iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 Issue: VI Month of publication: June 2021

DOI: https://doi.org/10.22214/ijraset.2021.34969

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI Jun 2021- Available at www.ijraset.com

# Analytical and Numerical Study of Glass Fiber-Reinforced Polymer (GFRP) strengthened Steel Tube under Axial Compression

Tushar P. Patil[1], Vishal V. Dhende[2]
[1]*M. tech Student,* [2]*Assistant Professor, Department of Mechanical Design Engineering, Walchand College of Engineering, Sangli 416415, Maharashtra, India*

***Abstract: This article presents the results of an analytical and numerical study of the behaviour of circular hollow section (CHS) steel tubes strengthened by Glass fiber-reinforced polymer (GFRP). Glass, aramid, carbon etc. fiber composites are considered for strengthening applications. In this work, glass fiber is used and it is the most popular reinforcing fiber and it is more economical to produce and widely available fiber. Performance of steel tubes is enhanced by providing strength them with glass fiber reinforced polymer (GFRP) for investigating the effect of GFRP thickness, Specimen length, winding angle. FEA Analysis is performed on the steel specimen and model is simulated in ANSYS 16 software.***
***Keywords: GFRP (Glass fiber reinforced polymer), CHS (circular hollow section), GFRP thickness, winding angle, FEA Analysis, ANSYS 16.***

## I. INTRODUCTION

Steel pipes are widely used in the various steel structures such as stadiums, airports, bridges etc. due to their ability of easy construction and high load carrying capacity. However steel tubes also have some disadvantages of heavy self-weight and poor corrosion resistance, therefore it is necessary to find the other way to improve their performance. Fiber reinforced polymer (FRP) have a high specific strength and good corrosion resistance.

Therefore a combination of Fiber Reinforced Polymer with other structure components (such as concrete, aluminium alloy pipe and concrete-filled steel pipe) have obtained widely development and application in the engineering field. The application of fiber reinforced polymer (FRP) for repairing, rehabilitation and retrofitting metallic structures is increasingly attractive due to their in-service and high mechanical properties, including high strength and stiffness-to-weight ratio. External strengthening using FRP material significantly improves structural properties such as buckling behaviour, stiffness, and load-carrying capacity. Glass, aramid, carbon fiber composites may be considered for strengthening applications [1].

In common use, the glass is the economical to produce, most popular reinforcing fiber and widely available. Composite materials has high ultimate strength and lower density than steel, when taken together these two properties lead to fiber composites having a strength/ weight ratio higher than steel.

FRP composite is a two phase material, hence it has an anisotropic properties. It is composed of fiber and matrix, which are bonded at interface [2].

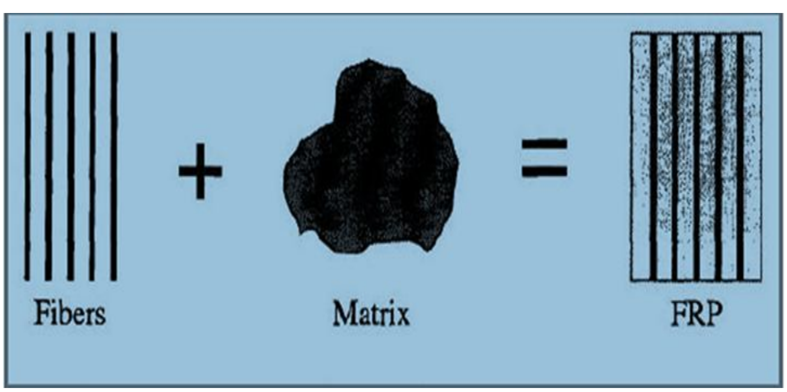



Fig.1. Formation of Fiber Reinforced Polymer Composite

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI Jun 2021- Available at www.ijraset.com

## II. METHODOLOGY

### A. *The Geometrical Parameters for the Specimens*

The most important parameters for determining the ultimate carrying capacity of FST (Fiber steel tube) component are the steel tube thickness and outer diameter (t and D respectively), GFRP thickness and winding angle ($t_c$ and θ respectively) and specimen length (L). For the convenience of analysing, the specimens were named as FST-L-θ-$t_c$-D-Dc-t [2].

Table. I. Geometrical Parameters

| Specimen label | Length (mm) L | Fiber orientation $[\theta - \theta]$ | FRP thickness (mm) $t_c$ | Diameter of steel tube (mm) D | Diameter of FRP tube (mm) $D_c$ | Thickness( mm) t | Slenderness ratio (Le/K) |
|---|---|---|---|---|---|---|---|
| FST-200-45-1-58-60-2 | 200 | [45-45] | 1 | 58 | 60 | 2 | 20.18 |
| FST-200-45-2-58-62-2 | 200 | [45-45] | 2 | 58 | 62 | 2 | 20.18 |
| FST-200-90-1-58-60-2 | 200 | [90-90] | 1 | 58 | 60 | 2 | 20.18 |
| FST-200-90-2-58-62-2 | 200 | [90-90] | 2 | 58 | 62 | 2 | 20.18 |
| FST-600-45-1-58-60-2 | 600 | [45-45] | 1 | 58 | 60 | 2 | 60.75 |
| FST-600-45-2-58-62-2 | 600 | [45-45] | 2 | 58 | 62 | 2 | 60.75 |
| FST-600-90-1-58-60-2 | 600 | [90-90] | 1 | 58 | 60 | 2 | 60.75 |
| FST-600-90-2-58-62-2 | 600 | [90-90] | 2 | 58 | 62 | 2 | 60.75 |
| S-200-58-2 | 200 | - | - | 58 | - | 2 | 20.18 |
| S-600-58-2 | 600 | - | - | 58 | - | 2 | 60.75 |

In the given table,
Slenderness ratio = Le/K
Where, Le = Effective Length,
K = radius of gyration = $\sqrt{\frac{I_{min}}{A}}$
Here, minimum moment of inertia, $I_{min} = \frac{\pi}{64} \times (D^4 - d^4)$
Area of hollow steel tube, A= $\frac{\pi}{4} \times (D^2 - d^2)$

### B. *Predictive formula for buckling load of FST component*

The most important parameters for determining the ultimate carrying capacity ($P_u$) of Fiber Steel Tube component are the steel tube thickness and outer diameter (t and D resp.), GFRP thickness and winding angle ($t_c$ and θ resp.) and specimen length (L). For the convenience of analysing, the specimens were named as FST-D-t-L-θ-$t_c$.[2]

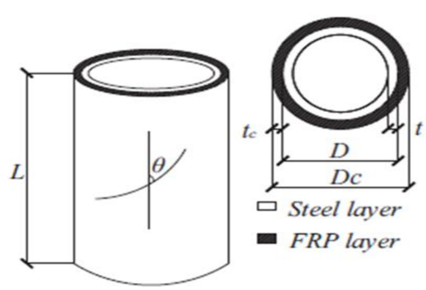



Fig 2.A detail of the FRP–steel (FST) components

GFRP's carrying capacity is determined by its equivalent stiffness:

$$\frac{1}{E_x} = \frac{\cos\theta^4}{E_1} + \left(\frac{1}{G_{12}} - \frac{2\vartheta_{12}}{E_1}\right)\sin\theta^2\cos\theta^2 + \frac{\sin\theta^4}{E_2} \qquad \text{.... (1)}$$

Where, $E_x$ = equivalent vertical stiffness

$E_1$ = longitudinal Young modulus

$E_2$ = Transverse Young modulus

$G_{12}$ = shear modulus in 1-2 plane

$\vartheta_{12}$ = Poisson ratio

Steel is the easier to analyse than FRP. Therefore, equalized the Fiber Reinforced Polymer as steel is a good way to predict the buckling load of FST specimen. For the FST specimen under the overall instability mode.

$$\Delta = \frac{E_{eq}^c . I_f + E_{eq}^t . I_f . \alpha}{E_{eq}^c . I_f + E_{eq}^t . I_f . \alpha + E_s . I_s} \qquad \text{.... (2)}$$

$$I_f = \pi[D_c^4 - (D_c - 2t_c)^4]/64 \qquad \text{.... (3)}$$

$$I_s = \pi[D^4 - (D - 2t)^4]/64 \qquad \text{.... (4)}$$

$$E_{eq}^c = 1/\left(\frac{\cos\theta^4}{E_1} + \left(\frac{1}{G_{12}} - \frac{2\vartheta_{12}}{E_1}\right)\sin\theta^2\cos\theta^2 + \frac{\sin\theta^4}{E_2}\right) \qquad \text{.... (5)}$$

$$E_{eq}^t = 1/\left(\frac{\sin\theta^4}{E_1} + \left(\frac{1}{G_{12}} - \frac{2\vartheta_{12}}{E_1}\right)\sin\theta^2\cos\theta^2 + \frac{\cos\theta^4}{E_2}\right) \qquad \text{.... (6)}$$

In the above equations, $I_f$ and $I_s$ are the moment of inertia of FRP and steel tube. $E_{eq}^c$ And $E_{eq}^t$ are equivalent fiber axial compression modulus and equivalent fiber circumference tension modulus, which are obtained by transformation equations. Es is steel young's modulus; α is the ratio of equivalent circumference strain to equivalent axial strain of FRP.

FRP can be equivalent to steel, as shown in Equations, where $t_{eq}$ is the equivalent thickness, $I_{eq}$ is the equivalent moment of inertia. The equivalent sectional area ($A_{eq}$) and section module ($W_{eq}$) of FST can be calculated by,

$$I_{eq} = I_s + \Delta . I_f \qquad \text{.... (7)}$$

$$t_{eq} = 0.5\left[\frac{64(I_{eq} - I_s)}{\pi} + D^4\right]^{1/4} - 0.5D \qquad \text{.... (8)}$$

$$A_{eq} = \frac{1}{4}\pi\left[\left(D + 2t_{eq}\right)^2 - (D - 2t)^2\right] \qquad \text{.... (9)}$$

$$W_{eq} = \frac{1}{32}\pi\left[\left(D + 2t_{eq}\right)^3 - (D - 2t)^3\right] \qquad \text{.... (10)}$$

Now, Equivalent young modulus for the parallel composite circular tube is,

$$E_{equivalent} = \frac{A1E1 + A2E2}{A1 + A2} \qquad \text{.... (11)}$$

Where, A1 = Area of circular steel tube,
E1 = Young Modulus of steel tube,
A2 = Area of fiber-reinforced polymer,
E2 = Young Modulus of fiber-reinforced polymer

Table. II. Calculations of different parameters

| Specimen | $E^c_{eq}$ (GPa) | $E^t_{eq}$ (GPa) | $I_f$ ($mm^4$) | $I_s$ ($mm^4$) | $\Delta$ | $I_{eq}$ ($mm^4$) | $t_{eq}$ (mm) | $A_{eq}$ ($mm^2$) | $W_{eq}$ ($mm^3$) | $E_{eq.}$ | $P_{cr.}$ (KN) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| FST-200-45-1-58-60-2 | 6.75 | 6.75 | 80675.3 | 138104.4 | 0.24 | 170059 | 1.32 | 597 | 6432.6 | 169.2 | 938.2 |
| FST-200-45-2-58-62-2 | 6.747 | 6.734 | 169834. | 138104.4 | 0.49 | 176467 | 1.85 | 699.70 | 7600.7 | 165.8 | 949.5 |
| FST-200-90-1-58-60-2 | 8.04 | 44.82 | 80675.3 | 138104.4 | 0.56 | 172695 | 1.39 | 611.20 | 6584.5 | 170.4 | 982.3 |
| FST-200-90-2-58-62-2 | 8.04 | 44.82 | 169834 | 138104.4 | 0.11 | 157246 | 2.46 | 819.11 | 8995.9 | 160.6 | 992.5 |
| FST-600-45-1-58-60-2 | 6.75 | 6.75 | 80675.3 | 138104.4 | 0.24 | 170059 | 1.32 | 597.85 | 6432.6 | 169.2 | 198.39 |
| FST-600-45-2-58-62-2 | 6.74 | 6.732 | 169834 | 138104.4 | 0.49 | 166467 | 1.35 | 699.70 | 7600.7 | 165.8 | 203.7 |
| FST-600-90-1-58-60-2 | 8.04 | 44.82 | 80675.3 | 138104.4 | 0.57 | 172695 | 1.39 | 611.20 | 6584.5 | 170.4 | 231.4 |
| FST-600-90-2-58-62-2 | 8.04 | 44.82 | 169834 | 138104.4 | 0.11 | 157246 | 2.46 | 819.11 | 8995.9 | 160.6 | 243.7 |
| S-200-58-2 | - | - | - | 138104.4 | - | - | - | 351.85 | - | 200 | 871.15 |
| S-600-58-2 | - | - | - | 138104.4 | - | - | - | 351.85 | - | 200 | 194.15 |

### *C. Material Properties*

Steel tube with thickness 2 mm is used in this study. The mechanical properties of the steel tube are given in the table.3-4. According to the Grade Fe 450. This High strength low carbon steel (Mild steel) is most versatile and the most widely used of all structural steels. These are low carbon steel pipe, they offer good properties such as formability, weldability and machinability. The chemical composition of the steel is given in the table.2-3.

Table IV. Material properties of Mild Steel

| Young Modulus $E_s$(N/mm$^2$) | Yield strength $F_y$(N/mm$^2$) | Ultimate strength $F_u$ (N/mm$^2$) | Poisson's ratio $\vartheta$ |
|---|---|---|---|
| 200000 | 275 | 450 | 0.3 |

Table V. Chemical composition of Mild Steel

| Carbon | Manganese | Sulphur | Phosphorus |
|---|---|---|---|
| 0.25 | 1.20 | 0.04 | 0.04 |

### *D. Theoretical Approach for Properties of Composite Beam*

A unidirectional fiber-reinforced polymer is treated as orthotropic material which shows the planes parallel and transverse to direction of fiber. The x-axis (x1) is to be considered as the reference to the fiber direction. Perpendicular to x-axis in the plane of lamina considered to be transverse axis (x2). [3]

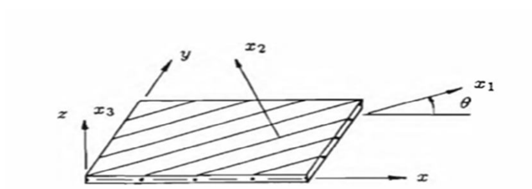



Fig.3. Global and material coordinates of a lamina

Longitudinal modulus, $E_1 = E_f V_f + E_m V_m$, …. (12)

Transverse modulus, $E_2 = E_f E_m \div (E_f V_m + E_m V_f)$ …. (13)

Major Poisson's ratio, $\vartheta_{12} = \vartheta_f V_f + \vartheta_m V_m$ …. (14)

Shear modulus, $G_{12} = G_f G_m \div (G_f V_m + G_m V_f)$ …. (15)

Where, $G_f = E_f \div 2(1+\nu_f)$ and

$G_m = E_m \div 2(1+\nu_m)$ …. (16)

Table VI. Material properties of glass fiber and matrix [4]

| Properties | Fiber (Glass) | Matrix (Epoxy) |
|---|---|---|
| Elastic Modulus ($N/mm^2$) | $E_f$ = 72400 | $E_m$ = 3450 |
| Rigidity Modulus ($N/mm^2$) | $G_f$ = 29670 | $G_m$ = 1277 |
| Poisson Ratio | $\vartheta_f$ = 0.22 | $\vartheta_m$ = 0.35 |
| Mass Density ($gm/cm^3$) | $\rho_f$ = 2.6 | $\rho_m$ = 1.2 |

The following table. (VII) Shows the calculated value of properties of the glass fiber reinforced polymer (GFRP).

Table VII. Table Properties of GFRP

| $E_1$ ($N/mm^2$) | $E_2$ ($N/mm^2$) | $\vartheta_{12}$ | $G_{12}$ ($N/mm^2$) |
|---|---|---|---|
| 44820 | 8040 | 0.28 | 2990 |

## III. FINITE ELEMENT ANALYSIS OF THE SPECIMEN

*1)* Static structural analysis is performed on the 200 mm and 600 mm steel tube

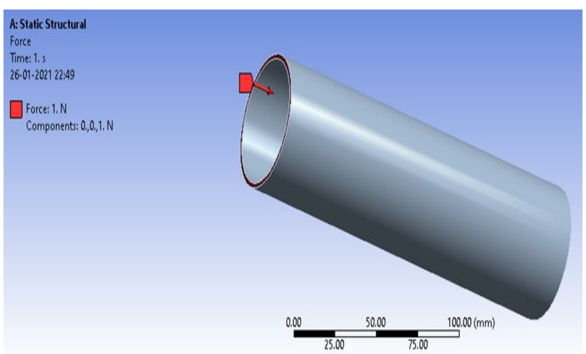



Fig.4. Static Structural Analysis

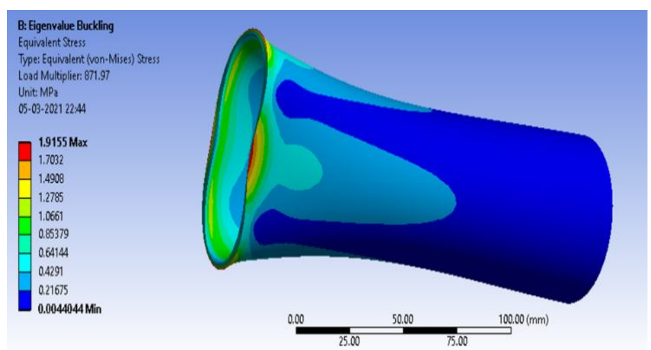



Fig.5. Equivalent stress

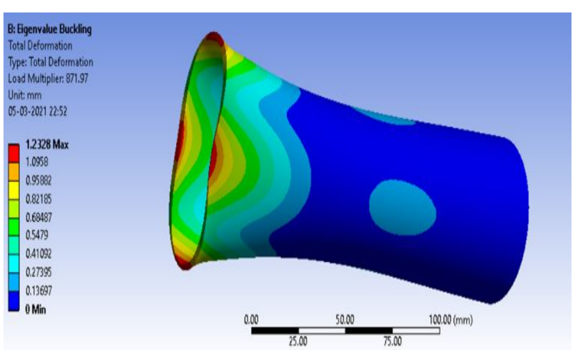



Fig.6. Total Deformation

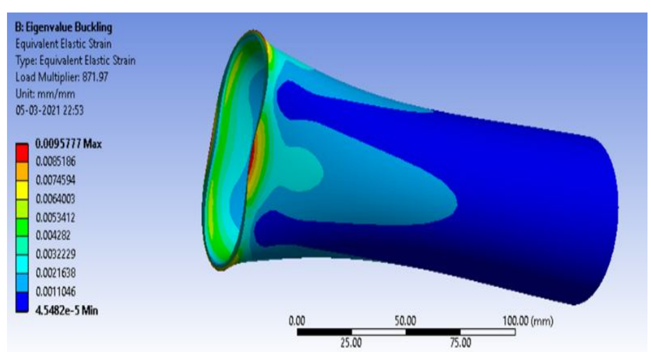



Fig.7. Equivalent Elastic Strain

*2)* Boundary Conditions

*a)* A unit compressive load (1N) is applied on one end of the specimen.

*b)* Other end is kept fixed.

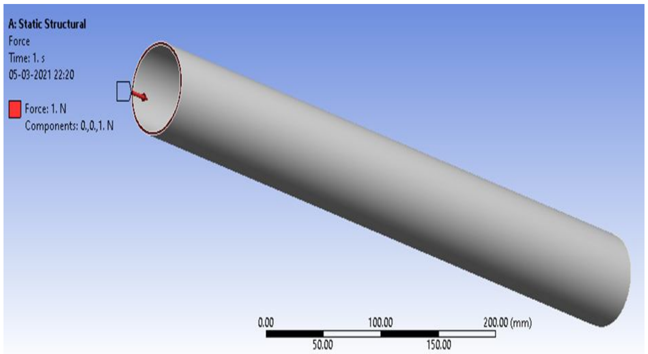



Fig.8. Static Structural Analysis

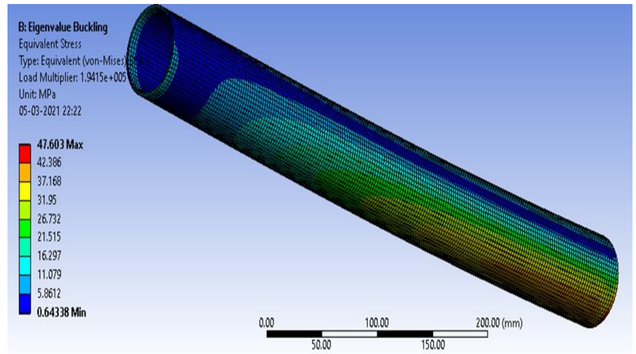



Fig.9. Equivalent Stress

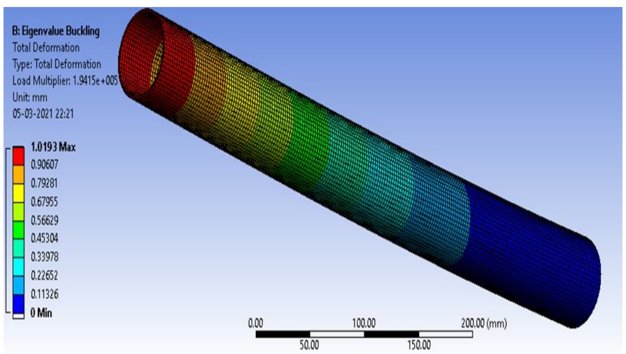



Fig.10. Total Deformation

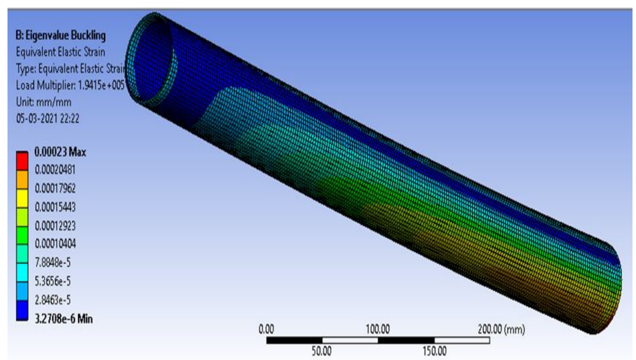


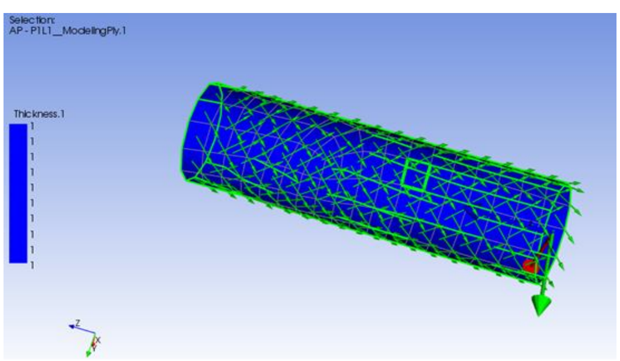

Fig.11. Equivalent Elastic Strain

*3)* GFRP steel tube are modelled in the ACP model by using the different geometric parameters:

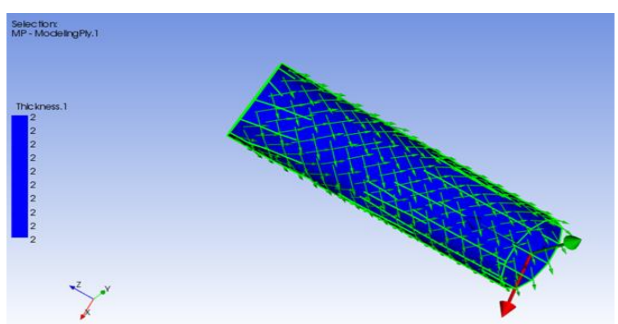
Steel tube of 200 mm and 600 mm length

*a)* As shown in the fig 3.9 and 3.10 Different models are created in the ANSYS Composite Prep-Post (ACP) model given in the following figures by taking different geometric parameters such as Specimen length, winding angle, FRP thickness.

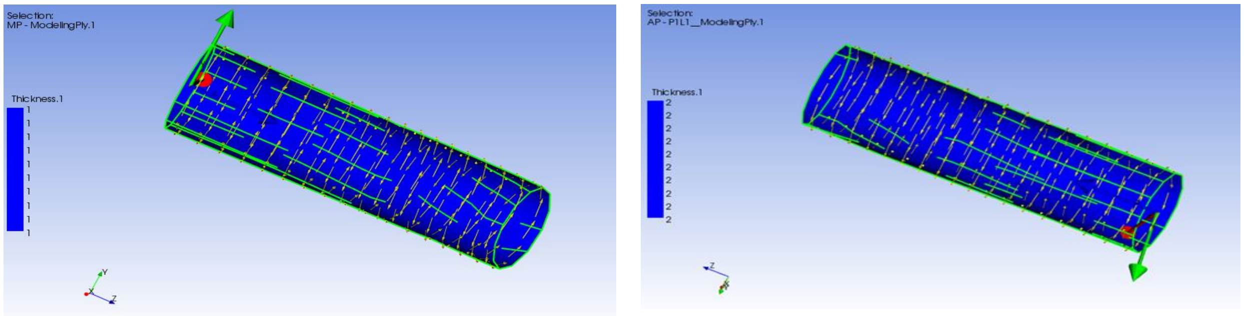
*b)* The GFRP composites are considered as an orthotropic material. Which means their properties are different in all directions such as Young modulus, Shear modulus, Poisson ratio.




a) FST-200-45-1-58-60-2

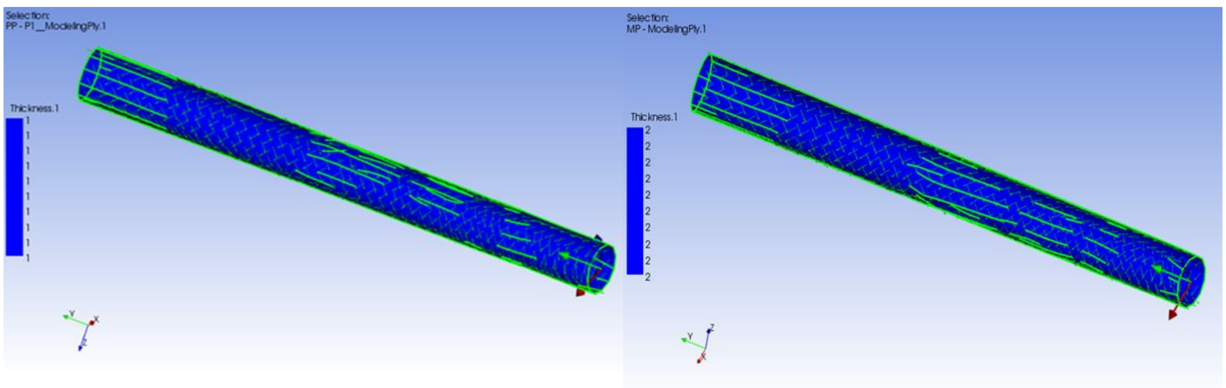



b) FST-200-45-2-58-62-2

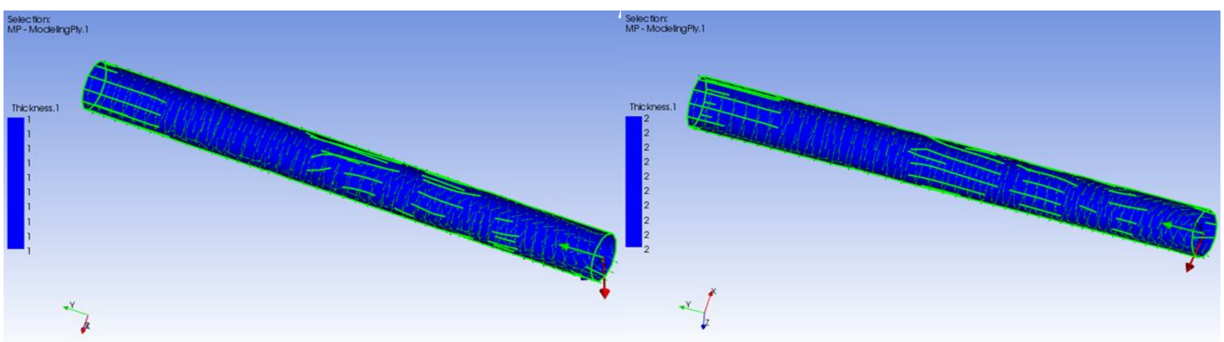


c) FST-200-90-1-58-60-2 d) FST-200-90-2-58-62-2

Fig. 12. GFRP model of short tube



e) FST-600-45-1-58-60-2 f) FST-600-45-2-58-62-2



g) FST-600-90-1-58-60-2 h) FST-600-90-2-58-62-2

Fig.13. GFRP model of long tube

## IV. MANUFACTURING PROCESS OF GLASS FIBRE STEEL TUBES

### *A. Pre-requisite method*

Eight circular steel tubes Electro Resistance welded (ERW) pipes of a required length were confined with GFRP yarns using the winding filament technique by wrapping epoxy resin-impregnated with fibres in the hoop direction and Inclined direction to form a wrap with the required thickness.

### *B. The setup for making glass fiber steel tubes*

First of all, the steel pipes are cleaned with the clothes to remove the dirty particles. Then Epoxy resin is prepared by taking the proper mixture of Part A (base) and Part B (Hardener). The mixture is then applied on the whole surface of steel pipe, by taking the precautions as mention in the user manual. The steel pipe is supported using the holding equipment.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VI Jun 2021- Available at www.ijraset.com

### *C. Preparation of Epoxy Resin*

The Epoxy resin made from two component part A (base) and Part B (Hardener) as shown in the fig (3.11) and (3.12). This mixture is nothing but epoxy resin. Epoxy resin is a matrix material, it is a viscosity fluid epoxy resin. To create proper mixer, stir the mixer at least 3 minutes properly. The ratio of the part A to Part B by weight is 100:35[4]

Fig.14. Base (Part A)

Fig.15. Hardener (Part B)

The typical properties of epoxy resin is given in below table.

Table VIII. Typical Properties of epoxy resin

| | |
|---|---|
| Appearance Gray | liquid |
| Mixed density | 1.15 kg/litre |
| Mixing Ratio, by weight | 100 : 35 |
| Volume solids | 100 % |
| Pot life | 25 Minutes at 25°C |
| Setting time | 5 Hours at 25°C |
| Mixed viscosity | at 25°C (cps.) 3000 ± 500 |
| Full cure | 7 Days |
| Coverage ratio for 750 gsm fibre sheet | 1.2 $kg/m^2$ |

FST-200-45-1-58-60-2 FST-200-45-2-58-62-2 FST-200-90-1-58-60-2 FST-200-90-2-58-62-2

Fig. 4.3. Manufactured short composite steel tube (200 mm)

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
*ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429*
*Volume 9 Issue VI Jun 2021- Available at www.ijraset.com*

FST-600-45-1-58-60-2 FST-600-45-2-58-62-2 FST-600-90-1-58-60-2 FST-600-90-2-58-62-2

Fig. 4.4. Manufactured long composite steel tube (600 mm)

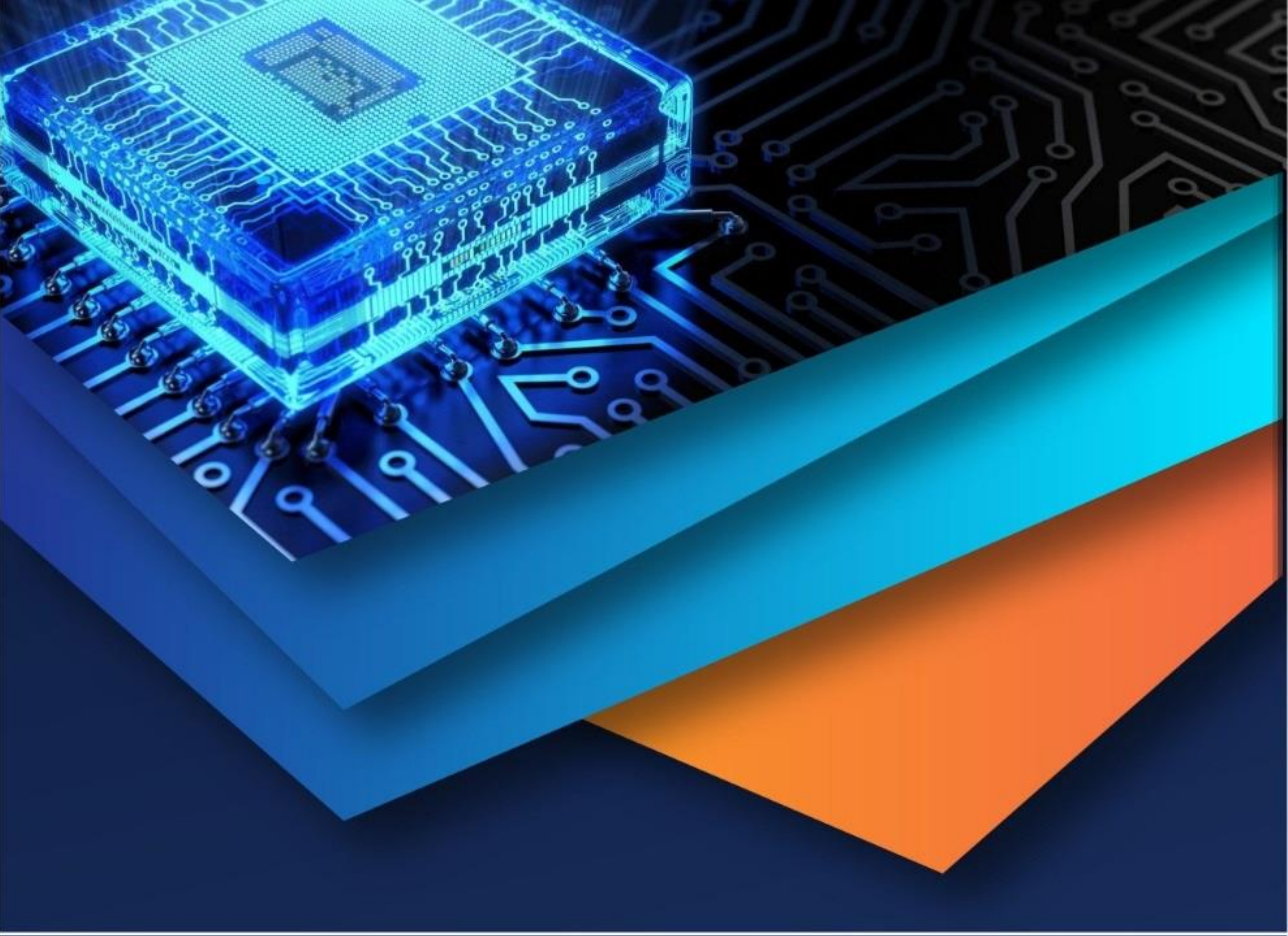
## V. CONCLUSION

Following results and conclusions are drawn from the study made during this work till now:

*A.* Studied variable parameters of the GFRP Strengthened steel tube such as steel tube thickness and outer diameter, GFRP thickness, winding angle and specimen length.
*B.* GFRP Steel tubes are designed and manufactured using the different parameters.
*C.* Steel tube models are created in the ANSYS software.
*D.* Static structural analysis, eigenvalue buckling analysis are carried out and GFRP steel tubes are modelled in the ACP Model.

## REFERENCES

[1] Abderrahim Djerrad, Feng Fan, Xudong Zhin, Qijian Wu. “Experimental and FEM analysis of AFRP short and long steel tube under axial compression” Journal of Thin-Walled Structures. 139 (2019) 9–23
[2] Qijian Wu, Xudong Zhi. “Experimental and numerical study of GFRP-reinforced circular steel tube under axial compression”. Journal of Constructional Steel Research. 168 (2020) 105990.
[3] J N REDDY “MECHANICS OF LAMINATED COMPOSITE PLATES AND SHELLS” on the Theory and Analysis of laminated composite plate and shells. Second Edition Book (2002)
[4] G. Rathnakar, Dr.H. K. Shivanand “fibre orientation and its Influence on the Flexural strength of glass fibre and graphite fibre reinforced polymer composites”. Journal of innovative research in Science, Engineering and Technology (2013).
[5] Urmi Devi and Khan Mahmud Amanat. “Non-Linear Finite Element Investigation on the Behaviour of CFRP Strengthened Steel Square HSS Columns under Compression” International Journal of Steel Structures. (2015) 671-680.
[6] Liang Huang, Peing Yin, Liebo Yan, Bohamill Kasal. “Behaviour of hybrid GFRP–perforated-steel tube-encased concrete column under Uniaxial compression” Journal of composite structures. (2016) 313-324.




10.22214/IJRASET

INDEX COPERNICUS 45.98

ISRA JIF IMPACT FACTOR: 7.129

SJIFactor Scientific Journal Impact Factor TOGETHER WE REACH THE GOAL IMPACT FACTOR: 7.429

ISI


# INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY