Analysis of Notched Shaft of ATV Using Composite Material

Mr. Swapnil S Bhandwale[1], Mr. S.S. Pimpale[2]
[1]Dept of Mechanical
[2]Associate Professor, Dept of Mechanical
[1, 2] JSPM's Rajarshi College of Engineering, Pune-411033.

Abstract- *Notch shaft is the most important component to any power transmission application; automotive notch Shaft is one of this. A notch shaft is a mechanical part that transmits the torque generated by a vehicle's engine into usable motive force to propel the vehicle. Due to higher specific stiffness and strength Composite structures have many advantages over conventional metallic structures. This work deals with the replacement of conventional steel notched shafts with fiberglass epoxy composite notched shaft for an automotive application. With the objective of minimizing the weight of composite notched shaft, the design parameters were optimized. The design optimization also improves the performance of notch shaft. Present work deals with FEA analysis of composite shaft made of glass fibers. It includes the modeling of shaft in CATIA. The meshing and boundary condition application will be carried using Hypermesh; Structural analysis of composite shaft will be carried out using ANSYS. After getting satisfactory results, model is fabricated and tested on UTM. The two results i.e. from numerical and experimental should be in line to each other. The conclusion of the work will be, notched shaft made of composite material will have better strength than conventionally used MS shaft. Using composite material will reduce the weight of the shaft which ultimately helps in increasing efficiency.*

Keywords- Notched Shaft, ATV, Composite Material, Glassfibre, Carbonfibre,

I. INTRODUCTION

An all-terrain vehicle (ATV), also known as a quad, quad bike, three-wheeler, or four-wheeler, is defined by the American National Standards Institute (ANSI) as a vehicle that travels on low-pressure tires, with a seat that is balanced by the operator, along with handlebars for steering control. Rapid technological advances in engineering design field result in finding the alternate solution for the conventional materials.

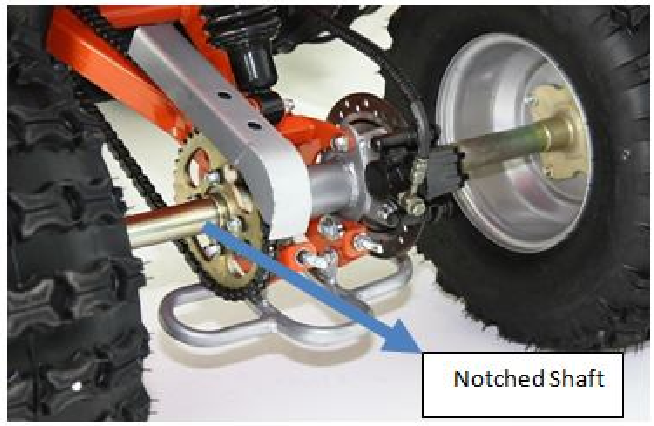


Fig.1 Location of notched shaft in ATV

The design engineers brought to a point to finding the materials which are more reliable than conventional materials. Notched shafts are used as power transmission.

In designing the metallic shaft, knowing the torque and the limiting shear stress for the material, the size of the shaft's cross section can be calculated. In today's days there is a heavy requirement for light weight materials vehicle. Combined cyclic tension, bending and torsional loads during operations known as multiaxial loadings, where principal stresses rotate and change non-proportionally their magnitudes during a loading cycle. Due to the abundance of engineering components with stress concentrations being subjected to complex multiaxial loading histories, studying multiaxial loading of notched members is of great practical importance. In addition, due to the relatively high strength to weight ratio of aluminum, an increasing number of components in key industries, such as automotive and aerospace, are being manufactured from various aluminum alloys. Therefore, it is of special interest to be able to understand the multiaxial loading behavior of these materials. Despite the significance of understanding multiaxial notched loading behavior, limited literature exists on the subject due to the synergistic complexities involved in studying this topic

Fig.2 Notched shaft (Sample Drawing)

- **Composite shaft :-**

The advanced composite materials such as Graphite, Carbon, Kevlar and Glass with suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Enhanced composite materials seem theoretically suited for long, power driver shaft (propeller shaft) applications. Their elastic properties can be tailored to increase the torque they can carry as well as the rotational speed at which they operate.

II. LITERATURE SURVEY

Mehmet Firat[1] :- In this paper, a notch analysis model is presented for the numerical prediction of multiaxial strains of a notched 1070 steel specimen under combined axial and torsion loadings. The proposed model is based on the motion of a structural yield surface and uses a small-strain cyclic plasticity model to describe stress– strain relations. In this paper, a numerical model was presented to predict notch strains of a notched specimen under proportional and non proportional cycling tension–compression–torsion loadings. The proposed model uses elastically calculated notch stresses and a notch stress–strain curve to describe material hardening at the notch root.

Mehmet Firat[2] :- A notch analysis method using a finite element basis is integrated with two critical plane multiaxial fatigue criteria to simulate combined bending–torsion fatigue of SAE 1045 notched specimen. For both in-phase and out-of phase loading tests, predictions were in accord with experimental results and mostly conservative. .In this paper, a simplified method for the calculation of notch stresses and strains was presented and applied for numerical simulation of combined bending–torsion fatigue of a notched specimen.

Ayhan Ince[3] :- A computational fatigue analysis methodology has been proposed here for performing multiaxial fatigue life prediction for notched components using analytical and numerical methods. The intended multiaxial fatigue analysis approach consists of an elastic-plastic stress/strain model and a multiaxial fatigue failure parameter. Results of the proposed multiaxial fatigue analysis methodology are compared to sets of experimental data.

Ayhan Ince , Grzegorz Glinka[4] :- In this paper, two different forms of an original multiaxial fatigue damage parameter related to the maximum fatigue damage plane are proposed for performing fatigue life prediction under various loading conditions loadings. In addition, the damage parameters show reasonably acceptable correlations with experimental fatigue data of SAE 1045 steel notched shafts subjected to proportional and non-proportional loadings. Two different forms of the original damage parameter (the GSE and GSA) have been proposed to estimate the fatigue life for mechanical components under the multiaxial loadings.

AInce, G. Glinka, A. Buczynski[5] :- In this paper, a computational modeling technique of the multiaxial stress–strain notch analysis has been developed to compute elasto-plastic notch tip stress–strain responses using linear elastic FE results of notched components. The simple and adequate multiaxial notch analysis model, which is based on the Garud cyclic plasticity model integrated with the multiaxial Neuber correction rule, has been developed to estimate the elastic–plastic notch tip material behavior of the notch components subjected to the multiaxial non-proportional loadings using linear-elastic FE stress solution.

Nicholas Gates, Ali Fatemi[6] :- The effect of notches on multiaxial fatigue behavior was studied using thin-walled tubular 2024-T3 aluminum specimens with a circular transverse hole. Constant amplitude fully reversed axial, torsion, and in-phase and 90_ out-of-phase axial–torsion tests were performed in load control. Stress analysis was carried out using both Neuber's rule and FEA to study local stress distributions.

III. PROPOSED WORK

Objective:

The main objective of the study is to suggest new material for notch shaft which will enhance its performance

Problem Statement:

Our problem is regarding the weight of shaft. Suitable material must be found to lower the weight of the shaft because world is moving towards using optimized components only.

IV. FEA ANALYSIS

A. Design of notch shaft based on conventional parameters

This chapter design and analysis of notch shaft of dissertation includes design and analysis of existing notch shaft. Dimensions of the existing notch shaft have been extracted from the reverse engineering and CAD model has been prepared in CATIA V5. The finite element analysis is carried out by using Hypermesh and ANSYS.

1. CAD Model Generation

The Notch shaft is measured by hand as the geometry is simple and can be easily measured. The Notch shaft of the ATV is then modeled using CATIA. Shaft dimensions were taken by vernier caliper.

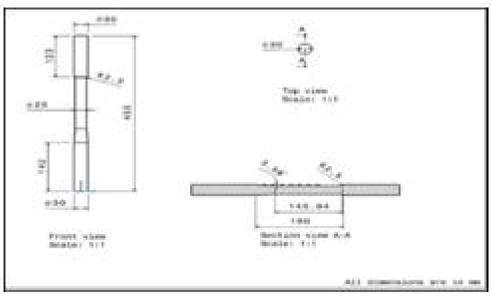


Fig. 3: Model Generation

2. Force Calculation

1) Inputs:

- Wheel base: 47.9 inches ≅ 1.22 m
- Curb weight: 408 pounds ≅ 185 Kg
- C.G: 22 inches ≅ 0.55m
- Total weight including rider: 255 kg
- Weight distribution: Generally, weight
- Distributions on two axles are in the ratio of 45:55. So, 55% of the curb weight will be on rear axle i.e. notched shaft. Therefore, static weight can be calculated as: Static weight on front axle (W1) = 0.45 X 185 = 83 kg
- Static weight on rear axle (W2) = 0.55 X 185 =102kg = 1000N

3. Dynamic Loads

Dynamic loads on front and rear axles are found by considering acceleration at 2.5 m/s^2.

1) Dynamic load on front axle

$$W_f = W_1 + \left(\frac{a}{g}\right) W \left(\frac{h}{L}\right)$$

$$W_f = 83 + \left(\frac{2.5}{9.81}\right) \times 255 \times \left(\frac{0.55}{1.22}\right)$$

$$W_f = 112.3Kg \cong 1101.6N$$

2) Dynamic load on rear axle

$$W_r = W_2 - \left(\frac{a}{g}\right) W \left(\frac{h}{L}\right)$$

$$W_r = 102 - \left(\frac{2.5}{9.81}\right) \times 255 \times \left(\frac{0.55}{1.22}\right)$$

$$W_r = 72.7Kg \cong 713N$$

4. Torque Calculation

Specification:

Power = 41.3 HP
N= 4500 RPM

Power = $\left(\frac{2\pi NT}{60}\right)$

T = 65 Nm

B. FEA analysis of Composite notch shaft

Table I
Material Properties For Steel Material

Property	Value
Young's Modulus, E	205 GPa
Poisson's Ratio ,ν	0.29
Density, ρ	7850 kg/m3

Table Ii
Material Properties For Composite Material

Property	Value
E1	40 GPa
E2	6 GPa
E3	40 GPa
Poisson's Ratio ,ν	0.24
Gxy	15 GPa
Gyz	2.3 GPa
Gzx	15 GPa
Density, ρ	2000m3

Static Analysis Results:
Von-mises Stress:

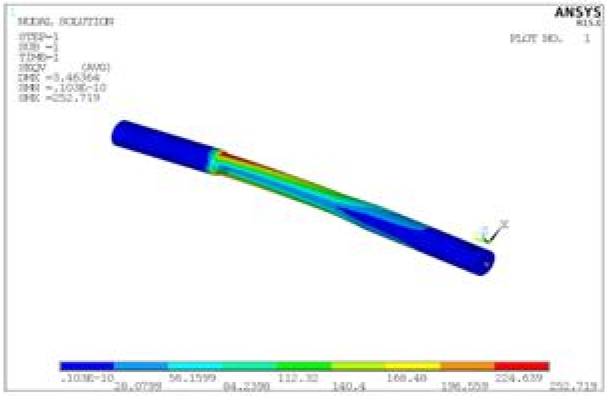


Fig.4: von-mises stress for notch shaft

Stress value of notch shaft is 252.7 N/mm^2 which is well below the critical value (For steel, yield stress = 390 MPa). Hence, design is safe.

- Deformation:

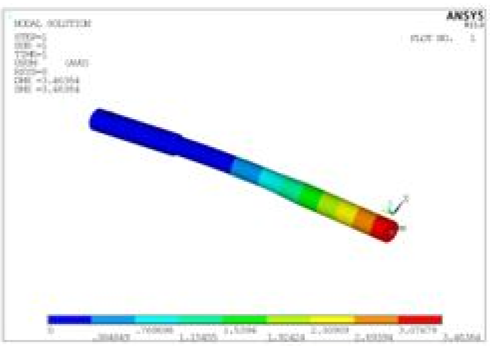


Fig.5: Displacement result of notch shaft

From fig, deformation of notch shaft is 3.46mm

- Closure:

For the dissertation work this chapter is very important, because it gives the relevant information about existing notch shaft. From results of finite element analysis it is checked that the maximum stress value is found out to be 252.8 N/mm^2 which is within the safety limit. There is a great potential to optimize this safety limit which can be done by using composite material thus optimizing its weight without affecting its structural behavior. The maximum displacement value is 3.46mm which is also very less.

- FEA analysis of Composite notch shaft

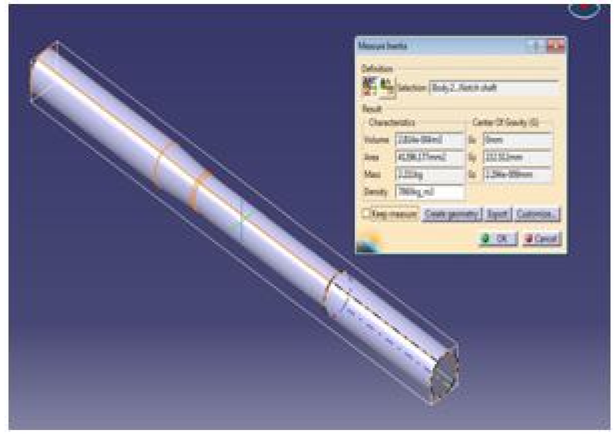


Fig. 6: Assigning Properties to material for conventional material shaft model

Fig. 7: Assigning Properties to material for composite material shaft model

- Analysis on notch shaft by applying bending load

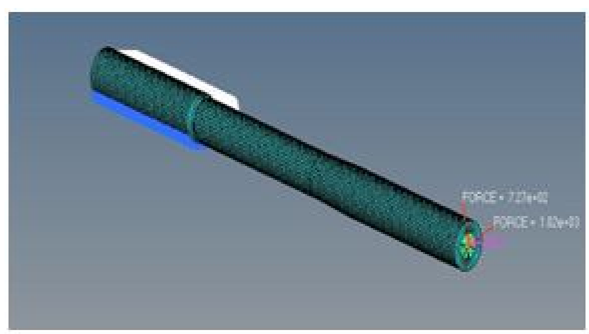


Fig.8: Meshed model for bending test

- Following are the results displayed for stress and deformation:

Von-Mises stress for notch shaft:

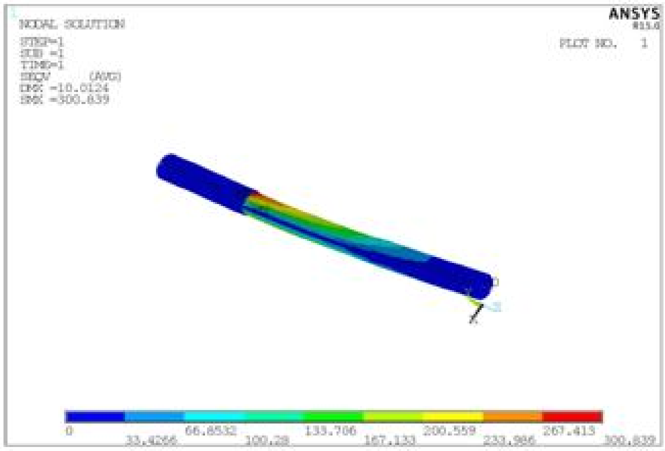


Fig. 9: Von-Mises stress for notch shaft

Stress value for composite notch shaft is 300.83 N/mm^2 which is well below the critical value (For glass fiber, yield stress = 1850 MPa). Hence, design is safe.

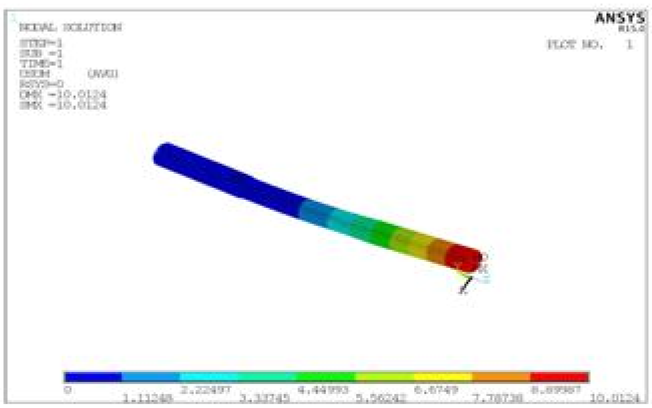


Fig 10: Displacement result for notch shaft

From fig, deformation for composite notch shaft is 10.01 mm.

➢ Analysis on notch shaft by applying torque

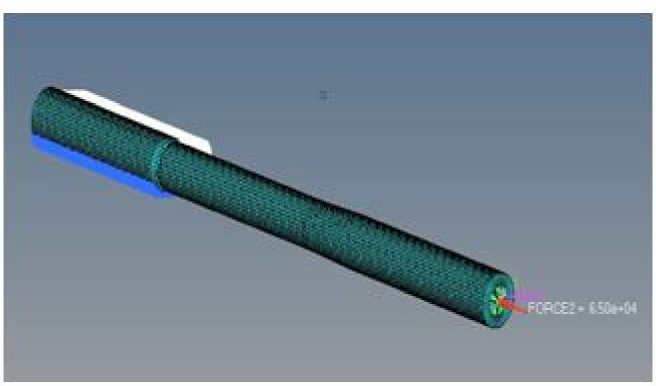


Fig. 11: Meshed model for Torsion test

➢ Following are the results displayed for stress and deformation:

Von-Mises stress for notch shaft:

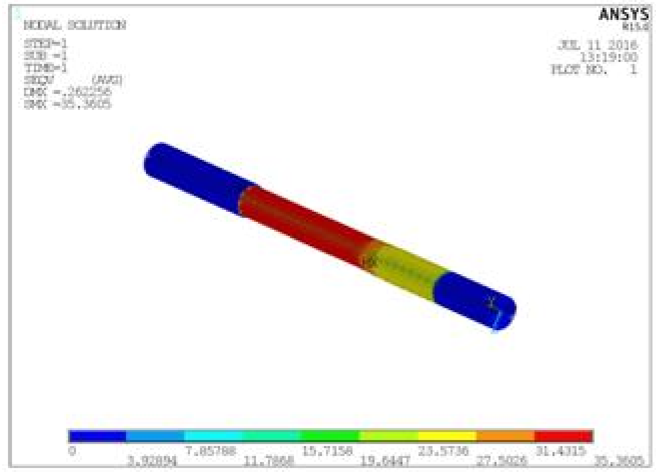


Fig 12: Von-Mises stress for notch shaft

Stress value for composite notch shaft is 35.36 N/mm^2 which is well below the critical value (For glass fiber, yield stress = 1850 MPa). Hence, design is safe.

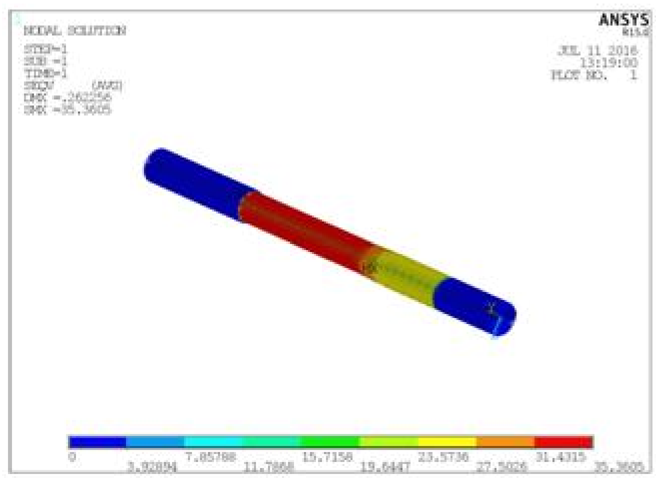


Fig. 13: Displacement result for notch shaft

From fig, deformation for composite notch shaft is 0.26 mm

- Comparison for properties:

Table 3
Comparison Between Properties Of Conventional Steel And Composite Material

Material	Steel	Glass Fiber
Young's Modulus (E)	210GPa	E1-40GPa E2-6Gpa
Poisson's Ratio(υ)	0.3	0.35
Density (ρ)	7850 kg/m3	2000 kg/m3
Yield Stress (σ_{yield})	390 MPa	1850 MPa
Ultimate Tensile Stress (σ_{uts})	450 MPa	2000 MPa

- Comparison for FEA results:

Table 4
Comparison Between Stress And Deformation Limit Obtained By Fea

Material	Max. Stress	Max. Displacement
Steel	252.7 MPa	3.46 mm
Glass Fiber	297.15 MPa	10.05 mm

- Comparison for Manufacturing details:

Table 5
Comparison Between Manufacturing Details Of Steel And Composite Shaft

Material	Raw material cost (Rs.)	Fabrication cost (Rs.)	Wt. of shaft (kg)
Steel	250 (3kg)	300-500	2.211
Glass Fiber	500 (1kg)	2500	0.535

From results of finite element analysis it is observed that all the analysis have stress values less than their respective permissible yield stress values. So the design is safe.

From analysis results and comparison of properties of the materials, it is found that glass fiber is the material which is having the least density; also it is easily available and cheap as compared to other alternate materials. Also machining cost for glass fiber is less. Hence it is the best suited alternate material for notch shaft and is expected to perform better with satisfying amount of weight reduction.

- Fabrication of Prototype:

A prototype is fabricated using epoxy composite material for testing purpose. The prototype is fabricated in KK Engineering, Katraj, Pune.

➢ Fabrication process of composite Notch Shaft:

1. First sheets of glass fiber are taken with width more than length of shaft.
2. Then these sheets rolled over each other layer by layer.
3. While rolling the glass fiber sheets resin is applied after each layer.
4. Then they formed roll of glass fiber is compressed into the mold to have proper adhesion.
5. Then it is kept for drying for two days.
6. After drying, mold is removed and the shaft is turned on the lathe for required size.

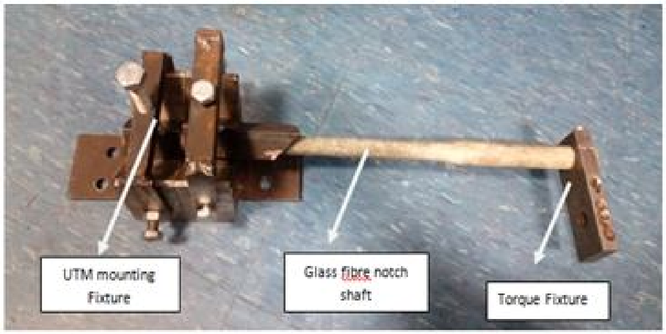


Fig. 14: – Final prototype with fixture

V. EXPERIMENTAL ANALYSIS

The experimental investigation is performed on fabricated prototype on universal testing machine at Praj Metallurgical Lab, Kothrud, Pune. Compression test has been performed on the prototype produced. The input conditions are recreated in the lab while the component is being tested. The loading and the boundary conditions are matching the practical working conditions in which the vehicle is expected to perform. An equivalent maximum torque of 65N-m is applied on the prototype for testing purpose.

➢ For Bending load:

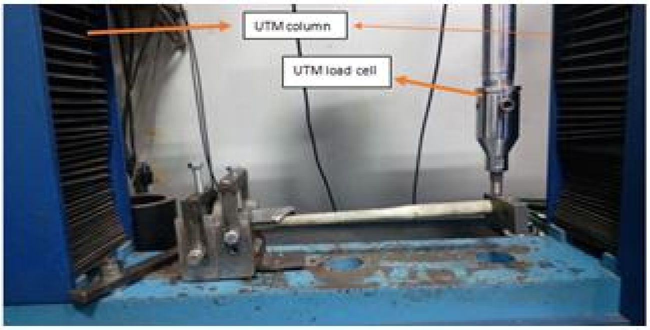


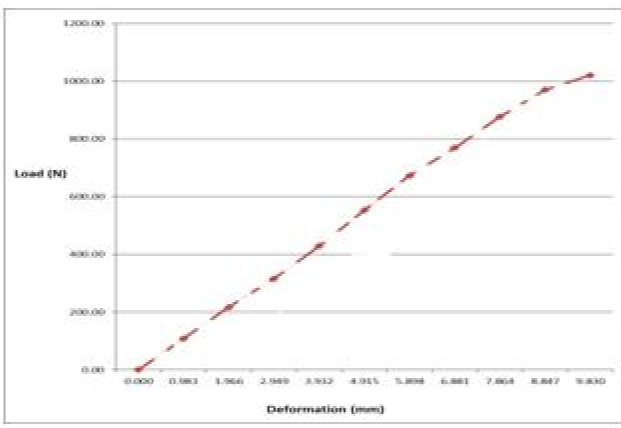
Fig. 15: Fixture loaded on UTM for bending test

- Procedure:

For bending test of the notch shaft, shaft is fixed at one end as shown in the above image. Bending force is applied at the other (free) end of the notch shaft.

- Graph for Bend load Test :

Below graph shows load vs deformation results plotted during bending test on composite specimen. From this graph, we got the values for maximum yield stress and its deformation in elastic region.



Graph 1: Deformation vs Load for bend test

Numerically we got 10.01 mm where in experimental testing it was 9.830. Difference is not so much large and error is 1.79% so we can neglect it and design is safe.

- For Torsional Load:

test

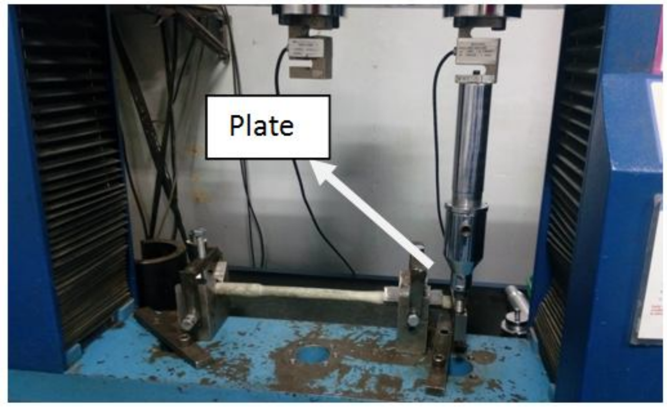


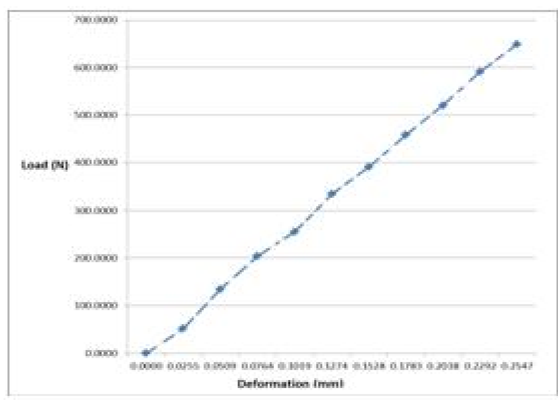
Fig. 16: Fixture loaded on UTM for torsion

- Procedure:

For torsional testing of the notch shaft, shaft is fixed at one end such that it shouldn't slip in the fixture while application of the torque. A plate is attached at the other (free) end of the notch shaft as shown in the above image. Then the force is applied at the free end of the attached plate which will apply torque on the shaft due eccentric loading condition.

- Graph for Torsional Load Test :

Below graph shows load vs deformation results plotted during torsion test on composite specimen.



Graph 2: Deformation vs Load for Torsion test

From this graph, we got the values for maximum yield stress and its deformation in elastic region. Numerically we got 0.2620 mm where in experimental testing it was 0.2547. Error is of 2.78% so we can neglect it and design is safe.

- Comparison for FEA and Experimental Testing for composite shaft :

Table 6
Comparison Between Fea Result And Experimental Results For Composite Shaft.

Sr. No.	Results	Deformation (mm)	
		Bending	Torsional
1	FEA results	10.01	0.2620
2	Experimental results	9.830	0.2547
3	% error	1.79 %	2.78 %

VI. CONCLUSION

1. Notch shaft is manufactured using glass fiber by a layer by layer approach and simulation is carried out in FEA.
2. The different orientations of the layers result in good results for different loading conditions
3. The fabricated model is tested for bending & torsional loadings and then validated experimentally against FEA results.
4. From the validation of FEA results, it is shown that the use of glass fiber as the material for notch shaft has reduced the deformation of notch shaft under bending and torsional loadings.
5. Hence the objective of the project to reduce weight of shaft has been satisfied.

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