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AEROSPACE RECOMMENDED PRACTICE

SAE ARP5606

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Composite Honeycomb NDI Reference Standards

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1. SCOPE:

This recommended practice establishes generic reference standards that will accommodate nondestructive inspections (NDI) on a broad range of non-metallic composite honeycomb structures found on aircraft.

1.1 Purpose:

The purpose of this Aerospace Recommended Practice (ARP) is to describe the design and production of composite honeycomb calibration standards to be used in ultrasonic, resonant, and tap test NDI equipment calibration for accomplishment of damage assessment and post-repair inspection of aircraft composites. These standards may also be appropriate for other NDT methods but will need to be assessed as appropriate prior to their use. The standards are representative of damage found in the field and include typical flaw scenarios such as disbonds and delaminations. It is intended that these standards be adopted by aircraft Original Equipment Manufacturers within procedures contained in their Nondestructive Testing Manuals. Depending on the nature of the inspection, it may be necessary to compensate for variations in material properties through the use of correction factors or by adjusting for these differences on the part or structure being inspected. In certain instances, it may be desirable or necessary to design a new reference standard to accommodate a specific inspection application.

Currently, the recognized number of composite honeycomb construction variables makes the resulting number of specimens very large and unmanageable. Inspection characterizations and equipment responses have been used to determine the important variables needed in a composite reference standard thus eliminating unnecessary standard configurations. This ARP describes a workable number of reference specimens that can meet the needs of a broad range of honeycomb structures found on aircraft.

1.2 Background:

The CACRC Inspection Task Group developed this ARP in an effort to establish a single, generic set of composite honeycomb reference standards that would accommodate inspections on the majority of non-metallic honeycomb structures found on aircraft. The advantages of industry-wide accepted composite standards include: (1) providing a consistent approach to composite inspection thus helping to minimize false calls, (2) reducing standard procurement costs, and (3) aiding the assessment of composite inspection technologies. The goal of this project is to develop standards that will allow for repeatable, accurate inspections in light of increases in the number of composite structure inspection tasks. Specific use of the honeycomb standards described in this ARP can be achieved through the OEM inspection procedures found in Nondestructive Testing Manuals and Nondestructive Testing Standard Practice Manuals.

1.3 Supporting Data:

The number of construction variables encountered in composite honeycomb structure makes the number of potential reference standards needed to support the inspections very large. In an effort to reduce the number of standards needed with proper engineering justification, key construction variables were identified and their affects on inspection results were assessed. The variables evaluated were: skin material, skin thickness, core material, core thickness, core weight, and cell size. Additionally, various methods of manufacturing flaws were evaluated to ensure repeatable and accurate representation of disbonds and delaminations. A suite of 64 honeycomb panels, representing reasonable bounding conditions of the construction variables listed above were manufactured and inspected using a wide array of sonic and ultrasonic NDI techniques. In this manner, the effects of each variable on NDI could be assessed in order to provide justification for minimizing the number of calibration standards.

An analysis of the resulting data identified skin material, skin thickness, and core material as the key variables affecting the inspection method used. A final set of minimum honeycomb reference standards were designed and fabricated to include these key variables. A sequence of NDI experiments were completed to demonstrate that this minimum honeycomb reference standard set is able to fully support inspections over a wide range of honeycomb construction scenarios.

1.4 Use of Standards:

It is hoped that these honeycomb standards will be applicable to most composite honeycomb structures found on aircraft, however, the specific range of construction variables certified in this study are listed in Table 1. Reference [1] presents the NDI testing and analysis that was carried out to arrive at the final set of honeycomb standards described in this ARP. Specific testing will be needed to certify the use of these standards outside the type and range of variables listed in Table 1.

Furthermore, when using these standards, consideration needs to be given to surface coatings such as paint or lightning protection plies. This is a reference standard construction document and not an inspection document. Inspection procedures, from OEM or users' maintenance manuals, must accompany the use of these reference standards for each unique family of composite honeycomb construction.

TABLE 1 - Range of Composite Honeycomb Construction Variables
Tested to Arrive at the Standards Listed in This ARP

Composite Construction Variable	Bounding Conditions Studied
Laminate Material	Carbon & Fiberglass
Laminate Thickness	3 plies - 12 plies
Honeycomb Core Material	Nomex & Fiberglass
Honeycomb Core Thickness	0.25" - 2.0" thick (6.35 - 49 mm)
Honeycomb Cell Size	0.125" - 0.25" width (3.18 - 6.35 mm)
Honeycomb Core Density	2 - 8 lb/ft^3

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The applicable issue of the referenced publications shall be the issue in effect on the date of the purchase order.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE-AMS-C-9084 Cloth, Glass, Finished, For Resin Laminates

2.1.2 Other Publications:

Roach, D.P., Dorrell, L.R., Kollgaard, J., Dreher, T., "Improving Aircraft Composite Inspections Using Optimized Reference Standards", SAE Airframe Maintenance and Repair Conference, Nov. 1998, SAE Technical Paper 98AEMR-34

Industry specifications are listed for information in 4.1

2.2 Nomenclature:

ARP Aerospace Recommended Practice
NDI Nondestructive Inspection
NDT Nondestructive Testing
NEMA National Electric Manufacturers Association
OEM Original Equipment Manufacturer

3. TECHNICAL REQUIREMENTS:

3.1 Fabrication and Materials:

Fabrication of the honeycomb/composite panels (see Figures 11 and 12) consists of three tasks: (1) fabrication of the composite laminate plates for the top and bottom of the sandwich assembly, (2) preparation of the honeycomb core material, and (3) secondary bond of laminate to honeycomb core to produce the honeycomb panels.

Appendix A contains a series of photos showing the steps involved in the three major panel production activities: (1) laminate skin preparation, (2) honeycomb core preparation, and (3) honeycomb panel assembly. These photos should be referenced as the fabrication instructions below are carried out.

3.1.1 Laminate: Prepare the laminates as per the specimen drawings CHRS-1 and CHRS-2 contained in these instructions. Also see 3.1.4 regarding the engineered flaws. Place laminates on smooth tool as per lay-up shown in Figure 1 and cure per the laminate temperature profiles shown in Figure 2. All "pillow insert" flaws are located two plies down from the "peel ply" side shown in Figure 1 below.

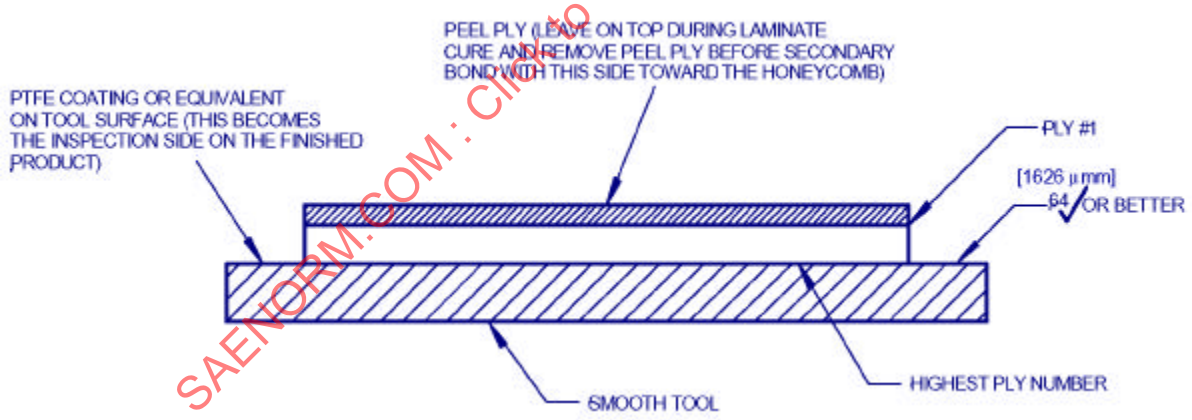

FIGURE 1 - Laminate Lay-Up on Smooth Tool

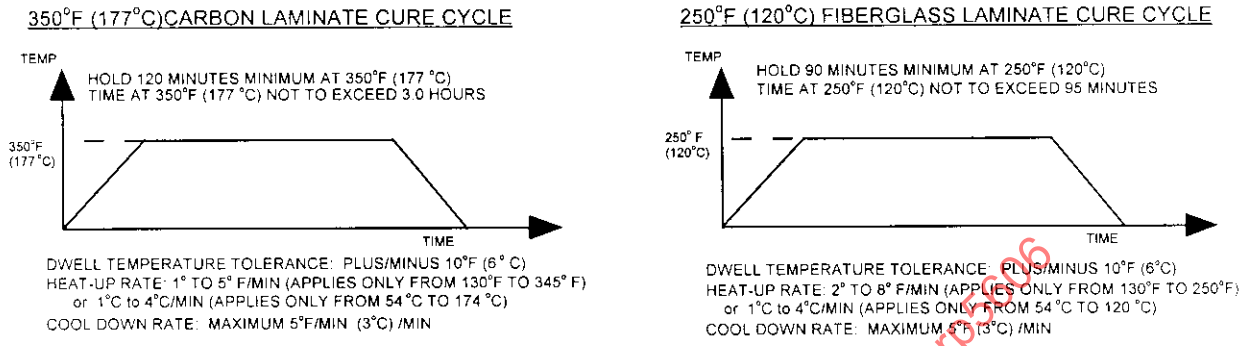

FIGURE 2 - Laminate Cure Temperature Profile

3.1.1 (Continued):

Produce 16 laminate plates, two each of each material type (carbon and fiberglass) at 3, 6, 9, and 12 ply thicknesses. One laminate of each material type and ply thickness will contain flaws and the other will not. Size and layout for laminates during cure cycle is shown in Figure 3. Use an autoclave or automated oven and cure laminates in a vacuum bag at 11 to 12 psi (568.9 to 620.6 mm Hg; 75.9 to 82.7 kPa). Note: In order to create the proper attenuation and desired laminate response properties do not exceed 12 psi in the cure pressure.

FIGURE 3 - Summary of Individual Laminate Sheets
[Dimensions in brackets are in mm]

3.1.1 (Continued):

NOTE: There are two laminate plates per specimen – one with flaws and one without flaws. Laminates are cured first and then bonded to the honeycomb in a secondary process.

3.1.1.1 Laminate Lay-Up:

3 ply lay-up: [+45, 90, -45]
6 ply lay-up: $[+45, 90, -45]_2$
9 ply lay-up: $[+45, 90, -45]_3$
12 ply lay-up: $[+45, 90, -45]_4$

3.1.2 Honeycomb: Prepare the honeycomb in accordance with the engineering drawings shown in 3.3 and summarized in Table 2. The honeycomb preparation consists of: (1) adding the machined core flaws, (2) producing a potted core region, and (3) making a core splice using a foaming adhesive. Before joining the laminates to the honeycomb ensure that the ribbon direction is on the X-axis along the 12.00 inch (304.8 mm) dimension (see Figure 4). Join the laminates to the honeycomb using a secondary bond per the cure temperature profiles shown in Figure 5. The "tool side" of the laminate (see Figure 1) should face outward (inspection surface) and the "peel ply" side of the laminate should be placed toward the honeycomb (bonded surface). For typical setup of honeycomb to laminate bond see Figure 6. Note: actual peel ply should be removed from laminates before secondary bonding process.

TABLE 2 - Summary of Laminate and Honeycomb Types with Reference to Engineering Drawings for Fabrication

Engineering Drawing & Specimen Number	Laminate Material	Core Material	Number of Plies
CHRS-1-3	Fiberglass	Nomex & Fiberglass	3
CHRS-1-6	Fiberglass	Nomex & Fiberglass	6
CHRS-1-9	Fiberglass	Nomex & Fiberglass	9
CHRS-1-12	Fiberglass	Nomex & Fiberglass	12
CHRS-2-3	Carbon Fabric	Nomex & Fiberglass	3
CHRS-2-6	Carbon Fabric	Nomex & Fiberglass	6
CHRS-2-9	Carbon Fabric	Nomex & Fiberglass	9
CHRS-2-12	Carbon Fabric	Nomex & Fiberglass	12

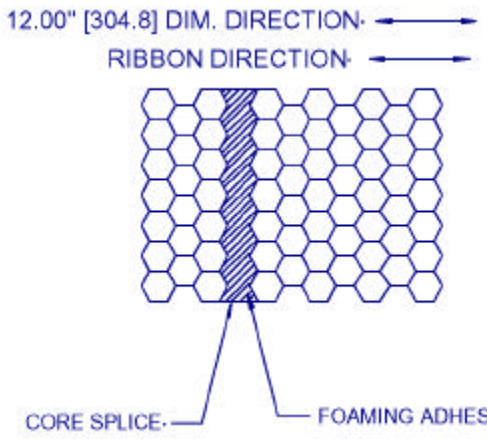

FIGURE 4 - Honeycomb Ribbon Direction

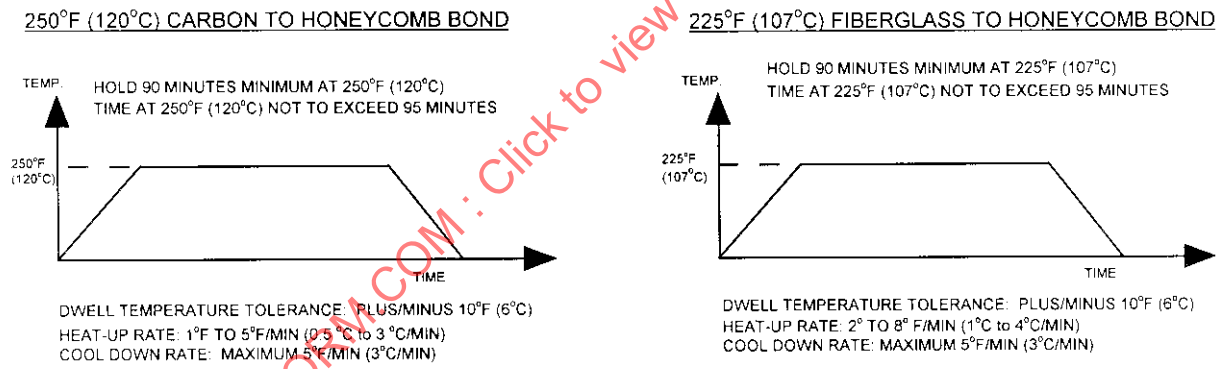

FIGURE 5 - Cure Temperature Profile for Secondary Bond of Laminate to Honeycomb Core

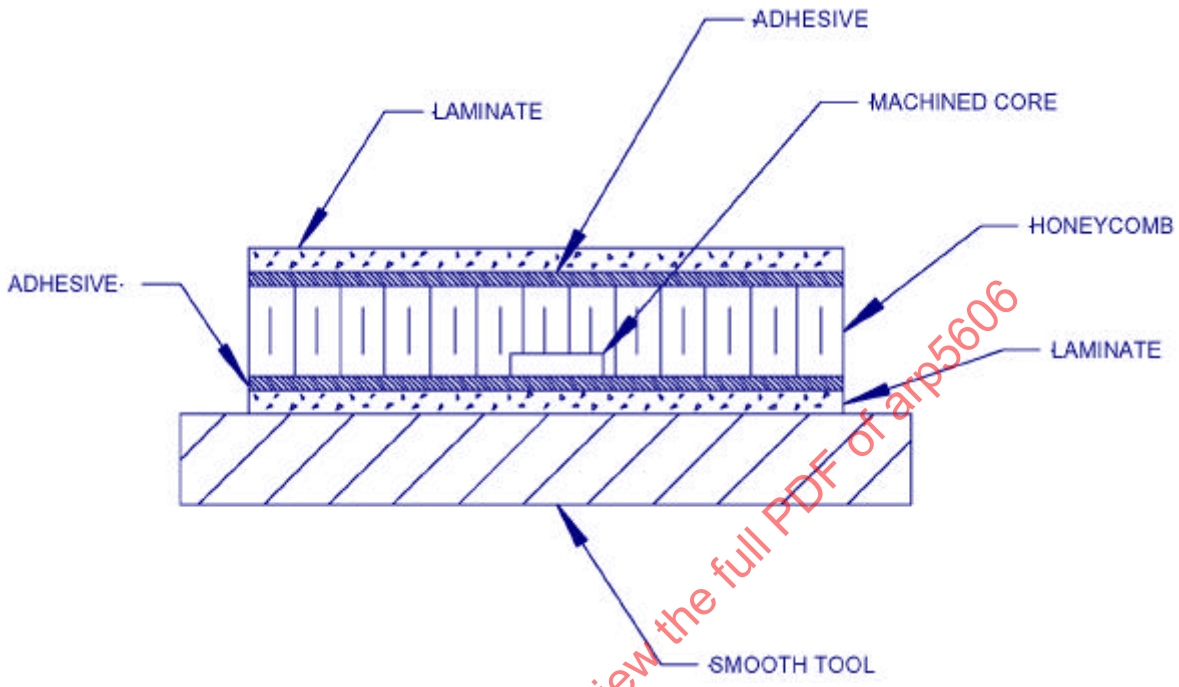

FIGURE 6 - Laminate to Honeycomb Lay-Up

3.1.3 Cure Pressure: Use of an autoclave or an automated oven will be required for all bonds. Cure all bonds in a vacuum bag at 11 to 12 psi (568.9 to 620.6 mm Hg ; 75.9 to 82.7 kPa).

3.1.4 Engineered Flaws and Special Panel Areas:

a. Skin-to-Honeycomb Disbond

Machined core areas will be milled out of the honeycomb using a dremel tool, router, or equivalent to produce a flat-bottomed hole as per Figure 6 (also see Appendix A). Depth of machined core flaws in the honeycomb will be approximately 0.250 inch (6.35 mm).

b. Pillow Inserts

Pillow inserts consist of four layers of tissue held together between two layers of heat resistant, polyamide film tape (see Figure 7). Insert the 1.0 inch (25.4 mm) diameter pillow inserts into the laminate lay-up at the locations called out in Figures 11 and 12.

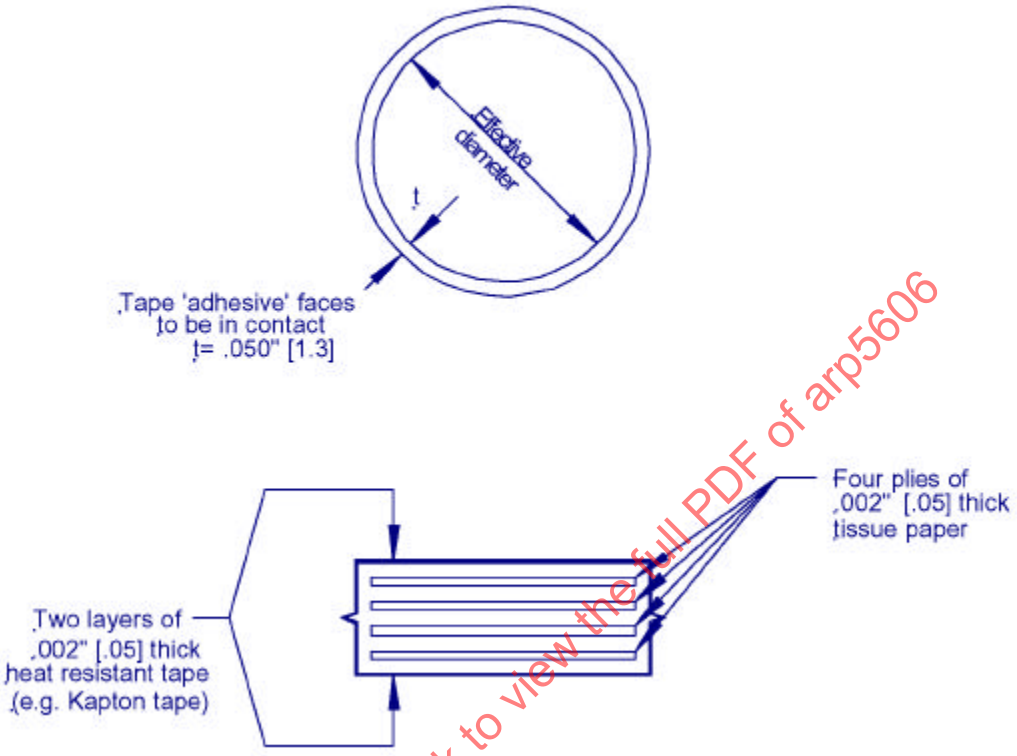

FIGURE 7 - Pillow Insert Construction

3.1.4 (Continued):

c. Core Splice Area

Core splice area will be fabricated using a single strip of foaming adhesive. Note the ribbon direction as shown in Figure 4. Cure under a vacuum bag at 250 °F (120 °C) for 90 minutes.

d. Potted Core Areas

Potted core areas will consist of filling the honeycomb cells in a 1.0 inch (25.4 mm) diameter area with potting material and curing under a vacuum bag for 90 minutes at 250 °F (120 °C). The individual cells can be filled or all cells in the 1.0 inch (25.4 mm) diameter region can be removed and the entire area potted with one fill. The summary of the process is as follows. Place masking tape over the bottom of the cells that are to be filled with potting material (see Figure 8). Mix the core potting material thoroughly in a container. Draw a vacuum on the container to remove any trapped air in the mixture. Use a syringe to inject the potting material into each cell within the 1 inch (25.4 mm) diameter area of interest (see Figure 8). Make sure that the potting material is flush with the top of each cell. After the material has cured sand off any excess so that the potting material is not above the top of the cells. Step-by-step directions for producing potted cores follows.

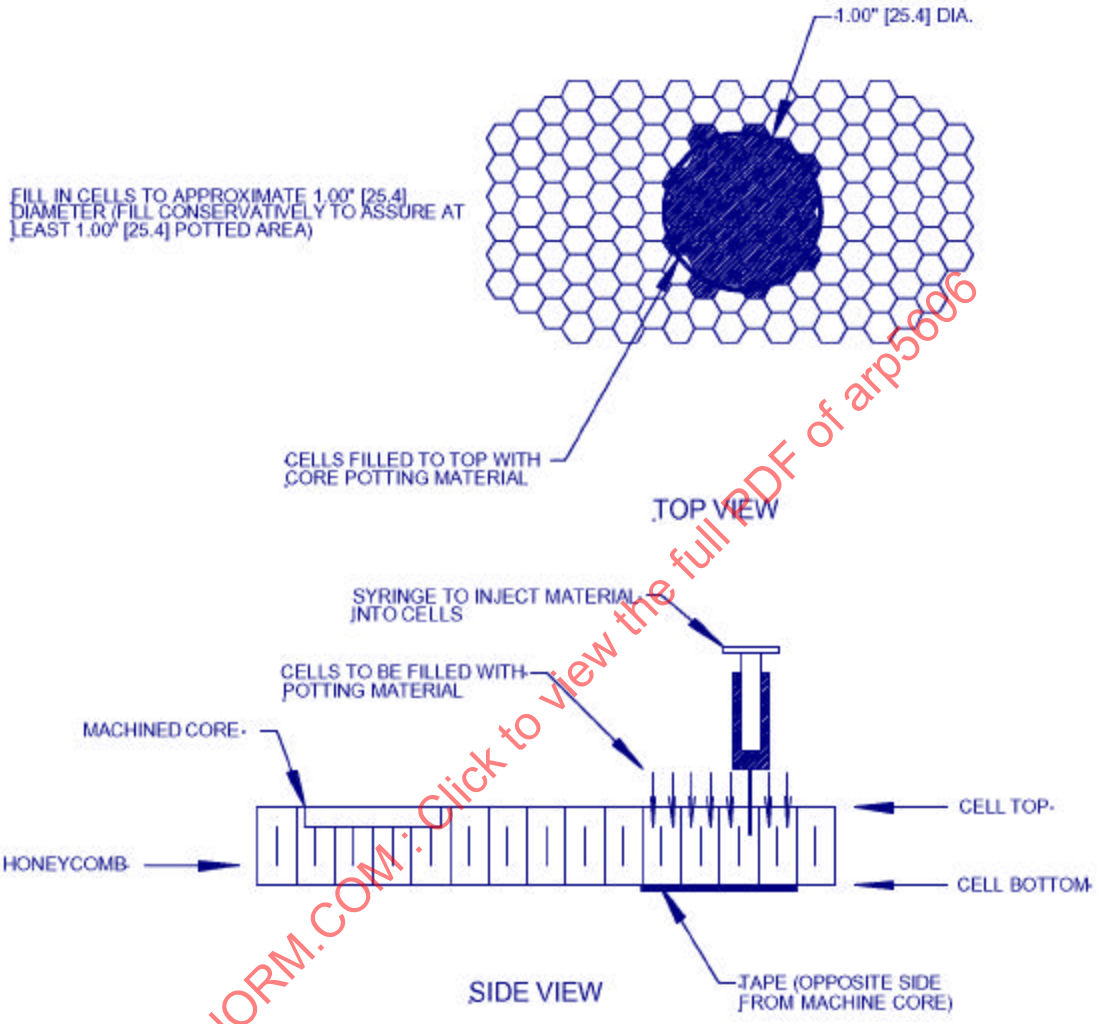

FIGURE 8 - Process for Creating Potted Honeycomb Core Areas

3.1.4.1 Step-By-Step Directions for Producing Potted Honeycomb Core Regions: Figure 8 and Appendix A should be referenced while following these directions for producing potted cores.

a. Prepare a half-batch of CG1305 epoxy resin (or equivalent – see materials list 4.1). The CG1305 standard ratio is 100/20.

- Part A: 50 grams
- Part B: 10 grams

NOTE: With this batch size, two 1 inch (25.4 mm) diameter sized areas can be encapsulated before the resin starts to gel; 30 minute pot life. A power syringe can be used if large areas need to be encapsulated. If the material has started to gel discontinue process and prepare another fresh batch of resin.

b. Mix batch by hand for 2 minutes using a wooden tongue depressor, spatula, or equivalent.

c. Place mixing container with material into an vacuum chamber and evacuate the mixture (approximately 10 to 11 psi) until all volume reduction is achieved. Remove mixing container from the vacuum chamber.

d. Pour the epoxy into a 30 cc plastic syringe. Set the syringe on its base and allow any air bubbles to rise to the free surface.

NOTE: While filling the syringe, tilt the syringe at an angle and slowly pour the material into the syringe. Avoid trapping or generating any air bubbles in the resin system.

e. Place a metallic syringe needle onto the syringe. Use a minimum 1/16 inch (1.6 mm) diameter ID needle with this resin system. The length of the needle will be determined by the thickness of the honeycomb cells being filled. The needle should reach to the base of the honeycomb. After the resin is void-free. Run the plunger up though the syringe to eliminate any free space in the syringe.

f. Seal the base of the honeycomb cells that are to be filled with potting material using masking tape. Make sure that the panels and work surfaces are flat and parallel. Assorted plates can be used as weights to ensure that the honeycomb panels are kept flat around the areas to be potted.

g. Carefully begin filling the honeycomb cells by inserting the needle into each cell. The needle should be touching the bottom of the cell. Slowly fill the cell approximately 3/4 full withdrawing the needle as the material fills the cell. Remove the syringe and continue filling the desired area/pattern in the honeycomb. After the area has been filled, top off any cells which need additional resin.

3.1.4.1 (Continued):

h. Cure for 2 to 3 hours at room temperature followed by a 250 °F (120 °C) post-cure per specifications (or other as per manufacturer's specifications).

NOTE: The masking tape should be removed before the panels are exposed to the 250 °F (120 °C) post-cure. Maintain flatness during the post-cure. Thin PTFE sheets, flat plates, and dead weights can be used to keep the panels flat. Make sure that any weighting system is distributed evenly over the honeycomb. Localized weights may crush honeycomb cells.

3.1.5 Sealing: When the laminates have been bonded to the honeycomb core, a complete composite/honeycomb sandwich assembly will be produced in accordance with Figure 9. It is now necessary to seal each panel around the periphery to avoid moisture ingress and to provide mechanical protection. The sealing process is as follows. Rout the honeycomb to remove approximately 0.250 inch (6.35 mm) of honeycomb material around the perimeter of the panel. The honeycomb is now recessed from the upper and lower laminates as shown in Figure 9. Seal all honeycomb edges using the sealant called out in 4.1. It may be necessary to add a stiffener such as milled fiberglass to the sealant for easier workability and proper set-up. Once the sealant is set, it should be sanded/finished such that it is smooth and flush with the laminate edges (see Figure 9).

3.1.6 Materials: Representative materials are listed in 4.1.

3.1.7 General Requirements:

a. All other aspects of fabrication (surface preparation, clean room, etc.) should be in accordance with industry standards.

b. Fill in the checklist/as-built form to verify materials and processes used during the construction of the panels. Provide completed "As-Built" forms to customer.

c. Ensure that marking of specimen numbers and flaw locations is permanent. Label the flaw side of each finished product with the corresponding specimen number (see Figures 11 and 12).

d. Numbers that are in [ ] on Figures are millimeters.

e. Perform a certification inspection in accordance with 3.2. Provide C-scan results, with attenuation levels labeled as specified in 3.2, to customer.

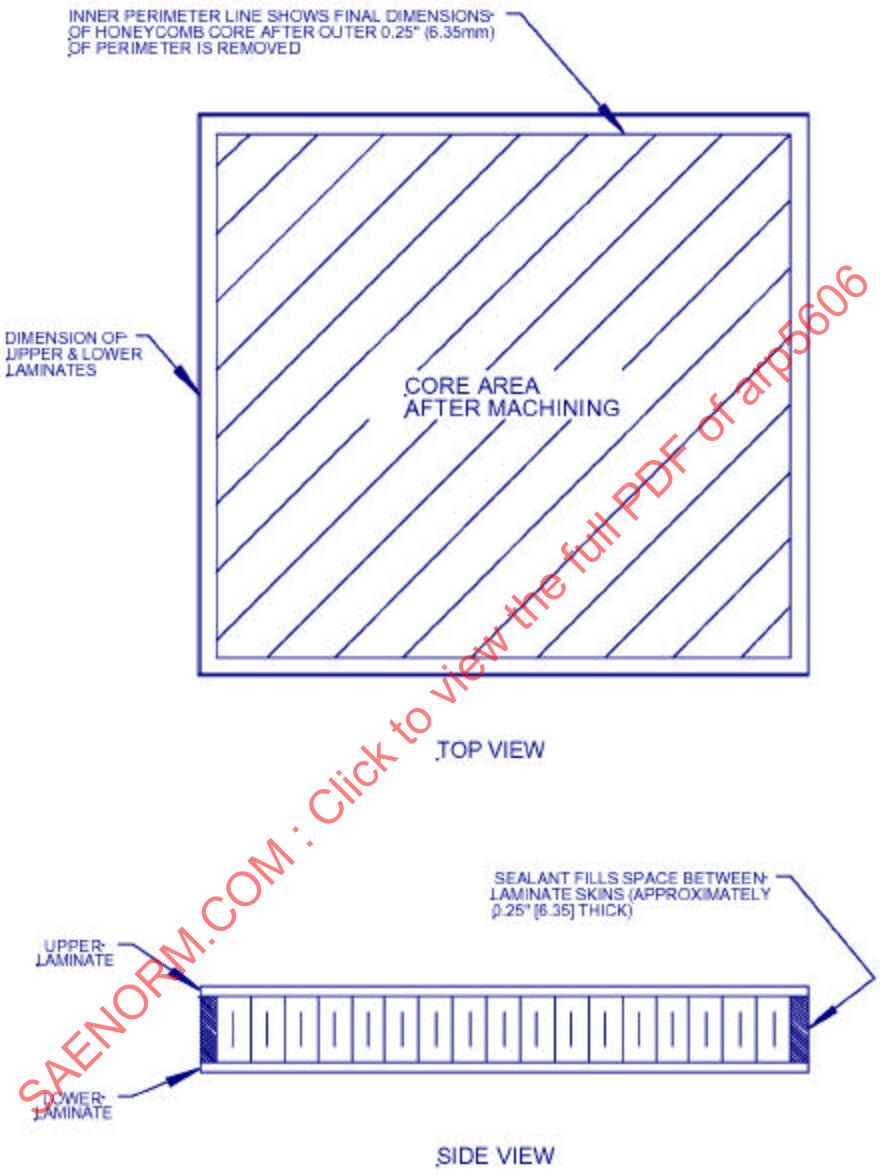

FIGURE 9 - Application of Sealant Around Perimeter of Honeycomb Panels

3.2 Acceptance Criteria:

The acceptance criteria shall be as defined in Table 3 and Figure 10.

TABLE 3 - Acceptance Criteria for Ultrasonic Inspection of Standards

Reference Standard Location	Acceptance Limits *
Pillow Insert (Interply Delamination)	The ultrasonic attenuation of the Pillow Insert areas must be at least 12dB greater than the attenuation of the Ref. Std. areas without defects.
Machined Core (Disbond)	The ultrasonic attenuation of the Machined Core areas must be at least 12dB greater than the attenuation of the Ref. Std. areas without defects.
Potted Core	The ultrasonic attenuation of the Potted Core areas must be at least 6dB less than the attenuation of the Ref. Std. areas without defects.
Unflawed Area	The ultrasonic attenuation of unflawed areas must be at least 18dB less than the attenuation of the foam tape on the Ref. Std.

* Use a 1 MHz Through-Transmission Ultrasonic (TTU) inspection system.

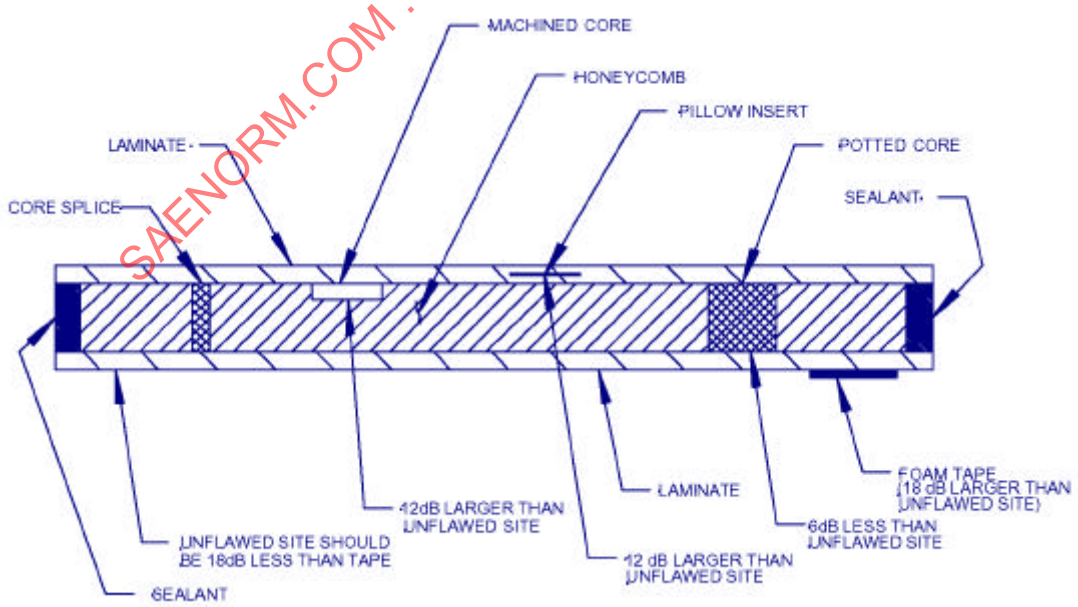

FIGURE 10 - Attenuation Acceptance Limits

3.2.1 The Reference Standards must be certified using a Through Transmission Ultrasonic (TTU) 'C' scan inspection. Label each flaw with the corresponding attenuation value determined by the TTU inspection.

3.2.2 Ultrasonic indications outside the defect areas must be no greater than 0.50 inch (12.7 mm) in diameter. An ultrasonic indication is an area with ultrasonic attenuation that is at least 6 dB larger than the attenuation of the adjacent areas without defects. Multiple indications must be at least 1.00 inch (25.4 mm) apart. There should be no more than three (3) anomaly indications in the non-defect regions of the specimen. If there are more than three areas with deviations of 6 dB or more, the panel is rejected. The location of all of these UT indication regions should be permanently marked on the standard to show "no calibration" areas on the specimen. If any UT indication in the unflawed region exceeds 18 dB, the specimen shall be rejected.

3.2.3 See Figure 10 for Attenuation Acceptance Limits.

3.2.4 Flaw Sizing: A 1.0 inch [25.4 mm] diameter piece of foam tape (see 4.1) shall be placed on the specimen during the TTU inspection. In addition to providing relative attenuation levels for flaw certification, the tape will be used to ensure correct flaw sizing. Indications from the machined core and pillow insert flaws shall be recorded on the TTU C-scan image. The size of these manufactured flaws shall be within +10% of the foam tape anomaly size shown in the C-scan. As per Table 3, the manufactured flaw areas should produce 12 dB or larger attenuation. Individual, unflawed areas surrounding the manufactured flaws that produce less than 12 dB but greater than 3 dB of attenuation shall not exceed 20% of the flaw dimension.

3.3 Engineering Design Drawings for Fiberglass Skin (CHRS-1) and Carbon Skin (CHRS-2) Honeycomb Reference Standards:

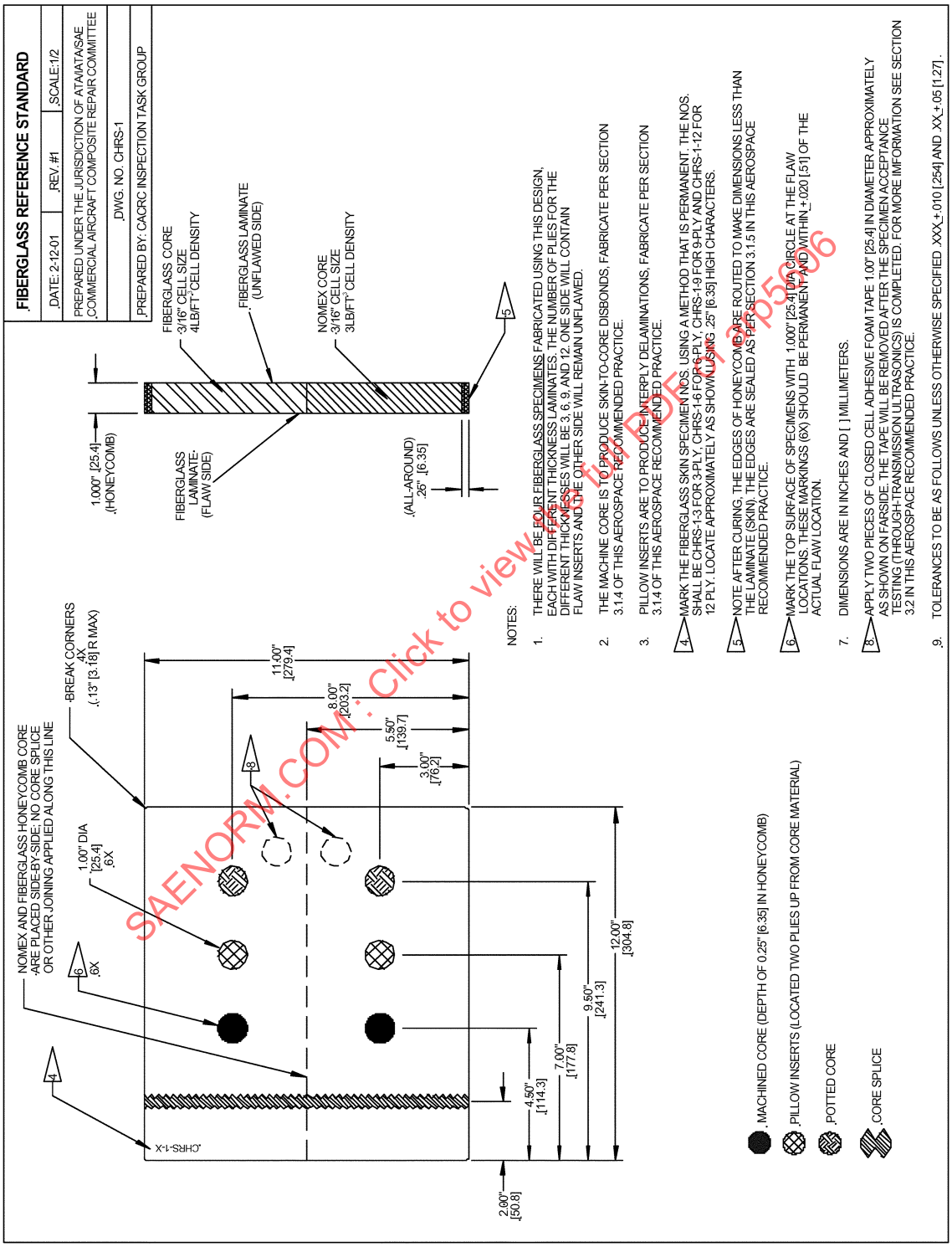

FIGURE 11 - CHRS-1 Fiberglass Reference Standard

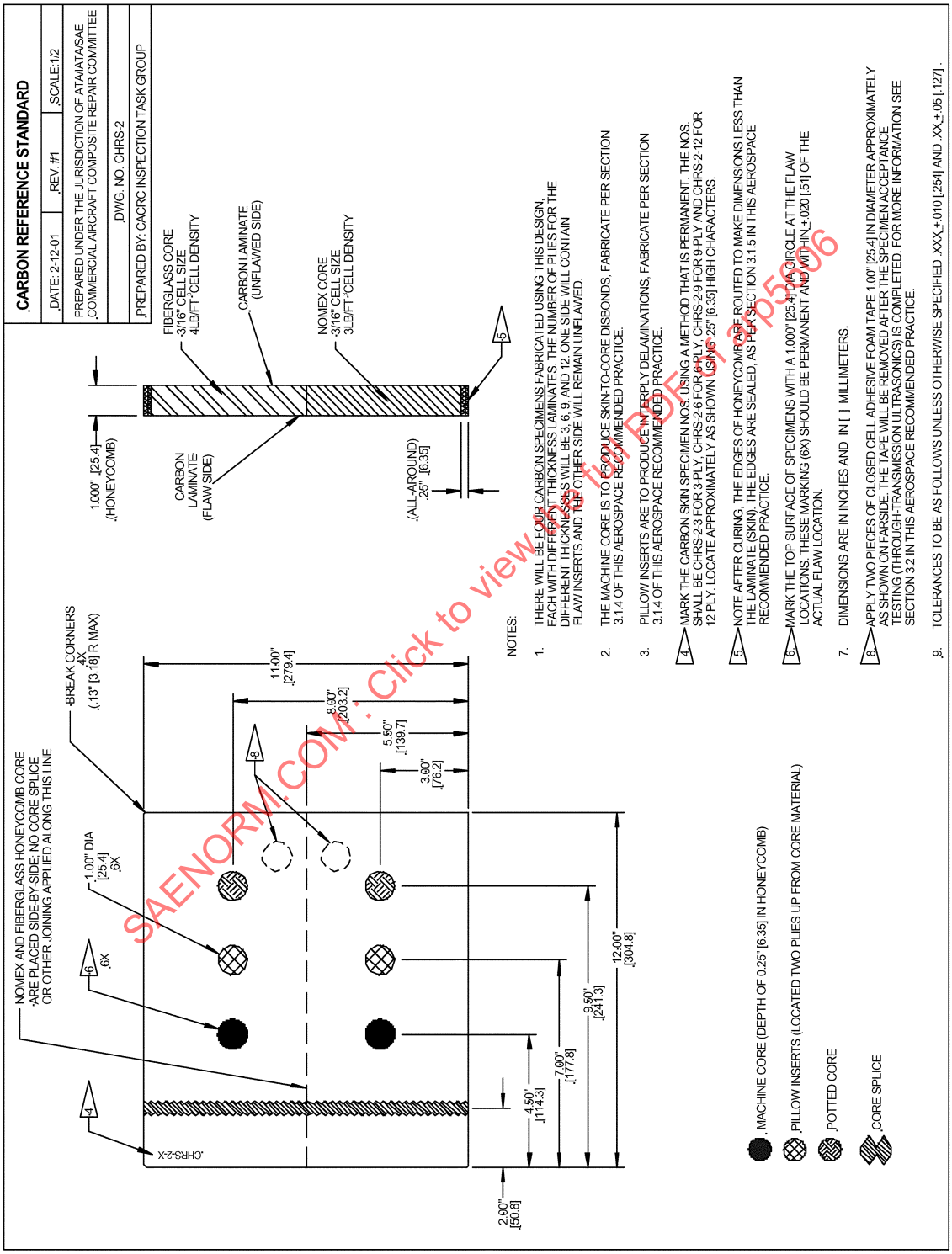

FIGURE 12 - CHRS-2 Carbon Reference Standard

3.4 Forms:

PANEL NUMBER/DESCRIPTION _____

GENERAL

Honeycomb Panels Labeled by Specimen Number on Side with Flaws? _____
Smooth (tool side) of Laminate Facing out on Honeycomb Sandwich? _____
Honeycomb Oriented with Core Ribbon along 0° Axis? _____
Honeycomb Oriented with Machined Core Facing Down During Laminate-to-Core Bonding? _____

MATERIALS USED

Laminate Material Type: _____
Number of Plies: _____
Honeycomb Material Type: _____
Weight of Honeycomb: _____
Adhesive for Laminate-to-Honeycomb Bond Cure: _____
Potted Core Material: _____
Core Splice Material: _____
Edge Sealant Material: _____

LAMINATE CURE TEMPERATURE PROFILE

Ref. Aviation Industry Specification: _____ (if applicable)

Target Cure Temperature (degrees F/C): _____
Target Dwell Time (minutes): _____
Allowable Heat-up Rate: _____
Allowable Cool-down Rate: _____

Beginning Temperature (degrees F/C): _____
Beginning Time (minutes): _____

Elapsed Time to Target Cure Temperature (minutes): _____
Maximum Temperature During Dwell Time (degrees F/C): _____
Minimum Temperature During Dwell Time (degrees F/C): _____
Elapsed Time at Dwell Temperature (minutes): _____
Elapsed Time from End of Dwell to End of Cool-down (minutes): _____

Ending Temperature(F/C): _____
Ending Time (minutes): _____

FIGURE 13 - As-Built Form for Composite Honeycomb Reference Standards

LAMINATE-TO-HONEYCOMB CURE TEMPERATURE PROFILE

Ref. Aviation Industry Specification: _____ (if applicable)

Target Cure Temperature (degrees F/C):_____
Target Dwell Time (minutes):_____
Allowable Heat-up Rate:_____
Allowable Cool-down Rate:_____

Beginning Temperature(degrees F/C): _____
Beginning Time (minutes): _____

Elapsed Time to Target Cure Temperature (minutes): _____
Maximum Temperature During Dwell Time (degrees F/C): _____
Minimum Temperature During Dwell Time (degrees F/C): _____
Elapsed Time at Dwell Temperature (minutes): _____
Elapsed Time from End of Dwell to End of Cool-down (minutes): _____

Ending Temperature (degrees F/C): _____
Ending Time (minutes): _____

CURE PRESSURE

Bag Pressure During Laminate Cure:_____
Bag Pressure During Laminate-to-Honeycomb Bond Cure:_____

NOTES

_____
_____
_____
_____
_____
_____

Fabrication Performed By:	Date:

FIGURE 13 - As-Built Form for Composite Honeycomb Reference Standards (Continued)

4. NOTES:

4.1 Materials:

The following industry specifications and material designations listed in this Recommended Practice are for information purposes. Such listings shall not be construed as an endorsement or guarantee of performance by SAE.

a. Plain Weave, Pre-Preg, 350° Carbon Graphite Cloth:

- BMS 8-256 Plain Weave Graphite
  → Industry Descriptor: Class 2, Type IV, 3K-70-PW:
  - HMF 970/PWC(TY) (Cytec Fiberite, U.S.A.)
  - W3T-282(Y)-XX-F593-18 (Hexcel, U.S.A. & Japan)
- A.0086/00
- 6814NT
- ABR1-0009, 1-0013, 1-0026

b. Plain Weave, Pre-Preg, 250° Fiberglass Cloth:

- BMS 8-79 1581
- BMS 8-79 7781
- 1581-F155-5-F69 (Hexcel, U.S.A. & Japan)
- 1581-F155-5-CS272 (Hexcel, Belgium)
- MXB7701/1581-Z6040 (Kasei Composites, Japan)
- MXB7701-1581-B3 (Cytec Fiberite, U.S.A.)
- G1581/F6986S03-S920NM (Yokohama Rubber, Japan)
- HG120/RS1212-Z6040 (Han Kuk Fiberglass, Korea)

c. Honeycomb:1 inch thick.

- Fiberglass 3/16 inch cell size, 4 lb/ft^3 density
- Nomex 3/16 inch cell size, 3lb/ft^3 density

d. Adhesive: 2 plies (each side) of 0.005 inch (0.13 mm) adhesive or 1 ply of 0.010 inch (0.26 mm) adhesive; type for 225 to 250 °F (107 to120 °C) secondary bond.

- BMS 5-101 Grade 10
- AF163 epoxy film

4.1 (Continued):

e. Potting Material (Potted Core):

- CG-1305 epoxy (Ciba-Geigy)
- BMS 5-28 Type 7
- BM 3500 B/A
- ABR 2-0055
- Cytec Fiberite BR 623PR-5LTR
- Scotch Weld EC3439 HAT-AF
- Stycast 1090SI

f. Foaming Adhesive (Core Splice):

- BMS 5-90
- AF-3028
- FM410-1.050
- AF 3024.050
- L 657.050
- ABR 2-0049

g. Sealant:

- BMS 5-28 Type 7 with 1305 Resin/Hardener, recommend adding chopped fiberglass to make resin more viscous and easier to apply around entire perimeter at one time.
- Stycast 1090SI
- Ciba Araldite 2020 A/B
- EA 9395
- Any epoxy type sealant that will produce a watertight seal around the perimeter. Transparent seals are preferred as they allow honeycomb type to be visible.

h. Tissue Paper:

- Thin paper such as used for tracing: 0.002 inch (0.05 mm) thick.

i. Heat Resistant, Polymide Film Tape:

- 0.002 inch (0.05 mm) thick (e.g., Kapton tape)

j. Foam Tape:

- Closed Cell Vinyl Foam Tape (e.g., 3M part no. 4416)

4.2 Key Words:

Non-destructive inspection, composite honeycomb, reference standards, NDI

PREPARED UNDER THE JURISDICTION OF
ATA/IATA/SAE COMMERCIAL AIRCRAFT COMPOSITE REPAIR COMMITTEE (CACRC)