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NCAMP Process Specification

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Fabrication of NMS 191 Qualification, Equivalency, and Acceptance Test Panels

(Hexcel Hexply® M91 toughed epoxy prepreg)

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REVISIONS

Revision	Name	Date	Description
-	Jonathan John	10/21/2022	Initial Release
A	Jonathan John	8/7/2023	- Added "ultraweave and airweave breather" into the breather option in section 3.2 - Added ""teflease and flashbreaker tape" into the alternative mylar tape in section 3.7 - In section 4.1, changed the wording in the 2nd last sentence to reflect that "Any prepreg that contains defect beyond those allowed in the relevant material specification shall not be used" from "any prepreg that contains defects that are observed visually shall not be used" - In section 4.3, removed steel for caul plate options and use only aluminum. Increased the range of thickness as well from 0.125"-0.25" to 0.063" to 0.25". Made the use of roller to remove air bubble as optional instead of mandatory - Updated the bagging schematic image to add the note of using different types of breather rather than just a specific type. Added new bagging scheme for foam core layup - On section 4.4, on note 9, a second sentence was added to clarify the time tolerance is applicable only in the - Updated table 1 with more detailed info of ramp and cool rate, and time
B	Jonathan John	10/13/2025	- Pg 14, Table 1, updated the unit of the vacuum from psi to inHG

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1. SCOPE

This process specification describes the methods of fabricating test panels using NMS 191 prepregs. Specifically, this specification covers prepreg cutting, layup, vacuum bagging, and curing process with an autoclave 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 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. The latest issue of the NCAMP publications shall apply. When a referenced document has been canceled and no superseding document has been specified, the last published issue of that document shall apply.

2.1 NCAMP Publication

NMS 191	Autoclave Cure, High Toughness with High Residual Compression Strength Epoxy Prepregs
NMS 191/1	Autoclave Cure, High Toughness with High Residual Compression Strength Epoxy Prepregs, Hexcel M91/IM8-GS Unidirectional tape
NMS 191/2	Autoclave Cure, High Toughness with High Residual Compression Strength Epoxy Prepregs, Hexcel M91/IM8-GP 6K ZB Fabric

2.2 ISO Publication:

ISO 9000	Quality Management Systems

2.3 SAE Publication:

AS 9100	Quality Management Systems - Requirements for Aviation, Space and Defense Organizations

2.4 US Government Publication:

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

3. MATERIALS:

3.1 Vacuum bag,

- nylon film, 3 mils maximum, qualified for use at 375ºF or above, or equivalent
- Airtech International, Inc., 5700 Skylab Road, Huntington Beach, CA 92647
- Or equivalent

3.2 Breather,

- 300 GSM Glass Surface breather
- Ultraweave breather or equivalent

- Airweave breather, or equivalent

3.3 Breather string

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

3.4 Solid FEP film

- separator/release film, 1-2 mils thick, qualified for use at 375ºF or above
- Airtech International, Inc., 5700 Skylab Road, Huntington Beach, CA 92647
- Or equivalent

3.5 Solid (Nonporous) Teflon Coated Glass Fabric

- 3-5 mil
- Taconic, 3070 Skyway Drive, Bldg 203 Santa Maria, CA 93455
- Or equivalent

3.6 Pressure (Caul) Plate

- 0.060 – 0.2500 inch thick, aluminum is preferred, flat and smooth, or equivalent
- 0.032”-0.1” thick low alloy steel
- Open source

3.7 Mylar Tape

- Pressure Sensitive Mylar Tape qualified for use at 375ºF or above
- Keystone Tape, 3911 E. La Palma Ave., Suite V Anaheim, CA 92807
- Airtech International, Inc., 5700 Skylab Road, Huntington Beach, CA 92647
- Teflease Tape
- Flashbreaker tape
- Or equivalent

3.8 Tacky (Sealant) tape

- compatible with nylon vacuum bag, qualified for use at 375ºF or above
- Airtech International, Inc., 5700 Skylab Road, Huntington Beach, CA 92647
- Or equivalent

3.9 Mold

- (bottom tool), 0.250-0.500 inch thick, aluminum, flat and smooth, or equivalent
- Open source

3.10 Release Agents

- Frekote 44-NC, Frekote 55-NC, Frekote 700-NC
- Henkel, One Henkel Way, Rocky Hill, CT 06067
- Or equivalent

4. TEST LAMINATE FABRICATION

4.1 Prepreg cutting

Wear non-contaminating gloves such as disposable powder-free nitrile gloves when handling the prepreg. Make sure the material is warmed and thawed to ambient temperature before they are cut. The prepreg may be cut using conventional method (i.e. on a glass or non-contaminating polyurethane table top with utility knife) or automated method. The method of cutting must not contaminate the prepreg. **The prepreg shall be cut a minimum of ½" larger on each edge than the required panel dimensions. The required panel dimensions are specified in Appendix 2 of applicable test plan or work instruction.** Fiber orientation (e.g. warp versus fill directions) must be maintained during the cutting process. In Appendix 2 of applicable test plan, the warp/longitudinal directions are always larger than the fill/transverse directions; this rectangular shape helps maintain direction traceability. Any prepreg that contains defect beyond those allowed in the relevant material specification shall not be used. The prepreg storage life and exposure time shall be recorded and monitored so that it does not exceed the defined requirements in the material specification document.

4.2 Prepreg lay up 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 Appendix 2 of appropriate test plans. For material acceptance purpose, the panel layups should be in accordance with NMS 191. The lay up should be conducted in a clean and environmentally controlled temperature and humidity. When the Frekote release agent is being used, it should not be applied in the same room the parent prepreg is used. The filters in the air for the room should be replaced per the defined schedule to make sure the space is conducive for the intended application with minimal airborne particles.

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.

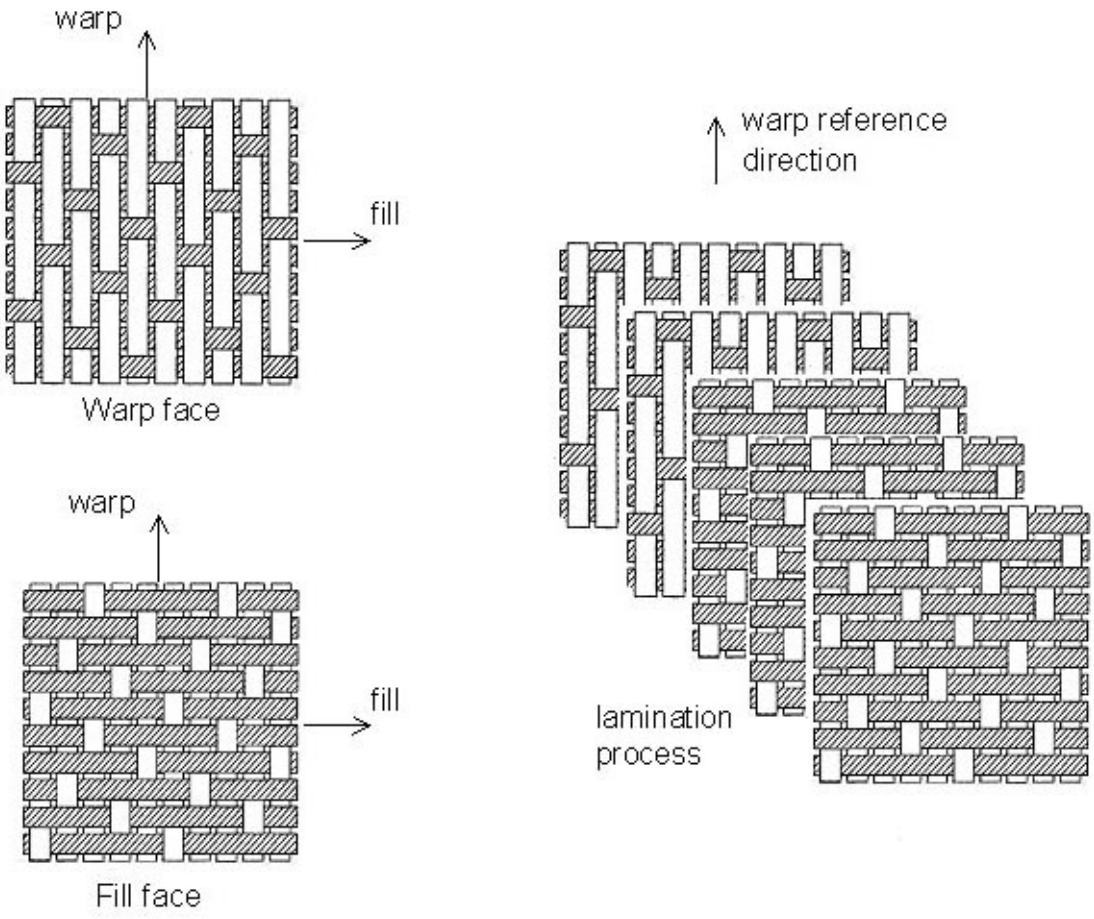


Figure 1 - Example Satin Weave Showing Warp and Fill Faces Used for Ply Collation

In order to maintain the fiber orientation, a reference edge should be indicated on each panel. Use a straight edge ruler/dam to ensure proper fiber orientation during layup. During the layup process, each ply must be laid up within ±5° for fabric, and ±3° for tape of the reference edge. In the layup process 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.

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 →" marking is near to the reference edge and actually points in the 0º direction or warp direction. Appendix 2 of the test plan contains the panel identification information.

4.3 Facility and Equipment Control

The facility that is to fabricate the test panels should have an autoclave that is able to handle a required vacuum of 20 in-Hg. It should meet the maximum pressure and heat called out on the process, which is 90psi and 350 F respectively. The control system on the autoclave should be calibrated to make sure it is right. The size of the autoclave should be able to fit the biggest panel size called out in the test plan.

The layup and bagging shall be conducted in a room in which the environment is controlled based on the processing specification of the company. The caul plates and base plates should be made out of aluminum. The thickness of the base plate is recommended to be within the range of 0.25” to 0.5”. The caul plate should possess a thickness between 0.063”-0.25”.

Cutting prepreg material should be done with the assistance of either a template, laser projection or an overlay to assist cutting. A tool bar should be used to align the ply orientation to the reference edge. During the process of layup, remove the backing paper and lay them up on the tool. Optionally, the use of a roller to ensure adequate ply adherence and to remove air bubbles is suggested. Make sure to save all the backing papers that have been removed, to make sure the ply count is verified.

Bagging scheme:

Each panel will be bagged per Figure 2. Wrinkle free non-perforated release must be used as shown on the bag side. Use of wrinkle free non-perforated release on tool side is optional. Breather strings must be placed at all corners and along the panel edge at spacing not to exceed 12 inches. For panel edges less than 12 inches long, breather strings are only required at the corner.

Breather strings should be constructed from E-glass continuous filament, 3700 yds/lb of yarn, 4 strands twisted together, or equivalent E-glass breather string. Breather strings should be folded in half and the folded end placed underneath the panel.

For bagging a cure, a minimum of one vacuum source and one vacuum gage line (transducer) is recommended. Alternatively, if only one port is used, a vacuum verification should be performed by removing the vacuum line and placing the gage. A minimum of 2 thermocouple is highly recommended under each vacuum bag, if more than one panel is bagged together.

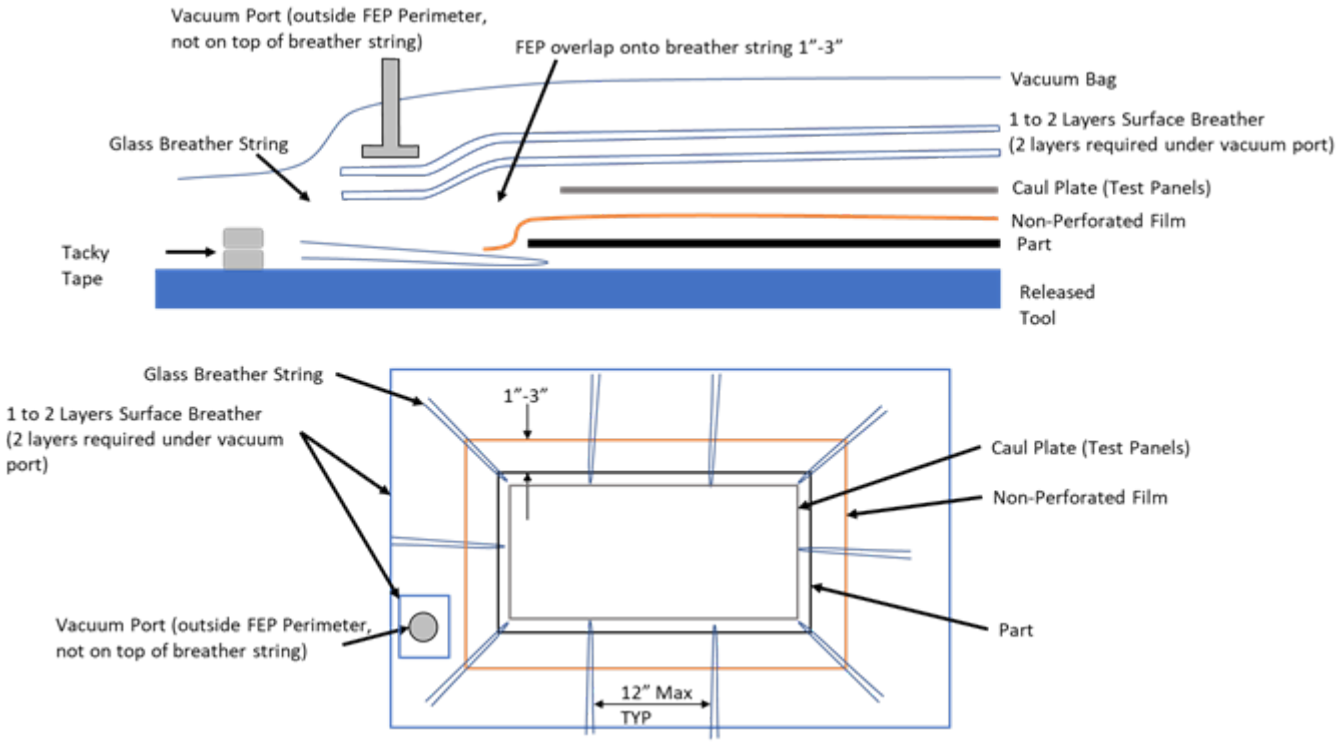
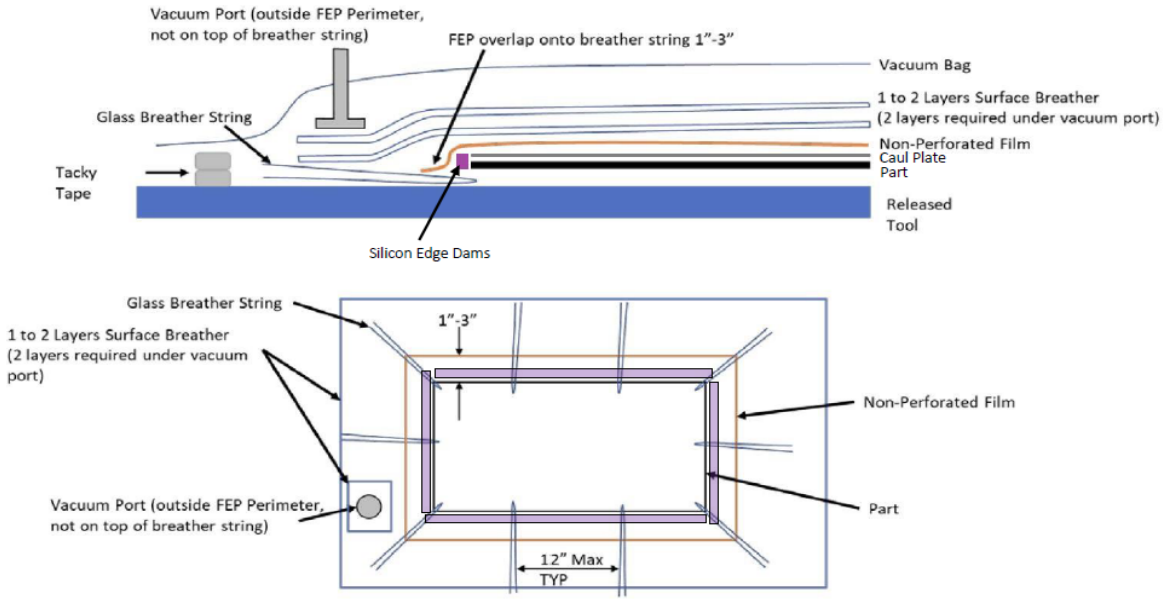


Figure 2 - Bagging scheme for flat laminate



Note:

1. For straight edge core, the edge dams are required around the periphery of the sandwich part.
2. The edge dams are made of silicone and taped using Flashbreaker.

Figure 3- Bagging scheme for Foam Core layup

4.4 Baseline Cure Cycle (C)

The baseline cure cycle shall be in accordance with the following process. For the purpose of specimen naming, this cure cycle is designated as "C." The material qualification panels are processed in accordance with the baseline cure cycle. Check vacuum bag integrity prior to starting cure cycle; leak rate shall not exceed 1" of Hg in 5 minutes. All temperatures are panel temperatures based on the lagging thermocouple unless otherwise specified. The vacuum and temperatures shall be recorded at 5 minute intervals maximum.

Two separate cure cycles will be used for the unidirectional and plain weave material form qualifications. The unidirectional cure cycle will be performed at 90 psi and the plain weave cure cycle will be performed at 35 psi.

Unidirectional Cure

The following baseline cure cycle is intended for the fabrication of :

1. Ensure the autoclave air temperature is below 100°F prior to inserting the tool in the autoclave.

2. Place the tool in the autoclave, install the thermocouple connectors and vacuum lines, and close the autoclave door.

3. Apply a minimum of 20 +10/-0 in-Hg full vacuum. Wait for 10-15 minutes to see if there are any leaks in the bagging.

4. Apply 15 ± 5 psig autoclave pressure.

5. Heat to 250°F ± 10°F at a rate of 1-3°F/min (target 2°F/min) based on lead part thermocouple.

6. Hold at 250°F ± 10°F (part temperature) for 60 minutes +30/-0 mins based on lagging part thermocouple.

7. Apply 90 psi ± 5 psi autoclave pressure, venting vacuum to a safety value of 6 in-Hg when autoclave pressure reaches 20 psi.

8. Heat to 350°F ± 10°F at a rate of 1-3°F/min (target 2°F/min) based on lead part thermocouple.

9. Hold at 350°F ± 10°F for 120 minutes +15/-0 minutes starting when the lagging part thermocouple reaches 340°F. The time tolerance is only applicable based on the lagging thermocouple.

10. Cool at 3°F to 9° per minute to below 150°F.

11. Vent autoclave pressure below 150°F.

12. Open the autoclave door only after the pressure is completely vented out, with the part temperature being below 150°F.

Plain Weave Cure

The following baseline cure cycle is intended for the fabrication of :

1. Ensure the autoclave air temperature is below 100°F prior to inserting the tool in the autoclave.

2. Place the tool in the autoclave, install the thermocouple connectors and vacuum lines, and close the autoclave door.

3. Apply a minimum of 20 +10/-0 in-Hg full vacuum. Wait for 10-15 minutes to see if there are any leaks in the bagging.

4. Apply 15 ± 5 psig autoclave pressure.

5. Heat to 250°F ± 10°F at a rate of 1-3°F/min (target 2°F/min) based on lead part thermocouple.

6. Hold at 250°F ± 10°F (part temperature) for 60 minutes +30/-0 mins based on lagging part thermocouple.

7. Apply 35 psi ± 5 psi autoclave pressure, venting vacuum to a safety value of 6 in-Hg when autoclave pressure reaches 20 psi.

8. Heat to 350°F ± 10°F at a rate of 1-3°F/min (target 2°F/min) based on lead part thermocouple.

9. Hold at 350°F ± 10°F for 120 minutes +15/-0 minutes starting when the lagging part thermocouple reaches 340°F. The time tolerance is only applicable based on the lagging thermocouple.

10. Cool at 3°F to 9° per minute to below 150°F.

11. Vent autoclave pressure below 150°F.

12. Open the autoclave door only after the pressure is completely vented out, with the part temperature being below 150°F.

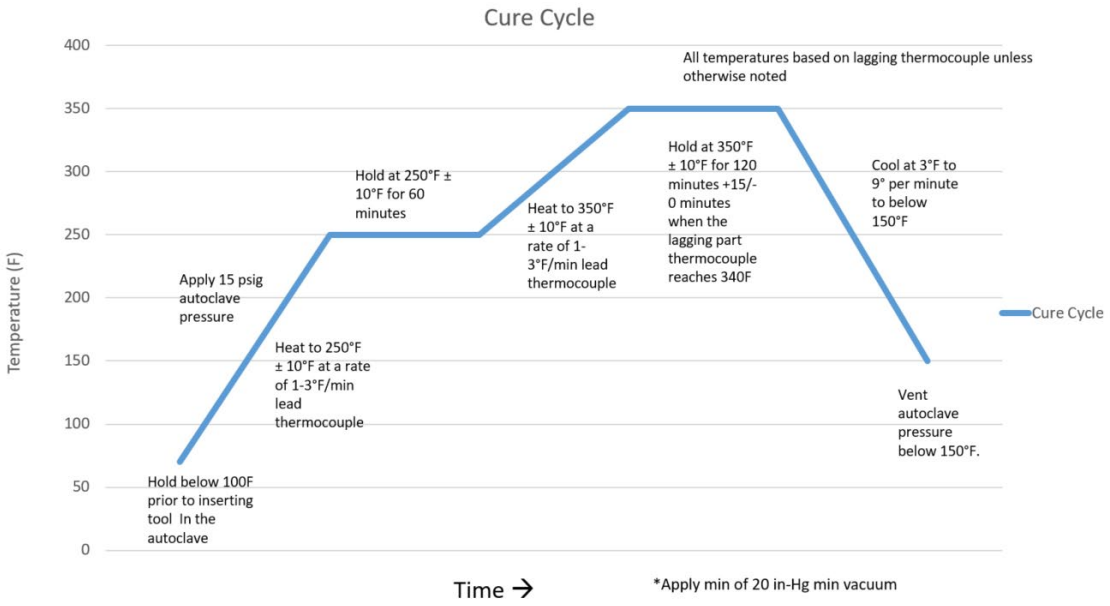


Figure 4 – Baseline and Alternate Low Pressure Cure Cycles

Parameter	**Application Intent**	**Application**	**Tolerances**
Temperature	Start Temperature	100°F	Maximum
Vacuum	Vacuum level during dwell	20 in-Hg	+10/-0 in-Hg
Pressure	Pressure during dwell	15 psig	+/- 5 psig
Ramp Rate	Ramp to dwell	2 °F/min	+/- 1 °F/min
Temperature	Dwell Temperature	250 °F	+/- 10°F
Time (based on lag TC only)	Dwell Time	60 minutes	+30/-0 minutes
Pressure	Pressure during cure	35 psig (plain weave) OR 90 psig (unidirectional)	+/-5 psig
Vacuum	Vacuum level during cure (vent to safety valve at 20 psig autoclave pressure)	6 inHG	Maximum
Ramp Rate	Ramp to cure	2 °F/min	+/- 1 °F/min
Temperature	Cure temperature	350 °F	+/- 10°F
Time	Length of cure	120 minutes	-0/+15 minutes
Cool Rate	Cool from cure	6 °F/min	+/- 3 °F/min
Temperature	Temperature for vent/end of cycle	150 °F	Minimum

Table 1 - Process parameter table

4.5 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 qualification 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.

4.6 Cured Panels

The reference edge 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.

5. QUALITY ASSURANCE

5.1 Process Control

In-process monitoring data such as part temperature, autoclave 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. The quality assurance organization has the responsibility to ensure that all the fabricated parts comply to the specifications that are called out. The quality crew should also make sure that the fabrication is performed by qualified technicians.

The quality assurance crew should also perform necessary inspection to make sure the autoclaves and freezers are calibrated per the defined schedule. Before the prepregs are cut, quality crew are also responsible in making sure that the proper material rolls are used for fabrication. All other prep work that is required before the material is layed up, including thawing, out time recording, etc. should be done in accordance to the material specifications called out in the NMS 191 spec.

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 shall be ultrasonically inspected by the testing lab in accordance with the applicable test plan.

5.3 Visual Inspection

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