The Characteristic Changes under the Repeated Thermal Exposure in the Process of Repairing Aircraft Sandwich Structures

2002年 2月
Abstract

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The Characteristic Changes under the Repeated Thermal Exposure in the Process of Repairing Aircraft Sandwich Structures

Abstract

Autoclave curing using the vacuum bagging method is widely used for the manufacture of advanced composite prepreg airframe structures. Due to increasing use of advanced composites, specific techniques have been developed to repair damaged composite structures. In order to repair the damaged part, it is required that the damaged areas be removed, such as skin and/or honeycomb core, by utilizing the proper method and then repairing the area by laying up prepreg (and core) then curing under vacuum using the vacuum bagging materials. It shall be cured either in an oven or autoclave per the original specification requirements. Delamination can be observed in the sound areas during and/or after a couple of times exposure to the elevated curing temperature due to the repeated repair condition. This study was conducted for checking the degree of degradation of properties of the cured parts and delamination between skin prepreg and honeycomb core. Specimens with glass honeycomb sandwich construction and glass/epoxy prepreg were prepared. The specimens were
cured 1 to 5 times at 260°F in an autoclave and each additionally exposed 50, 100 and 150 hours in the 260°F oven.

Each specimen was tested for tensile strength, compressive strength, flatwise tensile strength and interlaminar shear strength. To monitor the characteristics of the resin itself, the cured resin was tested using DMA and DSC. As a result, the decrease of $T_g$ value were observed in the specific specimen which was exposed over 50 hrs at 260°F. This means the change or degradative of resin properties is also related to the decrease of flatwise tensile properties. Accordingly, minimal exposure on the curing temperature is recommended for parts in order to prevent the delamination and maintain the better condition.
(core materials)],

[prepreg])

°­¼ºÆ¯¼ºÀ»°¡Áö´ÂÁ¢ÇÕǰÇüÅÂÀǺ¹ÇÕÀç·á¸¦¸¹ÀÌÀÌ¿ëµÇ°íÀִµ¥ÀÌ´ÂÁ߽ɿ¡»ç¿ëµÇ´Â±¸Á¶Àç·áÀÎÄÚ¾îÀç·á

(secondary structure)

(fire resistance)

(matrix)

[primary structure)]

(wing),

(fuselage),
Fig. 2 (a), (b), (c)
Fig. 1 Load in the element of a cored Structure.

(a) Graphite/epoxy

Fig. 2 Composite materials of Boeing 767 aircraft.

- To be continued -

- 5 -
(b) Kevlar

(c) Hybrid(Kevlar/graphite) composite
(epoxy)

(Bonding Shop)

(delamination)

(cure cycle)

flatwise tensile test, interlaminar shear test,
DMA (Dynamic Mechanical Analysis),
DSC (Differential Scanning Calorimetry) (repair).
2.1 2.1.1

2.1.1.1

2.1.1.1.1

(4) (5)
Table 1

<table>
<thead>
<tr>
<th>Table 1</th>
<th>...</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>...</td>
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<td>...</td>
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</tr>
</tbody>
</table>

- 10 -
2.2  ýåòîä èëèöèè èëèöèè

2.2.1  ýåòîä

(2.2.1) ðîçêëè Ñàïëèñàëüíèêîé äîçîôëÿ (composites structure)

2.2.1.1  ýåòîä - fiberglass (glass cloth)

(2.2.1.1)  ýåòîä - fiberglass (glass cloth)

(2.2.1.2)  ýåòîä - aramid
2.2.1.3 Carbon/Graphite (carbon/graphite)

PAN (Polyacrylonitrile) is a precursor of graphite.

Pitch is a precursor of polyacrylonitrile (PAN), which is further converted into polyacrylonitrile (PAN) after heating at 1000–2500°C to form carbon, and at 2500–3000°C to form graphite.

- Pitch is used to form spool with pitch (strong), pitch (stiff), and pitch (rigid strength).
- PAN is used to form prepreg with PAN (primary structure components).
- Polyacrylonitrile (PAN) is used to form bulkhead, ribs, and stringer (primary structure components).

The bulkhead, ribs, and stringer are used to form the structure with a weight of 50t / 8 tons.
2.2.1.4 (boron) 

2.2.1.5 (ceramic) 

Table 1
Table 1 Properties of reinforcing fiber.

<table>
<thead>
<tr>
<th>Property Fiber/Wire</th>
<th>Density Lb/in³</th>
<th>Tensile Strength 10³lb/in²</th>
<th>Specific Strength 10³lb/in</th>
<th>Tensile Stiffness 10³lb/in</th>
<th>Specific Modulus 10⁵lb/in²</th>
<th>Melting Point ºC</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Glass</td>
<td>0.082</td>
<td>500</td>
<td>54</td>
<td>10.5</td>
<td>11</td>
<td>1316</td>
</tr>
<tr>
<td>S-Glass</td>
<td>0.090</td>
<td>700</td>
<td>78</td>
<td>12.5</td>
<td>14</td>
<td>1650</td>
</tr>
<tr>
<td>Boron</td>
<td>0.093</td>
<td>500</td>
<td>54</td>
<td>60</td>
<td>65</td>
<td>2100</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.051</td>
<td>250</td>
<td>49</td>
<td>27</td>
<td>53</td>
<td>3700</td>
</tr>
<tr>
<td>Graphite</td>
<td>0.051</td>
<td>250</td>
<td>49</td>
<td>37</td>
<td>72</td>
<td>3650</td>
</tr>
<tr>
<td>Kevlar</td>
<td>0.052</td>
<td>525</td>
<td>101</td>
<td>16</td>
<td>35</td>
<td>249</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.097</td>
<td>90</td>
<td>9</td>
<td>10.5</td>
<td>11</td>
<td>660</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.170</td>
<td>280</td>
<td>16</td>
<td>16.7</td>
<td>10</td>
<td>1668</td>
</tr>
<tr>
<td>Steel</td>
<td>0.282</td>
<td>600</td>
<td>20</td>
<td>30</td>
<td>10</td>
<td>1621</td>
</tr>
</tbody>
</table>
2.2.2 マトリックスシステム (matrix system)

マトリックス樹脂システム (matrix resin system) と マトリックス樹脂 (thermoplastic) から成るシステム、および、プラスマックス樹脂 (thermoset) と、それらを含むシステム、の比較を示しています。

<table>
<thead>
<tr>
<th>システム</th>
<th>材料</th>
<th>品番</th>
</tr>
</thead>
<tbody>
<tr>
<td>マトリックス樹脂システム</td>
<td>ワインドシュール</td>
<td>Ep828, Ciba-Geigy MY720, Narmco 5208, Hexcel F151, 3501</td>
</tr>
</tbody>
</table>

Table 2 におけるデータから、これらのシステムの比較が示されます。
Table 2 Thermoplastic and thermoset.

<table>
<thead>
<tr>
<th>Item</th>
<th>Type</th>
<th>Thermosets</th>
<th>Thermoplastics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maturity</td>
<td>Proven Materials</td>
<td>Newer Materials</td>
<td>Limited Database</td>
</tr>
<tr>
<td></td>
<td>Good Database</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage</td>
<td>Refrigerated for Limited</td>
<td>No refrigeration</td>
<td>Unlimted out-time and shelf life</td>
</tr>
<tr>
<td></td>
<td>Out-Time and Shelf Life</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prepreg</td>
<td>High Quality - Tacky</td>
<td>Potential for high void</td>
<td>Low Formability</td>
</tr>
<tr>
<td>Cure Cycle</td>
<td>Normal Pressure/</td>
<td>High Pressure, Temperature, Fast Processing Cycle</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reparability</td>
<td>Patch Type Repair Required</td>
<td>Reheating, Reprocessing Required</td>
<td></td>
</tr>
<tr>
<td>Forming</td>
<td>Cure to Shape</td>
<td>Thermofoaming of Flat Sheet Required</td>
<td></td>
</tr>
</tbody>
</table>
2.2.3  HONEYCOMB SANDWICH STRUCTURE

2.2.3.1  HONEYCOMB SANDWICH STRUCTURE
(honeycomb sandwich structure)

- (facing)

- (inplane load)

- (bending rigidity)

- (pre-impregnated)

- (hybrid)

- (laminate)

- (Core)

- (shear rigidity)

- KRAFT

- (peel resistance)
2.2.3.2RESINS

The materials used in the materials are generally resin-rich (resin rich) and resin-lean (resin lean) in the cured state.

2. (lay-up).

3. Lay-up can be done in an air-conditioned environment (airworthy) or in a non-air-conditioned environment (unairworthy).

4. The lay-up process involves the placement of the fibers in the resin matrix. This is followed by the curing process where the resin hardens and solidifies.

5. The lay-up process can be done on a flat surface or on a curved surface, depending on the shape of the component being manufactured.

- 19 -
(thermosetting resin) A, B, C-stage

A-stage - ¼öÁö¿Í°æÈ­Á¦°¡¹èÇÕºñ¿¡µû¶ó´Ü¼øÈ÷È¥ÇÕ¸¸

B-stage - ¼öÁö¿Í°æÈ­Á¦°¡¾î´ÀÁ¤µµ¹ÝÀÀÀÌÁøÇàµÇ¾îÁ¡

C-stage - ¼öÁö¿Í°æÈ­Á¦ÀǹÝÀÀÀ̰ÅÀdz¡³ª°Å³ª¿Ï·áµÈ°Ü°è·Î¼­¼Öº¥Æ®³ª¿­¿¡¿µÇâÀ»¹ÞÁö¾Ê´Â»óÅÂÀÌ´Ù

°ú°Ç½Ä ÇÁ¸®ÇÁ·¹±×Á¦Á¶°øÁ¤Àº

Fig. 3 (b)

°­È­¼¶À¯¸¦Á÷¹°ÇüÅ·ÎÂ¥´Â´ë½Å¿¡½ºÇ® (spool)

Fig. 3 (a)
B-stage

Fig. 3 (a) (b)
(a) Hot melt prepreg process.

(b) Solvent prepreg process.

Fig. 4 The manufacturing process of prepreg.
2.3.3 ỌGA (core materials)

Fig. 4 ọga ọga ọga ọga ọga (rotor blade)

Fig. 5 ọga ọga ọga ọga ọga ọga (sandwich)

2.3.3.1 ỌGA ỌGA (honeycomb core)

<table>
<thead>
<tr>
<th>honeycomb core</th>
<th>sandwich structure</th>
<th>aerodynamic smoothness, noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>aluminum honeycomb, nomex honeycomb etc</td>
<td>aluminum sheet, glass fiber, carbon fiber, kevlar etc</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 5

- L” dimension
- W” dimension
- T” thickness
- Nodes
- Cell size
- Cell size
- Ribbon direction
- Density - pound per cubic foot (PCF) perforated honeycomb cell wall
- honeycomb curing adhesive resin gas adhesive non-perforated type.
Fig. 4 (a) Metal skin will bend and flex when forces are applied in flight. (b) Composites keep the structure foam flexing in flight, eliminating fatigue.

Fig. 5 The name of honeycomb core structure
- Corrugated process

Web material, corrugating roll, corrugated sheet, node, adhesive, block

Honeycomb core, adhesive, cell, slice, expansion (500), block, slice, fiber sheet, aluminum foil, node

Node, adhesive, titanium, nickel, honeycomb, spotwelding, brazing

Non metallic honeycomb, fiber sheet, phenolic resin, node bonding, resin, adhesive, fungus-resistant.
Fig. 6 (a) Expansion method of producing honeycomb core materials, (b) Corrugating production method.
Fig. 7 Example of a bonded sandwich assembly.
© 29 cell configuration

- Aluminum honeycomb
  - 2024 alloy (high room temperature properties)
  - 5052 alloy (general purpose)
  - 5056 alloy (high strength)
  - Aluminum commercial grade (low cost/non mil-spec)
- Glass reinforced honeycomb
  - Glass fabric reinforced plastic dipped in a heat resistant phenolic resin (350°F)
  - Bias weave glass fabric reinforced plastic dipped in a heat resistant phenolic resin (350°F, shear strength)
  - Glass fiber reinforced plastic initially impregnated in a nylon-modified phenolic resin and finally dipped in a polyester resin (180°F)
  - Bias weave glass fabric reinforced plastic dipped in a polyimide resin (500°F)
- Aramid fiber reinforced honeycomb
  - Aramid fiber paper dipped in a heat resistant phenolic resin (high strength & toughness / low density / damage resistant / formable / fire resistant / water & fungus resistant / good thermal electrical insulator / 300°F)
  - Aramid fiber paper dipped in a polyimide resin (above / excellent dielectric)
- Welded titanium honeycomb
- Welded nickel honeycomb
- Special honeycomb
- Water resistant core material (for air transportable shelter)
- Kevlar 49 reinforced plastic dipped in a epoxy resin (for space application / very low coefficients of thermal expansion)
Table 3 Factors of selecting honeycomb type.

(a)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Glass Fiber Reinforced Honeycomb</th>
<th>Aluminum Honeycomb</th>
<th>Aramid Fiber Reinforced</th>
<th>Special Application</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dipped In a Phenolic Resin</td>
<td>5052</td>
<td>2024</td>
<td>MOD</td>
</tr>
<tr>
<td></td>
<td>Incorporate with Bias Weave</td>
<td>5056</td>
<td>AI Commercial Grade</td>
<td>HIGH</td>
</tr>
<tr>
<td></td>
<td>Dipped In a Polyester Resin</td>
<td>5052</td>
<td>Dipped In a Phenolic Resin</td>
<td>MOD</td>
</tr>
<tr>
<td></td>
<td>Dipped In a Polyimide Resin</td>
<td>5052</td>
<td>Water Resistant Core</td>
<td>LOW</td>
</tr>
<tr>
<td>Cost</td>
<td>MOD</td>
<td>HIGH</td>
<td>LOW</td>
<td>MOD</td>
</tr>
<tr>
<td>Max Service Temp</td>
<td>350 °F</td>
<td>350 °F</td>
<td>350 °F</td>
<td>350 °F</td>
</tr>
<tr>
<td>Flammability</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Impact Resistance</td>
<td>F</td>
<td>G</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Moisture Resistance</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Fatigue Strength</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Heat Transfer</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
<td>LOW</td>
</tr>
</tbody>
</table>

(b)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Glass Fiber Reinforced Honeycomb</th>
<th>Aluminum Honeycomb</th>
<th>Aramid Fiber Reinforced</th>
<th>Special Application</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Dipped In a Phenolic Resin</td>
<td>5052</td>
<td>2024</td>
<td>MOD</td>
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<td></td>
<td>Incorporate with Bias Weave</td>
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<td>AI Commercial Grade</td>
<td>HIGH</td>
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<tr>
<td></td>
<td>Dipped In a Polyester Resin</td>
<td>5052</td>
<td>Dipped In a Phenolic Resin</td>
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<td></td>
<td>Dipped In a Polyimide Resin</td>
<td>5052</td>
<td>Water Resistant Core</td>
<td>LOW</td>
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<tr>
<td>Cost</td>
<td>MOD</td>
<td>HIGH</td>
<td>LOW</td>
<td>MOD</td>
</tr>
<tr>
<td>Max Service Temp</td>
<td>350 °F</td>
<td>420 °F</td>
<td>350 °F</td>
<td>350 °F</td>
</tr>
<tr>
<td>Flammability</td>
<td>E</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Impact Resistance</td>
<td>F</td>
<td>G</td>
<td>G</td>
<td>G</td>
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<tr>
<td>Moisture Resistance</td>
<td>E</td>
<td>E</td>
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<td>E</td>
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<tr>
<td>Fatigue Strength</td>
<td>G</td>
<td>G</td>
<td>G</td>
<td>G</td>
</tr>
<tr>
<td>Heat Transfer</td>
<td>HIGH</td>
<td>HIGH</td>
<td>HIGH</td>
<td>LOW</td>
</tr>
</tbody>
</table>

E: Excellent   G: Good    F: Fair    P: Poor
© Cell configuration

- Hexagonal core
  - Metal vs Non Metal
  - Over expanded core
    Hexagonal core vs over-expanded rectangular cell vs curving forming vs reducing anticlastic curvature (flex-core)

- Reduced anticlastic curvature (flex-core)
  - Formability

- Tube core
  - Flat aluminum foil vs corrugated aluminum foil vs adhesive vs tube vs core

- Other configuration
  - Reinforced L honeycomb, dovetail, chevron vs honeycomb type vs 90% factor
Fig. 8 Manufacture of honeycomb sandwich structure.
2.3.3.2 Центральный пенообразователь (Central foam)

(A) (Fire resistance), , .

(Fire resistance) . Fig. 9 .

(B) (solid fiber glass)

(C) (laminate)

Fig. 9.

(D) (styro foam)

canard, .

(E) (urethane foam)

(F) (Poly Vinyl Chloride - PVC)

PVC .

(G) (wood core)
Fig. 9 Honeycomb stiffens and strengthens a structure without materially increasing its weight.
3. アトクレーブ (Autoclave) や他の方法で

Fig. 10

Fig. 10

Fig. 10 (honeycomb sandwich)
Fig. 10 Lay-up of vacuum bagging materials.
3.1 444 444

3.1.1 444 444

3.1.2 444（lay-up）- 444

3.1.3 444
3.1.4 The cure cycle and heat cycle

The cure cycle and heat cycle are crucial in the fabrication of the composite material. The cure cycle is the period during which the resin is heated to cure and harden, while the heat cycle is the period during which the material is heated to a specific temperature for a certain time to enhance the curing process. Figure 11 illustrates the cure cycle, while Figure 12 shows the heat cycle.

Fig. 11

Fig. 12
Fig. 11 Process of Autoclave.
Step 1. Start with a clean, smooth tool plate. Note that any flaws or irregularities on the tool plate will show up on the cured laminate. This may necessitate sanding or washing the plate with solvent.

Step 2. Tape tool plate along edges with adhesive tape 1" wide. This keeps this area clean and free of any release agent in preparation for the application of sealant tape (step 15).

Step 3. Apply release agent as directed to tool surface.

Step 4. Peel the polyethylene backing off of each prepreg layer before laying it down on the tool.

Fig. 12 Honeycomb panel fabrication.
Step 5. Lay down the first ply in the center of the tool, making sure that it is smooth and free of wrinkles and distortion.

Step 6. Lay each subsequent ply directly over the first, lining up the edges. This is important to ensure proper fiber orientation. Include film adhesive where and if it is called for.

Step 7. A roller may be used to remove any trapped air bubbles and wrinkles from the layup.

Step 8. The core is laid down in the same manner as the prepreg, with the edges lined up with the prepreg plies.

- Continued -
Step 9. Subsequent prepreg plies are laid up on top of the core in the same way as shown in steps 5 through 7. Again, a roller may be used to smooth out the plies.

Step 10. Place a layer of release film over the laminate. This layer should overhang the laminate on each side by at least 3 to 4 inches (8 to 10 cm). The release film layer allows volatiles to escape while containing resin.

Step 11. Place supports around edges of the laminate to prevent core crush when vacuum and pressure are applied. The supports should be placed over the release film so that they do not stick to the laminate. 1/2" metal strips (flat stock) are used here.

Step 12. A caul plate is placed over the laminate. The plate, like the tool plate, should be both clean and smooth.
Step 13. Place four to six layers of breather ply material on top of the part. This allows for the movement of air and of volatiles while part is being cured.

Step 14. Remove adhesive tape from the edges of the tool.

Step 15. Replace with sealant tape and remove the sealant backing.

Step 16. Insert thermocouples on top of sealant tape. Thermocouples must be stripped at the point where they contact the sealant tape in order to avoid leakage. Put a piece of sealant tape over the thermocouples to secure and complete seal.

- Continued -
Step 17. Place vacuum bag material over assembly. The vacuum bag layer should be large enough to accommodate the volume of the part.

Step 18. Press the vacuum bag material down on the sealant tape to ensure a good seal.

Step 19. Turn on the vacuum pump and connect the vacuum lines. Pull 5 inches of Hg (17 kPa) of vacuum and hold for 20 to 30 minutes. Do not exceed this limit of 5 inches - higher vacuum may cause the facesheets to “dimple” over the honeycomb cells. During this 20 to 30 minute period a leak check can be made.

Step 20. Put the part into the autoclave and hook up the vacuum lines. Start the autoclave run.

- Continued -
Step 21. After cure, the part is removed from the autoclave...

Step 22. ...and the bag material, breather plies and release film are removed.

Step 23. The finished part is shown.

Step 24. The above picture shows the tools needed for this procedure.

-Continued-
15-20% manufacturing repair for OEM
maintenance repair for air lines
Boeing major
hot bond, cold bond, bolted repair
3
Co-cured
co-cured repair
depaint
random orbital sander
surface abrasion, step sanding
grit/diamond edge hole saw
hot bond repair
cold bond repair
wet lay-up
200F-230F, 250F, 350F
SRM (Structural Repair Manual)
Cold bond repair
150F
Damaged area
hot and cold
holding damaged area. Damaged area
damaged, skin, core masking.

oven autoclave, heating console.

masking, skin, core oven.

autoclave, heating console, heat blanket, 250F, 350F.

oven, autoclave, heating console.

heat blanket, 250F, 350F.

honeycomb kit, heat blanket.

Fig. 13 Kit

Fig. 14 (a) honeycomb kit.

Fig. 14 (b) honeycomb kit.

4.1 (heating)
2. (heat gun) : 适用于热风枪的热源，使用温度范围为 500～750°C。

3. (oven curing) : 适用于烘箱固化，温度范围从 350°C 至...
4.2 (applying pressure)

1. (heat gun)  
   ① Shot bag (clamp)
   ② Clecos (caul plate)
   ③ Spring clamp
   ④ Peel ply (bleeder)
   ⑤ Vacuum bagging

- Sealant tapes
- **Release fabrics and films**: These are used to protect the bond between the layers of a composite material. They are typically removed after the bonding process is complete.

- **Peel plies**: These plies are used to peel off the surrounding layers, allowing for easier access to the material being worked on. They are also used to protect the underlying layers from damage during the peeling process.

- **Fabric plies**: These plies consist of layers of fabric that provide reinforcement and strength to the composite material. They are used to distribute stress and improve the overall properties of the material.

- **Bleeder s**: These are used to control the flow of materials, especially during the peeling process. They help to prevent unwanted chemicals or materials from contaminating the composite material.

- **Breather s**: These are used to allow air or gases to escape during the peeling process. They help to prevent the buildup of pressure that can cause damage to the material.

- **Calking plate**: This plate is used to control the flow of materials, especially during the peeling process. It helps to prevent unwanted chemicals or materials from contaminating the composite material.

- **Insulation plies**: These are used to control the flow of materials, especially during the peeling process. They help to prevent unwanted chemicals or materials from contaminating the composite material.
Fig. 13 Repair kit.
Fig. 14 Diagram of composite repair.
5.1 CYTEC FIBERITE® glass/epoxy prepreg style

- CYTEC FIBERITE® glass/epoxy prepreg style
- 7781 honeycomb core
- 260°F 

- HEXCEL® Nomex honeycomb core, cell size 3/16”
- block 3M scotch-weld EC 2216 A/B

- CYT EC FIBERIT E glass/epoxy prepreg style

**Table 4**

- Out of freezer life
- Storage Life: 10°F (-12°C), 180 days
- Handling life:
  - -11~80 °F (27°C): 10 days
  - -81~100 °F (38°C): 30 days
  - -100 °F: 30 days

- 3/16” Nomex Hexagonal Cell

- 3M scotch-weld EC 2216 A/B
Table 4 The mechanical properties of the used prepreg.

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Style</th>
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<th>7781</th>
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<tr>
<td></td>
<td>Class 1</td>
<td>Class 2</td>
<td>Class 1</td>
</tr>
<tr>
<td>Compression ULT. (ksi)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75 ± 5 °F</td>
<td>54</td>
<td>45</td>
<td>54</td>
</tr>
<tr>
<td>350 ± °F</td>
<td>27</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>Compression Mod. (Msi)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>75 ± 5 °F</td>
<td>2.9</td>
<td>2.5</td>
<td>3.1</td>
</tr>
<tr>
<td>350 ± °F</td>
<td>2.2</td>
<td>2.1</td>
<td>2.7</td>
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<tr>
<td>Tensile ULT. (ksi)</td>
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</tr>
<tr>
<td>75 ± 5 °F</td>
<td>41</td>
<td>41</td>
<td>47</td>
</tr>
<tr>
<td>350 ± °F</td>
<td>25</td>
<td>25</td>
<td>27</td>
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<tr>
<td>Tensile Mod. (Msi)</td>
<td></td>
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<tr>
<td>75 ± 5 °F</td>
<td>2.9</td>
<td>2.9</td>
<td>3.1</td>
</tr>
<tr>
<td>350 ± °F</td>
<td>2.4</td>
<td>2.4</td>
<td>2.5</td>
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Table 5 The mechanical properties of the used honeycomb core.

<table>
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<tr>
<th>TYPE</th>
<th>DENSITY</th>
<th>Nomex honeycomb core</th>
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<tr>
<td></td>
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<td>Compress. Strength (psi)</td>
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<td></td>
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<td>ULT. psi</td>
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<tr>
<td>MIN. AVG.</td>
<td>MIN. AVG.</td>
<td>MIN. AVG.</td>
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<tr>
<td>I</td>
<td>3.0</td>
<td>250</td>
</tr>
</tbody>
</table>
5.2 Autoclave (Autoclave) and cure cycle (cure cycle)

Interlaminar shear test Flatwise tensile test 1, 2, 3, 4, 50, 100, 150, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200. Fig. 15

Interlaminar shear test, Fig. 17 Flatwise tensile test specimen.

Flatwise tension specimen 3M 2216 Adhesive Film 24, 70°C 1, 2, 3, 4, 5, 6, 7.5, 10, 20, 30, 40, 50, 100, 150, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200. Cross head speed 3~6

DMA (Dynamic Mechanical Analysis) 1.5, 3, 4.5, 6, 7.5, 10, 20, 30, 40, 50, 100, 150, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200.
Fig. 15 Autoclave cure and pressure cycle.
Fig. 16 Interlaminar shear test specimen in autoclave.

Fig. 17 Flatwise tensile test specimen in autoclave.
Fig. 18  Test specimen.
(a) Tensile  (b) Compressive
(c) Interlaminar shear  (d) Flatwise tensile
5.3 \textsection

5.3.1 \textsection

Fig. 19 The real shape of the used tensile test machine.
Fig. 20 The real shape of the used compressive test machine.
5.3.2 Interlaminar shear test

Interlaminar shear test. Fig. 21. Interlaminar shear test. (a) , (b) . (18)

Fig. 22. diamond wheel cutter machine.

Fig. 21 Type of shear load diagram.
Fig. 22 The diagram interlaminar shear test.
5.3.3 Flatwise tension Test

Fig. 23 The diagram and the real shape of flatwise tension specimen.

(a) (b)
5.3.4 DMA (Dynamic Mechanical Analysis); DSC (Differential Scanning Calorimetry)

DMA Laminate, 10°C/min, 40~250°C. Fig. 24. DMA Dupon Instruments DMA 983. Amplitude 2mm, DMA Resonant mode.

Fig. 25. DSC Aluminum Pan, 20°C/min, 40~180°C, 5°C/min, 180~40°C. TA Universal Analysis V2.6D DSC2010.
Fig. 24 DMA983 (Dynamic mechanical analysis).

Fig. 25 DSC 2910 (Differential scanning calorimeter).
Fig. 26 (a), (b) illustrate the matrix $\mathbf{A}$ and its transpose $\mathbf{A}^T$. The matrix $\mathbf{A}$ is defined as follows:

$$
\begin{bmatrix}
A_{11} & A_{12} & \cdots & A_{1n} \\
A_{21} & A_{22} & \cdots & A_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
A_{m1} & A_{m2} & \cdots & A_{mn}
\end{bmatrix}
$$

The transpose of $\mathbf{A}$ is obtained by swapping the rows and columns:

$$
\begin{bmatrix}
A_{11} & A_{21} & \cdots & A_{m1} \\
A_{12} & A_{22} & \cdots & A_{m2} \\
\vdots & \vdots & \ddots & \vdots \\
A_{1n} & A_{2n} & \cdots & A_{mn}
\end{bmatrix}
$$

- 69 -
Fig. 26  (a) Tensile Strength test Curve of average data.

- Continued -
(b) Compressive Strength test Curve of average data.
Interlaminar shear test\[ ub \] short beam\[ ub \]. Fig. 22 (b) Interlaminar shear load\[ ub \] (1)\[ ub \].

\[ F_{sbs} = 0.75 \times \frac{P_m}{b \times h} \]  

(1)

\( F_{sbs} \) = Short-beam strength, Mpa (psi)

\( P_m \) = Maximum load observed during the test, N (lbf)

\( b \) = measure specimen width, mm (in), and

\( h \) = measure specimen thickness, mm (in)

Interlaminar shear test\[ ub \] Flatwise tensile test\[ ub \]. Fig. 27 (b) Interlaminar shear test\[ ub \]. Fig 27 (b) 10\[ ub \] 10\[ ub \]. 10\[ ub \] 10\[ ub \] Flapwise tensile test\[ ub \].
Fig. 27 (a) Interlaminar shear test of average data.

- Continue -
(b) Flatwise tensile test Curve of average data.
Fig. 28  DMA (Dynamic Mechanical Analysis)

DMA: Dynamic Mechanical Analysis. DMA involves the measurement of the dynamic response of a material to an applied force or stress. This response includes the loss modulus, which is a measure of the material's mechanical damping capacity. The potential energy stored in the material during deformation is also considered.

Fig. 29  DSC (Differential Scanning Calorimetry)

DSC: Differential Scanning Calorimetry. DSC measures the heat flow as a function of temperature or time, which can be used to determine the glass transition temperature (Tg) and other thermal properties of materials. The rate of change of heat flow is given by (dQ/dt).

- 76 -
Fig. 28  Glass transition temperature of DMA.
Fig. 29  Glass transition temperature of DSC.
(1) 
(2) 
(3) 
(4) 
(5)
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CORE - Materials and Analysis” AIRCRAFT DESIGNS, INC, P 79


Artech International Inc. Asia-Pacific account manager Mr. Rocky Farquhar Heatcon Composite Systems vice-president Mr. Eric Casterin.