ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Design to Replace Steel Drive Shaft in Automobile with Hybrid Aluminium Metal Matrix Composite

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ABSTRACT:

Automobile industries are exploring composite materials in order to obtain reduction of weight without significant decrease in vehicle quality and reliability.

This is due to the fact that the reduction of weight of a vehicle directly impacts its fuel consumption. At the start of vehicle the most of the power get consumed in driving transmission system, if we able to reduce the weight of the propeller shaft that surplus available power can be used to propel the vehicle. Thus, in this work, the aim is to replace a forged steel drive shaft by a composite drive shaft with enhanced mechanical property with less weight. In the conventional steel drive shaft failure analysis of various methodologies was carried out to find root causes of shaft failure. For the above work, Aluminium was chosen as matrix metal of composite, and reinforcement materials are aluminium oxide (Al2O3) and zirconium diboride (ZrB4) was fabricated. Various mechanical test are to be conducted to determine the mechanical properties.

Based on the results of the properties the modelling of the drive shaft assembly is to be done using solid works 2012 and analysed using ANSYS 12.0 software. New composite material of hybrid aluminium metal matrix composite that would give the maximum weight reduction without affecting the dynamic factors of drive shaft at resonance state, while conforming to the stringent design parameters of passenger cars and light commercial vehicle with the help of ANSYS 12.0 software is to be developed. The various stress analysis will be performed based on finite element analysis and static structural simulation method. The stiffness of the drive shaft will be studied by plotting load versus deflection curve for whole working load range which shows the linear relationship. Using the constant amplitude loading, the fatigue damage and life of the shaft will be studied.

INTRODUCTION

The necessity for engineering materials with the technological importance for the areas of aerospace and land vehicles has led to a rapid development of composite materials. Composites have an edge over monolithic materials because of their unique properties such as high specific strength and stiffness, increased wear resistance, corrosion resistance, strength-to-weight, strength-to-cost, enhanced temperature performance together with better thermal and fatigue and creep resistance.

Optimum Design And Analysis Of A Composite Drive Shaft For An Automobile By Using Genetic Algorithm And Ansys' is studied by D.Dinesh, F.AnandRaju, they concluded,In present study the aim is optimize drive shaft weight by replacing a composite drive shaft for wheel drive automobile has been designed optimally by using Genetic Algorithm for E – Glass/ Epoxy, High Strength Carbon/ Epoxy and High Modulus Carbon/ Epoxy composites with the objective of minimization of weight of the shaft which was subjected to the constraints such as torque transmission, torsional bucking capacities and natural bending frequency. The weight savings of the E – Glass/ Epoxy, High Strength Carbon/ Epoxy and High Modulus Carbon/ Epoxy shafts were equal to 48.36%, 86.90%, and 86.90% of the weight of steel shaft respectively.The torque transmission capacity of the composite drive shafts has been calculated by neglecting and considering the effect of centrifugal forces and it has been observed that centrifugal forces will be reducing the torque transmission capacity of the shaft. Natural frequency using Bernoulli – Euler and Timoshenko beam theories was compared. The frequency calculated by using the Bernoulli Euler beam theory is high, because it neglects the effect of rotary inertia & transverse shear.

In this paper by M.Arun, T.Ponnusam, Saravana Kumar A,SaravanaPrabhu R, and ShyamaPrasad R on ‘Experimental Investigation on Aluminium LM4 Strengthened by Al2O3 Nano Particle ’ they tested results concluded as follows, Aluminium alloy reinforced with nano-sized aluminium oxide was successfully fabricated via stir casting method. The tensile properties of composite were considerably improved by the addition of Al2O3nano-particles, however tensile value of the composite was much higher than the unreinforced aluminium alloy. The distribution of nano-particles measured by using of microstructure test therefore stir casting was found as a suitable method for fabrication of this kind of composite and also hardness of fabricated composite value improved . Finally composite contain 1.5vol% Ah03 fabricated composite showed improved properties such tensile and hardness in comparison with other specimens

‘Preparation of Aluminium Matrix Composite by Using Stir Casting Method’ is studied by RajeshkumarGangaramBhandare, Parshuram M. Sonawane, they concluded,In present study the aim is study the various operating parameter of stir casting process. And to prepare AMC with help of stir casting process. For this Aluminium (6061) is selected as matrix phase while SiC, Alumina and Graphite act as reinforcement. With the help of stir casting process we had successfully manufactured AMC at less cost. While manufacturing AMC we come to know that process parameter are platy a major role for uniform distribution of reinforcement. We had some following conclusion 1) For uniform dispersion of material blade angle should be 45° or 60 ° & no of blade should be 4. 2) For good wettability we need to keep operating temperature at semisolid stage i.e. 630 for Al (6061). At full liquid condition it is difficult uniform distribution of the reinforcement in the molten metal. 3) Preheating of mould helps in reducing porosity as well as increases mechanical properties.[9]

K. Alaneme, “Mechanical behaviour of alumina reinforced with 6063 metal matrix composites” developed by two step – stir casting process. AA 6063–Al2O3 particulate composites having 6, 9, 15, and 18 volume percent of Al2O3 were produced. It is observed that AA 6063/ Al2O3p composites having low porosity levels (≤3.51 %porosity) and a good uniform distribution of the alumina particulates in the matrix of the AA 6063 were produced. The tensile strength, yield strength, and hardness increased with increase in alumina volume percent while the strain to fracture and fracture toughness decreased with increasing volume percent alumina.

G. B. Veeresh Kumar,Author examine the base matrix and the reinforcing phase for the present studies selected were AA 6061, AA 7075 and particles of Al2O3and SiC of size 20 μm. It can be observed that the densities of composites are higher than that of their base matrix, further the density increases with increased percentage of filler content in the composites. it can be observed that the tensile strength of the composites are higher than that of their base matrix also it can be observed that the increase in the filler content contributes in increasing the tensile strength of the composite. In microstructure studies it can be observed that, the distributions of reinforcements in the respective matrix are fairly uniform.[16]

W.M. Khairaldien produced Aluminium –Silicon Carbide composite by mixing various weight percentage of silicon carbide such as 5%, 10%,15%,20%,25%, and 30% to prepare aluminium metal matrix. The above

ISSN No: 2348-4845
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research shows a drop of strength at 15-20% weight percentage of silicon carbide due to the contact of Sic particle with the other and the increase in chance of more than two particle cluster together. Considering this in this present work we have fixed the percentage of reinforcement to maximum of 15% to have high strength and cost effective composites

2. OBJECTIVES OF PRESENT WORK

- Focus on the drive shaft failure of Toyota SEG.
- Select the suitable material for drive shaft with better reliable life time and weight reduction.
- Analyse the failure of drive shaft that used in Toyota SEG due to the hardness testing to determine the hardness of material, fatigue testing to determine endurance limit of the material and stress analysis to determine the maximum stress that can be stand by the driveshaft with the replacement of hybrid composite material due to high strength to weight ratio.
- Analysis was carried out using application of software package of ANSYS 15.0

MODEL CONSTRUCTION

While before constructing the finite element model of the composite material, time wasdedicated to learning the abilities and functions of Ansys, the software used for theProject. Prior use of other finite element packages proved valuable in learning Ansys, but modeling composite materials is more difficult than modeling isotropic materials such as steel. The help index and tutorials were the primary resource in becoming familiar with the layout of Ansys work bench 2015.

3.1Model Description

The goal of this project is to analytically model a composite shaft, and apply simplified torsional loads to the shaft. The shaft should be constructed in solid works keeping external diameter constantly as 80mm and internal diameter varies from 70,60,50,40 and 30mm. using these dimensionsthe static analysis, model (vibration) analysis and buckling analysis was carried in Ansys work bench 2015.

3.2Defining Elements, Real Constants, and Materials

There are several steps that must be taken in order to properly define the composition of a composite structure within Ansys work bench 2015. First is the selection of the element type. Ansys offers five element types for hollow materials or shell materials, which are listed in followingTable1.1 which can be used to define layered composites.

3.3Shell Elements

Due to the simple geometry of the model and the assumption of linear response inthis project, the Shell99 elements were selected. These elements are designed to model thin to moderately thick plate and shell structures, with a side-to-thickness ratio of 10 or greater. It is this fact that allowed for the generation of a moderately fine mesh, as opposed to a very fine mesh that takes longer to solve. Once the element type has been selected the material properties, layer orientation, and layer thickness must be defined within each element.

3.4Mesh and Boundary Conditions

When using Shell99 elements, the mesh density is governed by the side-to thickness ratio requirements, which are ten. In this model, the length was split into 0.01m in eachelements and the width was split into sameratio. This resolution provides an element side length of roughly 0.01m. With the thickness of the sheet at 0.01, the actual side-to-thickness ratio of the model is approximately 10 mm. This ratio is below the specification of 10, but was used anyway to allow for a slightly finer mesh that would be more sensitive to the response of the model.

3.5Simulation of Damage

The method used to simulate damage in the composite model was to assume thatthe modulus and shear modulus were nearly zero at the location of damage. In order to 12avoid singularity issues during calculation, the properties were not set exactly to zero.For all

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damage cases, the material properties assigned to that location were as follows:

Ex = Ey = Ez = 100Pa

Gxy = Gyz = Gxz = 50Pa

uxy = uyz = uxz = 0.3

4. MATHEMATICAL CALULATION OF EXISTING MODEL:

Weight of solid shaft:

$W_s = \rho * A * L$

$$w_s = \rho * \frac{\pi}{4} D^2 * L$$

$$= 7600 * \frac{\pi}{4} * 0.08^2 * 0.1$$

$$= 38.20 \text{ kg}$$

POLAR MOMENT OF INERTIA (J)

$$J = \frac{\pi}{32} * D^4$$

$$J = \frac{\pi}{32} * 0.08^4$$

$$= 4.0192 * 10^{-6} \text{ m}^4$$

TORSIONAL SHEAR STRENGTH (T_S)

$$T_S = \frac{T * D}{2 * J}$$

$$T_S = \frac{3500 * 0.08}{2 * 4.0192 * 10^{-6}}$$

$$= 34.832 * 10^6 \text{ N/m}^2$$

MAX. STATIC DEFLECTION:

$$\delta = \frac{5 m g cos\theta L^3}{384 * E * J}$$

$$\delta = \frac{5 * 38.20 * 9.81 * cos2 * 1^3}{384 * 207000 * 4.0192 * 10^{-6}}$$

$$\delta = 5.86 * 10^{-3} \text{ m}$$

NATURAL FREQUENCY

$$f_n = \frac{30}{\pi} \sqrt{\frac{g}{\delta}}$$

$$f_n = \frac{30}{\pi} \sqrt{\frac{9.81}{1.54306 * 10^{-4}}}$$

$$f_n = 389.123 \, Hz$$

CRITICAL BUCKLING TORQUE:

$$T_{cr} = (2\pi r^2 t) * (0.272) * (E_x E_y^{3})^{0.25} * (t/r)^{1.5}$$

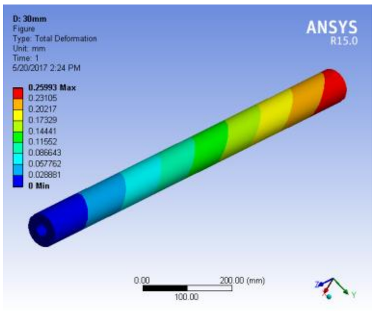
$$T_{cr} = (2\pi * 0.04^2 * 0.02) * (0.272) * \{207 * 10^9)^3\}^{0.25} * (0.02/0.04)^{1.5}$$

$$T_{cr} = 11876.68 \text{ N-m}$$

5.1STATIC ANALYSIS ON SHAFT:

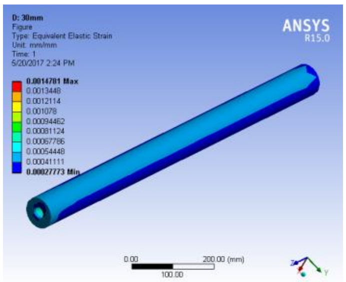
For static analysis shaft is fixed at one end and torque is applied at other end $3500*10^3$ N-m on the fixed rigid element with size 0.01m with center axis distance 1000mm.

The various size shafts total deformation, Von misses stress distribution and shear stress distribution of composite shaft of 30mm is shown in fig.



5.2 MODEL (VIBRATION)ANALYSIS ON SHAFT:

Modal analysis deals with un-damped free vibration of a structure. It does not involve any computation of response due to any loading, but yields the natural frequencies and corresponding mode shapes. For Eigen value analysis the boundary conditions are assumed as pinned-pinned condition. The first mode shapes obtained for Steel and aluminium metal matrix composite materials using ANSYS WORK BENCH V 15 of composite shaft of 30mm is shown in fig. The frequencies of first modes are multiplied by 60 to obtain critical speeds of drive shaft.



ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
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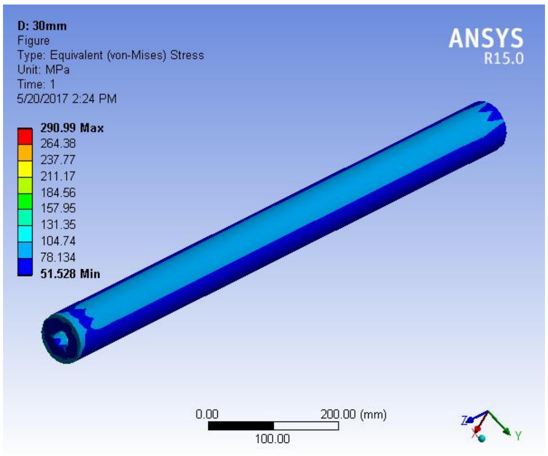
5.3 LINEAR BUCKLING ANALYSIS ON SHAFT:

Linear buckling analysis is performed to get the critical torsional buckling load. The buckling frequency and its corresponding mode shapes obtained for Steel and aluminium metal matrix composite ANSYS work bench v15 are shown in figures



RESULTS AND DISCUSSION

The analysis is carried out with one end fixed and a torque of 3.5×10^6 N-mm at other end and rotational speed is 6500 rpm applied. The shear and von mises stresses obtained from solver are compared with theoretical results. From the above transient analysis results the optimized shaft diameter selected 40mm as internal diameter. In the 70 mm as internal diameter hollow shaft produced more vibration and instability in critical speeds so the design is unsafe to use.

In the internal diameter 60mm drive shaft has shear stress distribution is more in deformation so this model also unsafe to use and the total deformation is very high at buckling torque.

In the internal diameter 50mm drive shaft has stress distribution is more in model analysis so the material failure occurs at critical speeds and torque so it is also difficult to use.

In the internal diameter 40mm drive shaft has better strength to withstand the critical speed and torque. And 30 mm internal diameter also possess good strength and equal to the solid shaft but when considering weight of the shaft parameter 40mm internal diameter is more suitable for the shaft design. The shear strength is used to describe the strength of a shaft where the ductile material fails in shear. FEA solver results, shows that torque carrying capacity is more in 40mm internal diameter composite shaft than conventional steel driveshaft. The steel drive shaft has lesser shear strength. Comparison of the theoretical and analysis results are tabulated in table6.1

Table: 6.1 Comparison of shear strength (MN/m^2)

Material / Diameters	Steel(SM45C)	
80	Theoretical	Ansys
	348	249
	Composite	
70	105	103
60	123	117
50	154	147
40	185	192
30	221	235

Table: 6.2 Comparison of total deformation (m)

Material / Diameters	Steel(SM45C)	
80	Theoretical	Ansys
	0.59	0.081
	Composite	
70	0.362	0.124
60	0.41	0.112
50	0.459	0.104
40	0.51	0.098
30	0.54	0.095

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Table: 6.3 Comparison of von-mises stress distribution (MN/m^2)

Material / Diameters	Steel(SM45C)	
80	Theoretical	Ansys
	370	163
	Composite	
70	641	328
60	542	263
50	493	252
40	404	219
30	384	196

6.2 MODAL (VIBRATIONAL) ANALYSIS OF STEEL AND COMPOSITE DRIVE SHAFTS

The analysis is used to determine the natural frequencies and corresponding mode shapes to find the critical speed of the shaft. Using solver, first natural frequency and its mode shape is extracted as the first few natural frequencies are more critical and dominated to failure.

The critical speed obtained from FE solvers for steel and aluminium metal matrix composite material. It is observed that composite material shafts have minimum amount of critical speed compared to the steel material shafts. The critical speed depends upon the shaft dimensions, materials and loads. In design optimization, the shaft dimensions and load are constant but stacking sequence is varied. As the critical speed depends upon stiffness and density, the material having high stiffness value will have maximum critical speed. Finally it is evident from the table 6.4 that composite materials have more torque carrying capability. This clearly establishes the fact that torque capability of any material is reflected through critical speed values.

Table: 6.4 Comparison of critical speed (rpm)

Material / Diameters	Steel(SM45C)	
80	Theoretical	Ansys
	11372	10876
	Composite	
70	4357	3347
60	4778	3678
50	5405	4205
40	10375	8975
30	10879	9876

Table: 6.5 Comparison of natural frequency (Hz)

Material / Diameters	Steel	
80	Theoretical	Ansys
	496.78	412.43
	Composite	
70	369.44	249.38
60	389.14	293.97
50	418.49	310.19
40	441.10	373.81
30	467.10	402.35

6.3 BUCKLING ANALYSIS OF STEEL AND COMPOSITE DRIVE SHAFTS

Buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. It is the mathematical instability leading to a failure mode. Buckling loads are critical loads where the structures becomes unstable and each load has an associated with buckled mode shapes.

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International Journal & Magazine of Engineering, Technology, Management and Research
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The critical buckled torque obtained from FE solvers for steel and aluminium metal matrix composite materials are tabulated in table 6.6 The composite material have load factor around 1 and have very high critical buckling torque. It is observed that the buckling strength of the composite shafts is high compared to steel shaft of the same geometry because these properties depend on the stiffness and cross section of the material. It also depends upon the length to radius ratio (L/R), radius to thickness ratio (R/t) and unsupported length. Therefore, the composite shaft has higher critical buckling torque.

Table: 6.6 Comparison of buckling torque (N-m) Load multiplier 97.984

Material / Diameters	Steel(SM45C)	
80	Theoretical	Ansys
	11876.98	15673
	Composite	
70	105.410	3201
60	562.377	4100
50	1414.80	5421
40	2597.80	8456
30	8364.68	10278

CONCLUSION

When a long monolithic hollow composite driveshaft is subjected to torsional load, an instability occurs which is more critical in the design of composite drive shaft. The prominent failure mode of composite drive shaft is shear buckling rather than material failure. In this work an attempt is made to check the suitability of one piece composite drive shaft with various internal diameters of composite material combinations to fulfill the functional requirements. Firstly, a finite element model of drive shaft made of Steel SMC45, aluminium hybrid metal matrix Composite is developed and analyzed for static, modal & buckling analysis using ANSYS WORK BENCH V15

Results clearly indicate that,

1. The optimized composite drive shafts designed using solid works 12 software and analysis was carried in ANSYS WORK BENCH V15 is safe under the peak torque loading of 3500Nm and rotational speed of 6500rpm.
2. The single piece steel drive shafts fail in shear.
3. Composite shaft is good in shear strength and bending natural frequency and are excellent from vibration point of view.
4. Composite is used as shaft material in drive shaft, the weight of the shaft can be reduced up to 24% of its own weight. So the composite material possesses good stability with lesser weight.
5. The obtained Finite element analysis results are compared with analytical values and observed that the single piece hollow composite drive shaft with internal diameter 40mm is better suitable for driveline applications in automobile LCVs. Thus the designed single piece composite drive shafts can be employed in the automobiles to result for considerable weight savings, thereby increasing the fuel efficiency.

However, high material processing cost together with its limited availability is a major limitation of the composite materials which need to be addressed, to make the employment of composite driveshaft in the automobile economical.

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