Chapter 18
Comprehensive Characterization of Carbon Fiber-Reinforced Epoxy Composite for Aerospace Application

D. Bino Prince Raja, B. Niharika, R. S. Manoj Kumar and C. G. Tejaswini

Abstract Carbon fiber-reinforced polymer (CFRP) is used in the aeronautical industry in the manufacture of different aircraft components. This paper is about studying the mechanical (tensile, flexural, interlaminar shear strength), thermal and moisture characterizations of the laminate. A carbon-reinforced polymer laminate of G939 material and 913 resin systems are selected to study the effect of moisture and thermal on the properties of the laminate. The composite lamina is made of different layer orientations like 0°/90°, 0°/45°, 0°/45°/90°, 0°/0° and 90°/90°. The laminate is fabricated by vacuum bagging and cured using autoclave. Interlaminar shear strength (ILSS) was carried out for the specimens. Thermal degradation of CFRP is molecular deterioration as a result of overheating, and as the temperature increases the bonding between the molecules gets weaker and starts reacting with each other which results in the change of properties of composites. Laminates of 0–90 orientation are fabricated, and interlaminar shear strength (ILSS) at 50, 100 and 150 °C was carried out according to Dutch Institute for Norms (DIN) for the specimens. Micro cracks in the matrix are observed due to moisture diffusion. Five different test liquids are chosen: water, diesel, petrol, lubricating oil and acid in which specimens are immersed for 2 days, 5 days and 7 days. This work will help composite materials' designers and manufacturers in designing high strength composite parts for aerospace.

Keywords Carbon fiber · Epoxy matrix · Mechanical · Thermal characterization · Aerospace applications

18.1 Introduction

Composite materials are made up of two or more constituent materials to obtain a new material with the desired properties. Composite materials are being developed and made with two kinds of objectives: One is to enhance the material properties and performance efficiency and another to design materials with combinations of

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desired properties [1]. Carbon fiber is used in industries where high strength and rigidity are required in relation to weight. We know that material density has a direct impact on its weight, and carbon fiber composite has a density two times less than aluminum and more than five times less than steel [2]. We have used carbon prepreg in which the resin system already includes the proper curing agent. Advantage of prepreg is it is less mess and less waste. In this paper, we have studied material, thermal and moisture characterization of CFRP laminate. Material characterization includes tensile, flexural and interlaminar shear strength. Interlaminar shear strength is the stress existing between layers of a laminated material [3]. Flexural test is done to know the bending strength of the laminate; it is the maximum stress acting on the outermost fiber of the laminate. Tensile test is done to determine the maximum load that a material can withstand. When moisture diffuses into the material, the strength of the material is decreased and fiber/matrix is degraded which results in the decrease of glass transition temperature [4].

A large share of growing market value is accounted for composites which are being used in both military and commercial applications of aeronautics. Nowadays, in the aeronautical industry, carbon fiber-reinforced polymer (CFRP) offers significant improvements over current conventional materials [5]. Different structural components are manufactured by composite materials due to their attractive specific mechanical properties [6]. When compared with metallic materials, polymeric composites have high strength to weight ratio, hence CFRP is processed using thermoset polymers, especially epoxy resins [7]. The bonding material that allows the fabric to form a composite material is the resin. Resin is a type of matrix which acts as a medium to transfer load. We have used carbon prepreg in which resin is pre-impregnated, and it is ready to use in the component. The resin system used is typically epoxy. Interlaminar shear strength is the stress acting between layers of a laminated material; usually, it is performed to characterize both fiber and matrix interfacial bonding [8]. Flexural test is done to know the bonding strength of the laminate, and it is the maximum stress acting on the outermost fiber of the laminate. And it is an important tool for optimization of process and evaluation of matrices and fiber resin interface. In order to verify specifications, quality assurance of project and also analysis of failure mode, tensile tests are carried out [9]. Moisture content is absorbed by epoxy resins from their surroundings which results in the decrease of glass transition temperature, Tg: typically 1% absorbed water reduces the glass transition temperature by 20 °C [9]. The result at elevated temperature strength and stiffness of resin is being reduced [9]. Thermal degradation is the process which is caused due to heat and chemical properties of a substance and changes due to temperature, and as the temperature increases the bonding between the molecules gets weaker and starts reacting with each other which results in the change of properties of composites. The result of physical and chemical changes composite degrades with environment [10, 11].

18.2 Experimental Work

18.2.1 Preparation of Material

The prepreg used in this work is HEXPLY G939, bidirectional (BD) material with 913 epoxy matrix system which is widely used in the fabrication of high strength composite materials. 913 epoxy matrix systems can be processed using a wide range of techniques.

18.2.2 Fabrication of Laminate

To fabricate composite laminate, consider material of size 200 × 200 mm which is prepared with different layers of orientation. A flat plate was considered as a base, and followed by vacuum bagging procedure the laminate was cured at 135 °C using autoclave. After completing the curing cycle, laminate was demolded and trimmed for extra part to required size. Now, the laminate is used for further testing process (Fig. 18.1).

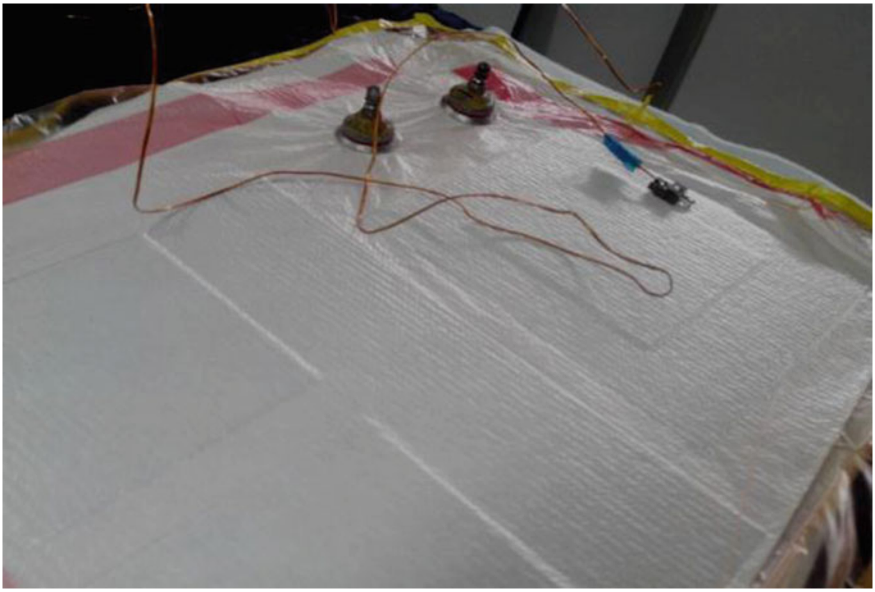


Fig. 18.1 Vacuum bag of laminates

18.3 Material Characterization of Composites

Five different orientations 0°/90°, 0°/45°, 0°/45°/90°, 0°/0° and 90°/90° were considered to study tensile, flexural and interlaminar shear strength (ILSS). The orientations and layers of the laminate are listed in Table 18.1.

18.3.1 Tensile Test

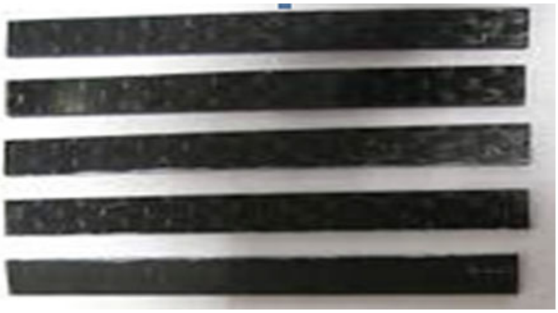
The tensile tests were performed according to ASTM D638 standard using a minimum of ten specimens (250 × 25 × 2 mm) for each laminate family. By bonding end tabs of carbon fiber/epoxy laminate, the specimens were prepared. The tests were carried out in an UTM (Fig. 18.2).

Table 18.1 Features of the layers and its orientations

Laminate No.	Orientation	0° layers used	90° layer used	45° layer used	Total no. of layers used
1	0/90	4	4	–	8
2	0/45	4	–	4	8
3	0/45/90	3	2	3	8
4	0/0	8	–	–	8
5	90/90	–	8	–	8

Fig. 18.2 Tensile test specimens

Fig. 18.3 Flexural test specimens



18.3.2 Flexural Test

This test was performed according to ASTM D790 standard. This is a bending test (three point loading) considering five samples (100 × 10 × 2 mm) for every laminate. The tests were carried out in an UTM at exact speed of 2 mm/min at room temperature (Fig. 18.3).

18.3.3 Interlaminar Shear Strength

The interlaminar shear tests (ILSS) were performed according to ASTM D2344 standard by considering five samples (short beam: 20 × 10 × 2 mm) for every laminate. The tests were carried out in an UTM (Figs. 18.4 and 18.5).

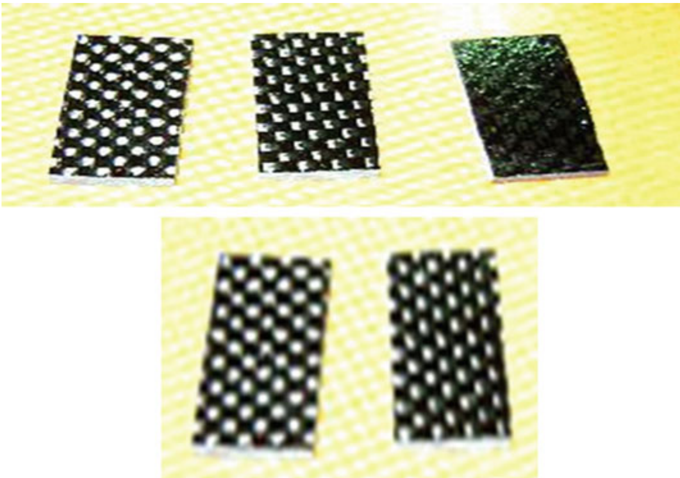


Fig. 18.4 ILSS test specimens

Fig. 18.5 ILSS test setup at UTM

18.3.4 Thermal Degradation

Select the specimen of 0/90 orientation and cut the specimen (20 specimens) as per ASTM D2344 standard for the ILSS test by increasing the atmospheric temperature. Now take the five specimens, test in the room temperature using UTM (ILSS) setup and note down the obtained values. Carry out the same procedure by taking 15 pieces into three parts and increase the test chamber temperature to 50, 100 and 150 °C, respectively. Now, calculate the percentage decrease in the strength of the material as the temperature increases.

18.3.5 Moisture Test

Select the specimen of 90/90 orientation and test the cut down laminate into required size as per ASTM D2344 standard. Then, weigh the specimen before dipping into various atmospheric samples like water, petrol, diesel, acid and lubricating oil in the room temperature and leave the specimen to absorb moisture for 2 days, 5 days and 7 days. Take out the specimens after the specified duration and weigh the specimens. Now, compare the results of normal room temperature tested specimen with the moisture absorbed specimens for 2 days, 5 days and 7 days (Fig. 18.6).

Fig. 18.6 Moisture test specimens

18.4 Results and Discussion

18.4.1 Material Characterization

18.4.1.1 Result of Tensile Test

Table 18.2 shows the mean outcome of tensile strength. The outcome obtained is according to ASTM D638 as represented. It is concluded that the 0°/90° orientation shows maximum strength, and comparison of different orientation with tensile strength is represented in Fig. 18.7.

Table 18.2 Tensile test values of the laminates studied

Sl. No.	Orientation	Tensile strength (Mpa)
1	0°/0°	887
2	90°/90°	945
3	0°/45°	857
4	0°/90°	1250
5	0°/45°/90°	998

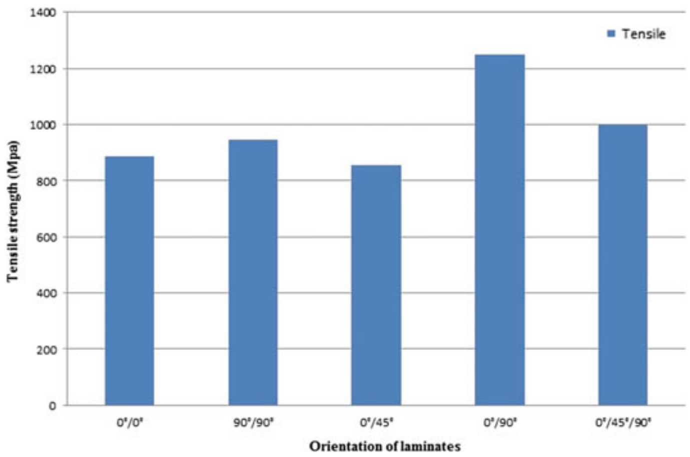


Fig. 18.7 Tensile values at different orientation

Table 18.3 Flexural values of the laminates studied

Sl. No.	Orientation	Peak load (N)	Flexural strength (Mpa)
1	0°/0°	374.36	844.313
2	90°/90°	341.04	835.101
3	0°/45°	390.00	671.26
4	0°/90°	284.20	859.33
5	0°/45°/90°	284.2	686.15

18.4.1.2 Result of Flexural Test

Table 18.3 shows the mean outcome of flexural strength. The outcome obtained is according to ASTM D790 standard. It is concluded that the 0°/90° orientation shows maximum strength, and comparison of different orientation with flexural strength is shown in Fig. 18.8.

18.4.1.3 Result of ILSS Test

Table 18.4 shows the mean results of ILSS. The outcome obtained is according to ASTM D2344 standard. It is found that the 0°/0° orientation shows maximum strength, and comparison of different orientations with ILSS is represented in Fig. 18.9.

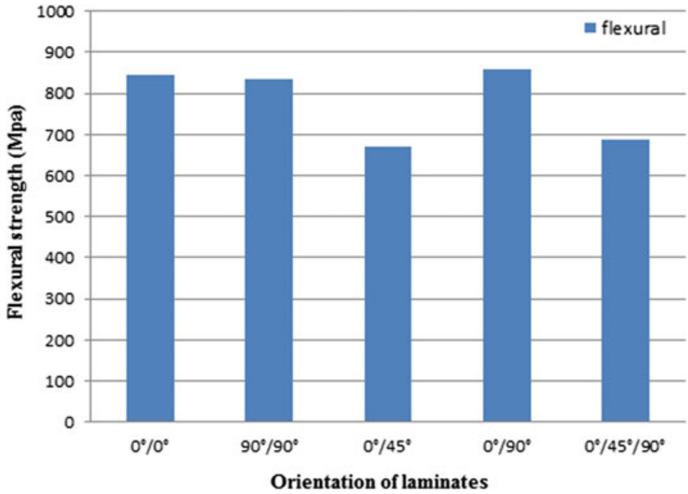


Fig. 18.8 Flexural values at different orientations

Table 18.4 Interlaminar shear values of the laminates studied

Sl. No.	Orientation	Load (kN)	Peak load (N)	ILSS (Mpa)
1	0°/0°	2.36	2365.62	81.20
2	90°/90°	2.31	2312.53	80.96
3	0°/45°	2.14	2144.73	74.00
4	0°/90°	2.52	2519.27	75.47
5	0°/45°/90°	2.21	2212.28	75.42

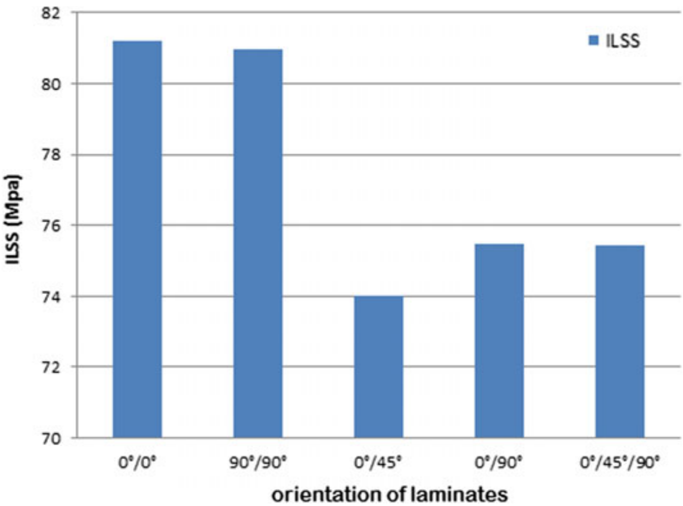


Fig. 18.9 ILSS values at different orientations

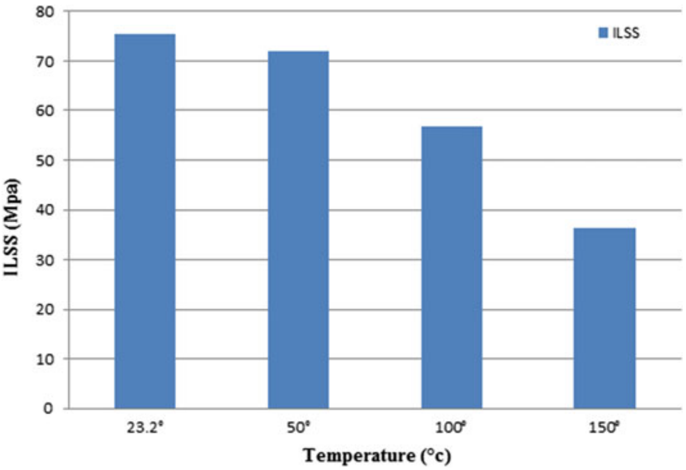


Fig. 18.10 ILSS values at different temperature conditions

Table 18.5 Interlaminar shear values of the laminates for thermal degradation

Sl. No.	Temperature in °C	Load (kN)	Peak load (N)	ILSS (Mpa)	Mode of failure
1	23.2 (room temperature)	2.52	2519.27	75.47	A
2	50	2.29	2288.63	71.85	A
3	100	1.84	1840.03	56.67	C
4	150	1.21	1207.77	36.17	C

A = Single shear; C = Plastic deformation

18.4.2 Thermal Degradation

The table below represents the mean outcome of interlaminar shear strength values for different laminates for thermal degradation. It is observed that as the temperature increases, the strength of the specimen decreases. Figure 18.10 represents variation of ILSS values at different temperatures (Table 18.5).

18.4.3 Moisture Test

The table below represents the average results of interlaminar shear strength values for studied laminates. Considering the ILSS results obtained in accordance with ASTM D2344 standard, it is observed that there is maximum decrease in strength as the moisture content increases. And comparison of ILSS at different moisture conditions is represented in plot 4 (Fig. 18.11; Tables 18.6, 18.7 and 18.8).

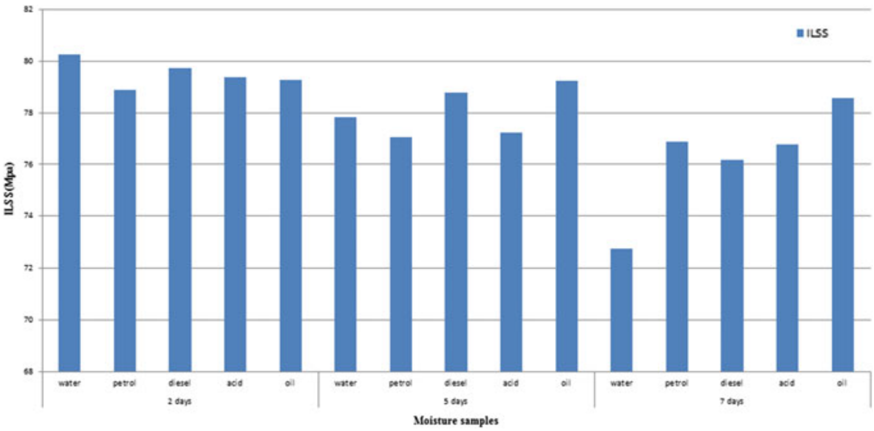


Fig. 18.11 ILSS values at different moisture conditions

Table 18.6 Moisture test values for 2 days

Sl. No.	Atmospheric environment	Load (kN)	Peak load (N)	ILSS (Mpa)
1	Water	2.32	2312.99	80.24
2	Petrol	2.30	2299.98	78.88
3	Diesel	2.26	2265.02	79.73
4	Acid	2.33	2327.84	79.37
5	Oil	2.29	2290.09	79.27

Table 18.7 Moisture test values for 5 days

Sl. No.	Atmospheric environment	Load (kN)	Peak load (N)	ILSS (Mpa)
1	Water	2.29	2292.62	77.81
2	Petrol	2.30	2298.64	77.07
3	Diesel	2.34	2338.65	78.79
4	Acid	2.32	2318.39	77.22
5	Oil	2.36	2358.81	79.25

Table 18.8 Moisture test values for 7 days

Sl. No.	Atmospheric environment	Load (mm)	Peak load (mm)	ILSS (Mpa)
1	Water	2.16	2158.67	72.76
2	Petrol	2.33	2328.16	76.89
3	Diesel	2.23	2211.99	76.18
4	Acid	2.31	2307.87	76.77
5	Oil	2.34	2344.70	78.57

18.5 Conclusion

- The composite laminate with 0°/90° orientation possesses maximum tensile strength of 1250 Mpa, which is higher than several other orientations of 0°/0°, 90°/90°, 0°/45° and 0°/45°/90°, respectively.
- The composite laminate with 0/90 orientation possesses maximum flexural strength of 859.33 Mpa, which is higher than several other orientations of 0°/0°, 90°/90°, 0°/45° and 0°/45°/90°, respectively.
- The composite laminate with 0/0 orientation possesses maximum ILSS of 81.20 Mpa, which is higher than several other orientations of 0°/0°, 90°/90°, 0°/45° and 0°/45°/90°, respectively.
- As the temperature increases, there is decrease in strength, and the laminate studied can withstand load up to 1207.77 N at 150 °C with ILSS of 36.17 Mpa.
- For the laminate studied, the ILSS decreased with an increase in the amount of absorbed moisture. The ILSS decreased by 80.24–72.76 Mpa for water, 78.88–78.81 Mpa for petrol, 79.73–76.18 Mpa for diesel, 77.22–76.77 Mpa for acid and 79.27–79.48 Mpa for oil.

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