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# Numerical Analysis and Optimization of Passenger Car Drive Shaft

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***Abstract – The main objective of the drive shaft is reduction of weight of passenger car. Drive shaft is one of the most important parts of the vehicle which transfers the motion from gear box to the rear wheel of the vehicle. The drive shaft is connected by transmission shaft with the help of a universal joint. The drive shaft rotates about its own axis, the conventional shaft is made up of a steel-SM45C, in this project the use of Aluminium alloy, composite material are studied and analyzed. The 3D cad model of drive shaft is created by using the software CATIA V5. Then the component is discretised in HyperMesh pre-processor, to apply the loads and boundary conditions as a part of pre-processing activity. The pre-processed FE model is exported to the MSC NASTRAN software file format to run the analysis. The analysis done on drive shaft of Maruti Omini with different materials like aluminium and composite material, it is consisting of three types of analysis such as static, buckling and modal are carried out on the component to understand its behaviour under defined loading conditions.***
***Keywords- Hypermesh V11, CATIA V5 Model, MSC NASTRAN etc.***

## I. INTRODUCTION

The drive shaft is one of the important components of the vehicle which is under the continuous rotation when the vehicle is in motion. Hence many researchers have been investigated on the drive shaft to optimize it for better performance. The drive shaft is normally made from seamless tube with a universal joint yokes and also welded at both ends of the shaft and it is connected through the engine gear box to the rear wheel of the axle. In conventional light motor vehicles uses two piece drive shaft which are interconnected to each other, which requires the extra joints and additional mechanical parts to connect. This may lead to increase in the weight of the drive shaft and also increases the complexity of the component. But main advantage of two piece drive shaft is that bending natural frequency can be increased by considering relation that bending natural frequency is inversely proportional to length of the shaft. The two piece driveshaft is rotating shaft that distribution of the power from front device to the rear wheel of the vehicle and it is also connected to pinion at the rear shaft end. it is consists of a three universal joints with a centre supporting bearing and brackets [1].

### *A. Introduction to Single Piece Drive Shaft*

It is a part of the machine is fixed at the centre part of the vehicle for rotating the rear axle to move the vehicle, it is consists of a two universal joints, the shaft is rotating a high speed and safety to rotate, on the outer diameter of the shaft welded small metal piece at the both end of shaft, because to balance the weight while rotating shaft to avoid the vibration of the passenger car, it is mainly used for passenger car and sports car.

### *B. Objectives of the work*

The design consisting of a driveshaft is taken from Maruti Omni the existing hollow drive shaft is made up of with particular dimensions. The many investigation of steel drive shaft is becoming weight of a passenger car due to less fuel efficiency, and so to reducing the weight by using with different types of materials such as Aluminium 6351-T6 and carbon fibre T700S Epoxy composite, here the design of the drive shaft is used for both hollow and the solid drive shaft. The Objectives Are

1) To design existing model of Drive Shaft.
2) To conduct static, modal and buckling analysis will be carried out with a different materials to understand structural behaviour of drive shaft
3) To achieve optimum weight reduction. due to weight reduction it increases the fuel efficiency


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4) To achieve optimum structural strength and stability for weight optimized model under static, modal and buckling conditions.

*C. Review of papers on drive shaft*

*1)* P. Jayanaidu, M. Hibbatullah, Prof. P. Baskar, It is deals with weight reduction of a drive shaft using ANSYS software. Drive shaft is manufactured by using materials like steel and Titanium alloy are substituted comparing both the driveshaft titanium alloy has increasing the advantages due to its high specific stiffness, high strength and less weight. [7]

*2)* Bhimagoud Patil, Fayaz Kandagal Vinoth M.A, The drive shaft is taken from the Toyota Qualis, the component is created by Hybrid composite material in that metal matrix composite (Al-Si), the steel drive shaft is replaced by Hybrid composite material, here the Aluminium MMC with Sic-Cenosphere as a reinforcement by a fabrication by casting. [8]

*3)* Naik Shashank Giridhar, Sneh Hetawal, Baskar P, The study of drive shaft is welded both the ends using universal joints with yoke analysis done on the ANSYS workbench. The universal joints certain, modifications are made in the existing design and the meshed the modal in pre-processor of ANSYS software and applying the boundary conditions and loading in the above reference paper from which the problem has been taken. [7]

*4)* Anup. A. Bijagare, P. G, Mehar, V. N. Mujbaile, The design of a drive shaft is used composite materials for rotating engine to the rear wheel of the drive shaft for application of automobiles. In this project work the conventional two pieces steel drive shaft is replaced to the single piece drive shaft by using the composite material that is carbon/Epoxy for automotive applications. Mainly the composite materials of a carbon/epoxy are manufactured by using the laminates; the laminates are used with a proper orientation of laminate inside the drive shaft to reducing the weight of a component. [7]

*5)* S. A. Mutasher et al, In this paper the composite material is choose and its many investigation on the maximum torsion capacity of drive shaft using composite material like e-glass and carbon/epoxy composite for using also Aluminium material, so it is a hybrid composite drive shaft, using different windings are wound on the outside of the aluminium drive shaft and made number of layers and stacking sequence, the shaft is under static torsion the numerical analysis is done on the shaft using the ANSYS software, analyse the specimen the linear elastic composite materials are Elasto-plastic properties are used on the aluminium tube. [9]

*D. Methodology*

A study on the existing design of Drive Shaft is conducted, for this drive shaft of Maruti Omni is selected. After extracting the dimensions from the design, cad model of drive shaft was created using CATIA V5 software. Then analysis on the component for static, modal and buckling conditions was carried out using Hyper Mesh v11.0 as pre-processor and NASTRAN as the structural solver and post-processor is Hyperview Analysis was carried out for following cases with respect to design and material properties:

*1)* Hollow Steel Shaft [Existing Design].
*2)* Hollow shaft of Aluminium alloy 6351 T6.
*3)* Hollow shaft of carbon fiber T700S [Epoxy composite].
*4)* Solid shaft of Aluminium alloy 6351 T6.
*5)* Solid shaft of carbon fiber T700S [Epoxy composite].

## II. DESIGN AND SPECIFICATION OF DRIVE SHAFT

In this project, Maruti Omni car drive shaft is taken for study and is shown in fig.1 for the understanding loading and boundary conditions. The dimensions of drive shaft are shown in below table 1 and drafting is done by aid of the measuring instruments.

Fig: 1 Physical model of Drive shaft



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TABLE: 1 DIMENSIONS OF AN EXISTING MODEL

| Sl.no | Parameters of driveshaft | Dimensions (mm) |
|---|---|---|
| 1 | Outer diameter of drive shaft ($D_1$) | 51 |
| 2 | Inner diameter of drive shaft ($D_2$) | 47 |
| 3 | Thickness of the drive shaft (T) | 4 |
| 4 | Overall Length of the drive shaft (L) | 793 |

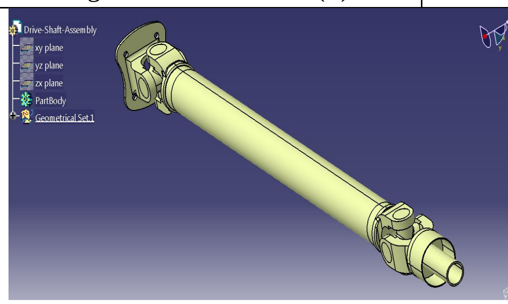


Fig: 2 The Cad Model of drive shaft.

*A. Analysis software's used for the study*

The type of analysis is carried out in the finite element analysis software as below mentioned the following table gives details are given below about software are used different analysis at different phases.

TABLE: 2. SOFTWARE USED FOR ANALYSIS

| Sl.no | Type of analysis | Pre-processor | Solving | Post-processor |
|---|---|---|---|---|
| 1 | Static analysis | HYPERMESH V11.0 | MSC NASTRAN V10.0 | HYPERVIEW V11.0 |
| 2 | Modal analysis | | | |
| 3 | Buckling analysis. | | | |

*1) Hypermesh:* Hypermesh is one of commercial software is widely used in the many applications, it is having both the pre-processing and post-processing software it is performing highly accurate results. In pre-processor the finite element analysis can perform a solid meshing, 1D, 2D, 3D meshing, the hypermesh is user interface to learn and it is support the direct use of cad geometry and existing finite element model, providing a robust interoperability and efficiency.

*2) Nastran:* MSC NASTRAN is one of worldwide used finite element analysis solver, MSC software aid to companies and associated with design and test manufactured products, this is advanced solver more efficiently it takes advantages of computing resources, the software is simulate with increase productivity and it finishes the complex simulation also. the engineers are analysed the products using MSc Nastran, to validation and optimization of the design using virtual prototypes and challenging to make fast and accurate results, the design decision are taken their companies and management and the confidence to change physical prototype. The types of analysis are done by using the MSC NASTRAN solver, for solving the variety of engineering problems.

*a)* Linear static analysis.
*b)* Nonlinear static analysis.
*c)* Dynamic or modal analysis.
*d)* Buckling analysis.
*e)* Thermal analysis.

TABLE: 3. MATERIAL PROPERTIES

| Material properties | symbols | units | Steel- SM45c | Aluminium 6351-T6 | Carbon fiber/ Epoxy composite |
|---|---|---|---|---|---|
| Young's modulus | E | GPa | 207 | 71 | 120 |
| Shear modulus | G | GPa | 80 | 27 | 42 |
| Density | ρ | $Kg/m^3$ | 7600 | 2710 | 1570 |
| Poisson's ratio | v | ---- | 0.3 | 0.33 | 0.3 |
| Shear strength | $S_s$ | MPa | 370 | 200 | 98 |


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*B. Torque calculations*

1) For hollow steel SM45C drive shaft

$$T=\frac{\pi}{16\,D_0}\times S_s\times(D_0^4-D_I^4) \qquad (2.1)$$

$T = 2.6859\times10^6$ N-mm

2) For Aluminium 6351 T6 hollow drive shaft

$T = 1.4518\times10^6$ N-mm

3) For Aluminium solid drive shaft

$$T=\frac{\pi}{16\,D_0}\times S_S\times(D_0^4) \qquad (2.2)$$

$T = 5.20919\times10^6$ N-mm

4) For carbon fiber T700S (epoxy composite) hollow drive shaft

$T = 711.40\times10^3$N-mm

5) Calculation for carbon/Epoxy of a solid drive shaft

$T = 2.552\times10^6$ N-mm

*C. Calculation of torsional buckling capacity*

$$\frac{1}{\sqrt{1-v^2}}\times\frac{L^2\times t}{(2r)^3} > 5.5 \qquad (2.3)$$

Where r is mean radius

$r = (r_{i+}r_o)_{/2}$

$11.206 > 5.5$

The above condition is satisfied then it is consider as a long shaft

Shear critical stress ($\tau_{cr}$)

$$\tau_{cr}=\frac{E}{3\sqrt{2}\times(1-v^2)^{3/4}}\times\left(\frac{t}{r}\right)^{3/2} \qquad (2.4)$$

*1). For Steel SM45C hollow drive shaft:*

$\tau_{cr} = 1.239\times10^3$ N/mm$^2$

$T_b = \tau_{cr}\, 2\pi\, r^2 t = 9.345\times10^6$ N-mm

The drive shaft is needs to withstand torsional buckling capacity is $T_b > T$

*2). For Aluminium hollow drive shaft:*

$11.320 > 5.5$

$\tau_{cr} = 425.57$ N/mm$^2$

$T_b = \tau_{cr}\, 2\pi\, r^2 t = 3.21\times10^6$ N-mm

*3). For Hollow carbon fiber T700S epoxy composite material:*

$= 11.206 > 5.5$

Hence drive shaft is consider as a long shaft

$\tau_{cr} = 708.4\times10^3$ N/mm$^2$

$T_b = \tau_{cr}\, 2\pi\, r^2 t = 5.340\times10^6$ N-mm

*4). For Solid driveshaft Aluminium 6351-T6:*

$= 128 > 5.5$

$\tau_{cr} = 18.2\times10^3$ N/mm$^2$

$T_b = \tau_{cr}\, 2\pi\, r^2 = 1901.2\times10^6$ N-mm

$T_b > T$

*5). For Solid drive shaft carbon Fiber T700S Epoxy composite:*

$126.72 > 5.5$

Hence it is considered as a long shaft.

$\tau_{cr} = 30.35\times10^3$ N/mm$^2$


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$T_b = \tau_{cr}\ 2\pi\ r^2 = 3163.15\times10^6$ N-mm

$T_b > T$

The above condition is considered as $T_b > T$, so drive shaft needs to withstand torsional buckling capacity

## III. STEPS FOR ANALYSIS OF DRIVE SHAFT

The cad model is created in CATIA V5 is imported to HyperMesh v11.0 interface for pre-processing. Then static, Modal and Buckling analysis done for different cases is carried out by using MSC NASTRAN 2010.1 structural solver.

Under the three different stages Analysis are done on Static, Modal and buckling is carried out.

Pre-processing

Solving

Post-processing

Meshed Model of Drive shaft and Applied Boundary Condition and Loading Condition

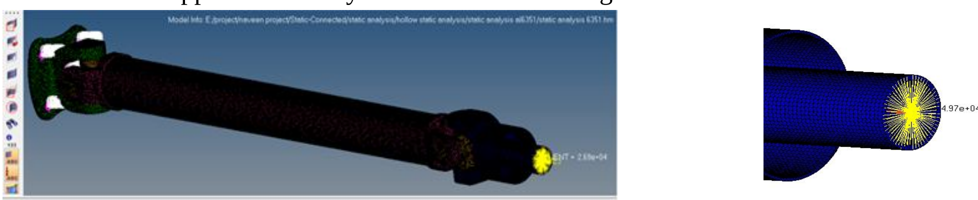

Fig: 3. Applied Boundary and loading Condition

### A. *Static analysis of Drive shaft:*

Static analysis is most commonly on rest conditions of any components, structure caused by load that do not induces significant force and damping effect, however, it includes the steady inertia loads such as gravitational force and varying loads in static analysis is assumed the loading conditions, this loads and components reply are assumed due to slowly varying with respect to time, then decided direction of torque (clockwise or anticlockwise) can be applied based on right hand thumb rule.

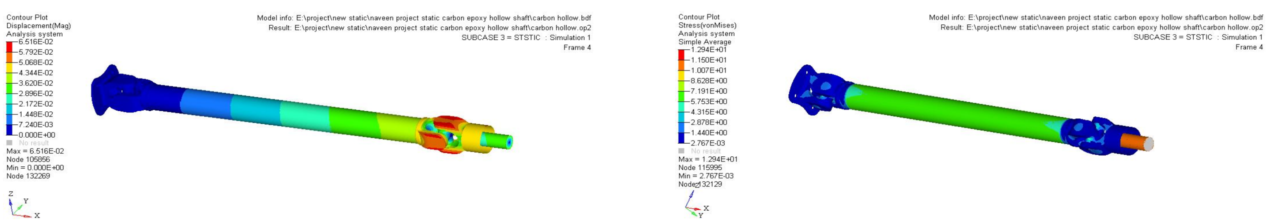

Fig: 4. Hollow drive shaft of carbon fiber T700s [epoxy composite] Displacement and Stress Results

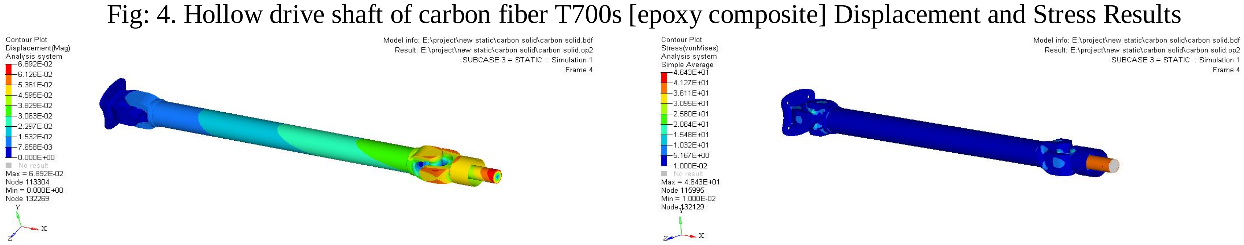

Fig: 5. Displacement and Stress result for static analysis of solid drive shaft using carbon/Epoxy T700S

### B. *Modal Analysis of Drive Shaft*

Modal analysis means a motion of a body which repeats the certain time of interval is called vibration, it is the motion of body connected displaced bodies from the equilibrium position, the vibration occurs when system displaced from position of stable equilibrium, under the influence of vibration inherent force is said to be a free vibration and it will vibrate natural frequency, Here in modal analysis the constraint is applied at rear end of the shaft and other end torque is not applied as per the operating conditions in modal analysis and calculated with different materials. The results will be calculated in the respective of the frequency (Hz) v/s displacement (mm).


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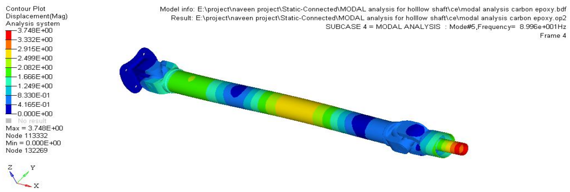

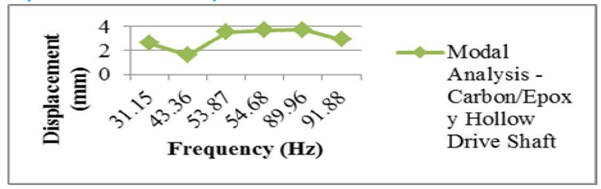


Fig: 6. Max Displacement result of modal analysis of hollow carbon/epoxy T700S drive shaft

*C. Buckling Analysis*

Before linear Buckling analysis to check whether the length of the shaft is long or short by using the equation to checked the shaft as shown in the above calculation part and equation, by using equations is calculated the critical shear stress and torsional buckling capacity, Applying the torsional buckling capacity (load) value in the software and is generated results such as different Eigen values at different displacement, $T_b$>T this condition of drive shaft is needs to withstand the torsional buckling capacity of the shaft. Here the results are formed in Positive and negative Eigen value with a Displacement.

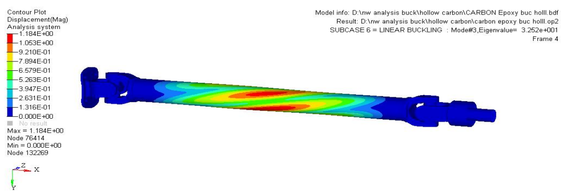

Fig: 7. Positive and Negative Eigenvalue v/s Displacement of carbon/Epoxy T700S Hollow driveshaft.

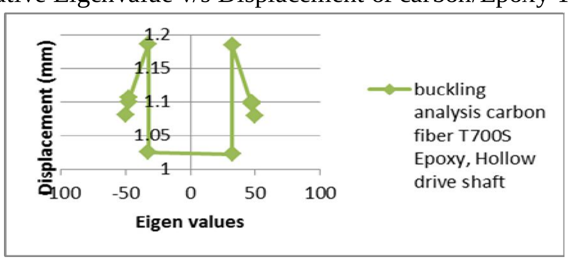


Fig: 8. Different range of an Positive and Negative Eigen value v/s Displacement of Hollow carbon/Epoxy

## IV. RESULTS AND DISCUSSION

The above numerical analysis results are obtained of drive shaft in static, buckling, modal analysis of existing model and having a yield strength of different material, the stress induced within their allowable stress, hence The above analysis observations are made on the drive shaft of a different material in the static analysis, the torque is applied for Hollow drive shaft steel-SM45C is $2.6859*10^6$, for Aluminium 6351 T6 Alloy is $1.4518*10^6$ and carbon/Epoxy is $711.40*10^3$, so it is clearly illustrate the Hollow drive Shaft of carbon fiber T700S (epoxy composite) with its in plane shear strength is 98 MPa and gives the better results for in terms of the displacement and stress, analyst has to conclude whether the component is safe or fail by comparing max stress value with yield or ultimate stress, the carbon/Epoxy composite Displacement is 0.06516 mm. as shown in the below table

TABLE: 4. STATIC ANALYSIS RESULTS OF THE HOLLOW DRIVE SHAFT.

| Sl.no | Materials | Stress(von misses) $N/mm^2$ | Displacement (mm) |
|---|---|---|---|
| 1 | Steel-SM45C | 48.86 | 0.1426 |
| 2 | Aluminium-6351-T6 | 26.37 | 0.2293 |
| 3 | Carbon/Epoxy | 12.94 | 0.06516 |



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TABLE: 5. STATIC RESULTS OF A SOLID DRIVE SHAF

| Sl.no | Materials | Stress(von misses) $N/mm^2$ | Displacement (mm) |
|---|---|---|---|
| 1 | Aluminium-6351-T6 | 94.63 | 0.2421 |
| 2 | Carbon/Epoxy | 46.43 | 0.06892 |

*A. Weight Calculation of Drive Shaft*

TABLE: 6. WEIGHT CALCULATION OF HOLLOW AND SOLID DRIVE SHAFT

| Sl.no | Materials | Hollow drive shaft (kg) | Solid drive shaft (kg) |
|---|---|---|---|
| 1 | Steel-SM45C | 4.266 | 9.6089 |
| 2 | Aluminium 6351-T6 | 1.515 | 3.42 |
| 3 | Carbon/epoxy | 0.8813 | 1.9850 |

*B. Calculation of Weight Reduction*

Weight of Steel-SM45C Hollow Drive shaft assembly = A
Weight of Carbon/Epoxy Hollow Shaft = B
Percentage of weight reduced = [(A – B) × 100] / A = [(4.266-0.8813) × 100] / 4.266
= 79.341 %
Weight of Steel SM45C Hollow shaft assembly = A
Weight of Carbon/Epoxy Solid Drive Shaft = B
Percentage of weight reduced = [(A – B) × 100] / A = [(4.266 – 1.9850) × 100] / 4.266
= 53.469 %

The comparison of the Hollow drive shaft for Steel-SM45C and the Solid Drive Shaft of carbon/Epoxy, it is clearly illustrate that the carbon fiber T700S is better weight reduction compare with the steel is 4 times of the less weight of the carbon T700S Epoxy composite material and the percentage of the weight reduction for hollow 79.34% and comparing hollow to solid of the Drive Shaft weight reduction is 53.46%.

## V. ADVANTAGES, LIMITATIONS AND APPLICATIONS

*A. Advantages of composite material*

1) It's having a high strength and less weight and high specific modulus, high strength.
2) The weight can be reduced increases the fuel consumption of the vehicle.
3) They having less noise and vibration compared to the conventional of steel drive shaft.
4) It's having a good corrosion resistance.
5) It's having a high impact resistance.
6) They are having a less power to transmit the shaft due to less weight.
7) It's having high damping capacity.
8) It's having good thermal conductivity.

*B. Limitations of composite and conventional material.*

1) Cost of the composite materials is high and manufacturing also.
2) Composite materials are very complex to combination some of the properties are to be selected.


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3) The conventional driveshaft weight is increased compare to the composite material.
4) The conventional steel driveshaft is less damping capacity compared to the composite driveshaft.
5) Steel driveshaft is low modulus of stiffness and strength compared to composite material.

### C. Applications of drive shaft

1) It is used in Automobile industries and heavy machinery parts etc.
2) It is used in Aerospace industries such as propeller shaft or cordon Shaft and also in aircraft, and ships etc.

## VI. CONCLUSION AND FUTURE SCOPE

### A. Conclusion

1) The carbon T700S Epoxy composite drive shaft which gives the good performance and also reduces the fuel consumption in the automobile compared to conventional steel SM45C and Aluminium 6351 T6 drive shaft. It also provides the good results of a stress and displacement in the composite material.
2) The carbon fiber T700S epoxy composite material result in the amount of weight reduction in comparison of hollow steel and carbon/Epoxy is in the range 79.341%. Compared with Hollow steel and solid carbon/Epoxy is in the range 53.46 % and it gives less stress distribution and less displacement compared to the conventional steel driveshaft.
3) The advantage is less weight and less power to transmitting driveshaft from engine to rear wheel of the vehicle and it gives less noise and vibration while rotating shaft, this is achieved in this project work.
4) It conclude that designed model of composite material is good to operating and weight reduction.

### B. Future Scope

1) The computational process of the future work is the above designed 3D modal of a drive shaft to determine displacement and stress using different grades of composite materials such as carbon/Epoxy-T800H grades, glass/Epoxy, Kevlar/Epoxy, polyester/Epoxy with a different thickness and diameter of the hollow and solid shaft.
2) The driveshaft analysis by using analytical method results are check by using numerical method and comparison of other materials are the one which is better in the weight reduction take the results of stress, displacement of the component. The processing FE model in the CAE interface in numerical method to deploy by determining the analytical results.

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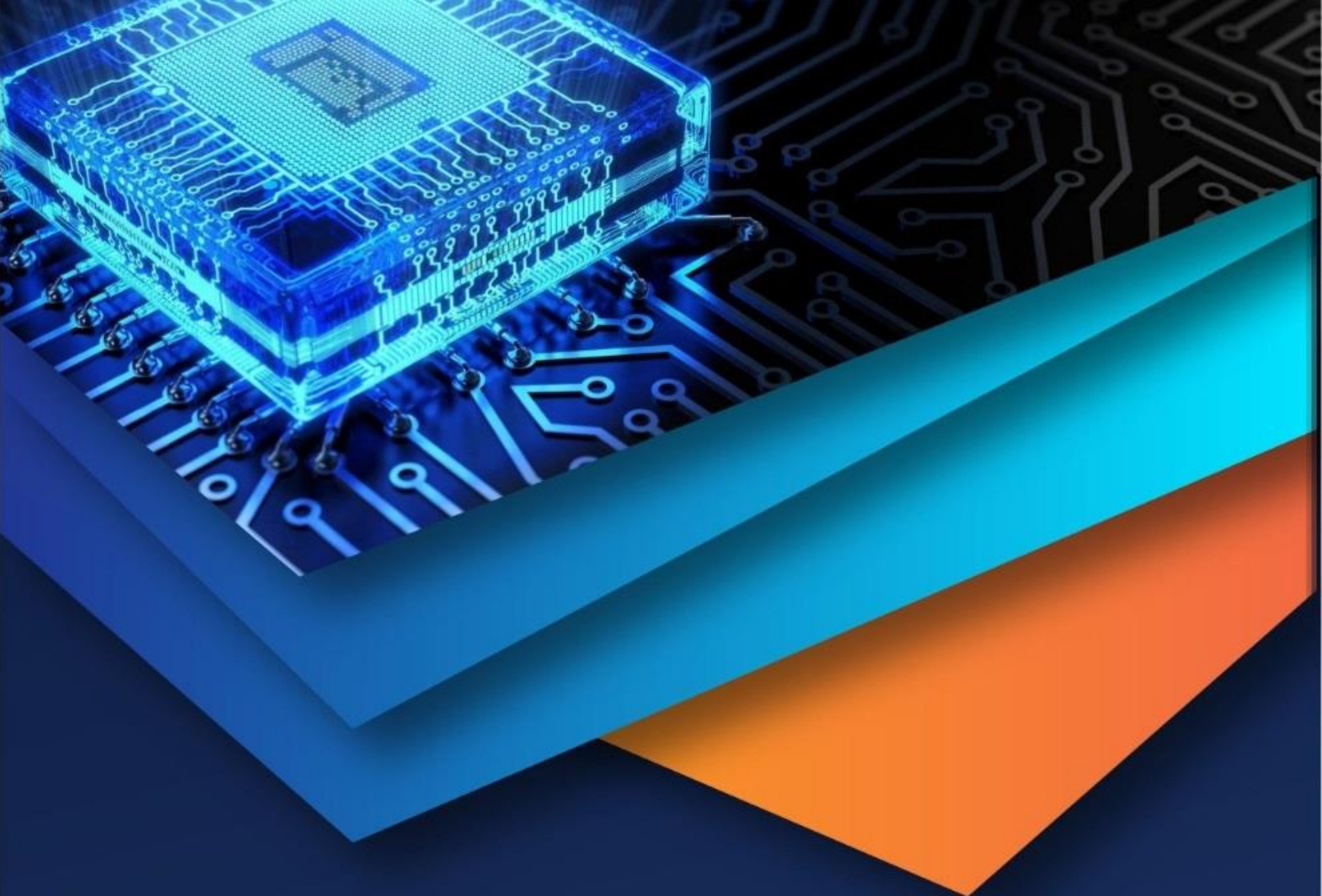


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