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Numerical and Buckling Analysis of Composite Hybrid Propeller Shaft

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***Abstract*—Composites structures have many advantages because of higher stiffness and strength of composite materials. This work deals with the replacement of conventional steel drive shafts with a hybrid aluminium/carbon fibre propeller shaft for an automotive application and was developed with a new manufacturing method, In which the carbon fibre layers is wrapped on the aluminium tube in order to attain the maximum strength. In this present work an attempt has been made to estimate the deflection, stresses, and natural frequencies under subjected loads using FEA (Ansys) for hybrid shaft and comparison is been made with conventional steel drive shaft in order to verify the optimum results.**
***Keywords*— Carbon fibre, Aluminium, epoxy, Bending natural frequency, buckling, wrapping**

I. INTRODUCTION

A. Composite Materials

A composite material is the mixing of two or more materials to improve strength to weight ratio. Composite materials consist of two phases; a matrix phase and a reinforcement phase. Matrix and reinforcement in combination of good material properties produce composite materials with better properties. In common, various reinforcements are added to matrix of the composite for improving the strength as well as the stiffness.
The role of matrix in Fiberreinforced composite is

To transfer stresses between the fibres
To provide the barrier against an adverse environment, and
To protect the surface of the fibres from mechanical abrasion

B. Hybrid Composites

Hybrid composites are more advanced composites as compared to conventional FRP composites. Hybrids can have more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases. They have better flexibility as compared to other fiber reinforced composites. Normally it contains a high modulus fiber with low modulus fiber. The high-modulus fiber provides the stiffness and load bearing qualities, whereas the low-modulus fiber makes the composite more damage tolerant and keeps the material cost low. The mechanical properties of a hybrid composite can be varied by changing volume ratio and stacking sequence of different plies.

1) Advantages Of Hybrid Composites: They offer better flexibility in the selection of fiber and matrix materials, which helpsin better tailoring of the mechanical properties. For example the modulus, strength, fatigue performance etc of glass reinforced composites can be enhanced by inclusion of carbon fibres.
Better wear resistance
Low thermal expansion coefficient
Combination of high tensile strength and high failure strain

2) Application Of Hybrid Composites: Helicopter rotor blades and drive shafts
Ailerons and floor panels of aircrafts
In automobile sector they are used in transmission units, chassis members,suspensions, and structural body parts of cars and lorries
CFRP/ARP hybrids are used for making bicycle frames
In sports industries Tennis racquets, fishing rods, skis, golf club shafts, yacht hulls, hockey sticks and paddles

C. Problem Definition

Almost all automobiles have transmission shafts .The weight reduction of the drive shaft will play a vital role in vehicle performance if it can be achieved 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 decrease the bending stresses by selecting best composition of materials for aluminium/composite hybrid drive shaft .By doing the same torque transmission and torsional buckling capabilities are also maximized.

D. Specification of the Problem

The torque transmission capability of the drive shaft for passenger cars, small trucks, and vans should be larger than3,500 Nm and fundamental natural bending frequency of the shaft should be higher than 6,500 rpm to avoid whirling vibration. The outer diameter (do) should not exceed 100 mm due to space limitations and here do is taken as 90 mm. The drive shaft of transmission system should be designed optimally to the specified design requirements.

E. Objective

The objective of this research work is to replace the conventional steel drive shaft with high strength aluminum/composite hybrid drive shaft for an automobile application adhering to the design constraints which is to be analysed in Ansys and solved theoretically the experimental investigation of the same will be carried out in future.

II. DESIGN OF COMPOSITE DRIVE SHAFT

A. Design Specifications

The following specifications were assumed suitably, based on the literature and available standards of automobile drive shafts:

The torque transmission capacity of the driveshaft (T) = 3500 N-m.

The shaft needs to withstand torsional buckling (T_b) such that T_b> T.

The minimum bending natural frequency of the shaft ($f_{nb(min)}$= 108 Hz.

Outside radius of the driveshaft (ro) = 45 mm.

Length of the driveshaft = 1.25 m.

B. Design Of Composite Drive Shaft

First, the conventional steel shaft was designed to facilitate comparison in terms of mass savings. Be it the conventional driveshaft or the composite one, the design should be based on the following criteria:

Torsional strength

Torsional buckling and

Bending natural frequency.

The properties of Hybrid drive shaft is :

Young's modulus (E)	=	175 GPa
Shear modulus (G)	=	80 GPa
Poisson's ratio (ν)	=	0.3
Density of steel (ρ)	=	7600 kg/m3
Yield strength (σy)	=	370 MPa.

1) Torsional Strength: Since the primary load on a driveshaft is torsion, the maximum shear stress (τ_{max}) at the outer radius (r_o) of the shaft is given by:

$$\frac{\tau_{max}}{F.S} = \frac{Tr_o}{J}$$

Substituting for **J**:

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$$\frac{\tau_{max}}{\mathrm{F.S}} = \frac{32 T r_o}{\pi(d_o^4 - d_i^4)}$$

Where,
T is the maximum torque applied in N-m
J is the polar area moment of inertia in m4
d_0 and d_i are outer and inner diameters of the shaft in m.
Assuming τ_{max} =265MPa and a factor of safety (**F.S**.) Of 3,
d_i=0.08299*m*. Hence, the inner radius is, r_i=0.04149 *m*.
Thus the wall thickness of the hollow steel shaft: t=$r_0 - r_i$

=3.50x10^{-3}m.

2) Torsional Buckling: A shaft is considered as a long shaft, if

$$\left(\frac{1}{\sqrt{1-\vartheta^2}}\right)\frac{L^2 t}{(2r)^3}>5.5$$

Where, r is the mean radius, such that:

$$r = \frac{r_i + r_0}{2} = 0.00432m.$$

Substituting,

$$\left(\frac{1}{\sqrt{1-0.3^2}}\right)\frac{1.25^2(0.00350)}{(2x0.0432)^3}=8.88>5.5$$

For a long shaft, the torsional buckling capacity:

$$T_b = \tau_{cr}(2\pi r^2 t)$$

Where, the critical stress (τ_{cr}) is given by,

$$\tau_{cr} = \left[\frac{E}{3\sqrt{2}(1-\vartheta^2)^{3/4}}\right](t/r)^{3/2}$$

Substituting, τ_{cr}=120.75×10^7N/m2

T_b=49.559×10^3N–m.

Thus,T_b>T.

C. Bending Natural Frequency: According to Bernoulli-Euler beam theory, by neglecting shear deformation and rotational inertia effects, the bending natural frequency of a rotating shaft is given by:

$$f_{nb} \quad \frac{\pi p^2}{2L^2}\sqrt{\frac{EI_x}{m'}}$$

Where, **m′** is mass per unit length in kg/m
$\mathbf{I_x}$ is area moment of inertia in x-direction (longitudinal) in m^4.
p is 1 for first mode of frequency

$$I_x = \frac{\pi}{64}(d_0^4 - d_i^4)$$

$$= 8.910 \times 10^{-7} m^4$$

$$\mathbf{m'} = \rho\left(\frac{\pi}{4}\right)(d_0^2 - d_i^2)$$

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= 7.228kg/m

Substituting these values, f_{nb} =160.58 Hz. Thus $f_{nb} > f_{nb\,(min)}$.

Thus the designed composite driveshaft meets all the requirements.

The total mass of the shaft is **m** = **m′L** Thus, m= 9.035 kg.

C. Deflection Of Shaft

The deflection of SMC45 Steel drive shaft is shown in fig 1

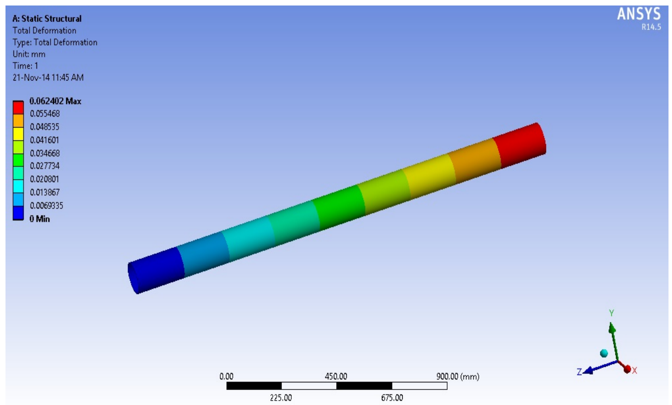

Fig 1 : Buckling analysis

The deformation of the drive shaft is 0.062402mm.

D. Buckling Analysis

Buckling analysis is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable, and buckled mode shapes (The characteristic shape associated with a structure's buckled response).

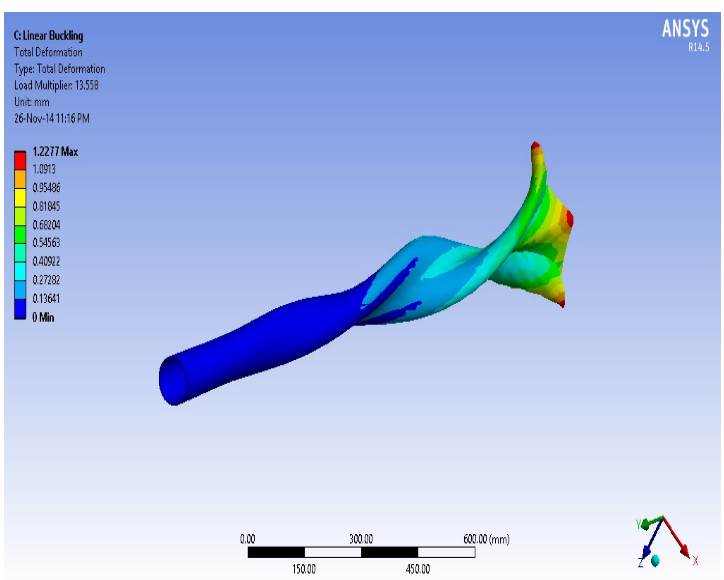

Fig1 : Buckling analysis

Load Multiple =13.558

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Maximum torque to be transmitted is 3500Nm

Therefore, Buckling torque is 13.558×3500=47453N

III. RESULT AND DISCUSSIONS

Thus the Bending natural frequency of the steel drive shaft is obtained from both numerical and analysis and has been validated .The first mode of bending natural frequency from analysis is 164Hz which is greater than the minimum bending natural frequency108Hz therefore the design is safe.

The buckling torque for the steel drive shaft has been calculated by analysis and numerically, in both the cases the buckling torque value is greater than the maximum torque transmission capability of 3500N-m of the shaft therefore the Design is safe.

Material	Hybrid shaft
Theoretical buckling torque in (Nm)	49559
Torque obtained from ansys (Nm)	47453

The total deformation of the shaft is 0.062402mm.

The mass of the composite shaft is nearly 50%lesser than that of the conventional steel shaft.

Thus the design and analysis of the hybrid drive shaft has been done successfully adhering to the design constraints.

IV. CONCLUSION

The finite element analysis is used in this work to predict the deformation bending natural frequency of shaft and torsional buckling and FEA analysis is done to validate the analytical calculations of the work. The frequency is calculated by Bernoulli – Euler theory because it neglects the effect of rotary inertia & transverse shear. The relationship between the frequency and the vibration modal is explained. This work presented a method to calculate the torsional buckling and bending natural frequency of a propeller shafts. The deflection of hybrid shaft is 0.062402mm and the mass of the composite shaft is reduced to nearly 50% lesser than that of the conventional steel propeller shaft. The theoretical calculations for the first mode bending natural frequency and torsional buckling results are compared with the analysis results which were carried out in Workbench 14.5.

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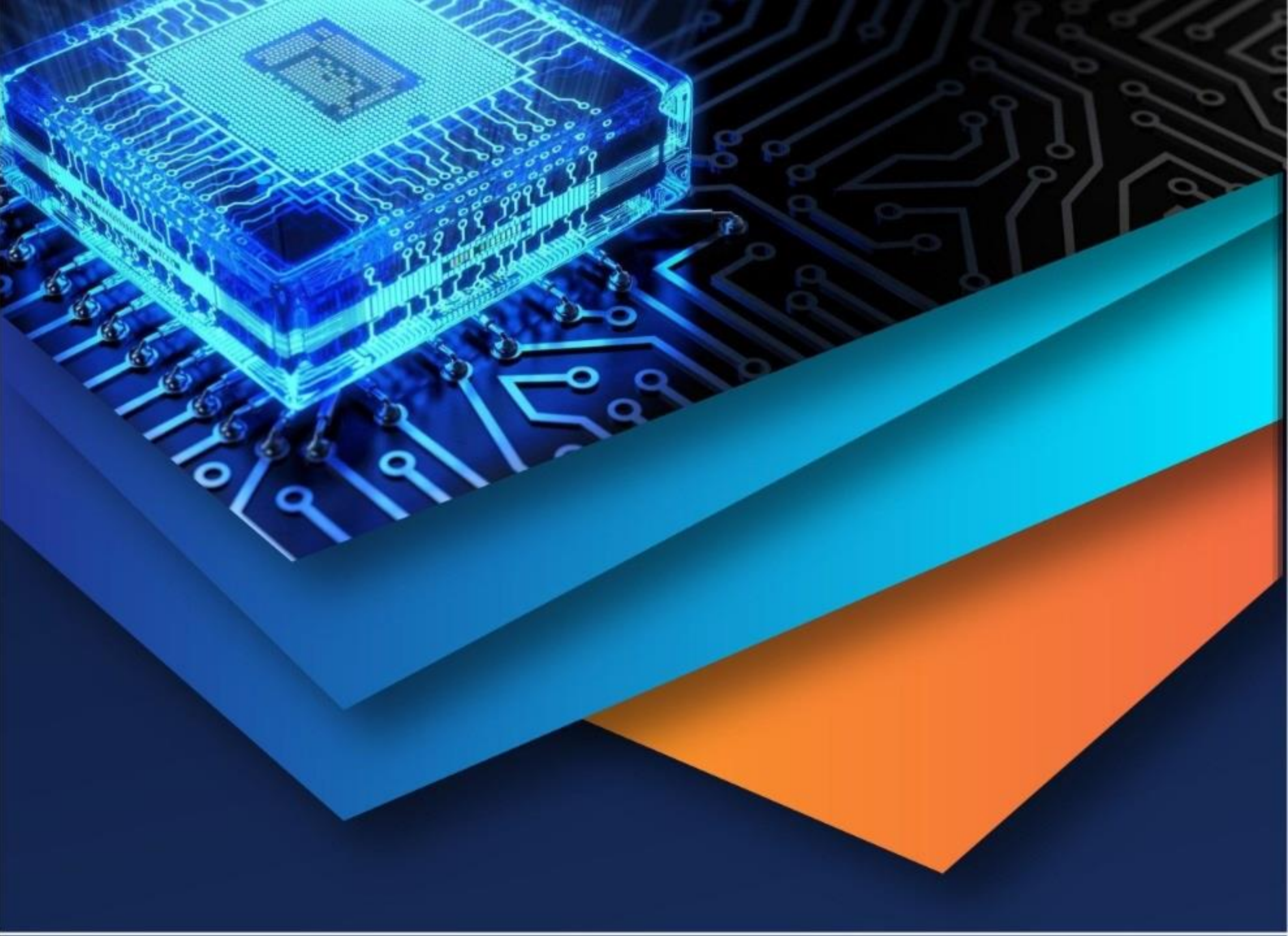

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