INDIAN JOURNAL OF SCIENCE AND TECHNOLOGY

RESEARCH ARTICLE

Experimental and Finite Element Analysis of Reinforced Composite Front Drive Axle

P J Patil[1]*, P G Inamdar[2], K D Joshi[1], P V Mulik[1], M R Jadhav[1]

1 Assistant Professor, Tatyasaheb Kore Institute of Engineering and Technology, 416113, Warananagar, India
2 M.Tech Student, Tatyasaheb Kore Institute of Engineering and Technology, 416113, Warananagar, India

OPEN ACCESS

Received: 30-03-2022

Accepted: 21-09-2022

Published: 10-11-2022

Citation: Patil PJ, Inamdar PG, Joshi KD, Mulik PV, Jadhav MR (2022) Experimental and Finite Element Analysis of Reinforced Composite Front Drive Axle. Indian Journal of Science and Technology 15(42): 2230-2239. https://doi.org/10.17485/IJST/v15i42.715

* **Corresponding author**.

pjpmech@tkietwarana.ac.in
rashika29may@gmail.com

Funding: None

Competing Interests: None

Published By Indian Society for Education and Environment (iSee)

ISSN
Print: 0974-6846
Electronic: 0974-5645

Abstract

Objective: The prime objective of this study is to find out the best replacement for a conventional Steel front drive axle to reduce its weight and to verify its suitability for vehicular application. The study also aims to suggest appropriate Composite material and the best manufacturing technique for the proposed axle. **Methods:** Front drive axle of Maruti Alto 800has been selected for analysis which is carried out by Experimental and Fe method, 3D CAD model for this purpose has been prepared in CATIA V5. In ANSYS preprocessor, boundary conditions have been applied on FE model of front drive axle to simulate actual working conditions. Experimental analysis of the axle, manufactured with reinforced composite is carried out by strain gauge technique. **Findings:** The comparative study of results obtained by FE method and experimental technique has been carried out to estimate percentage error between them. The study shows that there is a fairly good agreement between these results. The maximum error recorded is within 0.46%. Angular deformation and the stresses generated in the axle made up of only composite are larger than these in steel axle. Reinforcement is necessary in order to get benefits of weight reduction as well as strength. Composite material with the specification 54% SiO_2 -15% Al_2O_3-12% CaO is one of the best combinations for the replacement of steel front drive axle. The drive axle made up of steel with 5 mm coating of aforementioned composite material is the best replacement for a steel axle of Alto 800. **Novelty:** A 41% reduction in heaviness is possible by substituting the conventional steel [SM45C] front drive axle of by the one made up of reinforced composite.

Keywords: Front drive axle; FE analysis; Strain gauge analysis; Composite reinforcement

1 Introduction

Vehicle efficiency and performance mainly depends on its power to weight ratio [1]. In today's era the main objective of designer is to reduce the weight of various components of automobile without compromising mechanical requirements in order to enhance efficiency and performance. Vehicles are broadly classified as front drive vehicles and rear drive vehicles. A front drive vehicle does not have a propeller shaft and front drive axle is main component of power transmission system. In case of front drive vehicles, the absence of propeller shaft allows the designer to lower the floor height and increase the passenger section and trunk. In case of front drive axle of automobile weight reduction and strength are prime requirements. To optimize the performance and efficiency of vehicle, the axle must be light in weight, strong and tough [2]. Presently in case of weight sensitive applications such as automobile, aircraft etc composite materials with fiber reinforcement are best alternative for metal. Composite materials are being used in the automobile industry to reduce the weight [3]. Optimization of cost of manufacturing is possible with composite material [4]. Carbon and glass composites with epoxy resin have gained popularity due to their high strength and elasticity over conventional materials [5]. Replacement of the existing steel driveshaft with the one manufactured with high specific strength carbon epoxy composite provides improvements in maximum principal stresses, maximum shear stresses due to torsional moment [6,7]. A reinforced composite shaft with a coating angle of 45 degrees can withstand greater static torsion than that with 90 degrees [8]. Today's engineering calls for a precise and convergent method of analysis which necessitates the designer to revisit various standards therein to understand common engineering fundamentals [9] To verify and validate the efficiency of theoretical and numerical analysis, experimental methods are essential, though they are complicated and expensive, and can be used credibly in special cases like torsional stress analysis [10]. For evaluation of torsional strength of composite drive axle, maximum stress criteria are utilised [11]. The drop in weight of an automobile directly affects fuel efficiency of an automobile [12]. Maximum principal stress of composite driveshaft is more than permissible stresses also maximum shear stress developed in composite driveshaft is nearly 36 percent lower than the conventional steel driveshaft [13]. Polymeric conventional materials coated with artificial fibres, such as carbon, E-glass, and S-glass, provide better strength and toughness at a lower weight than existing materials such as concrete, wood, and steel [14]. It is interpreted that using strain gauge method, variation of the residual stresses can be predicted not only at the point of interest but in its vicinity as well. In strain gauge analysis, important parameters that should be considered to maintain accuracy in the results are selection and locations for mounting of strain gauges [15].

In order to reduce the weight of front axle, reinforced composite will provide the best replacement to steel. As front drive axle is one of the crucial components in automobile, it is a prime requirement to verify the reliability of composite reinforced front derive axle. As front drive axle is subjected to reversible stresses it is necessary to carry out its precise analysis. The best way is to determine the load that comes on axle and analyze.

To address all these issues, it is felt necessary to carry out experimental and Finite Element Analysis of Reinforced Composite Front Drive Axle with following objectives:

1. To evaluate the stress and angular deformation in Reinforced Composite Front Drive Axle
2. To estimate the optimum thickness of coating
3. To find out percentage weight reduction

In this study, the front drive axle of Maruti Alto 800 has been selected. Table 1 represents the dimension details of front drive axle. The material of conventional front drive axle is steel SM45C.

Table 1. Dimension Details of Steel Drive Axle

Parameters	Value (mm)
Diameter of axle shaft (d)	22
Diameter of Ends (d_1)	18
Length (L)	380

Speed of drive Axle = Tyre revolutions × Ratio of first gear

= 10.73 ×3.415 = 36.64 rev/sec

Torque in drive axle = $\frac{Torque\ produced\ by\ engine \times Speed\ of\ first\ gear}{Speed\ of\ drive\ axle}$

The torque acted on drive axle is 84600 N-mm.

2 Methodology

Experimental stress analysis of composite reinforced front drive axle of Maruti Alto 800 has been carried out using strain gauge technique. ANSYS 15.0 has been used to carryout finite element analysis of front drive axle with and without reinforcement. Finite element analysis of steel axles with various thickness of composite coating is carried out and the variant with 5 mm coating thickness was found to have the least angular deformation and induced stresses. The same variant was then tested experimentally on Strain recorder. The results, in terms of von-Mises stresses and Angular deformation obtained by both these methods have been compared and found to have a fairly good agreement between each other, with an error of a meagre 0.46%.

3 Finite Element Analysis of Conventional Front drive axle

FE analysis of steel front drive axle is carried out using ANSYS is as described below.

3.1 Modeling

The CAD model of front drive axle has been prepared in CATIA V5 software in such a way that it closely resembles the actual front drive axle.

3.2 Pre-processing

- Meshing

In ANSYS area of front drive axle is meshed using Tetrahedral element, Solid 182.

- Defining Material Properties

Following material properties of Steel [SM45C] have been defined:
Material Density = 7850 Kg/ m^3. Young's Modulus (E) = 2 X 10^5 N/ mm^2
Poisson's ratio (γ) = 0.3, Tensile Stress = 750 N/mm^2, Yield stress = 340 N/mm^2

- Loading and Boundary Conditions

Boundary conditions have been applied on the meshed model of axle to simulate actual working conditions. Application of torque and restricting the degree of freedom are two steps involved in defining boundary conditions. The FE model considers a moment in terms of torque 84600N-mm at one end and fixed displacement constraint at another end. Figure 1 represents meshed model along with constraints and applied torque.

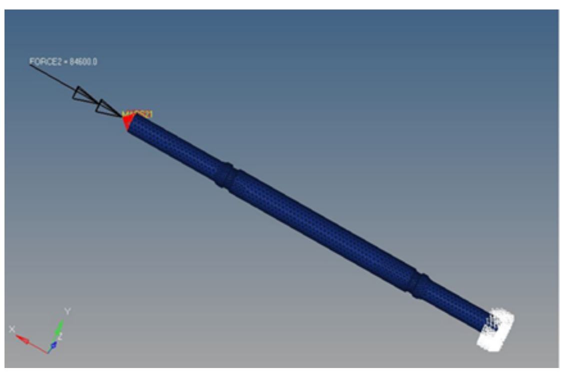

Fig 1. Tetrahedral meshing with boundary condition

3.3 Post Processing

The results obtained from the solver are displayed in the post-processor. The angular deformation and von-Mises stresses are as shown in Figure 2 & Figure 3. The results, such as maximum angular deformation and von-Mises stress are listed in Table 3.

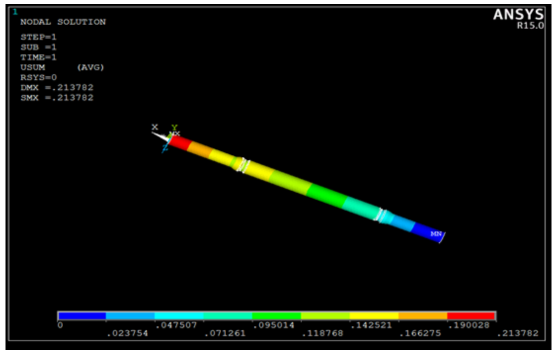

Fig 2. Angular Deformation plot (Steel)

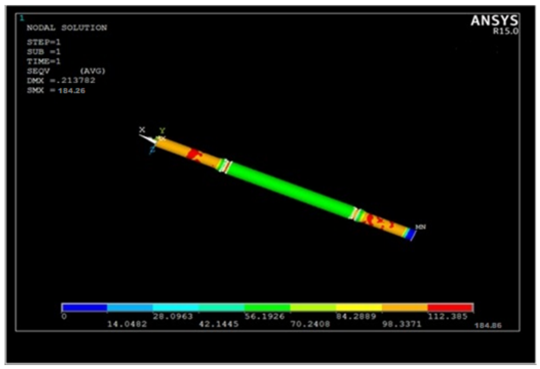

Fig 3. Von-Mises stresses (Steel)

4 FE Analysis of Front Drive Axle made up of Composite and Reinforced Composite

FE analysis of composite axle as with and without reinforcement. It is carried out using ANSYS as described below:

4.1 Pre-processing

- Modeling and Meshing

The meshed model of steel [SM45C] drive axle is coated with help of linear structural shell elements with optimal three layers of 1mm thickness with best stacking order [90, 45, -45] to obtain coating thickness of 3 mm. Similar procedure has been adopted to prepare models with coating thickness of 4 mm and 5 mm with best stacking order [90, 45, -45, 0] & [90, 45, -45, 45, 0] respectively.

- Defining Material Properties

Properties of composite material and steel are as listed in Table 2:

Table 2. Steel and Glass Fiber Properties

Property	Glass Fiber	Steel [SM45C]
Young's Modulus (Ex)	40300 MPa	207000 MPa
Young's Modulus (E_Y)	6210 MPa	-
Young's Modulus (E_Z)	40300 MPa	-
Poisson's Ratio (ν)	0.2	0.3
Density (ρ)	1723.65 kg/m^3	7600 Kg/m^3
Shear Modulus (G_{XY})	3070 MPa	80000 MPa
Shear Modulus (G_{YZ})	2390 MPa	-

Continued on next page

Table 2 continued

Shear Modulus (G_{ZX})	1550 MPa	-
Yield Strength- Tensile	2500 MPa	275 MPa
Yield Strength- Compressive	3150 MPa	370 MPa

- Loading and Boundary Conditions

Boundary conditions have been applied on FE models of both the variants of composite axle i.e. with and without the reinforcement so as to simulate actual working conditions. Applying torque and restricting the degree of freedom are two steps involved in defining boundary conditions. The FE model considers a moment in terms of torque of 84600N-mm at one end and fixed displacement constraint at another end. Figure 4 shows meshed FE model of the axle with 4mm thickness of composite as well as torque applied.

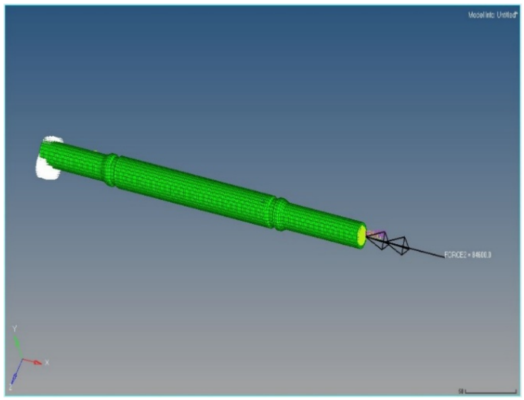

Fig 4. Meshed model with applied constraints and load (4mm coating thickness)

4.2 Post Processing for FE model of Composite axle and Reinforced Composite Front Axle

The results obtained from the solver are displayed by post-processor. von-Mises stresses and angular deformation in composite axle are as shown in Figures 5 and 6. Similarly, Figures 7 and 8 show the results in case of Reinforced composite axle with a coating thickness of 5 mm. Table 3 enlists the maximum angular deformation and von Mises stresses in composite and the Reinforced composite axle with 3, 4 and 5 mm coating thicknesses.

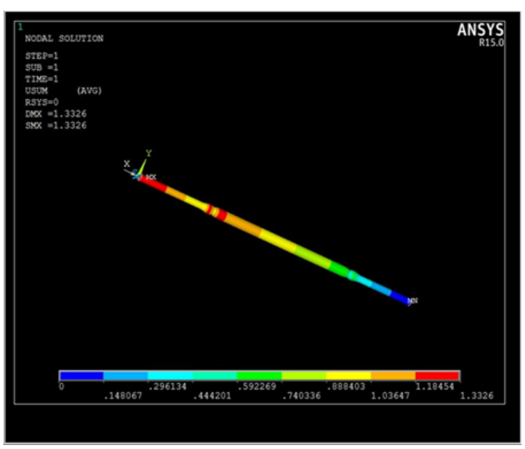

Fig 5. Angular Deformation plot (Composite)

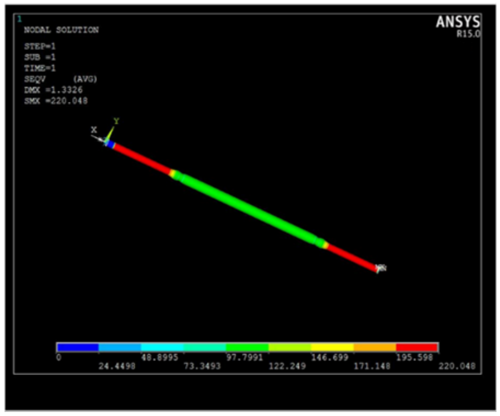

Fig 6. Von-Mises stresses (composite)

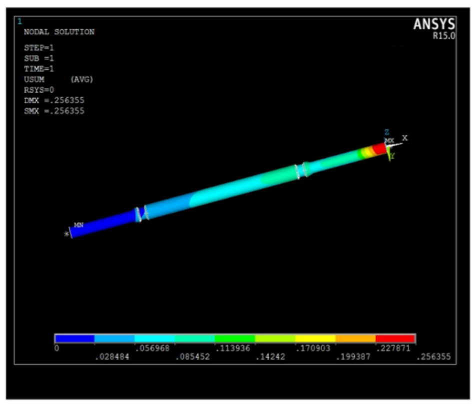

Fig 7. Angular Deformation plot (Coating thickness of5mm)

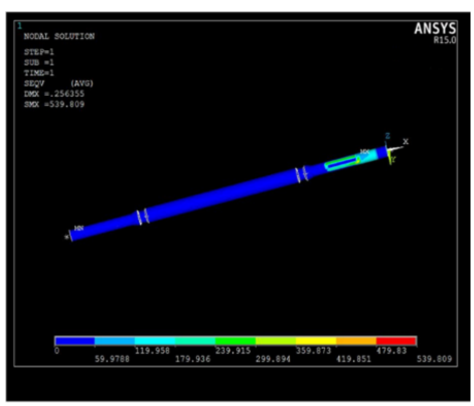

Fig 8. Von-Mises stress plot (Coating thickness of 5mm)

5 Optimization of Coating Thickness

Table 3 enlists the angular deformation and von-Mises stress distribution for steel axle, Composite axle and Reinforced composite axle with various coating thickness. It is clearly understood that Reinforced composite axle with 5 mm coating thickness (iteration 4) has experienced lower stress as well as least angular deformation. Hence to validate the FEA results, same variant has been selected for experimental analysis.

6 Experimental Analysis

Experimental stress analysis of reinforced composite front drive axle has been carried out using strain gauge technique wherein electrical resistance strain gauge are used. The composition of composite is 15% Al_2O_3-54 % SiO_2-12 % CaO.

6.1 Manufacturing of reinforced composite axle

To manufacture the reinforced composite axle, a steel axle of 12 mm diameter is used and layers of glass fiber reinforcement are applied on it. Finally, machining is carried out to obtain 5 mm thickness of the reinforcement layer so that the overall diameter of the axle will be 22 mm. The manufactured reinforced front drive axle is as shown in Figure 9.

Fig 9. Composite reinforced front drive axle with 5mm coating thickness

6.2 Selection of strain gauge and Bonding

Considering the load coming on the drive axle and strain developed in it, electrical resistance type strain gauge has been selected. Using SG496 adhesive, the strain gauges are bonded. Standard procedure of strain gauge mounting is followed and to verify the correctness of mounting, a multi-meter has been used to measure the strain gauge resistance (350 Ω).

6.3 Measurement of strain

To simulate actual loading conditions, the desired torque on reinforced composite front drive axle is applied using torsional testing machine. The strain developed in the axle due to application of desired torque is recorded with the help of a strain gauge recorder. Figure 10 represents the experimental setup.

Fig 10. Strain measurement setup

6.4 Evaluation of Stress

The strain registered by the strain recorder is in micro strain. Following calculations are performed to obtain stresses.

- Sample calculation

Strain recorded in reinforced composite axle is 319-micro strain for applied torque of 84600 N-mm.

For torsional analysis strain is considered to be $319\times\sqrt{2}$ =451.13 micro strain.

As per Hooke's law,

$$\sigma = E \times \varepsilon \tag{1}$$

As per the specification of composite glass fiber material,

Young's modulus (Ex) = 40300 x 10^7 N/mm^2

Substituting values of E and ε in equation 1,

$\sigma = 40300 \times 10^7 \times 451.13 \times 10^{-6}$

Induced Stress (σ) = 181.80 MPa.

7 Results and Discussion

In today's scenario, in order to enhance the efficiency of automobile, design engineers and researchers are looking for suitable lightweight material for manufacturing various components of automobile. Composite materials are being used in the automobile industry to reduce the weight. In case of composite materials its strength and reliability are the major issues particularly when component is subjected to high speed and torsional load. In order to get benefits of lightweight as well as strength reinforced composites are recently introduced as best replacements to conventional materials. This work is intended to identify the best option among various materials which include steel, composite and reinforced composite to manufacture a front drive axle of Alto 800, to optimize the coating thickness of composite material on steel front drive axle and to determine the percentage weight reduction. As such torsional stress analysis of conventional as well as composite and reinforced composite axle has been carried out using FE analysis. To verify the FEA results, experimental analysis of reinforced composite front drive axle has been carried out using strain gauge technique.

From the results listed in Table 3 it is clear that reinforced composite front axle with 5 mm coating thickness (iteration 4) has experienced lower stresses as well the least angular deformation. Composite material with the specification 54SiO_2-Al_2O_3-CaO is one of the best combinations for the replacement of steel front drive axle[5].

Table 3. Comparison of angular deformation and von-Mises stress for different coating thickness

Iterations	von Mises Stresses (MPa)	Angular Deformation (Radian)
Conventional	184.26	0.21
Iteration 1 (Only Composite)	220.04	1.33
Iteration 2 (3mm composite reinforcement)	210.07	0.256
Iteration 3 (4mm composite reinforcement)	198.-03	0.182
Iteration 4 (5mm composite reinforcement)	182.64	0.042

One of the significant conclusions that can be drawn from the results enlisted in Table 3 is that manufacturing a component, often working under impact load, fully with Composite material may make it light weight, as per the current industrial demand, but it induces not only large amount of angular deformations but the stresses as well that affects the strength[2]. On the other hand, it is seen that if the same composite is employed in layers as described in this paper over the conventionally used material, say Steel, it not only becomes a lightweight variant but the angular deformations induced are lowered accompanied by significantly reduced stresses. The thickness of the composites' layer can experimentally be varied to achieve a variety of desirable levels of weight and strength combinations and even a breakeven for a given component, thereby achieving safe levels of angular deformations.

Table 4 shows the torsional stresses obtained from various techniques for reinforced composite front drive axle with coating thickness of 5 mm. There is fairly good agreement between FEA and experimental results. The error recorded is less than 0.5 percent[1,3].

Table 5 shows the weight comparison of conventional as well as reinforced composite front drive axle. It is understood that there is 41% reduction in heaviness is possible by substituting the conventional steel [SM45C] front drive axle by its reinforced composite counterpart[4,7].

Table 4. Comparison of FEA and Experimental results of composite glass fiber reinforced front drive axle

Method	FEA Stress (MPa)	Experimental Stress (MPa)	Error (%)
Stress	182.64	181.80	0.46

Table 5. Weight comparison of conventional steel axle and reinforced composite axle

Material	Weight (Kg)
Conventional [SM45C]	0.978
Reinforced composite	0.568
Decrease in weight (%)	41

8 Conclusions

From this extensive FE and experimental analysis of steel, composite and Composite reinforced composite front drive axle, the following conclusions have been drawn:

- Composite material with the specification 54%SiO_2-15%Al_2O_3-12%CaO is one of the best combinations as a replacement to conventional steel front drive axle.
- The angular deformation and stress observed in drive axle made up of only composite material are more than in steel drive axle. This necessitates the drive axle to be manufactured in composite with reinforcement in order to improve the strength and achieve the weight reduction as well.
- In case of automobile components, reinforcement is necessary to get benefits of weight reduction as well as improvement in strength.
- The composite glass fiber reinforced front drive axle with a 5mm coating thickness is the best replacement to the steel front drive axle of Maruti Alto 800.
- Total 41% reduction in heaviness is possible by replacing the conventional steel [SM45C] front drive axle with a composite reinforced glass fiber front drive axle.

9 Future Scope

Experimental and finite element analysis methodology of reinforced composite glass fiber front drive axle can be further extended to dynamic state analysis.

10 Acknowledgement

I would like to thank the technicians at Mechanical Engineering Department's laboratory of TKIET, Warananagar for their assistance in providing me with the resources I needed to run the application and perform the experimentation

References

1) Reddy PSK, Nagarajun C. Weight optimization and Finite Element Analysis of Composite automotive drive shaft for Maximum Stiffness. *Materials today Proceedings*. 2017;4(2):2390–2396. Available from: https://doi.org/10.1016/j.matpr.2017.02.088.
2) Feroz AA, Harshit, Chawla D, Kumar R. To study and analyze the design of drive shafts for automobiles using composite material through empirical review on literature. *Materials Today: Proceedings*. 2022;56:3820–3822. Available from: https://doi.org/10.1016/j.matpr.2022.01.309.
3) Krishna SVG, Subrahmanyam BV, Srinivasulu R. Finite Element Analysis and optimization of Automotive Composite Drive Shaft. *International Journal of Engineering Trends and Technology*. 2013;5(7):346–351. Available from: https://ijettjournal.org/archive/ijett-v5n7p163.
4) Bhajantri VS, Bajantri C, Shindolkar M, Amarapure S. Design and analysis of composite drive shaft. *International Journal of Research in Engineering and Technolog*. 2014;3(3):2321. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.683.4694&rep=rep1&type=pdf.
5) Chopde PV. Analysis of Carbon/Epoxy Composite Drive Shaft for Automotive Application. *International Journal of Latest Trends in Engineering and Technology* . 2015;5(1):101–111.
6) Prakash BP, Sinha BK. Analysis of drive shaft. *International Journal of Mechanical and Production Engineering*. 2014;2(2):24–29. Available from: http://www.iraj.in/journal/journal_file/journal_pdf/2-40-139486466624-29.pdf.
7) Rothea CG, Bombatkar AS. Design and Analysis of Composite Material Drive Shaft. *International Journal of Innovative and Emerging Research in Engineering*. 2015;2(1):74–82.
8) Mutasher SA. Prediction of the torsional strength of the hybrid aluminum/composite drive shaft. *Materials & Design*. 2009;30(2):215–220. Available from: https://doi.org/10.1016/j.matdes.2008.05.024.
9) Patil PJ, Patil SM, Joshi DK. Dynamic state or whole field analysis of helical gear. *Journal of The Institution of Engineers (India): Series C*. 2019;100(1):37–42. Available from: https://doi.org/10.1007/s40032-017-0389-3.

10) Kumbhar VP, Patil PJ, Joshi MB. Diagnostic analysis of critical machines in thermal power plant using vibration analysis and matlab Software. *International Journal of Research and analytical Research Reviews*. 2022;9(2).
11) Patil PJ, Patil MS. Theoretical and Experimental Analysis of Helical Gear for Studying Effect of Pressure Angle on Bending Stress at root of Tooth. In: International Conference on Modern Era Research in Mechanical Engineering, RIT. India (IEI), Kolkata. 2016;p. 29–30.
12) Bankar H. Material Optimization and Weight Reduction of Drive Shaft Using Composite Material. *IOSR Journal of Mechanical and Civil Engineering*. 2013;10(1):39–46. Available from: https://docplayer.net/21777733.
13) Raikwar AK, Jain P, Raikwar R. Design and optimization of automobile propeller shaft with composite materials using FEM Analysis. *International Journal of Engineering Development and Research*. 2022;10(3).
14) Hatwar KP, Dalu RS. Design and Analysis of Composite Drive Shaft". *International Journal of Science and Research*. 2015;4(4).
15) Luh GC, Hwang RM. Measuring Non-Uniform Residual Stress in Thin Plates by a Proposed Hole-Drilling Strain Gauge Method. *The International Journal of Advanced Manufacturing Technology*. 1999;15(2):103–113. Available from: https://doi.org/10.1007/s001700050046.