iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: VII Month of publication: July 2018

DOI: http://doi.org/10.22214/ijraset.2018.7002

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 6.887
Volume 6 Issue VII, July 2018- Available at www.ijraset.com

Modal Analysis and Investigation of Torsion Bar Strength based on Layer Orientation Angle using Composite Material

Miss. Adhav Madhuri Vilas[1], Prof. Galhe D.S.[2], Prof. Hredaya Mishra[3]
[1]*PG Student, Jaihind College Of Engineering Kuran..*
[2]*Associate Professor, Jaihind College Of Engineering Kuran.*
[3]*Associate Professor, Jaihind College Of Engineering Kuran.*

Abstract: ***This paper presents an application of Finite Element Analysis (FEA) for strength improvement of torsion bar. Also provides fundamental knowledge of torsion bar analysis using composite material. The existing torsion baris modelled using CATIA and analyzed using ANSYS 16.0. The results for stresses are* 63.716*MPa and deformation is 1.5958 mm. First optimization is done based on fibre orientation angles of composite material. Further alternate material selection is done through study and optimization analysis is done for the same. Carbon epoxy-woven selected as material and gives final stresses as* 22.974*MPa and deformation is 1.255mm. The torsion deflections were obtained experimentally. The results of experimental study are compared with the FEA resultsand found in good agreement with FEA results.***

Keywords*: *Torsion bar; Optimization; composite material; fiber orientations.

I. INTRODUCTION

A torsion bar is a type of suspension system that is usually used in vehicles such as cars, trucks and vans. A suspension system is a significant and acute element of a vehicle's design. Irrespective of the design, all suspension systems do the same functions. They keep the tires in contact with the surface of the road, upkeep the weight of a vehicle and absorb the forces produced by the movement and motion of the vehicle.

A. Construction of a Torsion Bar

Torsion bars are basically metal bars that perform the role of a spring. At one end, the bar is fixed rigidly in place to the chassis of a vehicle. The last end of the bar may be fastened to the axle, suspension arm, or a spindle, depending on the vehicle's design. For instance a vehicle travels alongside the road, the forces made by the motion of the vehicle produce torque on the bar, which turns it along its axis.

Counteracting the torque is the fact that the torsion bar obviously wants to resist the twisting effect and return to its normal state. By doing so, the suspension supplies a level of resistance to the forces generated by the movement of the vehicle. This resistance is the basic principle behind a torsion bar suspension system.

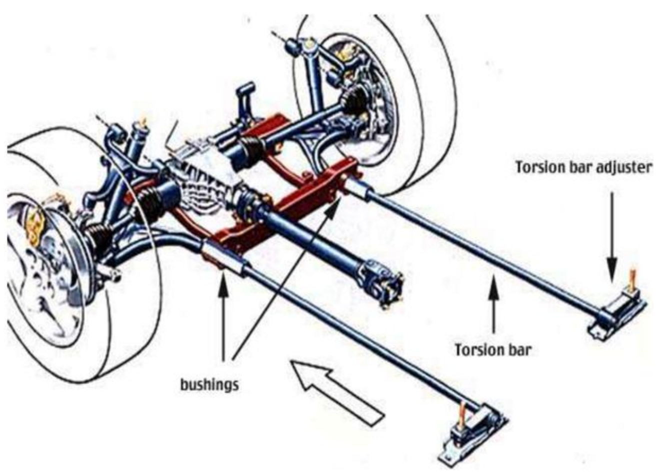

Fig 1: Torsion Bar connection in vehicle

A torsion bar suspension, also known as a torsion spring suspension (but not to be confused with torsion beam rear suspension), is a general term for any vehicle suspension that uses a torsion bar as its main weight bearing spring. One end of a long metal bar is attached firmly to the vehicle chassis; the opposite end terminates in a lever, the torsion key, and mounted perpendicular to the bar that is attached to a suspension arm, a spindle, or the axle. Vertical motion of the wheel causes the bar to twist around its axis and is resisted by the bar's torsion resistance. The effective spring rate of the bar is determined by its length, cross section, shape, material, and manufacturing process.

Torsion bars act as a linear spring that has one stationary end connected to the frame of the vehicle and one rotational end connected to the control arm. This style of spring produces torque to overcome the load force applied to the vehicle.

As a linear vertical load is applied to the tires, the load is transformed to the torsion bar, which results in a twisting motion. When the load is released or reduced from the tires, the torsion bar untwists allowing for the bar to reset to its neutral position. This style of suspension has a very low-profile, requiring minimal mounting volume.

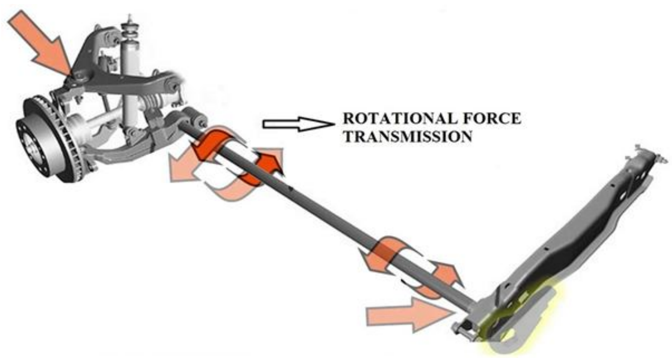

Fig 2: Working of Torsion Bar

B. Working of Torsion Bar

Torsion bars use the twisting properties of a steel bar to offer coil-spring-like functions. One end of a bar is fixed rigidly to the vehicle frame. The further end is fastened to a wishbone, which acts like a lever that travels perpendicular to the torsion bar. When the wheel hits at a stone or projections, vertical motion is shifted to the wishbone and then, through the levering act, to the torsion bar. The torsion bar then twists sideways its axis to offer the spring force. European car manufacturers used this system widely, as did Packard and Chrysler in the United States, through the 1950s and 1960s.

C. Advantages

In this system there are several key advantages. The design of the torsion bar suspension takes up less area than other suspension systems. This makes the vehicle designers to create a more spacious passenger compartment. The elevation of the bars can also be varied more easily than other suspension systems. They are also extremely durable and habitually have a long service life.

D. Disadvantages

There are also several disadvantages of torsion bar suspensions. The main disadvantage is that these bars generally do not offer what is known as a progressive spring rate. Generally in suspensions with a progressive spring, the coils of the spring are spaced at dissimilar distances from each other. This permits the suspension system to aids braking, firm steering and handling, although providing for a smooth and comfortable journey. Vehicles with torsion bars are repeatedly tuned to either provide a more firm driving experience at the expense of ride smoothness, or a smoother ride at the expense of the vehicle's handling quality.

Literature has been studied based on torsion bar and suspension system. Many of researchers have contributed in development of Torsion Bar and are listed below:

Prof. LaxminarayanSidramKanna et al. published paper on Feasibility of hallow stability bar. In this paper they considered Chromium-molybdenum material for stability bar and 30 mm diameter. Stability bar also referred to as Anti-rolls bar or sway bar. The bar's torsional stiffness (resistance to twist) determines its ability to reduce body roll, and is named as "Roll Stiffness". A stability bar improves the handling of a vehicle by increasing stability during cornering or evasive manoeuvres. P. M. Bora and Dr. P. K. Sharma analysed Vehicle Anti-Roll using FEA tool ANSYS. The aim of this project is to report the analysis of Vehicle anti-roll bars (stabilizer bars)used for suspension components limiting body roll angle using the finite element analysis tool ANSYS.G.Brabie:-"The effects of torsion on the initial geometry of bars have non-circular cross-sections." In this paper they have

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studying "The effects of torsion on the initial geometry of bars having non-circular cross-sections". In that they are important aspects such as aspects concerning the changes in length and aspects concerning the changes of the initial shape, when effect of torsion on bars twisted with large angles of twist. They have taken two geometry shape such as square cross- sectional shapes and rectangular cross- sectional shapes. Prof. P. N. Gore:-"The Effect of Specimen Geometry on Torsion Test Results". In this paper they have studying the effect of specimen geometry on torsion bar and also done by experimental by using Nadai method. In this method to determine the true shear stress-strain curve without measurement of radial and hoop strains. This method taken into accounts for change length in free-end torsion. This paper is comparing between solid and tabular (hollow) specimen but its results shows that tabular specimen is more reliable than solid specimen for torsion bar .When force is applied in axial direction then axial displacement is maintained constant, torque is increased, the axial load carrying capacity of specimen decreases. A rapidly drop in the axial load carrying capacity when the angle of twist is maintained constant and axial load is increases.

II. OBJECTIVES

A. To analyse existing Torsion bar using ANSYS.
B. To study composite Material for optimization analysis.
C. Optimization of Torsion bar based on c/s profile and composite material.

III.MODAL AND ANALYSIS OF EXISTING TORSION BAR

A. 3D Model of Torsion Bar

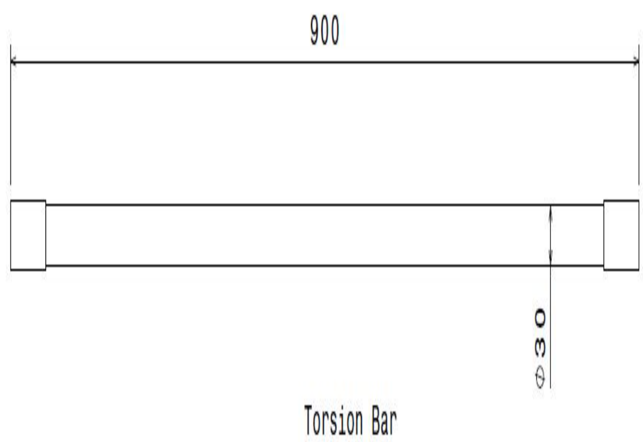

Fig 3: 2D drawing of torsion bar

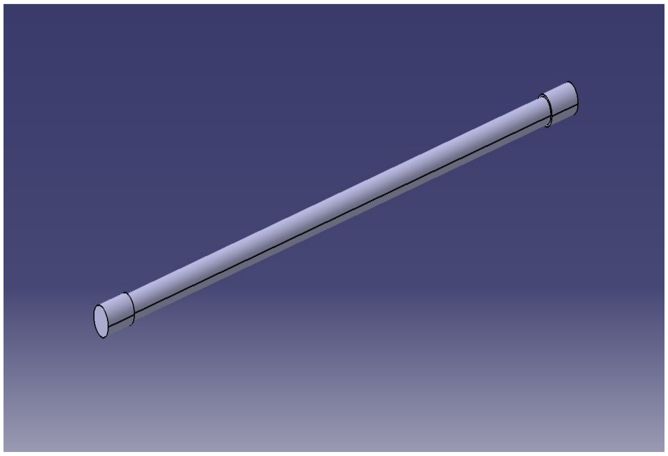

Fig 4: 3D model of torsion bar

B. Analysis of solid Torsion Bar

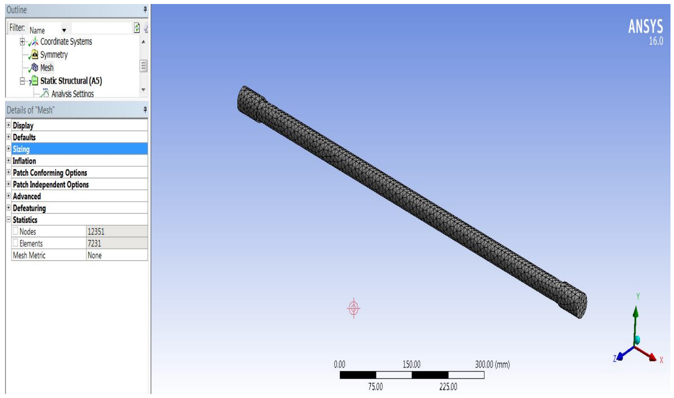

Fig 5: Meshing of Torsion Bar with tetrahedral elements

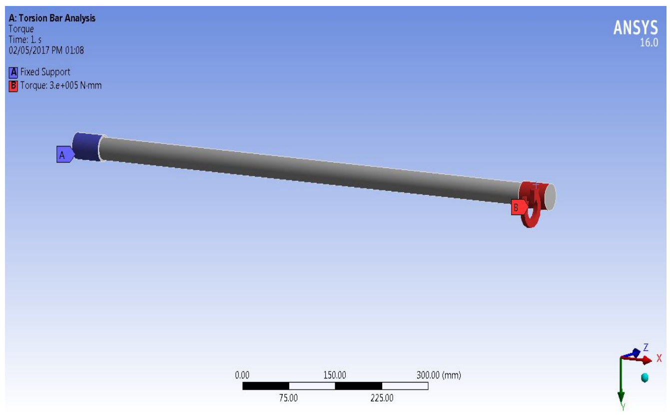

Fig 6: Applying the boundary conditions to Torsion Bar

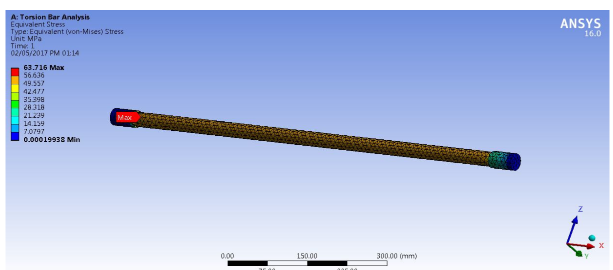

Fig 7: Stress at Torsion Bar

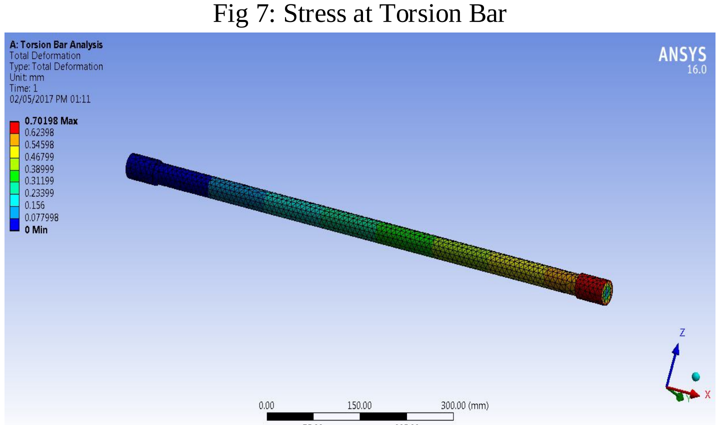

Fig 8: Deformation at Torsion Bar

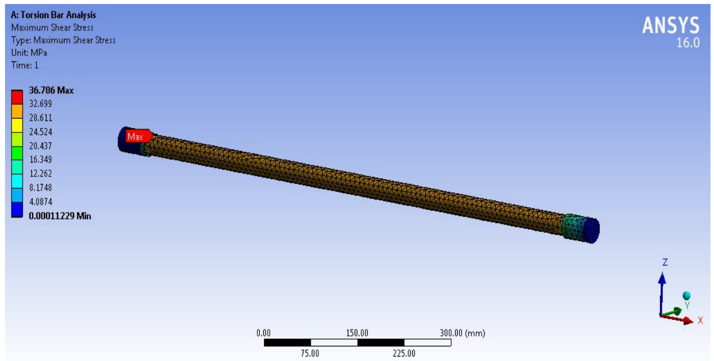

Fig 9: Shear Stress at Torsion Bar

C. Modal analysis

The goal of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. It is common to use the finite element method (FEM) to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The types of equations which arise from modal analysis are those seen in Eigen systems. The physical interpretation of the Eigen values and eigenvectors which come from solving the system are that they represent the frequencies and corresponding mode shapes. Sometimes, the only desired modes are the lowest frequencies because they can be the most prominent modes at which the object will vibrate, dominating all the higher frequency modes

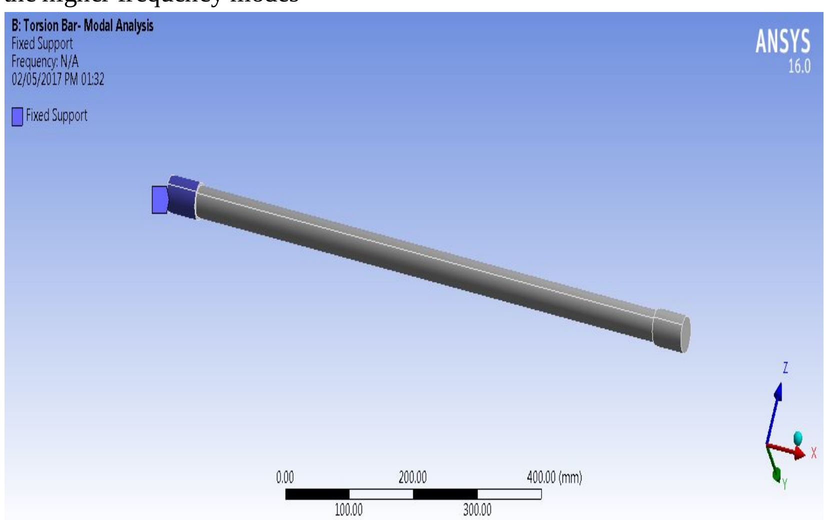

Fig 10: Boundary conditions for torsion bar modal analysis

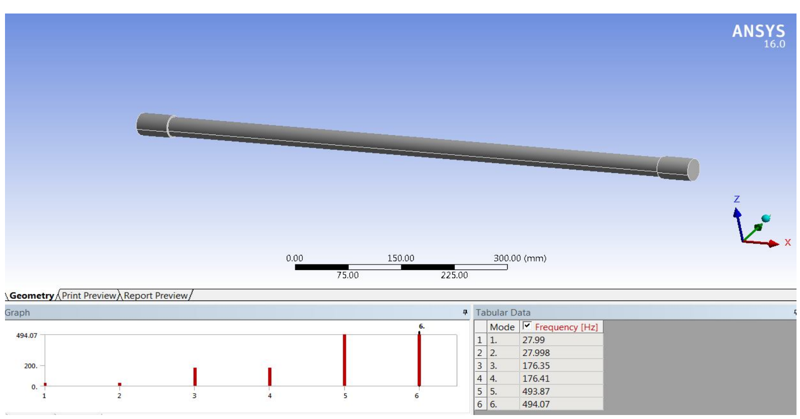

Fig 11: Natural Frequency of Torsion bar

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D. Mode shapes of existing Torsion Bar

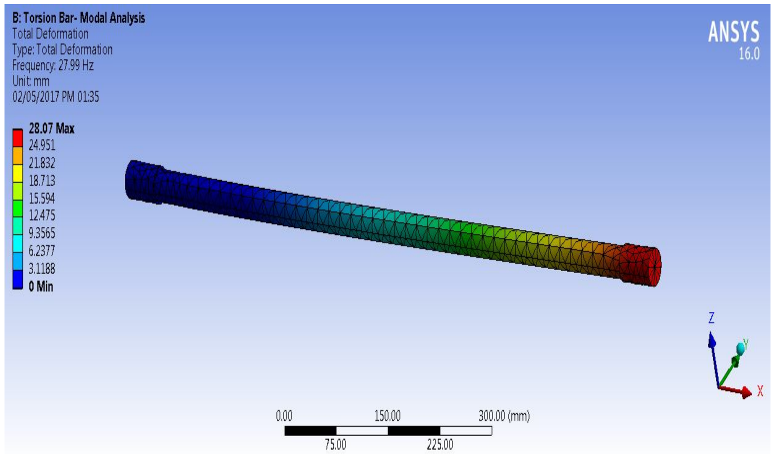

Fig 12: 1st Mode shape of Torsion Bar

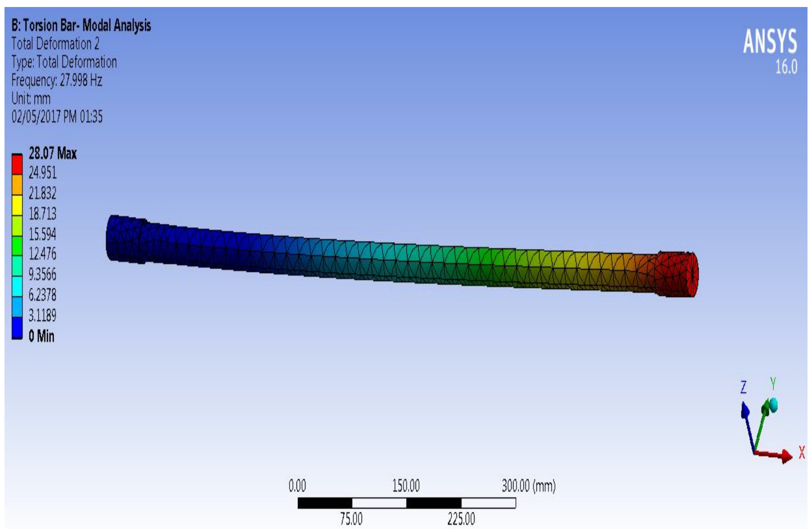

Fig 13: 2nd Mode shape of Torsion Bar

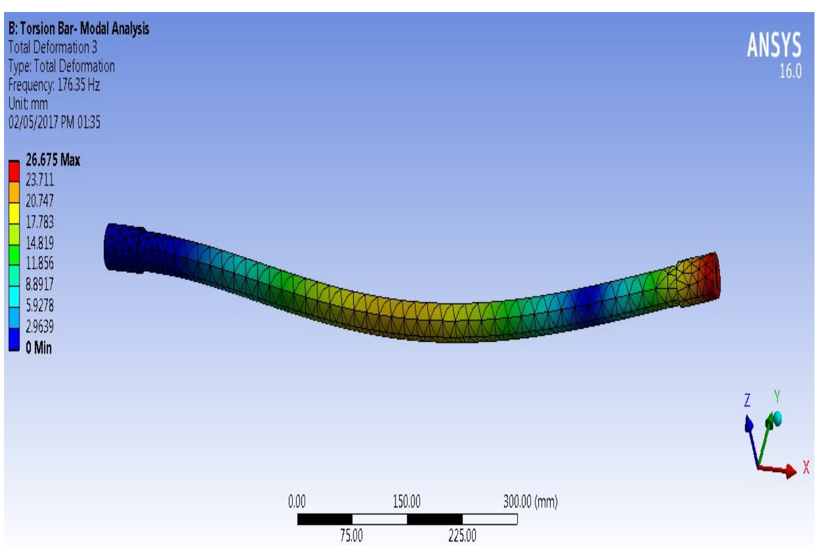

Fig 14: 3rd Mode shape of Torsion Bar

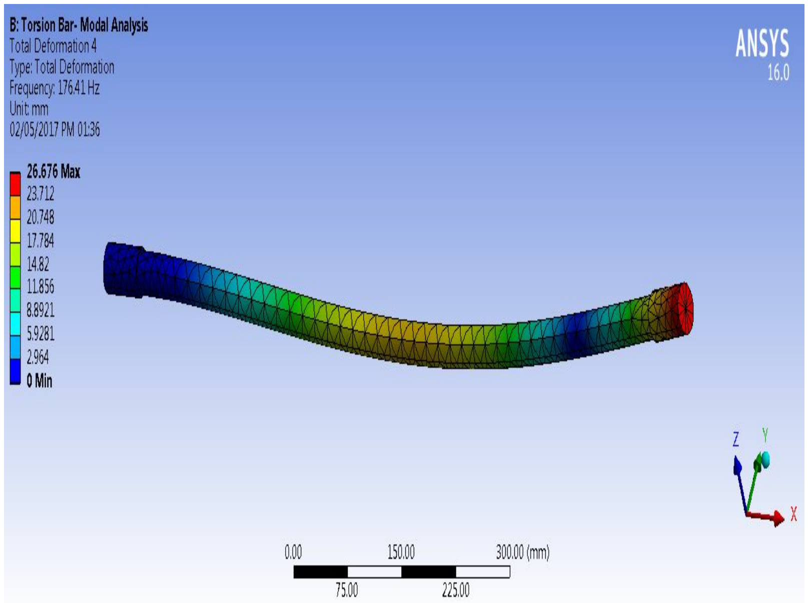

Fig 15: 4th Mode shape of Torsion Bar

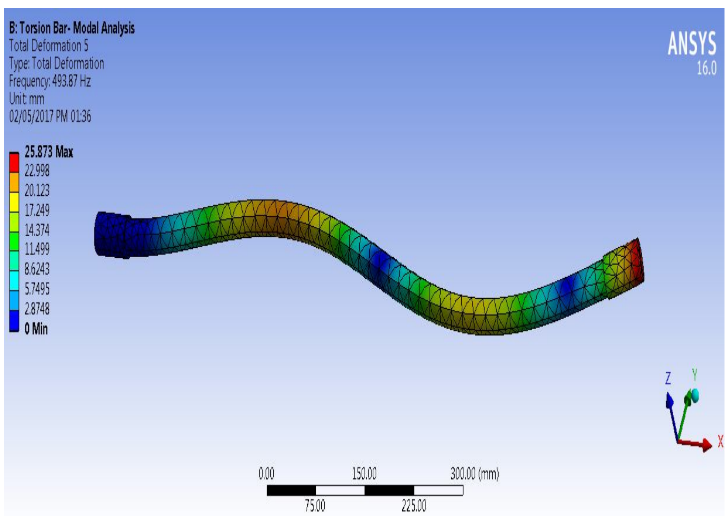

Fig 16: 5th Mode shape of Torsion Bar

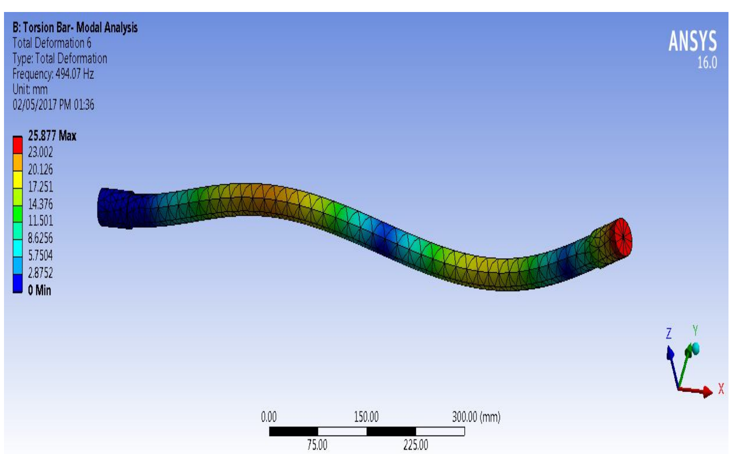

Fig 17: 6th Mode shape of Torsion Bar

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IV. ANALYSIS OF HOLLOW AND COMPOSITE SHAFT

A. Analysis of Hollow Shaft

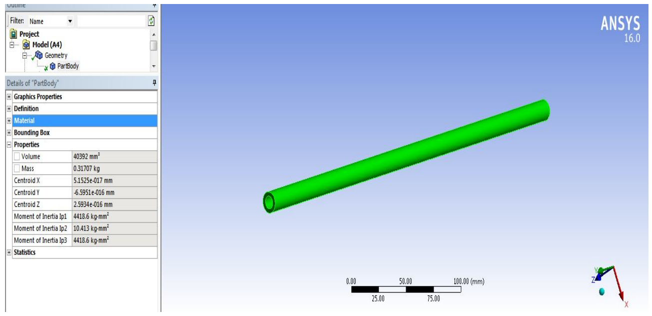

Fig 18: Hollow Shaft imported in ANSYS with weight

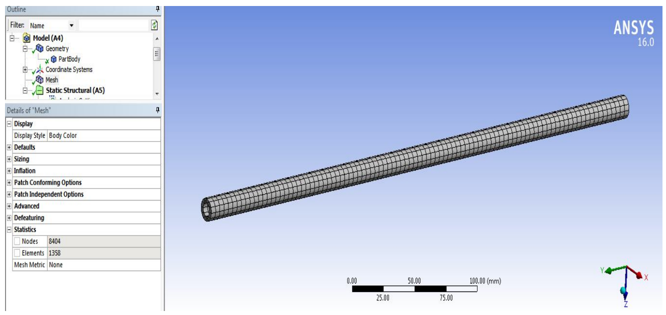

Fig 19: Meshing of the shaft (Hexahedron elements)

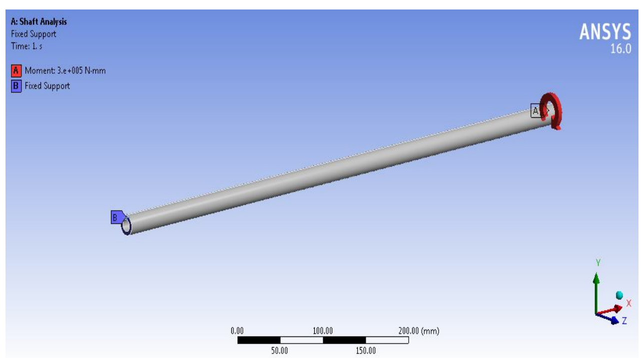

Fig 20: Loading conditions

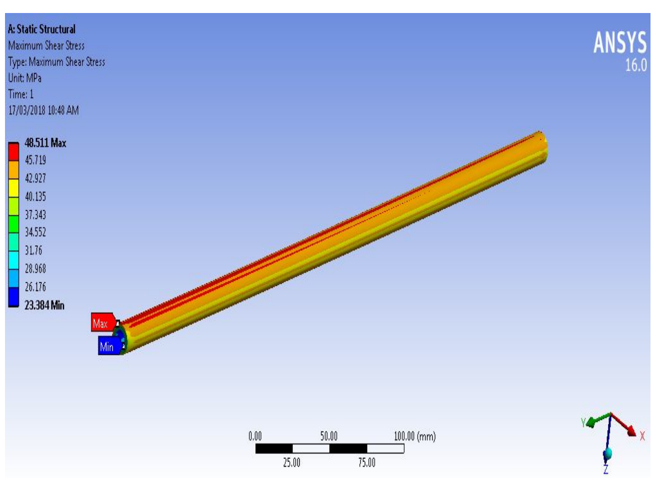

Fig 21: Shear Stress in Hollow shaft for loading

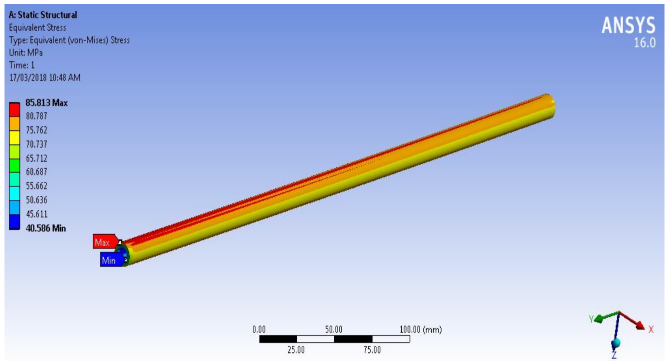

Fig 22: Von-mises Stress in Hollow shaft for loading

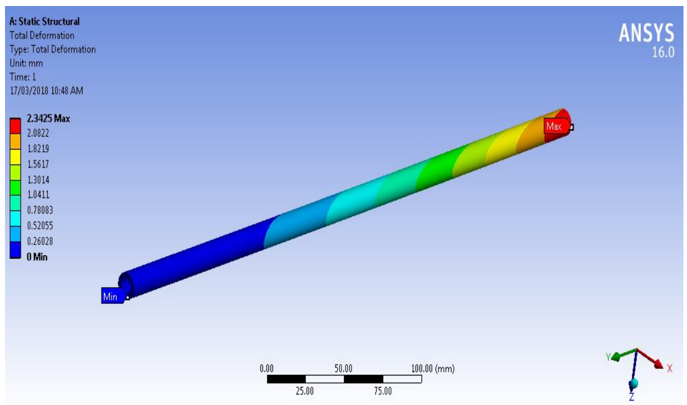

Fig 23: Deformation in Hollow shaft for loading

B. *Composite Solid shaft Analysis*

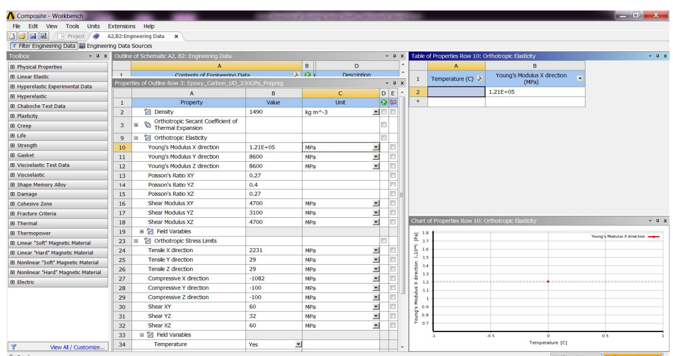

Fig 24: Carbon Epoxy -UD (Uni-directional) and related properties

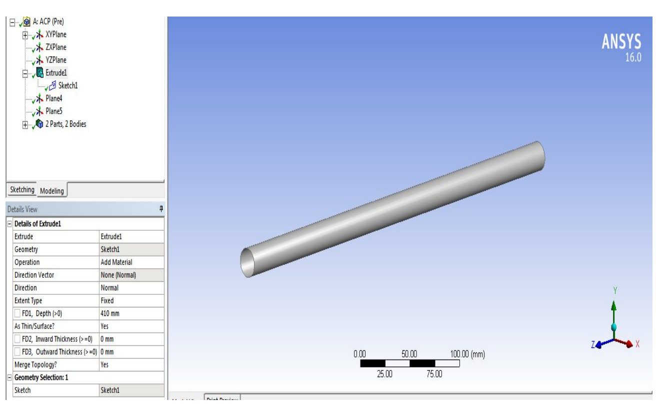

Fig 25: Model created in ANSYS modeller

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1) Layer Formations: (Orientations 0/0/0/0)

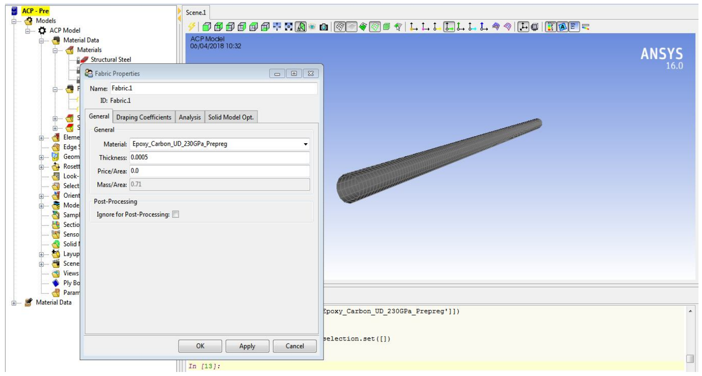

Fig 26: Material application for plies – Total 4 layers each of 0.5 mm thickness

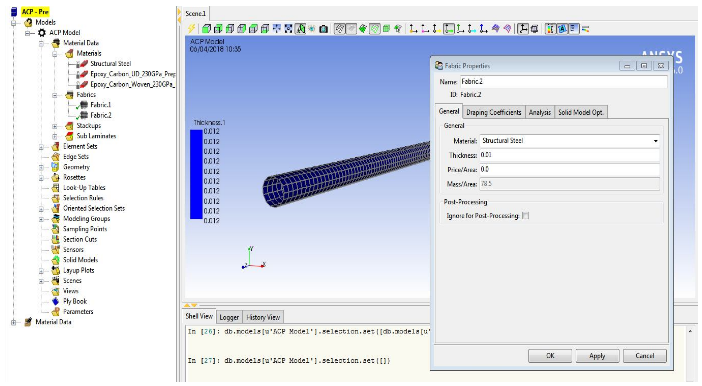

Fig 27: Steel fibre application

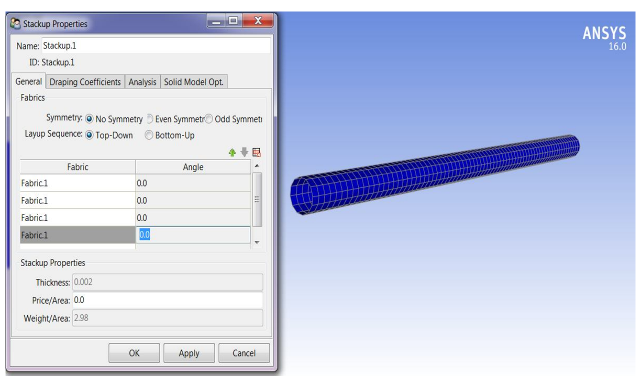

Fig 28: Fibre orientations application

Fig 29: Stacking of layers (From top: 0/0/0/0/Steel)

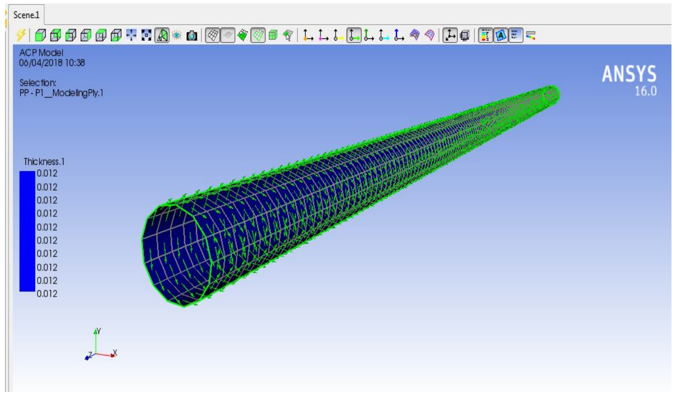

Fig 30: Fibre orientations (Green arrows) (0^0)

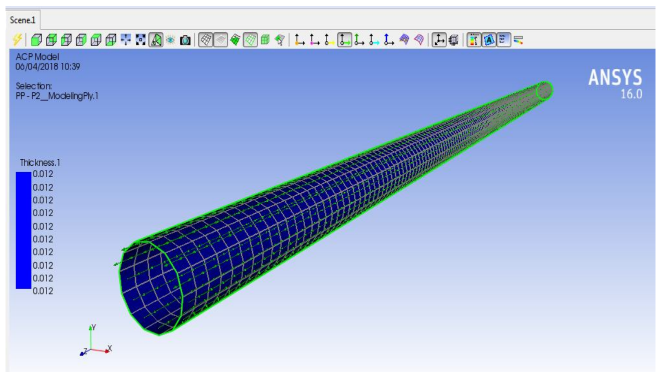

Fig 31: Steel orientations

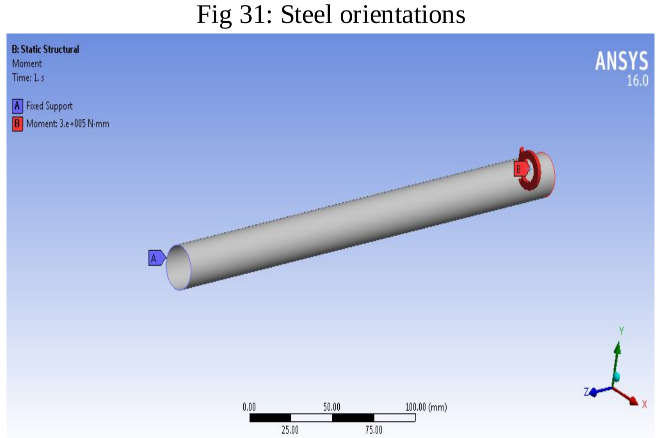

Fig 32: Boundary Conditions

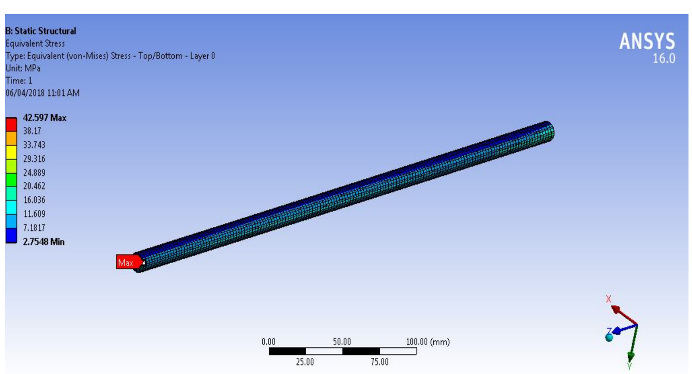

Fig 33: Stresses on Shaft

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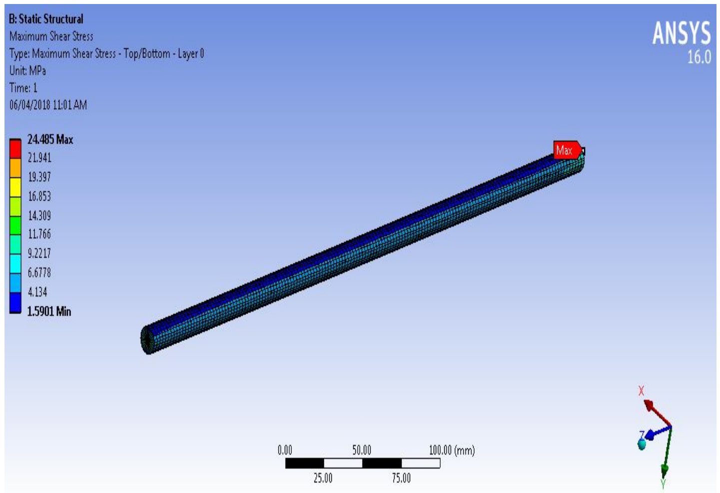

Fig 34: Shear Stresses on Shaft

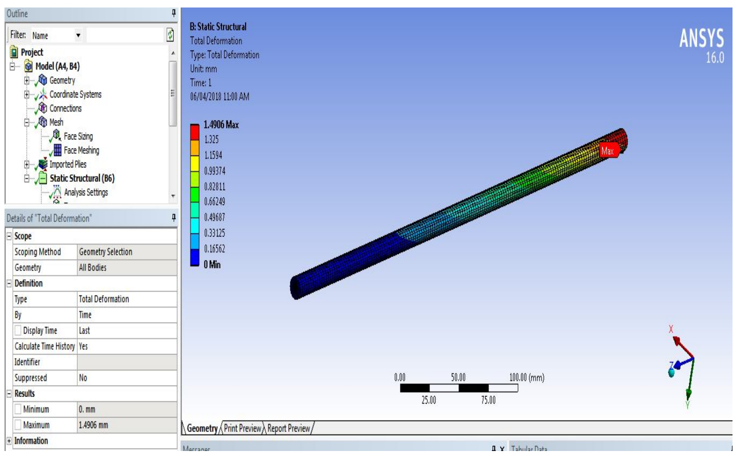

Fig 35: Deformation on Shaft

Table 1: Comparison of Solid steel, solid composite shaft and Hollow Shaft

	Stress, MPa	Shear Stress, MPa	Deformation, mm
Solid shaft	63.716	36.786	1.5958
Solid-Composite ECF UD-0/0/0/0	42.597	24.485	1.4906
Hollow shaft	85.813	48.511	2.3425

From above results we can see that composite shaft of same dimensions and loading gives very good results in stress, deformation; compared to solid and hollow shaft. Further hollow shaft with composite materials at various fibre orientations will be studied for weight reduction.

V. OPTIMIZATION ANALYSIS

A. Optimization of Torsion bar Based on Fibre Orientation Angle

Fiber orientations are selected and FEA analysis is done using the same. The stress and deformation results are summarized in below table.

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Table 2: FEA results for different fibre orientations angles

Fibre Orientation	Von-mises Stress, MPa	Shear Stress, MPa	Deformation, mm
0/0/90/90	52.031	29.917	1.5286
90/90/0/0	55.168	31.716	2.1956
0/0/0/0	42.597	24.485	1.4906
90/90/90/90	74.572	38.569	3.3283
0/0/45/45	50.48	27.728	1.6816
45/45/0/0	31.271	16.341	1.5461
45/45/45/45	46.302	25.325	2.3812
45/45/90/90	60.796	31.526	2.5902
90/90/45/45	61.671	34.599	1.8821

From above results we can see that 45/45/0/0 orientations gives better results than others. Hence selected for further analysis.

A. 45/45/0/0 Composite Analysis results:

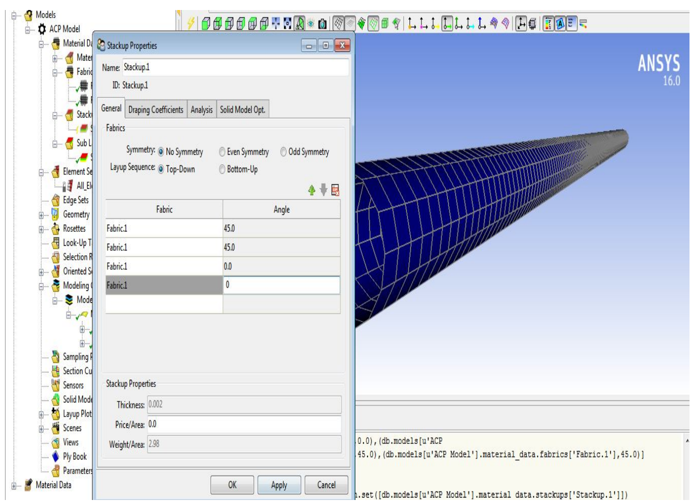

Fig 36: Fibre orientations application

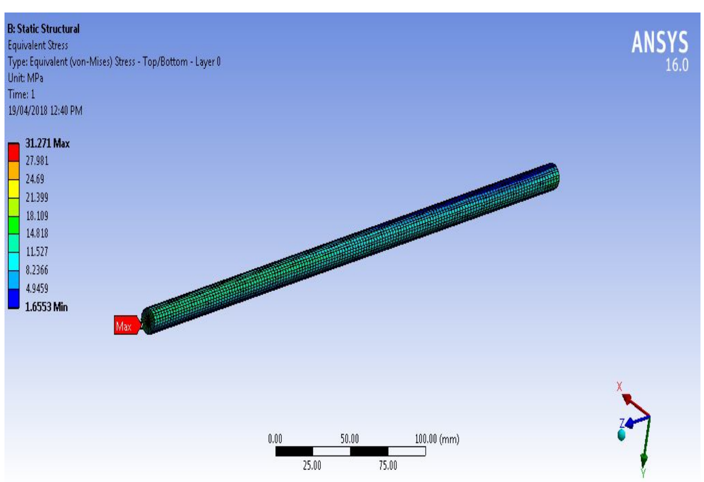

Fig 37: Stresses on Shaft

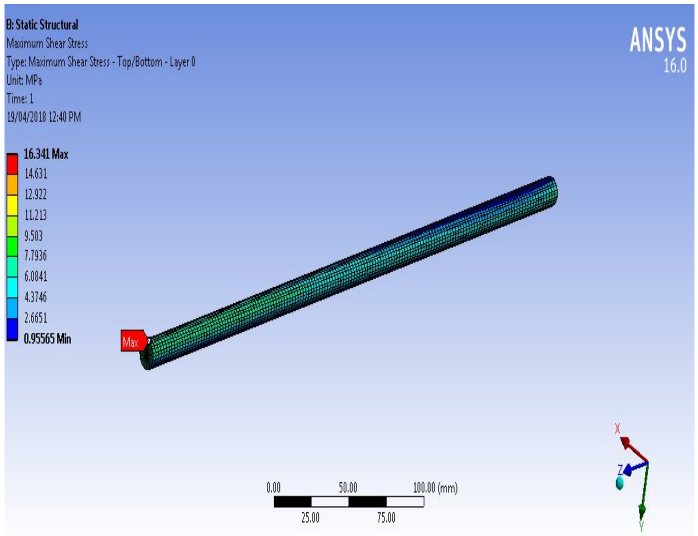

Fig 38: Shear Stresses on Shaft

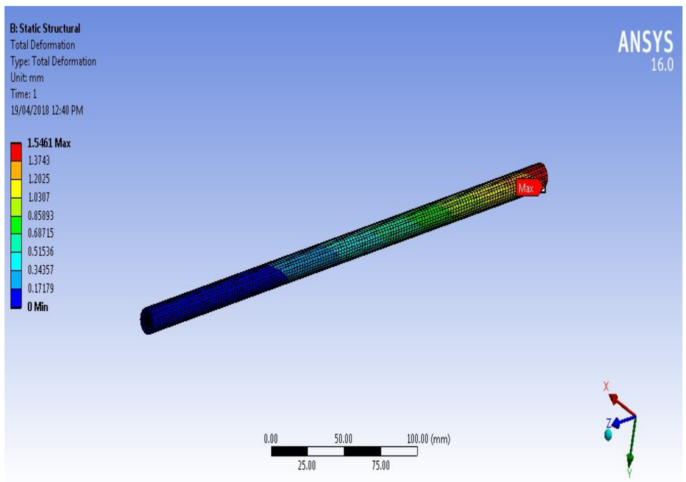

Fig 39: Deformation on Shaft

B. Analysis of selected Torsion bar at 45/45/0/0 fibre Orientations for Different Materials

Material analysis is done using composite materials for 45/45/0/0 orientaion angles and results are plotted in below table.

Table 3: FEA results for different composite materials at 45/45/0/0 orientations

Sr No	Orienta-tions	Material	Stress, MPa	Deforma-tion, mm
1	45/45/0/0	Carbon Epoxy – UD	31.271	1.5461
2	45/45/0/0	Carbon Epoxy – Woven	22.974	1.2555
3	45/45/0/0	E-Glass Epoxy	38.29	1.7577
4	45/45/0/0	Resin Epoxy	53.606	2.511

Carbon Epoxy with Woven (45/45/0/0) gives better results among selected materials.

B. Analysis of Carbon Epoxy with Woven at (45/45/0/0) orientation

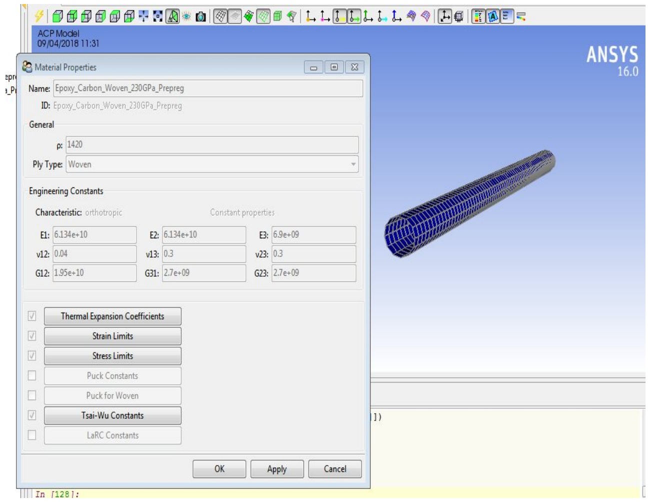

Fig 40: Application of Carbon Epoxy- Woven material

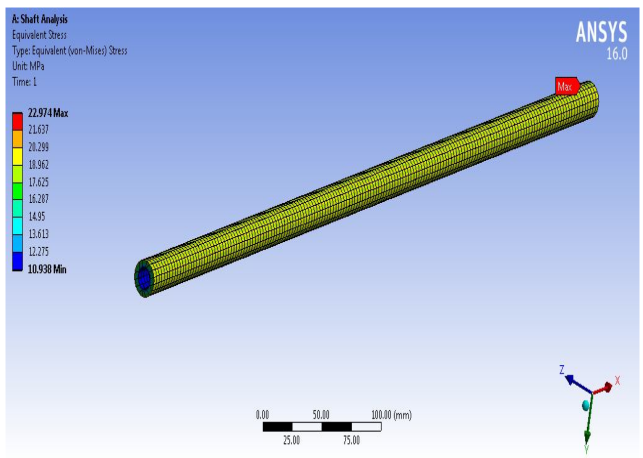

Fig 41: Stresses using Carbon Epoxy- Woven Material

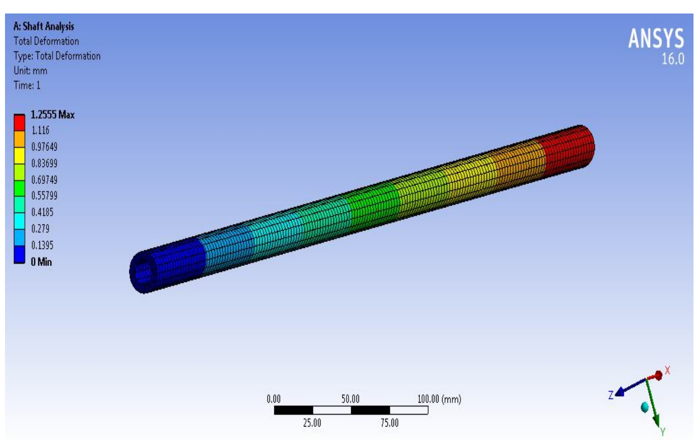

Fig 42: Deformation using Carbon Epoxy- Woven Material

VI. EXPERIMENTAL RESULTS

Experimentation is done for analyzing the torsion bar deformation. As FOS is high for torsion bar so stresses are of secondary importance. The results for deformation are as follows;

Table 4: Experimental deformation

Observation for Disc profile testing					
Parameter	Allowed Limit	Deflection, mm (Recorded during trials)			
Torsion bar - Carbon Epoxy with Woven at (45/45/0/0) orientation Deflection	1.8 mm	1	2	3	Avg
		1.3	1.28	1.28	1.29 mm

Fig 43: Experimental Setup

VII.RESULTS AND DISCUSSION

A. From existing analysis we get that stresses generated are 63.716MPa and Deformation is 1.5958 mm; while from optimized analysis we can see that Stresses are 22.974MPa and Deformation is 1.2555mm.

B. FEA deformation is 1.2555mm and experimental deformation is 1.29 mm and is close to each other.

VIII. CONCLUSION

A. Orientation optimization study is done and Final orientations selected are 45/45/0/0.

B. Material optimization is done and carbon epoxy material-woven is suggested.

C. Stresses and Deformation are less for optimized selection than existing torsion bar.

D. FEA and Experimental deformation results for optimized conveyor parameters shows only 2.67 % error.

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