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Analysis of torsional vibration reduction on automobile cardan shaft by using composite materials

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Abstract. The cardan shaft transfers torsional loads from the gearbox to the rear axle for vehicle motion. The dynamics of the cardan shaft can be very complex because although one head of the shaft is fixed to the gearbox, the other end can move in the vertical plane when the vehicle is running on an uneven road. The cardan shaft is twisted and bent at different rotational speeds. When the torsional oscillation frequency of the cardan shaft coincides with one of its natural frequencies, it will induce resonance and therefore causing structural damage.

The paper presents the analysis of the cardan shaft's natural frequencies with two different materials, one using the conventional sheet metal and one using the composite material. The calculations can be used as the basis for designing the cardan shaft in the vehicle powertrain system of vehicles. The results of the study have shown the effectiveness of using composite materials for the cardan shafts in the automotive powertrain system. Based on this study, it is also suggested to use composite materials for some other shaft parts in the vehicle.

Keywords: Cardan shaft, Torsion vibration, Composite material

1. Introduction

A driveline on automotive usually consists of a cardan shaft, half shafts, transmission gears systems and bearings, as well as other components. For all-wheel drive (AWD) vehicles, the driveline includes a front cardan shaft for the front axle, a rear cardan shaft for rear axle (or more than one cardan shaft is used). For front-wheel drive (FWD) vehicles, the most usually is the cardan shaft. In the cardan shaft design, the bending and torsional natural frequencies should be higher than the specific frequencies corresponding to the maximum rotation speed of the shafts, to prevent the resonance caused by the rotating unbalance force. The natural mode frequencies of parts should be designed or tuned to avoid resonance [1]. Fuel efficiency and the weight of the vehicle are two of the most important parameters to be considered in an automobile design. To reduce power loss in the powertrain, composite materials can be used to design cardan shafts with less weight while maintaining the required strength and stiffness [2]. A researched by performing FEA analysis on two different composite materials are E-GLASS and E-CARBON reducing Von Mises stress and weight comparing to structural steel. This can be concluded that the composite material can be used in the cardan shaft [3].

2. Composite materials selection

Cardan shaft for automobile is shown in Figure 1. Cardan shaft connecting the gearbox to a differential of rear axle to transfer power from the engine to the differential of the automobile through universal joints assembly. Cardan shaft has to withstand high rotational speeds and has to change its length while transmitting the torque required by the vehicle. The secondary motion of universal joints which is proportional to the angle between the driving and driven shafts has an effect on system vibrations. Constant velocity operation of cardan shaft obtained if the axes of the input and output shafts are truly parallel. There are, however, torque and velocity variations in the elements of conventional Hookes joints which give rise to secondary rocking couples; these affect the support bearing of the input-output shaft. Joint angles should thus be as small as possible to minimize these effects. Due to the limited installation location of the driveline system, therefore the use of composite materials is an effective solution in this case.

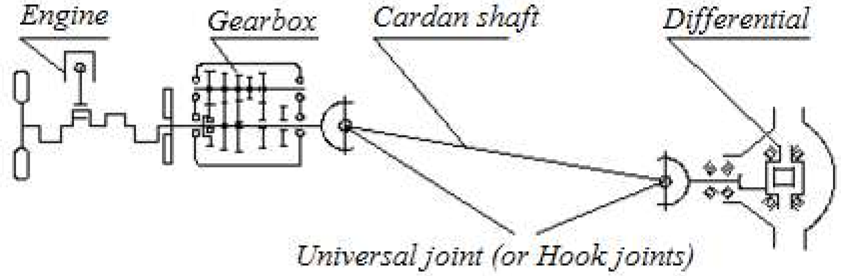

Figure 1. Cardan shaft of the driveline for Automobile

This research studies replacing the conventional steel materials with composite materials for cardan shaft. For reduction in the allowable working stress on the cardan shaft, for obtaining a given life expectancy, by analysis different composite materials for best-used selection.

The objective of this research is to replace C45 carbon steel material of cardan shaft assembled two Hook joints with composite material for a single shaft. The material mechanical properties of C45 carbon steel and E-glass epoxy, kevlar epoxy composite material are shown in Table 1. E-glass epoxy is a composite material that has been used extensively in engineering.

Table 1. Properties of materials

Mechanical Properties	Steel C45 carbon	E-glass Composite	Kevlar Epoxy Composite	E-carbon
Density (kg/m^3)	7850	1580	1402	1451
Young's Modulus (Pa)	2.0e+11	7.23e+10	9.571E+10	5.92E+10
Tensile Yield Strength, (Pa)	2.5E+08	7.8E+08	2.5E+08	5.13E+08
Tensile Ultimate Strength, (Pa)	4.6E+08	3.1E+07	4.6E+08	5E+07
Poisson's ratio	0.3	0.28	0.34	0.3
Shear Modulus (Pa)	7.679e+10	1.37E+10	3.57E+10	2.28E+10
Bulk Modulus (Pa)	1.67E+11	2.65E+10	9.97E+10	4.93E+10

The parameters of the cardan shaft shown in Figure 2, base length 1450 mm, outer diameter 90 mm, inner diameter 78 mm.

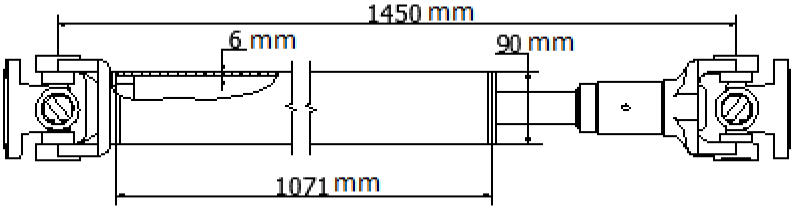

Figure 2. Geometric properties of the cardan shaft

3. Simulation Results and Discussion

3.1 Modal analysis

The finite element analysis done using Ansys Workbench software yields the mode shape, deformation, stresses and strain value in cardan shaft [4,5]. Modal analysis of other materials of cardan shaft was performed to evaluate the modal frequency and mode shape to prevent resonance. The modal analysis of the cardan shaft includes the modes must be verified to avoid mode coincidence and to have sufficient separation from vehicle body modes. In operation, the cardan shaft undergoes the excitations of both torque modulation and unbalance, and thus both torsional and bending vibrations are important. For torsional vibrations, the analysis procedure is similar to that of the engine crankshaft system. When the rotational speed of a shaft is sufficiently high, the unbalance excitation frequency could be identical to the bending natural frequency of the shaft. Under this situation, resonance occurs, and the corresponding specific speed is referred to as the critical speed. Operation at critical speed is likely to lead to failures of the shaft and system. Consider an elastic shaft with two ends connecting to universal joints, which can be modeled as a simply-supported beam on two ends. Its critical speed is:

$$f_n = 3.56\sqrt{\frac{EIg}{WL^4}} \tag{1}$$

in which E is the modulus of elasticity, I is the moment of inertia, g is the acceleration due to gravity, L is the length, and W is the weight of the cardan shaft [1].

The boundary conditions including frictionless support, the fixed support, rotational velocity and moment were used to simulate the same cardan shaft. The torsional moment is 320 Nm is applied on all the body with the rotational velocity of 2200 rpm (230.308 rad/sec). The torsional moment and boundary conditions on the cardan shaft are shown in Figure 3.

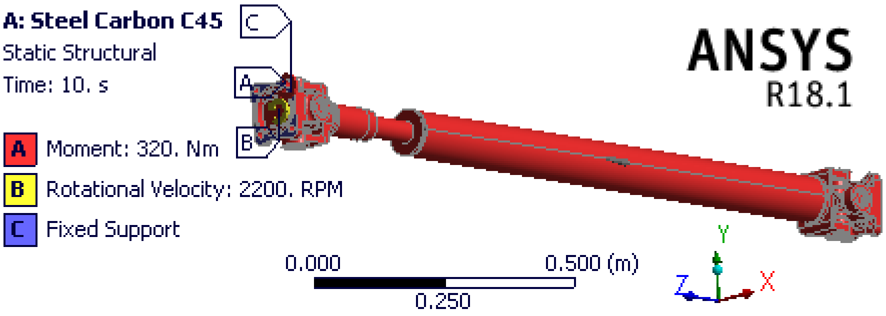

Figure 3. The torsional moment and working boundary conditions of the cardan shaft

The result of the mesh is shown in Figure 4 with 381312 nodes and 215054 elements.

Figure 4. Meshing of the cardan shaft

The results on mode shape and maximum total deformation in four types of materials of cardan shaft shown the highest natural oscillation frequency is in the 10th mode, in which the Kevlar cardan shaft has the highest nature oscillation frequency is 1156.7 Hz. The remaining axes are Steel cardan shaft is 707.3, E-glass cardan shaft is 609.87 Hz, E-carbon cardan shaft is 894.72 Hz. Others results shown that the deformation is equivalent to each mode shape. The deformation of E-carbon and Kevlar cardan shaft is equivalent coincidentally.

3.2 Static analysis

The result of the static analysis showed maximum total deformation, maximum equivalent elastic strain, and minimum, maximum equivalent (von-Misses) stress in four types of materials of the cardan shaft. The total deformation is shown in Fig.5. Deformation of E-glass cardan shaft has the highest is 2.9509 (m) and smallest is 0.82602 (m) has Kevlar cardan shaft. The equivalent elastic strain maximum has the highest is 4.86 (m/m) of E-glass material shown in Figure.6.

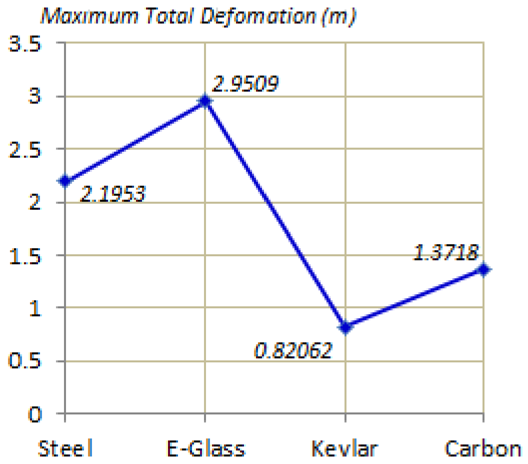

Figure 5. Total deformation (m)

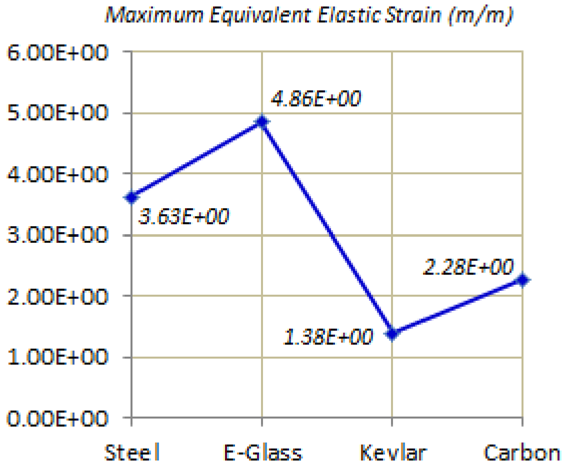

Figure 6. Equivalent Elastic Strain (m/m)

For easier comparison of the static analysis results for the four types of materials tabulated in Table 2. The steels cardan shaft specifications are 100% default, next column then the corresponding indices are the percentage reduction or increase.

Table 2. Results of Static Analysis

Materials	Steel	E-glass	Kevlar	Carbon
Weight (kg)	29.042	6.8444	5.1869	5.3682
Reduction in Weight (%)	100	76.4	82.1	81.5
Max.Total Deformation (m)	2.1953	2.9509	0.82062	1.3718
Max. Equivalent Elastic Strain (m/m)	3.6275	4.8607	1.3834	2.2779
Max.Equivalent (von-Mises) Stress (Pa)	6.7057e+11	1.5803e+11	1.1978e+11	1.2398e+11

The minimum and maximum of equivalent (von-Mises) stress has the highest is 6.71E+11 (Pa) of steel material of cardan shaft shown in Figure.7.

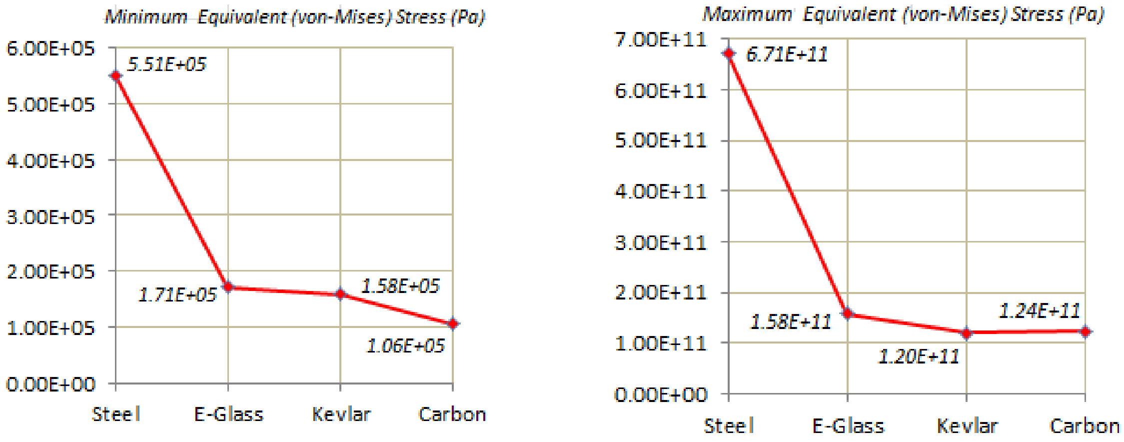

Figure 7. Equivalent (von-Mises) Stress (Pa)

Static analysis for weight comparison of C45 steel and composite E-glass, Kevlar, E-carbon materials of cardan shaft is shown in Figure 8.

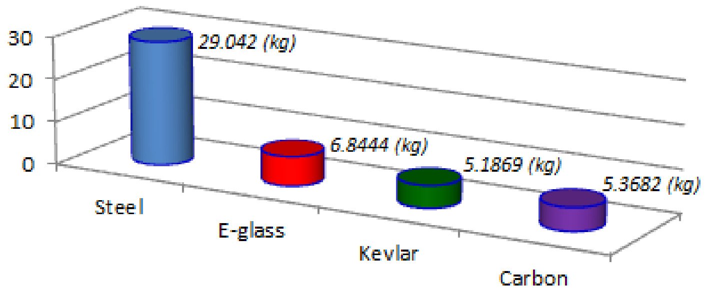

Figure 8. Graphical comparison of weights in four types of materials of cardan shaft

3.3 Dynamic analysis

To dynamically simulate the cardan shaft working conditions, the moments included the active torsional moment in the whole body of the cardan shaft of 320 Nm, resistance moment of 125 Nm having phase angle of 30 degrees (0.5236 rad). The rotational motion velocity is 2200 rpm (230.308 rad/sec), acceleration inertial is 1.41 m/s^2.

The results of the dynamic analysis is shown in Table 3.

Table 3. Results of dynamicc Analysis

Materials	C45 steel	E-glass	Kevlar	Carbon
Harnomic Maximum Total Deformation (m)	2.35E-03	2.08E-04	1.22E-04	2.1922E-04
Harnomic Maximum Equivalent Elastic Strain (m/m)	6.88E-02	8.03E-03	2.89E-03	5.40E-03
Harnomic Maximum Equivalent (von-Mises) Stress (Pa)	1.36E+10	1.09E+09	2.74E+08	3.1674e+08

The dynamic analysis was done using Harmonic in Ansys Workbench software finds the deformation, stresses, and strain dynamics value in the cardan shaft. In the Figure9 shown deformation of E-carbon cardan shaft has highest. In the Figure10 shown equivalent (von-Mises) steel cardan shaft has highest.

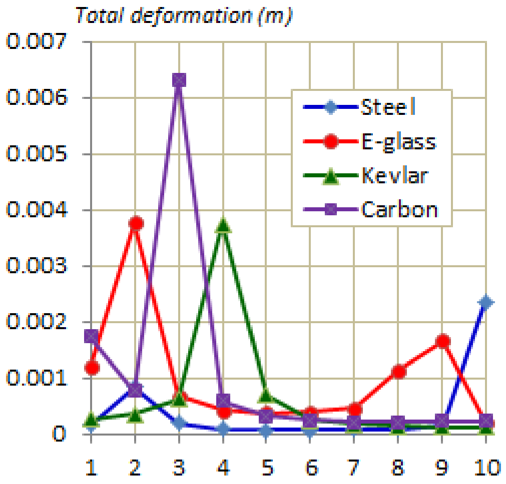

Figure 9. Dynamic deformation

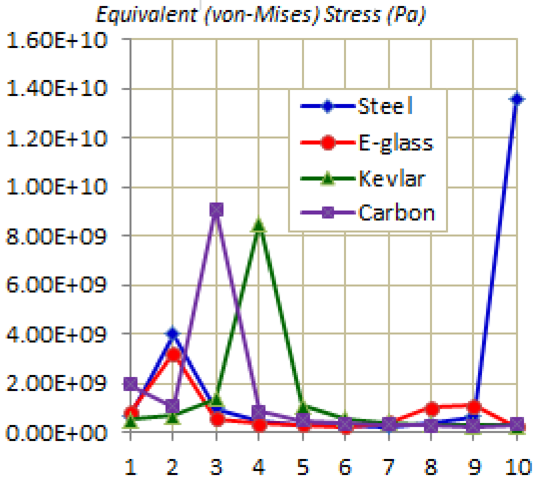

Figure 10. Dynamic equivalent stress

4. Conclusion

This research focuses on using composite materials. By the analysis of the cardan shaft's natural frequencies with four different materials, one using the conventional sheet metal and other using the E-glass composite, Kevlar, and E-Carbon material.

The results of the study have shown the effectiveness of using Kevlar composite materials for the cardan shafts in the automotive powertrain system. The Kevlar composite materials are the best specifications. In the static analysis has reduction in weight is 82 (%), total deformation is 0.82062 (m), equivalent elastic strain is 1.3834 (m/m), equivalent (von-Mises) stress is 1.1978e+11 (Pa) are smallest (Table 2). In the Dynamic analysis has total deformation is 1.22E-04 (m), equivalent elastic strain is 2.89E-03 (m/m), equivalent (von-Mises) stress is 2.74E+08 (Pa) are smallest (Table 3).

Composite is gradually consulted by engineers to replace steel in the automobiles. Because they have been improved with a solid surface that meets the demanding requirements of the body, chassis. Therefore, it reduce costs as easy to process and has many options as can give more for style, size and color of parts or components of automobiles.

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