Design and Analysis of Drive Shaft using Kevlar/Epoxy and Glass/Epoxy as a Composite Material

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Abstract. In automobile industry drive shaft is one of the most important components to transmit power from engine to rear wheel through the differential gear. Generally steel drive shaft is used in automobile industry, nowadays they are more interested to replace steel drive shaft with that of composite drive shaft. The overall objective of this paper is to analyze the composite drive shaft using to find out the best replacement for conventional steel drive shaft. The uses of advanced composite materials such as Kevlar, Graphite, Carbon and Glass with proper resins ware resulted in remarkable achievements in automobile industry because of its greater specific strength and specific modulus, improved fatigue and corrosion resistances and reduction in energy requirements due to reduction in weight as compared to steel shaft. This paper is to presents, the modeling and analysis of drive shaft using Kevlar/Epoxy and Glass/Epoxy as a composite material and to find best replacement for conventional steel drive shafts with an Kevlar/epoxy or Glass/Epoxy resin composite drive shaft. Modeling is done using CATIA software and Analysis is carried out by using ANSYS 10.0 software for easy understanding. The composite drive shaft reduces the weight by 81.67% for Kevlar/Epoxy and 72.66% for Glass/Epoxy when compared with conventional steel drive shaft.

1. Introduction
A driveshaft in automobile is used to transmit power from engine to wheels. Driveshaft must be operated by constantly changing angles between the transmission and axle. A high quality steel is a common material used for constructing drive shaft. The bending natural frequency of the beam is directly proportional to the square of the length and proportional to the square root of specific modulus. Because of that the steel drive shafts are manufactured by two pieces to increase the bending natural frequency. The two pieces of drive shaft with three universal joints, a bracket and a center supporting bearing, which increases the total weight of a vehicle and decreases the power transmission due to its inertial mass. Replacing conventional metallic structures with composite structures has many advantages due to its higher specific strength and stiffness of composite materials. Also its weight is lesser than steel and aluminum with similar strength. Composite drive shaft is manufactured by single piece it will eliminate the assemblies of three universal joints, a bracket and a center supporting bearing of two piece steel drive shaft. Also, composite drive shaft will have lower modulus of elasticity which results in decrease in stress and best shock absorber when torque is more. The advanced composite materials such as Kevlar, graphite, carbon and glass with proper resins ware resulted in notable achievements in automobile industry. Because of their elastic properties it will increase the torque they can carry as well as withstand the rotational speed. This project provides the
design and analysis of Kevlar/Epoxy and Glass/Epoxy as a composite material for the drive shaft and by comparing their result with conventional steel drive shaft to find the best replacement for it.

2. Material Selection

2.1 Materials for Steel drive shaft

Steel (SM45C) is a material mostly used for conventional drive shaft. The steel material which are used for conventional drive shaft must satisfy the specifications such as capacity of torque transmission, bending natural frequency and capability of buckling torque. The properties of the material steel (SM45C) are shown in Table 1.

2.2 Composite Materials for drive shaft

A composite material is a material made by combining two or more constituent materials with different physical or chemical properties and to produce a material with uniqueness different from the individual components. The individual components remain separate and dissimilar within the completed structure. In practice high performance composites are formulated using a bulk material (the matrix) and fiber or fabric reinforcement to increase the strength and stiffness of the matrix. Reinforcements may be in the form of fibers, particles or flakes which gives the length, orientation, shape and material. The matrix factors gives the compressive strength, transverse modulus, shear modulus and strength, co-efficient of thermal expansion and thermal resistance.

Glass Fiber

These are made by blending quarry products like sand, kaolin, limestone, colemanite at 1,600°C to get liquid glass then it is passed through micro-fine bushings and at the same time it is cooled to produce glass fiber filaments from 5-24μm in diameter. By varying the quarry products, different types of glass can be produced. E-glass is the most common reinforcing fiber used in polymer matrix composites. because of its good tensile and compressive strength, stiffness and poor resistance. It is available in the form of strand, yarns and Rovings. Strand is a compactly associated bundle of filaments, yarns are closely associated bundle of twisted filaments and rovings are loosely associated bundle of untwisted filaments.

| Properties          | Symbols | Units | Steel |
|---------------------|---------|-------|-------|
| Young's modulus     | E       | GPa   | 207   |
| Shear modulus       | G       | GPa   | 80    |
| Poisson’s Ratio     | V       | ---   | 0.3   |
| Density             | ρ       | Kg/m³ | 7600  |
| Yield strength      | Sy      | MPa   | 370   |
| Shear strength      | Ss      | MPa   | ---   |

Kevlar Fiber

Kevlar fiber is developed by Stephanie Kwolek at DuPont in 1965, it was first used as a replacement for steel in racing tyres because of its high strength. Later it is used as a fiber or as a ingredient of composite materials in ropes or fabric sheets. Kevlar fiber has a tensile strength of about $3.620 \times 10^6$ KPa, and relative density of 1.44. Kevlar's structure consists of relatively rigid molecules which will perform a sheet like structures fairly like silk protein. By measuring high tensile strength to weight ratio of Kevlar with steel, Kevlar is 5 times stronger than steel because of that it has many applications on bicycle tires, racing body armour and to make modern drumheads due to its high impact strength.
Table 2. Material properties of composite materials

| Properties                          | Symbols | Kevlar/Epoxy | Glass/Epoxy | Units |
|-------------------------------------|---------|--------------|-------------|-------|
| Young's modulus X direction         | E       | 95.71e9      | 5e10        | Pa    |
| Young's modulus Y direction         | E       | 10.45e10     | 1.2e10      | Pa    |
| Young's modulus Z direction         | E       | 10.45e10     | 1.2e10      | Pa    |
| Major Poisson's Ratio XY            | V       | 0.34         | 0.3         | ---   |
| Major Poisson’s Ratio YZ            | V       | 0.37         | 0.3         | ---   |
| Major Poisson’s Ratio ZX            | V       | 0.34         | 0.3         | ---   |
| Shear modulus XY                    | G       | 25.08e9      | 5.6e9       | Pa    |
| Shear modulus YZ                    | G       | 25.08e9      | 5.6e9       | Pa    |
| Shear modulus ZX                    | G       | 25.08e9      | 5.6e9       | Pa    |
| Density                             | ρ       | 1402         | 2100        | Kg/m³ |

3. Material Fabrication and Testing
The specimens were prepared with the Kevlar/Epoxy and Glass/Epoxy laminates according to the ASTM standard. The specimens were undergoing for tensile testing, flexure testing and impact testing by Universal testing machine and Impact testing machine.

3.1 Laminate Materials
In this laminate, Kevlar fiber and Glass fiber were used as a reinforcement and matrix Epoxy. Resin, adhesive LY556 and Hardener HY951 were used at the ratio of 10:1. Epoxy polymer materials physically consist of two necessary components, a resin and a hardener. Initially it will be in the form of liquid and by chemical reaction it will be converted into the solid. These type of polymers are mechanically strong and more adhesive during the conversion of liquid to solid. The resin and hardener are prepared with the right quantity relative to one another to bring out the chemical reaction and these are kept in a separate container in liquid form.

3.2 Laminate Methodology
The material fabrication usually involves mixing or saturating the reinforcement and then allowing the matrix to bind together into a rigid structure with the help of chemical reaction. The operation is usually done in an open mold by Hand Lay-up method. Resins are concentrated by hand into fibers which are in the form of woven, stitch or bonded fabrics. This is usually done by rollers or brushes, for forcing resin into the fabrics by means of rotating rollers and a tub of resin. Then the laminates are left to cure under normal atmospheric conditions.

**Step 1** - The surface of the mold is cleaned and a release agent is applied. The release agent will be in the form of liquid or solid and the improper cleaning of mold will affect the function of release agent.

**Step 2** - The primary layer of fiber glass structure is made with same resin is laid up on the mold surface. This layer protects the laminate from surface irregularities and surface abrasion. A peel ply is placed on the top of the primary layer, it will be removed finally.

**Step 3** - Prepare the epoxy resin by mixing the adhesive (LY556) and hardener (HY951) in the ratio 10:1 and mixing it continuously for lamination.

**Step 4** - The first peel ply is placed upon the mold and subsequent plies are placed one upon another. Press each layer after applying resin to get better lamination. Pressure will be given by a roller or other small hand tool, it will also remove vacuum between the layers. It is important that the reinforcement material have sufficient tack so that it sticks slightly to the layers of peel plies.
Step 5 - Make more number of layers to get the lamination of 3mm thickness. Finally place the primary fabric glass fiber, it will cover both the lamination surface. Apply uniform load along the surface of the lamination of 4 to 5 kg about 48 hours.

Step 6 - The reinforcement plies are cut according to design specifications (150mmX25mm). They can be cut by hand using hand shears or a steel knife.

Step 7 - Sealant tape is placed around the entire periphery of the lay-up. The vacuum bag is cut to size and placed over the lay-up.

3.3 Mechanical Testing

Tensile Testing
Tensile test is one of the fundamental mechanical test, commonly used to select material under quality control and reaction of material under different types of force. A specimen is prepared in a square section depending on the standard gauge length of the machine. Both end of the specimen was holded by the cross heads and they are firmly gripped during testing. Force will be applied on the specimen by driven cross head until it fractures, during this process applied force and elongated length is measured to find the tensile strength.

Flexure Testing
Flexure testing is used to find the bending strength of the material and modulus of the rupture. Flexure test is done on the same tensile testing machine, here the specimen is placed on the bench wise and force will be applied on the center of the specimen until it gets fractured. The figure 1 shows specimen testing.

Impact Testing
The impact test is used find the toughness of the material it is also known as the V-notch test, determines the amount of energy absorbed by a material during fracture. The impact testing machine has a pendulum of known length and mass, then the pendulum of mass is made to impact a notched specimen. This absorbed energy is a measure of a toughness of the given materials and acts as a tool to study temperature dependent ductile brittle conversion.

4. Modeling and Analysis of Drive Shaft

4.1 Modeling of Drive Shaft
The 3-D modeling of composite drive shaft is done by using CATIA and analyzed using ANSYS. A comparisons has been made between composite and steel drive shaft with respect to weight, cost and strength. The figure 2 shows the 3-D modeling of drive shaft.
4.2 Analysis of Drive Shaft

Analysis is carried out by using ANSYS 10.0 software, the following figures shows total deformation and Equivalent Stresses on Tensile test, Flexure test and Impact test of steel, Kevlar/Epoxy and Glass/Epoxy drive shafts under the application of 750N load. In that red zone indicates the maximum deflection area and blue zone indicates the minimum deflection area, which is shown by probe.

**Total Deformation on Tensile Testing** - The figure 3 shows the analysis of total deformation on tensile testing for Steel, Kevlar/Epoxy and Glass/Epoxy Drive Shafts Respectively.

![Total Deformation on Tensile Testing](image)

**Figure 3.** Total Deformation on Tensile Testing of (i) Steel, (ii) Kevlar/Epoxy (iii) Glass/Epoxy Drive Shafts Respectively.

**Equivalent Stress on Tensile Testing** - The figure 4 shows the analysis of equivalent stress on tensile testing for Steel, Kevlar/Epoxy and Glass/Epoxy Drive Shafts Respectively.

![Equivalent Stress on Tensile Testing](image)

**Figure 4.** Von-Misses Stress on Tensile Testing of (i) Steel, (ii) Kevlar/Epoxy (iii) Glass/Epoxy Drive Shafts Respectively.
Total Deformation on Flexure Testing-The figure 5 shows the analysis of total deformation on flexure testing for Steel, Kevlar/Epoxy and Glass/Epoxy Drive Shafts Respectively.

**Figure 5.** Total Deformation on Flexure Testing of (i) Steel, (ii) Kevlar/Epoxy (iii) Glass/Epoxy Drive Shafts Respectively.

Total Deformation on Impact Test-The figure 6 shows the analysis of total deformation on impact test for Steel, Kevlar/Epoxy and Glass/Epoxy Drive Shafts Respectively.

**Figure 6.** Total Deformation on Impact Testing of (i) Steel, (ii) Kevlar/Epoxy (iii) Glass/Epoxy Drive Shafts Respectively.

Equivalent Stress on Impact Testing-The figure 7 shows the analysis of equivalent stress on impact test for Steel, Kevlar/Epoxy and Glass/Epoxy Drive Shafts Respectively.

**Figure 7.** Von-misses stress on Impact Testing of (i) Steel, (ii) Kevlar/Epoxy (iii) Glass/Epoxy Drive Shafts Respectively.
5. Results and Discussions
The figure shows the deformation of Steel, Kevlar/Epoxy and Glass/Epoxy with respect to load. For tensile testing and flexure testing, the deformation of steel is less when compared to Glass/Epoxy and Kevlar/Epoxy. Glass/Epoxy has higher deformation than the Kevlar/Epoxy. But the deformation of Steel is higher than Glass/Epoxy and Kevlar/Epoxy under impact load. Kevlar/Epoxy and Glass/Epoxy are having more deformation under tensile and flexure load hence it replaces the two pieces of steel drive shaft into single shaft with better transmission of power. Because of their elasticity, they decrease the stress and act as a best shock absorber when the torque is more. Also Kevlar/Epoxy and Glass/Epoxy having less deformation under impact load so that it can absorb more energy because of its toughness.

![Graphs Load Vs Deformation]

Figure 8. Graphs Load Vs Deformation

Table 3. Results of Weight Optimization

| Parameters | Steel | Kevlar/Epoxy | Glass/Epoxy |
|------------|-------|--------------|-------------|
| d_o (mm)   | 100   | 100          | 100         |
| d_i (mm)   | 90    | 90           | 90          |
| L (mm)     | 1250  | 1250         | 1250        |
| Weight (Kg)| 14.30 | 2.62         | 3.91        |
| Weight saving (%) | - | 81.67 | 72.66 |
| Tensile Strength (%) | - | 72.5 | 69.7 |
From table 3 it is observed that the composite drive shaft is lighter and more economical than the conventional steel drive shaft with similar design specifications. It is observed that the weight reduction of drive shaft is achieved up to 81.67% in case of Kevlar/Epoxy and 72.6% in case of Glass/Epoxy than steel.

6. Conclusion
This project made an attempt to make a better replacement for a conventional steel drive shaft by a composite material of Kevlar/Epoxy and Glass/Epoxy. It can be observed that the Kevlar/Epoxy and Glass/Epoxy are having more deformation under tensile and flexure load hence it replaces the two pieces of steel drive shaft into single shaft with better transmission of power. Because of their elasticity, they decrease the stress and act as a best shock absorber when the torque is more. Also Kevlar/Epoxy and Glass/Epoxy having less deformation under impact load so that it can absorb more energy because of its toughness. The composite drive shaft reduces the weight by 81.67% for Kevlar/Epoxy and 72.66% when compared with conventional steel drive shaft. The introduction of Kevlar/Epoxy and Glass/Epoxy composite materials will reduce the weight of the drive shaft without any drop in torque transmission capacity and stiffness.

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