Study on Effect of Voids on the Mechanical Properties of CFRP Composite

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Abstract – Composites are materials created by combining dissimilar materials with a view to improve their properties or to create materials with desired properties. This project synthesizes our work on voids in Carbon/polymeric (composite) laminates. During manufacturing, there are chances of formation of voids which hampers the performance of the component with respect to its mechanical properties. The aim of work carried out upon carbon G939 is to obtain void content acceptability criteria enabling quality control cost to be reduced to a large extent. After carrying out ILSS and Flexural strength tests, it is concluded that the permissible acceptance range of voids should be within 3.5%. This range enables the composite part manufacturer to reduce the total production and quality control costs.

Index Terms – Carbon fibre Reinforced Polymer (CFRP) composite, voids, Interlaminar Shear strength (ILSS), Flexural Strength.

1. INTRODUCTION

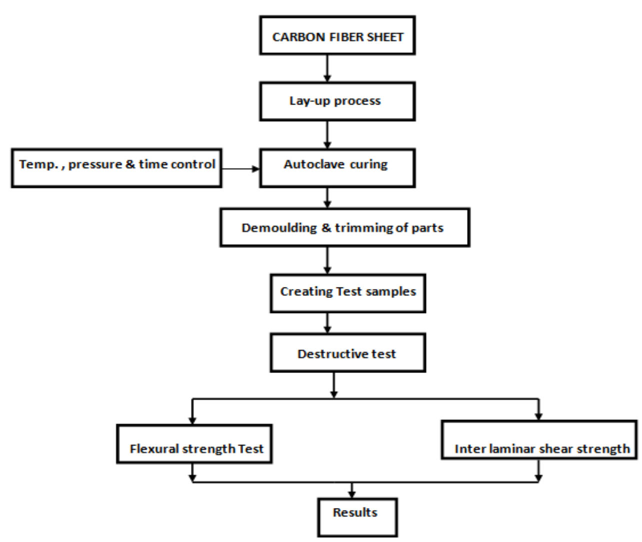
Composites have been in use since time unknown in various forms like fiber (straw), reinforced mud bricks for huts and laminated wood, metal armor etc. The rapid increase in the demand for the use of composites in the avionics field made the dynamic engineers to invent more and more efficient materials to meet the challenges of high performance in aircrafts. Realization of cost effective and reliable aviation systems to meet the complex functional requirements of rescue, remote sensing, critical maneuvering operations and other missions has made innovative application of modern technologies a necessity.

USE OF COMPOSITE MATERIALS IN AVIATION PROGRAMS: - The use of composite materials, similarly assisted in both design and application by the use of computers, has grown from the occasional application for a nonstructural part (e.g. a baggage compartment door) to the construction of complete airframes. These materials have the additional advantage in military technology of having a low observable (stealth) quality to radar. Some aircraft of composite materials began to appear in the late 1930s and '40s; normally these were plastic-impregnated wood materials, the most famous (and largest) example of which is the Duramold construction of the eight engine Hughes flying boat. A few production aircraft also used the Duramold construction materials and methods. During the late 1940s, interest developed in fiberglass materials, essentially fabrics made up of glass fibers. By the 1960s, enough materials and techniques had been developed to make more extensive use possible. The use of composite materials opened up whole new methods of construction and enabled engineers to create less expensive, lighter, and stronger parts of more streamlined shapes than had previously been feasible.

2. EXPERIMENTAL DETAILS

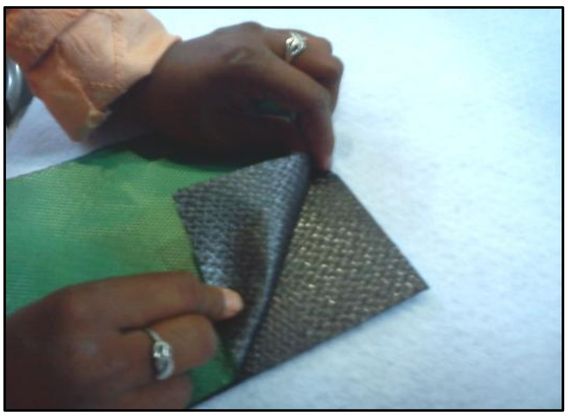
2.1. Methodology

The effects of voids on mechanical behaviour of carbon fibre determined by conducting inter laminar shear strength and flexural strength test.

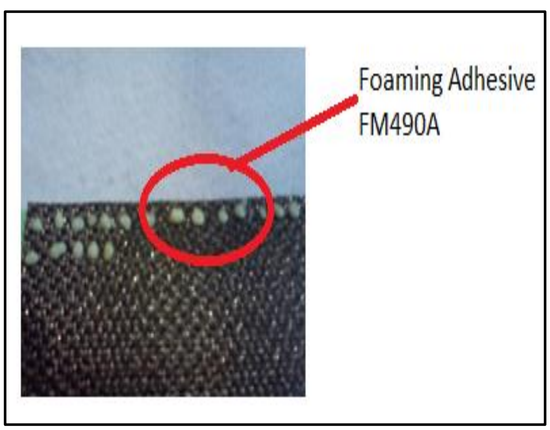


2.2. Fabrication of The Specimens:

CFRP composite laminates were produced with G939 pre-preg. Foaming adhesive FM 490A is used between the layers to create voids (fig. 1b). In this process one master piece laminate was created without any void in the laminates and 3 trial specimens with voids are considered (table 1). A vacuum bag and autoclave curing technique are used to obtain laminates. The standard cure cycle recommended by manufactures was used. The temperature was about 1750 C and pressure is 0.3-0.4 MPa to form cured laminates. The curing process takes about four hours. During this curing process foaming adhesive placed within the layers begin to melt & vaporize causing the formation of voids in their place. The purpose of this paper is to study the effect of voids on the mechanical properties. Stacking sequence for this study is (00/900)4 lay-ups (fig.1a).



(a)



(b)

Fig. 1 a) Lay-up of pre-pregs according to required dimensions b) uniform distribution of FM490A

Once the components were cured, the laminates were removed from the autoclave and demolded. The laminates were then sanded and trimmed to get rid of the rough edges formed due to the resin seeping out of the component layers.

Trail no.	Lay up	Material	% of voids
Master piece	04/904	CARBON G939	Nil
Trail no. 1	04/904	CARBON G939	1.35
Trail no. 2	04/904	CARBON G939	2.7
Trail no. 3	04/904	CARBON G939	5.4

Table 1. Specimen specification during lay-up process

2.3 Inter Laminar Shear Strength Test:

The master piece and trial laminates were cut into several pieces measuring 20×10×2 mm specimens (fig. 2). Select the 500kg load cell for the test Position the fixture on the UTM and Place the specimen on the test fixture in UTM (fig. 3). Select the speed rate 2mm/min and start the test. The load should increase to a peak value and after sample failure the load will decrease, manually halt after the peak load reaches. The test results have been tabulated and the corresponding graphs recorded.

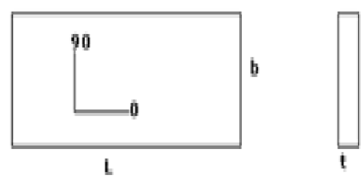


Fig 2. ILSS test specimens

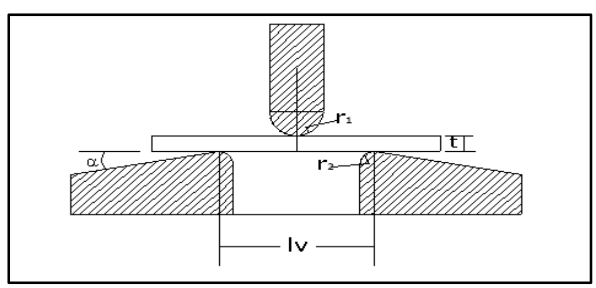
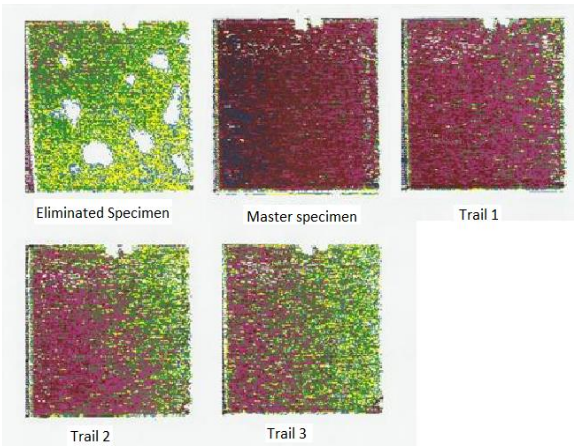


Fig. 3 UTM loading

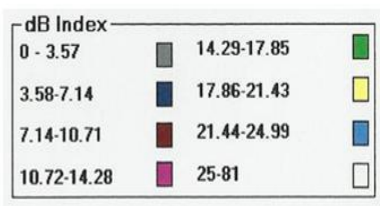
3. RESULTS AND DISCUSSION

2.1. Ultrasonic C Scan Test

Ultrasonic C scan test has been carried on test samples to determine the distribution of voids in the test samples. The result obtained from ultrasonic test is showed in the below fig. 4



(a)



(b)

Fig. 4 (a): ultrasonic c-scan report (b): ultrasonic attenuation (dB) index

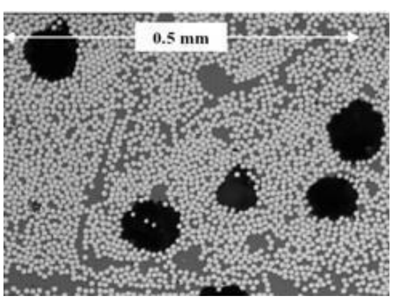


Fig 5: Microscopic view of voids

It can be observed from the Ultrasonic C-scan report where the master specimen does not show any variation in its color. The gain input is between 7.14-10.71 dB. But at the same time, the trial specimens are exhibiting variations in its color due to the presence of FM 490A(voids). This has in turn led to the formation of voids and thus there is an increase in the ultrasonic attenuation which can be observed from the dB index. Based on the above observation and with reference to ultrasonic color coding chart, we have tabulated the results as follows

SPECIMEN	GAIN (Db)	% OF VOIDS	ACCEPTANCE
MASTER	9	NIL	ACCEPTED
TRIAL 1	9+3 = 12	1.08 - 3.1%	ACCEPTED
TRIAL 2	9+5 = 14	1.7 - 3.4 %	ACCEPTED
TRIAL 3	9+8 = 17	3.55 - 6.34%	REJECTED

Table 2. Result obtained from ultrasonic C Scan Test

2.2. Inter Laminar Shear Strength Data Result

MASTER SPECIMEN:

Sl. No	Max Load (N)	Max Disp (mm)	Inter Laminar Strength (Mpa)
1	2220.68	3.85	71.79
2	2162.86	3.7	70.51
Avg:	**2191.77**	**3.775**	**71.15**

TRIAL 1:

NO.	Max Load (N)	Max Disp (mm)	Inter Laminar Strength (Mpa)
1	2035.46	3.1	63.79
2	1982.5	3.05	62.74
Avg:	**2008.98**	**3.075**	**63.265**

TRIAL 2:

NO.	Max Load (N)	Max Disp (mm)	Inter Laminar Strength (Mpa)
1	1980.58	3.4	66.21
2	1978.62	3.25	64.24
Avg:	**1979.6**	**3.325**	**65.225**

TRIAL 3:

NO.	Max Load (N)	Max Disp (mm)	Inter Laminar Strength (Mpa)
1	1799.64	3.2	58.11
2	1893.36	3.15	58.99
Avg:	**1846.5**	**3.175**	**58.55**

2.3. FLEXURAL STRENGTH

FORMULA USED

$$\sigma = \frac{3}{2} * \left[P * \frac{S}{b*h*h} \right] \text{ Mpa}$$

CARBON G939 (0.25 mm thick) - [0/90/0/90/90/0/90/0]

- $\sigma(\text{MASTER}) = \frac{3/2 \text{ x } [2220.68\text{x}10]}{10.00 \text{ x } 2.32^2} = 618.87\text{Mpa}$
- $\sigma(\text{TRIAL 1}) = \frac{3/2 \text{ x } [2035.46\text{x}10]}{9.97 X 2.4^2} = 531.66 \text{ Mpa}$
- $\sigma(\text{TRIAL 2}) = \frac{3/2 \text{ x } [1980.58\text{X}10]}{9.67\text{x } 2.32^2} = 570.79 \text{ Mpa}$
- $\sigma(\text{TRIAL 3}) = \frac{3/2 \text{ x } [1887.48\text{x}10]}{10.01 X 2.46^2} = 467.37 \text{ Mpa}$

PERCENTAGE OF VOIDS v/s ILSS:

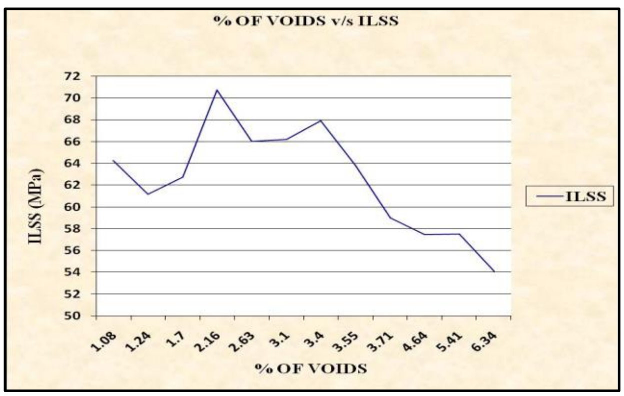


Fig 6: Percentage of voids v/s ILSS

From the above graph it can observed that ILSS varies from 60 Mpa to 70 Mpa ranging from 1.08-3.55 % of voids but there is a steep decline from 3.55 % indicating failure of the component after 3.55 % of voids.

PERCENTAGE OF VOIDS v/s FLEXURAL STRENGTH

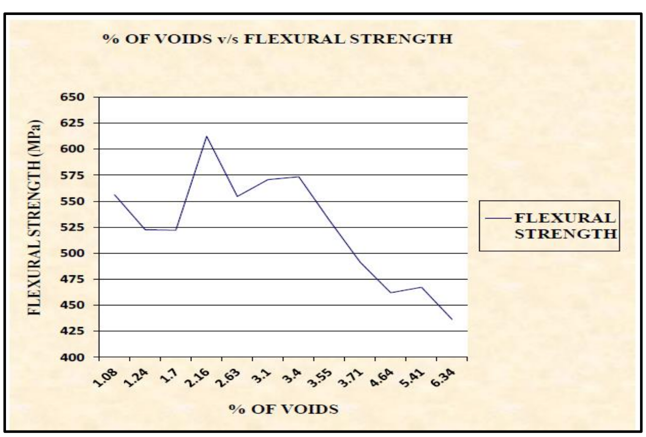


Fig 7: Percentage of voids v/s Flexural strength

CONTROL CHART

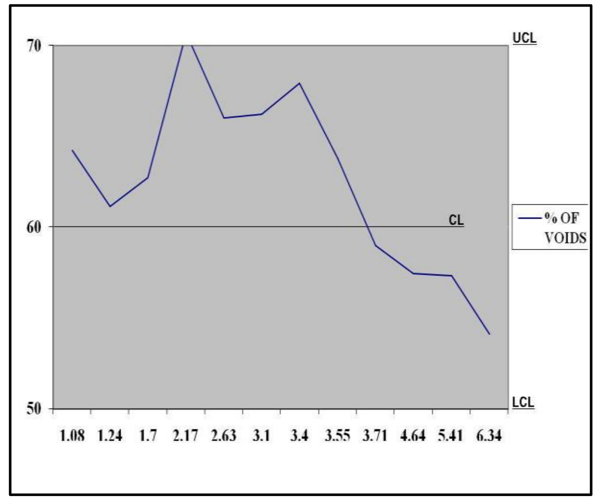


Fig 8: Control Chart

The permissible range for safe ILSS is within 60-70 Mpa as per DIN standards. The percentages of voids till 3.55 are all lying above the control limit. Thus, it can be observed from the above control chart that the percentages of voids ranging from 1.08-3.55 are within limits as they are within permissible ILSS as per the DIN standards. Therefore, the acceptance criteria can safely vary till 3.55 %, beyond which it is not favorable.

4. CONCLUSIONS

The changes in various physical and mechanical properties affected by void content have been determined. An interrelation between Ultrasonic absorption and % of voids and laminates mechanical behaviour has been settled. This should contribute to reduce the quality control costs by avoiding performing some of the mechanical and chemical tests. However, in order to complete and improve the method described in this project, sets of laminates undergoing lower void contents (i.e. % of voids ranging from 0 and 3.55%) made of carbon G939 material have to be manufactured. After carrying out the tests, it is concluded that the permissible acceptance range of voids should be within 3.55%. This range enables the composite part manufacturer to reduce the total production and quality control costs.

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