A Review on "Design and Development of Composite Drive Shaft"

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ABSTRACT

Advanced composites has resulted a great success in many fields such as marine, medicine, aerospace, sports, automobiles , engineering, etc. More and more research works are being conducted to study the characteristics and to explore the potential applications of these environment friendly materials. In this context as far as composite materials are concerned, natural fibers are fast emerging as the most promising reinforcing elements with their inexpensive and some excellent properties that cannot be obtained from synthetic fibers. Now-a-days natural fibers are gradually replacing synthetic fibers in various applications. The goal is to replace a conventional drive shaft by composite drive shaft with high strength, low weight, high stiffness etc for commercial vehicle

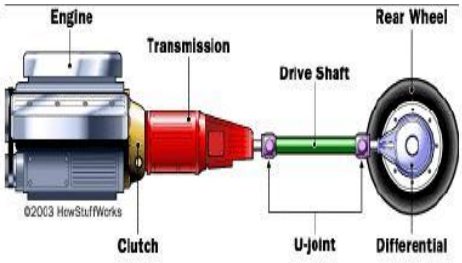
.**Keywords :** Composite drive shaft, Polymer

1. INTRODUCTION

1.1. INTRODUCTION TO DRIVE SHAFT

There are different names for shaft which varies according to application such as transmission shaft, axle, spindle, machine shaft etc. The term Drive shaft is used to refer to a shaft, which is used for the transfer of motion from one point to another. Drive shafts as power transmission element are used in many applications, including cooling towers, pumping sets, aerospace, trucks and automobiles.[1] In metallic shaft design, knowing the torque and the allowable shear stress for the material, the size of the

Figure1. Single-Piece Composite Drive Shaft



shaft's cross section can be determined. The propeller shaft is a longitudinal drive shaft used in vehicles . A propeller shaft is an assembly of one or more tubular shaft connected by universal, constant velocity or flexible joints.[2]

1.2 INTRODUCTION TO COMPOSITES

Composite materials are constituents which are combined at microscopic level and not soluble in each other. The main difference between an alloy and composites are that, in case of composite constituent materials are insoluble in each other and retain their individual properties and in case of alloys, constituents are soluble in each other and form a new material with totally different properties from their individual constituents.[3]

The reason for the some common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. John Weeton worked on the composite material and find out the possibilities of replacing conventional material by composite material. He researched on leaf spring in automobile and also on drive shaft. The advanced composite material with proper resin is preferred to replace conventional material because of their high specific strength and modulus.

In 1985, the first experiment was done on composite material shaft by spicer u-joint divisions of Dana corp. in the ford econoline van models. For power transmission, drive shaft is used in many applications like aerospace, automobile, pumping sets etc. In large rear wheel drive automobile, drive shaft is manufacturing in 2 pieces. This two pieces drive shaft assembled and results in heavy assembly.[4] The main agenda for two piece assembly is to increase its natural frequency. Nowadays, energy conservation is most important objective in the design of automobile and the effective measure is to reduce the weight of automobile.

Actually, there is direct relation between vehicle's weight and fuel consumption. In the drive line application the torque produced in the engine has to be transferred to the rear wheels to move the vehicle. For realistic driveshaft system, improved lateral stability characteristics must be achieved together with improved torque carrying capabilities. In recent years research is going on to replace a two piece drive shaft with a single piece

shaft without sacrificing the functional requirements. [5]

As the single piece drive shaft is long and thin walled, the failure mode is torsional buckling rather than material failure .research work have been carried out to in this direction to replace two pieces drive shaft with single piece made of composite.

The modern composite materials such as graphite, carbon, Kevlar, Boron and Glass with Suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). Advanced composite materials seem ideally 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 [1]. The automotive industry is exploiting composite material technology for structural components construction in order to obtain the reduction of the weight without decrease in vehicle quality and reliability. The main difference between composites where as in alloys, constituent materials are soluble in each other and form a new material which has different properties from their constituents. But in case of composite constituents are combined at a macroscopic level and or not soluble in each other [2]. Some shafts are used for power transmissions and primarily withstand torque instead of bending. Such drive shafts are often applied in cooling towers, pumps and automobiles. Filament wound composite tubes have been preferred over metal counterparts in drive shafts because they are strong and light-weight. The focus of this study was a drive shaft made of a composite material.[3]

1.5 ADVANTAGES OF COMPOSITES:

1) Better fatigue resistance
2) Improved corrosion resistance
3) High impact resistance
4) High stiffness to weight ratio
5) High strength to weight ratio
6) Good thermal conductivity
7) Low coefficient of thermal expansion. As a result, composite structures may exhibit a better dimensional stability over a wide temperature range.
8) High damping capacity.[3]

1.6. LIMITATIONS OF COMPOSITES

1) Rework and repairing are difficult
2) The fabrication cost of composites is high
3) They do not necessarily give higher performance in all properties used for material Selection
4) The design of fiber reinforced structure is difficult compared to a metallic structure, mainly due to the difference in properties in directions
5) They do not have a high combination of strength and fracture toughness as compared to metals
6) Mechanical characterization of a composite structure is more complex than that of metallic structure[4]

1.7. APPLICATIONS OF COMPOSITES

The common applications of composites are extending day by day. Nowadays they are used in medical applications too. The other fields of applications are:[5]

Field of application	Area of use
1. Space	payload bay doors, remote manipulator arm, high gain antenna, antenna ribs and struts etc.
2. Aviation And Aircrafts	Drive shafts, rudders, elevators, bearings, landing gear doors, panels and floorings of airplanes etc.
3. Electrical & Electronics	Structures for overhead transmission lines for railways, Power line insulators, Lighting poles, Fiber optics tensile members etc
4. Automotive	Drive shafts, clutch plates, engine blocks, push rods, frames, Valve guides, automotive racing brakes, filament–wound fuel tanks, fiber Glass/Epoxy leaf springs suspension arms and bearings for steering system.

2. PROBLEM STATEMENT

All automobile with rear wheel drive have transmission shaft. Because of two or three piece assembly of transmission shaft leads to increase in weight of overall assembly.it was noticed that using of composite material in automobile application especially as shaft leads to weight reduction and also using single piece composite shaft, the first natural frequency of shaft is increase.

3. SUGGESTED SOLUTION

a) Two-piece steel drive shaft can be replaced in single piece hybrid drive shaft by using hybrid material.
b) Design of hybrid drive shaft can be carry out by using macro mechanical and micro mechanical analysis.
c) Verification of the results is done by using software analysis.

4. LITERATURE REVIEWS

Y.A. Khalid , S.A. Mutasher, B.B. Sahari, A.M.S. Hamouda [6] studied that by using of composite material in shaft leads to significant saving in weight. In their work Glass Fiber with matrix of Epoxy resin and hardener were used .Study shows that aluminium tube wounded by different layers of composite materials and fiber orientation angles, four possibilities are study. During Fatigue loading using a rotating fatigue machine the first damage is matrix cracking, The crack initiated in outer part of resin and as number of cycles increase the second damage is in fiber matrix then in aluminium tube crack start and final failure occurs.

M.A. Badie, E, Mahdi, A.M.S. Hamouda [7] investigate into hybrid carbon/glass fiber with epoxy resin automotive drive shaft. Works show on the effect of natural frequency, buckling torque , torsional stiffness. Carbon fiber has more contribution over glass in torsional stiffness. The bending natural frequency increase by decreasing fiber orientation angle. Buckling torque increase by orienting fibers at 90^0.

B. James Prasad Rao D.V. Srikanth , T. Suresh Kumar, L. Rao [8] studied the composite propeller shaft using FEA. Large amount of weight saving is seen in carbon/epoxy shaft and glass/epoxy shaft compare to conventional steel shaft. The torsional buckling load is also higher than ultimate transmission by shaft. The stresses developed in shaft under static and dynamic condition using composite materials was good. Due to elastic property of materials there is increase in torque as well as rotational speed at which they operate.

Lien Wen Chen , Wen Kung Peng [9] studied the behaviour composite shaft under compressive loading condition. The present study is about finite element model based upon Timoshenko beam theory to obtain matrix equations of motion for rotating shaft. Here we get an idea critical speed is calculated using Layer wise beam theory (LBT) and equivalent modulus beam theory (EMBT) single piece. It depend upon L/R ratio and type of boundary condition.

Durk Hyun Cho, Dai Gil Lee[10] carry out work of one piece drive shaft with aluminium and composite materials. The present study is about carbon fiber epoxy composite and aluminium tube was designed and manufactured to reduced weight and vibration. Hybrid drive shaft was lighter than steel drive shaft as well as fundamental natural frequency in bending of hybrid drive shaft was better.

Hak Sung Kim , Dai Gil Lee[11] carry a work on stainless steel/carbon epoxy hybrid shaft for cleaning LCD glass panels. It was found that mass of the hybrid shaft was 8.1 kg while that of conventional stainless steel shaft was 8.1 kg. So overall 46% weight saving is done by using composite material shaft .

Along with that hybrid brush shaft was could perform reliable cleaning without any vibration. Fundamental natural frequency of hybrid shaft is too better than conventional shaft by theoretical and experimental .

Jong Woon Kim , Jin Kook Kim ,Hak Sung Kim , Dai Gil, Lee[12] carry a work on aluminium/ composite drive shaft. Here four carbon fiber epoxy composite layers and one glass fiber composite layers on mandrel then mandrel with wrapped composite layers into the aluminium tube. Natural frequency of hybrid shaft is higher than design specifications. There is significant in mass reduction of drive shaft. The mass of hybrid shaft was 3.3 kg which was 25% of steel shaft. Static torque caring capacity is much more better in composite material shaft.

O. Montagnier, Ch. Hochard[13] done a work on optimization of high modulus/high strength carbon fiber plastic composite drive shaft using genetic algorithm. Here the work deal with supercritical motion, failure strength and torsional buckling of carbon fiber reinforcement plastics is found to be accurately. To maximized axial stiffness carbon/epoxy plies should be at 0^0 and to maximize torsional buckling carbon/epoxy plies should be at 90^0.

Ercan Sevkat , Hikmet Tumer [14] carry out a work on residual property of composite shafts in loading condition. Here E-glass/ epoxy , carbon/epoxy and carbon E-glass/epoxy hybrid shafts residual torsional property was investigated. Composite material shaft was manufactured by filament winding method. Energy absorption ability and resistance to impact in loading condition of hybrid composite shaft was found to be good between finite element method and experimental results .

Won Tae Kim and Dai Gil Lee [15] study on various types of the adhesively bounded tubular lap joints, such as the circular single lap with and without scarf, the circular double lap with and without scarf, the hexagonal single lap and the elliptical single lap joints, were manufactured.

Hasim Pihtili [16]carry an investigation of wear of glass fibre/ epoxy resin and glass fiber/ polyester resin on composite shaft. The wear in the woven glass fibre– epoxy resin composite specimens is lower than the woven glass fibre–polyester resin composite for all the speed and the load according to the sliding distance.

P.Satheesh Kumar Reddy and Ch.Nagaraju [17] deal a work with the reduction of drive shaft by optimizing the design parameters by fulfilling all

the constraints. Here static , free vibration and torsional buckling analysis was done between E-glass/epoxy , Carbon/epoxy with vary wall thickness the weight saving on material is better than steel.

Harshal Bankar, Viraj Shide, P.Baskar [18] carry out a work in material optimization and the weight reduction of drive shaft using composite materials. The use of composite materials reduces weight of shaft because of lower density. The natural frequency of carbon fiber drive shaft is two times than of steel or aluminium.

V.S. Bhajantri , S.C. Bhajantri, A.M. Shindolkar, S.S.Marapure [19] done a work on design and analysis of composite materials drive shaft. Here work deals with changing conventional two piece steel drive shaft with a single piece of glass/epoxy or hybrid material. The weight saving was seen using carbon/epoxy composite materials than steel shaft. Regression analysis was carry out between fibre orientation angles and other parameter between each layer which helps us to optimize the design of composite shaft .

S.A.Mutasher [20] study on a prediction of torsional strength of hybrid aluminium composite drive shaft.The hybrid shaft consists of aluminium tube wound outside by E-glass and carbon fiber epoxy composite. It was analyze by the ANSYS to perform numerical analysis for hybrid shaft. Result obtained of carbon fiber/epoxy composite winding angle 45^0 was 295 Nm.

Saeed Karimi, Alireza Salamat and Sirus Javadpour [21] carryout a new approach for design and optimize of composite drive shafts based on Bees algorithm (BA). It was performed on a specific filament wound composite drive shaft which was installed in a cooling tower. BA is an appropriate tool for designing and optimizing of the hybrid shafts. The CFRE and the hybrid drive shafts are the lightest and cost effective.

Kyung Geun Bang and Dai Gai Lee [22] done a work on design of a carbon fiber composite shaft for high speed air spindle. In this dynamic and static characteristics of composite high speed air spindle were investigated by FEA. The bending stiffness of composite shaft was improved between inner and middle part of shaft using 90^0 plies.

Kyoshi Mizuuchi, Kanryu Inoue , Masami Sugioka, Masao Itami and et-al [23]carry out an investigation on Microstructure and mechanical properties of boron-fiber-reinforced titanium-matrix composites produced by pulsed current hot pressing (PCHP).Various holding temperatures between 973 and 1273K at a pressure of 32 MPa for 600s. It was found that the boron fiber and the Ti-matrix were well bonded when process was carried out at 1073K. Tensile tests were carried out at room temperature for the composites fabricated at 1073K.

R.V. Choudri , S.C. Soni , A.N. Mathur [24] done a work on Tensile Fracture strength of Boron (SAE-1042)/Epoxy/Aluminium (6061-t6) laminates. The 3 specimen were tested with same dimension on tensile strength, Yield Strength, and percentage elongation was study. They developed Boron/Epoxy/ Aluminium Laminated Metal Composite was shown on stress- strain diagram. coatings were prepared and applied on glass to obtain thermally and mechanically stable coatings. Modified epoxy matrix with boron acrylate monomer possess a better thermal stability at high temperature conditions.

Tuba Cakir, Kubra Kaya, I.Ersin Serhatli [25] carry a work regarding a Boron containing UV-curable epoxy acrylate coatings. Boron containing epoxy acrylate

G. Zhang, Z. Zhou, G. Ding, C. Xie, J. Zhang and Y. Hu [26] study about carbon fibre-reinforced polymer drive shaft consisting of a carbon fibre/epoxy composite tube connected to two adhesively bonded steel flanges was designed. Next, finite element method was used to analyse the carbon fibre-reinforced polymer shaft's static torsional properties.

H. Yefa1, Y. Jin1, Z. Jinguang, D. Guoping1, S. Chunsheng1 and H. Baojian [27] carry out work in field of material design parameters of the carbon fibre reinforced plastics drive shaft were analysed. The parameters are fibre orientation angle and proportions of the fibre with different orientation angles. Finite element analysis was used to conduct simulations, and Tsai–Wu failure criterion was applied to estimate the effect of layer parameters on the performance of the drive shaft. A carbon fibre reinforced plastics driveshaft was made by taking into account the finite element analysis results. Then, static torque failure experiment was performed on the shaft.

Yefa Hu, Mo Yang, Jinguang Zhang, Chunsheng Song and Weiming Zhang [28] investigate that the design of lay-up has a great influence on the mechanical properties of carbon fiber–reinforced plastic drive shaft. In this research, the stress states of each layer in the carbon fiber–reinforced plastic drive shaft were studied, which were different under opposite torque directions. The Tsai–Wu criterion was used to see the torsional stability of the composite laminates.

CONCLUSION:

Composite materials used for drive shaft consists of superior properties such as stronger and stiffer than metals on density basis ,for the same strength it is lighter than steel by 70% and aluminium by 50% .It have superior stiffness to weight ratio. The presented work was about reducing the fuel consumption of automobiles for drive shafts. The usage of composite materials has resulted in considerable amount of weight saving in the range of 66 % to 52% when it was compared with conventional steel shaft. Finally one piece composite drive shaft is manufactured with reduction in fuel economy of vehicle.

REFERENCES

[1] John W, "Engineers Guide to Composite Materials", American Society for Metals, 1986.
[2] Ever J. Barbero ,"Introduction to Composite Materials Design ", Third Edition, CRC press.
[3] Deborah D.L. Chung ,"Composite Materials–Science and Applications", Second Edition, Springer.
[4] Chawla , Krishan K," Composite Materials–Science and Engineering " Third Edition, Springer.
[5] F.L. Matthews D Rawling, "Composite Materials-Engineering and Science ", First Edition, ELSEVIER.
[6] Y.A. Khalid, S.A. Mutasher, B.B. Sahari, A.M.S. Hamouda "Bending fatigue behavior of hybrid aluminum/composite drive shafts " Vol. 7(44), pp. 3797-3808.
[7] M.A. Badie, E. Mahdi, A.M.S. Hamouda " An investigation into hybrid carbon/glass fibre reinforced epoxy composite automotive drive shaft ", ISSN : 2248-9622, Vol. 7, pp.42-48 .
[8] B. James Prasad Rao ,D.V. Srikanth , T. Suresh Kumar, L. Rao , "Design and Analysis of Automotive Composite Propeller Shaft using FEA", ICMRA: (2016), 3673-3679.
[9] Lien Wen Chen , Wen Kung Peng , " The Stability behavior of rotating composite shaft under axial compressive loads. ", Composite Structure, Vol - 41, (1998) 253-263.
[10] Durk Hyun Cho, Dai Gil Lee , " Manufacture of one piece automotive drive shafts with Aluminium and Composite materials.", Composite Structure Vol - 38, No. 1-4 , pp.309-319.
[11] Hak Sung Kim , Dai Gil Lee , " Design and manufacture of stainless steel/carbon epoxy hybrid shaft for cleaning large LCD glass panels " Composite Structure , Vol - 80, (2007) 279-289.
[12] Jong Woon Kim , Jin Kook Kim ,Hak Sung Kim , Dai Gil, Lee, " Design and Manufacture an automotive hybrid Aluminium/Composite drive shaft. " , Composite Structure -63,(2004) ,87-99.
[13] O. Montagnier , Ch. Hochard , " Optimisation of hybrid high-modulus / high- strength carbon fiber reinforced plastic composite drive shafts. " , Materials and Design 46 (2016) 88-100.
[14] Ercan Sevkat , Hikmet Tumer , " Residual Torsional properties of composite shafts subjected to impact loadings.", Materials and Design 51 (2013) 956-967.
[15] Won Tae Kim and Dai Gil Lee , " Torque transmission capabilities of adhesively bonded tubular lap joints for composite drive shafts. " , Composite Structure -30,(1995) ,229 – 240.
[16] Hasim Pihtili , " An experimental investigation of wear of glass fibre –epoxy resin and glass fibre- polyester resin composite materials. " , European Polymer Journal 45 (2009) 149-154.
[17] P.Satheesh Kumar Reddy and Ch.Nagaraju , "Weight optimization and Finite Element "Analysis of Composite automotive drive shaft for Maximum Stiffness", ,Material Today : Proceedings 4 (2017), 2390-2396.
[18] Harshal Bankar, Viraj Shinde , P. Baskar , " Material Optimization and weight reduction of drive shaft using composite material. , IOSR Journal, Vol 10, Issue 1, PP 39-46.
[19] V.S. Bhajantri , S.C. Bhajantri, A.M. Shindolkar, S.S.Marapure,"Design and Analysis of Composite drive shaft", IJRET, ISSN : 2321-7308.
[20] S.A. Mutasher , "Prediction of the torsional strength of the hybrid aluminum/compo--site drive shaft. " , Materials and Design,30 (2008) 215-220 .
[21] Saeed Karimi, Alireza Salamat and Sirus Javadpour," Designing and optimizing of composite and hybrid drive shafts based on the bees algorithm". Springer : Journal of Mechanical Science and Technology 30 (4) (2016) 1755-1761.
[22] Kyung Geun Bang and Dai Gil Lee , "Design of carbon fiber composite shafts for high speed air spindles. " , Composite Structure -55,(2002) ,247-259.
[23] Kiyoshi Mizuuchia ,et-al , "Microstructure and mechanical properties of boron-fiber-reinforced titanium-matrix composites produced by pulsed current hot pressing (PCHP) " , Material Science Engineering 428 (2006) 175-179.
[24] R.V. Choudria, et-al , "Tensile Fracture strength of Boron (SAE-1042)/Epoxy/Aluminium (6061-t6) laminates " , Materials Today 4, (2017) 3407-3415 .
[25] Tuba Cakir Canak , et-al ," Boron containing UV-curable epoxy acrylate coatings" , Organic Coating 77 (2014), 1911-1918.
[26] G. Zhang, Z. Zhou, G. Ding, C. Xie, J. Zhang & Y. Hu "Static property analyses based on finite element method and torsion tests on carbon fibre composite motor drive shaft." Journal of Taylor and Francis, ISSN: 1432-8917 ,1433-075X.
[27]H. Yefa, Y. Jin1, Z. Jinguang, D. Guoping1, S. Chunshengand H. Baojian ,"Material design and failure experiment of a carbon fibre reinforced plastics drive shaft", Journal of Taylor and Francis, ISSN: 1432-8917 ,1433-075X.
[28]Yefa Hu, Mo Yang, Jinguang Zhang, Chunsheng Song and Weiming Zhang," Research on torsional capacity of composite drive shaft under clockwise and counter-clockwise torque." Advances in Mechanical Engineering, 1–7, 2015 ISSN: 1687814015582109.