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Design and Analysis of Drive Shaft with a Critical Review of Advance Composite Materials and the Root Causes of Shaft Failure

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Abstract - A review paper seeks to examine the numerous forms of shaft failure, shaft reliability and traditional material substitution for certain advanced lightweight alloys and composite materials. We have examined extensive literature in this regards to tackle this issue. Specific materials were examined in this review as contrasted with traditional heavy weight steels. They performed FEA and analytical estimation. The results demonstrate that lightweight alloys and composite materials find strong strength, low weight, low stress rate , high impact tolerance, high stability, high resistance to corrosion, plasticity and shaft weight reduction. This paper demonstrates the different forms, and also the root causes of shaft damage. A crack surface defect through analysis of the macroscopic and microscopic morphologies. The chemical structure, metallographic study and mechanical properties of the material, and theoretical measurements of finite elements of the shaft, also a vast range of light weight composite and alloy materials are compared with their Torsional capacity, Natural bending frequency and deformations.[1]

Key Words: **FEA, Shaft Failure, Composite Material, Hybrid Shaft, Manufacturing**.

1. INTRODUCTION

A shaft is an aspect of a spinning system that transmits power from one position to another. Certain tangential force delivers the power to the shaft. And the resulting torque (or twisting moment) inside the shaft allows the power to be transferred to different devices connected to the shaft. Usually bearings, flywheels, gears, clutches and other machine elements are mounted on the shaft, and help in the process of power transmission. In fact, shafts have no standardized diameter and are stepped with shoulder braces where bearings, gears or other parts are placed. Based of the specification, shafts can be hollow or solid with various names such as Axle, Spindle, Countershaft, Jackshaft, Line Shaft etc. Mostly following properties are preferred when designing any shaft; high strength , good machinability, low sensitivity factor; good properties for heat treatment, high wear resistance. The shafts' loading requirements are very difficult, not only to withstand the wheel's vertical power, stopping power and reaction force, but also to withstand the line's impacting loads and moving device's pulling force and reaction force etc. In this article, the study of durability, replacement and fracture loss of various shafts was carried out.

2. LITERATURE REVIEW

2.1 P. Jayanaidu1, M. Hibbatullah1, Prof. P. Baskar2:

This paper's case analysis on replacing traditional steel driveshaft with titanium alloys (Ti-6Al-7Nb). Because of its strong resistance and low weight. The shaft model was developed in Pro-E and simulation was carried out by Appling Boundary Condition as Fixed one end in ANSYS program and applies a torque at 3000rpm of shaft on the other end. From the analysis, MAX Stress and Equivalent Stress parameters were obtained after Calculation Deformation. This shows that the Titanium alloy (Ti-6Al-7Nb) is a better choice for a drive shaft due to its low weight and Total deformation of steel and titanium alloy. The Simulation also shows the two frequency modes

Table: 1

Modes of frequency		**Average deformation factor**	
Min: Frequency in 1st mode	55.021Hz	Steel	0.000564 mm
Min: Deformation in 2nd mode	55.065Hz	Titanium	0.000519mm.

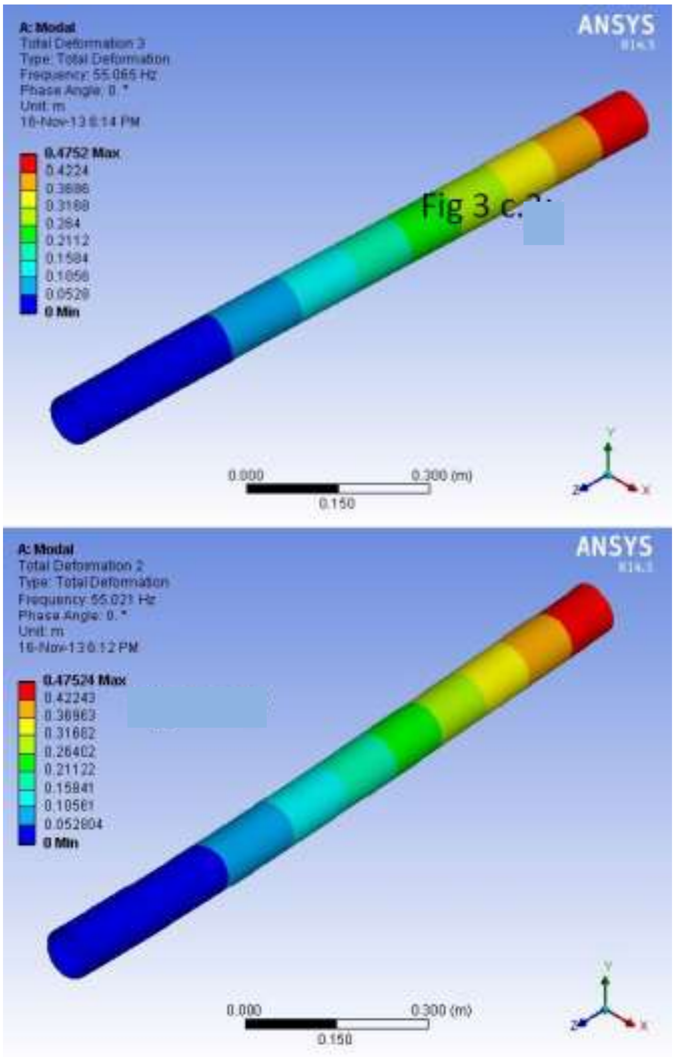


Fig: 1&2 Modes of frequency [2]

2.2 M.A.K. Chowdhuri1, R.A. Hossain2:

For this article, the two separate composite materials that are Graphite / Epoxy lamina were chosen for the shaft and others are Graphite / Epoxy Aluminum which satisfy all specifications relevant to power, rigidity, etc. Each 0.125 mm thick graphite lamina and 1.65 mm thick aluminum lamina. Torsion and its consequences like torsional bending, normal frequency bending, are the main load on shaft. Those is all calculated by utilizing Formulas, Equations and PROMAL Software to complete all measurements. The contrast that with the appropriate weight, if the cost is a prime consideration then the Aluminum Hybrid concept is appropriate[3]

Table: 02

Dimensions For the Shaft	
Drive Shaft Length	1850mm
Mean Radius of shaft	50mm

2.3 Dr. B. P. Patel1, Hiren. R. Prajapati2, Dutt. B. Thakar3:

This paper focused on the detailed review of shaft design with varying discontinuities and different loading conditions. And they also have literate previous papers on analyzing failure, designing shaft, and fatigue also fracture also used different analytical methods such as mathematical methods, visual inspection. But they observe less on discontinues and combine loading and suggest to researchers to work on it. [4]

2.4 C.ElanchezhianA, B.Vijaya RamnathB,K.N Sripada RaghavendraC, Mithun MuralidharanD G.RekhaE:

In this paper they build a drive shaft of (SM45C) Steel and equate it with Kevlar composite material shaft to address the problem of weight on automobiles. To test the strength of both shafts and their efficiency. The designing portion was performed using Catia V5 and Ansys program was used to perform the Torsional study. Such analyzes analyzed torque transfer strength, buckling torque capabilities and natural frequency bending. They propose replacing steel shaft with Kevlar composite material due to its excellent power , low density and weight.

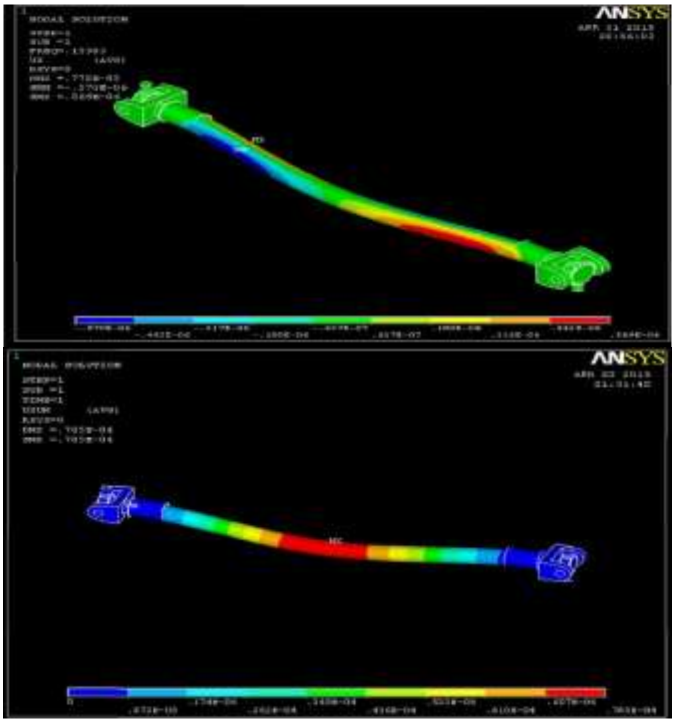


Fig: 3&4 Steel and Kevlar Stress Distribution after bending[5]

2.5 P Karthikeyan1, RGobinath2, L Ajith Kumar3, D Xavier Jenish4:

This article is a update of previous study. They choose two separate forms of composite material to substitute the steel drive shaft. Products as durable as Kevlar / Epoxy, Glass / Epoxy etc. The shaft model was scheduled for study using Catia V5 and Ansys. Deformation of composite material is stronger but the shock effect is low as torque increases as a consequence of stiffness will high. Composite driveshaft reduces the weight of Kevlar / Epoxy by 81.67 percent and 72.66 percent.

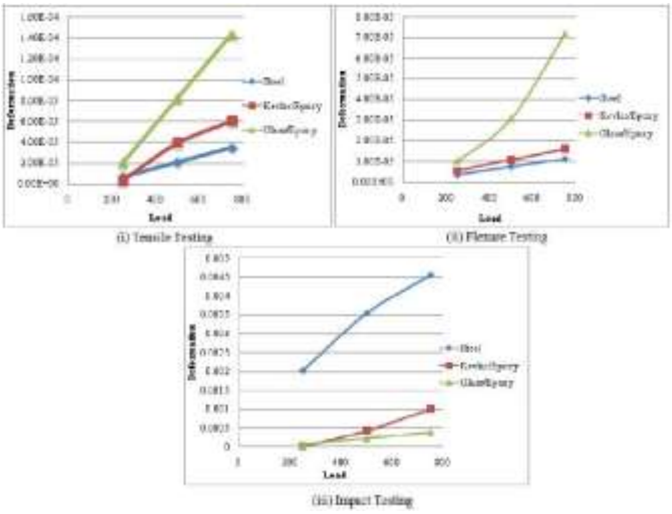


Fig: 5, 6 & 7 Deformation VS Graph Load for Steel, Kevlar/Epoxy and Glass/Epoxy[6]

2.6 Mahmood M. Shokrieh a, Akbar Hasani a, Larry B Lessard b:

Within this paper they also research the torsional stability of a composite driveshaft by concentrating on the design standpoint. In Ansys, the buckling torque of composite drive shafts is measured using finite element analysis. And simulation findings were contrasted with experimental results they assume that the fiber position, packing sequences of composting substance layer greatly influences the bucking torque.

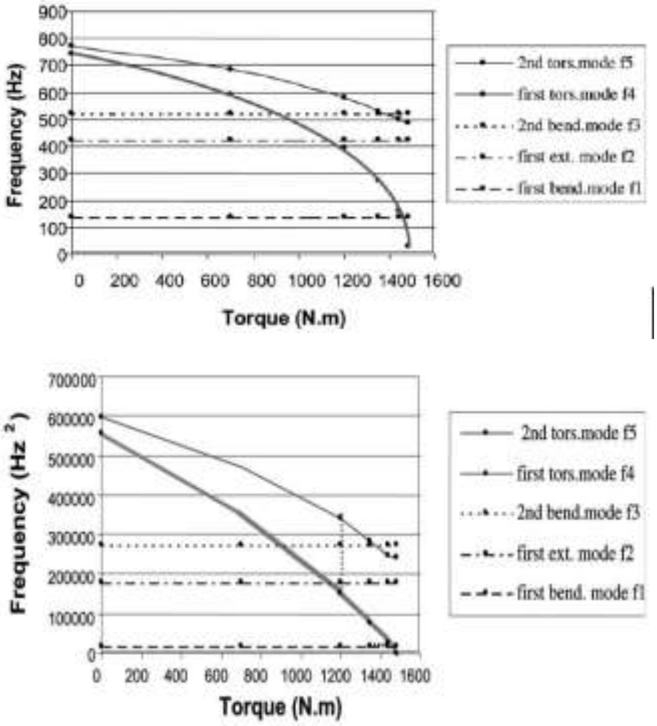
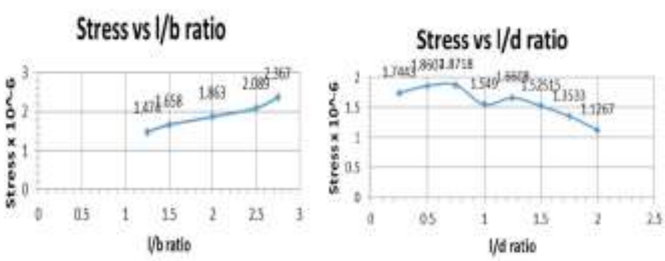


Fig: 8 & 9 Comparison of first five Natural and Squared frequencies of composite shaft according to input torque. [7]

2.7 Jeegar Joshi, Chirantan Andhariya & Jayraj Gorecha:

Discussion and simulation of varies Shapes, such as conventional cylinders, square, rectangular, triangular, and elliptical, are conducted and their results are compared in this article. Component design is made in Pro-E, and calculations were made in Ansys . Results indicate that in all of the above designs elliptical cross-section has the least stress produced and also has the intense stress on the keyway which is the form of joint.



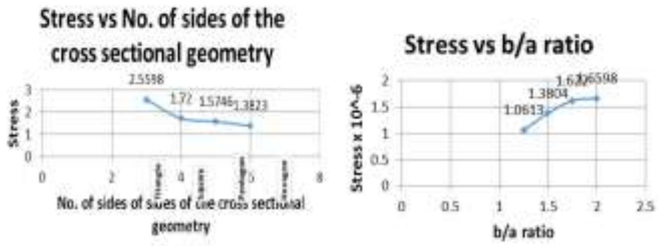


Fig: 10, 11, 12 & 13 Comparison of Stress I/b, b/I and I/d of Rectangular, Rectangular with semi-circle, Elliptical and no. of side of cross sectional geometry of the shaft.[8]

2.8 Muni kishore, Jaligam Keerthi, Vinay kumar:

In this study Different material is studied by measuring stress and deformation the key goal is to substitute steel drive shaft with an E-glass / epoxy, E-carbon / epoxy pierce. Dynamic Structural, Rigid, and System dynamics evaluate perfume to identify the deformation, stress. Since composites have low elasticity, they act as shock absorbers when they act at high torque. Consumption of fuel is noted which is caused by weight increases. The results show that E- Glass / Epoxy Composite can be replicated with steel because of its low weight reduction and stress stiffness.[9]

Table: 03

	Results		
	Steel	**E-glass**	**E-Carbon**
Deformation(mm)	0.05013	0.1639	0.15262
Stress(mpa)	19.835	8.228	12.928
Strain	0.70904	0.719	0.617

2.9 He Pan1:

He is writing a thorough analysis of various materials which are lightweight and high-resistance. Firstly, he defines steel as high-strength steel with a resistance ratio of 270-700MPa, advanced high-strength steel and beyond 700MPa. Research reveals that 60% of automotive fuel usage is attributed to the weight of cars themselves. And they're looking to build content that's lightweight and high power. Japanese developed BL385, SA440, and SA630, with tensile strengths of up to 550 MPa, 590 MPa and 780 MPa. China's demand for HSS is strong due to extensive usage of the building industry. The type of low-weight high-strength material is aluminum alloy which is second in high demand after steel high-strength aluminum alloys. High-strength aluminum alloy performance: Al-Li alloy-Lithium is the lightest metal product. The density can be decreased by 3 percent with every 1 percent rise of lithium ingredient of aluminum alloy, and the module can be increased by 5 percent. Magnesium alloy is the lightest structural metal material with a density of 1.75g / cm3, approximately 2/3 of aluminum alloy, 1/4 of steel. Titanium alloy tensile strength up to 1500MPa, compared with ultra-high-strength steel, though pure titanium mass is just 4.5kg / cm3, just 50 percent of steel.[10]

2.10 Hariom1, Prof. Vijoy Kumar 2, Dr. Chandrababu D.3:

This paper would include the thorough analysis of roller shaft failures and can be improved by mechanical repair strategies that are preventive. He included a number of earlier research showing the study of faults and working conditions. A analysis that Conveyor's pulley breakdown of shaft triggered by fatigue. Another study showed the draft fan shaft failed in a steam boiler that is because of the actual chamber radius less. Another study of the failure of locomotive turbocharger. Due to the use of bearing sleeve various analytical approaches such as Spectroscope, Finite Element Analysis using ANSYS, Charpoy Fractography studies using SEM, spectrometer[11]

2.11 Yusuf Abdulfatah Abdu1, Tijjani M Shfi'i1, Salisu Umar Musa1, Umar Shasu1,HamzaAlhassan1, Prof. U.K. Gupta1:

The case analysis of this paper indicates that they have the concept of utilizing the composite based drive shaft to eliminate the standard steel shaft. By utilizing durable content such as Carbon / Epoxy and Kevlar / Epoxy in Polymer Matrix. Design for the analysis of torsional strength, natural frequency bending, and torsional buckling. All of the analysis was using ANSYS software.[12]

Table: 04

The Weight Saving			
Carbon / Epoxy	VS	Steel	87.01%
Kevlar / Epoxy	VS	Steel	74.76%.

2.12 Harshal Bankar1, Viraj Shinde2, P. Baskar3:

They worked on composite materials to get a weight reduction. Vehicle weight is approximately equal to fuel intake. Steel, Boron / Epoxy Composite, Kevlar / Epoxy Composite, Aluminum – Glass / Epoxy Hybrid, Carbon –

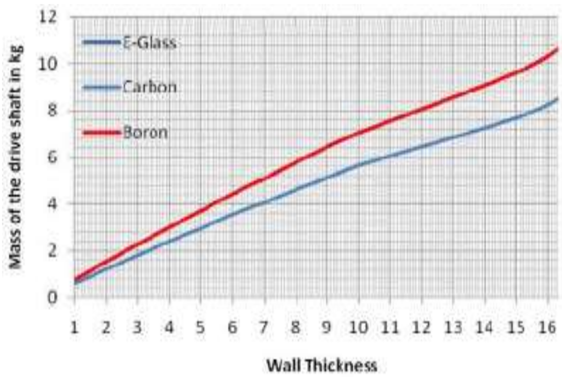
Glass / Epoxy Hybrid are chosen are selected. The natural frequency of carbon fiber driveshaft can be measured twice as large as that of steel or aluminum. And study of various composite materials was done by adjusting the ply slope, no. of plies and ply thickness, even recommending the hollow shaft over solid shaft this paper suggested carbon / epoxy with hollow shaft due to lightweight and strong resistance. We found a ridiculous drop in weight.[13]

Table: 05

Weight Saving				
Steel	E-Glass/ Epoxy	HS Carbon/E poxy	HM Carbon/ Epoxy	Polystyrene
8.58 kg	4.4434 kg	1.12S73 kg	1.1274 kg	1.4868 kg

2.13 P Satheesh Kumar Reddya and Ch. Nagarajub:

The objective of this study is to assess the efficiency of the composite drive shaft over the steel drive shaft. Results reveal in static study that Boron / Epoxy displays a strong tensional stiffness relative to the other two and seconds after plate. Buckling torques are even higher than the working torque (3500 Nm). Carbon / Epoxy is less dense than the other two among three composite materials.



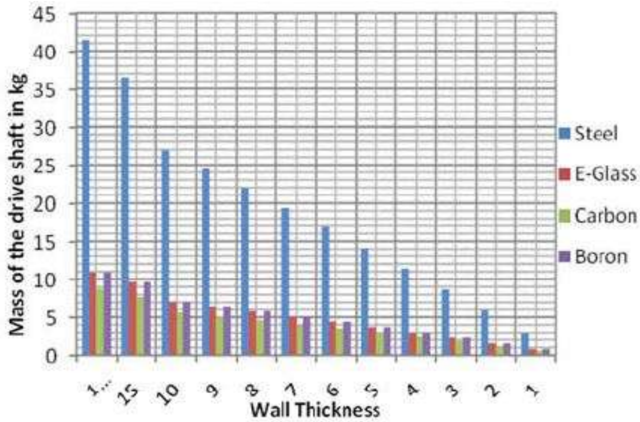


Fig: 14 & 15 Shows Weight reduction and Wall thickness under buckling torque. [14]

2.14 S. K Shoaib Nadeem SKa, G Giridharaa, H K Rangavittala:

A brief overview of the configuration and development of the shaft and the multiple FEM programs used for composite shaft study. Researchers use various software for modeling and analyzing the result, such as SolidWorks, CATIA, Abaqus and Ansys. Boron / Epoxy Composite, Kevlar / Epoxy Composite, Aluminum – Hybrid Glass / Epoxy, Carbon – Hybrid Glass / Epoxy. 81 per cent drop in weight. [15]

2.15AniketBhilare1, RiteshGirigosavi2, MayurDesai3, Pratik-Dhamdhere4, RiteshFegade5:

This article is aimed at minimizing automobile weight by modifying the different components. Two types of analysis have been perfumed, such as Equivalent Stress and Maximum Principal Stress. Below table showing the stress in selected three materials. [16]

Table: 06

Max. Equivalent Stress	
Steel	102.91MPa
Titanium	101.1MPa
Aluminum Alloy	102.04MPa
Maximum Principal Stress	
Steel	111.38MPa.
Titanium	113.69MPa
Aluminum Alloy	112.43MPa

2.16 N.F.Timerbaeva, A.R. Sadrtdinovb, R.G. Safinb:

This paper studies analytical software system. Usage of CAD / CAE-based operating systems in mechanical constructions. It has developed numerous CAD / CAE systems: APM Win-Machine, KISS-soft, SolidWorks and KOMPAS-3D. Use CAD / CAE systems helps one to greatly reduce the measurement time relative to the existing design methods in order to eliminate mistakes in measurement and increase their precision. Graphical design user friendly and intuitive, strong operating framework features. [17]

2.17 bhirud Pankaj Prakash, 2bimlesh Kumar Sinha:

The key goal is to substitute traditional steel driveshaft with a composite driveshaft of Kevlar / epoxy or E-glass polythene resin. The deflection, stresses, and natural frequencies under subjected loads utilizing FEA (Ansys) and weight savings in the region of 24-29 percent relative to standard steel shafts often minimize fuel usage.

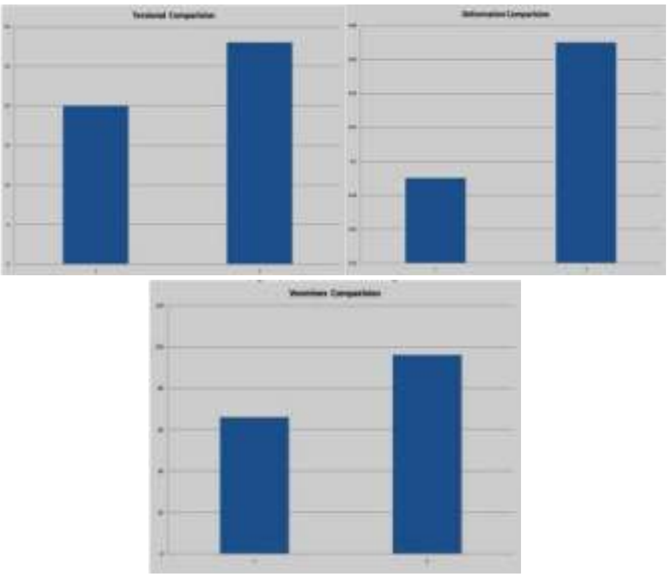


Fig: 16, 17 & 18 Comparison of Torsional load, Deformation and stress for both materials[18]

2.18 Kalaiyarasan A*1 and Sankareswaran N2:

This paper gives an description of the method of stir casting, parameter & MMC preparation. Analysis of the mechanical activity of metal matrix composite with the different components of graphite or Nanoparticle Sic and Al2O3 composite reinforcement particles formed by the stir casting technique. The maximum deflection caused in the drive shaft in Aluminum / Sic is 1.1927e-5 mm, and the stress of von misses is 1.398e6 Pa. The high quality Al-Sic composite also has the high strength weight savings. Al-Sic is nearly equivalent to 60 per cent of the steel shaft.

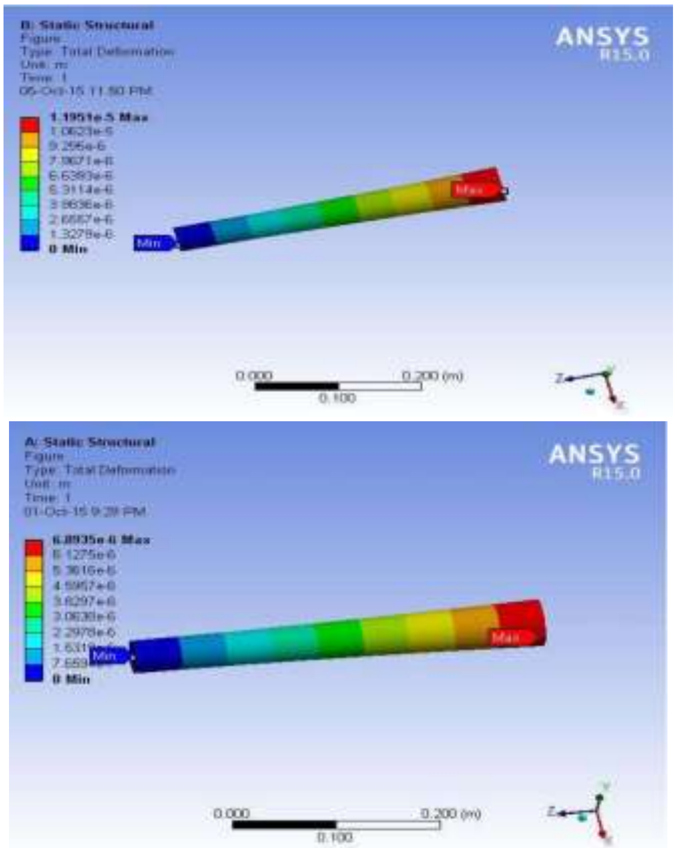


Fig: 19 & 20 The Total Deformation of Aluminum alloy and AL-Sic. [19]

2.19 Nizam S Sakeer 1, Thoufeek A2, Vyshak O R3, Hallaj J4, Mathews Thariyan:

This paper analyzes numerous composite material and suggests that the shaft can create essential whirling at high speed, and that the shaft vibrates vigorously to minimize friction. They pick the composite materials Al2O3 and AlSiC. Using composite material the shaft weight decreased to 28 percent and directly influenced the vehicle's shaft vibration and fuel consumption. [20]

2.20 Atul Kumar Raikwar*, Prof. Prabhash Jain1 & Rajkumari Raikwar2:

The main purpose of this work is to optimize composite materials design & weight. For the purpose of study, we choose 30% carbon fiber thermoplastic polyimide; Kevlar Epoxy, Epoxy carbon UD, and Epoxy EGlass UD. To obtain the best material as an substitute instead of conventional propeller shaft. After study, we believe that the most suitable for the substitution of standard steel shaft is thermoplastic polyimide with 30 per cent carbon fiber. And weight is up to 82.04 per cent minimizing.

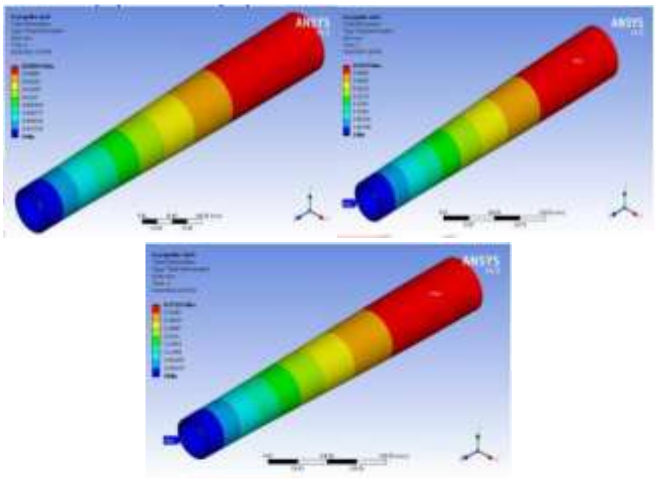


Fig: 21, 22 & 23 Total Deformation of propeller shaft for Steel, E-Glass/Epoxy & Epoxy Carbon-UD[21]

2.21 H. B. H. Gubran1 and K. Gupta2.

This paper comprises of analyzes and studies on a two-piece steel shaft and composite shaft with one-piece. We analyze the various parameters of Shaft weight, buckling torque, and shaft dynamic performance with the help of FEA. We assume that the usage of fiber-reinforced composite and aluminum tubes weighing less than a steel shaft and possessing a fundamental natural frequency above the level of the shaft operation.

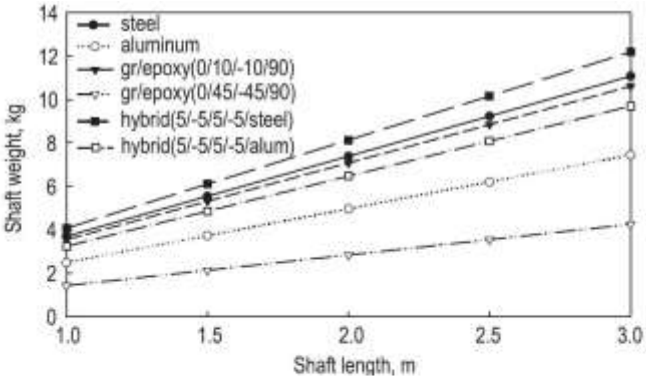


Fig: 24 Show the Weight reduction with length variation of drive shaft[22]

2.22 Sagar R Dharmadhikari1, Sachin G Mahakalkar2, Jayant P Giri3, Nilesh D Khutafale4:

This study uses the Genetic Algorithm and ANSYS to optimize the Drive shaft. Researcher concentrated on replacing traditional two-piece steel shaft with single piece High Strength-Carbon / Epoxy material. Studies suggest that single-piece composite material has many advantages such as high power , high rigidity, high impact tolerance and high resistance to corrosion and also decreases shaft weight[23]

2.23 Li-Hui Zhaoa,b,⁎, Qing-Kun Xingc, Jia-Yu Wanga, Shen-Long Lic, Song-Lin Zheng:

Two drive shafts have been used in this paper to investigate the failure and root cause of a recurring drive shaft fracture. The test revealed that drive shafts during operation displayed fatigue failure. The FEA performed in operation under high torque revealed an apparent concentration of stress which is compatible with the crack source location. And the tension accumulation from a limited fillet radius contributes to high tension, which can be inferred as the root cause of the breakdown of the drive shaft.

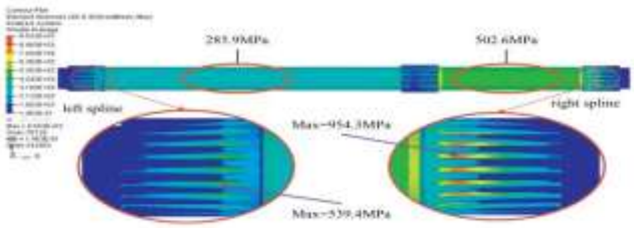
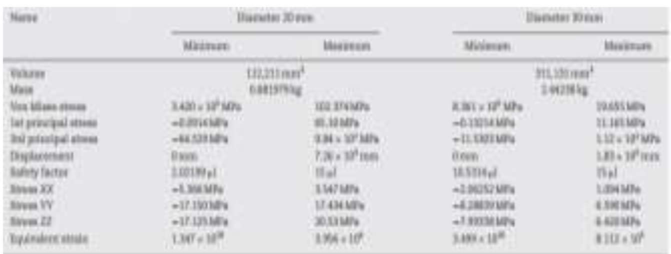


Fig: 25 Showing Stress Distribution of Shaft using FEA[24]

2.24 Samuel O. Afolabi a, Bankole I. Oladapo a,⁎, Christianah O. Ijagbemi b, Adeyinka O.M. Adeoye a, Joseph F. Kayode a:

This research was studied based on 3D modeling and FEA study of 30 mm dia of shaft palm kernel cracking machine. This indicates an optimal configuration, the load and the Von Mises stress 102.4 MPa for mild steel content under the overall yield stress of 156 MPa. Findings indicate that the 20 mm shaft diameter is ideal for manufacturing.



Name	Diameter 20 mm		Diameter 30 mm	
	Minimum	Maximum	Minimum	Maximum
Volume	[illegible]		[illegible]	
Mass	[illegible]		[illegible]	
Von Mises stress	[illegible]	[illegible]	[illegible]	[illegible]
1st principal stress	[illegible]	[illegible]	[illegible]	[illegible]
3rd principal stress	[illegible]	[illegible]	[illegible]	[illegible]
Displacement	0 mm	[illegible]	0 mm	[illegible]
Safety factor	[illegible]	[illegible]	[illegible]	[illegible]
Stress XX	[illegible]	[illegible]	[illegible]	[illegible]
Stress YY	[illegible]	[illegible]	[illegible]	[illegible]
Stress ZZ	[illegible]	[illegible]	[illegible]	[illegible]
Equivalent strain	[illegible]	[illegible]	[illegible]	[illegible]

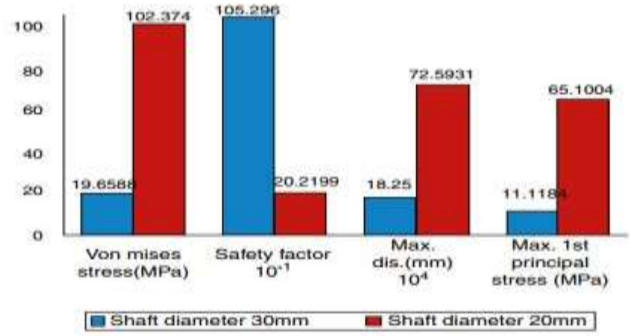


Fig: 26 & 27 Comparison between 20mm and 30mm at Max. Torque of 72 Nm. [25]

2.25 Nebojša RAŠOVIĆ, Adisa VUČINA, Remzo DEDIĆ:

This paper examined the driveshaft under EDC Company's specified increased input load. The study found the high value of flexion stress which caused a drastic deformation. It is also concluded that in the critical section, there is no impact of the change in chamfer length on decreasing stress values. We found some paper recommendations regarding to Increase its radius of revolution, use appropriate materials to change bearings after shaft.

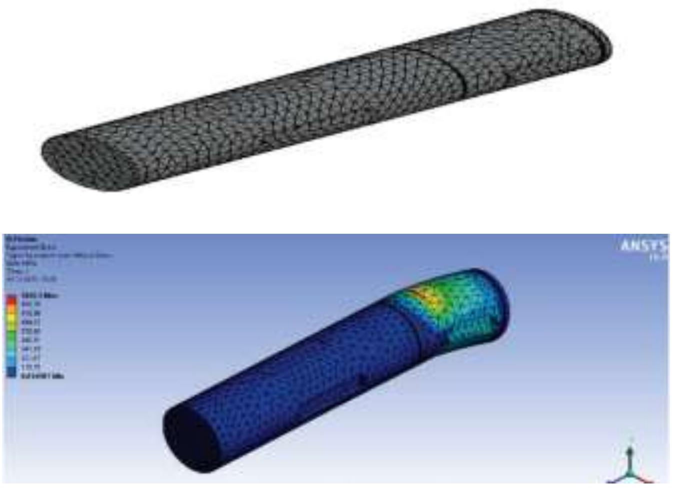


Fig: 28 & 29 Meshed part and FE analysis after load[26]

2.26 Carlos M.S. Vicente, Manuel Sardinha, Luís Reis:

In this study, the review of failure from a shredder of a coupled shaft is addressed. The study of the failure was carried out using all experimental approaches. And statistical measurements, aimed at identifying the root causes of coupled shaft failure. The shaft collapsed due to fatigue in the area of the connecting transverse opening, on a perpendicular plane to the rotation axis.

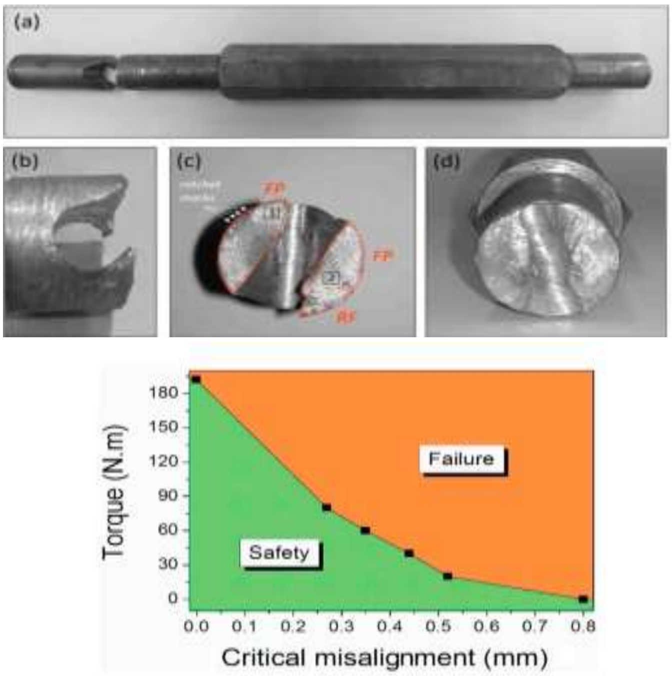


Fig: 30 & 31 Different views of Fracture surfaces and Failure diagram Assuming shaft life 1.26x10^4 cycles[27]

2.27 Chongfei Zhua,1, Jifan Heb,1, Jinfang Pengb,c,⁎, Yanping Renb, Xiuzhou Linc, Minhao Zhub:

Through this paper the premature breakdown of the power locomotive railway wheel shaft running three million kilometers was examined through China. Series of macroscopic and microscopic analyzes were conducted to accurately classify the axle's degree of Failure and malfunction process, and the root causes of the sudden loss were completely obtained. [28]

2.28 Dejan Momcˇilovic´ a, Zoran Odanovic´ a, Radivoje Mitrovic´ b, Ivana Atanasovska c,Tomazˇ Vuherer d:

This paper outlines the study of a 28 MW horizontal hydro turbine shaft main failure. Study of essential radius load-carrying power and Fractography study is provided. Significant focus is placed on evaluating in-service crack initiation metallurgical failure. Measurement of stress is achieved through FEM. It may be inferred that the seal box configuration resulted in a continuous flow of river water inside the critical radius section, culminating in fatigue cracks of corrosion and a significant failure of the turbine shaft. Checking the possibility of redesigning the transient radius to reduce the level of stress on a critical radius. [29]

2.29 B. Engel, Sara Salman Hassan Al-Maeeni:

The modes of Shaft failure are studied in detail. Spectra measurement research is conducted using an observational method with ABAQUS software to calculate forces, torques, and stresses. The fatigue durability limit has been calculated; after implementing a re-carburizing and refining method on the surface to suit the appropriate condition, the shaft is found to be reusable.

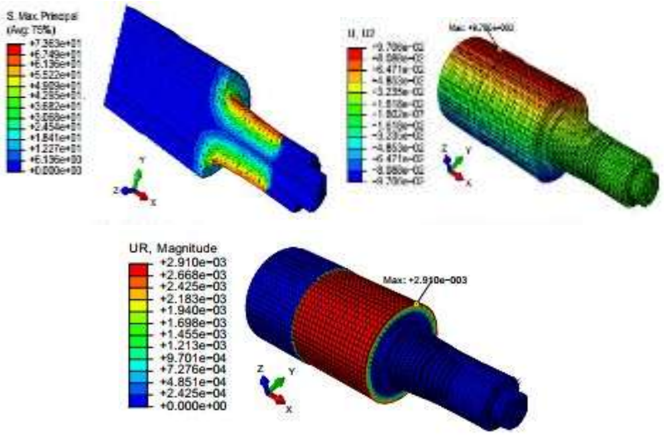


Fig: 32, 33 & 34 shows the Shear Stress, Bending Deflection and Von Misses in drive shaft. [30]

2.30 Facai Ren1, Xinghua Wu1 and Xiaoying Tang1:

The fracture failure study of a high-speed shaft was conducted in this article. It studied the shaft's chemical composition, metallography, and SEM micromorphology. Fracture macroscopically analyzing and scanning electron microscopic examination reveals that it is exhaustion that induces fracture loss of the high-speed shaft. [31]

2.31 Tong-Wei Nia, Qun Dinga, Zhen-Guo Yanga, Hong-Lian Zhengb, Xiao Loub:

Throughout this article, closely reviewed the premature fracture of the pump shaft which occurred after the pump serving just one year in a 1000 MW nuclear power station. To assess the root cause of the failure, metallographic examination, mechanical material check, wear and Fractography evaluation, micro-zone study and study of the mechanisms. Replacing flat key with a spline to lower bending tension. The outer diameter of the shaft could be better increased to improve the bending module and torsional modulus. [32]

3. CONCLUSIONS

Different researcher's use FE analysis to predict the Behavior of shaft. And use of Advanced Lightweight Composite materials and alloy's. In terms of fuel saving by reducing weight. A ridiculous weight reduction was found with composite material shaft, having good Strength, stiffness as compared with Steel etc.

Some researchers had written few effective papers in terms of weight reducing.

1. Carbon/Epoxy and Kevlar/Epoxy have weight saving over Steel are 87.01% and 74.76%.
2. Steel, E-Glass/Epoxy, HS Carbon/Epoxy, HM Carbon/Epoxy and Polystyrene noticed tremendous weight saves
3. Boron / Epoxy Composite, Kevlar / Epoxy Composite, Aluminum – Hybrid Glass / Epoxy, Carbon – Hybrid Glass / Epoxy saves 81% weight over steel.

Another aspect of this paper is to critically review the root causes of shaft failure, fatigue and fracture by using some technical methods such as Fractography, metallurgical, chemical composition and SEM micromorphology.

It noticed causes of failure. It found that due to fatigue, Corrosion Fatigue cracks, Porosity, Stress Concentration due to chamber, machining.

The Hollow Shaft is recommended over Solid shaft due to less stress distribution on inner layer of shaft.

To take prevention from these type of failures some possible solutions were found that by the proper heat treatment, increase the diameter and uses of adequate material it can be avoided.

To reduce the fuel consumption it recommended to use the lightweight material over Conventional steel

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