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Stress Analysis of FRP Cylindrical Composite Assembly under Mechanical and Thermal Loading

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Abstract—*Selection of Fiber Reinforced Polymer matrix (FRP) composites play a significant role when working under hygrothermal environment. The evaluation of stress distribution in different material phases of the composite are highly essential when subjected to static and dynamic loads. Cylindrical FRP composites have wide variety of applications in space structures, automotives, sports equipment and recreation systems. The current project evaluates the fiber-matrix interface behavior by introducing coatings of different modulus. The significance of coating as an individual phase for unidirectional fiber reinforced PMCs are studied to obtain several useful predictions.*

The present work carried to compute the stress distribution in four phase composite cylinder assemblage for a unidirectional fiber reinforced Polymer Matrix Composites (PMC) by developing a simulation model This model analyses the individual and combined effect of the temperature and mechanical loading. The analysis is carried out for the 90°C temperature condition which in general prevailed in space crafts. A simulation has been carried for the exposure of material in thermal environment and mechanical loading using ANSYS software. The stress distribution pattern has been analyzed and verified with strength properties.

Keywords: *Hygrothermal, fiber-matrix interface, five phase composite, Polymer Matrix Composite (PMC), Degradation*

1. INTRODUCTION

There are endless usage of sophistically fabricated fiber reinforce polymer matrix composites due to their specific strength, easy to fabricate, wide variety of macroscopic combinations of matrix and fiber materials. Fiber reinforced polymer matrix composites are best suitable materials for engineering applications seek materials of low cost and light weight and availability. Fiber reinforced composites consists stiff fibers combined with enough flexibility provided matrix combination made it a very significant material. Even though physical and chemical characteristics of the individual entities are differ their combination has very significant in properties are concerned. It has been proved that unidirectional fiber reinforced polymeric composites are effective and efficient than other types.

Carbon fibers are good at elasticity and strength for an adopted geometry which made it accessible in designing and manufacturing concerns of various applications. High Young’s modulus and able to sustain repetitive loads for large number of cycles are base for selection of carbon fibers. Life span of carbon or graphite fibers is more than that of aramid and glass fiber under repetitive loads. Safety and high temperature low thermal expansion are the properties of carbon fibers make its selection in propulsive applications.

S- Glass fiber is highly flexible, good mechanical properties and its availability made it familiar today in variety of engineering applications along with suitable matrix materials for load transformation. Also it offers attractive focal points as it can be produced required geometry and quality. Providing higher elasticity at lower weight and elongation along the fiber length is less than 3% indicates it dimensional stability. Also it acts has thermal insulator due to its higher surface area to weight ration. Chemically inert, possible to offer protection from sunlight, fungi and other micro organisms make it applications exposed to these environments. As it finds applications in armor jackets and other items, it becomes a product in demand. Major application of S Glass fiber is Exterior ornamentation, interior details, landscape furnishings, architectural projects, airfields runways and rocket launch pads.

P.C Upadhyay. et.al (1996) [1] computed “Stress field in created continuous fiber reinforced Polymeric composites due to hygrothermal loading”, and generated a four phased composite model cunctatory of the inter phases coated with high, low modulus coating and matrix and the effect of stresses developed in internal phase due to hygrothermal loadings are estimated. Also, the coating thickness, fiber volume fraction are addressed. It is observed that four phased model is more accurate and effective for assessing the hygrothermally induced stresses in the matrix and coating phases.

Jason Cain. et.al (2005) [2] has investigated on “Effects of Hygrothermal aging on cylindrical E-glass/Epoxy composites”, and has developed a cylindrical wound glass/polymer composite and used it as a mold for the casting of a concrete column. These columns are subjected to axial loadings and evaluated the stress pattern in the radial direction and also the stiffness of the column is considered along the circumference direction. It is observed that E-glass/Epoxy composites that underwent testing experienced little decrease in the tensile and compressive strength over the period of 100 days of subject to Hygrothermal aging.

Jason Cain. et.al (2009) [3] examined on “Testing of Hygrothermal aged E-glass/Epoxy cylindrical laminates using a novel fixture for simulating internal pressure”, and created a novel test fixture which is (fabricated) of polytetrafluoroethylene (PTFE) and a cylindrical E-glass/Epoxy composite of alternating hoop layers which is wounded helically and is subjected to radial loading which is aged under varying Hygrothermal environment. Through the tests it is observed that the rise in temperature also leads to faster strength degradation.

D Gopichand and T N Charyulu.et.al (2012) [4] developed a thick FRP `and another angle-ply. On “Analysis of FRP composite Cylinder”, the FRP composite is evaluated for the stresses and deflections developed due to transverse pressure load applied and following cases have been studied.

(i) Four layered cross-ply laminate with various diameter to thickness ratios (S) and varied stacking sequence.

(ii) Four layered angle-ply laminate with various diameter to thickness ratios(S) and varied fiber orientation.

(iii) Eight layered angle-ply laminate. From the analysis it is observed that in cross-ply laminates radial deflection increases proportionately with increase in the D/t ratio.

C Sasi Rekha.et.al (2013) [5] have demonstrated on “Stress Analysis of FRP composite cylinder with closed ends”, and evaluated the stress of a composite cylinder with closed ends (Semi circle) at top, middle and bottom end portion constructing of polymer matrix. It is observed that the stress is increased W.R.P to diameter to thickness ratio due to reduction in the layers.

S. Bhavya.et.al (2012) [6] carried “Failure analysis of a composite cylinder”, and studied the effects of diameter to thickness ratio, with respect to failure pressure and it is observed that introduction of hoop layers in composite cylinders the strength of the cylinder can be increased/improved.

R.R Das.et.al (2014) [7] examined on “Free vibration analyses of cracked laminate cylindrical shells made with FRP composites “and conducted a free vibration analysis on a laminate cylindrical shell made of FRP composites, (considering identically sized interlaminar cracks at edge and internal location) and studied the effect of free vibration of the laminated shell structure. It is noted that internally cracked stresses have more stiffened when compared to edge cracked shell structure.

T. Sushmita.et.al (2012) [8] worked on “Bucking analysis of thin cylindrical FRP composites”, and developed a four layered symmetric cylindrical composite laminate and conducted a buckling analysis [2 dimensional] and observed that buckling load decreases when L/D ratio and increased in one of its test costs.

S. Senthil Gavaskar and S Madhu.et.al (2020) [9] researched on “Torsional and compression properties of cylindrical glass fiber reinforced Polymer composite”, and confirmed from the comparative analysis on a cylindrical composite specimen under tensional and compressive Strength that glass fiber composites having lesser aspect ratios could be suggested for axial compression. Also made an analysis with different orientation types.

2. MODELING AND ANALYSIS

2.1 Properties of the Constituent Phases

In this study two types of composites have been selected. The selection is based on the application of these materials in space structures and missiles[1]. These two materials are: S-Glass Epoxy composite and Carbon/Graphite Epoxy composite. Which are considered under mechanical and thermal loading conditions. importance of the composite materials for various applications. Four phase cylindrical composite assembly[2] is considered for the analysis. These four phases are Fiber, low modulus epoxy, high modulus epoxy (which are acting as proper bonding agents) and Epoxy is the matrix material. The properties of these constituents are given in the table 2.1. The model developed based on these calculation has been shown in figure 3.1.

Table 2.1: Properties of constituent materials [2]

Properties	AS Graphite Fiber	S Glass Fiber	Epoxy matrix	Coating LM	Coating HM
Longitudinal modulus, (GPa)	220	86.2	3.45	2.2	5.2
Transverse modulus, (GPa)	13.8	86.2	3.45	2.2	5.2
Longitudinal shear modulus, (GPa)	13.8	35.7	1.27	0.8	1.93
Transverse shear modulus, (GPa)	5.5	35.7	1.27	0.8	1.93
Major poisson ratio,	0.2	0.22	0.35	0.43	0.35
Longitudinal tensile strength, (MPa)	3100	4825	103.5	55.2	138
Transverse tensile strength, (MPa)	345	4825	103.5	55.2	138

Longitudinal shear strength, (MPa)	1550	2410	89.7	55.2	103.5
Transverse shear strength, (MPa)	172	2410	64.8	55.2	103.5
Density, (gm/cc)	2.26	2.485	1.14	0.2 5	0.35
Thermal conductivity, k (W/Mk)	900	1.275	0.25	1.299	2.25

2.2 Geometry and Composite Properties:

The geometry of cylindrical composite assembly and properties of composite phase are evaluated based on rule of mixture and utilized for stress evaluation. Table 2.2 shows properties of composite phase for different types of composites. The model constructed based on developed geometry using CATIA is given in figure 3.1

Table 2.2: Properties of Composite materials[4]

Parameters	AS Graphite (LM coating)	AS Graphite (HM coating)	S Glass (LM coating)	S Glass (HM coating)
Longitudinal modulus, (GPa)	152.83	152.887	60.535	60.568
Transverse modulus, (GPa)	7.067	7.20	4.6017	2.0196
Longitudinal shear modulus, (GPa)	3.347	3.4316	3.89	3.905
Major poisson ratio,	0.2713	0.2473	0.2611	0.2603
Density, (gm/cc)	1.9016	1.9017	2.0591	2.0601
Thermal conductivity, k (W/Mk)	0.0079	0.01207	0.007	0.0106
tensile strength, (MPa)	2170.602	2171.43	3360	3361.6

For S-Glass epoxy and graphite fiber reinforced polymer matrix composites the geometry details are as given in Table 2.3 and 2.4. Note that coating has maximum amount of weight percentage of 10 for both low modulus and high modulus coatings.

Table 2.3: Geometry of S- Glass Composite

Material				
Assignment	Matrix	S-Glass 2	LOW Modulus 2	High Modulus 2
Nonlinear Effects	Yes			
Thermal Strain Effects	Yes			
Bounding Box				
Length X	120. mm	60. mm	70. mm	80. mm
Length Y	120. mm	60. mm	70. mm	80. mm
Length Z	100. mm			
Properties				
Volume	6.269e+005 mm³	2.1126e+005 mm³	1.0176e+005 mm³	1.1771e+005 mm³
Mass	1.4105 kg	0.52814 kg	0.22895 kg	0.26485 kg
Centroid X	23.325 mm			
Centroid Y	3.0428e-015 mm	-1.1968e-015 mm	-4.5568e-015 mm	4.8845e-015 mm
Centroid Z	50. mm			
Moment of Inertia Ip1	3000.3 kg·mm²	587.64 kg·mm²	311.78 kg·mm²	406.81 kg·mm²
Moment of Inertia Ip2	3000.3 kg·mm²	587.64 kg·mm²	311.78 kg·mm²	406.81 kg·mm²
Moment of Inertia Ip3	3649.7 kg·mm²	295.05 kg·mm²	241.97 kg·mm²	372.21 kg·mm²
Statistics				
Nodes	59077	19716	13094	17470
Elements	12900	4150	2225	3175

Table 2.4: Geometry of Graphite composite

Material				
Assignment	Matrix	Graphite 2	LOW Modulus 2	High Modulus 2
Nonlinear Effects	Yes			
Thermal Strain Effects	Yes			
Bounding Box				
Length X	120. mm	60. mm	70. mm	80. mm
Length Y	120. mm	60. mm	70. mm	80. mm
Length Z	100. mm			
Properties				
Volume	6.269e+005 mm³	2.1126e+005 mm³	1.0176e+005 mm³	1.1771e+005 mm³
Mass	1.4105 kg	0.47533 kg	0.22895 kg	0.26485 kg
Centroid X	23.325 mm			
Centroid Y	3.0428e-015 mm	-1.1968e-015 mm	-4.5568e-015 mm	4.8845e-015 mm
Centroid Z	50. mm			
Moment of Inertia Ip1	3000.3 kg·mm²	528.88 kg·mm²	311.78 kg·mm²	406.81 kg·mm²
Moment of Inertia Ip2	3000.3 kg·mm²	528.88 kg·mm²	311.78 kg·mm²	406.81 kg·mm²
Moment of Inertia Ip3	3649.7 kg·mm²	265.55 kg·mm²	241.97 kg·mm²	372.21 kg·mm²

3. LOADING AND BOUNDARY CONDITIONS:

Based on the calculated geometry, the composite has been modelled using Ansys as shown in fig. 3.1

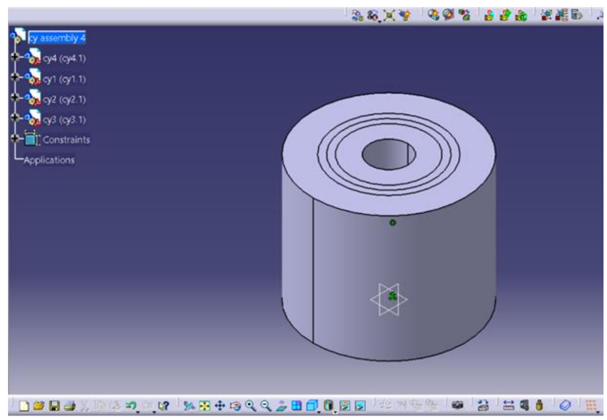

Fig. 3.1: Four-phase model on the ANSYS.

Loading conditions are represented in Table 3.2 and also shown as Ansys part of the diagrams.

Table 3.1: details of mechanical loading

Object Name	Thermal Condition	Fixed Support	Force
State	Fully Defined		
Scope			
Scoping Method	Geometry Selection		
Geometry	4 Bodies	4 Faces	
Definition			
Type	Thermal Condition	Fixed Support	Force
Magnitude	90. °C (ramped)		
Suppressed	No		
Define By			Components
Applied By			Surface Effect
Coordinate System			Coordinate System
X Component			0. N (ramped)
Y Component			0. N (ramped)
Z Component			-10000 N (ramped)

Table 3.2: Details of thermal loading(convection load)

type	Times(s)	Temperature [^oC]
Environment temperature	1	22
Surrounding temperature	1	90

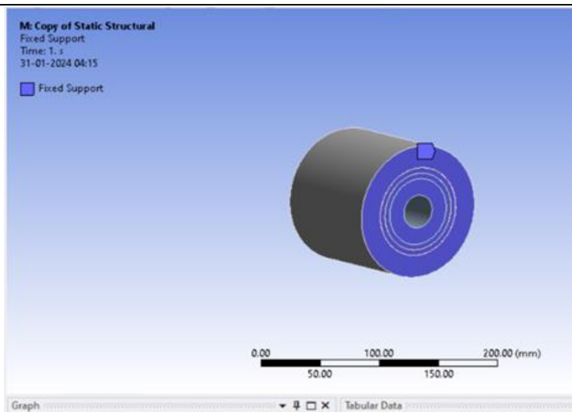

Fig. 3.2: ANSYS model under fixed support

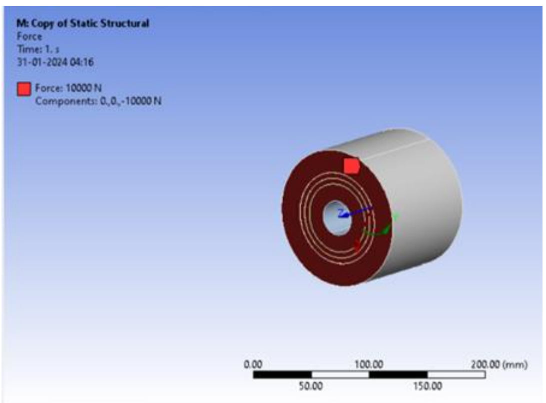

Fig. 3.3: ANSYS model under loading with 10KN

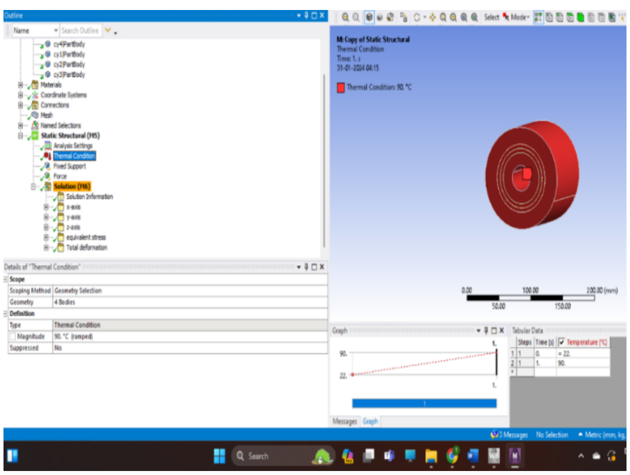

Fig. 3.4: ANSYS model with 90^0C Temperature Limits.

Combination of thermal and mechanical load:
For this set the loading condition are combination of all the above.

- Mechanical load: 10KN
  Thermal load:
  Body temperature:22℃
  Surrounding temperature: 90℃

The above loading conditions are applied for both AS Carbon fiber and S Glass fiber with LM and HM coating.

4. RESULTS & DISCUSSION

4.1 Radial stress vs ditsance graph

From the figure 4.1, the radial stress variation in different phases, it has been observed that maximum stress induced in fiber phase and in the coating, it is very low in magnitude. This reveals that maximum load is being carried by fiber phase, the coating is able to transfer maximum amount of load to the fiber phase. Note that the nature of stress in the fiber phase is transferred from tension in the centre of the fiber to compression when radius of fiber increases.

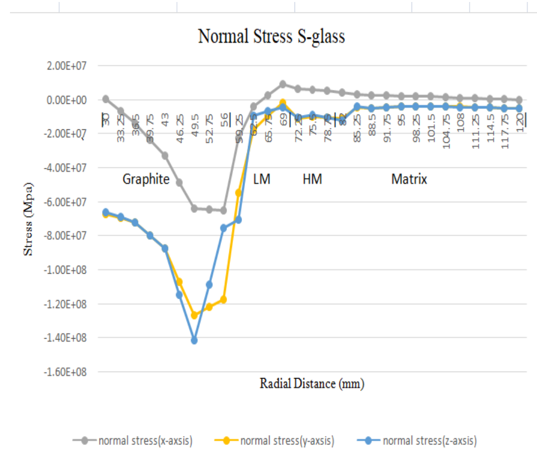

Figure 4.1: Variation of Radial Stress in the S glass FRP

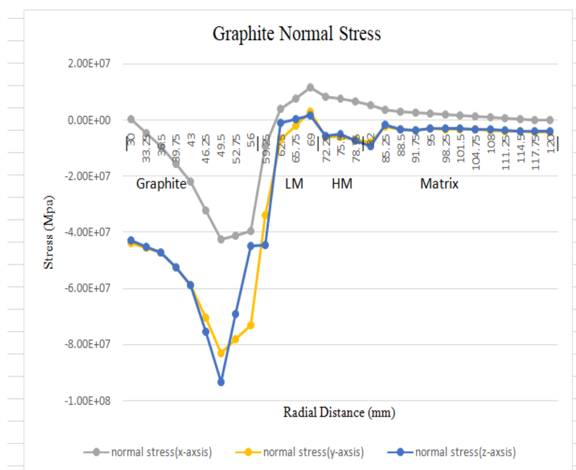

Figure 4.2: Variation of Radial Stress in the Graphite FRP

From the figure 4.2, the radial stress variation in different phases, it has been observed that maximum stress induced in fiber phase and in the coating, it is very low in magnitude. This reveals that maximum load is being carried by fiber phase, the coating is able to transfer maximum amount of load to the fiber phase. Note that the nature of stress in the fiber phase is transferred from tension in the centre of the fiber to compression when radius of fiber increases.

4.2 Total Deformation in Graphite& S Glass

From the figure 4.3, the deformation in different phases, it has been observed that minimum deformation is at fiber phase and it gradually increases from the coating phase and is maximum at the matrix phase. It is also observed that there is a large variation when transitioning from fiber phase to coating.

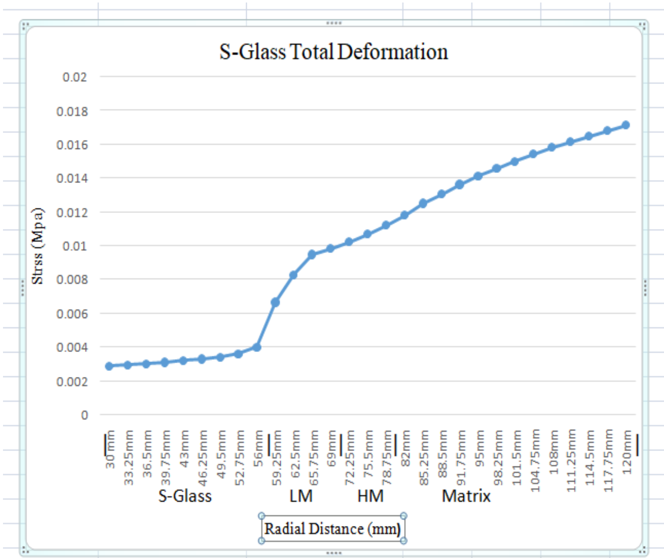

Figure 4.3: Variation of Deformation in S-glass composite

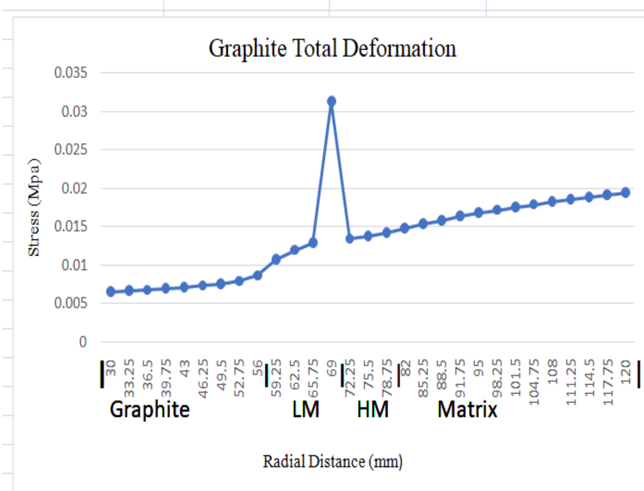

Figure 4.4: Variation of Deformation in Graphite composite

From the figure 4.4, the deformation in different phases, it has been observed that the maximum deformation is taking place in the transition between the coating phases and a sudden high deformation can be seen at that point in the coating phase. The deformation is linear at the fiber phase and has a minimal variation at the matrix phase.

4.3 Comparison of Normal Stress and Equivalent Stress In S- Glass and Graphite

From the figure 4.5, the Normal stress in different phases of both s-glass fiber composite and graphite composite, it has been observed that the maximum Stress induced is at the fiber phase of the graphite and the stress induced in coating phase of graphite is higher than s-glass and it is also observed that graphite induces Higer tensile stress at the coating phase when compared to s-glass. The stresses at the matrix phase of both the cylindrical composites is linear in nature. From this graph it can be drawn that stresses induced in graphite are higher than the s-glass.

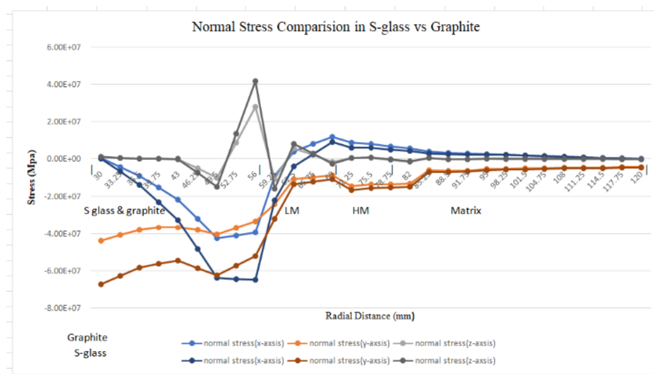

Figure 4.5: S-Glass vs Graphite Normal Stress Variation

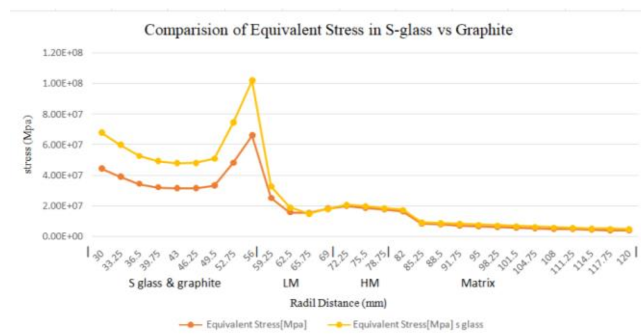

Figure 4.6: S-glass vs Graphite Equivalent Stress Variation

From the figure 4.6, the Normal stress in different phases of both s-glass fiber composite and graphite composite, it has been observed that the maximum Stress induced is at the fiber phase of the graphite and it is observed that there is a sudden increase in stress at the end of the fiber phase in both the composites but it drastically reduced in the lower modulus coating phase of the composites and tends to increase again in higher modulus coating phase. It is also observed that the stress is linear in the matrix phase of both the composites.

5. CONCLUSION

Analysis of cylindrical Fiber Reinforced Polymer matrix (FRP) composites has been made in the present work. It is concluded that

1. When graphite fiber is compared to S- glass fiber the stress induced along radial distance is found to be significantly higher in the fiber phase of Graphite fiber composite. At low radius the stress in the fiber is in tension and when radius is increasing the stress transferred from tension to compression gradually
2. The stress induced in the matrix phases of both S glass and graphite when subjected to similar loading is tensile in nature. The magnitude of stresses is slightly high in all directions in case of composite made of glass fibers than the Graphite fibers.
3. For the coating of both Low modulus and high modulus it is observed that the stress induced in theses phases are higher for s glass when compared to that of the graphite. The variation of stress in the composite part is almost linear.
4. It is also observed that the coating phase in which deformation initiate first as the coating phase is very thin and low modulus as it is the agent between transfer of load from matrix to composite.
5. It is observed that the magnitude of deformation is very high in the coating phase of the graphite fiber composite whereas the s-glass composite experiences maximum deformation at the matrix phase

6. ACKNOWLEDGEMENTS

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