Document No.: NPS 81451, Revision D, September 23, 2022

NCAMP Process Specification

This specification is generated and maintained in accordance with NCAMP Standard Operating Procedures, NSP 100

Fabrication of NMS 451 Qualification, Equivalency, and Acceptance Test Panels (Solvay (Formerly Advanced Composites Group (ACG) MTM45-1 prepregs))

Prepared by: Yeow Ng (NCAMP), John Tomblin (NIAR), Vinsensius Tanoto (NCAMP)

Reviewed by: Dusty Penn (Umeco), Danny Wienecke (Umeco), Munir Zanial (Bombardier), Royal Lovingfoss (NCAMP), Chris Ridgard (Solvay), Clay Scoggins (Solvay)

REVISIONS

Revision	Date	Description
-	3/18/2011	Initial Release
A	4/7/2011	Added “MTM45” to the title page. Added “ACGP 1001-01” sections 1 and 2.4.
B	9/25/2012	Updated based on feedback received through NCAMP Portal review. Updated section 3 with more specific material descriptions.
C	8/1/2018	Adding note for NMS 451/4 7781 E Glass and NMS 451/12 S-2 Glass Fabric materials into Section 4.3. Formatting and adding LH, M, and AH cure cycles into Section 4.4.
D	8/1/2022	Moved Revisions table to after cover page. Section 3.5: Additional caul plate (Chipboard) material for NMS 451/4 7781 E Glass and NMS 451/12 6781 S-2 Glass was added. Section 3.11: 120 Style Glass Fabric was added. Section 4.2: Figure 2 “chipboard” was added. WFI and FFI information for NMS 451/4 7781 E Glass and NMS 451/12 6781 S-2 Glass was added. WFI and FFI typos were fixed, there is no change on the materials. Section 4.3: WFI and FFI information was moved to Section 4.2.

Table of Contents

1. SCOPE....4
1.1 Purpose....4
1.2 Health and Safety....4
2. APPLICABLE DOCUMENTS....4
2.1 NCAMP Publications....4
2.2 ISO Publications:....4
2.3 US Government Publications:....5
2.4 Advanced Composites Group (ACG) Publications:....5
3. MATERIALS:....5
3.1 Vacuum bag....5
3.2 Breather....5
3.3 Breather string,....5
3.4 Solid FEP, separator/release film....5
3.5 Caul plates....5
3.6 Tape....6
3.7 Sealant tape....6
3.8 Mold....6
3.9 Release Agents....6
3.10 Peel-ply, uncoated....6
4. TEST LAMINATE FABRICATION....6
4.1 Prepreg cutting....6
4.2 Prepreg layup and bagging....7
4.3 Baseline "MH" Cure Cycle....9
4.3.1 Vacuum Requirements....9
4.4 Alternative Cure Cycles....10
4.4.1 Alternative "LH" Cure Cycle....10
4.4.2 Alternative "M" Cure Cycle....11
4.4.3 Alternative Autoclave "AH" Cure Cycle....11
4.5 Cured Panels....12
5. QUALITY ASSURANCE....12
5.1 Process Control....12
5.2 Ultrasonic Non-Destructive Inspection....12
5.3 Visual Inspection....12
6. SHIPPING....12

1. SCOPE

This process specification describes the methods of fabricating test panels using NMS 451. Specifically, this specification covers prepreg cutting, layup, vacuum bagging, and curing process with a forced-air convection oven equipped with vacuum ports. In addition to the instructions contained in this specification, users are advised to obtain hands-on guidance directly from the prepreg manufacturer.

This specification does not contain all the necessary information typically required in a composite process specification for the fabrication of composite structures, such as personnel qualification and layup room requirements. Users should refer to their existing company process specification and Advanced Composites Group Process Specifications ACGP 1001, ACGP 1001-01, and ACGP 1001-02 for such information. DOT/FAA/AR-02/110 provides guidance for the development of composite process specifications.

1.1 Purpose

The purpose of this process specification is to provide processing information for the fabrication of test panels for use in material qualification, equivalency, and acceptance testing. This process specification may also be used as a baseline by material users to develop a process specification for the fabrication of aerospace composite parts.

1.2 Health and Safety

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. APPLICABLE DOCUMENTS

The following publications form a part of this specification to the extent specified herein.

2.1 NCAMP Publications

NMS 451	Medium Temperature, Out-of-Autoclave, Oven-Vacuum-Bag Cure Epoxy Resin Impregnated Fiber Reinforced Composite Materials

2.2 ISO Publications:

ISO 9000	Quality Management Systems

2.3 US Government Publications:

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

2.4 Advanced Composites Group (ACG) Publications:

AI/TR/1392	Design Allowable Property Data Acquisition and Test Plan For MTM45 & MTM45-1 Prepregs
ACGP 1001	Advanced Composites Group Process Specification, Fabrication of Medium Temperature Cure, Epoxy Resin Impregnated Fiber Reinforced Composite Parts
ACGP 1001-01	Advanced Composites Group Process Specification, Fabrication of Qualification, Allowable, Equivalency & Acceptance Laminate Test Panels of ACGM 1001 (MTM45 Resin Prepreg) Materials
ACGP 1001-02	Advanced Composites Group Process Specification, Fabrication of Qualification, Allowable, Equivalency & Acceptance Laminate Test Panels of ACGM 1001 (MTM45-1 Resin Prepreg) Materials

3. MATERIALS:

3.1 Vacuum bag, nylon 6 film, 2 mils, -80 to 400ºF use temperature
Sources:
- De-Comp Composites, Inc., RR 4 Box 4460, Cleveland, OK 74020 USA
- Airtech International, Inc., 5700 Skylab Road, Huntington Beach, CA 92647
- Or equivalent

3.2 Breather, 2.0 to 10 oz/yd2 or equivalent, non-woven polyester felt
Sources:
- De-Comp Composites, Inc., RR 4 Box 4460, Cleveland, OK 74020 USA
- Or equivalent

3.3 Breather string, glass roving strings/threads, ECDE 75 1/0, any finish (may be extracted from 7781 style glass fabric).
- Open source

3.4 Solid FEP, separator/release film, 1 to 2 mils, 375ºF minimum use temperature
Sources:
- A5000 Red or equivalent, 1 mil, from Umeco Process Materials, 12801 Ann Street, Santa Fe Springs, CA 90670
- Or equivalent

3.5 Caul sheets (caul plates), flat and smooth, aluminum, composite, or steel, 0.125-inch to 0.250-inch thick or 0.02" - 0.06" thick Paper Chipboard sheet (cut to the same dimensions as the panel).

- Open source

Note. Paper Chipboard was used for NMS 451/4 7781 E Glass and NMS 451/12 6781 S-2 Glass Qualifications.

3.6 Tape, Pressure Sensitive Flashbreaker Tape 375ºF minimum use temperature
Sources:
- D574A or equivalent #75 Blue Silicone, De-Comp Composites, Inc., RR 4 Box 4460, Cleveland, OK 74020 USA
- Or equivalent

3.7 Sealant tape, compatible with nylon vacuum bag, 375ºF minimum use temperature
Sources:
- SM5142 or equivalent, Umeco Process Materials, 12801 Ann Street, Santa Fe Springs, CA 90670
- Airtech International, Inc., 5700 Skylab Road, Huntington Beach, CA 92647
- Or equivalent

3.8 Mold (bottom tool), 0.25 to 0.50 inch thick, aluminum, steel, or composite, flat and smooth
- Open source

3.9 Release Agents
Sources:
- Frekote 700-NC, K.R. Anderson, Inc., 18330 Sutter Blvd. Morgan Hill, CA 95037 or equivalent

3.10 Peel-ply, uncoated
Sources:
- D1600 or D1700 or equivalent, De-Comp Composites, Inc., RR 4 Box 4460, Cleveland, OK 74020 USA
- Or equivalent

3.11 120 Style Glass Fabric
Sources:
- Open source

4. TEST LAMINATE FABRICATION

4.1 Prepreg cutting

Wear non-contaminating gloves such as disposable powder-free nitrile gloves when handling the prepreg. The prepreg may be cut using conventional method (i.e. on a polyurethane table top with utility knife) or automated method. The method of cutting must not contaminate the prepreg. Fiber orientation (e.g. warp versus fill directions) must be maintained during the cutting process. All the panels should have rectangular shapes;

intended to help maintain warp and fill direction traceability.

4.2 Prepreg layup and bagging

Wear non-contaminating gloves such as disposable powder-free nitrile gloves when handling the prepreg. The panel layups (stacking sequences) for qualification and equivalency purposes should be in accordance with appropriate test plans. For material acceptance purpose, the panel layups should be in accordance with NMS 451/X, where ”X” is the appropriate detail specifications.

In the case of materials which are not mid-plane symmetric, such as satin weave fabrics, plies must be orientated such as to give a mid-plane symmetric laminate as best as possible, as shown in Figure 1.

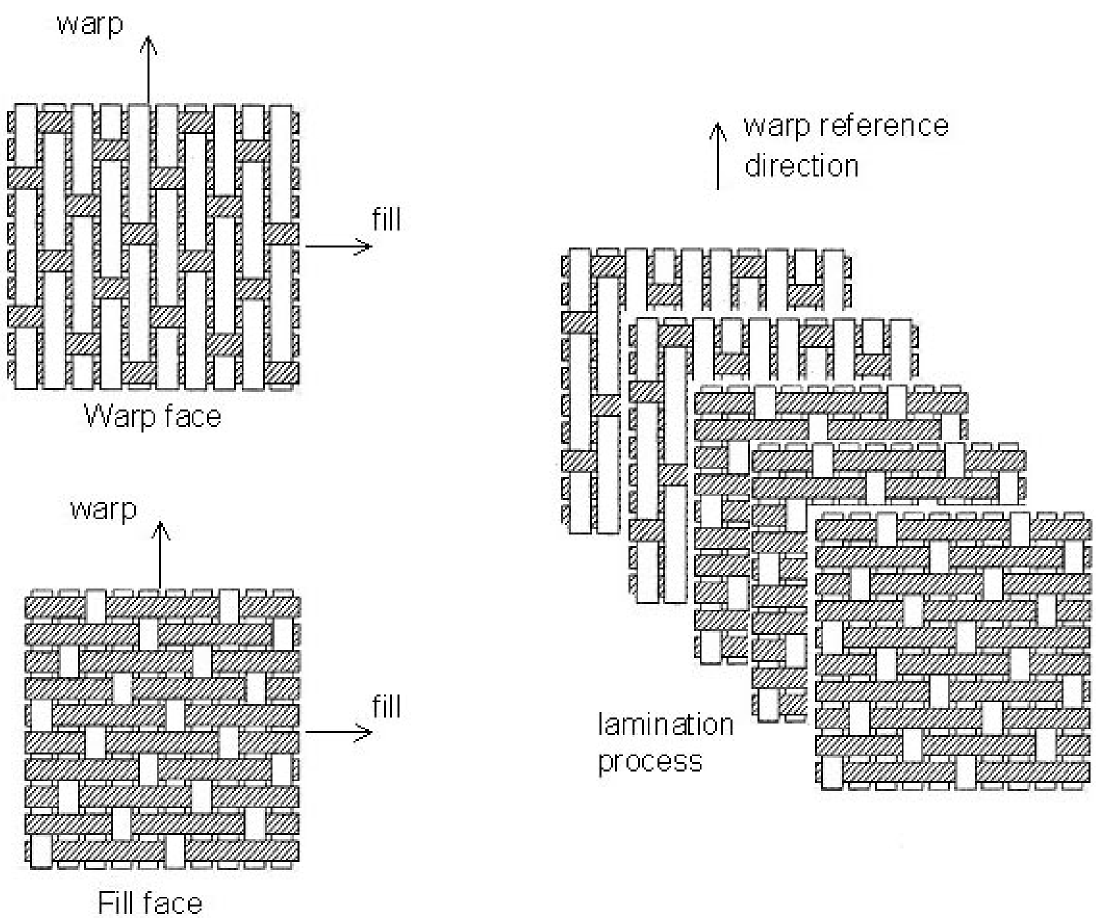

Figure 1 Example Satin Weave Showing Warp and Fill Faces Used for Ply Collation

In the layup of unidirectional prepreg, plies may be butt spliced in the 90º direction; ply splicing is not allowed in the 0º direction. Ply splicing is not allowed in the layup of woven fabric prepreg in any direction.

Figures 2 shows the bagging arrangement which is used for the manufacture of mechanical test panels from unitape and fabric prepregs. One edge of each panel, perpendicular to the 0° direction, will be molded against aluminum or steel edge reference bar to facilitate sub panel and specimen cutting and machining (not depicted in Figure 2). The caul sheets will contain scribe lines parallel to the 0° direction and will be butted against the edge reference bar. The caul sheet will not extend beyond the edge of the layup. If peel ply or 120 style glass fabric is used in place of the caul sheet reference lines parallel to the 0° will be drawn on the cured panels to replace reference lines from the caul sheet scribe lines. If peel ply or 120 style glass is used in place of the caul sheet breather shall not be placed directly over the part(s) so as to prevent “breather mark-off”.

In material qualification and equivalency programs, for panel identification purpose, place a label within ½-inch from the prepreg edge with the following information: “0º direction →, Test Plan Document Number -Prepregger ID - Material Code - Fabricator ID - Test Type - Batch ID - Cure Cycle ID -Test Panel ID.” Make sure that the “0º direction →” actually points in the 0º direction or warp direction. Appendix 2 of the test plan contains the panel identification information. Use a laser printer to print the labels on standard printer paper.

Thermocouple wires should be used to monitor and record the temperature of representative test panels. One method is to place the thermocouple junctions at the laminate mid-plane and near the edge of the laminate where they will be trimmed off after the panels have been cured. An alternative method is to place the thermocouple junctions on the part. The latter method allows the thermocouples wires to be reused if the thermocouple junctions are wrapped with Teflon or flash-breaker tape so that they can be removed from the part after cure. Thermocouples may be placed outside the bag only if it has been previously demonstrated that there is negligible temperature difference between the inside and outside of the bag.

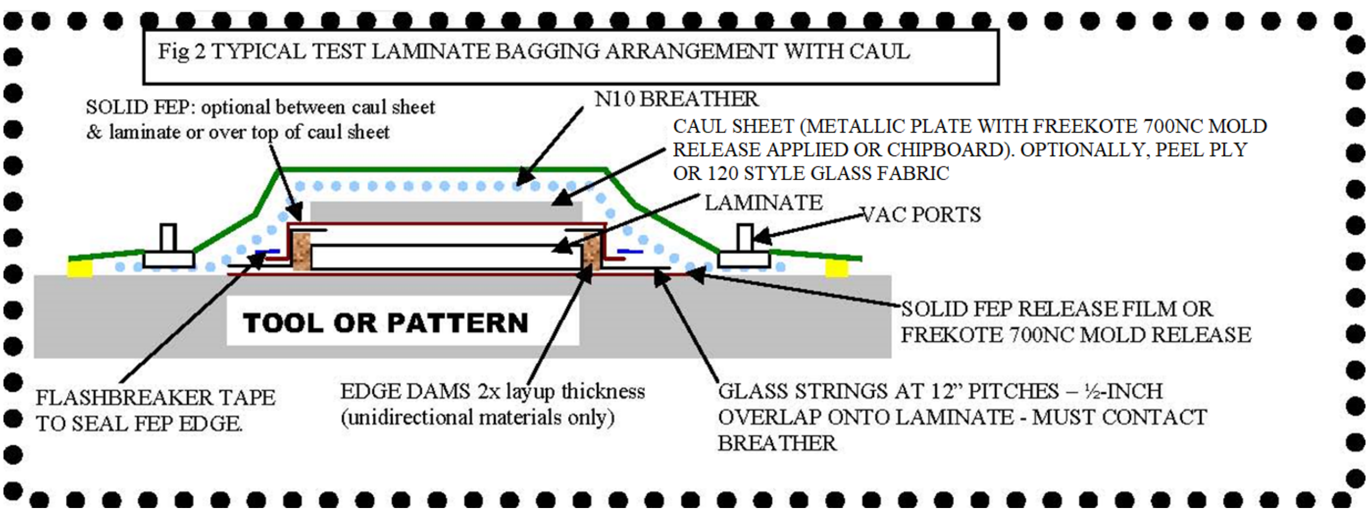

Figure 2 Bagging Technique (note: aluminum or steel edge reference bar not depicted)

NOTE FOR NMS 451/4 7781 E Glass: This material is 8HS reinforced with resin impregnation on the fill face only. It is recommended for potential users to use the same layup configuration as the Qualification which is Warp-Face-In (WFI), dry to dry mid-plane. Warp face is the dry side of the prepreg.

NOTE FOR NMS 451/12 6781 S-2 Glass: This material is 8HS reinforced with resin impregnation on the warp face only. It is recommended for potential users to use the same layup configuration as the Qualification which is Fill-Face-In (FFI), dry to dry mid-plane. Fill face is the dry side of the prepreg.

4.3 Baseline “MH” Cure Cycle

NOTE: Dwell times shall be determined from the time at which the lagging part/tool temperature reaches the minimum of the target temperature tolerance. A part/tool temperature overshoot of tolerance on heat-up is allowed to 10°F and 10 minutes maximum.

The Medium temperature cure/High temperature postcure “MH” cycle:

1. Insert the bagged lay-up into an oven not exceeding 120°F.
2. Connect vacuum line(s) and thermocouple(s).
3. Confirm thermocouples are functioning and applied vacuum meets the requirements of section 4.3.1 below and check for vacuum leak(s).
4. Maintain full vacuum of 28 inches Hg minimum throughout the cure.
5. Heat the oven to achieve a part temperature and ramp rate of 175 – 190°F and 1 to 5.5°F per minute.
6. Dwell the part temperature at 175 – 190°F for minimum three (3) hours, maximum five (5) hours.
7. Heat the oven to achieve a part temperature and ramp rate of 250 ± 10°F and 1 to 5.5°F per minute.
8. Dwell the part temperature at 250 ± 10°F for minimum three (3) hours, maximum five (5) hours.
9. Cool the part(s) in the oven under full vacuum to ambient or maximum part temperature of 140°F and demold.
10. Freestanding postcure at part temperature and ramp rate of 350 ± 10°F and 35°F per hour maximum from 250°F to 350°F and dwell for one (1) to two (2) hours at 350 ± 10°F. Oven may be preheated to 250°F or ramp rate to 250°F maximized. Cool the part(s) in the oven to ambient or maximum part temperature of 140°F before handling. Demolding for postcure is optional for test panels.

Alternative Post Cure at 350°F:

- Post Cure may be done on the tool under vacuum as a continuation of the previous cure cycle.

4.3.1 Vacuum Requirements

The quality of vacuum, especially for final cure, has been found to have a profound effect on the quality of oven/vacuum bag cured laminates. The minimum required vacuum level is 28" Hg under average sea level conditions with an assumed ambient barometric pressure of 30" Hg. The requirement may be reduced for lower barometric pressure levels due to altitude or atmospheric conditions, the required vacuum gauge reading being reduced by the difference between the actual ambient barometric pressure and 30" Hg. In the absence of a direct measure of barometric pressure being available, the requirement of 28"Hg may be reduced by 0.001"Hg per foot of elevation above sea level.

Tools larger than 3 ft^2 or longer than 5 feet shall have at least two vacuum connections at opposite ends or corners of the tool. Tools longer than seven feet shall have at least one vacuum connection every three feet of tool length.

Prior to the start of the cure cycle, the vacuum bag shall be checked for leak rate by applying full vacuum (minimum 27 inches Hg in Tulsa, OK) then removing the vacuum source. The maximum leak rate of the bag shall not exceed five inches mercury (Hg) over a minimum five minute period as measured immediately after removing the vacuum source. It is recommended the vacuum gage be located as far as possible from the vacuum source by a “dead-end” gage.

For vacuum bag cure processes, vacuum level shall be verified and recorded minimum at start and end of cure. An analog vacuum gage located in line at the source manifold will suffice.

4.4 Alternative Cure Cycles

Based on limited historical data, a resin cure kinetics model, and a viscosity model, the lamina and laminate material properties are believed to be robust to some minor changes in the cure cycle, although deviations from the baseline “MH” cure cycle may increase the risk of equivalency failure. The cure cycle tolerance (i.e. upper and lower cure cycle envelope) has also not been thoroughly investigated. **Since not all properties are investigated in a typical equivalency program, users should not assume that successful equivalency demonstration also means that all other properties are equivalent; a more extensive test matrix that includes more test methods and test conditions may be necessary to thoroughly evaluate the true equivalency of the alternate cure cycle(s). Based on the popularity of the alternate cure cycle(s), NCAMP may perform more extensive testing to investigate the equivalency of the alternate cure cycle(s).**

Users who wish to use the alternate or any other cure cycles may contact NCAMP to have the cure cycles evaluated against the cure kinetics model and the viscosity model. This evaluation will provide a reasonable level of confidence about the similarities of the two cure cycles and may improve the chance of successful equivalency demonstration.

4.4.1 Alternative “LH” Cure Cycle

This cure cycle may not show a successful equivalency demonstration to the Qualification baseline MH cure cycle. Users may contact NCAMP if this cure cycle is being considered. NCAMP may be able to share a published LH Equivalency reports.

An alternative Low temperature cure/High temperature postcure or "LH" cure cycle to permit low cost tooling:

1. Insert the bagged lay-up into an oven not exceeding 120°F.
2. Connect vacuum line(s) and thermocouple(s).
3. Confirm thermocouples are functioning and applied vacuum meets the requirements of section 4.3.1 below and check for vacuum leak(s).
4. Maintain full vacuum of 28 inches Hg minimum throughout the cure.
5. Heat the oven to achieve a part temperature and ramp rate of 175 – 190°F and 1 to 5.5°F per minute.
6. Dwell the part temperature at 175 – 190°F for minimum seventeen (17) hours, maximum twenty (20) hours.
7. Cool the part(s) in the oven under full vacuum to maximum part temperature of 140°F before releasing vacuum and de-mold.
8. Freestanding postcure at part temperature and ramp rate of 350 ± 10°F and 35°F per hour maximum from 175°F to 350°F and dwell for one (1) to two (2) hours at 350 ± 10°F. Oven may be preheated to 175°F or ramp rate to 175°F maximized. Cool the part(s) in the oven to ambient or maximum part temperature of 140°F before handling. Demolding for postcure is optional for test panels.

Alternative Post Cure at 350°F:

- Post Cure may be done on the tool under vacuum as a continuation of the previous cure cycle.

4.4.2 Alternative "M" Cure Cycle

This cure cycle may not show a successful equivalency demonstration to the Qualification baseline MH cure cycle. Users may contact NCAMP if this cure cycle is being considered. NCAMP may be able to share a published M Equivalency reports.

A Medium temperature cure or "M" cure cycle for medium temperature performance:

- Cure same as MH cure cycle above except dwell at 250 ± 10°F for minimum four (4) hours, maximum six (6) hours and eliminate the postcure.

4.4.3 Alternative Autoclave "AH" Cure Cycle

This cure cycle may not show a successful equivalency demonstration to the Qualification baseline MH cure cycle. Users may contact NCAMP if this cure cycle is being considered. NCAMP may be able to share a published AH Equivalency reports.

The Autoclave High temperature Cure "AH" cycle:

1. Insert the bagged lay-up into the autoclave.
2. Connect the vacuum lines and thermocouples.

3. Confirm that the thermocouples are functioning and applied vacuum meets the vacuum leak check requirement of 5" of Hg in 5 minutes.
4. Apply minimum vacuum of 22" of Hg.
5. Heat at 1 to 6°F per minute to 355±10°F and ramp autoclave pressure to 85-100 psig.
6. Before temperature reaches 140°F and when autoclave pressure is 20±10 psig, vent vacuum bag to atmosphere.
7. From 325°F to 355±10°F a minimum heat-up rate of 0.3°F/minute is acceptable.
8. Hold 355±10°F for 120+60/-0 minutes.
9. Cool down rates from cure temperature to 150°F shall be no more than 10°F/minute.
10. Release autoclave pressure when lagging thermocouple is below 150°F or minimum 1 hour into cool down, whichever occurs first.

4.5 Cured Panels

The reference edge created in section 4.2 should be clearly marked on each panel. This reference edge will be used as datum for subsequent machining process. Sharp edges should be removed from cured panels so that they can be handled and packaged safely. No more than 0.5-inch shall be removed inside of the original edge of the prepreg.

5. QUALITY ASSURANCE

5.1 Process Control

In-process monitoring data such as part temperature, oven temperature, vacuum, and part vacuum readings through the cycle should be in accordance with user's applicable company process specification or an approved shop practice. For material qualification and equivalency purposes, the in-process monitoring data should be provided to the appropriate organizations in accordance with the applicable test plan. Process control testing is not required for the fabrication of test panels.

5.2 Ultrasonic Non-Destructive Inspection

Panel fabricator need not perform ultrasonic non-destructive inspection on the test panels. For material qualification and equivalency purposes, the panels may be ultrasonically inspected by the testing lab in accordance with the applicable test plan.

5.3 Visual Inspection

Verify that there is no obvious defect such as warpage and dry spots. Panels for material qualification and equivalency purposes should be labeled in accordance with applicable test plan for identification purposes.

6. SHIPPING

For material qualification and equivalency purposes, it may be necessary to send the panels to a designated test lab. The panel shipping instruction is typically included in the applicable test plan.