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Design and Analysis of Composite Drive Shaft

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Abstract: ***Polymeric materials reinforced with synthetic fibres such as glass, carbon, and aramid provide advantages of high stiffness and strength to weight ratio as compared to conventional construction materials, i.e. wood, concrete, and steel. Despite these advantages, the widespread use of synthetic fibre-reinforced polymer composite has a tendency to decline because of their high-initial costs, their use in non-efficient structural forms and most importantly their adverse environmental impact. In the recent days, there is a huge demand for a light weight material such as fiber reinforced polymer composites seems to be a promising solution to this arising demand. These materials have gained attention due to their applications in the field of automotive, aerospace, sports goods, medicines and household appliances. The overall objective of this work is to analyze a composite drive shaft for power transmission. This work deals with the replacement of conventional steel drive shafts composite drive shaft for an automotive application.***

Keywords: automotive, composite, cost, drive shaft, fibre

1. Introduction

A driveshaft is a rotating shaft that transmits power from the engine to the differential gear of a rear wheel drive vehicles. Driveshaft must operate through constantly changing angles between the transmission and axle. The drive shaft should provide a smooth, uninterrupted flow of power to the axles. High quality steel is a common material for construction.

Composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. Definition stated by Jartiz "Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form". . They have high specific modulus and strength, reduced weights. Due to the weight reduction, fuel consumption will be reduced. They have high damping capacity hence they produce less vibration and noise. They have good corrosion resistance. Greater torque capacities than steel or aluminum shaft. The fundamental natural frequency of the carbon fiber composite drive shaft can be twice as high as that of steel or aluminum because the carbon fiber composite material has more than 4 times the specific stiffness of steel or aluminum, which makes it possible to manufacture the drive shaft of passenger cars in one piece.

There are varieties of commercial FEA software available over the market. Development of the finite element method closely parallels the timetable of the Development of the digital computer. Prior to the advent of the digital computer, work during the 1940's involved the approximation of continuous solids as a collection of line elements (bars and beams). However, due to the lack of computation tools, the number of line elements had to be kept to a minimum. The first appearance of two-dimensional elements appeared in a paper published in 1956 by Turner, Clough, Martin, and Top [1]. Some of the popular commercially available FEA software are as follows. • Adina • Abaqus • Ansys • MSC/Nastran • Cosmos • NISA • Marc • Ls-Dyna • MSC/Dytran • Star-CD.

ANSYS is a general-purpose finite element-modeling package for numerically solving a wide variety of mechanical problems. It enables engineers to perform the following tasks - build computer models or transfer cad models of structures, products, components or system, apply operating loads or other design performance conditions, study physical responses such as stress levels, temperature distributions or electromagnetic fields, optimize a design early in the development process to reduce production costs, carryout prototype testing in environment where it otherwise would be undesirable or impossible. ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping. With virtual prototyping techniques, users can iterate various scenarios to optimize the product life before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

2. Literature Survey

- D.G. Lee [2] manufacture Drive Shaft using Carbon/Epoxy composite with aluminum and find performance of Drive Shaft.
- Bhirud Pankaj Prakash [3] Design and Analysis Composite Drive Shaft for Automotive by using E glass polyester resin with ansis to find deformation.
- Sagar R dharmadhikari [4] Design and Analysis Composite Drive Shaft for Automotive by using Carbon/Epoxy and genetic algorithm.
- M.R. Khoshravan [3] Design a Composite Drive Shaft and its Coupling for Automotive Application using HM carbon/epoxy.
- R. P. Kumar Rompicharla [6] Design and Optimization of Drive Shaft with Composite Materials. The drive shaft of Toyota Qualis was chosen for determining the dimensions.
- D.dinesh [7] done Optimum Design and Analysis of a Composite Drive Shaft for an Automobile by Using Genetic Algorithm and Ansys using Carbon/Epoxy.

- Bhushan K. Suryawanshi Design and Analysis Composite Drive Shaft for Automotive by using Carbon/Epoxy composite with aluminum and find the static torque capability and the fundamental natural frequency.
- Harshal Bankar [9] done Material Optimization and Weight Reduction of Drive Shaft Using Composite Material Boron/epoxy.
- M.A.K. Chowdhuri [10] done Design Analysis of an Automotive Composite Drive Shaft Using Graphite/ Epoxy and Aluminum.
- V. S. Bhajantri [11], Arun Ravi [12] Design and Analysis Composite Drive Shaft for Automotive by using Carbon/Epoxy.
- K.D Ghatage [13] done Optimum design of automotive composite drive shaft with genetic algorithm as optimization tool.
- R. Srinivasa Moorthy [14] Design Automobile Driveshaft using Carbon/Epoxy and Kevlar/Epoxy Composites.
- Parshuram D [15] Design and Analysis Composite/Hybrid Drive Shaft for Automotive. They uses Crowfoot satin woven glass fiber epoxy, Carbon/Epoxy composite with aluminum.

3. Selection of Material

3.1 Selection of Reinforcement Fiber

Fibers are available with widely differing properties. Review of the design and performance requirements usually dictate the fiber/fibers to be used. Carbon/Graphite fibers: Its advantages include high specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance, and high electrical conductivity. Glass fibers: Its advantages include its low cost, high strength, high chemical resistance, and good insulating properties. The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue strength, and high density, which increase shaft size and weight. Also crack detection becomes difficult.

3.2 Selection of Resin System

The important considerations in selecting resin are cost, temperature capability, elongation to failure and resistance to impact (a function of modulus of elongation). The resins selected for most of the drive shafts are either epoxies or vinyl esters. Here, epoxy resin was selected due to its high strength, good wetting of fibers, lower curing shrinkage, and better dimensional stability.

Table 1: Material properties of steel (sm45)

SN	*Mechanical properties*	*Symbol*	*Units*	*Value*
1	Young's modulus	E	GPa	207.0
2	Shear modulus	G	GPa	80.0
3	Poisson's ratio	υ	----	0.3
4	Density	ρ	Kg/m3	7600
5	Yield strength	Sy	MPa	370
6	Shear strength	Sx	MPa	275

Table 2: material properties of carbon/epoxy composite and glass/epoxy composite

SN	*Property*	*Symbol*	*Units*	*Carbon/Epoxy*	*Glass/Epoxy*
1	Longitudinal Modulus	E11	GPa	190	50
2	Transverse Modulus	E22	GPa	7.7	12
3	Shear Modulus	G12	GPa	4.2	5.6
4	Poisson's Ratio	υ	-----	0.3	0.3
5	Density	ρ	Kg/m3	1600	2000
6	Longitudinal Tensile strength	St1	Mpa	870	800
7	Transverse Tensile strength	St2	Mpa	540	40
8	shear strength	Ss	Mpa	30	72

4. Design of Drive Shaft

4.1 Assumptions

1) The shaft rotates at a constant speed about its longitudinal axis.
2) The shaft has a uniform, circular cross section.
3) The shaft is perfectly balanced, i.e., at every cross section, the mass center coincides with the geometric center.
4) All damping and nonlinear effects are excluded.
5) The stress-strain relationship for composite material is linear & elastic; hence, Hooke's law is applicable for composite materials.
6) Acoustical fluid interactions are neglected, i.e., the shaft is assumed to be acting in a vacuum.
7) Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

4.2 Selection of Cross-Section

The drive shaft can be solid circular or hollow circular. Here hollow circular cross-section was chosen because:

- The hollow circular shafts are stronger in per kg weight than solid circular.
- The stress distribution in case of solid shaft is zero at the center and maximum at the outer surface while in hollow shaft stress variation is smaller. In solid shafts the material close to the center are not fully utilized.

Table 3: Specification of the drive shaft

Sr.no.	Name	Notation	Unit	Value
1	Ultimate torque	T	Nm	3500
2	Max. speed of shaft	N	Rpm	6500
3	Length of shaft	L	mm	1250
4	Max. diameter of shaft	do	mm	100
5	Thickness of shaft	t	mm	3.32

4.3 Mass of Drive Shaft

m= ρAL= $\rho(do^2 - di^2) * \frac{L}{4}$

Where do = outer diameter (m)

di = inner diameter (m)

m = 8.58 Kg

4.4 Torque Transmition Capacity of Drive Shaft

$$T = S_s \frac{\pi(do^4 - di^4)}{16tdo}$$

Torsional Buckling Capacity of Drive Shaft

If $\frac{1}{\sqrt{1-\gamma^2}} \frac{L^2 t}{(2r)^3} > 5.5$

It is called as long shaft otherwise short and medium shaft

For long shaft critical stress is given by,

$$\tau cr = \frac{E}{3\sqrt{2}(1-\gamma^2)^{3/4}} (t/r)^{3/2}$$

For short and medium shaft critical stress is given by,

$$\tau cr = \frac{4.39E}{(1-\gamma^2)} (t/r)^2 \sqrt{1 + 0.0257(1-\gamma^2)^{3/4} \frac{L^3}{(rt)^{1.5}}}$$

The relation between tortional buckling capacity and critical stress is given by, $Tcr = \tau cr 2\pi r^2 t$

or

$$Tcr = (2\pi r^2 t) * (0.272) * [E11 * E22^3]^{\frac{1}{4}} * \left(\frac{t}{r}\right)^{\frac{3}{2}}$$

4.5 Lateral or Bending Vibration

Bernoulli-euler beam theory – Ncrbe

fnbe= $\frac{\pi p^2}{2L^2} \sqrt{\frac{EIx}{m1}}$

Where p=1, 2……

Ncrbe=60fnbe

Timoshenko's beam theory-Ncrt

fnt= $Ks \frac{30\pi p^2}{L^2} \sqrt{\frac{Er^2}{2\rho}}$

Ncrt=60fnt

$$\frac{1}{ks^2} = 1 + \frac{(n\pi r)^2}{2L^2}[1 + \frac{fE}{G}]$$

Where fs=2 for hollow shaft

Table 4: Design Solution

	Torque transmition capacity (Nm)	Torsional buckling capacity (Nm)	Frequency (rpm)
steel	43101.25	13361.84	9660
carbon/Epoxy	4701.93	3951.44	20160
Glass/Epoxy	11284.632	3947.55	9300
specification	3500(O.K)	3500(O.K)	6500(O.K)

5. Analysis of Drive Shaft Using Ansys

5.1 Modeling and simulation

In this section the 3D CAD models and 3D FE Models along with the loads and boundary conditions will be presented.

Step1: 3D PROE Model Creation was done based on considered Specifications and design consideration from passenger car, small truck, van specifications.

Step2: 3D FE Model Creation The 3D FE model for drive shaft was created by using FE modeling software. The mesh has been generated using relevance as 10 in ANSYS workbench.

Step-3: using model with boundary conditions in ansys12.0 required results are predicted.

Step-4: By applying boundary conditions and loading conditions obtained results will compared and suitable material suggested which gives less torsional value and frequency nearer to steel.

5.2 Static analysis

A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads. In static analysis loading and response conditions are assumed, that is the loads and the structure responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis includes, Externally applied forces, moments and pressures Steady state inertial forces such as gravity and spinning Imposed non-zero displacements. If the stress values obtained in this analysis crosses the allowable values it will result in the failure of the structure in the static condition itself. To avoid such a failure, this analysis is necessary.

Boundary conditions

The finite element model of HS Carbon / Epoxy shaft is shown in Figure .One end is fixed and torque is applied at other end.

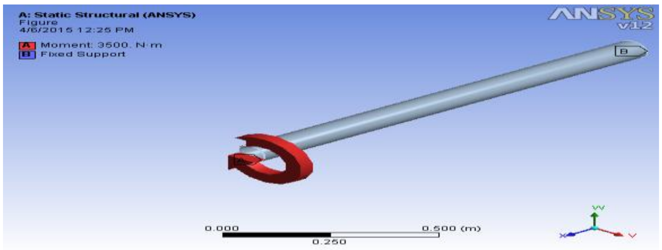


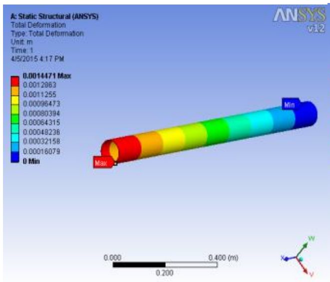
Figure 1: ANSYS Model with boundary conditions

5.3 Modal Analysis

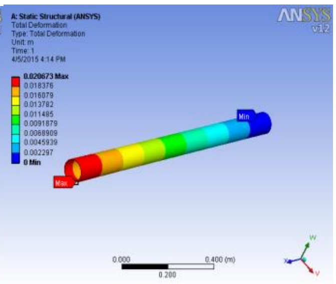
When an elastic system free from external forces can disturbed from its equilibrium position and vibrates under the influence of inherent forces and is said to be in the state of free vibration. It will vibrate at its natural frequency and its amplitude will gradually become smaller with time due to energy being dissipated by motion. The main parameters of interest in free vibration are natural frequency and the amplitude. The natural frequencies and the mode shapes are important parameters in the design of a structure for dynamic loading conditions. Modal analysis is used to determine the vibration characteristics such as natural frequencies and mode shapes of a structure or a machine component while it is being designed. Most designs are sub critical, i.e. rotational speed must be lower than the first natural bending frequency of the shaft. The natural frequency depends on the diameter of the shaft, thickness of the hollow shaft, specific stiffness and the length.

5.4 Buckling Analysis

Buckling analysis is a technique used to determine buckling loads (critical loads) at which a structure becomes unstable, and buckled mode shapes. For thin walled shafts, the failure mode under an applied torque is torsional buckling rather than material failure. For a realistic driveshaft system, improved lateral stability characteristics must be achieved together with improved torque carrying capabilities.



(a)



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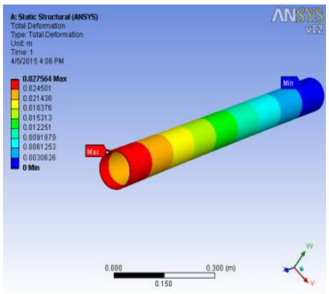
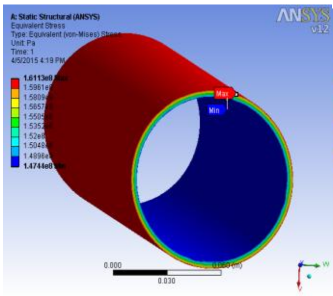


(c)

Figure 2: Total deformation (a) Steel, (b) Glass/Epoxy Composite, (c) Carbon/Epoxy Composite



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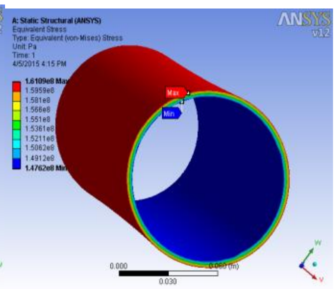

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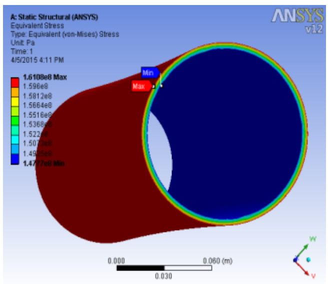
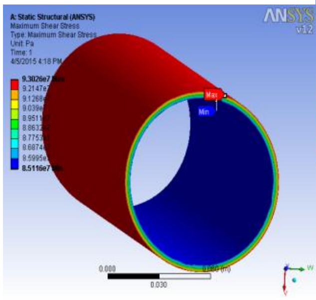
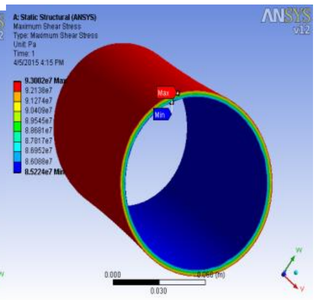


(c)

Figure 3: Equivalent (von-Mises) Stress (a) Steel, (b) Glass/Epoxy Composite, (c) Carbon/Epoxy Composite



(a)



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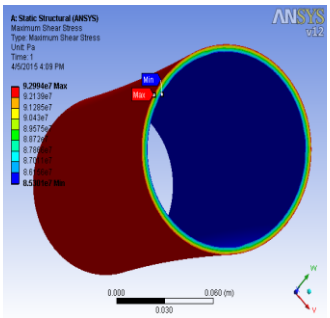
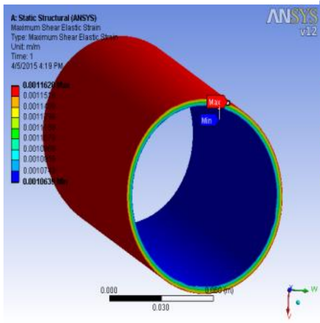
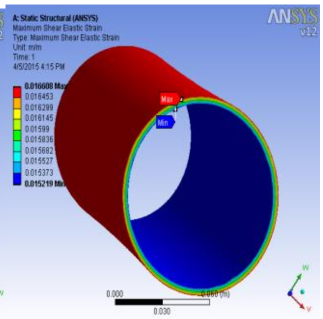


(c)

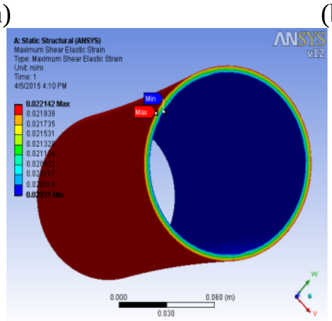
Figure 4: Maximum Shear Stress (a) Steel, (b) Glass/Epoxy Composite, (c) Carbon/Epoxy Composite



(a)



(b)



(c)

Figure 5: Maximum shear Strain (a) Steel, (b) Glass/Epoxy Composite, (c) Carbon/Epoxy Composite

6. Analytical Calculations

Moment of inertia $I = \frac{\pi(Do^4 - Di^4)}{64}$

Polar moment of inertia $J = 4I$

Maximum shear Strain $\emptyset = \frac{TL}{GJ}$

Total Deformation $\delta = \emptyset l$

Maximum Shear Stress $\tau = \frac{Tc}{J}$; $c = Do$

Normal Stress $\sigma 1 = \frac{F}{A}$; $F = \frac{T}{r}$

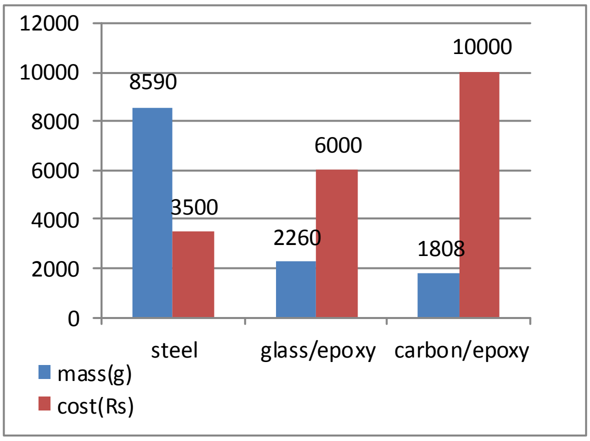
Torsional Stress $\sigma 2 = \frac{T}{Zo}$; $Zo = \frac{J}{Do}$

Equivalent (von-Mises) Stress $\sigma' = \sqrt{\sigma 1^2 + \sigma 2^2 - \sigma 1 * \sigma 2}$

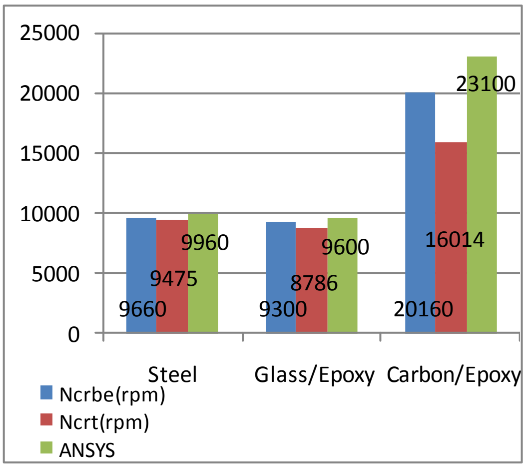
Table 5: Validation and comparisons of analytical and ANSYS results

Results	Steel		Carbon		Glass	
	Ansys	Analytical	Ansys	Analytical	Ansys	Analytical
Total Deformation(m)	0.0015	0.0025	0.027	0.048	0.021	0.036
Maximum shear Strain(m/m)	0.0012	0.0021	0.022	0.038	0.017	0.029
Maximum Shear Stress(MPa)	93	92.65	93	92.65	93	92.65
Equivalent (von-Mises) Stress(Pa)	161.1	160.6	161.1	160.6	161.1	160.6
Natural frequency (Hz)	166	161	385	336	160	155
Mass(Kg)	8.5888	8.5888	1.808	1.808	2.26	2.26

7. Mass and Cost Comparison



8. Frequency Comparison



9. Recycling

Considering the increasing costs, environmental issues, and legislative limitations associated with landfilling and incinerating FRP waste, recycling and reusing waste is becoming an increasingly viable alternative for managing FRP waste. Recycling FRP can be categorized into two main groups:

(1) Reclaiming the fibers from the polymeric matrix, and

(2) Mechanical recycling.

Fiber reclamation consists of recovering the fibers from the FRP, typically by employing an aggressive thermal or chemical process to break-down the thermoset matrix so that the fibers can be released and collected. Fiber reclamation processes can be attractive options for recycling carbon fiber reinforced polymer (CFRP) materials for two reasons:

(1) Carbon fibers have high chemical stability, and usually their superior mechanical properties are not significantly affected during reclamation, and

(2) Reclamation processes are costly and have economic justification only for extracting expensive filaments such as carbon fibers. Several companies have been reclaiming and reusing high-value carbon fiber from CFRP waste. Companies such as Boeing and Airbus have invested in efforts to Polymers 2014, 6 1813 recycle carbon composites in order to develop methods that are as robust as those for aluminum, steel and other metals and achieve high recycling percentages. While recently some successful efforts have been made for reclaiming glass fibers from GFRP waste, it is not yet economical to reclaim lower cost glass fibers. An overview on carbon fiber reclamation processes is presented by Pimenta and Pinho. Three main methods have been used for fiber reclamation:

(1) Pyrolysis, (2) oxidation, and (3) chemical recycling.

Pyrolysis is the thermal decomposition of organic molecules in an inert atmosphere (e.g., Nitrogen), and is one of the most widespread recycling processes for CFRP. During pyrolysis, the CFRP is heated up to 450–700 °C. In this temperature range, the polymeric matrix is volatilized into lower-weight molecules, while the fibers are minimally affected and recovered.

Oxidation is another well-documented thermal process in which the polymeric matrix is combusted in a hot and oxygen-rich flow of a gas such as air. Compared to pyrolysis, this method has a higher tolerance to waste contamination, but can result in shortening and significant strength loss of fibers.

In chemical recycling (also known as solvolysis), FRP waste is exposed to a reactive material such an acid under low temperature (typically less than 350 °C), resulting in the decomposition and separation of the polymeric matrix material. Chemical methods can, however, cause negative environmental impacts if they make use of hazardous materials.

Mechanical recycling started commercially in the 1970s. There are different types of mechanical recycling, though all of them involve breaking down the composite material and successively reducing the particle size of recycled materials through shredding, crushing, milling, or other similar mechanical process; the resulting scrap pieces can then be segregated, by using sieves and cyclones, into powdered products (rich in resin) and fibrous products (rich in fibers). Mechanical recycling is the most widely used approach for recycling FRP thermoset polymeric fibrous composite materials. Finally, there are recycling techniques that can be performed and be used for producing specific types of FRP products. For example, Adams et al. developed a method that incorporates splitting, crushing, and hot forming of GFRP sheets obtained from boat hulls to create new GFRP plates and tubes. They showed that by using their method over 50% of the original mechanical properties, such as the Young's modulus, tensile strength, and interlaminar shear strength, can be retained.

10. Conclusion

- The usage of composite materials has resulted in considerable amount of weight saving in the range of 81% to 72% when compared to conventional steel drive shaft.
- Taking into account the weight saving, deformation, shear stress induced and resultant frequency it is evident that composite has the most encouraging properties to act as replacement to steel
- The present work was aimed at reducing the fuel consumption of the automobiles in particular or any machine, which employs drive shaft, in general. This was achieved by reducing the weight of the drive shaft with the use of composite materials. This also allows the use of a single drive shaft (instead of a two piece drive shaft) for transmission of power to the differential parts of the assembly.
- Apart from being lightweight, the use of composites also ensures less noise and vibration.
- If we consider cost of glass/epoxy composite, it is slightly higher than steel but lesser than carbon/epoxy.
- The composite drive are safer and reliable than steel as design parameter are higher in case of composite.
- The composite are recyclable so they can be reuse.
- Apart from being lightweight, the use of composites also ensures less noise and vibration.
- So in comparison of mass, cost, safety and recycling steel shaft can be replaced by composite drive shaft.
- Natural frequency using Bernoulli-euler beam theory and Timoshenko's beam theory are compared. The frequency calculated by using Bernoulli-euler beam theory is high as it neglects rotary inertia and transverse shear.
- The successful application of the present design can make a huge improvement in automotive industry.

11. Future Scope

- This study leaves wide scope for future investigations. It can be extended to newer composites using other reinforcing phases and the resulting experimental findings can be similarly analyzed.
- Tribological evaluation of glass/carbon fiber reinforced epoxy resin composite has been a much less studied area. There is a very wide scope for future scholars to explore this area of research. Many other aspects of this problem like effect of fiber orientation, loading pattern, weight fraction of ceramic fillers on wear response of such composites require further investigation.

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