RESEARCH ARTICLE OPEN ACCESS

Experimental Characterization of Carbon Fibre T700 / Epoxy towpreg for Space Applications

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Abstract
This document covers detailed experimental characterization of Carbon Fibre T 700/Epoxy towpreg.The experimental characterization of carbon fibre T 700/Epoxy towpreg composite material is necessary required for generation of mechanical properties data for analysis, design, and fabrication of structural components using that material and for quality control of the material. The testing of composite materials offers unique surprises because of the special characteristics of composites. Factors not considered important in metals testing are very important in testing composites. For example, composites are anisotropic, with properties that depend on the direction in which they are tested. Speed must be carefully monitored at the time of testing of specimens and also fiber content, void content, specimen conditioning (drying, storage, etc) have important effects on material properties.
In order to design composite products, a thorough experimental characterization of carbon fibre T 700 / Epoxy towpreg composite material and its behaviour is necessary.
Keywords: Carbon Fibre T 700 / Epoxy towpreg, Mechanical properties, Characterization, Composite material

I. INTRODUCTION

Ongoing Agni Missile programme requires large diameter of composite rocket motor casings (CRMC) for solid propellant casting. The carbon fibre reinforced plastic (CFRP) material is used for CRMC is having high strength and high stiffness. Currently Composite Rocket Motor Casings are fabricated with carbon fibreT-70and epoxy resin system by wet filament winding process.

Composite material in the form of towpreg is the state of the art of technology. Towpreg find wide application in composite manufacture, especially, where components are manufactured by filament winding process. Handling point of view towpreg makes its easy and simple. Towpreg has consistent and uniform resin content and high friction factor to carry out non geodesic winding than wet winding material. Tensile strength and modulus of composite depends on fibre volume fraction of composite. Towpreg composite has high fibre volume fraction (6- 65 %) than wet winding processed composite material. Percentage of Translation of carbon fibre strength in composite is higher in towpreg than that of filament wet winding process. Because the towpreg has control resin content, the need for measuring and mixing is eliminated and the possibility for contamination is minimized producing parts of consistent, high quality. Wet winding has a fairly high scrap rate, primarily related to these resin issues. Production throughput increases with towpreg because much less setup and cleanup time is required, and the winding speed is no longer limited by the fiber we tout requirements. The tacky prepreg resin protects the fibers as well, so winders can be run at higher speeds without the risk of fraying damage. Finally, curing is much simpler, because towpreg parts do not require a cosmetic gel coat, and they do not need to be rotated during cure to prevent sagging or running of excess resin that can occur with wet winding.

When comparing pot life and shelf life, however, the trade-off is less clear. Raw fibers and resins practically have an indefinite shelf life at room temperature, but once mixed, the pot life of a resin can be measured in hours. Most towpregs, on the other hand, have a limited shelf life and require cold storage, but can sit out for days before being used in the winding process

Towpreg systems deliver more of fiber strand tensile strength, compared with wet wind systems, and the finished parts exhibit a smaller variation in properties. The net result is that less material can be used for towpreg vessels of equal performance.

II. EVALUATION OF CARBON FIBRE T700 / EPOXY TOWPREG FOR PHYSICAL PARAMETERS

Indigenous developed Carbon fibre T700/Epoxy

Towpreg was received from M/s Chemapol industries, Mumbai for characterization purpose. The specifications of the carbon fiber T700/Epoxy Towpreg are given below. The Towpreg must be evaluated for their respective properties before processing of laminates by filament winding process as shown in the table.

S.No.	Parameter	Specified Value
1	Carbon fibre T 700	MakeToray , Tow size 12k
2	Resin	Modified Epoxy resin (Proprietary)
3	Resin Content	30 ± 2 %(by weight)
4	Longitudinal Tensile strength of UD laminate, Mpa.	2000 (Minimum)
5	Longitudinal Tensile Modulus of UD laminate, Mpa.	140 (Minimum)
6	ILSS, Mpa.	80 (Minimum)
7	Fibre Volume Fraction, %	60- 65 %
8	Glass Transition temperature	120^0C (Minimum)

Cure cycle of towpreg

The towpreg will be cured at 120^0C/2h and 150^0C /4h to get above properties of the composites

Shelf life of towpreg

The towpreg will be stored in cold storage at -18^0 C . The shelf life of towpreg is one year from the date of manufacturing.

Evaluation of Carbon Fibre T700/ Epoxy Towpreg for Physical Parameters

The antecedents of the carbon fibre T70/Epoxy towpreg shall be verified as regards to the adherence to storage conditions and shelf life of the materials after receipt at ASL. It shall also be ensured that the test reports from the supplying agency, if possible, are obtained. Also, the following tests shall be carried-out as per standards specified and the test values should be within the specified limits.

Visual Inspection

Visual inspection shall be carried out in order to find out defects such as stains, discolored patches, fibe cuts, etc, where such defects observed, the material shall be rejected.

Resin content in Tow preg

The resin content in towpreg shall be determined from the weight of 1 meter length tow preg and from the tex of carbon fibre T 70, 12K (taking from the Toray technical sheet)or resin content in the towpreg shall be determined as per ASTM D 3529.

<u>Resin Content of Towpreg will done as per the following ASTM D 352procedure.</u>

- Weigh Towpreg using precision balance with about one milligram accuracy. Let the weight of prepreg (approximately 1-2 grams weight) w1grams.
- Place test specimen in the beaker
- Pour the solvent Dichloromethane to the breaker and stir it till the separation of the fibre. Resin dissolves in the solvent and the separate resin solution from the fibre.
- Rinse the fibre with the solvent dichloromethane till the resin is extracted completely from the fabric.
- Dry the fibre in air circulating oven at 110^0c for one hour and cool it in the desiccators and weigh the fibre and repeat the process till to get the constant weight of fibre. Let the dry weight of the fibre be w2 grams

Fibre Content by weight ,% = (w2 / w1) x 10

Resin Content by weight, %= (10 Fibre content)

Where W1 Weight of towpreg in grams.

W2 Dry weight of fibre after resin extraction from the in grams.

The acceptance value for Resin content in towpreg shall be in the range of 32 % by weight .

Tensile Test of cured Single Towpreg

This test provides data on percentage of translation of fibre strength in the cured towpreg and also this test provides average fibre tensile strength and tensile modulus. Towpreg spool is shown in the figure No. 1.Tensile specimens of single towpreg was prepared by using rectangular mandrel by filament winding process. Winding specimens were be cured as per cure cycle to get tensile specimens of towpreg. Tensile specimens will be tested for tensile strength, tensile modulus and % strain as per ASTM D4018. Glass fabric /epoxy resin composite tabs were bonded on cured Tow tensile specimens to get failure of specimen in gauge length. Extensometer was mounted on tow tensile specimen for measurement of strain during testing for calculation of tensile modulus. Tensile modulus was measured in the strain range limits between 1000με to 6000με for a failure strain of the fibre greater than 12000με . Cured Single towpreg specimens were tested by using UTM by mounting extensometer .Tow tensile specimens with end tabs. Tow tensile Testing in UTM and specimens failure mode is shown in the figure No.1.

Acceptance value for
Tensile strength of cured towpreg : 420MPa (Mini)
Tensile Modulus of cured towpreg : 20GPa (Mini)

FIGURE 1: Tow tensile Testing in UTM and specimens failure mode

Cure Characteristics of Resin in towpreg by DSC
Cure characteristics of resin in towpreg was evaluated by Differential Scanning Calorimetry (DSC). 5 mg of resin mix was taken for DSC run .DSC experiment was carried out from room temperature to 3000c with heating rate 100c /minute in nitrogen atmosphere (flow of gas 5ml/minute).DSC scan for cure characteristics of resin is shown in the figure no. 3.Cure characteristics of resin from DSC scan are given below

Cure initiation Temperature (Ti) = 126.87oC
Cure Onset Temperature (T onset) = 144.84oC
Cure Peak Temperature (T peak) = 170.79oC
Cure Completion Temperature (T Comp) = 276.87oC
Heat of Polymerisation = 84.71J/g

The above data of cure characteristics and heat of polymerization of resin in tow preg will be useful for evaluation of shelf life during storage period of towpreg.

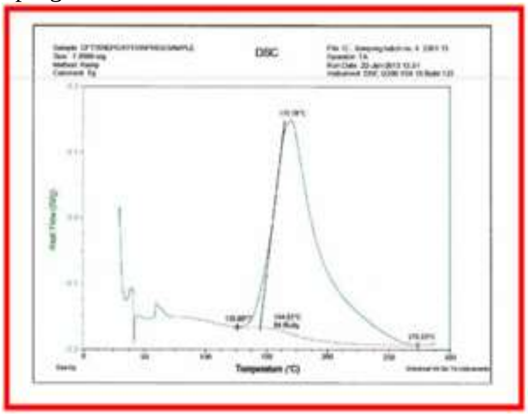


FIGURE 3 : Cure characteristics of resin from DSC scan

% Strain : 2.0 (Mini)
Tensile stress vs. strain curve for cured single towpreg is given in figure no. 2

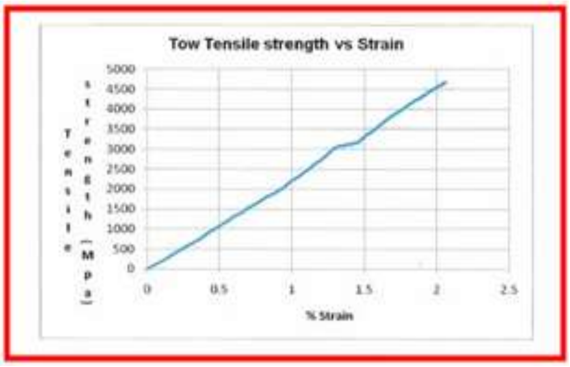


FIGURE 2: Tensile stress vs. strain curve for cured single towpreg

III. EXPERIMENTAL CHARACTERIZATION OF TOWPREG COMPOSITE

Characterization means determination of all effective Properties over sufficiently large volumes to represent composite and which are statistically reproducible.

The main purpose of Experimental characterization data are

- for checking micromechanical analysis
- for design and analysis of practical structures
- for Fabrication Process QA / Product QC
- for Comparison of properties between candidate materials

When selecting a material for a specific product application like Composite Rocket Motor Casing for a missile system, the relevant properties of proposed composite material need to be determined experimentally designing a particular product to meet a specific structural requirement of the composite product.

Characterization is essentially the process whereby materials, components, sub-systems and systems are defined in terms of their distinctive attributes, qualities, properties and functions. Composite materials behave in a complicated fashion due to macroscopic anisotropic effects and other coupling effects. Hence, the experimental characterization of composite materials is more complicated than for conventional, homogenous, isotropic materials. Since there are more independent material properties for composite materials, it is necessary to obtain more different types of data. It is also necessary to expend much effort on selection of suitable of test, specimens, test specimen design, fabrication and appropriate analysis of experimental data. Material characterization is done in terms of measurable parameters that the designer may relate to his design parameters.

Physical properties of laminate such as density as per ASTM D792, resin content and fibre volume fraction is determined by acid digestion method as per ASTM D3171.

For minimum characterization of a unidirectional composite, four independent elastic constants, namely the elastic moduli in longitudinal and transverse directions, the in plane shear modulus, the major Poisson ratio and five independent strengths namely tensile and compressive strength in the longitudinal and transverse directions and the in plane shear strength are to be determined. Static testing is done on universal testing machine (Instron UTM) to evaluate the ultimate or failure properties of materials in various configurations as per ASTM standards.

Experimental characterization of carbon fibre T700/ Epoxy towpreg composite was carried out for generation of design input data for design and analysis of composite rocket motor casings and other composite products.

Sl.NO	PROPERTY	ASTM No	No. of Specimens
1.0	**DESIGN PROPERTIES**		
1.1	L. Tensile Strength(σT_{11}),	D3039	9
1.2	L. Tensile Modulus (E_{11})		
1.3	Major Poison's ratio, ν_{12}		
1.4	T.Tensile Strength(σT_{22})		6
1.5	T.Tensile Modulus (E_{22})		
1.6	L. Compressive Strength (σC_{11}),	D3410	6
1.7	T. Compressive Strength (σC_{22}),		6
1.8	Inplane shear strength (τ_{12})	D3518	7
1.9	Inplane shear modulus (G_{12})		
2.0	**QUALITY CONTROL PROPERTIES**		
2.1	NOL Ring Tensile Strength	D2290	5
2.2	Flexural Strength	D790	10
2.3	Flexural Modulus		
2.2	Interlaminar shear Strength, MPa	D2344	10
3.0	**PHYSICAL & THERMALPROPERTIES**		
3.1	Fiber volume fraction , V_f	D 3171	3
3.2	Density (ρ), g/cc	D 792	3
3.4	Glass Transition Temp. Tg , °C	E 1356	3

FIGURE 4: The physical, mechanical and thermal tests for experimental characterization of carbon fibre T700/Epoxy towpreg composite.

IV. MANUFACTURING PROCESS OF UD LAMINATES AND NOL RINGS

Fabrication of Unidirectional (UD) laminates

Flat UD laminates can be fabricated by filament winding in order to provide the stock from which flat test specimens can be prepared. One process for doing this involves winding a unidirectional mat over a large mandrel, cutting and removing the fibers, as wound material, from the mandrel, then plying, consolidating and curing (in an autoclave) to the flat configuration. The material resulting from the process can be quite different from the material in a filament wound composite structure.

Towpreg was winding to a flat rectangular plate by filament winding by heating towpreg to temperature about 60^0C by hot air gun at pay out eye and also heating at winding surface by IR lamps to temperature about 60^0C to get good inter layer bonding during winding. 2 kg Tension was maintained per spool during winding. This flat shaped mandrel was specially designed and fabricated to prepare UD laminate (as shown in the Fig no .6).

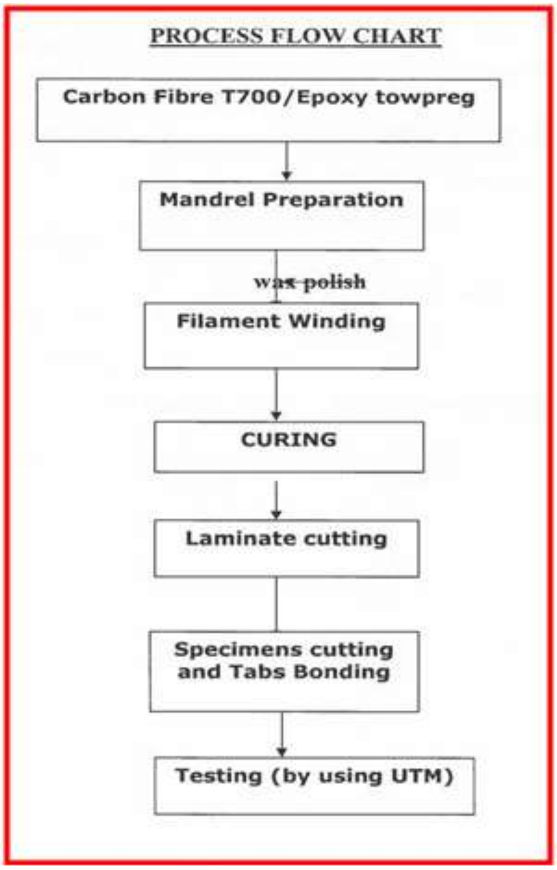


FIGURE 5: The flow chart of manufacturing of laminate and specimen preparation.

FIGURE 6: Fabrication of Carbon Fibre /Epoxy resin UD Laminate by Filament Winding Process

Curing

After Filament winding, the laminate is cured in an oven having accurate temperature control. The flat mandrel is placed inside the oven on metal stands . The following cure cycle (as shown in Fig no .7) was followed.

- Raise temperature of the oven from room temperature to 120^0C in 3minutes With heating rate of 2^0 to 4^0C per minute
- Hold the temperature at 120^0C ±5^0C for 2hours.
- Raise temperature of the oven from 120^0C to 150^0C in 3 minutes with heating rate 2^0 to 4^0C per minute.
- Hold the temperature at 150^0C ±5^0C for 4 hours
- Switch off the oven and allow the component to cool naturally.
- Open the door and remove mandrel when it is below 40^0C

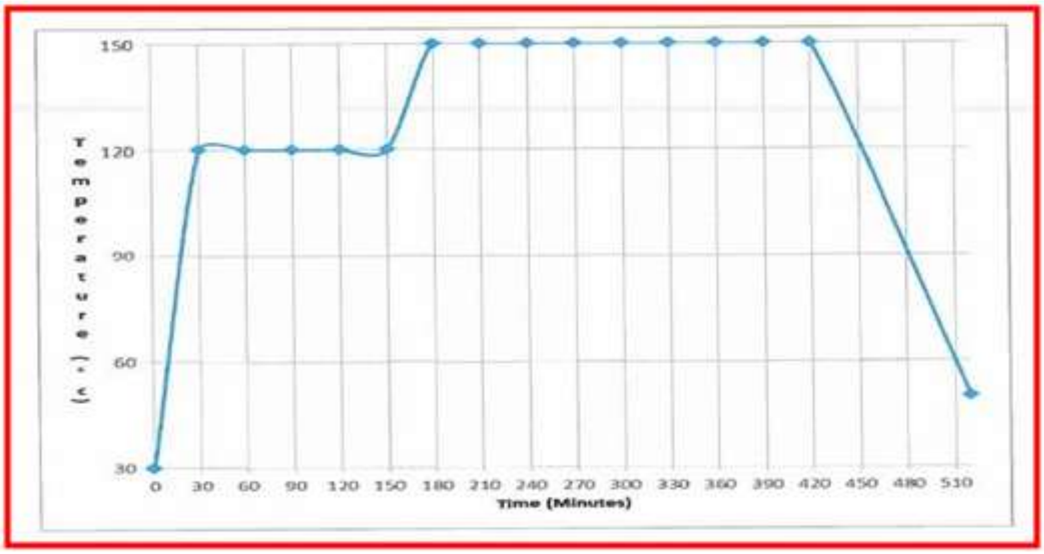


FIGURE 7: Cure Cycle for Carbon Fibre T-700 / Epoxy Towpreg Composite

Fabrication of NOL Ring Specimens

NOL (Naval ordnance laboratory) Ring specimens that simulate the cylindrical geometry of composite over wrap pressure vessel (COPV). NOL ring specimens are prepared by Carbon fibre T700/Epoxy towpreg by filament winding technique on NOL ring mandrel as shown in the figure . NOL ring mandrel was specially designed and fabricated to prepare a laminate simulating the real filament wound. Hoop winding is carried out on the mandrel and followed above process parameter of towpreg mentioned in the preparation of UD laminates. Curing of NOL ring winding was carried out in oven with cure cycle. After curing, NOL Ring winding was machined on lathe to remove accumulated resin on winding during curing to get uniform thickness of rings and winding was partitioned into standard width as ASTM 229 to get NOL Rings. The dimensions of NOL ring specimen is shown in the Fig no .8, NOL winding and partition of winding into rings as shown in the Fig no .9.

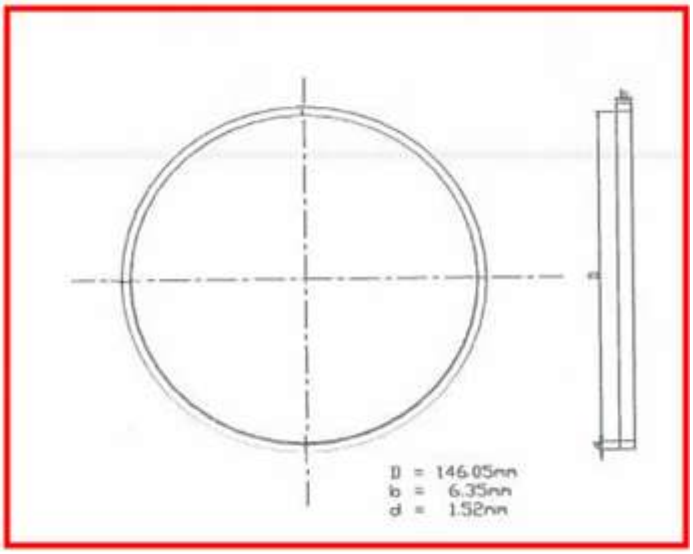


FIGURE 8: The dimensions of NOL ring specimen (ASTM D 2290)

ISSN: 2248-9622, Vol. 5, Issue 12, (Part - 1) December 2015, pp.01-14

FIGURE 9: NOL winding and partition of winding into rings

Specimens Preparation from UD laminates

When selecting the type of test specimen to use in an experimental characterization, one of the most important point is to use a type of specimen which has been made in the same manner as the full scale end product structure. In the characterization programme described herein, the end product is carbon-epoxy filament wound rocket motor casing.

It is desirable to characterize experimentally the properties of a single ply of the composite material for design purpose. However, practical considerations often prevent their construction. Thus, it becomes necessary to conduct tests on multi-layered specimens and use appropriate laminate theory to reduce the results in terms of single-ply properties.

The dimensions of different types test specimens ((as shown in figure no.10). Specimens are prepared from laminates with the help of a diamond wheel cutting machine (as shown in figure no 11).

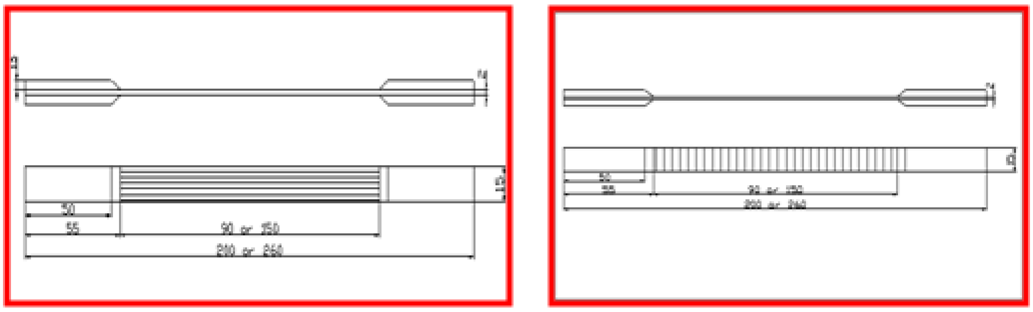


FIGURE 10: (a) Longitudinal & Transverse Tensile Test Specimens (ASTM D 3039)

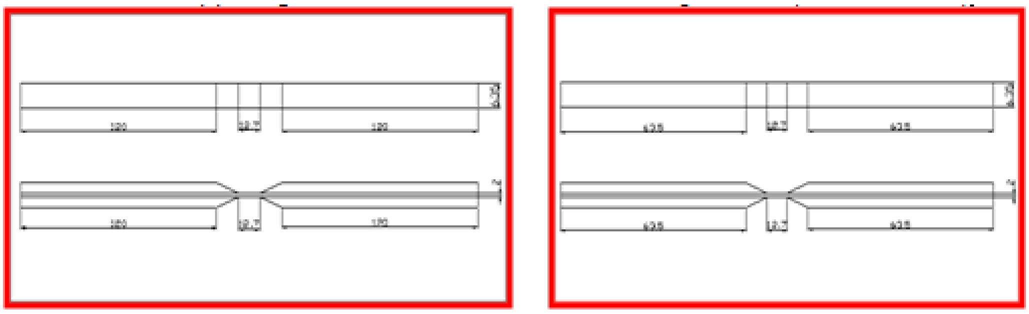


FIGURE 10: (b) Longitudinal & Transverse Compressive Test Specimens (ASTM D 3410)

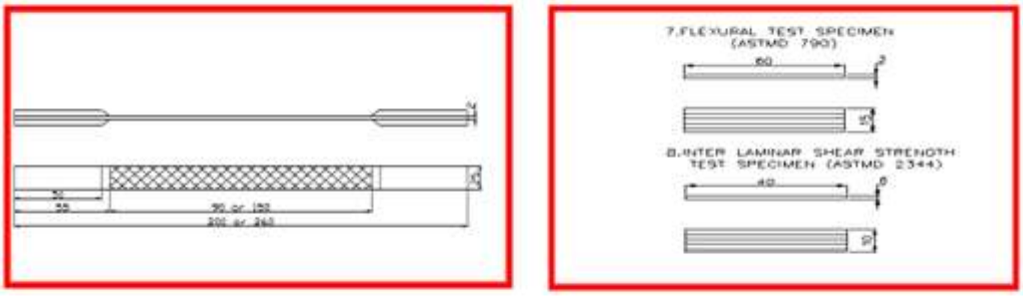


FIGURE 10: (c) In plane Shear Test Specimen (ASTM D 3518) & Flexural specimens as per

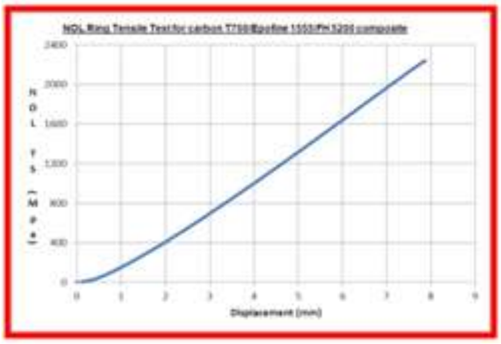
(ASTM D 790) & ILSS Specimen as per (ASTM D 2344)

TEST METHODS FOR LAMINATES

NOL Ring Tensile Test

This method covers the determination of the comparative apparent tensile strength of ring or tubular composites. An apparent tensile strength rather than a true tensile strength is obtained in this test because of a bending moment imposed during test. The method is applicable to many types of tubular shaped specimens either parallel-fiber reinforced, extruded or molded. Parallel fiber reinforced specimen is prepared and tested as per ASTM D229using split disc test fixture for determining the apparent hoop tensile strength of the composite .NOL ring specimens were tested using NOL test fixture (as shown in Fig). A plot Apparent Hoop tensile strength vs. displacement of NOL Ring test is shown in Figure. Failure modes of NOL Rings is shown in Figure. The test results of NOL ring are shown in the Table.

FIGURE 11: NOL Test Fixture (ASTM D 229)



Specimen No.	NOL Ring TS (MPa)	Failure Mode
1	2086	Splitting & delamination
2	1846	Splitting & delamination
3	2043	Splitting & delamination
4	2069	Splitting & delamination
5	2056	Splitting & delamination
AVERAGE	2020	
Standard deviation	99	
% Coefficient of Variance	5.0	

FIGURE 12: Plot for Tensile Strength Vs Displacement and NOL Test Results

FIGURE 13: Plot for Tensile Strength Vs Temperature & NOL Rings were failed in delamination and circumferential splitting failure Test Results

Longitudinal (0) Tensile Test and Transverse (90) Tensile Test

The tension test on longitudinal specimens is conducted to determine longitudinal tensile strength (XT), Modulus (EL) and major Poisson's ratio (LT). In this method, the specimen with end tabs have been used. Rosette Strain gauge was bonded on specimens as per standard procedure of strain gauge bonding.

Specimen preparation and testing is carried out as per the standard ASTM D3039.Rosette strain gauge was bonded on specimens for measurement of modulus and Poisson ration as shown in the figure no. 15. Longitudinal tensile strength is determined from the ultimate load and longitudinal tensile modulus is calculated from the stress-strain curve. The Tensile testing of UD laminate specimens in UTM with strain gauge data logger system ,failure modes of specimens and the plot of Tensile strength vs. strains is given in the Figure No.14, for calculation of Ultimate tensile strength, Tensile modulus, poisson ratio. The values of the longitudinal strength, modulus, poisson ratio and ultimate failure strain are given in the Table.

The tension test on flat (90) Transverse specimens is carried out to determine transverse tensile strength and transverse tensile modulus. Specimen preparation and testing is done as per the test standard ASTM D3039. An Extensometeroruni axial strain gauge are used to measure strain along the loading direction. Transverse tensile strength is calculated from the failure load and the transverse tensile modulus from the stress-strain curve, the plot of Tensile strength vs. strains, failure modes of transverse specimens and the test results are shown in the Table.

Longitudinal (0) compressive Test and Transverse (90) compressive Test

The comprsession test on flat (0) longitudinal specimens and the comprsession test on flat (90) Transverse specimens are carried out to determine longitudinal compressive strength.

Specimen preparation and testing is done as per the test standard ASTM D341by using IITRI fixture as shown in the Figure No 15. Gauge length12mm was used for compressive testing of composites. Longitudinal compressive strength is calculated from the failure load .The plot of Tensile strength vs. strains, failure modes of transverse specimens and test results are shown in the fig.

FIGURE 14: (a) The Tensile testing of UD laminate specimens in UTM with strain gauge data logger system

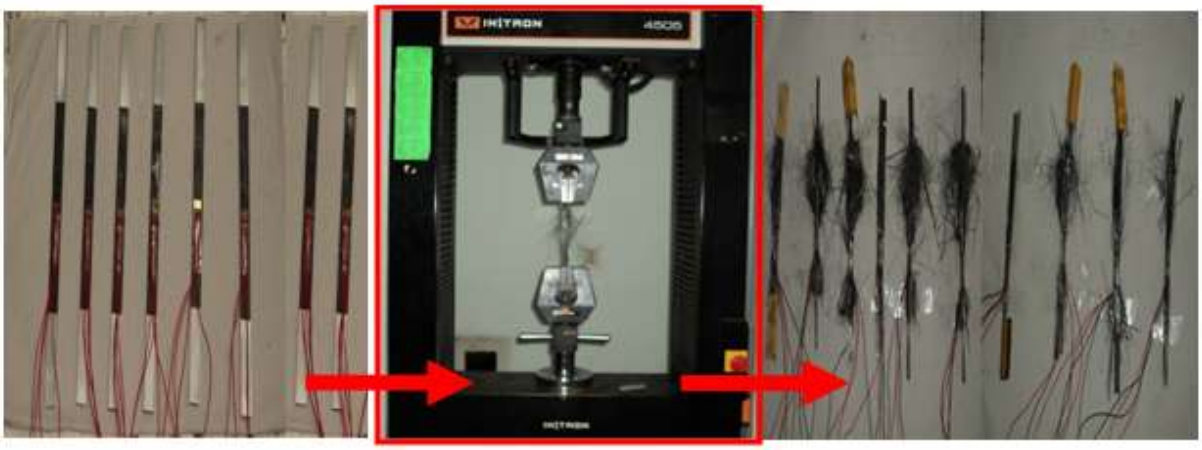


FIGURE 14: (b) Failure modes of specimens

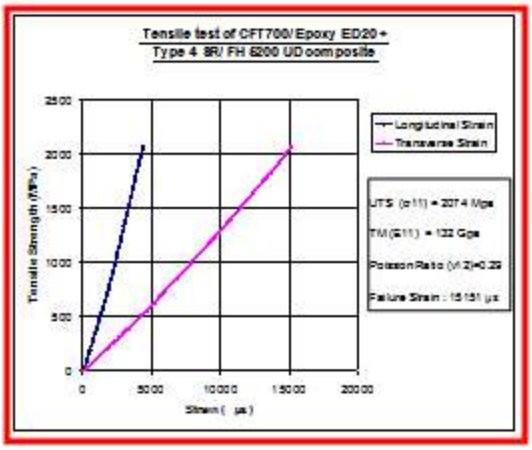


FIGURE 14: (c) Tensile stress vs. strains

Specimen No.	Ultimate Tensile Strength σ11,(MPa)	Tensile Modulus E11(GPa)	Poisson Ratio ν12	Failure Mode
1	2498	–	–	XGM
2	2480	–	–	XGM
3	2434	–	-	XGM
4	2383	144	0.29	Splitting
5	2504	145	0.29	XGM
6	2560	140	0.29	XGM
7	2231	137	0.28	Splitting
8	2533	–	–	XGM
9	2295	138	0.31	Splitting
AVERAGE	2435	141	0.29	
Standard deviation	112	3.56	0.011	
% Coefficient of Variance	4.6	2.5	3.8	

FIGURE 14: (d) Test Results of specimens

Specimen No.	UCS (MPa)	Failure Mode
1	936	Through thickness shear
2	894	Through thickness shear
3	1044	Through thickness shear
4	968	Through thickness shear
5	1012	Through thickness shear
6	995	Through thickness shear
AVERAGE	975	
Standard deviation	54	
% Coefficient of Variance	5.5	

FIGURE 15: (a) The Compressive IITRI Test Fixture & Test Results of laminate specimen's

S.No	UCS (MPa)	Failure Mode
1	163	Through thickness shear
2	146	Through thickness shear
3	152	Through thickness shear
4	140	Through thickness shear
5	137	Through thickness shear
6	145	Through thickness shear
Average	147	
Standard deviation	9.3	
% Coefficient of Variance	6.3	

FIGURE 15: (b) The Compressive Test Results of laminate specimen's and Failure modes Of test specimen's

In plane Shear Test

The properties that are determined through the tests are the shear strengths and shear modulus. In these tests the specimen is subjected to loads that produce a pure shear state of stress and the resulting strains are measured.

The test in which shear distortion takes place entirely in the plane of the composite material laminate are termed in-plane shear tests. The in plane shear strength (τ) and in plane shear modulus (G) are determined by this test. In this characterization programme of carbon-epoxy composites, the in-plane shear properties are determined by the uniaxial tension test on ± 45^0 specimens as per the test standard ASTM D3518.

The stacking sequence chosen for the preparation of the laminate is +45,-45. The importance of a laminate with the stacking sequence is that, such a laminate is specially orthographic with respect to in-plane forces and strains, and the bending-stretching coupling effects and the in plane and bending anisotropic effects are avoided.

Rosette Strain gauge is bonded on specimens to measure strains along the loading direction and perpendicular to it as shown in Fig. The in plane shear modulus is calculated from the stress versus strain curve. The plot of shear Tensile strength vs. strain is given in the Fig. Failure modes of transverse specimens and test results are given in the fig.

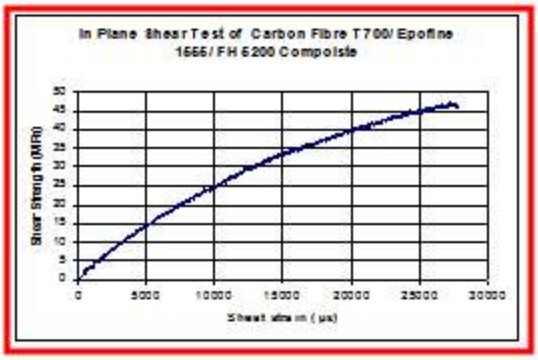
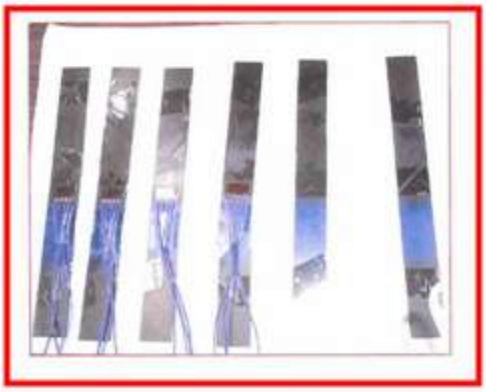
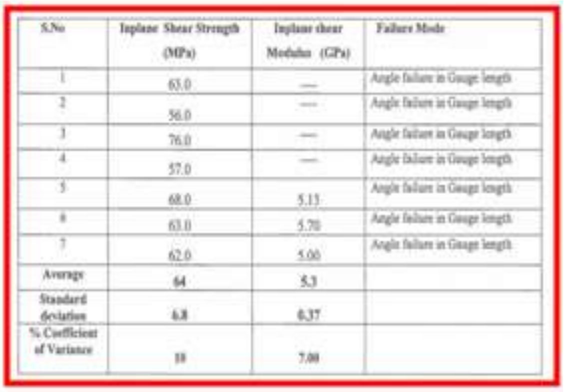


FIGURE 16: (a) Rosette Strain gauge is bonded on ± 45^0 specimen’s tensile test (in plane shear) and shear stresses and shear strain on ± 45^0 tensile test





S.No	Inplane Shear Strength (MPa)	Inplane shear Modulus (GPa)	Failure Mode
1	63.0	—	Angle failure in Gauge length
2	56.0	—	Angle failure in Gauge length
3	76.0	—	Angle failure in Gauge length
4	57.0	—	Angle failure in Gauge length
5	68.0	5.13	Angle failure in Gauge length
6	63.0	5.70	Angle failure in Gauge length
7	62.0	5.00	Angle failure in Gauge length
Average	64	5.3	
Standard deviation	6.8	0.37	
% Coefficient of Variance	10	7.00	

FIGURE 16: (b) Failure modes of ± 45^0 tensile test (in plane shear) specimen’s and Test Results of In plane shear test of Towpreg T700 / Epoxy Specimen’s

3 point flexural test

The Flexural strength modulus are evaluated using a three-point test fixture. The specimen is prepared as per test method ASTM D790. Flat specimens, machined with same care and precision as previously described for tensile testing, are selected for measurements. The material direction under investigation must be oriented along the length dimension of the specimen. The test pieces require a span/depth (l/d) ratio high enough to achieve failure in bending rather than shear and minimize the influence of shear.l/d ratio 40:1 was used for testing. The Flexural strength (FS) is calculated as follows,

FS = 3PL /2bd2

Where, p Maximum load

L Support span length

b width of specimen

d thickness of specimen

Flexural testing of UD specimens in UTM and failure modes are shown in the fig. A plot of Load vs. displacement of Flexural Test and the values of Flexural Strength and modulus are is shown in fig.

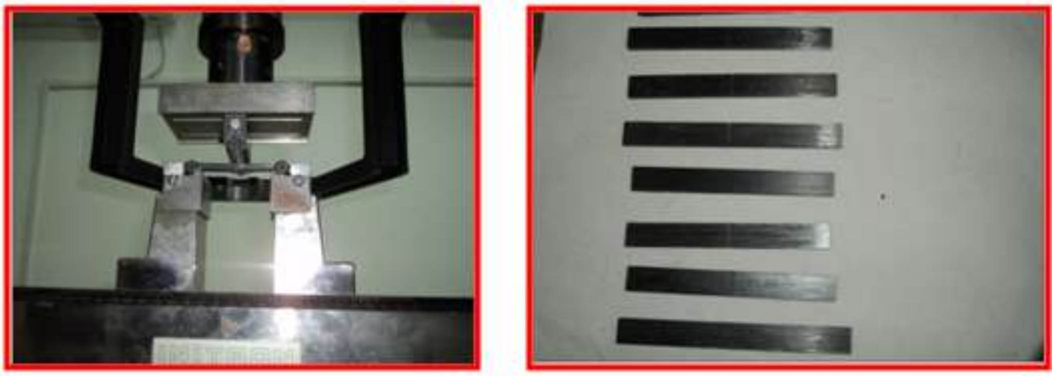
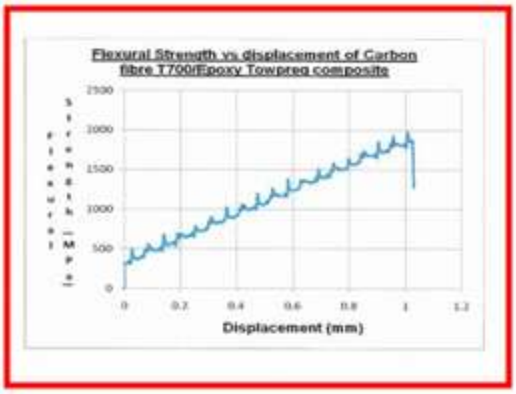


FIGURE 17: (a) 3 point flexural test Fixture and tested longitudinal UD specimens



S.No	Flexural Strength (MPa)	Flexural Modulus (GPa)	Failure mode
1	1955	–	Compressive failure
2	2044	–	Compressive failure
3	1928	–	Compressive failure
4	1901	147	Compressive failure
5	1979	152	Compressive failure
6	1809	151	Compressive failure
7	1862	–	Compressive failure
8	1858	152	Compressive failure
9	1868	144	Compressive failure
10	1698	151	Compressive failure
Average	1890	149	
Standard deviation	96	–	
% Coefficient of Variance	5.0	–	

FIGURE 17: (b) Plot for flexural strength vs. displacement and test results of flexural towpreg specimen's.

Inter laminar shear strength (ILSS)

The Inter laminar shear strength is evaluated using a three-point test fixture. The specimen is prepared as per test method ASTM D2344. Flat specimens, machined with same care and precision as previously described for tensile testing, are selected for measurements. The material direction under investigation must be oriented along the length dimension of the specimen. The test pieces require a span/depth (l/d) ratio low enough to minimize the influence of bending deformation and to achieve failure shear rather than bending. l/d ratio41 was used for testing

The Interlaminar shear strength (ILSS) is calculated as follows,

ILSS = 3p/4bd

where, p maximum load

b width of specimen

d thickness of specimen

ILSS Test of UD specimen in UTM and samples after tested are shown in fig. A plot of Load vs. displacement of ILSS Test and the values of Interlaminar Shear Strength (ILSS) are is shown in fig.

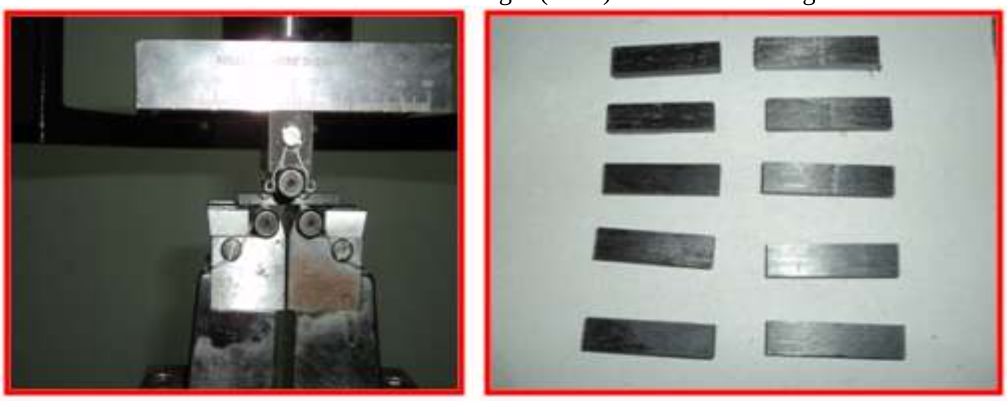
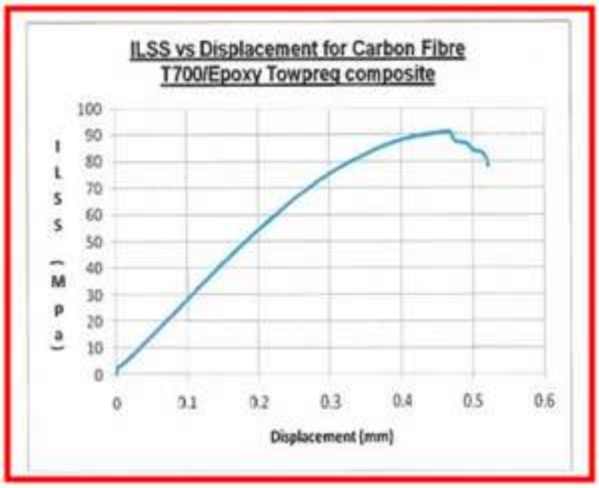


FIGURE 18: (a) 3 point flexural test Fixture and tested longitudinal UD specimens



S.No	ILSS (MPa)
1	92.67
2	92.78
3	93.64
4	91.11
5	93.59
6	90.44
7	92.51
8	95.17
9	91.12
10	91.87
Average	92.00
Standard deviation	1.42
% Coefficient of Variance	1.54

FIGURE 18: (b) Plot for ILSS vs. displacement and test results of ILSS towpreg specimen's.

Glass Transition Temperature

Glass transition temperature of unidirectional composite specimen was investigated as per ASTM E 1356 by recording DSC (DSC Q200) traces in Nitrogen atmosphere and flow rate5L/minute was used. A heating rate of 10^0C/minute and a sample size of 11.8 mg was used. The value of Glass transition temperature found by DSC was 125-129^0C.DSC scan of composite sample is shown in the Fig.

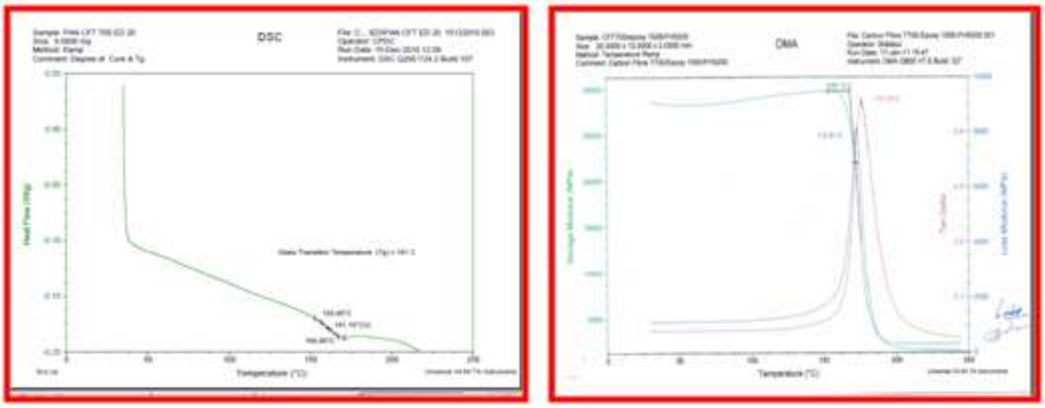


FIGURE 19: DSC and DMA scan for Glass Transition Temperature

V. TEST RESULTS

All the tests were carried out using Instron Universal testing machine, model 4505 and the results of all tests and failure modes of specimens under their type of loading.

Statistical Analysis

Composite materials are sensitive for their variability in mechanical properties. The variability is even more prevalent in carbon-epoxy composites due to their inherent flaws and inhomogenities. It is important, therefore to present the spread of results, which is in itself a property of the material. Mechanical properties are given as the arithmetic mean (X) of a sample of n specimens, then

x = Xn/n

The standard deviation (n-1 is then calculated using the following formula:

SD = ((xi2 nx2) / (n-1))1/2

The spread of results are then expressed in terms of Coefficient of Variation, which is defined as percentage

CV = (SD/x)*100%

Overall properties obtained in this characterization is summarized and placed in fig.20

SLNO	PROPERTY	ASTM No	No. of Specimens	Average Value	% CV
1.0	**DESIGN PROPERTIES**				
1.1	L. Tensile Strength (σT_{11}), MPa	D3039	9	2435	4.6
1.2	L. Tensile Modulus (E_{11}) , GPa			141	2.5
1.3	Major Poison's ratio (ν_{12})			0.29	3.8
1.4	T.Tensile Strength (σT_{22}) , MPa		6	42	12.0
1.5	T.Tensile Modulus (E_{22}) , GPa			9.4	8.0
1.6	L. Compressive Strength (σC_{11}), MPa	D3410	6	975	5.5
1.7	T. Compressive Strength (σC_{22}), MPa		6	147	6.3
1.8	Inplane shear strength (τ_{12}), MPa	D3518	7	64	10.0
1.9	Inplane shear modulus (G_{12}) , GPa			5.3	7.0
2.0	**QUALITY CONTROL PROPERTIES**				
2.1	NOL Ring Tensile Strength , MPa	D2290	5	2020	2.0
2.2	Flexural Strength , MPa	D790	10	1890	5.0
2.3	Flexural Modulus, GPa			149	--
2.2	Interlaminar shear Strength, MPa	D2344	10	92	1.54
3.0	**PHYSICAL & THERMALPROPERTIES**				
3.1	Density (ρ), g/cc	D792	3	1.55	---
3.2	Fiber volume fraction , V_f	D3171	3	65	--
3.3	Glass Transition Temp. Tg , °C	E1356	3	125-129	--

VI. CONCLUSION

Carried out thorough experimental characterization of carbon fibre T700/Epoxy towpreg which was indigenously developed by M/s Chemapol Industries, Mumbai and its behaviour under tension, compression, shear and bending loads.

Mean values, standard deviation and% coefficient of variance were calculated for each mechanical property. Coefficient of variation was found between 3-10%. Based on this confidence level, the designers can utilize the generated data for design and analysis of Composite Rocket Motor Casings.

VII. ACKNOWLEDGEMENT

The authors gratefully acknowledge the laboratory Support extended by D.R.D.O, Advanced Technology Development, CPDC (ASL), Hyderabad.

The authors also gratefully acknowledge to the Head of the Department, Mr.Rama swami (Scientist-F) CPDC, Hyderabad for his continuous Guidence and suggestions throughout my research work.

Finally the authors also gratefully acknowledge to the management of M/s BEML Ltd and Department of Metro Production, Bangalore for their kind support at all the times

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