

Design, Development and Testing of CFRC Tie Rod

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Abstract - Design of suspension components in an automotive is very critical as they are constantly under varying loads. The tie rod is an important part of suspension system. It connects the steering to the suspension in order to transform the motion. Buckling of tie rod is commonly occurring failure mode. Tie rod is made up of steel or alloy steel. Current material of tie rod is replaced with carbon/epoxy composite material. Strength to weight ratio of steel and alloy steel are less as compared with carbon fiber reinforced composites. Replacement of current material of tie rod with composite material leads to reduction in weight of vehicles hence increase in economy. Properties of carbon/epoxy composite material are calculated by micromechanical analysis. Ratio of reinforcing material to matrix material is taken as 70:30. The tie rod is modeled by using CATIA. Critical buckling load results and total deformation results are obtained using ANSYS. Using filament winding technique, the composite rods are fabricated. The buckling test is carried out on UTM. Finally, it has been found that carbon composite material found out to be best replacement for steel rod.

Key Words: Tie rod, Carbon fiber, Buckling, FEA

1. INTRODUCTION

Tie rod get fail due to fluctuating forces during steering and bumping of vehicle. Failure of tie rod may cause instability of vehicle and leads to an accident. Also, the indications given by the tie rod before failure are very less. Faulty tie rods can negatively affect a car's front-end alignment which may result in uneven wear of the inner and outer edge of a vehicle tire. Moreover, as tie rod ends are subjected to wear, it can slacken and loose gradually thereby, resulting in failure which may affect the driver's ability to steer and control the car. Hence a tie rod should be designed in such a way that it should not get fail under any circumstances. Effort has been taken for improving performance of tie rod but these efforts either lead to increase in material cost, manufacturing of component and weight of component. To achieve required strength along with minimum cost and weight of component, appropriate material and manufacturing technique must be selected. The composite material has superior mechanical properties. composites are light in weight. Also, one of the best characteristics of composite material is strength of composite can be obtained in any specific direction

1.1. PROBLEM STATEMENT

Tie rods is an integral part of vehicle's steering system. Tie rod get fail due to varying forces and bumping of vehicle during steering. Tie rod is mostly subjected to compressive stresses. Buckling of tie rod under compressive stresses leads to uneven tire wear. So, research work is aimed to assess strength and compare performance of carbon fiber reinforced composite (CFRC) material with existing material of tie rod.

2. LITERATURE REVIEW

Ikpe Aniekan Essienubong et al. have carried out static analysis of tie rod to determine resulting buckling displacement. First, the load case scenarios were discussed. The maximum and minimum loads and their nature (tensile or compressive) acting on tie rod were obtained using ADAMS software. The maximum load was of 18.5 KN compressive and 13.6 KN tensile nature.

Owunna Ikechukwu et al. have investigated tie rod failure in relation with forces which acts on the suspension system. The various causes of tie rod failure and factors affecting the tie rod performance were investigated McPherson suspension model was simulated in ADAMS software and maximum tensile and compressive stress values were obtained. Various load case scenarios were discussed, and corresponding values of loads were obtained using ADAMS software. Reverse Brake and Bump scenario for compressive load and Cornering and Bump scenario for tensile load were found to have the most severe impacts on the tie rod during its service life, coupled with other factors such as Fatigue, Corrosion, poor manufacturing route, misalignment, service loading, though not too severe as the compressive and tensile forces. Rod manufacturers must pay attention to these forces as well as the material properties during design, as this is one of the ways to make the tie rod less prone to buckling or fracture and failure.

Raelvim Gonzalez Henriquez et al. have given an overview of filament winding process and the discussed technology to produce fibre reinforced composites. An overview of process parameters that influence the mechanical properties of filament wound composites is provided. Moreover, general design and fabrication considerations related to composite product performance are explored, followed by mechanical testing of filament-wound structures for quality control (QC).

Autar K. Kaw has given a brief introduction of composite materials and their classification. Fibre properties of various materials such as steel, aluminium, carbon, glass, Kevlar and matrix material such as epoxy, were compared. The applications of composite materials along with their manufacturing technique were discussed in detail. Micro mechanical analysis of lamina has carried out to find out to the engineering constants unidirectional/bidirectional lamina in terms of the stiffness and compliance parameters of the lamina.

3. METHDOLOGY

The methodology developed is as shown in fig,

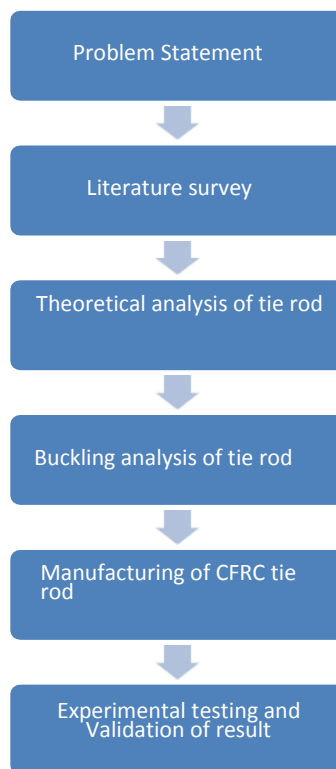


Fig-1: Methdology

4. THEROTICAL ANALYSIS OF TIE ROD

The properties of carbon/epoxy composite are derived using theoretical calculations. New carbon/epoxy-steel composite material properties are obtained, and new material is created in ANSYS 14.5 material data source. This material is assigned for the tie rod model. Critical buckling load results are obtained for new material and aluminum alloy and steel.

4.1. Micromechanical analysis

A composite material consists of two or more constituents; thus, the analysis and design of such materials is different from that for conventional materials such as metals.

Here, reinforcing material is taken as Carbon fiber and matrix material is taken as epoxy resin. Carbon fiber is a material consisting of fibers about 3-15 μm in diameter and composed mostly of carbon atoms. The crystal alignment gives the fiber high strength-to-volume ratio. Carbon fibers show high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion. Epoxy resin has high flexibility and low viscosity. Also, it is easily available. The reactivity of resin can easily be adjusted as per the demands using combination of both resin and hardeners.

The approach to analyze the mechanical behavior of composite structures is as follows:

- 1) Find the average properties of a composite ply from the individual properties of the constituents. Properties include stiffness, strength, thermal, and moisture expansion coefficients. Note that average properties are derived by considering the ply to be homogeneous. At this level, one can optimize for the stiffness and strength requirements of a lamina. This is called the micromechanics of a lamina.
- 2) Develop the stress-strain relationships for a unidirectional/bidirectional lamina. Loads may be applied along the principal directions of symmetry of the lamina or offaxis. Also, one develops relationships for stiffness, thermal and moisture expansion coefficients, and strengths of angle plies. Failure theories of a lamina are based on stresses in the lamina and strength properties of a lamina. This is called the macromechanics of a lamina.

A structure made of composite materials is generally a laminate structure made of various laminas stacked on each other. Knowing the macromechanics of a single lamina, one develops the macromechanics of a laminate. Stiffness, strengths, and thermal and moisture expansion coefficients can be found for the whole laminate. Laminate failure is based on stresses and application of failure theories to each ply. This knowledge of analysis of composites can then eventually form the basis for the mechanical design of structures made of composites.

So on the basis of above theory properties of composite material that is CFRC material in this case is obtained as below,

Volume fraction of fibre – 0.7 (70%) Volume fraction of matrix – 0.3 (30%) Volume of composites – 1 (100%) Density of composite (P_c) is given by

$$P_c = P_f V_f + P_m V_m \quad \dots (1)$$

Young's modulus in longitudinal direction is given by,

$$E_1 = E_f V_f + E_m V_m \quad \dots (2)$$

$$\text{Young's Modulus in transverse direction is given by, } (1/E_2) = (V_f / E_f) + (V_m / E_m) \quad \dots (3)$$

Major Poisson ratio (μ_{12}) is given by,

$$\mu_{12} = (\mu_f V_f) + (\mu_m V_m) \quad \dots (4) \text{ Minor poisson ratio is given by,}$$

$$\mu_{21} = \mu_{12} * (E_2 / E_1) \quad \dots (5)$$

So, the important properties of composite based on above equations are enlisted in the table 1.

Table-1: Properties of composite (carbon fiber and epoxy resin)

Sr. No	Composite Properties	Symbol	Value	unit
1	Young's Modulus (Longitudinal direction)	E1	170.3	Gpa
2	Young's Modulus (Transverse direction)	E2	9.7	Gpa
3	Major Poison's ratio	μ_{12}	0.3	-
4	Minor Poisson's ratio	μ_{21}	03	-

4.2. BUCKLING ANALYSIS OF TIE ROD

An eigen value buckling analysis is carried out for tie rod. A model of tie rod is created in CATIA V5 and then imported in ansys. Fine meshing is selected for better accuracy. An eigenvalue buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. Eigenvalues are values of load at which buckling takes place. An eigenvalue buckling analysis must be linked to static structural analysis. A static structural analysis determines the displacements, stresses, strains, and forces in structures. The results calculated by the eigenvalue buckling analysis are buckling load factors that scale all of the loads applied in the static structural analysis.

Buckling analysis of steel material is carried out. Total deformation results and critical buckling load results are obtained. Total deformation result for steel is shown in Fig.2. The maximum deformation for 1 N force is 4.997 mm

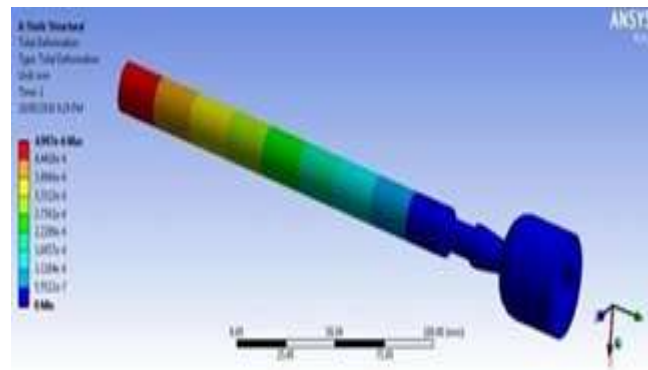


Fig-2: Total deformation result for steel

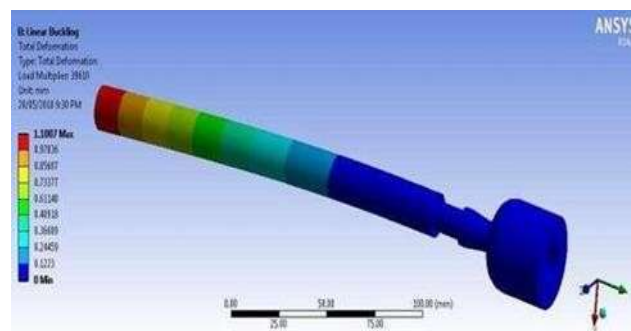


Fig-3: Critical Buckling Load result for steel

The results calculated by the eigenvalue buckling analysis are buckling load factors that scale all of the loads applied in the static structural analysis. The load multiplier is 39610. Hence critical buckling load for steel material is 39610 N. The critical buckling load is shown in fig 3.

The combined properties of composite material are obtained by using properties of steel and carbon/epoxy composite. The combined properties of steel and composite are obtained by averaging method. Buckling analysis of CFRC and steel composite material is carried out the total deformation results and critical buckling load results are obtained. Total deformation result for carbon/epoxy and steel composite is shown in Fig.4. The maximum deformation for 1 N force is $5.4022e -6$ mm.

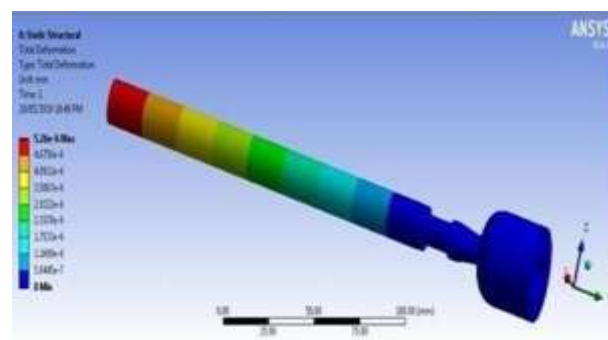


Fig-4: Total deformation result for CFRC and steel composite

The Eigen value buckling results for CFRC and steel composite are obtained and are shown in Fig.5. The load multiplier is 36639. Hence the critical buckling load for CFRC and steel composite is 36639 N.

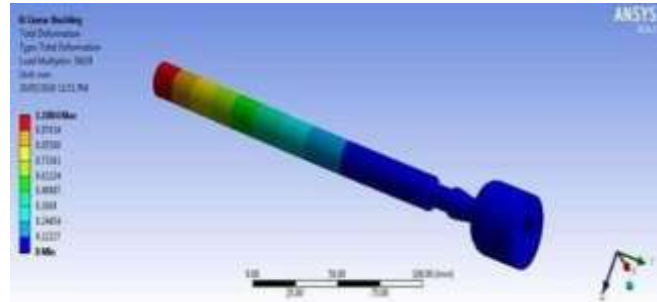


Fig-5: Critical buckling load result for CFRC and steel composite

• **Stiffness of Materials**

Stiffness is the extent to which an object resists deformation in response to an applied force. Stiffness is nothing but force per unit deformation.

Mathematically, stiffness is given by,

$$F = KX \quad \dots (6)$$

Where, F = applied force in N X = Deformation in mm

K = Stiffness in N/mm.

The stiffness of steel and composite materials is calculated theoretically. The static deformation obtained in ANSYS 14.5

14.5 is used to obtain stiffness of material.

• Stiffness of steel material –

As discussed in section 4.2 from Fig. 2 the maximum deformation for steel is 4.997×10^{-6} mm for 1 N force. Hence stiffness of steel can be obtained using eq. 6 as,

$$1\text{N} = K \times 4.997 \times 10^{-6}\text{mm}$$

$$K = 200.120 \text{ KN/mm}$$

Hence stiffness of steel material is 200.12 KN/mm.

• Stiffness of CFRC and steel composite –

As discussed in section 4.2 and from Fig. 4 the maximum deformation for Carbon/Epoxy and steel is 5.4022×10^{-6} mm for 1 N force. Hence stiffness of CFRC and steel composite can be obtained using eq.3.20 as,

$$1\text{N} = K \times 5.4022 \times 10^{-6}\text{mm} \quad K = 185.109 \text{ KN/mm}$$

Hence stiffness of Carbon/Epoxy composite material is

$$185.109 \text{ KN/mm}$$

• **Weights of tie rod materials**

Weight of material is given by,

$$W = \rho V \text{ gram}$$

Where, ρ = Density of material, g = Acceleration due to gravity V = Volume of rod = $\pi R^2 H$

R = Radius of rod = 8 mm

H = Height of rod = 200 mm

The weights of steel and composite material are found to be 307 grams and 125 grams respectively.

5. MANUFACTURING OF CFRC TIE ROD

The manufacturing of CFRC tie rod is done by filament winding process as it has greater fiber orientation control. In filament winding technique, fiber strands are loosened up and passed constantly to the resin tank. In resin tank, fiber strand are impregnated totally with the resin.

Presently, these resin impregnated strands are passed onto a turning mandrel. These strands are twisted around the mandrel in a controlled way and in a particular fiber orientation. The reason for choosing filament winding process is that filament winding process ensures high degree of uniformity in fiber distribution, orientation, and placement. Fiber can be oriented in specific direction. A tie rod is subjected to axial forces hence fibers can be oriented in such a way that maximum strength can be obtained. The actual representation of filament winding process is as shown in the fig.6.



1 - Carriage, 2- Preimpregnated carbon fiber, 3-Mandrel, 4 - Carbon fiber winding on mandrel

Fig-6: Filament winding of carbon fiber

6. EXPERIMENTAL TESTING

For the validation of numerical result experimental testing is done. The Critical buckling load for new composite material is obtained experimentally by using computerized universal testing machine MODEL STS 248. The testing was carried out at Praj laboratories, Pune. Three sample specimens of composite were tested. The testing is carried out by referring standard procedure.



1- Upper fixture, 2- bottom fixture, 3- Carbon/Epoxy Rod, 4- Clamp

Fig-7: Experimental setup

7. RESULT AND DISCUSSION

The FEA analysis is carried out to find critical buckling load for steel and composite tie rod. The experimental result for composite tie rod is obtained to test the accuracy of analysis and experimental result.

Table 2 shows the tabular representation of experimental critical buckling load and compressive strength of sample

Table-2: Critical buckling load and compressive strength of samples

Sr. No.	Specimen	Critical Buckling load (N)	Compressive strength (MPa)
1	Specimen 1	31879.4	158.491
2	Specimen 2	32242	160.294
3	Specimen 3	33780.6	167.943

Average critical buckling load is taken into consideration for comparison. The average critical buckling load is 32634 N.

Fig. 8 shows buckling load to weight ratio of steel and composite material. Buckling load to weight ratio is obtained by dividing critical buckling load carrying capacity by weight of material. The Fig shows buckling load of carbon composite is much higher relative to weight.

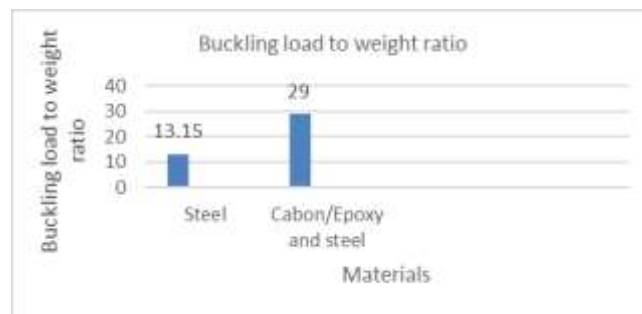


Fig-8: Buckling load to weight ratio for steel and composite material

Fig. 9 shows the stiffness of steel and CFRC material. In section 4.2 stiffness values are calculated. Stiffness of material indicates resistance to deformation. From Fig. 9 steel

Table 3 shows comparison between numerical and experimental value of critical buckling load.

Table-3: Comparison of Numerical and experimental results

Numerical value of critical buckling load N	Experimental value of critical buckling load N	Percentage variation
36639	32634	10.93

The numerical value and the experimental value of critical buckling load have percentage variation 10.93. This variation occurs because we do not consider the micro-voids during analysis of composite material

The critical buckling load for steel and CFRC material is obtained theoretically using software and experimentally by using UTM. The comparison based on strength and density is shown in Table 4.

Table-4: Numerical Results of critical buckling load for steel and CFRC

Sr. No	Material	Critical buckling load (N)	Density (Kg /m ³)
1	Steel	39610	7800
2	Carbon / Epoxy and steel composite	36639	2900

is having maximum stiffness while carbon fiber composites have nearly same stiffness value as steel. Direct co- relation can be seen from stiffness and critical buckling load. As stiffness of material increase resistance to deformation increases.

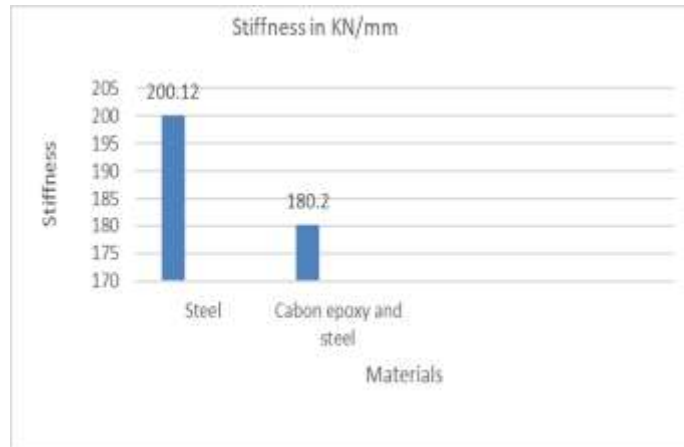


Fig-9: Stiffness of steel and CFRC composite

The experimental and numerical values of critical buckling load are compared. The comparison of results shows that CFRC material show higher value of strength to weight ratio as compared to steel. As weight of vehicle is directly related to fuel consumption which in turn directly related to vehicle's engine efficiency. Thus, by reducing weight we can increase the efficiency. Also, with the decrease in weight of material, material cost also decreases.

8. CONCLUSION

The design, analysis and fabrication of inner end of tie rod using CFRC material has been done. The failure of tie rod occurs when it is subjected to compressive and buckling loads. A polymer-based composites material is replacement for steel alloy tie rod. Filament winding method is used for fabrication. Following conclusions can be drawn based on study: 1) The FEA predicted result deviates by 10.93% from experimental result. 2) CFRC material shows very close stiffness to steel. 3) More than two times weight reduction can be possible by use of carbon/epoxy composite along with steel without compromising much strength. 4) The steel tie rod can be replaced by CFRC material without compromising strength.

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