Design Review of Hybrid Drive Shaft

Mr. Nishikant Tanaji Narale[1] Dr. S. Y. Gajjal[2] Prof. S. J. Thorat[3]
[1]P.G Student [2]Professor [3]Assistant Professor
[1,2]NBN Sinhgad School of Engineering, Ambegaon (BK), Pune

Abstract—Substituting hybrid structures for conventional metallic structures have many advantages because of higher specific stiffness and higher specific strength of hybrid materials. First we will study design of shaft concentrating on critical speed, static torque, and fibre orientation etc. Experimental set up will carried out to find static and dynamic results, torsion behaviour of hybrid drive shaft. Finite element analysis will give us optimal stacking sequence of the product considering the proper interface between the metallic tube and the composite layer.
Keywords: Hybrid shaft, Specific stiffness, composite layer, static analysis, dynamic analysis

I. Introduction

Drive shafts as power transmission tubing are used in many applications, including cooling towers, pumping sets, aerospace, trucks and automobiles. The term Drive shaft is used to refer to a shaft, which is used for the transfer of motion from one point to another. Whereas the shafts, which propel (push the object ahead) are referred to as the propeller shafts. Propellers are usually associated with ships and planes as they are propelled in water or air using a propeller fan. However the drive shaft of the automobile is also referred to as the propeller shaft because apart from transmitting the rotary motion from the front end to the rear end of the vehicle, these shafts also propel the vehicle forward. The shaft is the primary connection between the front and the rear end (engine and differential), which performs both the jobs of transmitting the motion and propelling the front end. Thus the terms Drive shaft and propeller shafts are used interchangeably.[3]

In other words, a propeller shaft is a longitudinal drive shaft used in vehicle where the engine is situated at the opposite end of the vehicle to the drive wheels. A propeller shaft is an assembly of one or more tubular shafts connected by universal, constant velocity or flexible joints.

When the length of steel drive shaft is beyond 1500 mm, it is manufactured in two pieces to increase the fundamental natural frequency, which is inversely proportional to the square length and proportional to the square root of specific modulus. A drive shaft of hybrid offers excellent vibration damping, cabin comfort, reduction of wear on drive train components and increasing tires traction. In addition, the use of one piece torque tube reduces assembly time, inventory cost, maintenance, and part complexity. It is possible to manufacture hybrid drive shaft in one piece without whirling vibration over 9200rpm. [1]

A. Introduction to Composites and Hybrids:

The advanced composite materials such as graphite, carbon, Kevlar and Glass with Suitable resins are widely used because of their high specific strength (strength/density) and high specific modulus (modulus/density). 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. The drive shafts are used in automotive, aircraft and aerospace applications. 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. It is known that energy conservation is one of the most important objectives in vehicle design and reduction of weight is one of the most effective measures to obtain this result. Actually, there is almost a direct proportionality between the weight of a vehicle and its fuel consumption, particularly in city driving. Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. The constituents are combined at a macroscopic level and or not soluble in each other. 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.

1) Properties of Hybrid and Composite Materials:

The physical properties of composite materials are generally not isotropic (independent of direction of applied force or load) in nature, but rather are typically orthotropic (depends on the direction of the applied force or load). For instance, the stiffness of a composite panel will often depend upon the orientation of the applied forces and/or moments. Panel stiffness is also dependent on the design of the panel. In contrast, isotropic materials (for example, aluminum or steel), in standard wrought forms, typically have the same stiffness regardless of the directional orientation of the applied forces and/or moments. While, composite materials exhibit different properties in different directions. The relationship between forces/moments and strains/curvatures for an isotropic material can be described with the following material properties: Young's Modulus, the Shear Modulus and the Poisson's ratio, in relatively simple mathematical relationships. For the anisotropic material, it requires the mathematics of a second order tensor and up to 21 material property constants. For the special case of orthogonal isotropy, there are three different material property constants for each of Young's Modulus, Shear Modulus and Poisson's ratio--a total of 9 constants to describe the relationship between forces/moments and strains/curvatures.

Hybrid materials are those formed by combining both the conventional (steel, aluminium etc.) and non-conventional (composites) materials. It gives the combined properties of the both and forms new one.

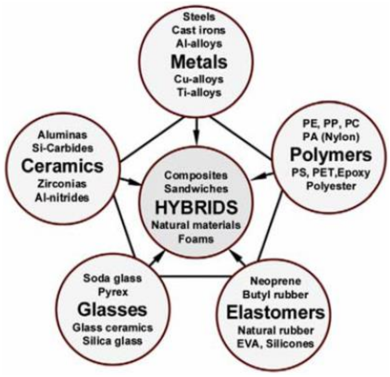

Fig. 1: Formation of Hybrid Material

2) *Advantages of Hybrid over the Conventional Materials:*
- High strength to weight ratio
- High stiffness to weight ratio
- High impact resistance
- Better fatigue resistance
- Improved corrosion resistance
- Good thermal conductivity
- Low coefficient of thermal expansion. As a result, composite structures may exhibit better dimensional stability over a wide temperature range.
- High damping capacity.

3) *Limitations of hybrid materials:*
- Mechanical characterization of a hybrid structure is more complex than that of metallic structure.
- The design of fiber reinforced structure is difficult compared to a metallic structure, mainly due to the difference in properties in directions.
- The fabrication cost of hybrid is high.
- Rework and repairing are difficult.
- They do not have a high combination of strength and fracture toughness as compared to metals.
- They do not necessarily give higher performance in all properties used for material Selection.

4) *Applications of hybrid materials:*

The common applications of hybrids are extending day by day. Nowadays they are used in medical applications too. The other fields of applications are,
- Automotive : Drive shafts, clutch plates, engine blocks, push rods, frames, Valve guides, automotive racing brakes, filament–wound fuel tanks, fiber Glass/Epoxy leaf springs for heavy trucks and trailers, rocker arm covers, suspension arms and bearings for steering system, bumpers, body panels and doors
- Aircraft: Drive shafts, rudders, elevators, bearings, landing gear doors, panels and floorings of airplanes etc.
- Space: payload bay doors, remote manipulator arm, high gain antenna, antenna ribs and struts etc.
- Marine: Propeller vanes, fans & blowers, gear cases, valves &strainers, condenser shells.
- Chemical Industries: Composite vessels for liquid natural gas for alternative fuel vehicle, racked bottles for fire service, mountain climbing, underground storage tanks, ducts and stacks etc.
- Electrical & Electronics: Structures for overhead transmission lines for railways. Power line insulators, Lighting poles, Fiber optics tensile members etc.[8]

B. Problem Statement:

Almost all automobiles have transmission shafts. The weight reduction of the shaft can have a certain role in the general weight reduction of the vehicle and is a highly desirable goal, if it can be achieve without increase in cost and decrease in quality and reliability. It is possible to achieve design of composite drive shaft with less weight to increase the first natural frequency of the shaft and to decrease the bending stresses using various stacking sequences. By doing the same, the torque transmission and torsional buckling capabilities are also maximized.

C. Suggested Solutions:

1) By incorporating hybrid material, two piece steel drive shaft can be replaced in single piece hybrid drive shaft.
2) Design of hybrid drive shaft can be carry out by using macro mechanical and micro mechanical analysis.
3) Verification of the results is done by using software analysis.

II. LITERATURE REVIEW

Dai Gil Lee et. al.[1], Author explained that Substituting composite structures for conventional metallic structures have many advantages because of higher specific stiffness and higher specific strength of composite materials. In this work, one-piece automotive hybrid aluminum/composite drive shaft was developed with a new manufacturing method, in which a carbon fiber epoxy composite layer was co-cured on the inner surface of an aluminum tube rather than wrapping on the outer surface to prevent the composite layer from being damaged by external impact and absorption of moisture. From experimental results, it was found that the developed one-piece automotive hybrid aluminum/composite drive shaft had 75% mass reduction, 160% increase in torque capability compared with a conventional two-piece steel drive shaft. It also had 9390 rpm of natural frequency which was higher than the design specification of 9200 rpm.

M.A. Badie [2], In this paper examined the effect of fiber orientation angles and stacking sequence on the torsional stiffness, natural frequency, buckling strength, fatigue life and failure modes of composite tubes. Finite element analysis (FEA) has been used to predict the fatigue life of composite drive shaft (CDS) using linear dynamic analysis for different stacking sequence. FEA results showed that the natural frequency increases with decreasing fiber orientation angles.

Robert S. Salzaret. al.[3], this paper demonstrates a logical step in the application of fiber-reinforced composites is to take advantage of their light-weight/high-strength potential and replace traditional monolithic shaft designs with composite materials. In the case of aircraft engine shafts where the high-temperature environment excludes the use of most traditional materials, a high-strength titanium alloy is recommended. The feasibility of using lighter-weight/stronger composite shafts, as well as the complexity of the design problem, along with the careful consideration of practicality that must be taken prior to the abandonment of traditional monolithic designs in highly critical applications.

O. Montagnier [4], in this paper study deals with the optimization of hybrid composite drive shafts operating at subcritical or supercritical speeds, using a genetic algorithm. A formulation for the flexural vibrations of a composite drive shaft mounted on viscoelastic supports including shear effects is developed. In particular, an analytic stability criterion is developed to ensure the integrity of the system in the supercritical regime. Then it is shown that the torsional strength can be computed with the maximum stress criterion. A shell method is developed for computing drive shaft torsional buckling. In this research study yielded some general rules for designing an optimum hybrid/composite shaft without any need for optimization algorithms.

Charles W. Bert et. al. [5], In this paper it is mentioned that laminated composite, circular cylindrical hollow shafts are used extensively as primary load-carrying structures in many applications under various loading configurations. Advanced composite materials also seem ideally suited for long, power drive-shaft applications. At the same time, from a design point of view, local and general instability arising from the action of torsional loads often represents the limiting load condition. In the present study, a theoretical analysis is presented for determining the buckling torque of a circular cylindrical hollow shaft with layers of arbitrarily laminated composite materials by means of various thin-shell theories. Comparisons with previous investigations are listed for isotropic and arbitrarily laminated composite material drive shafts.

Y.A. Khalid [6], throughout the experimental study by author, a bending fatigue analysis was carried out for hybrid aluminum/composite drive shafts. The hybrid shafts used were fabricated using filament winding technique. Glass fiber with a matrix of epoxy resin and hardener were used to construct the external composite layers needed. Four cases were studied using aluminum tube wounded by different layers of composite materials and different stacking sequence or fiber orientation angles. The failure mode for all the hybrid shafts was identified. The macroscopic level tests indicate that the cracks initiating in the zones free of fibers or in the outer skin of resin and increase with increasing number of cycles until the failure of specimen. Results obtained from this study show that increasing the number of layers would enhance the fatigue strength of aluminum tube up to 40%, for [±45]3s.

A. R. Abu Talibet. al. [7], in this paper it is mentioned that the study, a finite element analysis was used to design composite drive shafts incorporating carbon and glass fibers within an epoxy matrix. A configuration of one layer of carbon–epoxy and three layers of glass–epoxy with 00, 450 and 900 was used. The developed layers of structure consist of four layers stacked as [+450Glass/-450glass/00carbon/900glass]. The results show that, in changing carbon fibers winding angle from 00 to 900, the loss in the natural frequency of the shaft is 44.5%, while, shifting from the best to the worst stacking sequence, the drive shaft causes a loss of 46.07% in its buckling strength.

Bhushan K. Suryawanshi [8], This paper deals with the study of replacement of conventional two-piece steel drive shafts with one-piece automotive hybrid aluminum/composite drive shaft & was developed with a new manufacturing method, in which a carbon fiber epoxy composite layer was co-cured on the inner surface of an aluminum tube rather than wrapping on the outer surface to prevent the composite layer from being damaged by external impact and absorption of moisture. The optimum stacking sequence is calculated with the help of Finite element analysis. The joining of the aluminum - composite tube and steel yoke with improved reliability and optimum manufacturing cost is done by press fitting.

M. Arun[9], In this paper, work deals with the replacement of conventional two piece steel drive shafts with a one piece Hybrid Aluminum E glass/epoxy composite drive shaft for an automotive application. The basic requirements considered here are torsional strength, torsional buckling and bending natural frequency. A hybrid of Aluminum and E-glass/epoxy as in which the aluminum has a role to transmit the required torque, while the E-Glass epoxy composite increases the bending natural frequency. An experimental study was carried out to study the static torsion capability. Four cases were studied using aluminum tube wounded by different layers of composite materials. Results obtained from this study show that increasing the number of layers would enhance the maximum static torsion approximately 66% for [+45/-45]3s laminates higher than the pure aluminum and mass reduction of 42% compared with of steel drive shaft. A one-piece hybrid composite full drive shaft is optimally analyzed using Finite Element Analysis Software and simulation results were compared with the existing steel drive shaft.

E. Sevkatet. al.[10], in this research paper, hybrid aluminium shafts were manufactured and tested. Their torsional properties were investigated. To see influence of the hybrid aluminium/composite interface properties on the torsional properties of hybrid aluminum/composite tubes; four different surface treatment on aluminum were applied. One aluminium was kept as purchased, second one sanded longitudinally, third one was knurled and last one was hole drilled. Then composite layer were designed using Composite Designer software. Filament winding machine was equipped with resin bath and fiber tension system as well as fiber storing shelf system. Hybrid materials having high specific stiffness and strength, excellent fatigue properties, corrosion resistance and increased natural bending frequencies.

III. DESIGN PROCEDURE FOR HYBRID DRIVE SHAFT

A. *Material Selection:*

In the design of the steel shaft we have to know the properties of the steel which are used in conventional steel drive shaft.

Mechanical properties	Symbol	Steel
Young's modulus (GPa)	E	207.0
Shear modulus (GPa)	G	80.0
Poisson's ratio	N	0.3
Density (Kg/m3)	P	7600
Yield strength (MPa)	Sy	370
Shear strength (MPa)	Ss	370

Table-1: Mechanical Properties of Steel (Sm45c)

Various properties of different composite materials, can be determined by finalizing there composition. As per there composition material properties will be changes.

Material Properties	Unidirectional carbon fiber Epoxy composite (USN150)	Unidirectional glass fiber epoxy composite (UGN150)
E_1 (GPa)	131.6	43.3
E_2, E_3 (GPa)	8.20	14.7
G_{23} (GPa)	3.5	3.5
G_{12}, G_{13} (GPa)	4.5	4.4
ν_{12}, ν_{13}	0.281	0.3
α_1 (×10-6/0C)	-0.9	6.3
α_2, α_3 (×10-6/0C)	27	19
S_1^t `(MPa)	2000	1050
S_1^c (MPa)	-1400	700
S_2^t S_3^t (MPa)	61	65
S_2^c S_3^c (MPa)	-130	-120
S_{23} (MPa)	40	65
S_{13}, S_{12} (MPa)	70	40
ρ (kg/m3)	1550	2100
t_{ply} (mm)	0.125	0.12

Table-2: Mechanical Properties of Composite Materials

The aluminum is required in this work is AA 6063. Mechanical properties of Aluminum (T6-6063) are

Mechanical Properties	Symbol	Units	Aluminium
Young's Modulus	E	GPa	72
Shear modulus	G	GPa	27
Poission Ratio	V	-	0.33
Density	*P*	Kg/m^3	2700
Yield Strength	Sy	Mpa	131
Shear Strength	Ss	Mpa	150

Table-3: Mechanical Properties of Aluminum (T6-6063)

B. Design of Steel Drive Shaft:

The steel drive shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency.

The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft is taken as 75 mm. The drive shaft of transmission system is to be designed optimally for following specified design requirements which are as follows. The following specifications are assumed which are based on literature and available standards of automobile drive shaft.

1) Design of Steel Shaft Based on Torsional Strength Basis:

Torsional Strength: The primary load in the drive shaft is torsion. The maximum shear stress, t_{max} in the drive shaft is at the outer radius, and is given as

$$\tau = \frac{16M_t}{\prod d_o^3(1-C^4)} \text{.............................[1]}$$

We know,

$$C = \frac{d_i}{d_o}$$

2) Design of steel shaft based on Rigidity basis:

$$\theta = \frac{584M_t L}{Gd_o^4(1-C^4)} \text{..............................[2]}$$

The permissible angle of twist for machine tool application is 0.25^0 per meter length. For line shaft in between 3^0 to 4^0 is the limiting value.

3) Thickness of Steel Drive shaft:

$$t = \frac{d_o - d_i}{2} \text{...[3]}$$

4) Mean Radius of Steel Drive Shaft:

$$r_m = \frac{r_i + r_o}{2} \text{..................................[4]}$$

5) Mass of steel drive Shaft:

$$m = \rho AL \text{...[5]}$$

$$m = \rho \times \frac{\pi}{4}(d_o^2 - d_i^2) \times L$$

6) Torque buckling capacity of the drive shaft:

$$T_b = (2\Pi r^2_m\, t)(0.272)(E)(\frac{t}{r_m})^{\frac{3}{2}} \text{...........................[6]}$$

Where,
r_m = mean radius of the shaft (m)
t = wall thickness of the drive shaft (m)
E = young's modulas (Pa)
The value of critical torsional buckling moment is larger than the applied torque of 1472.45 N-m. Thus the shaft need to withstand torsional buckling (T_b) capacity such that T_b>T. Hence the condition is satisfied.

C. Natural frequency can be found by using two theories

1) Bernoulli Euler theory
2) Timoshenko beam theory

1) Bernoulli Euler Theory [3]:

It neglects both transverse shear deformation as well as rotary inertia effects. Naturals frequency based on the Bernoulli Euler theory is given by

$$f_{nt} = \frac{\pi P^2}{2L^2}\sqrt{\frac{EI_X}{m_1}} \text{...............................[7]}$$

Where,
F_{nt} = natural frequency based on Bernoulli Euler theory, HZ
P =1, first natural frequency
r = mean radius of shaft
I_x =Area moment of inertia in x direction in m4
m_1 = mass per unit length in kg/m
Now the second moment of inertia, I is

$$I_x = \frac{\prod}{4}(r_0^4 - r_i^4) \text{..[8]}$$

The mass per unit length of the shaft is

$$m = \prod(r_0^2 - r_i^2)\rho \text{..................................[9]}$$

To get the natural frequency following Bernoulli Euler formula is used.

$$f_{nt} = \frac{\pi P^2}{2L^2}\sqrt{\frac{EI_X}{m_1}} \text{...........................[10]}$$

This value is greater than the minimum desired natural frequency of 60 Hz. Thus, the steel design of a hollow shaft of outer diameter 75 mm and thickness 3.05 mm is an acceptable design.

The critical speed of shaft is given by,

$$N_{crt} = 60\, f_{nt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots [11]$$

D. Design of the Hybrid Drive Shaft [3]:

The aluminum/composite drive shaft should satisfy three design specifications such as static torque capability, buckling torque capability and bending natural frequency. The major role of the aluminum tube is to sustain an applied torque while the role of the Carbon fiber/ glass fiber epoxy composite is to increase bending natural frequency.

1) Selection of cross-section and materials [3]:

The following assumptions were made in calculations:

- The shaft rotates at a constant speed about its longitudinal axis;
- The shaft has a uniform, circular cross section;
- The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the geometric center;
- All damping and nonlinear effects are excluded;
- The stress-strain relationship for composite material is linear & elastic; hence, Hook’s law is applicable for composite materials;
- Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

2) Design procedure for hybrid drive shaft[3]:

First we have to calculate the parameters, such as density of laminate, Young’s modulus in the transverse and longitudinal direction, weight of fiber, weight of matrix etc.by using micro mechanical analysis. In the design of hybrid aliminium composite first we have to calculate the elastic constant by using the matrix transformations. After these calculations we get E_x and E_y i. e. Young’s modulus of the shaft in axial and loop direction respectively.

E. Torque transmitted by the hybrid drive shaft:

The torque transmitted by the hybrid drive shaft, Tis the sum of the torque transmitted by the aluminum tube, Tal and that by the composite layer, T_{co}

$$T = T_{al} + T_{co} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [12]$$

Considering geometric compatibility and material properties of each material, the torque transmitted by the aluminum tube is calculated as follows:

$$T_{al} = \frac{G_{al} \times J_{al}}{G_{al} \times J_{al} + G_{com} \times J_{com}} T \ldots\ldots\ldots\ldots [13]$$

But,

$$T_{co} = 2\pi r_m^2 * 0.272 * (E_x E_y^3)^{0.25} \left[\frac{t}{r_m}\right]^{1.5} \ldots\ldots\ldots [14]$$

Where G is shear modulus, J is the polar moment of inertia, and subscripts al and co represent the aluminum tube and the composite layer, respectively. The shear modulus G_{al} and the polar moment of inertia of the aluminum tube J_{al} are much larger than those of the composite layer because only thin layer of unidirectional composite can increase sufficiently the natural frequency of the hybrid drive shaft. Therefore, the torque transmitted by the aluminum tube only is almost same as the torque transmitted by the hybrid aluminum/composite shaft. From now on, the static and buckling torque capabilities of the aluminum/composite shaft will be calculated neglecting the composite layer as follows

$$T_{static} = 2\pi r_{avg}^2 t_{al} S_{s.al} \ldots\ldots\ldots\ldots [15]$$

$$T_{Buckling} = \frac{\pi\sqrt{2E_{al}}}{3(1-v_{al}^2)^{0.75}} \sqrt{(r_{avg} t_{al}^5)} \ldots\ldots\ldots [16]$$

Where T_{static} and $T_{buckling}$ are the static and buckling torque capabilities of the hybrid aluminum/composite shaft respectively, and rave is the average radius of the aluminum tube, t_{al} is the thickness of the aluminum tube, $S_{S,al}$ is the shear strength of the aluminum, E_{al} is the elastic modulus of aluminum, and v_{al} is the Poisson’s ratio of aluminum.

F. Fundamental Bending Natural Frequency of Drive Shafts:

$$f_n = \frac{9.869}{L^2} \sqrt{\frac{E_{al} I_{al} + E_{co} I_{co}}{\rho_{al} + \rho_{co}}} \ldots\ldots\ldots [17]$$

IV. FACILITY REQUIREMENT FOR THE PROJECT

- Catia/AutoCAD Software for Modeling
- ANSYS Software for analysis
- Filament winding machine
- Torsional Testing machine
- FFT Analyzer

V. CONCLUSION

A one piece hybrid drive shaft has been designed for rear wheel drive automobile with objective of minimization of weight of the shaft which was constraint such as torque transmission, torsional buckling capacities and natural bending frequency.

REFERANCES

[1] Dai Gil Lee et. al , Design and manufacture of an automotive hybrid aluminum/composite drive shaft Department of Mechanical Engineering, ME3261, Korea Advanced Institute of Science and technology, 373-1 Guseong- dong, Yuseong-gu, Daejeon-shi 305-701, South Korea.

[2] Badie, et.al, “An Investigation into hybrid carbon/Glass fiber reinforced epoxy composite automobile drive shaft”, Materials and Design 32, 2011, pp- 1485–1500.

[3] Robert S. Salzar, “Design considerations for rotating laminated metal-matrix-composite Shafts, CUNY Graduate School of Civil Engineering, The City College of New York, NY 10031, USA, 20 July 1998.

[4] O. Montagnier Optimisation of hybrid high-modulus/high-strength carbon fiber reinforced plastic composite drive shafts, Écolesd’ Officiers de l’Armée de l’air (EOAA), Centre de Recherche de l’Armée de l’air (CReA), BA 701, 13361 Salon Air, France.

[5] Bhushan K. Suryawans, Review of Design of Hybrid Aluminum/ Composite Drive Shaft for Automobile International Journal of Innovative Technology and Exploring Engineering ISSN: 2278- 3075, Volume-2, Issue-4, March 2013.

[6] Charles W. Bert et.al, “analysis of buckling of hollow laminated Composite drive shafts.” School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, Oklahoma 73019-0601, USA, Dec-1994

[7] Y.A. Khalid “Bending fatigue behavior of hybrid aluminum/composite drive shafts” Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University Putra Malaysia, Serdang, 43400 Selango, Malaysia , 26 August 2005

[8] A.R. Abu Talibet. al. “Developing a hybrid, carbon/glass fiber-reinforced, epoxy composite automotive drive shaft”, Department of Aerospace Engineering, University Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia, 2010.

[9] M.Arun, K. Somasundara Vinoth, Design and Development of Laminated Aluminum Glass Fiber Drive Shaft for Light Duty Vehicles, International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 278- 3075, Volume-2, Issue-6, May 2013

[10] E. Sevkatet. al. Studied Torsional Fatigue Behavior Of Aluminum/Composite Tubes, Department of Mechanical Engineering, Meliksah University, 38280, Talas-Kayseri, TURKE