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Standard Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation[1]

1. Scope

1.1 This guide provides guidelines to facilitate the proper preparation of laminates and test specimens from fiber-reinforced organic matrix composite prepregs. The scope is limited to organic matrices and fiber reinforcement in unidirectional (tape) or orthagonal weave patterns. Other forms may require deviations from these general guidelines. Other processing techniques for test coupon preparation, for example, pultrusion, filament winding and resin-transfer molding, are not addressed.

1.2 Specimen preparation is modeled as an 8-step process that is presented in Fig. 1 and Section 8. Laminate consolidation techniques are assumed to be by press or autoclave. This practice assumes that the materials are properly handled by the test facility to meet the requirements specified by the material supplier(s) or specification, or both. Identification and information gathering guidelines are modeled after Guide E1309. Test specimens shall be directly traceable to material used as designated in Guide E1434. Proper test specimen identification also includes designation of process equipment, process steps, and any irregularities identified during processing.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C297/C297M Test Method for Flatwise Tensile Strength of Sandwich Constructions
D123 Terminology Relating to Textiles
D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D2734 Test Methods for Void Content of Reinforced Plastics
D3163 Test Method for Determining Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading
D3171 Test Methods for Constituent Content of Composite Materials
D3531 Test Method for Resin Flow of Carbon Fiber-Epoxy Prepreg
D3878 Terminology for Composite Materials
D3990 Terminology Relating to Fabric Defects
D4850 Terminology Relating to Fabrics and Fabric Test Methods
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
E1237 Guide for Installing Bonded Resistance Strain Gages
E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases (Withdrawn 2015)[3]
E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases (Withdrawn 2015)[3]

3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. Terminology D883 defines terms relating to plastics. Terminology D123 defines textile related terms. Terminology D4850 defines terms

[1] This guide is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.04 on Lamina and Laminate Test Methods.

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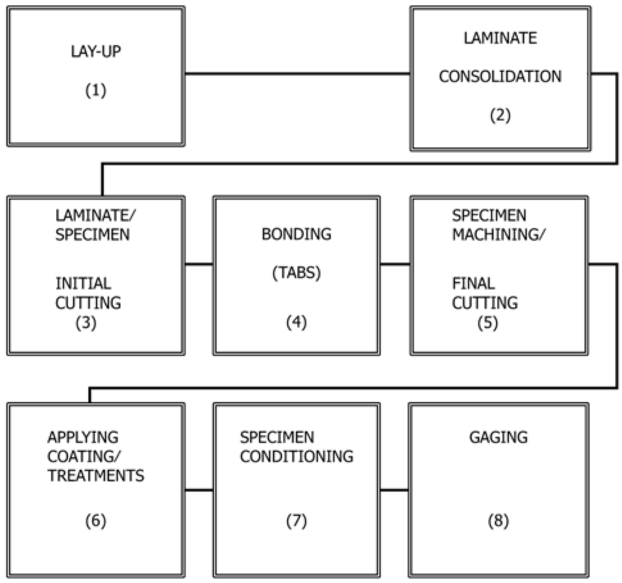
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.



NOTE 1—Material identification is mandatory. Continuous traceability of specimens is required throughout the process.

Process checks (Appendix X4) may be done at the end of each step to verify that the step was performed to give a laminate or specimen of satisfactory quality.

Steps 4 and 5 may be interchanged. For aramid fibers, step 5 routinely precedes step 4.

Steps 6, 7 and 8 may be interchanged.

FIG. 1 8 Step Mechanical Test Data Model

relating to fabric. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

3.2 *Description of Trems Used in This Standard*—The terms used in this guide may conflict with general usage. There is not yet an established consensus concerning the use of these terms. The following descriptions are intended only for use in this guide.

3.2.1 *bag, v*—the process of enclosing the ply layers within a flexible container. See *lay-up.*

3.2.2 *base plate, n*—a flat plate on which a laminate is laid up [usually made of aluminum and 6 mm [0.25 in.] or thicker with a flatness requirement of 0.05 mm [0.002 in.] or less].

3.2.3 *breather string, n*—a glass string connected from the laminate to a breather in the autoclave bag. It is used as a degassing aid; providing a path for gasses to be transferred from the laminate.

3.2.4 *caul plate, n*—a flat plate used to provide a flat surface to the top of the laminate during laminate consolidation [usually made of aluminum and 3 mm [0.125 in.] thick or thicker with a flatness requirement of 0.05 mm [0.002 in.] or less].

3.2.5 *cloth, n*—a piece of textile fabric containing woven reinforcement without a load transferring matrix.

3.2.6 *dam, n*—a solid material (such as silicone rubber, steel or aluminum) used in the autoclave bag to contain the matrix material within defined boundaries during laminate consolidation.

3.2.7 *debulk, v*—process of decreasing voids between lamina before laminate consolidation through use of vacuum or by mechanical means. Laminae can be debulked at ambient or elevated temperatures.

3.2.8 *doubler, n*—an unbonded tab used to hold the laminate specimen in a grip or fixture. See *tab.*

3.2.9 *fiber washing, n*—the tendency of fibers to change orientation due to resin flow from the original lay-up direction. Fiber washing may occur during the laminate consolidation process mainly at the sides of a laminate.

3.2.10 *fill, n*—(*1*) Fiber inserted by the shuttle during weaving also designated as filling. See Terminology D123. (*2*) The direction of fiber running perpendicular to the warp fibers.

3.2.11 *flip/flop, v*—the process of alternating plies through an angle orientation of 180° during laminate lay-up. This practice is commonly used if material of the same width as the laminate has a reoccurring flaw. The process changes the location of the flaw so that it does not unduly affect the laminate structure.

3.2.12 *flaw, n*—a material defect, typically occurring in the discrete fiber reinforcement, but possible in the matrix.

3.2.13 *flow, n*—the movement of uncured matrix under pressure during laminate consolidation.

3.2.14 *harness, n*—a weaving designation of how many fill fibers a warp float crosses in a satin weave. Typical weaves are 5-Harness and 8-Harness.

3.2.15 *joint, n*—a location where two edges of prepreg meet. Two common types of joints used in lay-up are a butt joint (where 2 plies are aligned edge to edge) and an overlap joint (where the edge of each ply is overlapped some specified width with another ply).

3.2.16 *lay-up, n*—the finished product of ply stacking and bagging operations.

3.2.17 *matrix, n*—the continuous constituent of a composite material.

3.2.18 *mold, n*—the support structure that holds the laminate or lay-up during the laminate consolidation process.

3.2.19 *non-perforated TFE, n*—a non-porous tetrafluoroethylene film.

3.2.20 *panel, n*—a uniformly contoured composite laminate, typically flat.

3.2.21 *peel ply, n*—a cloth with release capabilities. Usually used in conjunction with laminates requiring secondary bonding.

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

3.2.23 *ply, n*—a single layer of prepreg used in lay-up.

3.2.24 *press, n*—equipment consisting of heated, flat [usually within a tolerance of 0.3 mm [0.01 in.] or less] platens that supply pressure against a surface.

3.2.25 *satin, adj*—a weave pattern in which warp floats pass over several yarns before crossing under a single yarn. It is characterized by parallel fibers and no diagonal pattern.

3.2.26 *sealant, n*—a high temperature material used to seal the edges of a vacuum bag to the base plate during a consolidation or debulking cycle.

3.2.27 *staggered, adj*—the description of ply placement where the joints are not positioned in the same inplane location through some specified thickness of the laminate.

3.2.28 *tab, n*—a piece of material used to hold the laminate specimen in a grip or fixture for testing so that the laminate is not damaged, and is adequately supported. It is bonded to the specimen. An unbonded tab is termed a doubler.

3.2.29 *TFE coated cloth, n*—a cloth coated with a tetrafluoroethylene coating. This is used in the bagging process to allow gases or excess matrix material to escape during the laminate consolidation. It differs from perforated TFE in that it gives a textured surface to the laminate.

3.2.30 *traveler, n*—a coupon with the same nominal thickness and 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.

3.2.31 *vacuum bag, n*—a low gas permeable material used to enclose and seal the laminate during a consolidation or debulking cycle.

3.2.32 *vacuum couple, n*—the mechanical connection that seals the vacuum source to the lay-up during a consolidation or debulking cycle.

3.2.33 *warp surface, n*—the ply surface which shows the larger area of warp tows with respect to filling tows. Fabrics where both surfaces show an equal area of warp tows with respect to filling tows do not have a warp surface.

3.2.34 *warp nested, n*—warp plies alternated in the pattern warp surface up, warp surface down.

4. Summary of Guide

4.1 This guide describes the general process flow for preparation of flat composite panels and provides specific recommended techniques that are generally suitable to laminated fibrous organic polymer matrix composites for each of the process steps to test specimen fabrication.

4.2 The specific techniques included in this guide are the minimum recommended for common composite material systems as represented in the scope of this guide. For a given application other techniques may need to be added or substituted for those described by this guide.

5. Significance and Use

5.1 The techniques described in this guide, if properly used in conjunction with a knowledge of behavior of particular material systems, will aid in the proper preparation of consolidated laminates for mechanical property testing.

5.2 The techniques described are recommended to facilitate the consistent production of satisfactory test specimens by minimizing uncontrolled processing variance during specimen fabrication.

5.3 Steps 3 through 8 of the 8-step process may not be required for particular specimen or test types. If the specimen or test does not require a given step in the process of specimen fabrication, that particular step may be skipped.

5.4 A test specimen represents a simplification of the structural part. The test specimen's value lies in the ability of several sites to be able to test the specimen using standard techniques. Test data may not show identical properties to those obtained in a large structure, but a correlation can be made between test results and part performance. This may be due, in part, to the difficulty of creating a processing environment for test specimens that identically duplicates that of larger scale processes.

5.5 Tolerances are guidelines based on current lab practices. This guide does not attempt to give detailed instructions due to the variety of possible panels and specimens that could be made. The tolerances should be used as a starting reference from which refinements can be made.

6. Interferences

6.1 Specimen preparation practices should reflect those used on an applicable part, to the greatest extent practical. However, due to scaling effects, processing requirements for test laminates may not exactly duplicate the processes used in larger scale components. The user should attempt to understand and control those critical process parameters that may produce a difference in material response between the test coupon and the structure. Critical process parameters are material, application, and process dependent and are beyond the scope of this guide.

6.2 Laminate quality is directly related to the prevention of contamination during lay-up and processing.

7. Apparatus and Materials

NOTE 1—This section provides a listing of apparatus and material items that have been shown to be acceptable. The list is not meant to be all inclusive, but may be helpful to novice users.

7.1 *Equipment:*

7.1.1 *Lay-up Environment/Tools:*

7.1.1.1 *Tables*—Tables should be 1 m [3 ft] in height (or adjustable tables) with ample area for lay-up. The table should be accessible from all sides. The table surface should have a fully supported metal or wood undersurface. The table surface should be of (*1*) safety glass with edges protected by aluminum angle plate or (*2*) A toughened transparent plastic sheet.

7.1.1.2 *Convenient accessibility of lay-up materials*—Wall racks hold bulk cloth, TFE, and other expendable bagging materials. These racks typically consist of a steel rod which can hold a roll of material. The rods should be able to accommodate material rolls up to 1.5 m [60 in.] wide. The spacing between racks should be a minimum of 0.4 m [15 in.] spacing between rods with the bottom rod being no closer than 0.6 m [25 in.] to the floor and the top rod being no higher than 2.2 m [85 in.] from the floor. Cabinets and drawers hold other lay-up materials such as sealants, spare tape, vacuum couples, hoses, caul plates, thermocouple wire, and so forth. These should be compartmentalized for easy access.

7.1.1.3 *Vacuum Supply*—Overhead piping for vacuum with a flexible hose reel over the table has been found to be satisfactory. The vacuum pump should be located within 45 m [150 ft] of the lay-up site.

7.1.1.4 *Cleanliness and Airborne particulates*—Controlling dust in air, on surfaces and other contamination (such as from skin or material contact) should be a priority. Adequate particulate air filters, gloves, floor sweeping compound, and wiping cloths should be present to help minimize contamination.

7.1.2 *Tool Plate*—Plates of aluminum or steel have been found to be satisfactory. The plate should have a minimum thickness of 6 mm [0.25 in.] [base plate] or 3 mm [0.125 in.] thick [caul plate] with a flatness tolerance of 0.05 mm [0.002 in.]. The surface should be coated with a mold release, except around the edges where sealant is to be applied.

7.1.3 *Cutting Apparatus*—A cutting apparatus may range from a simple retractable knife blade to die or ultrasonic or laser devices. Whenever there is a cutting surface, this must be evaluated for wear. If the blade cuts without pulling the material the blade is adequately sharp and need not be changed.

7.1.4 *Vacuum Source*—The vacuum capacity at the lay-up site shall be at least 75 kPa [22 in. Hg] with a drop of no more than 3.5 kPa [1 in. Hg] in 5 min. Pump requirements are dependent on autoclave size and distance of pump from the lay-up. Standard oil type pumps have proven satisfactory.

7.1.5 *Debulking:*

7.1.5.1 *Bag*—Two types have been shown to be satisfactory: (*1*) commercially available rubber bag with a vacuum source or (*2*) an internally built bag made from a tool plate, vacuum coupling and vacuum bag materials.

7.1.5.2 A wooden or hard plastic roller or spatula may be used for mechanical debulking.

7.1.6 *Vacuum Ports*—Hose couplings that provide a flat surface against the breather material are preferred. The port is connected to the hose through quick connect couplings. The hose is a braid reinforced hose. Both hose and coupling must be able to withstand consolidation temperature and pressure.

7.2 *Lay-up Expendables:*

7.2.1 Bagging films are placed over the lay-up and sealed to the base plate with sealant.

7.2.1.1 For cures up to 200°C [400°F], use a 0.06 mm [0.002 in.] thick Nylon 6 film sold for vacuum applications.

7.2.1.2 For cures up to 230°C [450°F], use a 0.06 mm [0.002 in.] thick high temperature Nylon 66 film sold for vacuum applications.

7.2.1.3 For cures from 230°C to 425°C [450°F–800°F], specific bagging materials are temperature and application dependent.

NOTE 2—Most other lay-up materials (specifically sealant, bleeders, peel ply, vacuum couplings, hoses, thermocouples) may also need modification at higher temperatures. Some other items such as bleeders and breathers have no high temperature equivalent. Suppliers should be consulted for specific applications above 230°C [450°F].

7.2.2 Release cloths allow the laminate to be separated from other cloth materials.

7.2.2.1 *Peel Plies*—Several types of peel ply are commercially available. Release properties and shrinkage vary with both fiber and style. Nylon and polycarbonate are two common fibers used. Aramid may be used for higher temperature applications above 230°C [450°F]. Peel plies are generally used when secondary bonding is required.

7.2.2.2 *TFE coated release cloth*—Generally weaves that have significant air spacing are preferred. These are used to separate the laminate from bleeders.

7.2.3 *Non-porous TFE Film*—used as a release to separate ply stack from tool or caul plate.

7.2.4 *Breather*—Cloth which allows even gas flow over the lay-up surface. The breather also helps minimize bag puncture by metal plates. Use (*1*) batted material type 10 or (*2*) 1581 style glass cloth.

7.2.5 *Bleeder*—Cloth that allows matrix to flow into it. Use (*1*) 120 style glass cloth with finish or (*2*) CW1850 style mat.

7.2.6 *Thermocouples* allow for temperature monitoring:

7.2.6.1 Use type J, 24 gage thermocouple wire to 370°C [700°F]. Lower gage wire or same gage type K can be used for higher temperatures.

7.2.6.2 Use gold plated thermocouple 2 pole connectors.

7.2.7 *Dams*—May be silicone rubber or cork. These can be different thicknesses depending on the panel thickness [3 mm [0.125 in.], 4.5 mm [0.188 in.], or 6 mm [0.25 in.] thick]. The dam thickness should slightly exceed panel thickness. The dams are typically 25 mm [1 in.] wide with adhesive on one side.

NOTE 3—Dams and peel plies may have chemicals that could influence secondary bonding operations. There are various materials. Find a material that is suitable for the particular operation.

NOTE 4—Silicone rubber dams may be used to 280°C [545°F] due to limitations of adhesive backing. Moldable sealants may be used at higher temperatures.

7.2.8 *Moldable sealant,* capable of providing an adequate vacuum seal when placed between the base plate and the vacuum film. Several types are available for different temperature applications.

7.2.9 *Tape:*

7.2.9.1 For use in lay-up, tape with adhesive on one side. The tape remains in surface contact with a plate or dam under temperature and pressure, typically 25 or 50 mm [1 or 2 in.] wide. The tape must be able to withstand heat generated in consolidation.

7.2.9.2 Used as an aid during ply stacking, adhesive on both sides, typically 25 mm [1 in.] wide.

7.3 *Test Material*—The test material (prepreg) should be free of contaminants. It may be unrolled from a rack. Under no conditions should it be folded on itself. Taped ends should be removed before the material is plied.

7.4 *Consolidation Equipment:*

7.4.1 *Press*—A variety of hydraulic and air driven presses are available. Generally a hydraulic press with platen support posts is preferred. Cooling water is generally a requirement. A press that can ramp through a programmed cycle for both temperature and pressure control/monitoring is recommended. The press must be large enough to hold the lay-up and provide satisfactory pressure to the lay-up area. Press platens should have a flatness of 0.3 mm [0.01 in.]. A facility may determine press flatness with the press platens open or at minimal contact.

7.4.2 *Autoclave*—Capable of holding lay-up. Provides adequate control and monitoring of consolidation cycle including pressure application and temperature and vacuum if required.

7.4.3 *Oven*—Capable of holding lay-up and providing adequate vacuum and temperature control and monitoring.

7.5 *Machining Equipment*—Machining equipment is described in Table X3.1.

7.6 *Secondary Bonding:*

7.6.1 *Release Cloth*—Peel plies (Section 7.2.2) are recommended.

7.6.2 *Adhesives*—Obtain an adhesive suitable for the particular test requirements (for example do not use an adhesive with low shear strength if significant shear loads will be placed on the bond) and temperature and humidity conditions. Follow manufacturer's recommended use and cure conditions.

7.6.3 *Tooling*—Tools set gage length and tab position. Tools are typically steel or aluminum and coated with a mold release. Usually tab and gage distance are set either by spring loading the fixture or by set pins or spacers.

7.7 *Strain Gaging:*

7.7.1 *Soldering iron,* capable of heating solder to its melting point.

7.7.2 *Solder/Flux,* as recommended by the strain gage manufacturer based on gage and wire.

7.7.3 *Wire,* as recommended by strain gage or test machine manufacturer.

7.7.4 *Surface preparation:*

7.7.4.1 220 grit sandpaper is used to lightly abrade the surface.

7.7.4.2 The surface is cleaned with isopropanol or other chemical that does not attack the laminate and leaves a minimum of residue.

7.7.5 Strain gage selection is dependent on the material type, lay-up, specimen and test constraints. Section II of the *Manual on Experimental Methods for Mechanical Testing of Composites*[4] gives additional information for the strain gage selection.

7.7.6 Strain gage adhesive can be recommended by the gage manufacturer based on the specific environmental/test conditions.

7.7.7 Strain gage coatings may be recommended by the gage manufacturer based on the specific environmental conditions.

7.8 *Conditioning:*

7.8.1 A chamber contains humidity and temperature control and monitoring capability. The chamber must be capable of holding specimens and monitoring environment within the chamber.

7.8.2 Coatings for specimen protection depend on specific environmental or test condition.

8. Procedure

8.1 *Laminate Lay-up:*

8.1.1 Terminology and designation systems found in Terminologies D3878, D123, D883, D4850, D3990 and Guide E1309 are used in this document so that terminology and designation systems will be the same between test facilities. Ply orientation designations that determine laminate stacking are described in Appendix X1.

8.1.2 The area in which the lay-up is to be performed should be a clean area. Clean room definitions allow no more than a concentration of 35 000 particles greater than 5 µm in diameter per cubic meter (1000 particles greater than 200 µin. diameter per cubic foot). Clean room definitions may be too restrictive for some working environments. However, care should be taken that the area approaches clean room conditions, being visually free of dust. Work surfaces must be likewise free of residue dust or debris. Any agglomeration of contaminant on the panel during lay-up should be avoided. These conditions should be verified before commencing work. Care should be taken to minimize contamination while handling plies (hand oils, lotions, talc in gloves, fabric softener are some materials that have been shown to contaminate material).

8.1.3 *Laminate Dimensional Considerations*—More than one laminate will at times need to be made for the desired number of specimens. Since lay-up does play a role in specimen quality, the ideal situation is to make all specimens from the same laminate. Randomize specimens within the laminate if possible. If more than one laminate is used, randomize specimens between laminates.

8.1.3.1 The size of the laminate should be determined based on the size and number of specimens required. Additional area should be provided to make up for discarded or destroyed material. It is recommended that at least 15 mm [0.5 in.] from the laminate edges be discarded due to nonrepresentative matrix/fiber ratio or thickness taper. Typically, cutting destroys some material [1–2 mm [.03–.08 in.] or more] with each pass. This discarded or destroyed material should be considered when determining panel surface area.

8.1.3.2 The limitations of the lay-up tooling (base plates, caul plates) or consolidation apparatus (autoclave, oven, press) should be considered when determining laminate size.

8.1.4 *Lay-up materials and tooling:*

8.1.4.1 *Plate or mold flatness/surface preparation*—The mold or base plate should be flat [no more than 0.05 mm [0.002 in.] deviation in any square meter (in.^{2})]. Caul plates should show similar flatness. Interior of molds and the bottom surface of the caul plate shall be coated with a mold release or lined with nonperforated TFE film. Base plates shall be coated with a mold release or lined with a nonperforated TFE film except where sealant is to be applied. The surfaces in contact with the laminate should have a minimum average surface roughness of 0.8 µm [32 µin.] and preferably 0.4 µm [16 µin.]. Cutting operations shall not be performed on mold or base plates.

8.1.4.2 *Tool size*—The base plate should be large enough to encompass the laminates, and any other material to be placed on the baseplate such as dams, sealant and vacuum ports (ideally vacuum ports should not be placed over the laminate).

8.1.5 *The ply layer (1st ply and single ply considerations):*

[4] *Manual on Experimental Methods for Mechanical Testing of Composites*, Edited by Richard L. Pendleton, Mark E. Tuttle, Society of Experimental Mechanics.

8.1.5.1 Check the material consistency. Inclusion of material flaws such as fiber breaks, drags or pulls will affect specimen properties.

8.1.5.2 The facility has the option to use extra material for each ply layer, then trim the ply stack to size, or precut the plies to size prior to stacking. If the plies are trimmed, use a sharp blade and place as much of the cutting surface of the blade against the material as possible. This helps to minimize pulled material so that acceptable dimensional and fiber orientation tolerances are maintained.

8.1.5.3 Align the ply to the proper fiber orientation for the first ply in the stacking sequence. For unidirectional tape a tow can be pulled from the composite material to establish true zero degree fiber orientation. For fabrics this is assessed visually.

NOTE 5—Fill direction of samples shall be established prior to removing samples from a roll. Slippage and handling may alter the fabric appearance limiting the ability to distinguish warp and fill.

8.1.5.4 Place the ply on a reference surface (orientation grid or caul plate) maintaining the proper fiber orientation if applicable. The ply should adhere to the reference surface without shifting.

8.1.5.5 When joints are required, they should follow the applicable fiber orientation pattern. The amount of gap or overlap of the joint should be consistent through the length of the joint and between joints.

8.1.6 *Ply Stacking*—Additional plies should adhere to previous plies without causing bubbles between plies. A roller or spatula may be used to assure contact between plies is achieved in all locations. A needle may be used to prick open bubbles.

8.1.6.1 Maintain the orientation of the reference through addition of subsequent plies.

NOTE 6—Plies are stacked one at a time. A partial ply stack may be combined with another partial ply stack if a debulking operation is performed.

8.1.6.2 Since some fabrics have surface orientation this should be designated in the ply stacking nomenclature. Surface orientation may be controlled by the top ply (warp surface up, warp surface down, warp nested) or the symmetry plane through the middle of the thickness of the laminate. Subsequent plies are oriented to the previous surface in the proper surface orientation.

8.1.6.3 Recurring defects may be minimized by offsetting the subsequent ply layer (stagger or flip flop configuration). X2.1 gives an example of how staggering can be used to minimize the vertical effect of repeated defects or joints.

8.1.6.4 A check of ply count may be made by weighing one ply and comparing this weight to the weight of the ply stack. An alternative technique is to count pieces of the removed paper or plastic backing.

8.1.6.5 The ply stack should be identified after the ply stacking operation is complete. An easy way to do this is to place an aluminum tape or foil in the corner of the stack. The identification can be written with a pen or scribe.

8.1.6.6 If a delay of some period occurs before further lay-up operations, place some non-contaminating film or paper on the top and bottom of the stack, to protect the stack from dust. For thermosets, the stack may be placed in a moisture proof bag and placed in the freezer to slow matrix advancement. Operations may continue once the bag warms to room temperature.

8.1.7 *Bagging Considerations:*

8.1.7.1 *Debulking*—As the laminate increases in thickness a debulking step is required to avoid porosity in the laminate. Laminates of the same dimensions may show different porosities due to material type. A laminate should be debulked at least once for every 2.5 mm [0.1 in.] of thickness.

NOTE 7—Debulking cycles may be accomplished under vacuum at room temperature. An example is to place the lay-up into a vacuum chamber with a tooling base plate and a top sheet of rubber or nylon sealed around several plies of the unconsolidated laminate. Debulking cycles are dependent on both material and panel size. Debulking should be performed often enough during the lay-up so that the final laminate shows an acceptable level of voids.

8.1.7.2 *Breather string*—A breather string (X2.4) may be used to provide a path for volatile materials to escape during cure. The string is most effective when placed 90° to the fiber orientation.

8.1.7.3 *Control of matrix flow*—Matrix flow is related to material, temperature and pathway. Flow can occur both in a lateral and vertical direction.

(a) Dams and non-porous TFE help control lateral flow. A dam placed adjacent to the ply stack will minimize lateral flow. If the matrix flows into the dam material, a non-porous TFE film barrier will further restrict lateral flow.

(b) Non-porous, coated cloth and porous TFE, bleeder cloths and peel ply control vertical flow.

(c) Non-porous TFE film provides a barrier which keeps vertical flow close to the laminate surface. A release (porous or coated cloth TFE, and so forth) must be placed between the bleeder and the laminate or the bleeder will become consolidated into the laminate.

(d) Porous TFE or coated TFE cloth control the mechanism of how the vertical flow is directed to the bleeders (for example, a porous TFE film with more or larger holes provides less obstruction to the rapid flow of the matrix into the bleeder than a porous TFE film with less or smaller holes).

(e) Bleeders allow significant levels of vertical flow. The amount allowed depends on the matrix material, laminate dimensions, and bleeder type, and release barrier. Bleeders may be placed both above and below the ply stack. Several bleeders may be used to increase flow. The ability of the matrix to flow into each subsequent bleeder is reduced.

(f) Peel ply functions both as a release and bleeder. For best results cut peel ply and bleeders to the size of the laminate.

8.1.7.4 Air breather and vacuum bagging assure that the laminate is in a proper environment so that pressure can be applied and proper matrix flow can be achieved during an autoclave consolidation of the laminate. The vacuum bag should be checked for leakage prior to laminate consolidation. The sealed vacuum bag should hold at least 75 kPa vacuum [22 in. Hg]. Vacuum should not drop more than 1.5 kPa pascal [0.5 in. Hg] in any thirty second period.

8.1.7.5 *Surface considerations*—TFE coated cloth and peel ply will give a surface texture. Any film or cloth that is applied unevenly (doubles back, does not cover the entire surface) will cause an undesirable crease or other thickness variation in the laminate. Porous materials in contact with the laminate surface may allow resins to leach out, leaving outer filaments unsupported by the matrix.

8.1.7.6 Caul plates are used to minimize thickness variation in a laminate. The laminate should be trimmed to the dimensions of the caul plate. If a caul plate is used, dams are required. The top of the dam should be bordered by the edges of the caul plate. If the bottom of the caul plate is above the top of the dam, then the laminate may become convex toward the middle. If the top of the caul plate is below the top of the dam, then the laminate may become concave toward the middle.

8.1.7.7 *Lay-up methods*—Some recommended lay-up techniques for use in autoclaving of stacked laminates are shown in Appendix X2. Techniques utilizing presses may omit vacuum bag, vacuum port and air breather. Variations of these techniques are primarily based on the choice or availability of materials or process being used.

8.2 *Laminate Consolidation:*

8.2.1 Specific laminate consolidation conditions are recommended based on viscoelastic and thermal characteristics of specific fiber/matrix combinations. Consolidation specifics provided by the composite supplier or end user state the amount of pressure and if necessary, vacuum and heat that should be supplied to the lay-up. The consolidation should be consistent with the purpose of the data acquisition.

8.2.1.1 Good recommended practices during laminate consolidation using a press or autoclave include the following:

(*a*) *Pressure*—Press platens should be parallel to each other within 0.3 mm [0.01 in.] over the area of the mold that has pressure applied to it.

NOTE 8—Stopper shims should not be used unless specifically requested.

NOTE 9—Laminate quality is a function of (*1*) the flatness of baseplate, caul plate and press platens, and (*2*) overall laminate thickness. Tighter flatness tolerances will improve the laminate. Thinner laminates require tighter tolerances. For example a press tolerance of 0.5 mm may be fine for a laminate of 6 mm thick, but is too loose for a laminate of 1 mm thick. For panels smaller than 0.02 m^2 [30 $in.^2$] or larger than 0.1 m^2 [150 $in.^2$] flatness tolerances may be relaxed. Use tolerances that are practical to achieve and maintain, and give satisfactory flatness to the laminate.

Pressure application should occur within 0.5 min. of the time indicated in a particular consolidation cycle. Pressure should remain within 5 % of the indicated pressure at all times.

(*b*) *Temperature (Cures only)*—Temperature inside or near the laminate should be used for monitoring of temperature during cure. A tolerance of ±2°C [±5°F] is recommended from the specified temperature for the following conditions: uniformity of platen temperature in contact with the mold; ramp capability (platen or autoclave); and hold at temperature (platen or autoclave). The ability to meet these tolerances should be demonstrated on a periodic basis. Cured laminate should not be removed from the press or autoclave at a temperature which may cause thermal shock to the material. A guideline is to not remove the part from the sealed autoclave above 90°C.

NOTE 10—For low curing systems only [less than 150°C [300°F]] the following equation may be used:

$$T_R < 0.5(T_c - RT) + RT \quad (1)$$

where:

T_R = temperature of part at removal,
T_c = temperature of the cure hold step,
RT = ambient (room) temperature.

(*c*) *Vacuum.* Vacuum is not a requirement. However, it may be helpful. If vacuum is used, it will be continuously monitored on the bag. Amount of vacuum and duration is highly dependent on the material type. Vacuum may decline during a rapid pressurization or temperature ramp. Vacuum integrity should be considered compromised if the vacuum during a hold step declines more than 3.5 kPa pascal [1 in. Hg] in any 5 min period. For thermosets, vacuum is unimportant after the resin gels. Excess vacuum applied during the laminate consolidation of some systems may result in foaming or void propagation. Vacuum monitoring is not important after the vacuum is vented, except as an indicator of bag integrity. Vacuum ports should not be placed over the laminate. If a vacuum port is placed over the laminate, discard laminate material within a 50 mm [2 in.] diameter of the vacuum port.

8.2.2 Laminate post cure is considered as an extension of the laminate cure where pressure is not required.

8.3 *Initial Cutting of Laminates:*

8.3.1 The panel is initially cut into smaller parts. Fiber orientation of these parts should be marked or otherwise maintained as fiber orientation was maintained in the laminate. These parts act as smaller laminates (*1*) from which specimens of the same configuration can be made, (*2*) that are sized for secondary bonding (tabbing), (*3*) that are properly sized for further machining, or (*4*) provide final specimen configuration.

8.3.2 Initial cutting of laminates is typically accomplished with a rough cut abrasive grit band saw, water jet, or a fluid cooled diamond saw with a plexiglass backing (Appendix X3). The cut surfaces may be satisfactory without grinding if the cut edge does not taper more than 0.015 m/m of specimen length and does not show significant microcracking [no more than 0.2 cracks/mm [5 cracks/in.] at a magnification of 50×] on the cut edge. Aramid laminates may need to be sandwiched between layers of plexiglass or other suitable material during cutting.

8.3.3 Each initial cutting method has limitations. For example, the saw cannot perform cuts with any curvature. Use the proper equipment to meet the purpose of the initial cut.

NOTE 11—Tabbed specimens require proper alignment in a mold. Further machining (Section 8.6) may be needed to achieve proper alignment.

8.4 *Bonding of Tabs*—Bonded tabs are not required on all specimens. Depending on load, test, grip mechanism and specimen configuration, tabs and/or doublers may be required. If bonded tabs are necessary the cure of the adhesive should be evaluated to determine if it is compatible with the composite system and the tab material (if different). The following recommendations are designed to minimize effects of tabbing on test results:

8.4.1 Pressure and temperature during the adhesive cure should be controlled within the limits of 8.2.1.1.

8.4.2 The adhesive cure temperature should not exceed 80 % of the laminate matrix glass transition temperature (T_g) for thermosets if possible.

8.4.3 The adhesive cure cycle should not further cure the specimen, unless this is a desired effect.

8.4.4 It is recommended that adhesive and tabbing material shear strength be such that the shear failure load of the tab exceeds the specimen failure load. This may determine the tabbing area and the gripping apparatus required.

NOTE 12—The following formula may be used as a guideline when considering adhesive or tab materials:

$$F > \frac{P}{(w \times l) \times 2} \quad (2)$$

where:

F = shear strength of adhesive or tab material[5] (P)
P = expected failure load of specimen (N)
w = width of specimen bond on one side of specimen (cm)
l = length of specimen bond on one side of specimen (cm)
2 = factor to account for two sides of specimen

NOTE 13—This formula approximates shear stress average load and does not address peak stress. It is possible for tab or adhesive failure to occur even if the conditions of this equation are met. If a significant number of failures occur, then the tabbing or adhesive material strength must be improved.

8.4.5 If the tab configuration produced by the bonding process is not within the geometry requirements of the specimen configuration and the test fixture, further machining may be required on the tabs. Tab flatness tolerances should be the same as laminate flatness tolerances of .05 mm [0.002 in.].

8.4.6 Elevated temperature adhesive cures should follow the same good practice parameters as shown for laminate cures (8.2.1.1). Room temperature cures should apply a uniform pressure to the tab and monitor time of cure.

8.4.7 Adhesive should make thorough contact with the specimen and tab. This is helped by adequate surface preparation. Surface(s) should be rough enough to provide sites for adhesive bonding but not so irregular so that adequate contact cannot be made. A peel ply consolidated to the laminate, provides an adequate surface for bonding after the peel ply is removed. For best results remove peel ply immediately prior to bonding. If peel ply is not used the surface should be abraded with a fine grit to minimize surface irregularities, without damaging the reinforcement. If the resin and fiber produce different colors of dust, fiber damage can be subjectively viewed by a color change during the process. If the dust is more like the resin color, then mostly resin is being removed. Surface resin thickness varies due to lay-up and process, but a guideline is to remove no more than 0.03 mm from the surface of the laminate to minimize fiber damage. The laminate should then be cleaned with solvent that removes particulates but does not affect the laminate surface. Chemical agents that affect surfaces may be used to enhance the bond of the tab to the adhesive, or laminate to the adhesive.

8.4.8 If tabs are made from a different material (including weave) than the laminate, care should be taken that the thermal expansion difference does not introduce stress concentrations during the adhesive cure.

8.4.9 The following items are usually specified within the test method. Guidelines are given for the cases when test methods do not address these items.

8.4.9.1 Tabs or doublers may be tapered at the ends to reduce stress concentrations at the end of the tab. This is only necessary with loads that cause premature coupon breakage at the tab or doubler end.

8.4.9.2 Adhesive may be allowed in the specimen gage area if it does not affect the test.

8.4.9.3 Tabbed specimens should show symmetry (thickness of one side must be within 0.5 mm [0.02 in.] of the thickness of the other side) through midply of specimen.

8.5 *Specimen Machining/Final Cutting:*

8.5.1 Specimens may be machined with a variety of machining tools (Appendix X3). General guidelines are that the tool should have a fine grit, be hardened, be run at a high tool speed without wobble and be able to slowly move across or through the laminate. A single pass of the blade through the cut may be required due to the following conditions:

8.5.1.1 If the laminate shows greater than 0.025 mm [0.001 in.] taper of the cut edge through the thickness of the laminate.

8.5.1.2 If the laminate has an unsupported section (such as a tabbed tensile panel) which tends to bend to the table during cutting.

8.5.2 For laminates that do not have a sufficiently smooth edge as shown by fiber pullout or tapering [greater than 0.008 m taper per m of edge length [0.008 in./in.]], or significant microcracking, surface grinding should be the final surface edge preparation.

8.6 *Applying Coatings/Treatments:*

8.6.1 Specimens may require treatments or coatings for handling, monitoring of effects, or detection. Coatings should be applied in accordance with the manufacturer's recommendation. Consider mechanical and chemical surface changes for effects on the overall test specimen and the gage area being investigated.

8.6.2 Coatings for protection of the tab when the specimen is exposed to environmental conditioning should satisfactorily adhere to adhesive, tab and laminate material to provide a satisfactory seal from the particular environment. The particular treatment is dependent on materials and environment. For example, metallic tabs require surface treatments resistant to moisture exposure if placed prior to moisture conditioning.

8.7 *Specimen Conditioning*—Specimen conditioning may be addressed in the specific test methods produced by Committee D-30 or more generally in Test Method D5229/D5229M. Monitor temperature and humidity throughout conditioning. It is preferable to measure moisture pickup of the specimen. With tabbed specimens or other specimens where it is not practical to measure the actual specimen, a traveler should be used in place of the actual specimen. Measurement frequency may affect moisture pickup rate and time to equilibrium. Measurement frequency should be dependent on material type and specimen dimensions.

8.8 *Strain gaging:*

8.8.1 Guide E1237 is the standard guide for installing bonded resistance strain gages. Section III of the *Manual on*

[5] The strengths of both the adhesive and tabbing material shall be considered independently.

Experimental Methods for Mechanical Testing of Composites gives additional information for strain gage application on composites.

8.8.2 Strain gaging operations are typically performed towards the end of specimen conditioning (after moisture equilibrium has been achieved). Bonding of strain gages on wet specimens should be controlled so as to limit drying or monitor moisture loss during the operation. If the strain gage is applied prior to specimen conditioning, the adhesive must be capable of adhering to both the strain gage backing and specimen throughout all applied environmental conditions.

9. Report

9.1 Report the following information, or references pointing to other documentation containing this information, to the maximum extent applicable:

9.1.1 The date(s) and location(s) of the various preparation steps.

9.1.2 The name(s) of individual(s) involved in specimen preparation.

9.1.3 Any variations to this practice, anomalies noted or equipment problems during specimen preparation.

9.1.4 Identification of the material including: material type, material designation, age of material, manufacturer or other source, manufacturer's lot or material tracking number, tow or yarn filament count, sizing, form or weave, fiber areal weight, matrix type, and prepreg matrix content.

9.1.5 Description of laminate fabrication steps including: fabrication start date, fabrication end date, ply orientation stacking sequence, laminate consolidation cycle, consolidation method, and equipment used.

9.1.6 Average ply thickness of the consolidated laminate.

9.1.7 Method of preparing the test specimen, including specimen geometry, coupon cutting method, identification of tab geometry, tab material, tab adhesive, and fixtures or equipment used.

9.1.8 Calibration dates and methods for measurement devices.

9.1.9 If environmental conditioning is performed, conditioning parameters and results, use of travellers and traveller geometry, and method of evaluating moisture gain.

9.1.10 If strain gages are used, the type, resistance, size, gage factor, temperature compensation method, transverse sensitivity, lead-wire resistance, placement on the specimen and, adhesive and any correction factors employed.

9.1.11 Results of any process checks including both destructive and non-destructive evaluation.

10. Keywords

10.1 composite materials; laminates; panel preparation; polymer matrix composites; specimen preparation

APPENDIXES

(Nonmandatory Information)

X1. PLYING LAMINATES

X1.1 Designation

X1.1.1 *Tape and fabric plying designation*—Plying directions or designation of a tape plied laminate:

$$\text{Ply}\left[(A/)_{n_x}\ {}_C(B/)_{N_x}\ {}_C\cdots\right]_{D\,N_y} \qquad \text{(X1.1)}$$

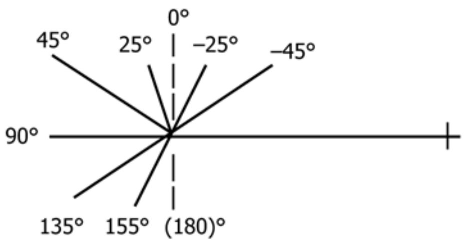
Where: A/ and B/ are the ply orientation (degrees) of the stacking sequence expressed in angle deviations from the laminate principal axis, each ply separated by a forward slash. An example would be 0/+45/−45/90 [0/45/135/90]. The slash is not applicable if all plies have the same stacking sequence.

NOTE X1.1—A ± angle orientation may be used (90° maximum angle) or a "positive" angle orientation may be used (180° maximum angle). The

TABLE X1.1 Notation Examples

Laminate Example	Notation	Actual Ply Sequence
Laminate for resin flow evaluation	$[(0/90)_2]$	0,90,0,90
0° Tension	$[0_7]_{Na}$ Na- Lay-up should be warp face up.	0,0,0,0,0,0,0 with additional instructions for orienting individual ply layers
Edge Delamination	$[(+25/-25)_{N1\ 2}/(90/\bar{0})_{N2}]_s$ or $[(25/155)_{N1\ 2}/(90/\bar{0})_{N2}]_s$ N1 = material type 1 N2 = material type 2	+25,−25,+25,−25,90,0,90,−25,+25,−25,+25
Open Hole Tension or Compression	$[+45/90/-45/0]_s$ or $[45/90/135/0]_s$	+45,90,−45,0,0,−45,90,+45
Compression After Impact	$[+45/90/-45/0]_{4s}$ or $[45/90/135/0]_{4s}$	+45,90,−45,0,+45,90,−45,0,+45,90,−45,0,+45,90,−45,0, 0,−45,90,+45,0,−45,90,+45,0,−45,90,+45,0,−45,90,+45

following grid shows both systems. Nomenclature should be consistent using either the ± or "positive" angle orientation throughout.



NOTE X1.2—An overhead line in the position before the last bracket] signifies that the last unit will not be repeated with respect to an operator. N_x is a note that applies to the items in parenthesis. An application is to state the reference to the type of material in a hybrid laminate. This field may be used to reference the material type if not explicitly stated in a drawing

$_C$ is the number of times that the ply stacking sequence order is repeated.

$_D$ designates if the panel is symmetric or not. If the panel is not symmetric this field is left blank. If the field is symmetric$_{D\,=\,s}$. This gives additional information to reverse the sequence given by *A, B* and *C* for the other half of the laminate.

$_{Ny}$ gives plying instructions not related to angle orientation, but related to ply location such as "flip flop" or "staggered," warp face, nested, and so forth.

X1.2 Summary of Practice

X1.2.1 Table X1.1 gives examples of notation use.

X2. ADDITIONAL LAY-UP GUIDES

X2.1 Staggering of plies for a lay-up

X2.1.1 Staggering of joints in the plying operation may be performed to make the laminate more uniform (for example if the prepreg shows an increase in resin content across its width). This consideration must be balanced with the consideration of making joints, which have the potential to weaken the laminate. If material width is less than the panel dimension, the material must be staggered. Fig. X2.1 gives an indication of how staggering could be done to uniformly distribute joints both laterally and vertically throughout the laminate by giving an example with one panel size with a target panel thickness of 1 mm [0.04 in.].

X2.2 Use of a Draftman's Grid for Plying Multidirectional Laminates

X2.2.1 The grid (see Fig. X2.2) is used to reference angle orientation about the laminate principal axis during plying.

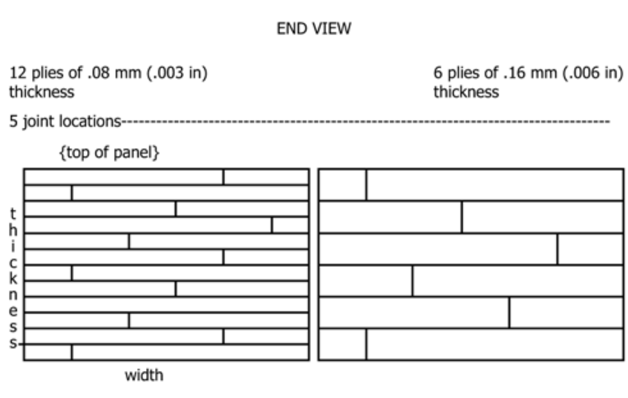


FIG. X2.1 Optimizing Staggered Joints Based On Laminate and Ply Thickness

X2.2.2 The grid may be placed under a transparent sheet of glass, acrylic or polycarbonate. The grid should reflect the particular ply orientations of the laminate being fabricated and should not contain excess angle marking.

X2.2.3 The edge of each ply should be aligned with the proper line of the draftman's grid while plying the laminate.

X2.3 Marking direction of reinforcement in the lay-up/laminate

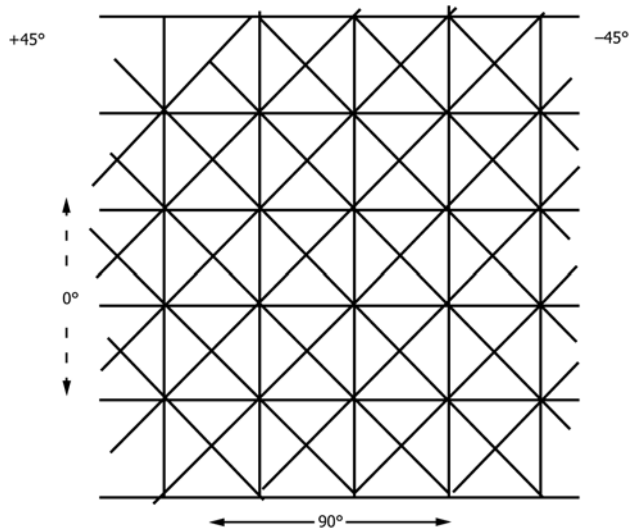
X2.3.1 It is advantageous to mark the reinforcement direction before the laminate is consolidated. Two methods of marking reinforcement direction:

X2.3.1.1 Place a small piece of aluminum foil or cloth (approximately 15 × 30 mm) at the bottom right hand corner of the laminate with the reinforcement orientation of the surface ply (for example warp, +45° or 0° and an arrow impressed into the foil (or written on the cloth) to indicate the reinforcement direction. (The foil or cloth will be covered with resin but will remain legible during the consolidation or cure process and post cure process.)

X2.3.1.2 Use an etched surface plate (caul plate) to indicate the reinforcement direction of an edge. (For square laminates ensure the etched side of the caul plate is properly aligned.)

X2.4 Basic Bagging Techniques

X2.4.1 Fig. X2.3 shows three recommended bagging techniques. What each technique provides is summarized in Figs. X2.4-X2.6.



NOTE 1—Mark the various ply directions on the lay-up table:
Right hand side "+"
Left hand side "–"

NOTE 2—Place and secure a backstop, align with the 90° line.

NOTE 3—Mark the 90° and the 0° direction over the grid.

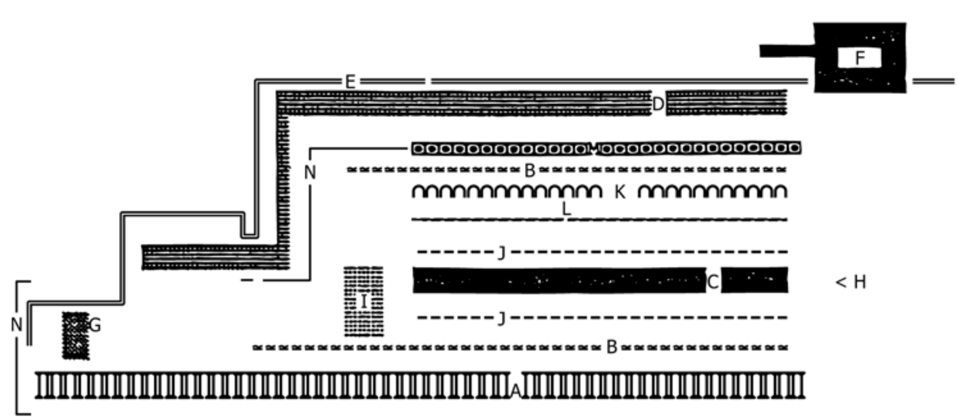
FIG. X2.2 A Draftsman Grid Lay-out For 0/90° and 45° Plying Operation

Key

A	Base Plate	J	Peel Ply (used on panels that undergo secondary bonding
B	TFE Film		
C	Laminate	K	Bleeder cloth (may be several plies)
D	Air Breather	L	Release Fabric
E	Vacuum Bag	M	Caul Plate
F	Vacuum Coupling	N	High Temperature Tape
G	Sealant	O	Breather string (optional along non 0° edges of laminate to provide a path for volatile escape. String must contact air breather).
H	Thermocouple		
I	Dam		
		P	25 mm (1 in.) wide bleeder cloth

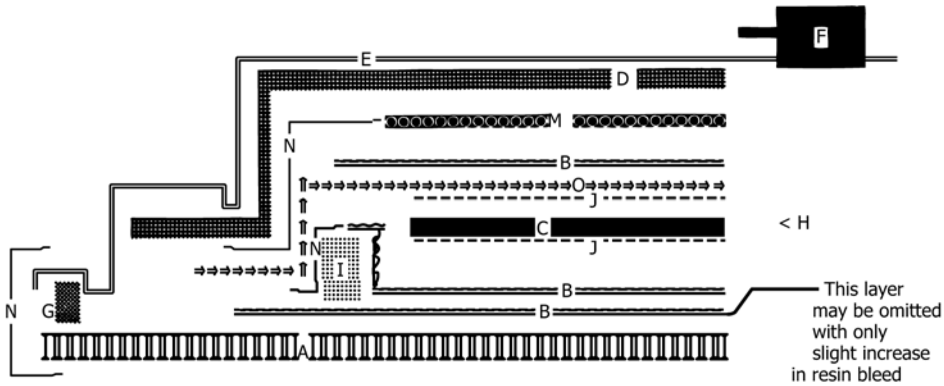
NOTE 1—Place thermocouple on caul plate no more than 25 mm (1 inch) from laminate.

FIG. X2.3 Laminate Vacuum Bagging Techniques



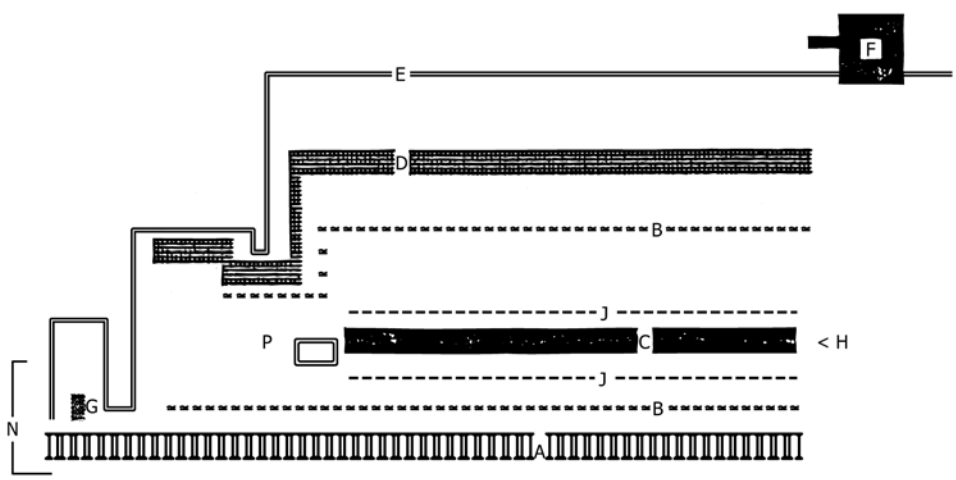
NOTE 1—Provides: 1) Vertical matrix flow during cure.
2) Limits lateral matrix flow.
3) Caul plate minimizes thickness variability.

FIG. X2.4 Technique #1 Vertical Bleed System—Bleeders



NOTE 1—Provides: 1) Smooth laminate surfaces.
2) Minimum resin flow from the panel.
3) Caul plate minimizes thickness variability.

FIG. X2.5 Technique #2 Composite Lay-up System—Resin Trap



NOTE 1—Provides: 1) Means for lateral resin flow.
2) Smooth laminate surfaces.
3) Increased thickness variability over caul plate.

FIG. X2.6 Technique #3 Lateral Bleed System—No Caul Plate

X3. CUTTING AND MACHINING TOOLS

X3.1 Table X3.1 describes typical machining tools, and gives some general recommendations for proper use. Limitations of the tool are also described.

TABLE X3.1 Laminate Cutting and Machining Equipment

Equipment	Part in Contact with Laminate	Speed/Pressure	Equipment Limitations
Fluid Cooled Saw	• Circular diamond grit blade (180 grit max)	• Tip speed [blade at table] of 180 m/min (7000 in./min) minimum.	• Provides only straight edged cuts, best accuracy .02 mm over 100 mm travel. • May be some wobble through thickness of cut. • Thickness taper is related to feed rate. • Tends to jog at interfaces of different materials including initial contact with specimen. • Surface finishes are no smoother than 0.80 µm (32 µin.).
Water Jet	Water stream (abrasive)	• 275 MPa (40 ksi) minimum with capability for abrasives if over 3 mm (0.1 in.) thickness	• Minimum accuracy is .01 mm over a 100 mm traverse. • Delaminates on initial piercing. A10 mm diameter (0.5 in.) hole is needed so that no predrilling is required. • Kerf width is .25 mm (.01 in.) minimum without abrasives and .75 mm (.03 in.) minimum with abrasives. • Delamination susceptibility increases with specimen feed rate. • Surface finishes are approximately 3.2 µm (125 µin.).
Band Saw	Band saw blade	• 915 m/minute (36,000 in./min) • 400–550 teeth/m (10–14 teeth/in.)	• Only straight, or wide kerf cuts. • Surface finish is usually rougher than 6.3 µm (250 µin.). Surface finishes in this range may not be adequate for specimen testing.
Drill	Bit	• 3000 rpm is recommended. • Boring type bits may reduce speed to 1500 rpm	• Only provides circular cutouts minimum accuracy is .01 mm (.004 in.) out of concentricity. • Drill wobble controlled by speed and feed rate. • Delamination is possible at surface plies of laminate (although the likelihood at the back end is greater. This is reduced by sandwiching laminate between like laminates. • Surface finish is no smoother than 0.80 µm (32 µin.).
Router	Diamond or carbide 12 mm (0.5 in.) bit	• 25,000 rpm minimum	• Cuts determined by ability to make template. • Water cooling recommended. • Will microcrack (particularly specimens with brittle matrices). • Accuracy dependent on template not router. • Surface finish is approximately 1.6 µm (64 µin.).
Sander	Abrasive grit	• Wide variety of hand and electric tools 180 grit minimum	• Difficult to provide even pressure/surface. • Applicable to portions of specimens or specimens with curvature.
Grinder	Wheel (180 grit or less)	• 3000 rpm • No more than .02 mm (.001 in.) material removed per pass	• Only provides a flat surface • Surface finish can be 0.4 µm (16 µin.) or smoother.

X4. PROCESS CHECKS

X4.1 Each facility may develop a set of non-destructive examination (NDE) or other processing checks to assure that each step of the specimen preparation process has been performed satisfactorily. If the specimen fabrication process is shown to be sufficiently controlled to eliminate deviations from acceptable specimens, then control of the process indicates control of the specimen. In these cases inspection is only an occasional verification of the process. In cases where the process has not shown that acceptable specimens are made by following process steps, an inspection protocol which defines inspections to be performed should be initiated and every specimen evaluated until there is confidence that the process shall make adequate specimens. Process capabilities should be periodically checked if there is any doubt that specimens will meet the requirement. See Tables X4.1 and X4.2).

X4.2 The contact surface of the material and the measuring device will determine the measured dimensions. Bridging of surface discontinuities and accounting for dimples [less than 0.8 mm (0.03 in.)] can substantially affect the data produced. Fig. X4.1 demonstrates this effect. Use of non-standard devices on the same tests within a facility can create typical test data variations (not material variations) of 5 % to 15 %, due solely to measurement inconsistencies. Calibration of the measurement devices should therefore be traceable.

X4.3 The precision of the dimensional examination of the specimen required depends on the specific type of measurement device. In performing dimensional examinations the accuracy of the overall test should be considered. A propagation of error analysis for the test may demonstrate the level of accuracy required in the dimensional tolerances of a specific test.

TABLE X4.1 Non-Destructive Process Checks

Process Step	Purpose	Non Destructive Examination Technique	When Tested
1) Laminate Plying	• Proper number of plies in laminate	• Techniques for assessing ply count. · Compare lay-up weight (L) of a number of plies (N) to ply weight (P). L should be closer to PxN than to Px(N + 1) or Px(N – 1). · Retain pieces of backing paper or polyfilm removed from the back of each ply before ply stacking. Count the number of pieces of this material to assess how many plies have been placed in the stack.	• After/during step 1
	• Verification of reinforcement direction(s) [Note: This may also be applicable to steps 2 & 3. Major orientation effect is in step 1]	• Proper orientation may be checked with a checkoff sheet as plies are stacked. Fiber orientation of the material or orientation of tracer yarns in the material provide visual confirmation.	
		• Polish cut edge and view laminar fiber orientations with a microscope. · Shape of fiber cut end (circular or elliptical) or intensity of reflected light are used to determine angle orientation of ply layers. · For a typical (0/90) orientation of fabric layers, the weave pattern may be evaluated at the edge of a cut laminate.	• After step 6
2) Laminate Bagging	• Proper assembly	• Diagram followed or check off as done (release material, number of bleeders, dam, caul plate). • It is useful to have an empirical based program that predicts ability off certain aspects of the layup. For example, a bleeder program should be able to predict how many bleeders are required to provide a specific laminate thickness or fiber volume.	• During Step 2
	• Bag integrity	• Supply at least 75 kPa pascal (22 in. Hg) of vacuum to the plate covered with a vacuum bag. Remove bag from vacuum source. Bag cannot lose more than 3.5 kPa pascal (1 in. Hg) in 15 minutes.	• After Step 2
3) Laminate Consolidation	• Consolidation conditions met.	• Monitor real time pressure and temperature/vacuum if used.	• During step 3
	• Laminate porosity is acceptable	• Porosity determination techniques · C scan using 3 mm (.1 in.) diameter defect as standard. · With vacuum and flow meter monitor pressure change from one side of laminate to the other. Use a .3 mm (.1 in.) hole as standard.	• After step 3
	• Laminate composition is acceptable. Laminate is uniform	• Measure thickness of laminate. Assess thickness variation. Variation should be no more than 2 % of laminate thickness from any two points separated by 2 cm (1 in.). • Flatness should be controlled within .05 mm (.02 in.). Note: Overall flatness requirements are a function of lay-up and overall panel thickness. Enhanced guidelines may be given from historical data.	• After step 3
		• Detect dry fiber · View dry fiber through a microscopic cross section. · View fuzzing along a cut edge. • Detect excess resin on surface by viewing laminate cross section under microscope. A grid pattern reticle would determine if there was excess resin on the surface. • Detect delaminations by C-scan	• After step 4
4) Initial Cutting	• Cutting damage	• Microscopic evaluation for microcracking. Cracks should not overlap, or extend more than 1 mm (.04 in.) into laminate. • Observe if there is edge charring visually or under magnification.	• After step 4
	• Dimensional integrity	• Use gage blocks (go/no-go) or standard dimensional measurement techniques to evaluate if tolerances are met.	
	• Cutting alignment	• Use a tracer yarn on laminate (put on top ply in ply stacking operation or caul plate mark (etched across the bottom surface of the caul plate) to show that initial cuts were straight.	
5) Bonding	• Taper of bond • Adhesive in gage area	• Visual inspection/microscope • Visual/microscope • Detect debonding by C-scan	• After step 6
6) Machining/Final Cutting	• Cutting damage • Dimensional integrity	• See step 4 • Dimensional measurement equipment · Go/no-go gages	• After step 6
	• Proper machine tolerances	· Dimensional measuring (parallelism, concentricity, curvature, and so forth)	
	• Surface finish	• Surface measurement · Comparison blocks · Profilometer	
7) Treatments/Coatings	• Coverage	• View cracking or peeling.	• After step 7
8) Environmental Conditioning	• Weight change of specimen	• ASTM D5229/D5229M. Determine by weighing.	• During step 8
	• Attack into specimen or coating by environmental media.	• View pitting or other environmental exposure effect.	• During or after step 8
9) Strain gaging	• Resistance • Proper bond to specimen	• ASTM E1237 section 11.2.3 • Appearance · Of solder joint · No bubbles under strain gage · Good bond appearance of strain gage substrate to specimen. • Acceptable resistance (ohmmeter)	• After step 9
	• Strain gage alignment	• Fits on alignment grid pattern	

TABLE X4.2 Destructive Process Checks

Process Step	Purpose	Destructive Technique	When Tested
1) Laminate Plying	• Verification of reinforcement directions		• After step 4
	· 0° layup	• Nick the laminate close to the 0° edge and using a knife, split the laminate in the 0° reinforcement direction. The edge should be straight without any taper through the thickness of the laminate. If this edge is not straight, the plying is faulty.	
	· Non unidirectional layup	• Use muffle furnace with sufficient heat to ash resin without totally destroying fiber. Plies can be removed to check orientation.	
	[Note: This may be applicable to steps 2 & 3. Major orientation effect is in step 1]		
3) Laminate Consolidation	• Verify laminate porosity and composition	• Perform resin digest and calculate density fiber volume and voids by ASTM D792, D3171 and D2734.	• After step 4
5) Bonding	• Adhesive strength	• Special tests	
		· Lap shear (ASTM D3163)	• Separate adhesive evaluation
		· Flatwise tensile (ASTM C297/C297M)	
		· Adhesive failure mode/voids	• After testing
	• Ability for adhesive to flow	• Flow by ASTM D3531 except with minimum pressure of 100 kPa (15 psi).	• Separate adhesive evaluation

The texture of the surface may lead to incorrect measures based on probe type and width.

DIMPLED SURFACE

If too narrow a probe is used, minimum thickness rather than average thickness will be measured.
If too wide a probe is used, maximum thickness rather than average thickness will be measured.

Two different sizes of measuring probes
Two different types of measuring probes

FLAT SURFACE

Probe width or shape has minimum effect.

Two different size measuring probes
Two different types of measuring probes

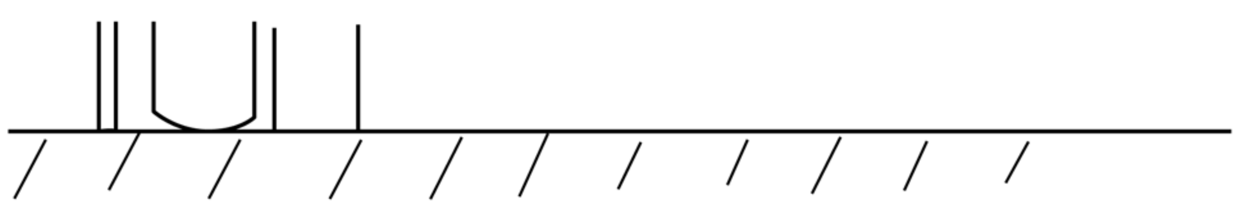


FIG. X4.1 Measuring of Laminate Surfaces