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Weight Optimization and FEA Analysis of Al-Si Metal Matrix Composite Drive Shaft

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Abstract

The main concept of this project is to reduce the weight of automotive drive shaft which is done through the fabrication of Al-Si matrix reinforced with SiC-Cenosphere composite material by stir casting with varying percentage of Cenosphere. Aluminium metal matrix composite have been used in many automotive components because of their properties such as low weight, corrosion free, high specific stiffness, ability to produce complex shapes and high specific strength etc. The effect of weight % of Cenosphere is studied and is used for Automotive drive shaft application. In automobiles the drive shaft is mainly used for the transmission of motion from the engine to the differential. The modeling of the drive shaft assembly was created using CATIA software. In present work an attempt has been to estimate deflection, stresses under subjected boundary conditions, analysis are carried out by Abaqus.

Keywords: *Cenosphere, Metal matrix composite, Drive shaft, CATIA, Abaqus.*

1. Introduction

Rapid technological advances in engineering design field result in finding the alternate resolution for the conventional materials. The design engineers brought to a point to finding the materials which are more reliable than conventional materials. Researchers and designers are constantly looking for the solutions to provide stronger and durable materials which will answer the requirements of fellow engineers. Aluminium-Silicon MMC's with SiC-Cenosphere as reinforcement is fabricated by Stir casting. It is found that increase in Tensile strength, compressive strength and hardness, Also Density is reduced with increase in percentage of cenosphere. In automotives drive shafts are used as power transmission tubing in numerous applications, including, pumping sets, cooling towers, trucks, aerospace and automobiles. In the design of metallic shaft, by knowing the torque and the allowable shear stress for the material, the shaft's cross section can be found. In the today's days there is an important requirement for light weight materials vehicle. The conventional steel material is replaceable by advanced Al-Si reinforced with SiC-Cenosphere composite materials. In present work present steel drive shaft is replaced by fabricated Al-MMC, then it is found that considerable weight reduction as compared to steel drive shaft without compromising with safety.

2. Material Selection

2.1 Al-Si Matrix

Al-Si alloys are widely used as components for engines, and machining is needed after casting to obtain a certain precision, several studies have been conducted on the machinability of cast Al-Si alloys. The matrix material used in this investigation was pure aluminium with 8 weight % of silicon alloy. Aluminium is the abundant metal with density of about $2.7 g/cm^3$. This is approximately one third value of steel. And silicon is in expensive metal with density $2.34 g/cm^3$.

2.2 Reinforcement Selection

Silicon Carbide: Silicon carbide particulates having average particle size of (<50μm) are used as reinforcement. Aluminum MMCs reinforced with SiC particles have up to 20% improvement in yield strength, lower coefficient of thermal expansion, higher modulus of elasticity and more wear resistance than the corresponding un-reinforced matrix alloy systems and its density is 3.21 g/cm^{3,} melting point is 2700 °C.

Cenosphere: Cenosphere is one of the most inexpensive and free flowing powder composed of hard shelled, hollow, minute spheres with low density (about 1.0 g/cm3) reinforcements. Which is extracted from fly ash ,fly ash is one of the waste byproduct generated in the combustion of coal. Cenosphere chemical composition in weight % is listed in Table 1.1

Table 1: Chemical composition of cenosphere

Components	*SIO_2*	*AL_2O_3*	*K_2O*	*FE_2O_3*	*MGO*	*CAO*	*TIO_2*	*NA_2O*
Wt. %	52-62	30-36	1.2-3.2	1.0-3.0	1.0-2.5	0.1-0.5	0.8-1.3	0.2-0.6

3. Fabrication of Al-Si Hybrid MMC

In this study the aluminium-Si alloy with SiC and Cenosphere as reinforcement in metal matrix hybrid composite was prepared by stir casting route. The Stir casting method (also called liquid state method) is used for the hybrid composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of stirring by motor. This set up is shown below in fig1.

Fig 1: Stir casting setup

Here pure Al-8 wt. % Si alloy was commercially prepared in a resistance heated muffle furnace and then casted. There after measured quantity of silicon carbide and cenosphere are preheated at 450°C for 3-4 hours to remove induced gases and moistures from the reinforcements. Then aluminium-silicon alloy is weighed is kept in clay-graphite crucible and melt temperature was raised up to 750-800 degree Celsius. The molten aluminium alloy is degassed by adding hexachloroethane pallets which remove the atmosphere gases particularly hydrogen. Moisture and gasses during casting will produce poor castings. Now reinforcements like preheated Silicon carbide and cenosphere particles were added at the rate of 10-30 g/min into the melt and mixed manually by stirrer with speed range of 350 to 500 rpm was maintained between 6 to 8 minutes. At same time the mould was preheated to 680 degree Celsius and chalk powder is applied in mould to avoid shrinkage of casting material. The molten Al-Si –SiC-Cenosphere is poured into the permanent metallic mold and melt was then allowed to solidify in the mould.

4. Mechanical Characterization

After Casting specimens are machined for testing purpose, tensile strength, compression strength, hardness and density are calculated and are shown in below table 2.1. It is found that increase in wt% of cenosphere results in improved mechanical properties i.e. tensile strength, compressive strength, and hardness is increased considerably and Density is reduced.

Table 2. Mechanical characterization of Samples.

Samples	***UTS (Mpa)***	***UCS (Mpa)***	***Hardness (BHN)***	***Density (g/cc)***
Al-8%Si	169	360	58	2.670
Al-8%Si-3%SiC	236	410	64	2.685
Al-8%Si-3%SiC-3%Cenosphere	287	430	73	2.634
Al-8%Si-3%SiC-6%Cenosphere	342	460	81	2.586
Al-8%Si-3%SiC-9%Cenosphere	395	485	87	2.536

5. Drive Shaft

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 shaft, which propel are called as the propeller shaft. Propellers are usually related with ships and planes as they are propelled in water or air using a propeller shaft because apart from transmitting the rotary motion from the front end to the rear end of the vehicle forward.

The shaft is the primary bond between the front and the rear end which performs both the motion and propelling the front end. Thus, the terms Drive Shaft and Propeller Shaft are used interchangeably. It can be observed that a drive shaft is one of the most important components, which is responsible for the actual movement of the vehicle once the motion is produced in the engine. The designing of such a critical component is usually stringent, as any fracture in this part could lead to as catastrophic failure of the vehicle when it is in motion.

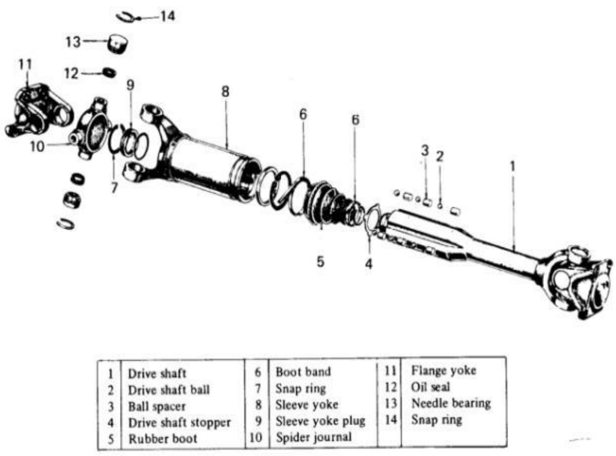

Figure 2. Parts of Drive Shaft.

5.1 Functions of the Drive Shaft

- First, it must transmit torque from the transmission to the differential gear box.
- The drive shaft must also be capable of rotation at the very fast speeds required by the vehicle.
- During the operation, it is necessary to transmit maximum low-gear torque developed by the engine
- The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movements due to torque reaction, road deflections, braking load and so on. A slip joint is used to composite for this motion. The slip joint is usually made of an internal and external spline. It is located on front end of the drive shaft and is connected to the transmission.
- The drive shaft must also operate through constantly changing angles between the transmission, the differential and the axles. As the rear wheels roll over bumps in the road, the differential and the axle move up and down

5.2 Demerits of a Conventional Drive Shaft

- They have less specific modulus and strength
- Its corrosion resistance is less as compared with composite materials.
- Increased weight
- Steel drive shafts have less damping capacity.
- Conventional steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural. Therefore the steel drive shaft is made in two sections connected by a support structure, bearings and U-joints and hence overall weight of assembly will be more.

5.3 Merits of Composite Drive Shaft

- They have high specific modulus and strength
- They have good corrosion resistance
- Reduced weight
- A one-piece composite shaft can be manufactures so as to satisfy the vibration requirements. This eliminates all the assembly, connecting the two piece steel shafts and thus minimizes the overall weight, vibrations and cost.
- Due to weight reduction, fuel consumption will be reduced.
- Longer fatigue life than steel and aluminum shaft
- They have high damping capacity and hence they produce less vibration and noise.
- Lower rotating weight transmits more of available power.

6. Material Used In Analysis and their Properties

We opted to do our work on material optimization on propeller shaft of Toyota Quails which transmits a maximum torque of 151N-m at 2400 rpm. We also extended the project by including Al-Si-3%SiC-9% Cenosphere hybrid composite material along with structural steel.

Dimension of Toyota Quails Drive shaft is as below:
Outer Dia=90 mm
Inner Dia= 83.36 mm
Length of Drive shaft=1250 mm

Table3. Materials used for drive shaft and their properties.

Properties	*Structural Steel (SM45C)*	*Al-Si MMC (9% Cenosphere)*
Young's modulus	2.07 e+11 Pa	85 e+11 Pa
Poisson's ratio	0.3	0.34
Density	7600 kg/m^3	2543 kg/m^3
Yield strength	370 e+06	320 e+06

7. Design and Analysis

7.1 CATIA modeling of Drive shaft assembly

Drive shaft is modeled using CATIA V5 as per standard dimensions of TOYOTA QUALIS, including couplings at both ends as shown below in fig 3.

Fig3. CATIA Model for Drive Shaft Assembly

7.2 Meshing of Drive shaft

FEA model is created using HyperMesh with Four node tetra hedral element shape, which have 156399 elements and 46773 nodes. Meshed model is shown in figure 4.

Fig4. Meshed model

7.3 Boundary Conditions

Boundary conditions are applied as shown in figure below. One end is fixed and 151 N-m torque is applied to other end.

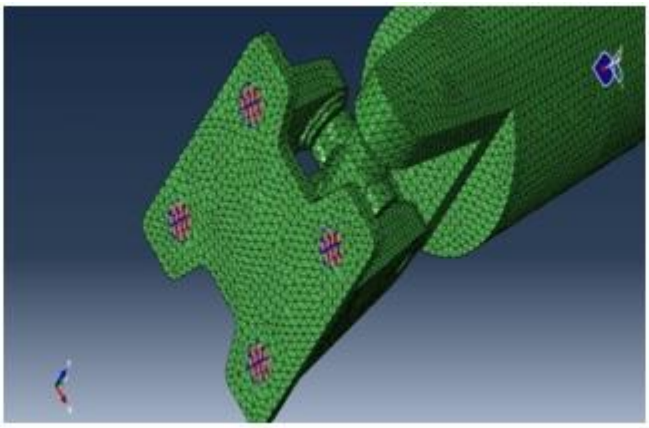

Fig 5. Fixed end of Drive Shaft

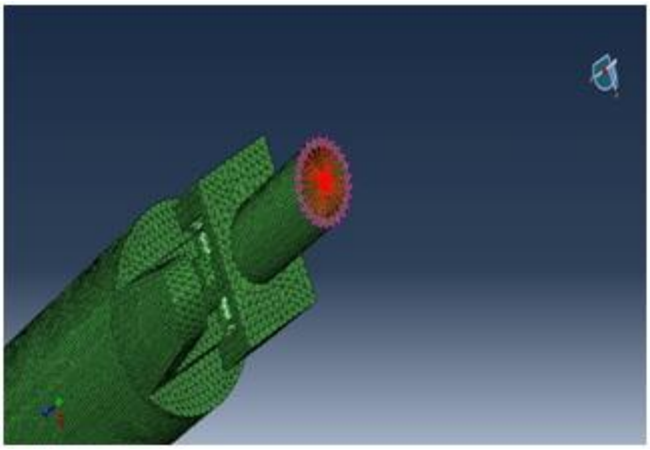

Fig 6. Torque end of Drive shaft

7.4 Analysis of Steel Drive shaft

7.4.1 Von Misses Stress

The maximum stress for Steel drive shaft is found to be 275.9MPa, at the pin neck, minimum stress is found to be 246.1 MPa and is shown in the figure 7.

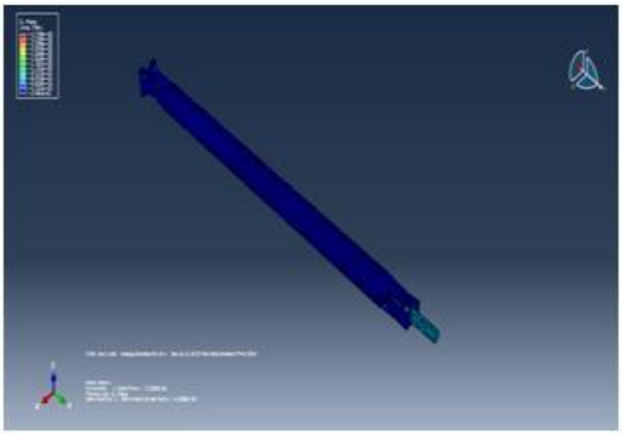

Fig7. Von-Mises Stress in steel drive shaft

7.4.2 Displacement

The maximum Displacement for steel drive shaft is found to be 0.314 mm, and is shown in the figure 8.

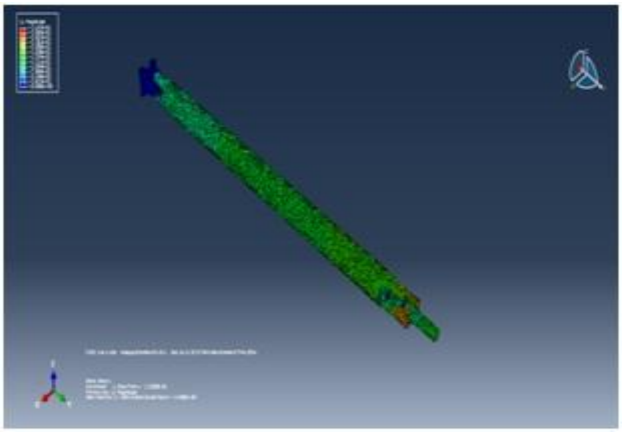

Fig8. Deformation in steel drive shaft

7.5 Analysis of Al-Si MMC Drive shaft

7.5.1 Von Mises Stress

The maximum stress for Al-Si MMC drive shaft is found to be 263.8 MPa, at the pin neck, minimum stress is found to be 253.0 MPa and is shown in the figure 9.

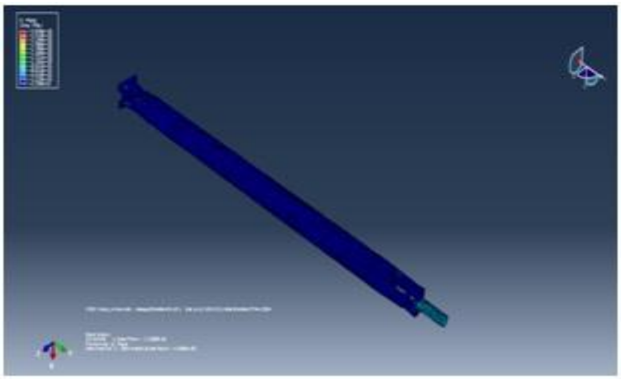

Fig 9 Von-Misses Stress in composite drive shaft

7.5.2 Displacement

The maximum Displacement for Al-Si MMC drive shaft is found to be 0.761 mm, and is shown in the figure 10.

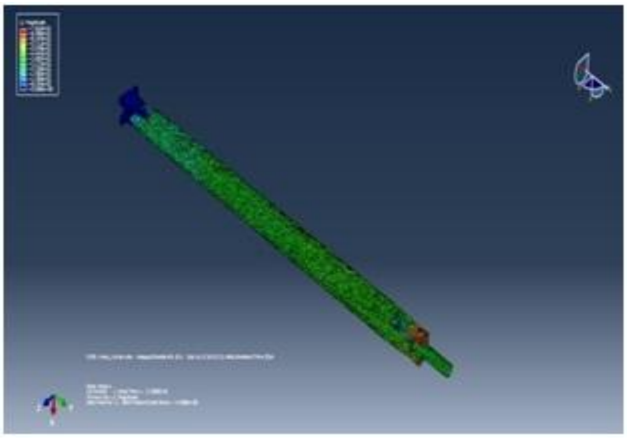

Fig10. Deformation in composite drive shaft

The following results are observed by the analysis and are shown in Table4.The weight of the drive shaft including couplings is found by ABAQUS.

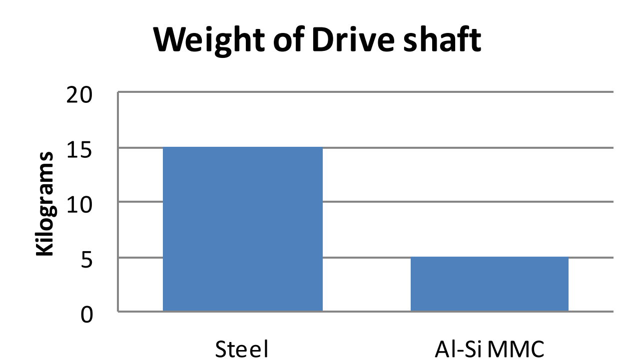

Fig11 . Weight comparison with composite

Table4. Analysis results

Properties	Steel Drive shaft	Al-Si MMC Drive shaft	% Reduction
Von Mises stress(MPa)	275.9	253.0	8.30
Displacement(mm)	0.314	0.761	-142.35
Weight(kg)	14.92	4.99	66.55

Conclusion

The present work was aimed at manufacturing Al-Si MMC reinforced with SiC-cenosphere and 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 Al-Si hybrid composite material.

The usage of Al-Si Metal matrix composite materials has resulted in considerable amount of weight saving in the range of 65.5% when compared to conventional steel drive shaft.

Taking into account the weight saving, deformation, and stress it is evident that Al-Si MMC material has the most encouraging properties to act as replacement to steel.

Apart from being lightweight, the use of composites also ensures less noise and vibration.

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