

工學碩士 學位請求論文

航空機用 複合材 部品 修理  
熱間露出 物性變化 研究

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

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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 results, the decrease of Tg 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.

1

가  
 ) , ( 가  
 ) ( )  
 (1)  
 가

(core materials) 가  
 (prepreg) 가  
 가 (specific strength) (specific stiffness),  
 , (fire resistance) ,  
 (matrix)

(2) Fig. 1

가 가  
 2 (secondary structure)  
 . 1  
 (primary structure) (wing), (fuselage),

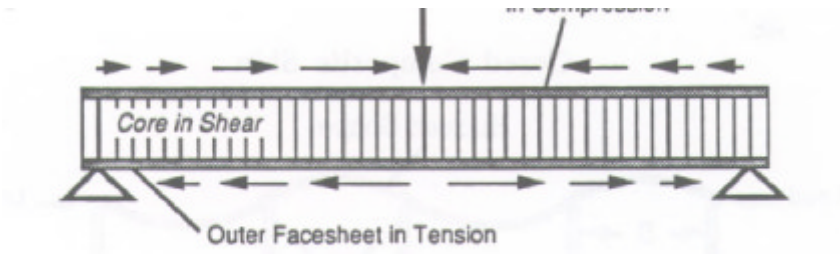
(empennage)

가

. Fig. 2 (a),(b),(c)

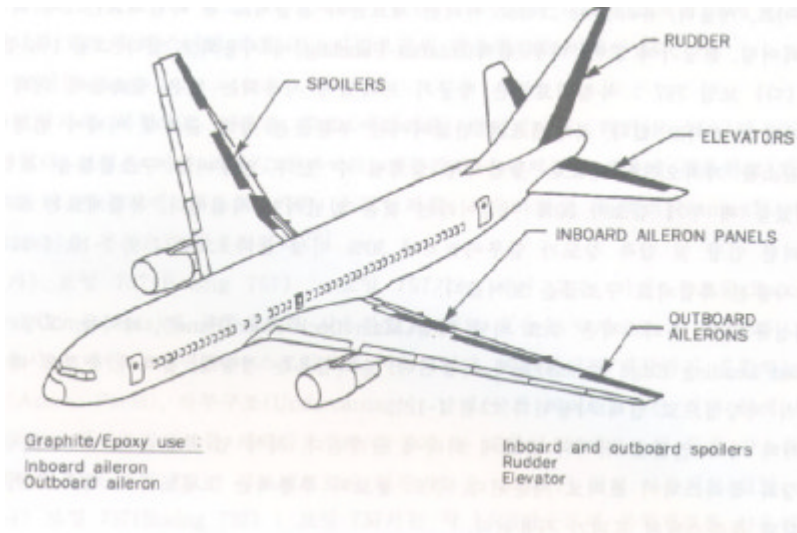
(3)





**Figure 1.1 Load in the Elements of a Cored Structure.**

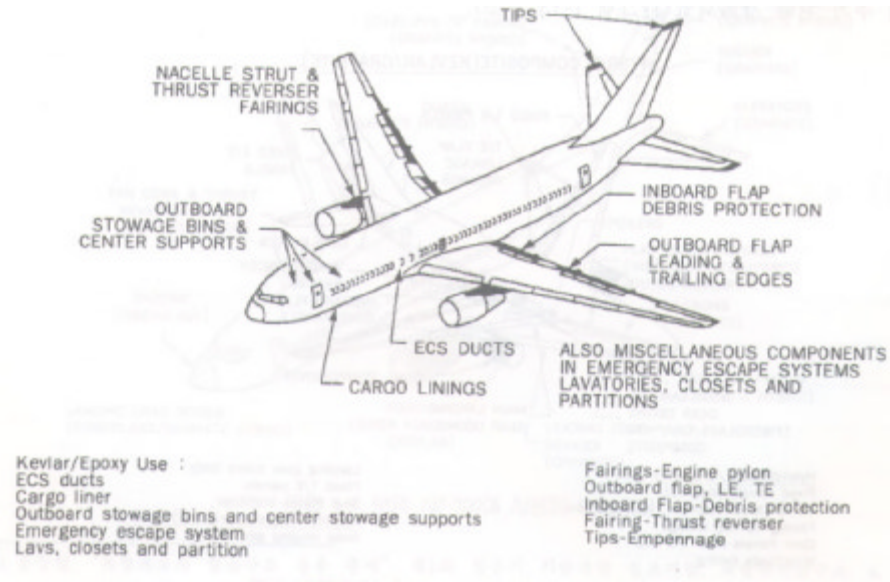
Fig. 1 Load in the element of a cored Structure.



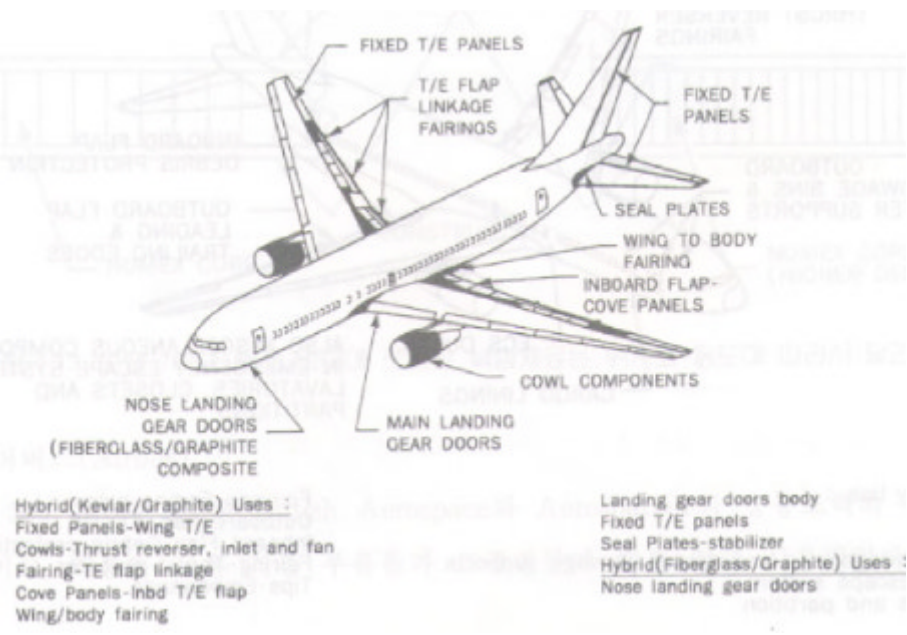
(a) Graphite/epoxy

Fig. 2 Composite materials of boeing 767 aircraft.

- To be continued -



(b) Kevlar



(c) Hybrid(Kevlar/graphite) composite

가

(epoxy) 가

(repair)

가

, 「Bonding Shop」

가

가

(delamination)

(cure cycle)

가

1

가

flatwise tensile test interlaminar shear test,

DMA(Dynamic Mechanical Analysis),  
DSC(Differential Scanning Calorimetry)  
(repair)

2

, ,  
, ,  
, , 가 , 가  
2 1

2.1

2.1.1

가 , 가  
가 , 4 10<sup>6</sup>  
.

. ( 가  
가  
) 1.5 2.0 .  
1/2 1/6

가  
(4)(5)

가.

	가	가
		가
Table. 1	가	가
가	가	가
		가
	가	
	가	
	가	
가	가	가
	가	가
2		

. 가

가

. 가 ,

가 가 가

가 가

2.2

2.2.1

(matrix) , (composite structure)

가

( - hybrid)

( - fiber science),

,

(foam)

(

- sandwich structure),

<sup>(6)</sup>

2.2.1.1 - fiberglass( - glass cloth)

(silica) 가

가 가

가

가

2.2.1.2 (aramid)

(organic fiber)

가

가

가



2.2.1.3 / (carbon/graphite)  
(precursor) 가

PAN(Polyacrylonitrile) pitch가 .  
Pitch pitch

polyacrylonitrile(PAN) polyacrylonitrile(PAN)  
1000~2500 carbon

2500~3000  
graphite

PAN 가 spool 가

(strong), (stiff), pitch  
(rigid strength)

/ (ribs)  
1 (primary structure components)

(high rigidity)  
(bulkhead), (ribs), (stringer)

1

가

가

50t/mm<sup>2</sup>

2.2.1.4 (boron)

(CVD, Chemical Vapor Deposition)

가

가 E-glass

가

가

2.2.1.5 (ceramic)

2,200.

(heat resistant)

Table. 1

Table 1 Properties of reinforcing fiber.

Property Fiber /Wire	Density Lb/in <sup>3</sup>	Tensile Strength 10 <sup>3</sup> lb/in <sup>2</sup>	Specific Strength 10 <sup>5</sup> in	Tensile Stiffness 10 <sup>6</sup> lb/in	Specific Modulus 10 <sup>7</sup> in	Melting Point °C
E-Glass	0.092	500	54	10.5	11	1316
S-Glass	0.090	700	78	12.5	14	1650
Boron	0.093	500	54	60	65	2100
Carbon	0.051	250	49	27	53	3700
Graphite	0.051	250	49	37	72	3650
Kevlar	0.052	525	101	18	35	249
Aluminum	0.097	90	9	10.6	11	660
Titanium	0.170	280	16	16.7	10	1668
Steel	0.282	600	20	30	10	1621

2.2.2 (matrix system)

(matrix resin system)

(thermoset) 가 (thermoplastic)  
 가 가  
 가 가  
 가 가  
 가 windshield  
 (plexiglass) windshield  
 windshield 가  
 가

(7)

가

, 2 ,

가

Shell Ep828, Ciba-Geigy MY720,  
 Narmco 5208, Hexcel F 151, 3501

Table 2 가

Table 2 Thermoplastic and thermoset.

Item \ Type	Thermosets	Thermoplastics
<b>Maturity</b>	<ul style="list-style-type: none"> <li>■ Proven Materials</li> <li>■ Good Database</li> </ul>	<ul style="list-style-type: none"> <li>■ Newer Materials</li> <li>■ Limited Database</li> </ul>
<b>Storage</b>	<ul style="list-style-type: none"> <li>■ Refrigerated for Limited Out-Time and Shelf Life</li> </ul>	<ul style="list-style-type: none"> <li>■ No refrigeration</li> <li>■ Unlimited out-time and shelf life</li> </ul>
<b>Prepreg</b>	<ul style="list-style-type: none"> <li>■ High Quality - Tacky</li> </ul>	<ul style="list-style-type: none"> <li>■ Potential for high void</li> <li>■ Low Formability</li> </ul>
<b>Cure Cycle</b>	<ul style="list-style-type: none"> <li>■ Normal Pressure / Temperature</li> </ul>	<ul style="list-style-type: none"> <li>■ High Pressure, Temperature, Fast Processing Cycle</li> </ul>
<b>Reparability</b>	<ul style="list-style-type: none"> <li>■ Patch Type Repair Required</li> </ul>	<ul style="list-style-type: none"> <li>■ Reheating, Reprocessing Required</li> </ul>
<b>Forming</b>	<ul style="list-style-type: none"> <li>■ Cure to Shape</li> </ul>	<ul style="list-style-type: none"> <li>■ Thermoforming of Flat Sheet Required</li> </ul>

2.2.3

2.2.3.1

가  
 가 (honeycomb sandwich structure) .  
 (facing)  
 가 (inplane  
 load) (bending rigidity)  
 가 (pre-impregnated)  
 (laminare) 가 (hybrid)  
 (Core)  
 가  
 (shear rigidity)  
 KRAFT 가  
 가  
 (peel resistance)  
 가

2.2.3.2

(8)  
가  
(resin  
rich) (resin lean)  
(lay-up)  
가  
(unairworthy)  
/

가 가 가

(thermosetting resin)

A, B, C- stage 3

- A- stage - 가
- B- stage - 가
- C- stage - 가

Flow

(hot melt prepreg process)

(solvent prepreg process)

Fig. 3 (b)

가

가 (roll)

(drying tower)

Fig. 3 (a)  
(spool)

가

가

가

가

가

prepreg pre-impregnation( )

B- stage

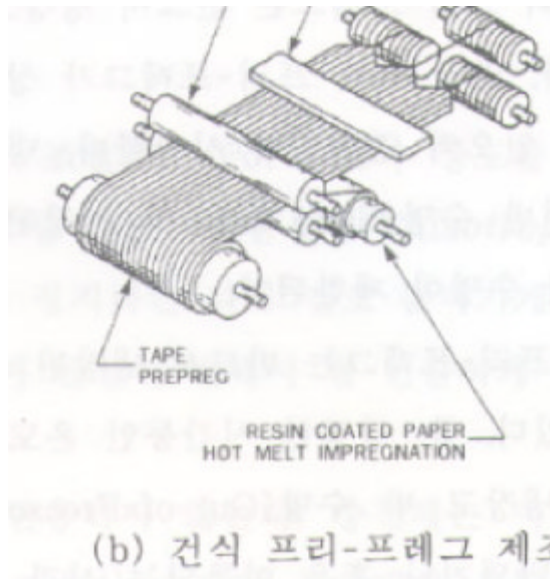


B- stage

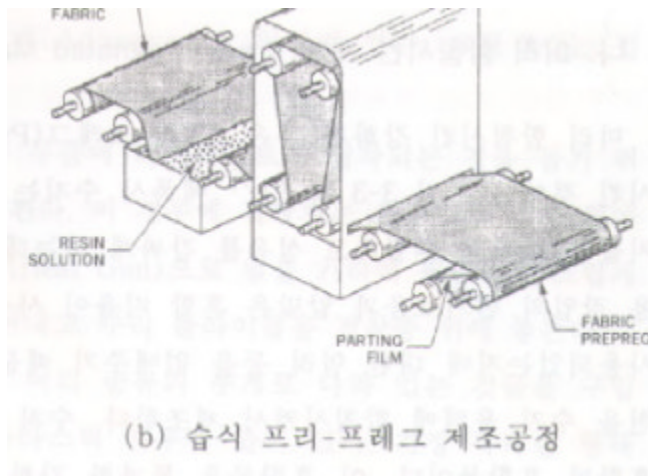
-20

6 가

Fig. 3 (a) (b)



(a) Hot melt prepreg process.



(b) Solvent prepreg process.

Fig. 4 The manufacturing process of prepreg.

2.3.3 (core materials)

Fig. 4 가 (rotor blade) 가 (foam core)가 80%

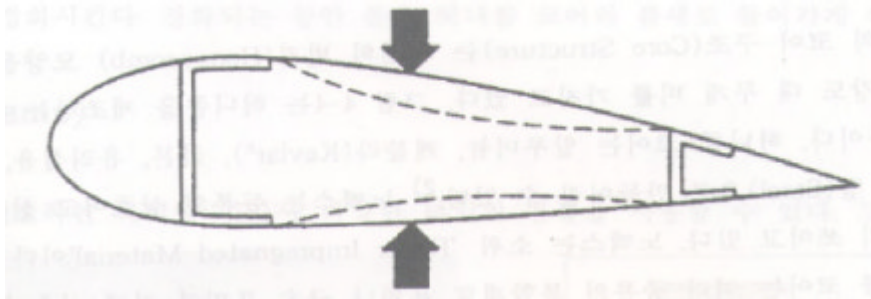
2.3.3.1 (honeycomb core)

composite sandwich structure 가 가 aerodynamic smoothness, noise /

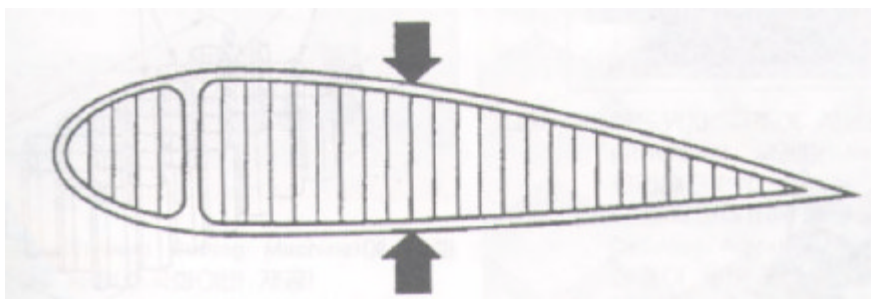
Fig. 5 sandwich 가 (faces) aluminum sheet, glass fiber, carbon fiber, kevlar etc (Core) aluminum honeycomb, nomex honeycomb etc

Fig. 5

- L" dimension --- /
- W" dimension --- /
- T" thickness ---
- Nodes ----- Cell
- Cell size -----  
Cell
- Ribbon direction- Node
- Density - pound per cubic foot (PCF) perforated  
honeycomb cell wall
- honeycomb curing adhesive resin  
gas adhesive
- non-perforated type



(a)



(b)

Fig. 4 (a) Metal skin will bend and flex when forces are applied in flight. (b) Composites keep the structure from flexing in flight, eliminating fatigue.

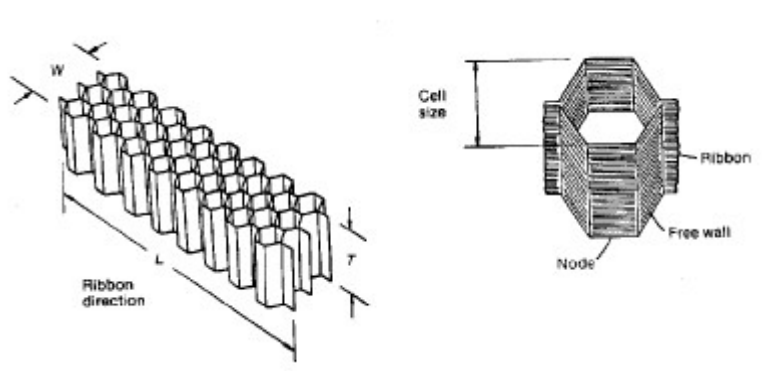


Fig. 5 The name of honeycomb core structure

honeycomb expansion  
corrugated process가 가

가) Node line adhesive가 web material

) adhesive line curing expansion

block

) block slice

expansion cell

Corrugated process

Web material corrugating roll

corrugated sheet node adhesive

block

Honeycomb core adhesive cell

가 ( 500 ) ,

fiber sheet aluminum foil

가 node

Node adhesive 가

titanium, nickel honeycomb spotwelding

brazing

non metallic honeycomb fiber sheet

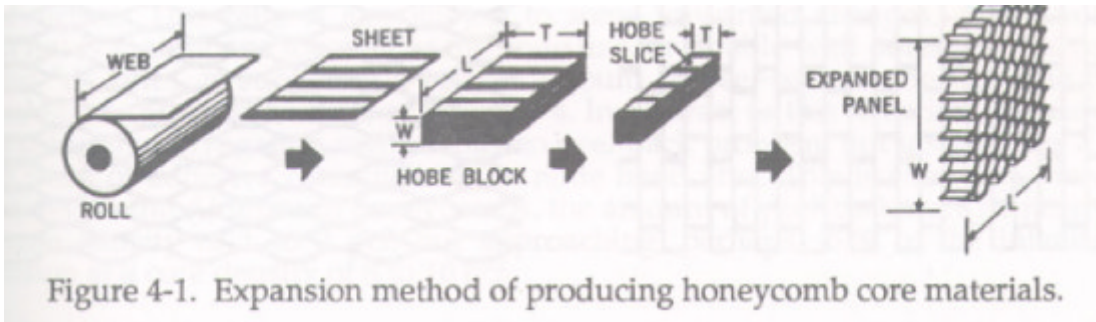
phenolic resin (preimpregnated), dip

coating node bonding resin

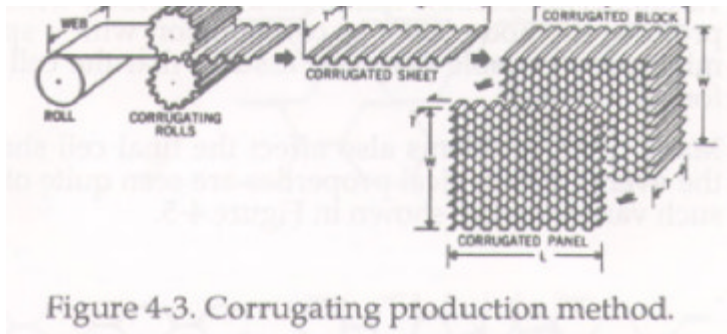
adhesive

resin fungus-resistant

Fig. 6 (a) (b)



(a)



(b)

Fig. 6 (a) Expansion method of producing honeycomb core materials, (b) Corrugating production method.

Fig. 7 Fig. 5

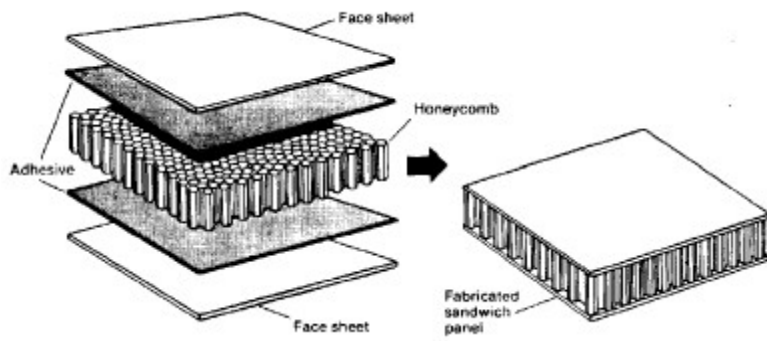


Fig. 7 Example of a bonded sandwich assembly.



## cell configuration

### - Aluminum honeycomb

- 2024 alloy (high room temperature properties)
- 5052 alloy (genetal 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 가 )
- Bias weave glass fabric reinforced plastic dipped In a heat resistant phenolic resin (350 가 , shear strength 가)
- Glass fiber reinforced plastic initially impregnated in a nylon-modified phenolic resin and finally dipped In a polyester resin (180 가 )
- Bias weave glass fabric reinforced plastic dipped in a polyimide resin (500 가 )

### - 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

가

- 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)

honeycomb type

가 factor

factor

Table 3 (a),(b)

Table 3 Factors of selecting honeycomb type.

(a)

Factor / 구분	Glass Fiber Reinforced Honeycomb			
	Dipped In a Phenolic Resin	Incorporated with Bias Weave	Dipped In a Polyester Resin	Dipped In a Polyimide Resin
Cost	MOD	MOD	MOD	HIGH
Max Service Temp	350 °F	350 °F	350 °F	350 °F
Flammability	E	E	E	E
Impact Resistance	F	G	F	F
Moisture Resistance	E	E	E	E
Fatigue Strength	G	G	G	G
Heat Transfer	LOW	LOW	LOW	LOW

(b)

Factor / 구분	Aluminum Honeycomb			Aramid Fiber Reinforced	Special Application
	5052 5956	2024	Al Commercial Grade	Dipped In a Phenolic Resin	Water Resistant Core
Cost	MOD	HIGH	LOW	MOD	LOW
Max Service Temp	350 °F	420 °F	350 °F	350 °F	350 °F
Flammability	E	E	E	E	P
Impact Resistance	G	G	G	E	F
Moisture Resistance	E	E	E	E	G
Fatigue Strength	G	G	G	E	F
Heat Transfer	HIGH	HIGH	HIGH	LOW	LOW

E: Excellent    G: Good    F: Fair    P: Poor

Cell configuration

- Hexagonal core
  - 가 Metal Non
- Over expanded core
  - Metal
  - Hexagonal core W over-expand rectangular
  - cell L curving forming
  - Hexagonal core W L
- Reduced anticlastic curvature (flex-core)
  - hexagonal core 가
  - formability가
- Tube core
  - Flat aluminum foil adhesive corrugated aluminum foil tube core
- Other configuration
  - reinforced L honeycomb, dovetail, chevron core가
  - 90% honeycomb type
  - 가 factor

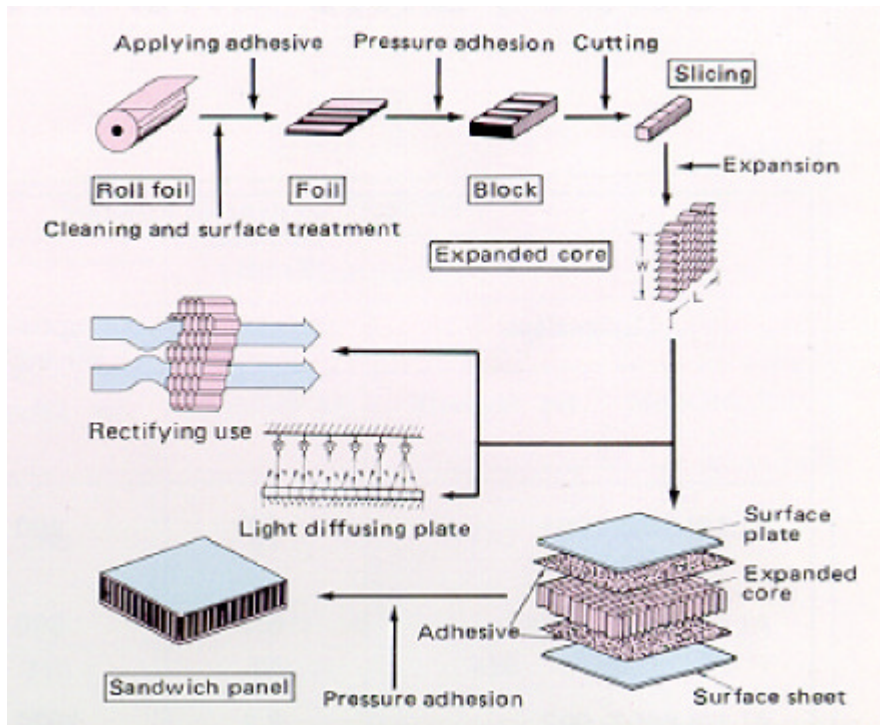


Fig. 8 Manufacture of honeycomb sandwich structure.

2.3.3.2 (Central foam)

(Fire resistance) , ,

. Fig. 9

(solid fiber glass)

(laminate) 4

가 . Fig. 9 2

2 가

가 6% 가

가 37

10 가 가

가

(styro foam)

canard,

(urethane foam)

가

가 , 가

(Poly Vinyl Chloride - PVC)

PVC

(wood core)

(balsa wood)

가

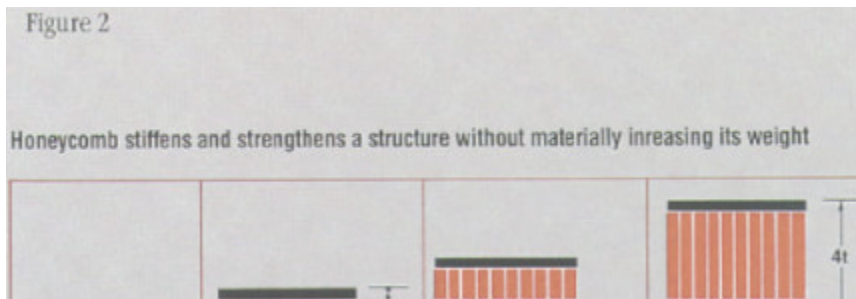


Fig. 9 Honeycomb stiffens and strengthens a structure without materially increasing its weight.

3 (Autoclave)

Fig. 10 (bug) 가 가  
(  
)  
,  
가 가  
(9)  
,

(honeycomb sandwich)  
, (batch)

가 (10)





Fig. 10 Lay-up of vacuum bagging materials.

### 3.1

#### 3.1.1

, 가

, ,

.

, .

.

#### 3.1.2 (lay-up) -

, , ,

.

.

#### 3.1.3 ,

, ,

.

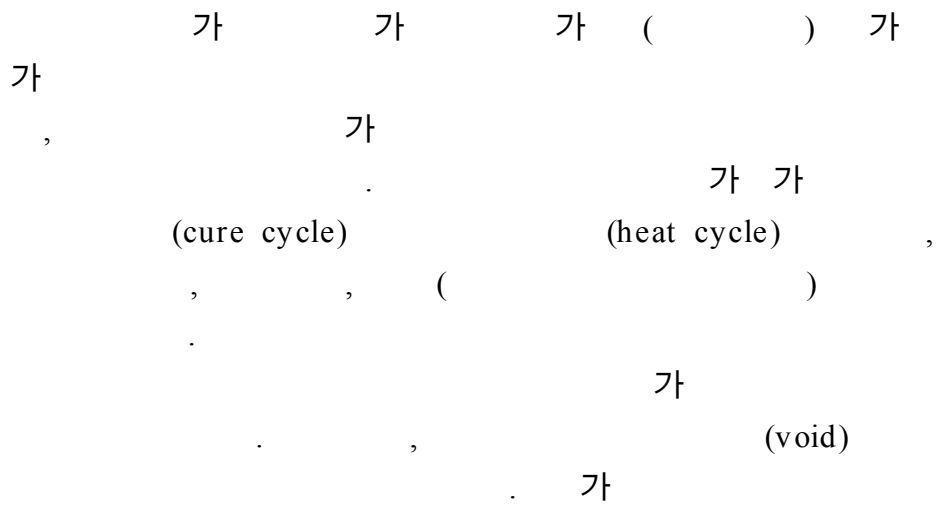
, , .

, , ,

.

CFRP 가

3.14



(cure cycle)

3.15

Fig. 11

Fig. 12

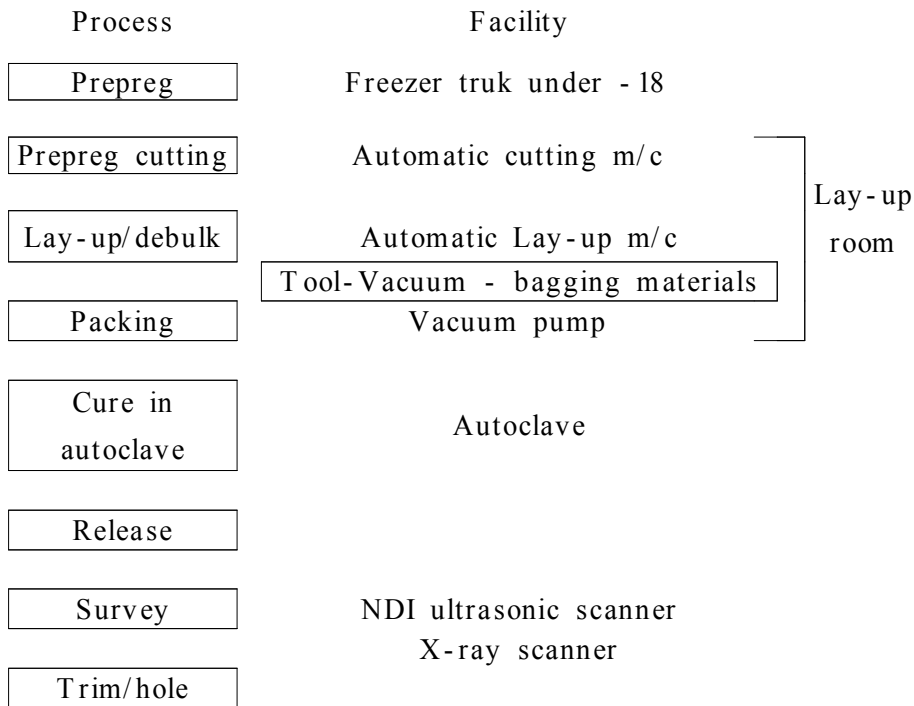


Fig. 11 Process of Autoclave.



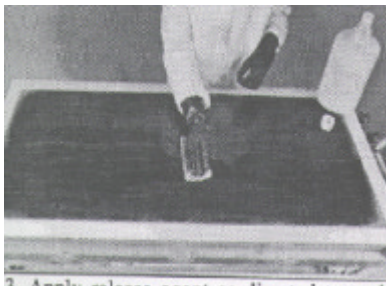
1. Start with a clean, smooth tool plate. Note that any flaws or irregularities on the tool plate will show up on the cured laminate. This may necessitate sanding or washing the plate with solvent.



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 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 of any release agent in preparation for the application of sealant tape(step15).



3. Apply release agent as directed to tool



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

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.



5. Lay down the first ply in the center of the tool, making sure that it is smooth and free of wrinkles and distortion.



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 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.



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

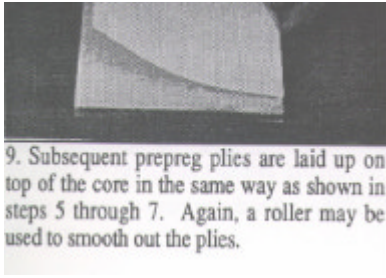


8. The core is laid down in the same manner as the prepreg, with the edges lined up with the prepreg plies.

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 -



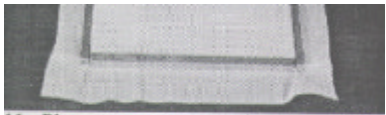
9. Subsequent prepreg plies are laid up on top of the core in the same way as shown in steps 5 through 7. Again, a roller may be used to smooth out the plies.

Step 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.



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 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.



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 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.



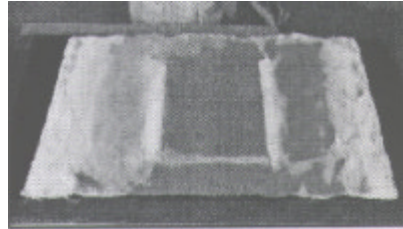
12. A caul plate is placed over the laminate. This plate, like the tool plate, should be both clean and smooth.

Step 12. A caul plate is placed over the laminate. The plate, like the tool plate, should be both clean and smooth.

- Continued -



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.



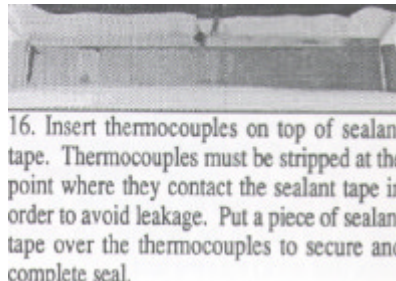
14. Remove adhesive tape from the edges of the tool.

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.



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



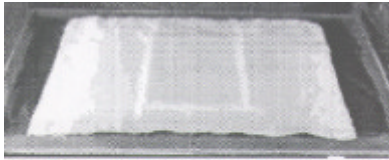
16. Insert thermocouples on top of sealant tape. Thermocouples must be stripped at the point where they contact the sealant tape in order to avoid leakage. Put a piece of sealant tape over the thermocouples to secure and complete seal.

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

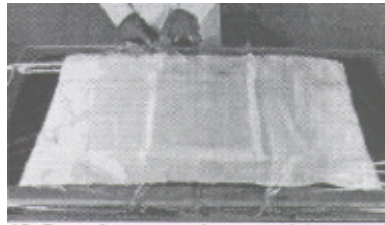
Step 16. Insert thermocouples on top of sealant tape. Thermocouples must be stripped at the point where they contact the sealant tape in order to avoid leakage. Put a piece of sealant tape over the thermocouples to secure and complete seal.

- Continued -





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



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

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.

Turn on the vacuum pump and connect vacuum lines. Pull 5 inches (17kPa) 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.

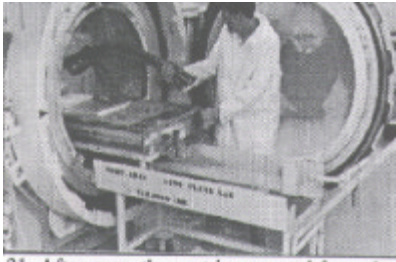


20. Put the part into the autoclave and hook up the vacuum lines. Start the autoclave run. Table 5.1 shows a typical autoclave cure cycle.

Step 19. Turn on the vacuum pump and connect the vacuum lines. Pull 5 inches of Hg(17kPa) 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 -



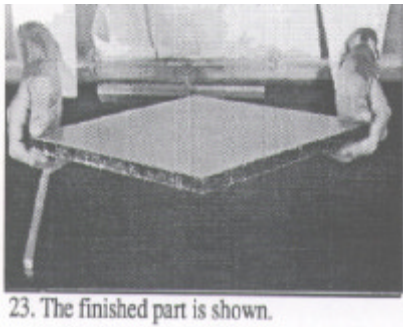
21. After cure, the part is removed from the autoclave...

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



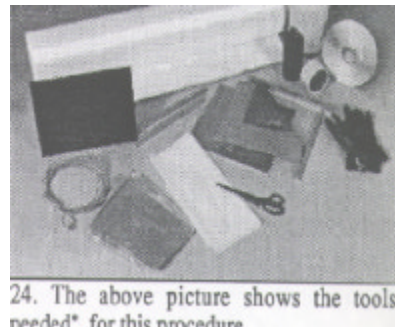
22. ...and the bag material, breather plies and release film are removed

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



23. The finished part is shown.

Step 23. The finished part is shown.



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

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

- Continued -

4

가 가  
 가 가  
 15-20%  
 manufacturing repair for OEM  
 maintenance repair for air lines  
 Boeing major  
 hot bond, cold bond, bolted repair 3가  
 ( )  
 가  
 가  
 가  
 Co-cured  
 가  
 가  
 가 )  
 co-cured repair

, / / , ,  
 , , , 7가  
 .  
 depaint  
 random orbital sander ,  
 surface abrasin, step sanding 가  
 1 .  
 grit/diamond edge hole saw .  
 hot bond repair cold bond repair  
 . Hot bond repair wet lay-up  
 200F - 230F, 250F, 350F  
 SRM(Structural Repair Manual) . Cold bond  
 repair 가 150F ,  
 . Damaged  
 area , ,  
 가  
 가 가  
 , 가  
 .  
 hot and cold 가

holding . Damaged area  
 NDI . masking  
 , skin, core .  
 oven autoclave, heating console .  
 , heating console , heat  
 blanket .  
 , 250F, 350F .

가 가 가 ,  
 honeycomb kit가  
 , kit  
 가 가 . Fig 13 Kit

(11)  
 Fig. 14 (a)  
 Fig. 14 (b)

가  
 4.1 가  
 가 가  
 가 (heating) :

가	가		
가	(heat gun) :	가	
	가	500 750	
		가	350
가	가		
가	(thermocouple)		
	(control unit)		
	(oven curing) :		
		가	
	(autoclave) :		
			가
	(heating blankets) :		
	가	가	
			가
		가	
		가	
(heat patch bonding machine)			
	(hot patch bonding machine) :		
	가		
	가		

가 .  
gun) . 가 (heat

4.2 가 (applying pressure)

가 , 가  
가 .  
가 .

(vacuum bagging) 가  
가 .  
(shot bag) : (clamp)

(clecos) :  
plate) . (caul  
(spring clamp) :

(peel ply) : (peel ply)

(bleeder),  
(vacuum bagging) :  
가 가 . 가

가 .  
- :  
- (sealant tapes) :

- (release fabrics and films) :

- (peel plies) :

- 가  
: 가  
가

- (bleeders) :

- (breathers) : 가  
가

- (calking plate) :

- (insulation plies) :  
가



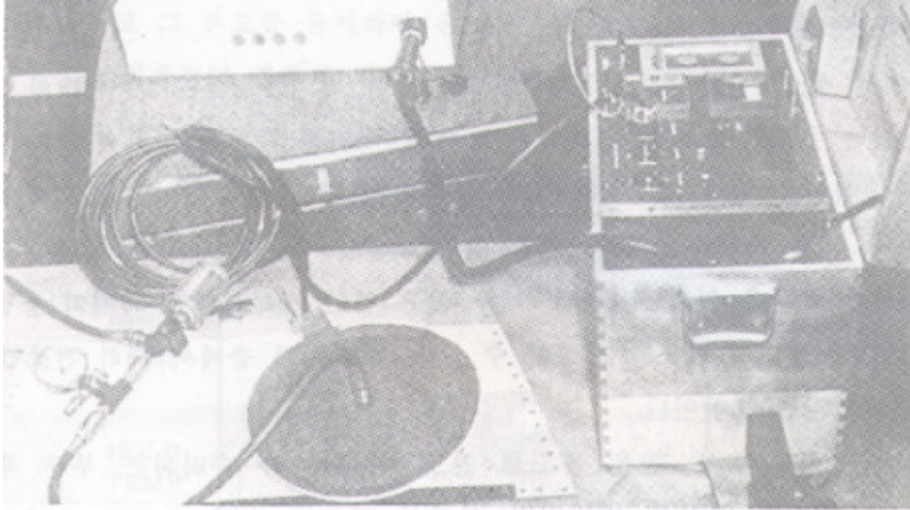
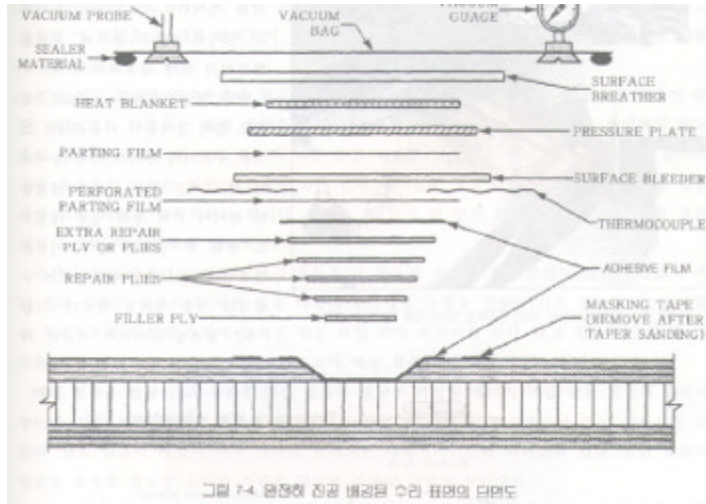
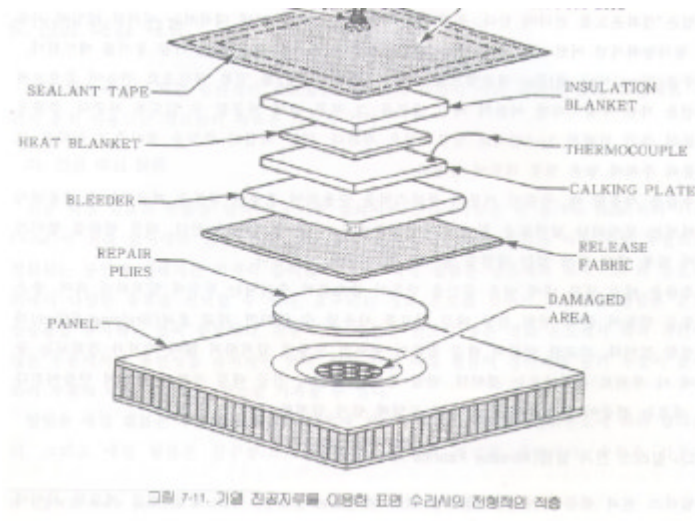


그림 8-1. 진공 가열(Vacuum Heating) 담요로 수리 부위를 경화시키는 장면

Fig. 13 Repair kit.



(a)



(b)

Fig. 14 Diagram of composite repair.

5.1

CYTEC FIBERITE社 glass/epoxy prepreg style  
 7781  
 260 °F HEXCEL社 Nomex  
 honeycomb core , cell size 3/16  
 block 3M scotch-weld EC 2216 A/B

가 가 가  
 'Out of  
 freezer life' 가

'Out of Freezer Life'

- (Storage Life) : 10 ℥ (-12 ), 180 days
- (handling life)
- 11 80 ℥ (27 ) : 1
- 81 100 ℥ (38 ) : 3
- 100 ℥

HEXCEL 3/16 Hexagonal  
 Cell 가 Nomax Table 4

가 가

Table 4 The mechanical properties of the used prepreg.

Mechanical Properties	Style			
	120 or 220		7781	
	Class 1	Class 2	Class 1	Class 2
Compression ULT. (ksi)				
75 ± 5 F	54	45	54	45
350 ± F	27	24	32	25
Compression Mod. (Msi)				
75 ± 5 F	2.9	2.5	3.1	2.7
350 ± F	2.2	2.1	2.7	2.6
Tensile ULT.(ksi)				
75 ± 5 F	41	41	47	47
350 ± F	25	25	27	27
Tensile Mod. (Msi)				
75 ± 5 F	2.9	2.9	3.1	3.1
350 ± F	2.4	2.4	2.5	2.6

Table 5 The mechanical properties of the used honeycomb core.

T Y P E	D E N S I T Y	Nomex honeycomb core									
		Compre- ssion Strength (psi)		L. Shear Properties				W. Shear Properties			
				ULT. psi		MOD. psi		ULT. psi		MOD. psi	
		MIN. AVG.	MIN. IND.	MIN. AVG.	MIN. IND.	MIN. AVG.	MIN. IND.	MIN. AVG.	MIN. IND.	MIN. AVG.	MIN. IND.
I	3.0	250	200	155	140	5.200	4.500	84	67	2.800	2.500

5.2

(Autoclave)

(cure cycle)

100, 150  
50  
1, 2, 3, 4  
33  
50,  
Fig. 15  
90

Interlaminar share test Flatwise tensile test

10, 50,100, 150

Fig. 16

Interlaminar share test, Fig. 17 Flatwise tensile test  
specimen

Flatwise tension specimen

3M 2216 Adhesive Film

24 70 1

Cross head speed 3 6

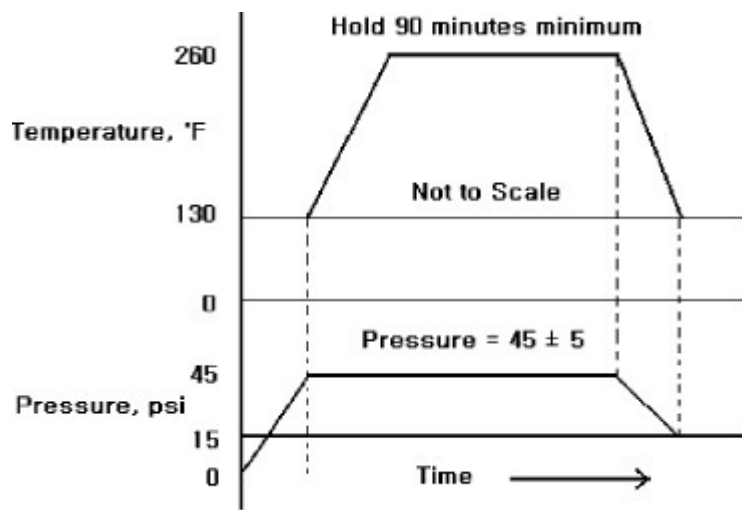
Fig. 17

DMA(Dynamic Mechanical Analysis)

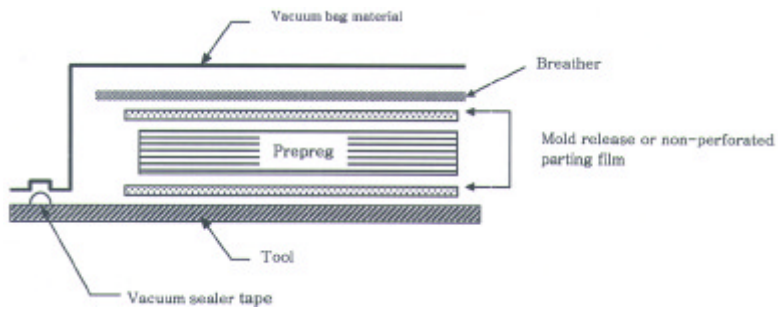
1.5, 3, 4.5, 6, 7.5

DSC(Differential Scanning Calorimetry)

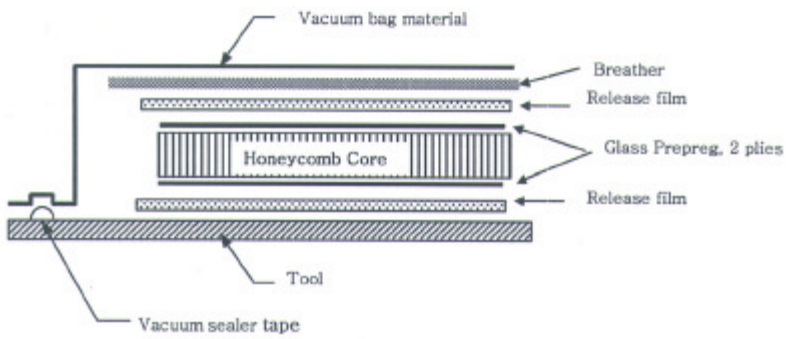
1, 2, 10, 20, 30, 40, 50, 100, 150



**Fig. 15** Autoclave cure and pressure cycle.



**Fig. 16** Interlaminar shear test specimen in autoclave.



**Fig. 17** Flatwise tensile test specimen in autoclave.

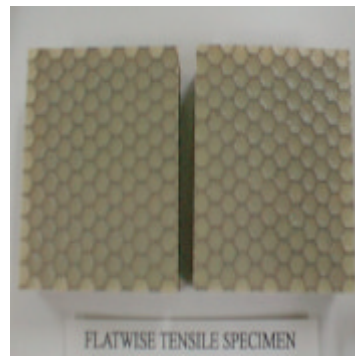




(b)



(c)



(d)

**Fig. 18** Test specimen.

(a) Tensile

(b) Compressive

(c) Interlaminar shear (d) Flatwise tensile

### 5.3

#### 5.3.1

test . Fig. 19 Fig 20  
strain 가

(13)(14)(157)(16)(17)



Fig. 19 The real shape of the used tensile test machine.

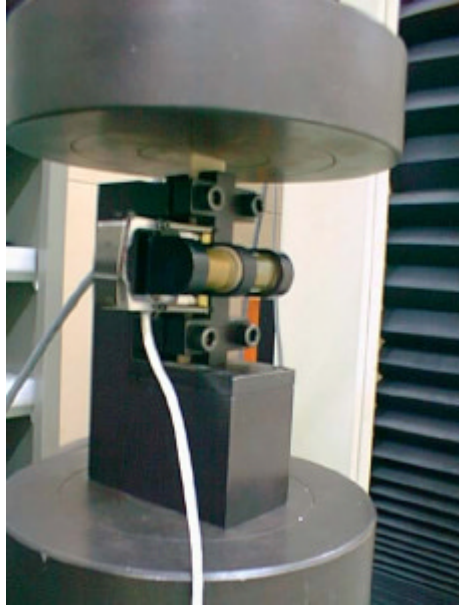


Fig. 20 The real shape of the used compressive test machine.

### 5.3.2 Interlaminar shear test

#### Interlaminar shear test

가 . Fig. 21 Interlaminar shear test  
가 test . (a)

, (b)

(b)

(18)

Fig. 22  
machine

diamond wheel cutter

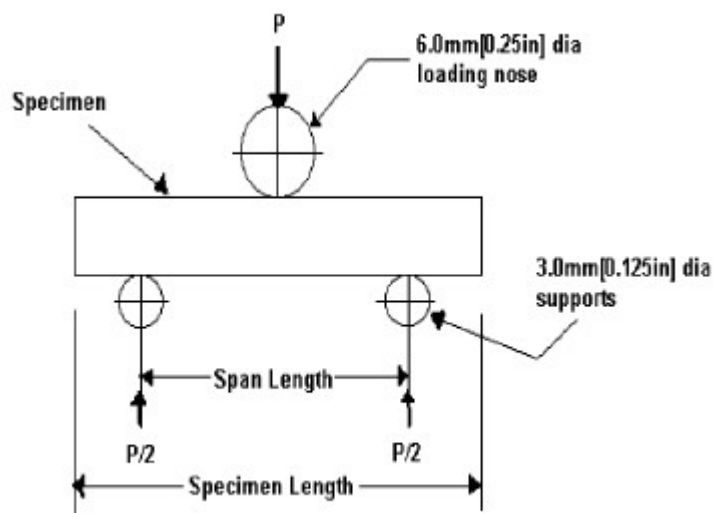


Fig. 21 Type of shear load diagram.

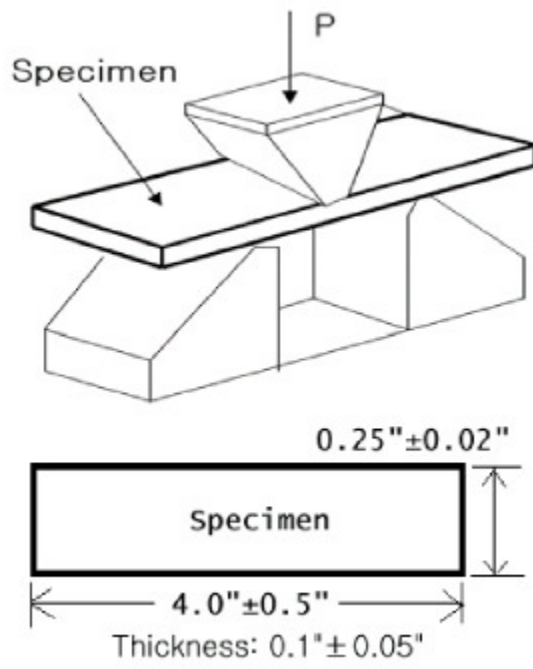


Fig. 22 The diagram interlaminar shear test.

### 5.3.3 Flatwise tension Test

Fig. 23 Flatwise tension specimen

Flatwise tension specimen  
interlaminar shear test  
가 가  
glass/epoxy prepreg style 7781  
가  
가  
Flatwise tension test machine  
test (19)

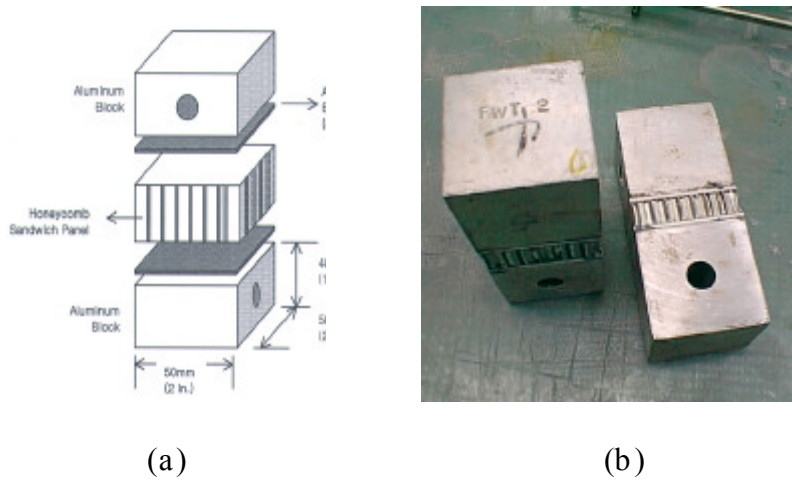


Fig. 23 The diagram and the real shape of flatwise tension specimen.

5.3.4 DMA(Dynamic Mechanical Analysis) · DSC(Differential Scanning Calorimetry)

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

Fig. 25 DSC . Aluminum Pan  
20 /min 40 180  
, 5 /min 180 40  
20 /min 40 180 , 5  
/min 180 40 . TA Universal Analysis  
V2.6D DSC2010 <sup>(20)</sup>



Fig. 24 DMA983 (Dynamic mechanical analysis).



Fig. 25 DSC 2910 (Differential scanning calorimeter).



6

Fig. 26 (a) (b)

가 .  
가 .  
가 .  
가 .  
가 .  
matrix

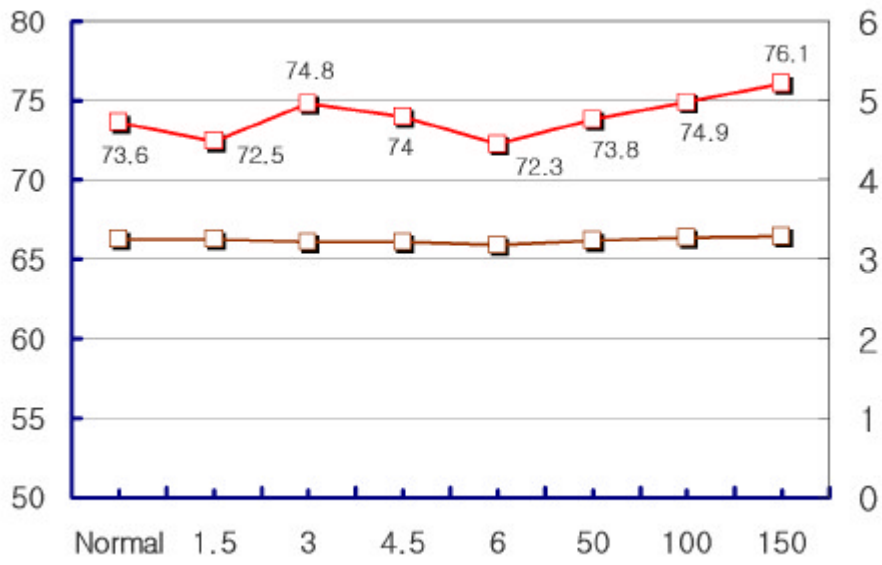
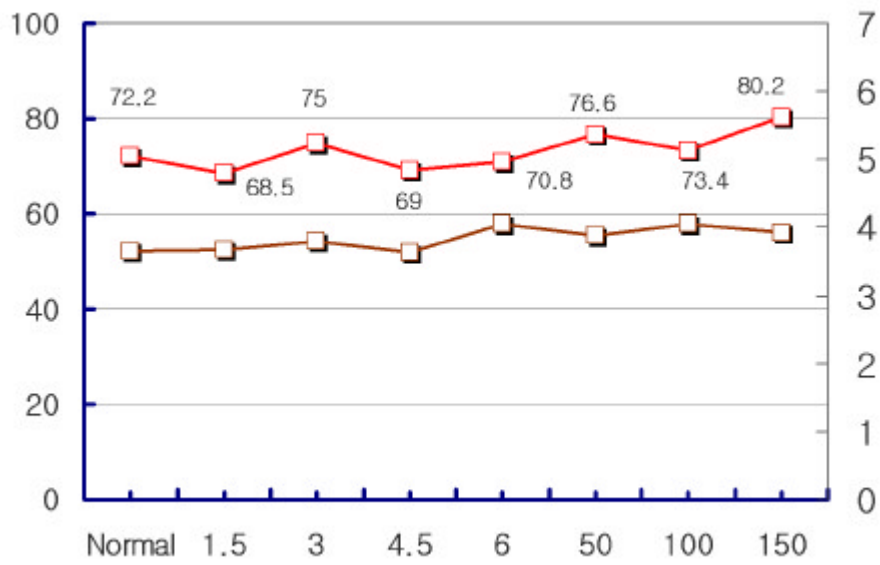


Fig. 26 (a) Tensile Strength test Curve of average data.

-Continued-



(b) Compressive Strength test Curve of average data.

Interlaminar shear test

short beam

. Fig.

22 (b) Interlaminar shear load

(1)

$$F^{sbs} = 0.75 \times \frac{P_m}{b \times h} \quad (1)$$

$F^{sbs}$  = 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

가

가

Flatwise tensile test

Fig . 27 (b)

Interlaminar shear test

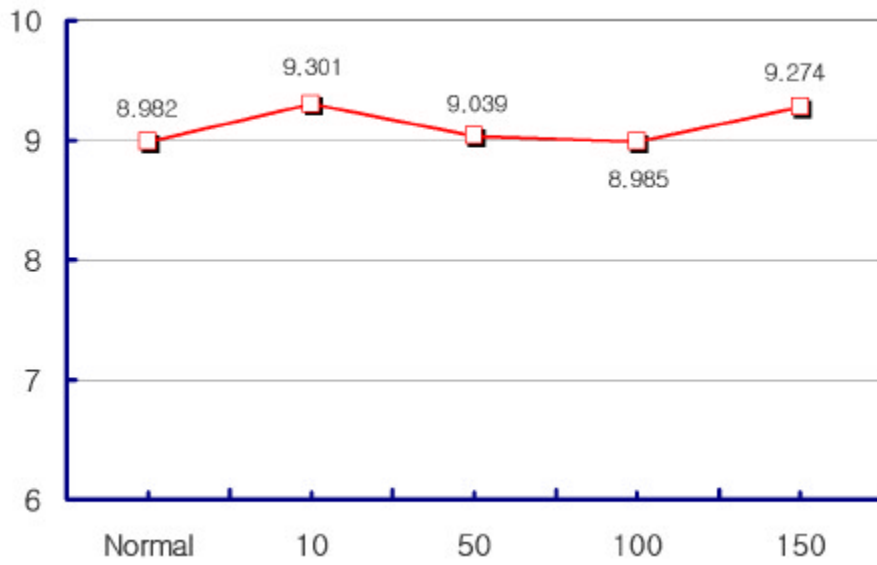
, Fig 27 (b)

10

10

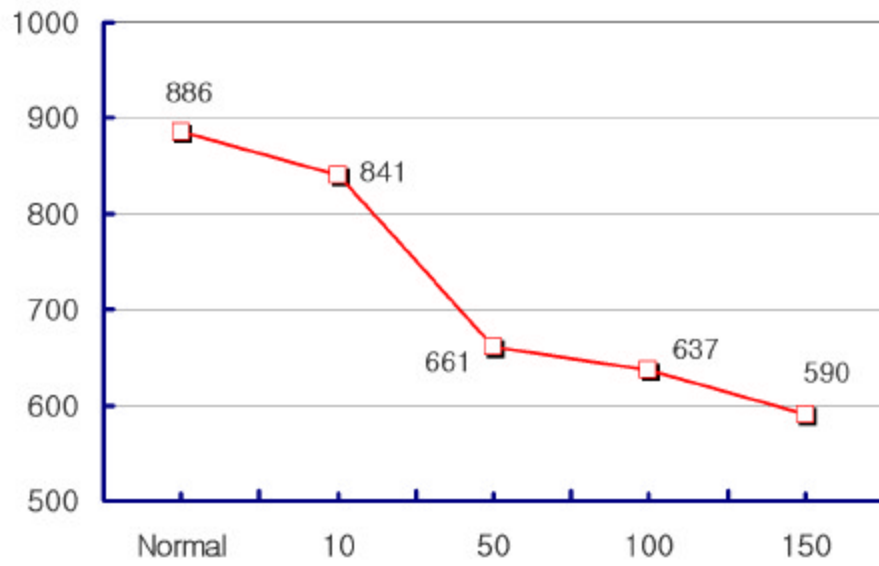
Flatwise tensile test

가



**Fig. 27** (a) Interlaminar shear test of average data.

-Continue-



(b) Flatwise tensile test Curve of average data.

Fig. 28 DMA(Dynamic Mechanical Analysis)

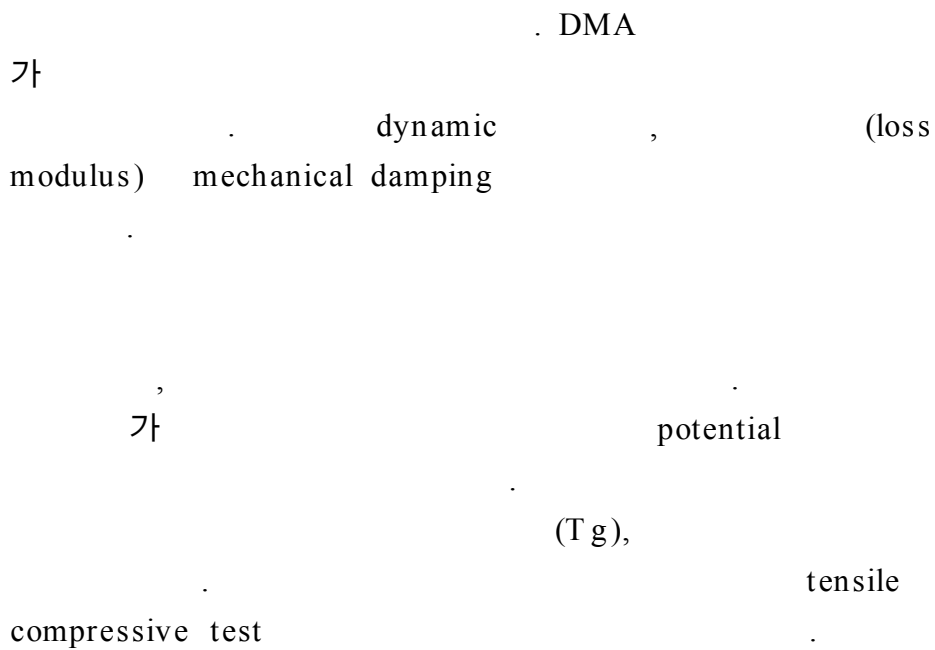
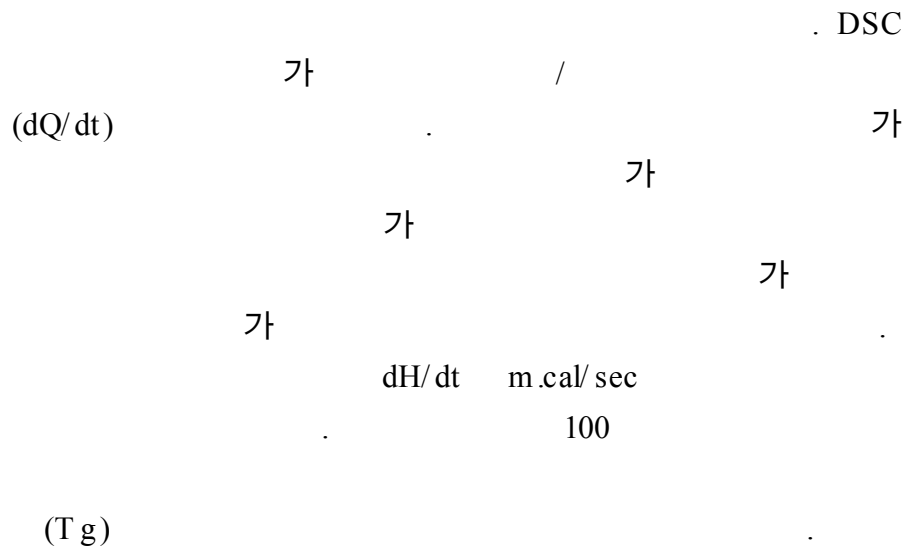
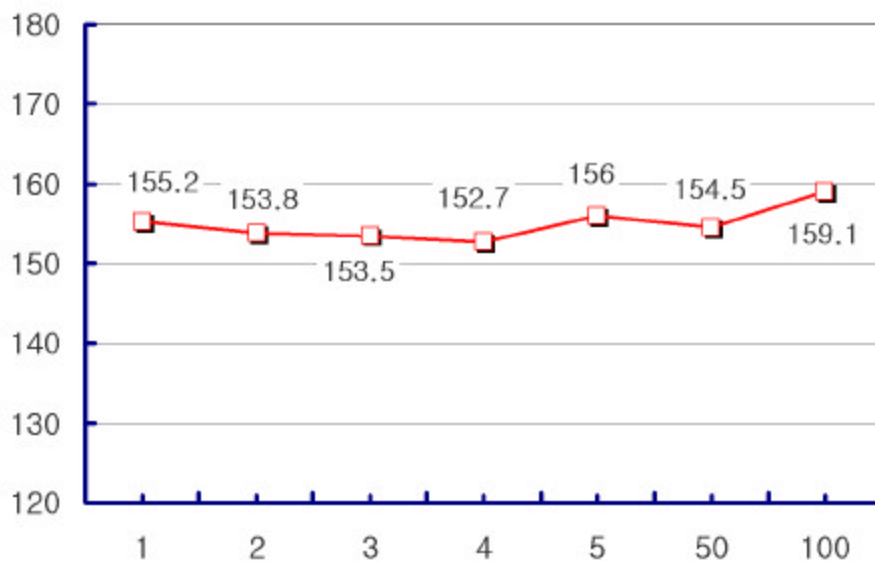


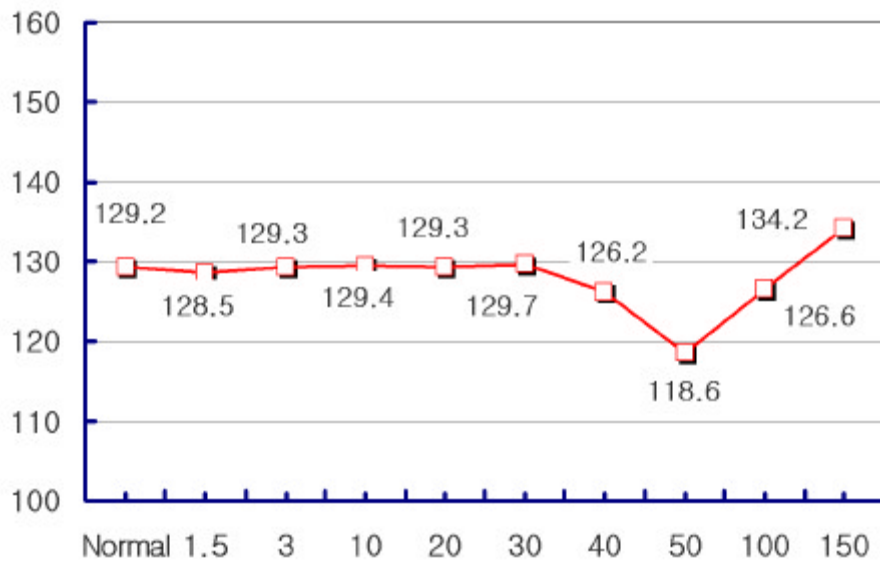
Fig. 29 DSC(Differential Scanning Calorimetry)







**Fig. 28** Glass transition temperature of DMA.



**Fig. 29** Glass transition temperature of DSC.

7

(1)

가

(2)

(3)

(4)

가

가

(5)

postcure가

가

가

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가

가

2

LA

Airtech International Inc.社 Asia-Pacific  
 account manger Mr. Rocky Farquhar ,  
 Heatcon Composite Systems社  
 Vice-President Mr. Eric Casterin .

DSC/DMA

Industrial Corporation      , Showa Aircraft  
Mr. Hiroshi Fujimoto

가

가