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DESIGN, DEVELOPMENT AND TESTING OF COMPOSITE PRESSURE TUBE

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ABSTRACT

An Axi-symmetric full diameter opening composite pressure tube (out of E – glass fiber and epoxy matrix), is designed by Classical Lamination Theory (CLT) approach, and analyzed by ANSYS. Reasons for the chosen materials and process, are presented. Due material characterization (mechanical) has been done on Bi-directional E-Glass fabric laminates and hoop wound E - glass roving, as per ASTM standards.

Existing "Drum winder", together with a mandrel designed and fabricated out of steel, has been used to realize the Composite pressure tube, with designed BD fabric and Roving plies. The tube is examined by NDE methods such as Coin tapping test, "Dry-scan ultra-sonic" and "X – Ray radiography", for voids and they are plotted. The Pressure tube is tested for hoop tensile strength and hoop stress, with duly designed test fixture incorporating a rubber bladder, in view of the permeable nature of the composite when exposed to pressurized fluids directly.

KEYWORDS: composite pressure tube, CLT, Drum winder, NDE techniques, Pressure Testing

INTRODUCTION

In the pipe line industry, pressure vessels, the need for better equipment is increasing as the industry is developing. Because of new environments where the pressure is high or the temperatures are extreme, the interest in composites has increased. Composites are very versatile and can be tailor-made. Therefore, they can be a solution to the needs in the future. Pipes used in the pipeline and gas industry today are mainly made of steel.

These are well known materials which satisfy many of the traditional requirements. However, when these pipes are used in industries, weight becomes an issue. Composites have a good strength to weight ratio and can be a possible substitution for the standard metal pipes in this situation. This master thesis is based on filament winding technology and testing is as per ASTM standards.

TASK DEFINITION

This thesis will investigate how well short, small diameter tubes with thin wall thickness can withstand internal pressure. The purpose of this work is to gain knowledge about the creation of glass fiber tubes using filament winding, their behavior when exposed to internal pressure and analysis methods used to predict buckling. To perform the analysis, realistic input data has to be found.

AIM OF THE PROJECT

The specific strength of composite is far greater than of known metallic materials, coupled with tailorability characteristic of – an isentropic composite results in realizing in different strengths in different directions and makes the product lighter. The design of composite pressure tube for a nominal pressure of 60 bars is compared with that of steel tube for the same ID, in terms of weight, by calculations. The same is demonstrated by realizing a composite pressure tube hardware and testing the same to the specified pressure levels. The existing drum winder machine doesn't have the helical winding capability and hence a combination of UD fabric and hoop plies is chosen.

A combination of helical and hoop winding with roving would have demonstrated higher weight savings .however the comparison is sans metallic end attachments, hence the weight savings projected are, on the higher side.

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LITERATURE REVIEW

Mr. PINAR KARPUZ studied determining of mechanical characteristics of the filament wound composite tubes working under internal pressure loads and the effects of the production variables on the behavior of the tubes. Pressure tests revealed that the carbon fiber reinforced composite tubes exhibited a better burst performance compared to the glass fiber reinforced tubes, and the maximum burst performance is achieved at a winding angle configuration of [±54°][90°].

Peoples SUMANA B G, VIDHYA SAGAR H N, M KRISHNA, RAJ KUMAR GR published a paper in International conference on advances in manufacturing and material engineering (AMME 2014) on "Investigation of burst pressure carbon /glass fiber reinforced polymer metal tube for high pressure applications" this thesis reveals glass fiber/ Carbon fiber reinforced epoxy composite was wound on aluminum tubular structure at orientation ±55° using filament winding machine.

THEORY AND METHODOLOGY

A composite material can be defined as a macroscopic combination of two or more distinct materials, having a recognizable interface between them. However, because composites are usually used for their structural properties, the definition can be restricted to include only those materials that contain reinforcement (such as fibres or particles) supported by a binder (matrix) material.

There are different types of composites based on the fiber orientation and shape. Some composite material systems are short fiber composites, particulate composites, long fiber composites, unidirectional lamina and woven fabrics.

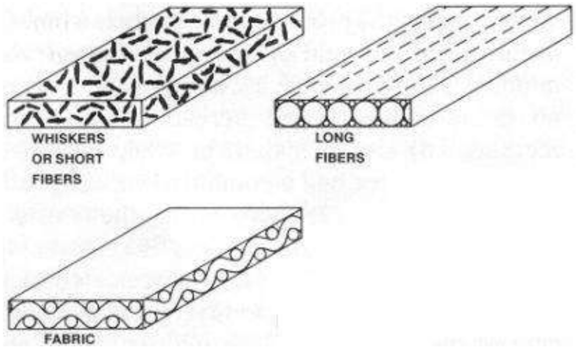
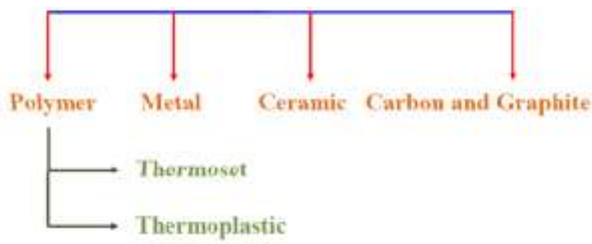


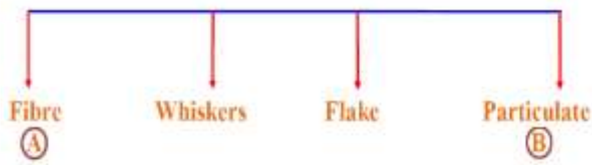
Fig 1. Composite material system

Classification of composites:

Composite materials are classified based on the matrix materials as well as the reinforcements as follows.
Based on the Matrix material



Based on the Reinforcement



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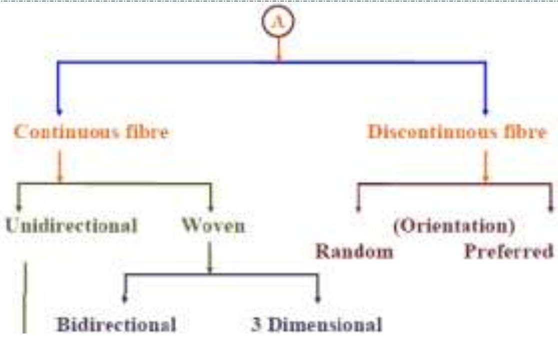

Advanced Fibres:
Glass fibres:
Ancient Egyptians made containers from coarse fibres drawn from heat softened glass produced by extruding molten glass at 200ºC passed through spinnerets of 1-2 mm diameter then drawing the filaments to produce fibres of diameter between 1-5 µm individual filament is small in diameter, isotropic in behavior and very flexible.


Fig 2 E – Glass Fabric

Types of Matrix materials:
Polymers:
- Thermoplastic**:** Soften upon heating and can be reshaped with heat & pressure
- Thermosetting**:** become cross linked during fabrication & do not soften upon reheating

Thermoplastics:
- polypropylene,
- polyvinyl chloride (PVC),
- nylon,
- polyurethane,
- poly-ether-ether ketone (PEEK),
- polyphenylene sulfide (PPS),
- polysulpone

Advantages:
- higher toughness
- high volume
- low- cost processing
- Temperature range ≥ 225ºC

Thermosets:
- polyesters,
- epoxies,
- polyimides
- Other resins

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Polyesters:

- Low cost
- Good mechanical strength
- Low viscosity and versatility
- Good electrical properties
- Good heat resistance
- Cold and hot molding
- Curing temperature is 120°C

Epoxy:

- Epoxy resins are widely used for most advanced composites.

Advantages:

- Low shrinkage during curing
- High strength and flexibility
- Adjustable curing range
- Better adhesion between fibre and matrix
- Better electrical properties
- Resistance to chemicals and solvents

Disadvantages:

- somewhat toxic in nature
- limited temperature application range upto 175°C
- moisture absorption affecting dimensional properties
- high thermal coefficient of expansion
- slow curing

Polyimides:

- Excellent mechanical strength
- Excellent strength retention for long term in 260-315°C (500-600°F) range and short term in 370°C (700°F) range
- Excellent electrical properties
- Good fire resistance and low smoke emission
- Hot molding under pressure and
- Curing temperature is 175°C (350°F) and 315°C

Problems with using polymer matrix materials:

- Limited temperature range
- Susceptibility to environmental degradation due to moisture, radiation, atomic oxygen (in space)
- Low transverse strength
- High residual stress due to large mismatch in coefficients of thermal expansion both fiber and matrix
- Polymer matrix cannot be used near or above the glass transition temperature

Metals:

- Aluminum
- Titanium
- Copper

Advantages:

  - Higher use temperature range Aluminum matrix composite – use temperature range above 300ºC and titanium at 800 ºC
  - Higher transfer strength, toughness(in contrast with brittle behavior of polymers and ceramics)
  - The absence of moisture & high thermal conductivity (copper)

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Disadvantages:
- Heavier
- More susceptible to interface degradation at the fiber/matrix interface and to corrosion

Ceramics:
- Carbon,
- Silicon carbide and
- Silicon nitride

Advantages:
- Ceramic have use very high temperature range > 2000 ºC
- High elastic modulus
- Low density

Disadvantages:
- Brittleness
- Susceptible to flows

STRESSES IN THIN WALLED CYLINDERS

Thin-walled tubes exposed to pressure generally develop two types of relevant stresses in the walls
1) Circumferential or hoop stresses (σ_1) work in the tangential direction perpendicular to the length of the tube.
2) Longitudinal or axial stresses (σ_2) work longitudinal or parallel to the axis of the tube.

The ratio between the radius and wall thickness of the tube needs to be higher than 10 for the tube to be considered as thin-walled ($\frac{t}{ID} < \frac{1}{20}$) The formulas defining hoop and axial stresses in a cylinder are in Equation (1) and (2).

$$\frac{PD}{2t} = \sigma_1 \quad \text{.........................(1)}$$

$$\frac{PD}{4t} = \sigma_2 \quad \text{.........................(2)}$$

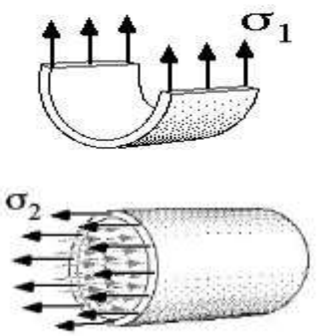

Fig 3 Hoop and axial stresses are acting on a thin walled cylinder

Failure criteria:
Typical failure modes for fiber-reinforced composites can be seen in Figure 4 and are:
- Fiber buckling
- Fiber breakage
- Matrix cracking
- Delamination

- **Fiber buckling** is characterized by a reduction of compressive stiffness and strength of the laminate. The onset and magnitude of the fiber buckling and the compressive property loss is dictated by the properties of the fibers and matrix.

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- **Fiber Breakage** occurs when fibers break, making them unable to carry tensile loads. When fibers are surrounded by a matrix, the matrix works as a bridge across the broken fiber transmitting the load. This is called fiber bridging.
- **Matrix cracking** in itself is not normally a reason for ultimate laminate failure. However, matrix cracks may cause other harmful effects. Among those effects are normally moisture absorption, stiffness reduction dominated by the matrix, and it may provoke delamination.

- **Delamination** is a failure mode where the layers of the material separate from each other. Transverse impact loads on the laminate is a normal cause of delamination.

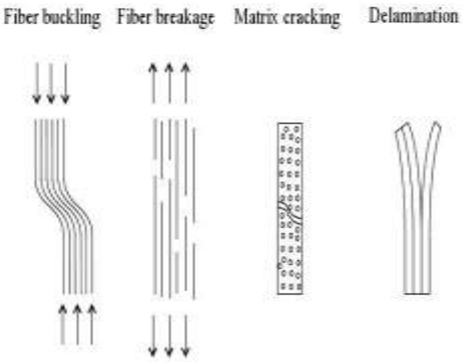

Fig 4 Typical failure modes in fiber reinforced composites

The maximum stress criteria:

The maximum stress criterion states that failure occurs when one stress component exceed the corresponding strength component

$f = Max\,(\frac{\sigma 1}{XT}, \frac{\sigma 1}{XC}, \frac{\sigma 2}{XT}, \frac{\sigma 2}{XC}, \frac{\tau 12}{S12})$

$< 1\ no\ failure$

$= 1\ failure\ limit$

$> 1\ failure$

In formula x, $\sigma 1$ is the stress in hoop direction while $\sigma 2$ is the stress in the axial direction. $\tau 12$ is the in-plane shear stress. This criterion is able to detect failure modes, and the modes that can be identified are:

- Fiber fracture
- Matrix cracking

Shear matrix cracking

Filament winding method:

The filament winding method was used for making the tubes in this thesis. Filament winding is the most cost efficient and effective method for fabrication of composite structures with complicated shapes. The method is based on winding fiber embedded in epoxy on a mandrel. Today, most of the winding machines are computer aided and consist of minimum three axes.

For making even more complex shapes, machines with six axes are commonly used. This advanced technology gives winders the ability to wind non-cylindrical and non-symmetrical shapes.

The fibers are pulled through a resin bath and then through an eye that controls the angle of the fiber on to the mandrel. The carriage travels along the rotating mandrel applying the fibers embedded in epoxy on to the mandrel with desired tension. Applying the right amount of tension when winding is important because the tension dictates the frictional force between the fibers and the mandrel, as well as the resin control.

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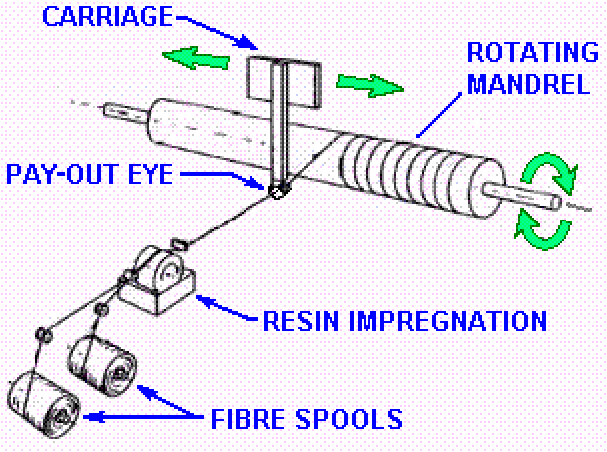

Fig 5 Filament winding concept

Out of available composite reinforcing fibers, the following are in Indian market

- E-glass fiber in physical forms such as
- Chopped stand,
- Chopped stand mat,
- Roving,
- Woven roving mat,
- Twisted yarn,
- Woven fabrics,
- multi layered and stitched fabrics.

Note : Roving and fabrics, in that order exhibit highest strengths. Multi layered and stitched fabric are expensive and are utilized by wind mill turbine blade manufacturers. Also the MOQ (minimum Order quantity) is prohibitively high.

- Carbon fiber in physical forms such as
- Chopped stands,
- Tows,
- Woven fabrics.

Note: Per kg cost of carbon fiber is Rs 3500/- when compared to that of glass at Rs 100/-

- Aramid fiber in physical forms such as
- Yarn,
- Woven Fabrics,

Note: hygroscopic nature in Dry and composite form makes processing of Aramid fiber based composites difficult. Per kg cost is higher than carbon and MOQs are prohibitively high.

In view of the above, glass fiber in roving and fabric form is chosen for our project and epoxy resin is the best laminating matrix for structural composites hence this is the obvious choice.

All filament winding operations take a long time and hence call for higher pot life for the resin hardener combinations, and the chosen LY556 + K6 has a pot life of 30min. This is manufactured by world renowned Huntsman Inc, USA.

PROCESSING TECHNIQUES

Continuous fiber reinforced composites exhibit higher strength when compared to chopped stands randomly dispersed in matrix by molding operations hence it is ruled out.

Fibers when dispersed in matrix, in the straight fashion and without crossing over another fiber which is substantially perpendicular, will exhibit max. Strength for the composite. The strength of the composite in such a ply is a function of

- tension in the fiber
- volume fraction of the composite
- cross over stations in helical windings
- cross over in woven fabrics.

Hence filament winding is considered to be the processing techniques which can yield maximum volume fractions, leading to high strengths.

The state of art in terms of capital equipment and machinery at Vignan institutions in Hyderabad is drum winder. Hence the processing technique chosen are

- Hoop winding under tension by filament winding, and UD fabric contact laid up

Material Properties

Technical specifications: fabric

1. Nomenclature : 13 MIL E-GLASS FABRIC
2. Thickness, mm : 0.36
3. Width, inch : 40"
4. Weave : 4 H S
5. Construction
   Warp, Threads/inch: 48
   Weft, Threads/inch: 36
6. Weight per Sq.mtr : 455.400
7. Breaking Strength per 50 mm :
   Warp :383.000 Kgs
   Weft : 258.000 Kgs

Technical specifications: fiber

E-glass rovings =1200 TEX

BD fabric + epoxy resin (LY556+HY972) has been characterized and the conclusions are listed below

- Tensile strength(90^0) =282 (N/mm^2
- Tensile strength(0^0) =224 (N/mm^2)
- Tensile strength(0^0 /90^0) = 217 (N/mm^2)
- In plane shear strength = 177 (N/mm^2)

Note : The strength of 250MPa is assumed for tensile strength as per literature.

Design specifications of the component

Component sizing

1) cylindrical length of mandrel = 700 mm
2) uneven volume fractions per side = 25 mm
3) volume fraction test chamber requirement = 25 mm
4) net useful length of the component =700 - 2(25+25) =600 m
5) .Inner diameter of the component =200 m
6) .pressure =60 bars
7) Proof pressure = 1.1 x MEOP =1.1 x 60 =66 bars
8) Burst pressure = 1.25 x MEOP =125 x 60 =75 bars
9) Factor of safety = 1.25
10) Design pressure = 1.25x75 =93.75 bars
11) Design allowable strength for glass epoxy composite(as per configuration below) is =250 MPa.
12) configuration = alternative plies of BD fabric and UD hoop plies.
13) Thickness (t) = (PD/2 x allowable strength) =$\frac{93.75 \times 20}{2 \times 250}$ =0.375cm =3.75 mm.
14) For the sake of shape stability thickness of 5mm is chosen.
15) Edge bearing strength of composite is = 125 MPa.

EXPERIMENTAL WORK

Processing:

Mandrel preparation: The mandrel is cleaned of the debris of the previous component. Edges of the mandrel if damaged on account of extraction of the previous component are de-burred and sanded. The mandrel is thoroughly cleaned with acetone and coated uniformly with wax polish and finished with a polishing cloth. The mandrel is loaded on the filament winder.

JIT pre-pregs:

2.1 Spread polythene sheet on the work table.
2.2 Cut and lay flat a 1000mm*2000mm E-glass fabric on the polythene sheet.
2.3 The fabric has a GSM of 450.

This means 2m*1m fabric weighs 900 grams. To achieve 50:50 weight fraction for fiber and matrix, we have to wet the said fabric area uniformly with 900gms of matrix material that is equal to the resin + hardener weight. LY556 and K6 are specified by the supplier in the weight ratio of 1:10. This implies 900gms of LY556 resin mixed with 100gms of K6 hardener. For the sake of convenience and since the specific gravity of K6 is very close to 1, as a first approximation, we can volumetrically measure out the hardener and is same as weighing it. Hence 100ml of hardener is measured out using a measuring jar and mixed with 900gms of resin, to arrive at 1000gms of resin mix.

2.4 Mark out 4 squares of 700mm*700mm on the spread out fabric, pour measured quantity of 220gms of resin mix at the geometric center of each square and spread the resin mix outwardly towards the periphery of each square, working with a brush. This ensures uniform spreading of the resin mix and results in a JIT pre-preg which means just in time previously impregnated.

Templates:

The dimensions of each ply lead to manufacture of template either out of 1.6mm steel sheet or , still better, 3mm thick thermo plastic sheets. JIT pre-pregs are cut to yield JIT pre-preg developments with the baking plastic film, for the pressure tube component.

Ply sequence and contact lay up

It is proposed to resort to the following ply sequence

- Position a thin plastic flat having a width of 25mm on the mandrel surface, in the direction of meridian, at the circumferential location where the two opposite edges of development are likely to overlap.
- JIT BD fabric pre-pregs cut to full development shall be laid on the mandrel face down, ensuring that the opposite edges of development overlap just above the plastic flat mentioned above. The fabric development is pressed against its substrate by working through the polythene sheet using dry brushes/rollers/hands, making it stick to its substrate.
- Place a steel straight edge in the direction of meridian, just above the stack of plastic flat and two edges of the development, and cut through the both edges of the development with a sharp knife.
- Remove the straight edge, remove waste portions of the development edges and pull out the embedded plastic flat.
- Paste back the disturbed edges of the development resulting in a clean butt joint of the edges in the BD fabric ply. Now remove the covering plastic film gently without disturbing the stuck BD fabric development.
- Put the second ply on the mandrel by E-glass roving epoxy hoop winding which
- Further de bulks its BD fabric development substrate , and
- Contributes totally to hoop strength of the component.
- The above pairs of plies, namely BD fabric development followed by hoop winding is repeated till the designed thickness is achieved.

Iron constantan thermo couples made by spark- Bead method, and calibrated by water bath, are inserted at mid thickness of the component, on either end and in the trim-able portion of the composite. The extra length of the thermo couple wire is secured firmly to the mandrel shafts.

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Fig 6 Preparation of Mandrel

Fig 7 making an exact butt joint

Curing

- The instrumented composite lay-up is transferred, together with the mandrel, on to the metallic stand and said assembly is loaded into a hot air circulating – electrically operated.
- The heaters are set to result a temperature of 60^0 C in the air inside the oven.
- The temperatures are indicated by the embedded thermo couples is manually noted in 15 min intervals. The air temp. is also noted in the same intervals.
- If the comp. temp. Reaches 60^0 C , we can presume that the gel point for the matrix has reached, as per the manufacturer's literature.
- The air temp. is now set at 120^0 C, and the above process is repeated till the part temp. Reaches around 120^0 C .
- Air temp. is further raised to 180^0 C and curing is allowed to continue, till the part temp. reaches a value of 170^0 C.
- At this condition, the oven is allowed to continue for 3 hours, maintaining the matrix at alleviated temp. as specified by the manufacturer for complete curing.

After this heaters are shut down and the part is allowed cooled down naturally overnight

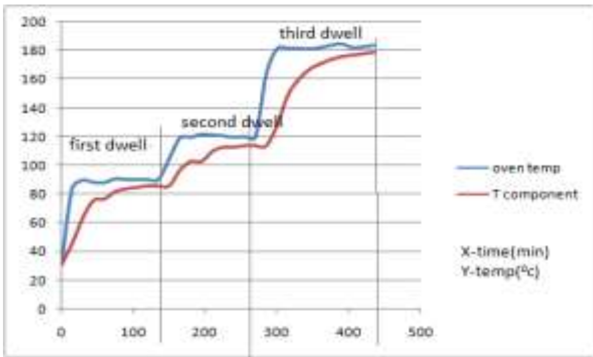

Fig 8 Cure Cycle

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Fig 9 Extraction after trimming of required length

Fig 10 Grid formation for NDT(ultrasonic test)

NON DESTRUCTIVE TESTING

Visual inspection

- Burrs if any are removed by filing
- Protective smear if not uniform, is rectified with one more coat
- Weigh the component and compare with specifications
- Carry out coin tapping test and outline with the chalk piece, the zones which give a duller sound.

Metrological

- Carry out geometrical, dimensional inspection, tabulate the deviations and compare with the specifications.

Non destructive examination

- Carry out ultra sonic through inspection at all the grid points and note down the attenuation and compare with previous data
- Based on the attenuation data of ultra sonic, mark out areas with higher attenuation for further study.

Carry out normal and tangential X-Ray radiography in the these higher attenuation zones and record the observations

Fig 11 Ultra sonic test

Destructive testing(Determination of Volume faction of reinforcement by Resin burn-off test(ASTM D-2584)

The weight fractions are obtained experimentally using "Resin Burnoff Test" utilizing muffle furnace and precision weighing balances. Based on this, Compute volume fractions of the reinforcement and thereby predict the load to failure.

This method is designed to determine the resin content percent of prepreg which is reinforced with inorganic fabric, by removal of the resin from the reinforcement using a burn-off test.

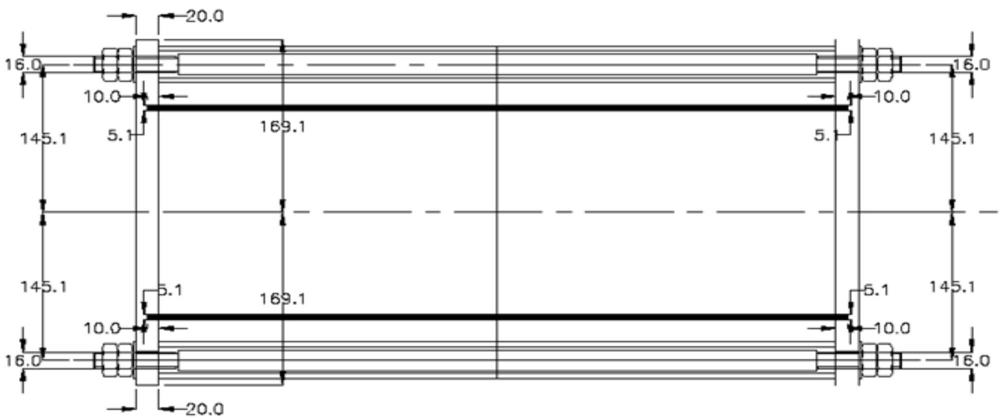
Fig 12 5 mm x 5mm specimens for Weight Fraction

The tested data is tabulated as follows

S.NO	Wt. comp	Wt. fiber	Wt. matrix	ρ comp	ρ fiber	ρ matrix	$Wf=\frac{Wf}{Wc}$	$Wm=\frac{Wm}{Wc}$	$Vf=Wf \times (\frac{\rho c}{\rho f})$	$Vm=Wf \times (\frac{\rho c}{\rho m})$
1	0.58	0.38	0.2	1.8	2.4	1.12	0.6551	0.3448	0.4913	0.5086
2	0.69	0.46	0.23	1.8	2.4	1.12	0.6666	0.3333	0.5	0.5
3	0.53	0.34	0.19	1.8	2.4	1.12	0.6415	0.35849	0.4811	0.5188
4	0.58	0.38	0.2	1.8	2.4	1.12	0.6551	0.3448	0.4913	0.5086
								Average	0.49097	0.5090

Weight Fractions And Volume Fractions

Internal pressure test
ASTM D 1599 standard was used to carry out the internal pressure test.



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Specifications of the test tube

1) Length of the tube = 600 mm
2) Internal diameter = 200 mm
3) External diameter = 210 mm
4) Wall thickness = 5 mm
5) Effective length = 600- 2(10) =580 mm

Testing procedure

The pressure tube is proposed to be burst tested with water. Since composite in general and filament wound composite in particular are not impervious to water, the water would come through the thickness of the composite wall, initially in small quantities which is referred to as sweating.

Fig 13 Test fixture with test tube

Result of internal pressure test

1) The outer diameter when internal pressure of the test tube is 60 bars is measured with the help of outside calipers as = 211mm.

Hence the circumferential dilation is = 211 -210 =1 mm.

Split disk testing

ASTM D2290 standard for split disc testing was used as a basis for the split disc test. The specifications of test fixture is as follows

2) Diameter of the disk = 200mm
3) Width of the disk = 30mm
4) Gap between two disks = 10mm

Fig 14 Split Disk Fixture

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The dimensions of hoop rings are as follows

1. Inner diameter of the hoop ring = 200 mm
2. Outer diameter of hoop ring = 210 mm
3. Thickness of the hoop ring = 5 mm
4. Width of the hoop ring = 30 mm

Result of hoop tensile strength load and elongations

S. NO	Thickness(mm)	Width (mm)	Inner diameter (mm)	Outer diameter (mm)	Hoop tensile strength (KN)	Elongation (mm)
1	5	30	200	210	128.34	18.5
2	5	30	200	210	136	19
3	5	30	200	210	137	19.5
4	5	30	200	210	140	21

Table 2 Result of hoop tensile strength

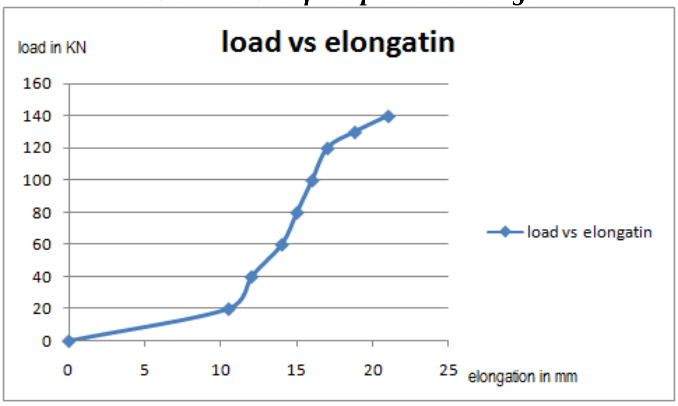

Fig 5.16 Load vs elongation for sample 4

stress vs strain

S.NO	Load in N	Cross sectional area(mm^2) =2 x 5 x30	Stress N/mm^2	Elongation mm	Original diameter mm	Strain
1	0	300	0	210.0	210	1
2	20e3	300	66.667	220.5	210	1.05
3	40e3	300	133.333	222.0	210	1.057143
4	60e3	300	200.000	224.0	210	1.066667
5	80e3	300	266.667	225.0	210	1.071429
6	100e3	300	333.333	226.0	210	1.07619
7	120e3	300	400.000	227.0	210	1.080952
8	130e3	300	433.333	228.8	210	1.089524
9	140e3	300	466.667	231.0	210	1.1

Table 3 Stress and strain result

Fig 5.17 stress vs strain diagram for sample 4

RESULTS AND DISCUSSIONS

NDT

1. By visual inspection came to know that there are no surface flaws on the surface of the component.
2. Due to coin tapping test found that there are no internal voids present in the tube.
3. Ultra Sonic test is carried and then found to be in internal voids are presented in the tube.

Weight fractions

1. The weight of the reinforcement is 66% which is almost 50% of volume in the total component
2. The weight of the matrix is 34% which is about 50% of volume in the component.

Hoop results

1. The average hoop tensile strength of hoop rings is 135 KN.
2. The highest hoop tensile strength is155 KN. The strength of 250 MPa is taken for calculation thickness , hence the ring is supposed to be failed at 250 MPa
3. By using ANSYS 15 software it is proved that the strength of the hoop ring exceeded to 250MPa hence it is failed.
4. The failure is purely due to tensile load. as shown fig 15.
5. Due to improper impregnation of fibers two of hoop rings are delaminated during the failure as shown in fig 16.
6. Since the angle of winding of hoop layers is 90^0 the ring is sustained for higher tensile loads
7. The component is cured for high temperature the bonding strength between fibers and fabric layers causes a big sound while breaking.

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Fig 15 Failure due to pure tensile load

Fig 16 Delamination of fiber layers from fabric

Internal pressure Test

1. The tube is sustained for its designed MEOP i.e 60 bars with 1mm of circumferential dilation.
2. From analysis it is found that dilation is 0.549mm and is approximately equals to 1mm.

CONCLUSION AND FUTURE SCOPE

- A composite pressure tube is fabricated with alternative plies of hoop wraps followed by BD fabric and is tested for its designed MEOP
- By using NOL test rig the hoop tensile strength of pressure tube is obtained.
- The obtained hoop tensile strength is compared with analytical result.
- With the availability of a 3 axis filament winding machine, and with the acquisition of soluble mandrel technology, I wish to upgrade this activity to the design, manufacture and testing of composite rocket motor casing with carbon
- T-300 fiber and epoxy resin and test the same in vertical condition carrying out the strain data acquisition on nozzle end dome along the meridian direction.

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