# CHARACTERISATION OF OVEN CURED PMC RADOME PANEL FOR AIR BORNE APPLICATION

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**SUMMARY:** In radome manufacturing, prepregs (pre-impregnated composites), which contain the required amount of resin (B-stage) in the fabric are more popular, because they offer ease of handling, better resin control and dimensional tolerance [1]. For curing of prepregs, autoclave is recommended to obtain uniform resin flow and better compaction. However, due to certain reasons, use of an oven for curing of a high technology large size airborne radome was necessitated. Curing is a critical operation in obtaining the optimum properties in the material for a radome. Due to the change in curing from autoclave to oven, there was a need for establishing the most suitable cure cycle for oven curing. In this paper the characterisation process performed to achieve the optimum oven cure cycle has been presented. Both destructive and non-destructive tests have been carried out to assess the properties of cured components. Samples cured in different cure cycles were tested as per ASTM standards [2] and results compared with the properties of an autoclave cured reference sample. Based on this characterisation process one cure cycle, which gave properties close to those of autoclave cured sample has been selected for the application.

**KEYWORDS:** Autoclave, C-Scan, Cure Cycle, Drum Peel, Fexural Strength, ILSS, Oven, Radome, Sandwich

## INTRODUCTION

An airborne radar is designed to give high performance, since it has to discriminate between targets and ground clutter, which is a major function. This is made possible with the use of very low side lobe antenna systems. To make the efforts of antenna designer useful, the antenna has to be protected by a radome that is equally of high performance [3]. Hence, the design requirements of an airborne radome (especially for Airborne Early Warning operations) are more critical in evaluating the overall performance of the radar system. For radome design, the requirements are based on military specification MIL-R-7705B [4].

The basic requirements of a radome are two fold: Electrical and mechanical. For the characterization process, it is better and appropriate to have some brief understanding of the radome requirements. In fact, electrical and mechanical requirements can be met to a greater

extent (other than the design) by the fabrication and curing process. Hence, characterization plays an important role in arriving at the radome requirement for best performance.

**Electrical Requirements**

Radomes cause four major electrical effects on antenna performance [5].

1. *Beam Deflection* is the shift of the electrical axis, which is very critical for tracking radars (like in airborne radars). This is the refraction effect (due to change in medium) and results in the distortion of the phase front, causing reduction in the antenna's gain [3]. This bending of the wave front is called the "Bore sight Error" (BSE). This BSE introduces an error in the target identification by an airborne early warning radar system.
2. *Transmission loss*, is the loss of energy due to reflection and absorption of the EM energy in the radome materials. This loss results in the loss of range of the radar, i.e., the distance up to which it can send its EM wave and receive back the echo. Though the absorption loss is very small, the reflection loss is as high as 20% of the incident energy, which could result in a loss of about 11% in the range [6].
3. *The reflected power*, has the effects of causing antenna mismatch and side lobes. The reflected energy causes reflection lobes, seen as side lobes, which occupy a large sector in space, which illuminate the ground thereby picking up the ground clutter. This clutter results in obstruction to target identification.
4. *The secondary effects*, due to radome include depolarization and increase in antenna noise. These effects manifest themselves as pattern distortion.

It may be seen that, there is no way that these effects can be eliminated. However, by following suitable design procedures these effects can be reduced to some extent. Hence, in a radome design the idea is to minimise these electrical effects to achieve a better performance of the radar system. This exercise is interlinked to a greater extent with mechanical design aspects with respect to material properties processing, thickness and layers selection.

**Mechanical Requirements**

The basic purpose of using a radome is to protect an antenna from its environment. It is required to withstand the various environmental effects like wind, rain, hail, snow, ice, sand, lightning, and in the case of high speed airborne applications, thermal erosion and aerodynamic effects. In fact, these environmental factors determine the mechanical design requirements of the radome [5]. In meeting these requirements there is no option but to compromise the desire for ideal electromagnetic transparency of the radome, because the mechanical and electrical requirements are often in conflict. As Leaderman [6] points out, when the mechanical specifications are severe (like in high-speed airborne radars), it is difficult to find a design that meets satisfactorily both mechanical and electrical requirements. Under such circumstances, it may be necessary to relax the electrical specifications to some extent. The five important mechanical requirements of radomes are as follow: [5]

1. ***Strength:*** To sustain the aerodynamic and handling loads
2. ***Stiffness:*** To provide elastic stability
3. ***Temperature Resistance:*** To tolerate extreme conditions in flight and on ground
4. ***Resistance to Moisture Absorption:*** To keep the material properties constant
5. ***Abrasion & Erosion Resistance:*** To reduce the effects of rain, hailstorm, dust, stone, etc.

## CHARACTERISATION PROCESS

Characterisation of a component refers to the process/operation of establishing the physical/ mechanical properties of the component/material through suitable experimentation/testing and evaluation. The aim was to characterize an A-sandwich radome panel made of glass fibre/epoxy resin prepreg with nomex honeycomb core using an oven curing process. The

properties of a proven component, based on autoclave curing were taken for reference [7]. In PMC composites, obtaining the desired mechanical properties is a result of the curing of the component using suitable cure cycle. In this, the basic cure cycle for the given resin matrix (as supplied by the resin manufacturer) is modified to suit the component size, shape and number of layers. In curing the first dwell represents the I and II stage reactions (i.e. beginning of cross linking and networking of the epoxyl groups, which depends on the size of the component and number of layers so that heat can flow up to the inner most point. Similarly II dwell indicates the cross-linking stage of the resin where the resin becomes hard and strong [8]. For any component, when it exceeds a given minimum size there is need for characterisation, so that optimum properties are obtained. In autoclave curing, the application of pressure before gelation ensures smooth flow of resin and hence proper compaction, curing and bonding properties. However, in oven curing the absence of external pressure (to the extent of 4-6 bar) does require a change in the cure cycle, especially a longer first dwell or an additional dwell, i.e., reaction time at the flow stage of the resin for proper compaction.

## Characterisation Procedure

The characterisation procedure followed is-

a) Selection of cure cycles
b) Fabricating and curing test samples
c) Testing the components/samples
d) Establishing the mechanical properties
e) Evaluating test results
f) Evaluating bonding characteristics

## Selection of Cure Cycles

Based on the above theoretical understanding 5 cure cycles have been selected for characterisation, which are listed in Table 1. In this table, the first one is the proven autoclave cure cycle and the rest are all the experimental cure cycles.

Table 1. Cure cycles for characterisation

| *Sl. No.* | *Type* | *Experiment No.* | *Cycle* | *Pressure* |
|---|---|---|---|---|
| 1. | Autoclave | AC 01 | $80^0$C-1 h, $130^0$C-1 h | 4 bar |
| 2. | Oven | OC 01 | $80^0$C-1 h, $130^0$C-1 h | atm. |
| 3. | Oven | OC 02 | $80^0$C-1 h, $90^0$C-1 h, $130^0$C-1 h | atm. |
| 4. | Oven | OC 03 | $80^0$C-1 h, $100^0$C-1 h, $130^0$C-1 h | atm. |
| 5. | Oven | OC 04 | $80^0$C-2 h, $130^0$C-1 h | atm. |

These cure cycles are graphically represented in figure 1.

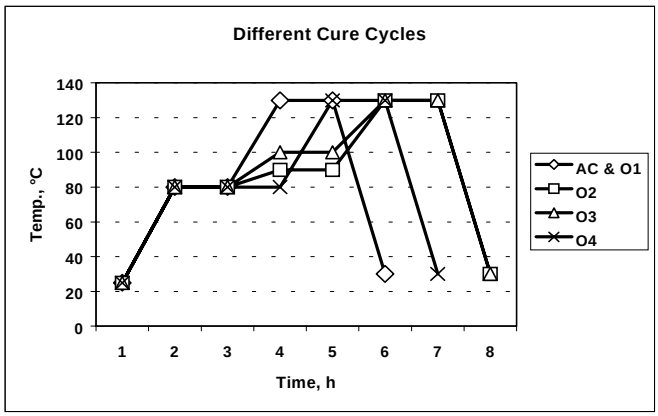


Fig. 1. Graphical Representation of various cure cycles

Each change in curing cycle parameter affects the bonding properties and hence the mechanical properties of the cured components. One of the above cure cycles in this experiment is expected to yield properties close to that of the cure cycle AC 01, which is the reference cure cycle in this characterisation process.

**Fabrication of NDE Coupons**

For physical characterisation of A-sandwich panel i.e. regarding surface finish and bonding, component/samples of size 300 mm x 300 mm panels, one each in different cure cycles have been fabricated. This has been subjected to visual, coin tap, light pass and C-scan testing. The fabrication details are given in Table 2:

Table 2. Fabrication of NDE coupons

| *Layer No.* | *Material* | *Orientation ($^0$)* |
|---|---|---|
| 1 | Fibredux 913G/50%/7781 | +45 |
| 2 | Fibredux 913G/37%/7781 | 0 |
| 3 | Fibredux 913G/37%/7781 | 0 |
| 4 | Fibredux 913G/50%/7781 | -45 |
| 5 | Nomex honeycomb core | - |
| 6 | Fibredux 913G/50%/7781 | -45 |
| 7 | Fibredux 913G/37%/7781 | 0 |
| 8 | Fibredux 913G/37%/7781 | 0 |
| 9 | Fibredux 913G/50%/7781 | +45 |

The cross-section of an A-sandwich radome test panel is schematically illustrated in figure 2.

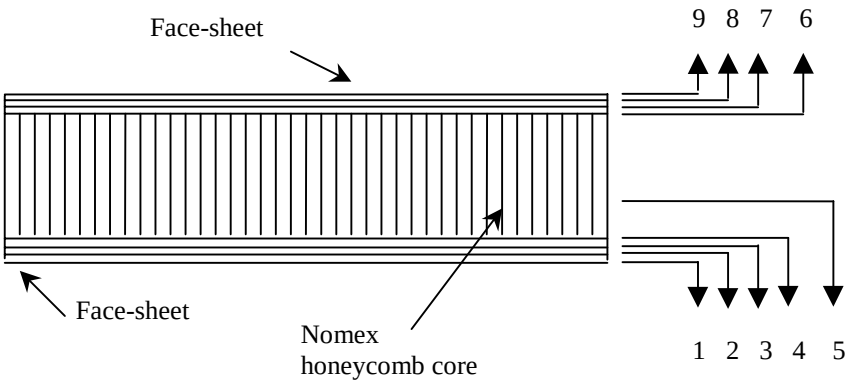


Fig. 2. C-scan Test specimen of A-sandwich radome panel

**Fabrication of Coupons for Destructive Testing**

The different destructive tests carried out are:

a) Inter Laminar Shear Strength (ILSS) test
b) Flexural test
c) Environmental test
d) Drum peel test

The layup sequence/samples for ILSS, Flexural and Environmental tests are the same. The layup sequence for ILSS and drum peel tests is given in Table 3 and 4.

Table 3. Layup for ILSS & Flexural Strength specimen

| *Layer No.* | *Orientation (°)* | *Material* |
|---|---|---|
| 1 | -45 | 913G/37/7781 |
| 2 | 0 | --- ” --- |
| 3 | -45 | --- ” --- |
| 4 | 0 | --- ” --- |
| 5 | -45 | --- ” --- |
| 6 | 0 | --- ” --- |
| 7 | -45 | --- ” --- |
| 8 | 0 | --- ” --- |

Table 4. Layup for Drum Peel Test Specimen

| *Layer No.* | *Orientation (°)* | *Material* |
|---|---|---|
| 1 | 0 | 913G/50/7781 |
| 2 | -45 | 913G/50/7781 |
| 3 | - | Aluminium core |
| 4 | -45 | 913G/50/7781 |
| 5 | 0 | 913G/50/7781 |

*Inter Laminar Shear Strength (ILSS):* It is the maximum strength between layers of laminated composites. It can be defined as the shearing force tending to cause a relative displacement between two adjacent laminates along the plane of their interface [2]. The three point ILSS test as per ASTM-D-2344 was conducted in this set of experiments.

*Flexural Strength:* It is the resistance of a material to breakage by bending stresses. It can be expressed as the tensile stress of the outer most fibres of the bent test sample at failure. This value is thus, higher than the tensile strength for polymeric material. It can be considered as an indirect measure of the tensile strength of the fibres, but under bending load. In general, it is an indicator of reinforcement strength in a composite. Usually for PMC composites flexural strength is almost ten times that of ILSS. Flexural strength test was carried out as per ASTM-D-790 standard using a three point loading system [2].

*Environmental tests:* Environmental tests were conducted to determine-

a) Moisture absorption when exposed to high temperature humid atmosphere.
b) Loss of resin content
c) Loss of strength (ILSS) due to moisture absorption

Higher resistance to moisture absorption under high temperature humid conditions indicates a higher environmental stability and durability of the composites.

Resin content and moisture absorption test are conducted by treating the samples at $70^0$C in water 90-95 RH for 30, 60, 90 and 120 days. The strength loss tests (ILSS) have been conducted by treating the samples in hot water ($70^0$C), 90-95 RH for 120 days.

*Drum Peel Test:* As the name indicates it is a peeling test conducted on sandwich panels of size 225 mm x 75 mm x 12.5 mm. It uses an aluminium core (stronger than the nomex honeycomb core) and two face sheets on top and bottom. The test measures the torque

required to peel the facing from the core. It depends on the resilience of the adhesive bond and on the core strength. This test is an indication of the bond strength between the face sheets and the honeycomb core. In testing, the face sheet is peeled by a rotating drum and hence the name drum peel test. The load required to peel the face sheet from the core is indicated as the bond strength in terms of N/75 mm width. The tests are conducted as per standard ASTM-D-1781.

## RESULTS

The results of various destructive and non-destructive (mainly C-scan) tests are tabulated in Tables 5 to 11 and graphically illustrated in Fig. 3 to Fig. 6.

Table 5. ILSS Test Results (in M Pa)

| *Trial No.* / *Cure Cycle* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* | *10* | ***Average Value*** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| AC 01 | 53.62 | 57.37 | 58.12 | 57.75 | 58.87 | 58.12 | 57.32 | 56.62 | 56.65 | 56.25 | ***57.03*** |
| OC 01 | 56.25 | 57.75 | 48.3* | 51.00 | 54.37 | 55.87 | 54.37 | 57.75 | 53.25 | 57.00 | ***55.29*** |
| OC 02 | 54.37 | 48.3* | 57.00 | 55.87 | 53.25 | 54.74 | 50.62 | 52.12 | 56.25 | 51.32 | ***53.95*** |
| OC 03 | 54.37 | 60.0* | 56.25 | 56.25 | 53.25 | 53.62 | 55.25 | 54.75 | 53.62 | 55.52 | ***54.75*** |
| OC 04 | 52.87 | 55.50 | 54.75 | 55.50 | 54.75 | 51.75 | 52.87 | 53.65 | 52.65 | 55.85 | ***54.00*** |

* Spurious value is not considered.

Table 6. Flexural Strength Test Results (in M Pa)

| *Trial No.* / *Cure Cycle* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | ***Average Value*** |
|---|---|---|---|---|---|---|---|---|---|
| AC 01 | 472 | 463 | 457 | 469 | 457 | 438 | 441 | 452 | ***456.13*** |
| OC 01 | 577* | 463 | 450 | 505 | 486 | 442 | 502 | 504 | ***478.86*** |
| OC 02 | 461 | 487 | 476 | 492 | 475 | 462 | 457 | 473 | ***472.9*** |
| OC 03 | 493 | 489 | 515 | 512 | 485 | 512 | 522 | 562* | ***504.0*** |
| OC 04 | 470 | 511 | 517 | 505 | 495 | 494 | 498 | 507 | ***499.6*** |

* Spurious value is not considered.

Table 7. Drum Peel Test Results (in N/75 mm width)

| *Trial No.* / *Cure Cycle* | *1* | *2* | *3* | ***Average Value*** |
|---|---|---|---|---|
| AC 01 | 276 | 285 | 290 | ***283.67*** |
| OC 01 | 272 | 265 | 242 | ***259.67*** |
| OC 02 | 286 | 278 | 282 | ***282*** |
| OC 03 | 263 | 257 | 270 | ***263.33*** |
| OC 04 | 276 | 265 | 240 | ***260.33*** |

Table 8. Comparison of Various Test Results

| *Test* | *ILSS, MPa* | *Flexural Strength, MPa* | *Drum Peel, N/75 mm width* |
|---|---|---|---|
| Autoclave | 57.03 | 456.13 | 283.67 |
| OC 001 | 55.29 | 478.86 | 259.67 |
| OC 002 | 53.95 | 472.90 | 282.00 |
| OC 003 | 54.75 | 504.00 | 263.33 |
| OC 004 | 54.00 | 499.60 | 260.33 |
| Min. Desired [ 7] | 26.00 | 260.00 | 180.00 |

Table 9. Environmental Tests: ILSS (in M Pa) test results of Specimens Treated in Water at 70°C, 90-95 RH for 120 days

| *Trial No.* / *Cure Cycle* | *1* | *2* | *3* | *4* | *5* | ***Average Value*** |
|---|---|---|---|---|---|---|
| AC 01 | 19.79 | 19.05 | 22.20 | 22.20 | 20.10 | ***20.7*** |
| OC 01 | 17.7* | 25.09 | 26.39 | 22.63 | 21.43 | ***23.89*** |
| OC 02 | 20.34 | 22.12 | 21.23 | 22.21 | 20.21 | ***21.22*** |
| OC 03 | 19.63 | 21.20 | 20.60 | 19.80 | 22.10 | ***20.6*** |
| OC 04 | 20.73 | 19.35 | 18.81 | 18.61 | 19.48 | ***19.4*** |

* Spurious value is not considered.

Table 10. Environmental Tests: Resin Loss & Moisture Absorption Test results of samples treated at 70°C, 90-95 RH

| *Cure Type* | *Resin after cure (% wt.)* | *Glass (% wt.)* | *Moisture content after 'x' days* | | | |
|---|---|---|---|---|---|---|
| | | | *30* | *60* | *90* | *120* |
| Autoclave | 36.0 | 64.0 | 1.31 | 1.61 | 1.61 | 1.91 |
| Oven 01 | 34.2 | 65.8 | 1.21 | 1.31 | 1.7 | 1.7 |
| Oven 02 | 37.0 | 63.0 | 1.31 | 1.31 | 1.61 | 1.7 |
| Oven 03 | 35.6 | 64.4 | 1.12 | 1.31 | 1.61 | 1.89 |
| Oven 04 | 36.0 | 64.0 | 1.3 | 1.4 | 1.97 | 1.91 |

Table 11. Environmental Test: ILSS values after Boiling Water Test – Ciba-Giegy [9]

| *Sl. No.* | *Test after days* | *ILSS, M Pa* |
|---|---|---|
| 1 | ½ | 81 |
| 2 | 4 | 39 |
| 3 | 42 | 31 |
| 4 | 100 | 18.78* |

* Extrapolated value based on 2$^{nd}$ and 3$^{rd}$ value

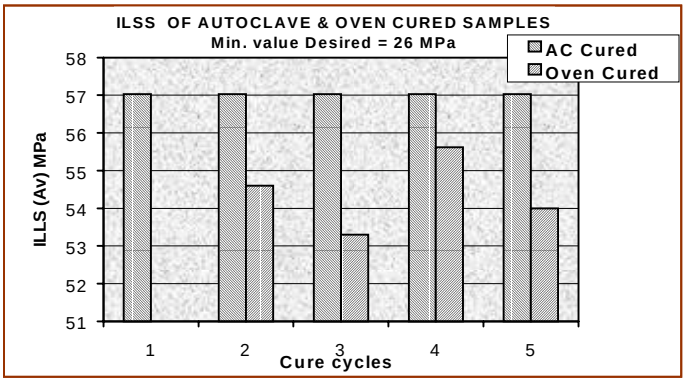


Fig. 3. ILSS Test Results

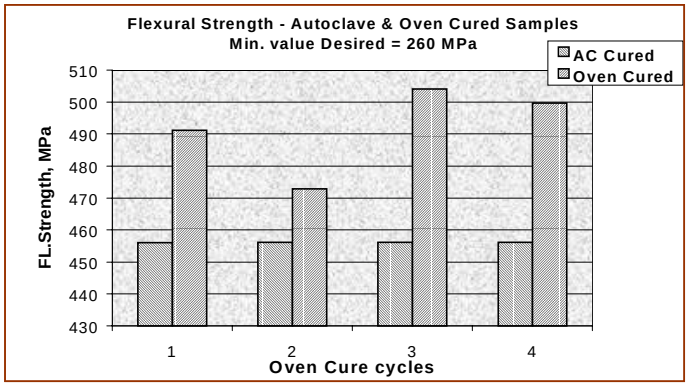


Fig. 4. Flexural Strength Test Results

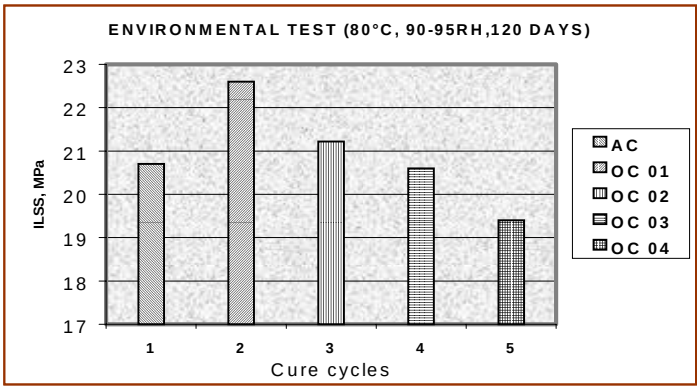


Fig. 5. Environmental Test Results

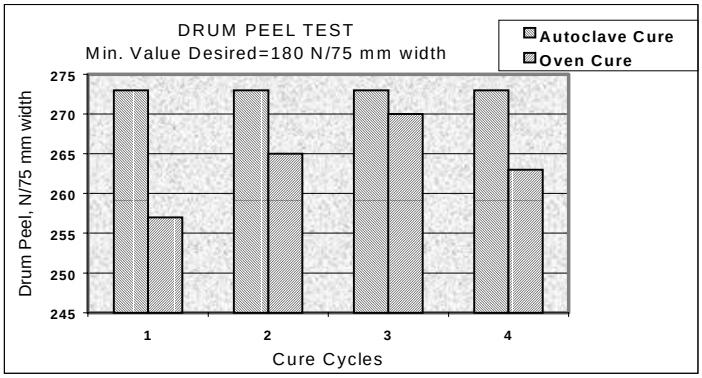


Fig. 6. Drum Peel Test Results

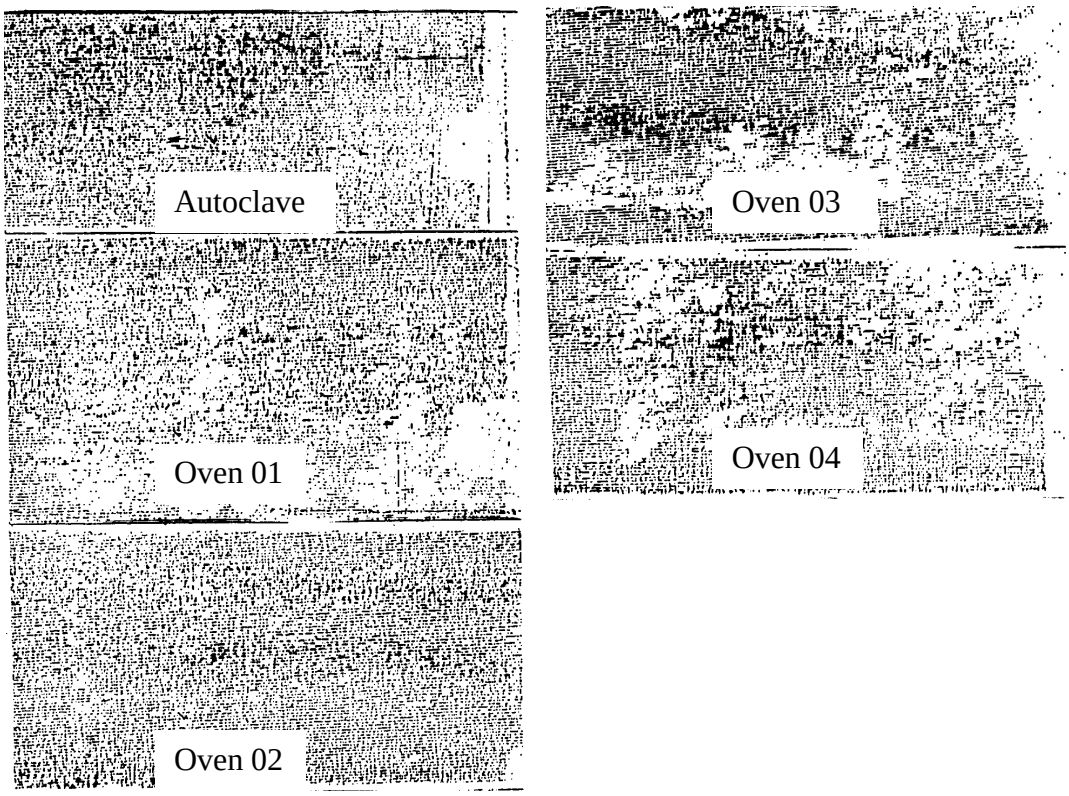


Fig. 7. C-scan Test Results of A-sandwich Panels

## DISCUSSION

*a) ILSS Test:* It can be seen from the comparative values, in Table 8, that the ILSS values are slightly lower in the oven cure cycles (in the range of 53 to 55 MPa), where as the value of autoclave cured sample is 57.03 MPa. However the results are above the minimum desired design value of 26 MPa. It shows that obviously the ILSS of autoclave cured sample is superior, but still the values of oven cured sample are at acceptable levels.

*b) Flexural Strength:* In the case of flexural strength, the above trend is reversed. The value of Flexural Strength of autoclave cured sample is slightly lower than that of oven cured samples. Though the exact reason for this trend reversal could not be analysed, all the values are above the minimum desired value, and hence acceptable.

*c) Drum Peel Test:* The third comparison is that of drum peel test results, which indicate the bond strength between the face sheets and the honeycomb core. It can be seen that the value of autoclave cured sample is higher than those of oven cured sample. It can also be seen that the drum peel strength of oven cured sample 002 is close to that of autoclave cured sample, indicating that the bonding in oven cure cycle 002 is almost equivalent to that of autoclave curing. This statement is further strengthened by the C-scan test results (10 MHz).

*d) Environmental Test:* Table 9 and 10 show the comparison of environmental test results. The ILSS value after keeping the sample in hot water for 120 days (at $70^0$C) is in the range of 19 to 22 MPa for oven cured samples and 20.27 MPa for autoclave cured sample. This can be compared with boiling water test values provided by Ciba-geigy (Table 11), in which case the ILSS is about 18.78 MPa for 100 days. Hence, it can be taken that the environmental test ILSS value are in close conformity with that of raw material supplier's values. The resin content loss and moisture absorption results in Table 10 show that there is no resin loss and the moisture absorption is minimal in the sample cured by oven cure cycle 002. There is considerable resin loss and moisture absorption in other oven cured samples.

*e) C-scan Test Results:* The graphical representation of C-scan test results (at 10 MHz frequency) in Fig. 7 gives a clear indication of defective areas of bonding. It can be seen that there are no bonding defects (no white patches) in autoclave cured sample. But in all other oven cured samples bonding defects are seen as white patches. This is a clear indication of non-application of pressure and insufficient resin flow. However, the sample with oven cure 02 has negligible white patches as compared to other oven cured samples indicating that the resin flow and bonding are better in this case. In the oven cure cycle $80^0$C-1 h, $90^0$C-1h and $130^0$C-1 h, the additional dwell of $90^0$C-1 h could have provided a resin flow leading to improved bonding as compared to other cure cycles.

## CONCLUSIONS

Based on the results the oven cure cycle 02 has been chosen as the equivalent of autoclave cure cycle. Though it is not 100% equivalent to the original autoclave cure cycle, the oven cure cycle 02 is capable of yielding results in close conformity to that of autoclave cure cycle. In the absence of an autoclave of large size (4mx8m) for radome curing, and with an oven of this size available the oven cure cycle 002 has been selected as the practicable one for project. This research has shown that, it is possible to cure prepregs without the application of external pressure (autoclave) but still achieve the desirable results to satisfactory limits.

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## REFERENCES

1. Kozakoff D.J., “Analysis of Radome Enclosed Antennas”, Artech House, Norwood, 1997.
2. “Composites Engineered Materials Hand Book”, Vol.1 ASM International, Ohio, 1987.
3. Benjamin Rulf., “Problems of Radome Design For Modern Airborne Radar”, Microwave J., JAN 1985 & MAY 1985.
4. MIL-R-7705B, “Military Specifications For Radomes”, JAN 1975.
5. Skolnik, M.I., “Radar Hand Book”, McGraw Hill Book Company, N.Y., 1970.
6. Candy, W.M. and Leaderman, “Radar Scanners & Radomes”, Radiation Laboratory Series, McGraw-hill, 1948.
7. Murali Mohan, KR., “Manufacture and Quality Assurance of ASWAC Radome”, An internal report on training at MBB, West Germany, JUL 1989.
8. Leonard Hollaway, “Hand Book of Polymer Composites For Engineers”, Jaico Publishing House, Bombay, 1995.
9. Data Sheet FTA 46d, Technical Data sheet, from CIBA-GEIGY, on “FIBREDUX 913 For Composites with Top ‘Hot-Wet’ Performance”, Cambridge, MAY 1983.
10. Walton J D, Jr., “Radome Engineering Hand Book, Design and Principles”, Marcel Dekker, N.Y. 1970.
11. Niranjanappa AC, “Characterisation of Radar Transparent PMC A-sandwich Radome Panel Through Oven Curing”, M.Sc (Engg) Thesis, Dept. of Metallurgy, Indian Institute of Science, Bangalore.