pulse echo. Three methods of recording and display generally used are: A-scan, B-scan, and C-scan. An A-scan is an amplitude versus time display for a specific point on the part inspected. It generally lends itself to the contact pulse-echo methods. B-scans display a long cross-sectional view of the part under test and show discovered discrepancies. C-scans display the effect in a plane view usually on a paper that is rolled across the printer bar. C-scans provide no defect depth or orientation information; however, they are capable of detecting defects in the magnitude of 0.01 square inch. Ultrasonic techniques can generally be used to detect porosity, laminar inclusions, delaminations, and fastener hole flaws. The disadvantage of the ultrasonic method is the inability of the method to distinguish between voids and small delaminations since the attenuation characteristics of the two flaws are identical.

(5) Mechanical Impedance. These are methods in which structural response to strain excitation is measured to detect delaminated areas or disbonds. The sensitivity of this method decreases with increasing structural flexibility or discrepancy depth.

e. Controlling Nondestructive Inspection Techniques. In order for nondestructive inspection techniques to be effective, repeatable, and reliable, certain controls are required. These controls should be approved by the production approval holder or applicant. The following controls are recommended:

(1) A QC approved NDI specification and procedure to be used.

(2) Periodic qualification of personnel conducting the inspection technique. This would normally include regularly scheduled vision examinations and inspection of a standard with a known defect.

(3) Establishment of realistic acceptance standards for use by in-process and final inspection personnel.

(4) Calibration of equipment used in the inspection technique including any QC standards with known defects that may be used. The calibration system should provide for periodic requalification of any such equipment at specific time intervals.

(5) An internal audit program for validating the effectiveness of the NDI program.

10. STORAGE AND HANDLING. Composite materials and adhesives may be subject to deterioration if not stored under proper environmental conditions. Storing these materials at low temperatures (e.g., 0 degrees) in freezers retards partial curing of polymer materials and extends their shelf life. Therefore, it is essential that composite material handling and storage procedures are established, followed, and subjected to periodic independent auditing to ensure continued conformity to the materials' chemical, physical, and specified mechanical properties.

a. Uncured Material Storage. Because composite structures are made from polymeric materials (resins, prepregs, adhesives), procedures which ensure that these materials are acceptable at the time of use in the manufacturing area should be established.

(1) Material suppliers should provide documents with each shipment that identify the environmental conditions under which the purchased material was previously stored and shipped, i.e., temperature and humidity conditions and accumulated time in and out of refrigeration.

(2) Material should be stored under environmentally controlled conditions and monitored for compliance with specification requirements. Historical records for all stored material should be maintained, i.e., periodic recording of storage conditions, time in and out of storage, etc.

(3) Materials are generally stored in sealed plastic bags or containers to prevent moisture from condensing on the cold material and migrating into the polymer when it is removed from the freezer and allowed to warm to ambient temperature. The time interval from when the material is removed from the freezer to the time when the material bag or container may be opened is generally empirically determined. Physical characteristics such as material roll, stacking height thickness, or material type (e.g., tape vs broadgoods) must be considered when determining this time interval. Therefore, the production approval holder or applicant should establish the minimum time interval between removal of material from its freezer and its use to prevent premature removal of materials from storage bags or containers before material temperature stabilization occurs.

b. Handling of Cured Parts. Composite materials and structures require specific handling procedures to protect them from damage during production and storage. Accordingly, procedures for handling and storing composite materials and structures should be established and followed. These procedures should be an integral part of the manufactures' QC system and should provide protection during receiving inspection, material storage, material handling, manufacturing process, cure cycle, final inspection, and final product storage.

William J. Sullivan, Acting
Director, Aircraft Certification
Service

APPENDIX 1. DEFINITIONS

Adhesive. A substance capable of holding two materials together by surface attachment. Structural adhesives produce attachments capable of transmitting significant structural loads.

Chemical Characterization. A series of chemical examinations to identify and/or quantify the critical constituents of a material and thereby establish a fingerprint of the material which can be used as a basis for future comparison.

Composite. A material containing two or more distinct materials (fillers, reinforcing materials, and compatible plastic resin) designed to exhibit specific performance properties.

Cure. To change the physical properties of a material by chemical reaction, by the action of heat and catalysts, alone or in combination, with or without pressure.

Delamination. The separation of layers in a laminate through failure of the matrix.

Fiber. A single homogeneous strand of material used as a principal constituent in advanced composite materials because of its high axial strength and modulus.

Filament. Fiber of extreme length, used in yarns and other compositions.

Filament Winding. Process in which resin impregnated strands are applied over a rotating mandrel to produce high strength, reinforced cylindrical shapes.

Laminate. A product obtained by bonding together two or more laminae of the same material or of different materials.

Layup. A fabrication process involving the placement of successive layers of materials. Also, the arranged set of laminae.

Gelation. The formation of a gel, which is a jelly like semi solid material state formed by a network of solid aggregates retaining a liquid phase.

Hand Layup. Method of positioning successive layers of reinforcement material (which may or may not be preimpregnated with resin) on a mold by hand. Resin is used to impregnate or coat the reinforcement material. The resin is then cured to permanently fix the formed shape.

Matrix. The essentially homogeneous material in which the fibers or filaments of a composite material are imbedded.

Polymer. A high molecular weight organic material (natural or synthetic) formed by linking together a large number of repeating chemical units (monomers). When two or more monomers are involved, the product is called a copolymer.

Preimpregnated Material (Prepreg). A term generally used to describe fibrous material which has been preimpregnated with a liquid resin and cured to the B-stage.

Pultrusion. A process by which continuous lengths of fiber are pulled through a pre-shaper of the desired cross-section and on through a heating source from which they emerge fully cured.

Resin. Any of the various solid or semi-solid amorphous natural or synthetic organic substances with indefinite and usually high molecular weights and no sharp melting point.

Reinforcement Fibers. Materials such as roving, tow, and woven fabric used to produce a structural material superior to the base resin.

Sandwich Construction. A structural panel concept consisting in its simplest form of two relatively thin, parallel sheets (face sheets) of structural material bonded to, and separated by, a relatively thick, lightweight core.

Wet layup. A process in which dry fabric is laid into a mold and impregnated with liquid resin as part of the layup process.