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Materials Today: Proceedings XX (2016) XXX–XXX

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PMME 2016

Design and Comparison of the Strength and Efficiency of Drive Shaft made of Steel and Composite Materials

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Abstract

In the present scenario weight of an automobile, Vehicle is a major issue. Many composite materials are used now a day in order to overcome this issue. In this paper, Drive shafts made of SM45C Steel is compared with the Kevlar composite shaft. The Strength and Efficiency of the composite drive shaft is also tested. For this, CATIA v5 is used software for the 3D modeling and ANSYS is used for the analysis.

Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

Keywords: Steel (SM45C); Kevlar; Drive shaft; Composites; ANSYS; CATIA v5; Stress; Displacement

1. Introduction

A driveshaft is a rotating shaft that transmits power from drive to wheels. Driveshaft must operate through constantly changing angles between the transmission and axle. High quality steel (Steel SM45) is a common material for construction. Steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely Proportional to the square of beam length and Proportional to the square root of specific modulus. The two piece steel drive shaft consists of three universal joints, a cross center supporting bearing and a bracket, which increase the total weight of a vehicle. Substituting composite structures for conventional is metallic structures has many advantages because of higher specific stiffness and higher specific strength of composite materials. Composite materials can be tailored to efficiently meet the design requirements of strength, stiffness and composite drive shafts weight less than steel or

2214-7853
Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

aluminum of similar strength. It is possible to manufacture one piece of composite. Drive shaft to eliminate all of the assembly connecting two piece steel drive shaft. Also, composite materials typically have a lower modulus of elasticity. As a result, when torque peaks occur in the driveline, the driveshaft can act as a shock absorber and decrease stress on part of the drive train extending life. Many researchers have been investigated about hybrid drive shafts and joining methods of the hybrid shafts to the yokes of universal Joints. But this experiment provides the analysis of the design in many aspects. 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. 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.

1.1 Purpose of the Drive Shaft

It must transmit torque from the transmission to the differential gear box [1]. The drive shaft must also be capable of rotating at the very fast speed required by the vehicle. The drives shaft must also operate through constantly changing the angles between the transmission, the differential and the axels. The length of the drive shaft must also be capable of changing while transmitting torque. The torque that is produced from the engine and transmission must be transferred to the rear wheels to push the vehicle forward and reverse. The drive shaft must provide a smooth, uninterrupted flow of power to the axles. The drive shaft and differential are used to transfer this torque.

1.2 Functions of the Drive Shaft

First, it must transmit torque from the transmission to the differential gear box. During the operation, it is necessary to transmit maximum low-gear torque developed by the engine. The drive shafts must also be capable of rotating at the very fast speeds required by the vehicle. 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 axles move up and down. This movement changes the angle between the transmission and the differential. The length of the drive shaft must also be capable of changing while transmitting torque. Length changes are caused by axle movement due to torque reaction, road deflections, braking loads and so on [2]. A slip joint is used to compensate for this motion. It is located on the front end of the drive shaft and is connected to the transmission.

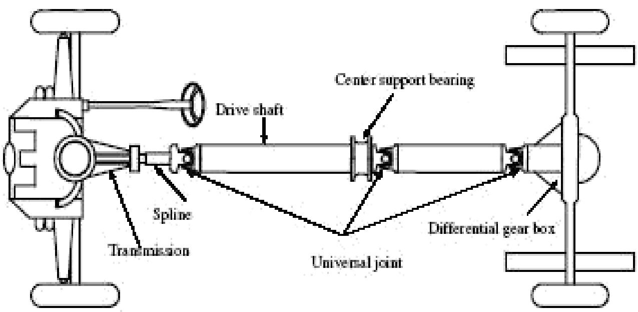

Fig. 1 Conventional two-piece drive shaft arrangement for rear wheel vehicle driving system [2].

1.3 Background

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 composite and an alloy are constituent materials which are insoluble in each other and the individual constituents retain those properties in the case of composites, where as in alloys, constituent materials are soluble in each other and forms a new material which has different properties from their constituents [3].

2. Classification of Composites

A composite material can be defined as a material consisting of two or more phases embedded in a continuous phase. The discontinuous phase is reinforcement and continuous phase is the matrix. Materials form an integral part of the way composite structures perform. They are broadly categorized into three types [4]:

- Reinforcements
- Resins
- Core materials

In general, carbon, aramid fibers and other specialty reinforcements are used in the marine field where structures are highly engineered for optimum efficiency. Architecture and fabric finishes are also critical elements of correct reinforcement selection. Resins are the bonding materials which are used to attach the core materials with reinforcements. They are of two types, viz. Orthophthalic and Isophthalic of which the latter exhibits better mechanical resistance, chemical properties and increased resistance to water permittivity. Core materials form the basis for sandwich composite structures that have promising prospects in marine construction. The dynamic behavior of a composite structure is integrally related to the characteristics of the core material used.

2.1 Advantages of Fiber Reinforced Composites

The advantages of composites over the conventional materials are [1, 2]

- 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 a better dimensional stability over a wide temperature range.
- High damping capacity.

2.2 Disadvantages of Composites

Joining processes are complicated. Poor compressive strength and Creep pose problems to the structure of the ship. Low vibration tolerance is a risk factor. Poor abrasion resistance leads to wear and tear. Quality Control is difficult. Lay-up and Assembly are laborious. Composites are highly combustible and vulnerable to heat and fire. Installation of systems proves to be a difficult task. High cost is a major drawback. A number of other technical issues combined with the above drawbacks are constraining the large scale introduction of composites into the large structure marine market. Composite ship joints often have similar design features as welded steel joints even though the joining process is difficult in joining composites, and as a consequence joints made of glass-reinforced plastic can have lower strength and fatigue resistance [5, 6, 7].

3. Design of Steel Drive Shaft

The design specifications of the Steel Shaft (SM45C) is as follows,

The torque transmission capability of drive shaft is taken as **151 Nm**
The outer diameter of shaft is (R_o) **= 0.036 m**
The inner diameter of shaft is (Ri) **= 0.011 m**
The length of the shaft is (l) **= 1.5 m**

The fundamental natural bending frequency for passenger cars, small trucks, and vans of the propeller shaft should be higher than 6,500 rpm to avoid whirling vibration and the torque transmission capability of the drive shaft should be larger than 3,500 Nm. The drive shaft outer diameter should not exceed 100 mm due to space limitations. Here outer diameter of the shaft is taken as 90 mm. Steel (SM45C) used for automotive drive shaft applications. The material properties of the steel (SM45C) are given in Table 1 [8]. The steel drive shaft should satisfy three design specifications such as torque transmission capability, buckling torque capability and bending natural frequency.

Table 1 Mechanical properties of Steel (SM45C)

Mechanical properties	Symbol	Units	Steel
Young's Modulus	E	GPa	207.0
Shear modulus	G	GPa	80.0
Poisson's ratio	ν	-----	0.3
Density	ρ	Kg/m^3	7600
Yield Strength	S_y	MPa	370
Shear Strength	S_s	MPa	--

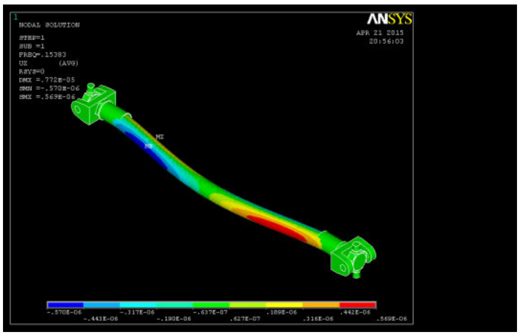

Fig.2 Stress distribution of the steel shaft after bending

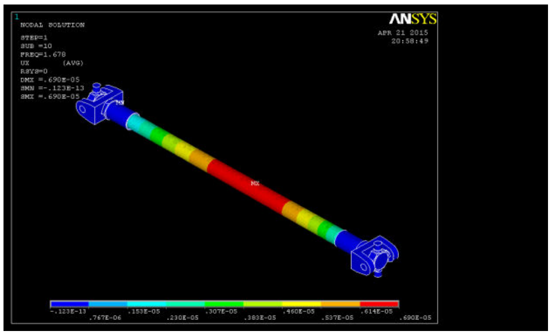

Fig 3 Stress distribution of steel shaft before bending

3.1 Drive Shaft Vibration

Vibration is the most common drive shaft problem. Small cars and short vans and trucks (LMV) are able to use a single drive shaft with a slip joint at the front end without experiencing any undue vibration [9]. This condition is usually by dirt or foreign material on the shaft, and it can cause a rather noticeable vibration in the vehicle. Torsional vibration occurs from the power impulses of the engine or from improper universal join angles. It causes a noticeable sound disturbance and can cause a mechanical shaking. In excess, both types of vibration can cause damage to the universal joints and bearings. From the theory of whirling, it has been found that the critical whirling speed of the shaft is inversely proportional to the square of the shaft length. If, therefore, a shaft having, for example, a critical whirling speed of 6000 rev/min is doubled in length, the critical whirling of the new shaft will be reduced to a quarter of this, i.e. the shaft will now begin to rotate at 1500 rev/min [10].The vibration problem could solved by increasing the diameter of the shaft, but this would increase its strength beyond its torque carrying requirements and at the same time increase its inertia, which would oppose the vehicle's acceleration and deceleration. Another alternative solution frequently adopted by car, van, and commercial vehicle manufacturers is the use of two-piece drive shafts supported by intermediate or centre bearings [11].

4. Design of a Composite Drive Shaft

The specifications of the composite (Kevlar) drive shaft of an automotive transmission are same as that of the steel drive shaft for optimal design [10].

The torque transmission capability of drive shaft is taken as **151 Nm**
The outer diameter of shaft is (R_o) = **0.036 m**
The inner diameter of shaft is (R_i) = **0.011 m**
The length of the shaft is (l) = **1.5 m**

4.1 Assumptions

- 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, Hooke's law is applicable for composite materials.
- Acoustical fluid interactions are neglected, i.e., the shaft is assumed to be acting in a vacuum.
- Since lamina is thin and no out-of-plane loads are applied, it is considered as under the plane stress.

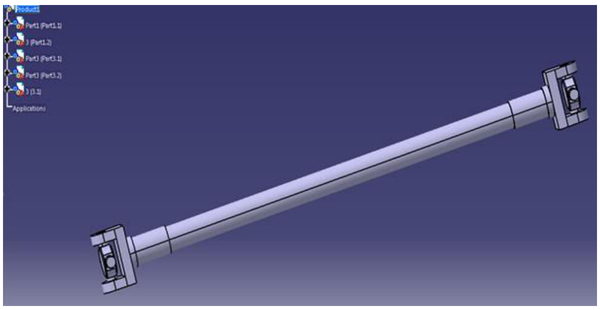

Fig 4 CATIA v5® model of composite drive shaft

The Fig. 4 and 5 shows that, 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.

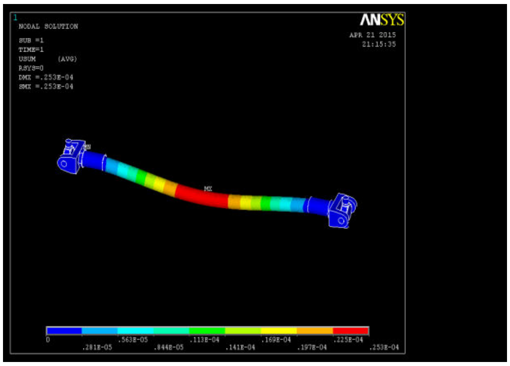

Fig. 5 Stress distribution of the Kevlar shaft after bending

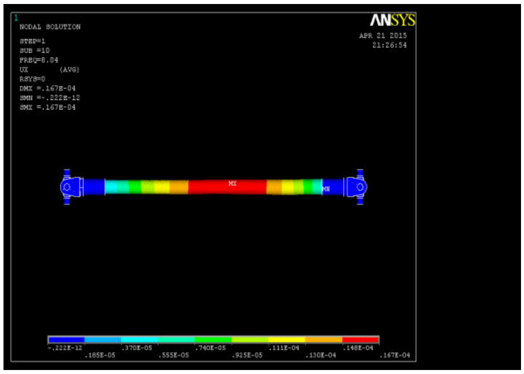

Fig. 6 Stress distribution of the Kevlar shaft before bending

5. Results and Discussion

Steel and composite materials and weight of the shaft is optimized and stress intensity factor found for both Steel and composite drive shafts. Theoretical and ANSYS results simulation of the drive shaft for simplicity has been first idealized as a hollow cylindrical shaft which is fixed at one end and on other end, to which a torque of 151Nm is applied as represented below in Fig. 8,

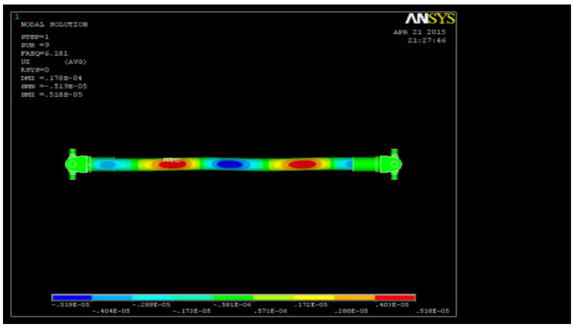

Fig. 7 Stress intensity factor for Steel and composite drive shaft

5.1 Demerits of a Conventional Drive Shaft

They have less specific modulus and strength [11]. Increase in weight. Conventional steel drive shafts are usually manufactured in two pieces to increase the fundamental bending natural frequency because the bending natural frequency of a shaft is inversely proportional to the square of beam length and proportional to the square root of specific modulus. Therefore the steel drive shaft is made in two sections connected by a support structure, bearings and U-joints and hence over all weight of assembly will be more [12]. Its corrosion resistance is less as compared with composite materials [12]. Steel drive shafts have less damping capacity.

5.2 Merits of Composite Drive Shaft

The fundamental natural frequency of the carbon fiber composite drive shaft can be twice as high as that of steel or aluminium because the carbon fiber composite material has more than four times the specific stiffness of steel or aluminium, which makes it possible to manufacture the drive shaft of passenger cars in one piece. A one-piece composite shaft can be manufactured 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 the total cost [13]. Due to the weight reduction, fuel consumption will be reduced [13]. They have high damping capacity hence they produce less vibration and noise [14]. They have good corrosion resistance [13].Greater torque capacity than steel or aluminium shaft [14]. Longer fatigue life than steel or aluminium shaft [14]. Lower rotating weight transmits more of available power [15].

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