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Experimental Characterization of ILSS of CFRP Laminates

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***Abstract* — The high strength fiber composite parts are made up of several plies with different fiber orientations with a designed balanced layup sequence, however the destructive tests are carried only on the test laminates which are fabricated and cured along with the actual parts. The (ILSS) inter laminar shear strength is a vital destructive test carried on the test laminates as per the ASTM D2344 standards, based on these test results the actual parts are qualified for final assembly. Hence there is a need to find an accurate ILSS value of the actual part to predict its quality and strength. Earlier researchers stated that the ILSS values vary on the layer orientations and on the layup sequence, hence the apparent ILSS values obtained from these test coupons may vary with the actual part since the layer orientations followed to manufacture the part and test laminates are different. It is essential to find the strength of the actual part based on the values obtained from the test laminates and to analyze its properties. Efforts were made in this work to obtain the ILSS values of the test laminates fabricated with [0/45]s, [90/45]s, [0/90]s [0/45/90]s orientations and to find a correction factor to evaluate apparent ILSS for the actual part. This work will help composite materials designers and manufacturers to design high strength composite parts for aerospace.**

Keywords—Composites,Curing,FiberOrientaion,Interlaminar Shear Strength(ILSS), Layup

I.INTRODUCTION

Composites in aeronautic/aerospace applications, both military and commercial, are accounting for a large share of the growing in market value. Composite materials offer many superior properties that have enabled composites manufacturers to gain significant market share in a variety of industries. Increased usage of composites in military and space systems, as well as in commercial aircraft development, is expected to continue far into the foreseeable future.

The stresses acting on the interface of two adjacent plies in composite laminates are called inter laminar stresses (ILSS) , Even today there is no method available for the exact determination of the strength property. However an approximate values of the inter laminar shear strength called the apparent inter laminar shear strength can be determined by using various test methods. So far short beam shear test method has been well developed and established to find out ILSS. Short Beam Shear Test is a bending test carried on a short specimen designed such that breaking occurs under the effective of the shearing load and not according to the normal stresses. However, concerns arise about this test because of a non-uniform bending moment along the shear plane and strong localized damage occurring underneath the loading rollers [1]. Earlier few research was carried on the characterization of voids and to find the relations between the void content and the ILSS [2-4] , similarly few researchers [5] have done experiments to show the influence of UTM cross head speed on ILSS and Flexural Strength of CFRP laminates. In this method a laminate specimen with a low value of L/h ratio where ‘L’ is the length of the support span and ‘h’ is the specimen thickness subjected to three point loading based on the classical beam theory[6-7], the maximum τ_{max} can be related to the maximum bending stress σ_{max} using the

equation.1 $$\tau_{max} = \sigma_{max} \frac{h}{2L} \quad \text{---- (1)}$$

From the above equation it is observed that an inter laminar shear failure would be assured if it satisfies the relation

$$\frac{2L}{h} \; \alpha \; \frac{S1}{S2} \quad \text{------------------------------ (2)}$$

Where S1 = tensile or compressive strength whichever is less.
S2 = inter laminar shear strength.

To ensure that the inter-laminar shear failure occurs prior to flexural failure; the length to height ratio must satisfy the above equation , If the span is short the failure is initiated and propagated by inter laminar shear strength[8].

In accordance to the classical beam theory the value of the transverse inter laminar shear stress τ_2 at the mid plane of the laminated beam can be calculated using the formula

ILSS at mid plane $$\tau_2 = \frac{3P}{4bh} \quad \text{---------(3)}$$

Where P = the maximum load recorded, b = the width of the specimen, h = thickness of the specimen.

The above equation is based on the assumptions of a parabolic shear stress distribution across the thickness, the term “apparent” is used in the title of the ASTM method.

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The stress distributions across the width have been assumed to be uniform in the beam theory but this may not be uniform.

It is noted that the stress distribution near the loading point and at the support point are quite complicated which cannot be predicted accurately using the classical beam theory and classical laminate theory.

Let us consider an element of a rectangular cross section with width ‘b’ and depth ‘h’ as shown in the Fig. 1. Let ‘NA’ be the neutral axis and the shear stress distribution over the cross section is given by the equation (4)

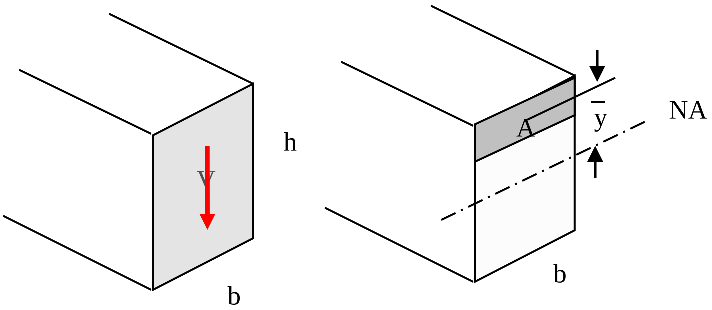


Fig 1. A rectangular c/s view of an element

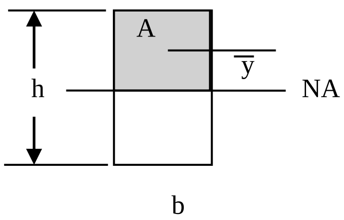
The shear stress $\tau = \frac{VQ}{It}$ ----------------(4)

Where, V = internal shearing force, t = width of section

Q = 1st moment of area above the line of interest about the neutral axis and is given by

$Q = A\,\bar{y}$ --------------- (5)

‘t’ represents the width of material that separates the area A from the rest of the material of the cross section. In this case, t is equal to the width b. (t = b)



$Q = A\,\bar{y} = \left(\frac{1}{2}\,bh\right)\left(\frac{1}{4}h\right) = \frac{1}{8}\,bh^2$-----------(6)

We know moment of Inertia $I = \frac{1}{12}\,bh^3$ ------(7)

Substituting in eq. 6 & 7 in equation (4) we get

Shear Stress ‘τ’ $= \frac{VQ}{It} = \frac{3V}{2\,bh}$ ---------------- (8)

The shear stress will be maximum when the shear force V is maximum and is given by V= P/2
Substituting the value of ‘ V’ in equation(8) we get

Maximum Shear Stress $\tau_{max} = \frac{3P}{4bh}$ ---------(9)

This formula is used to calculate the interlaminar shear strength of the composite specimen which provides the information on the mechanics behaviour of the resin or the fibre resin liaison.

II.EXPERIMENTAL WORK

A. Materials Used

The material used in this work was HexPly 913/ G801 bidirectional (BD) carbon epoxy prepreg, which is widely used in fabrication of high strength primary and secondary composite structures for advanced light aircrafts. This prepreg material has a versatile 913 epoxy matrix system which can be processed using a wide range of techniques..

B. Specimen Preperation

Laminates of size 200 X 200 mm are prepared with different layer orientations. A flat composite base plate was considered as a tool for lay-up and the layers are stacked on the tool in a balanced sequence as shown in the Fig.2.

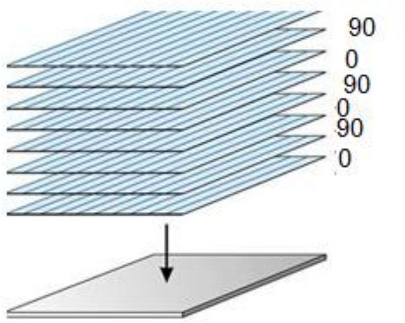


Fig.2 Shows the [0/90] symmetric layup

Each laminate was fabricated with 18 layers and the details of the layers used and its orientations to fabricate the laminates is as shown in the table.1.

Table. 1 Details of the layers and its orientations

Laminate. No.	Layer Orientation	No. of 0° Layers	No. of 90° Layers	No. of 45° Layers	Total no. of Layers
1	0/45	9	-	9	18
2	45/90	-	9	9	18
3	0/90	9	9	-	18
4	0/45/90	6	6	6	18

After layup the laminates are vacuum bagged and ensured for vacuum leak rate of 50 mbar for 5 mins as shown in Fig. 3, later cured in an autoclave using two step cure cycle under controlled temperature of 135 °C, 5 bar pressure and 0.8 bar vacuum.

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After curing the laminates are demoulded from the tool and are tested using Ultrasonic 'C' Scan test through transmission mode with probe of 10 mm dia operating under 2.25 MHz and the scan speed of 200 mm/sec.
to ensure the laminates are voids free without any internal defects as shown in the Fig.4 and the 'C' scan profile of a laminate is as shown in the Fig. 5

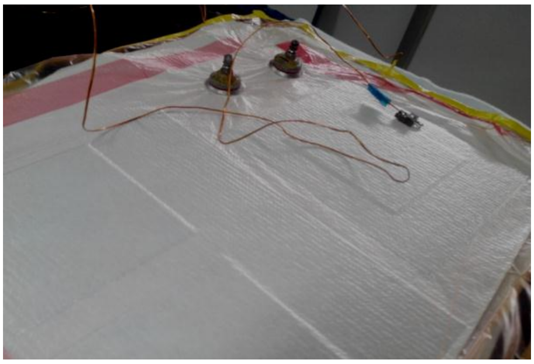

Fig.3 shows the vacuum bag of laminates.

Fig.4 shows the 'C' Scan set up of cured laminate.

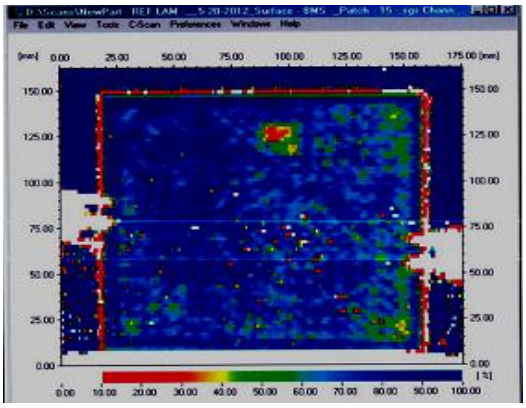

Fig.5 shows the 'C' Scan profile view of a laminate.

The 'C'Scan results are evaluated for each cured laminates and the values are found within the acceptable limits of 22 DB which ensures that the cured laminates are defect free and there is no evidence of the voids or delaminations, six test specimens are prepared from each laminate as per the ASTM D2344 standards as per the dimensions 20 X 10 X 2 mm (l X b X t) to check the Interlaminar shear strength (ILSS) as shown in the Fig.5.

ILSS was carried out on a Universal Testing Machine of capacity up to 5 Tonne, supplied by Star Testing System, Mumbai. The applicable test environments for ILSS Test at composite Lab are: (1) Temperature (RT): 20 to 30^{0}C & (2) Relative Humidity: 40 to 75%

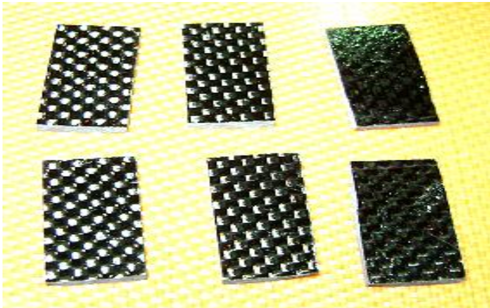

Fig. 5 ILSS test specimens

III.RESULTS & DISCUSSIONS

Six specimens prepared from each test laminate are tested for ILSS using Universal Testing machine as shown in the Fig. 6 and the average ILSS values are tabulated as shown in the table 2.below.

Fig. 6 Interlaminar Shear Strength test set up at UTM.

Table.2 ILSS values of specimens with correction factor.

Laminate. No.	Layer Orientation	Load N	Exp. ILSS MPa	% error	Correction factor β
1	0/45	1900.58	68.42	0.0363	0.96
2	0/90	1957.92	70.8	0.0003	1
3	45/90	1617.49	63.63	0.1038	0.89
4	0/45/90	1925.33	70.27	0.0103	0.99

It is observed from the experimental ILSS values of the specimens obtained from the test laminates fabricated at different orientations are varying and the laminate fabricated with 0/90 orientation exhibits higher strength compared to other laminates as shown in the Fig. 7

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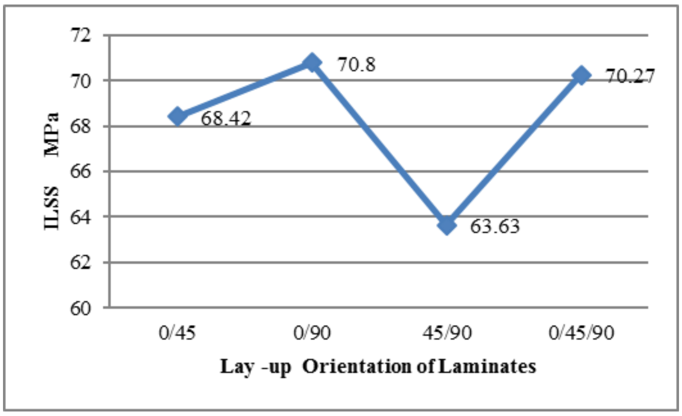

Fig. 7 ILSS curve at different orientations.

It is clear from the above ILSS curve that the interlaminar shear strength varies with the layer orientations and hence the correction factor was calculated for each laminate considering the laminate with 0/90 orientation as the master laminate, since it is recommended by the standards for testing ILSS of the test laminates which are fabricated along with the actual parts. Hence the ILSS value of the actual part with a layers of 0/45/90 orientation can be calculated by multiplying the correction factor to the ILSS values obtained from the test specimens that consists of 0/90 layer orientation.

IV .CONCLUSIONS

The ILSS values found experimentally for laminates with different fiber orientations proved to be varying with the standard test laminate of 0/90 degree fiber orientation laminate, however this laminate is considered as the master laminate since this combination exhibits higher strength compared with the other laminates.

The ILSS values found were helpful in finding the respective correction factor that can be multiplied with test specimen ILSS value to find the accurate strength of the actual part.

This data helps the designers to design the layup sequence for composite structures with different orientations for different applications.

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