Analysis of Helical Suspension Spring for Different Material Using Finite Element Method

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Article Info
Page Number: 788-795
Publication Issue:
Vol. 70 No. 1 (2021)

Article History
Article Received:*26 January 2021*
Revised: *07 February 2021*
Accepted: *25 February 2021*
Publication: *15 March 2021*

Abstract
There is tough competition in the automobile industry to reduce the weight and optimize the characteristics of suspension system. In this paper discussion about analysis of helical suspension spring carried out. Helical suspension spring analyzed for different material like steel, carbon fiber composite, Kevlar fiber composite. To get the higher stiffness to weight ratio composite material are used. Spring Geometry is modeled in CATIA software and another hand it is analyzed in ANSYS Workbench under different loading condition.

Keyword — Helical suspension spring, Composite, Carbon fiber, Kevlar fiber, Catia, Ansys Workbench.

1.1 1.Introduction

Helical springs are simple forms of springs, commonly used for the suspension system in wheeled vehicles. Vehicle suspension system is made out of springs that have basic role in power transfer, vehicle motion and driving. Therefore, springs performance optimization plays important role in improvement of car dynamic. The automobile industry tends to improve the comfort of user and reach appropriate balance of comfort riding qualities and economy. There is increased interested in the replacement of steel helical spring with composite helical spring due to high strength to weight ratio. On the other hand, there is a limitation at the amount of applied loads in springs. The increase in applied load makes problem at geometrical alignment of car height and erodes other parts of car. So, springs design in point of strength and durability is very important. Reduction of spring weight is also principal parameter in improvement of car dynamic. By replacement of steel helical spring with composite helical spring will reduce spring weight in addition to resistance raise under the effect of applied loads. In this research, a static analysis is employed to investigate behavior of steel and composite helical spring related to light vehicle suspension system. Steel spring has been replaced by three different composite helical in ANSYS software and results have been compared with analytical solution. The objective is to compare the load carrying capacity, stiffness and weight savings of composite helical spring with that of steel helical spring.

Advanced composite fibers such as glass, carbon and Kevlar- reinforced suitable resins, are expected to be widely used in vehicle suspension system application so that spring of different shapes can be obtained. This refers to the high specific strength (strength – to- density ratio) and high specific modules (modules – to- density ratio) of this advanced composite materials. Although epoxy is relatively sensitive to moisture, it has better mechanical property relative to other polyesters.

The method used for the production of the springs is a variation of the RTM (Resin Transfer Molding) process. Through this method, the dry braids are positioned in the mold before being impregnated with the resin, making production very clean. In this case, an open mold consisting of a helically grooved mandrel is used, and the braids are impregnated by plunging in a bowl filled with resin. The production process can be explained in few steps:
A silicon tube is filled with stand in order to let the braids keep a circular shape when winded. The braids are then wound around the mold. The mold is put in the oven to warm up together with the resin, in order to facilitate the impregnation. The resin is cured while turning on its axis. This allows the resin in excess to be equally removed from the spring. After the curing time the mold is then easily removable from the mold.

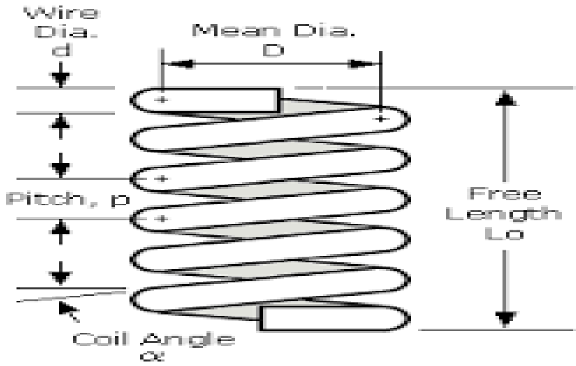

Fig.1.Specification diagram of spring

1.2 Steel Spring:

Depending upon the applications the classification of materials are done for various types of metallic springs. Initially there is no application of load but later on the load is applied in an ascending order. The spring which we are using for the analysis is compression helical spring in other words known as open coil spring. These springs are used in shock absorbers of suspension systems in automotive vehicles and some other applications such as drum brake springs for maintaining the force between contacting surfaces. The strain energy of the material of the spring is an important factor to be considered.

1.3 Composite Fibres and their properties:

1.4.1 Carbon Fiber-Reinforced Polymer (CFRP) Composites :

Carbon is a high-performance fiber material that is the most commonly used reinforcement in advanced (i.e., nonfiberglass) polymer-matrix composites.The reasons for this are as follows:
1. Carbon fibers have the highest specific modulus and specific strength of all reinforcing fiber materials.
2. They retain their high tensile modulus and high strength at elevated temperatures; high-temperature oxidation, however, may be a problem.
3. At room temperature, carbon fibers are not affected by moisture or a wide variety of solvents, acids, and bases.
4. These fibers exhibit a diversity of physical and mechanical characteristics, allowing composites incorporating these fibers to have specific engineered properties.
5. Fiber and composite manufacturing processes have been developed that are relatively inexpensive and cost effective.

To form a composite carbon fibers are mixed with other materials. Plastic resin is combined with carbon fiber by wounding or molding methods to form carbon fiber reinforced polymer which is also known as carbon fiber which has a very high strength to weight ratio. The rigidity of this material is extremely high which can also be considered as brittle material. Hence carbon fibers can also be mixed with some other materials like graphite to form carbon-carbon composite which has high heat tolerance . The carbon fiber has high stiffness, high tensile strength, high chemical resistance, high temperature tolerance, low thermal expansion and low weight. Hence it is in demand in aerospace structural applications, automotive applications and military purpose as well as in sports. The only drawback of carbon fiber is they are very expensive compared to glass fibers and plastic fibers. In the manufacturing of carbon fiber the carbon atoms are bonded together in crystals and alignment is made parallel to long axis of the fiber. This alignment gives the fiber high strength to volume ratio which is very strong for its size like this many carbon fibers are bundled together to form a tow which is further used in woving into a fabric

1.4.2 Kevlar:

Kevlar is a para-aramid fiber which displays excellent dimensional stability over a wide range of temperatures for prolonged periods. Even at temperature of 320F. Kevlar shows essentially no strength loss Kevlar fiber does not melt or support combustion but will start to decompose at about 800F. Currently, Kevlar has many applications, ranging from bicycle tyres and racing sails to body armour because of its high tensile strength to weight ratio by this measure it is five times stronger than steel on an equal weight basis

1.3. Literature Survey

In all industrial and automobile applications, springs those have high potential energy reserving capacity have undeniable role. So many researchers have concentrated on optimization of design and use of different materials to geteffective results. Analytical solution of spring compared with finite element analysis, and study of steel helical spring under effect of uniform loading [1]. Afterwards, composite helical spring E-glass/epoxy has been used at the place of steel spring [6]. Steel spring has been compared with spring weight, maximum stress, and deflection of composite spring and calculation of applied load on the factor of safety. In automobile sector innovation and competition increment replace the old product by new product with different material. Regularly the new innovations are carried out in suspension area of vehicle. FRP components are the main interest of automobile industry to replacing the steel component due to its" high strength to low weight" ratio. [19] To reduce the weight and fuel consumption some extant, so automobile industries using the GFRP open coil spring in suspension system of vehicle at the place of steel open coil spring. GFRP open coil spring fabricated by braiding process and a semi mechanized pultrusion process [E-glass and epoxy resin]. For variable parameters study it is tested in lab. Steel helical coil spring is replace by the combination of steel and E-glass fiber epoxy reinforced composite materials [7]. The design of such spring is very costly and bulky because of required stiffness. It was successful in increasing the stiffness of system and decreasing the weight. There are some factors that affect the overall stiffness of the suspension system like cost, manufacturing of E-glass fiber, very low stiffness of single composite spring. So conventional steels and metal matrix composite is used instead of fibers. The main aim to use MMC is to improve overall stiffness and life of the system.In suspension system major requirement is to increase the overall stiffness of the suspension system. Also increase the load carrying capacity of system. So it can be reduced because of combination use of composite and steel. [8] Employing composite material in the structure of automobiles decrease the weight of automobiles and increase the fuel efficiency of automobile [9]. Composite helical spring is used at the place of metal spring because of high strain energy, less weight and high corrosion resistance [10]. In this a rectangular helical spring is designed for a pay load 1400N and deflection 30mm [11]. The structural behavior of metallic and composites of varied orientations predicts by Finite Element analysis. Tape winding technology is used for manufacturing of composite helical spring.

Carbon fiber ± 45 degree orientation is used for manufacturing of composite spring. For study of mechanical behavior test will conduct on spring. Up to 600N load result show large variation in deformation. For 1400N load onhelical spring result indicate 27.5mm deflection in the composite helical spring. Composite helical spring may be used for high strength application, due to high strain energy and high corrosive resistance [12]. The main purpose for conducting the experiment is in automobile suspension springs have replaced the steel springs with glass fiber. But there are some drawbacks in utilizing the glass spring like low strength which may cause the suspension system to fail at critical load application. Hence in this paper the utilization of superior composite fiber such as Carbon fiber and Kevlar fiber have been compared with the steel springs.

2.Solid Modeling of spring:

A coil spring is designed by using PRO-E as per the specifications and analysed by ANSYS 14.0software. In this the spring behaviour will be observed by applying different materials loads, to optimum stresses and the result shows best material. The characteristic parameter of the helical spring affects their behavior. The important dimension used for modeling the spring are wire diameter(d) and mean diameter(D), number of active loops(N) and the distance between two consecutive loops i.e. pitch(P). These are the parameters which affect the behavior of the spring. These parameters are shown figure 2. Steels, Carbon fiber and Kevlar Fiber are the spring materials used for the experimental comparative study. Dimensions of the spring for different materials are depicted in the table 1.

Table 1.Dimensions of the spring for different materials

Materials	Steel	Carbon Fibre	Kevlar Fibre
DIAMETER OF SPRING	14.5	14.5	14.5
COIL OUTER	110.1	110.1	110.1
MEAN COIL	95.6	95.6	95.6
COIL INNER DIAMETER	81.1	81.1	81.1
NUMBER OF ACTIVE	7.5	7.5	7.5
PITCH (P) mm	44	45	46
SPRING HEIGHT mm	345	346	347

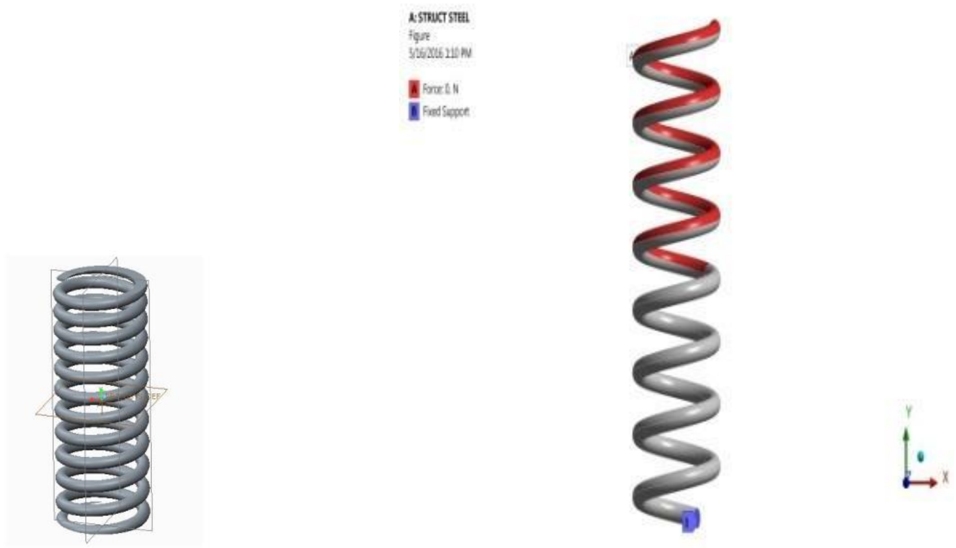

Figure 3. Meshing of coil springs and load and boundary condition for coil spring

Table 1:Meshing of spring

	Steel	Carbon Fibre	Kevlar Fibre
Mesh Size (m)	0.005	0.005	0.005
Number of Nodes	34874	34874	34874
Number of Elements	6678	6678	6678

The force acting on the spring is calculated using the equation (1) where d is the wire diameter and r is mean diameter of the spring.

$$F = \frac{\pi}{16}\frac{d3}{r}\tau$$

---(1)

To calculate the spring deflection analytically the equation (2) is used, where d is the wire diameter and r is mean diameter of the spring and n is the number of active loops in the spring.

$$f = \frac{64nr3F}{D4\ G}$$

----(2)

The spring is analyzed under different loading conditions. The boundary condition of the spring is fixed at the bottom and the load is applied from the top. The load is acting along the negative y-direction in the case of compression. The load ranges from 0 KN to 5 KN with an interval of 0.5 KN. The Free-meshing is done using ANSYS workbench. The mesh size is 5mm. The meshing and the boundary condition is shown figure 3.

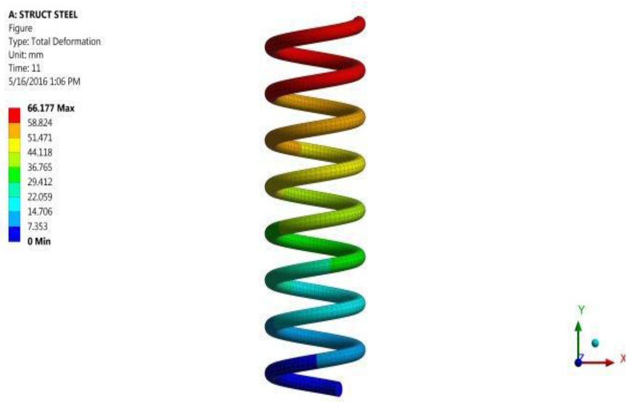

Figure 4. Maximum Deformation of Steel Coil Spring

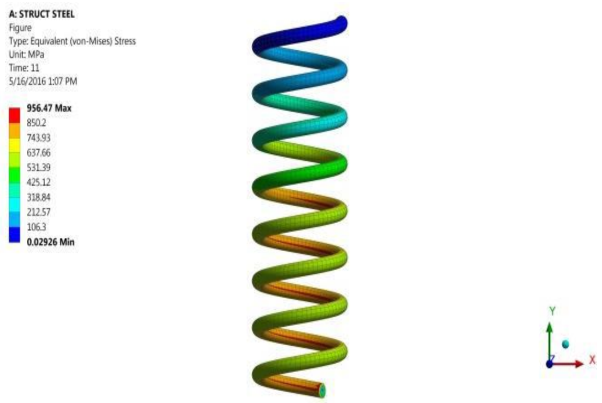

Figure 5. Equivalent Stress of Steel Coil Spring at 5KN

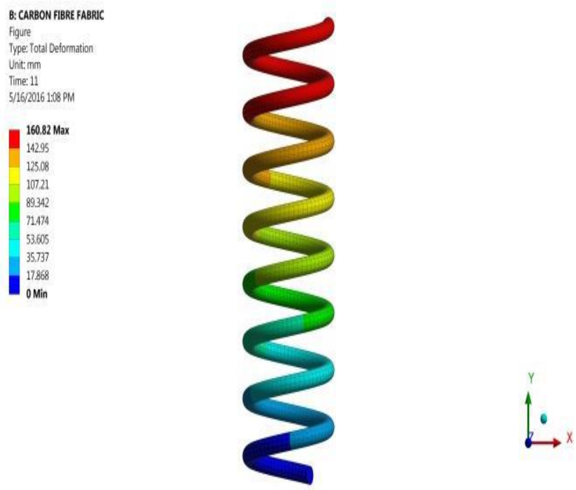

Figure 6. Maximum Deformation of Carbon Fiber Fabric Coil Spring

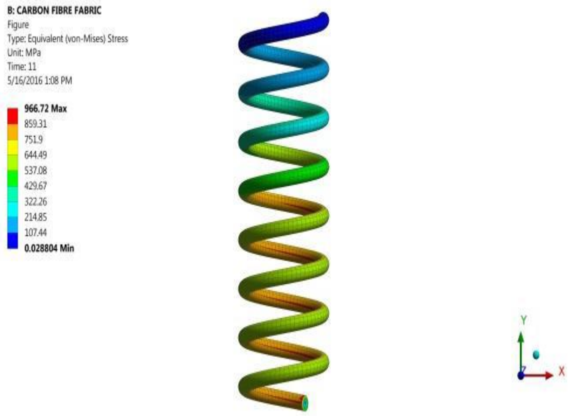

Figure 7. Equivalent Stress of Carbon Fiber Fabric Coil Spring at 5KN

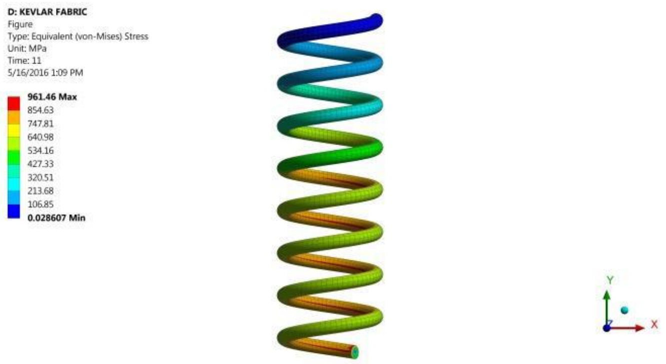

Figure 9. Equivalent Stress of Kevlar Fabric Coil Spring at 5KN

3. Use of composite material instead of steel

The steel helical spring has been replaced by two different composite helical spring which includes carbon fabrics/resin and Kevlar fabric/resin. The load and boundary condition applied to the composite helical springs are similar to that of steel spring static structural analysis i.e. the spring is fixed at the bottom and the load is applied from the top which is the negative y-direction at load varying from 0 to 5 KN with 0.5KN interval. The meshing is also similar to that of steel spring i.e. 5mm. The stress vs. strain graph and the load vs. defection graph are plotted. Both the graphs are linearly increasing.

3.1. Weight of Composite Helical Spring

The weight of steel spring is 3kg but after replacing the material property of the spring model to the composite materials the weight of the composite helical spring was drastically reduced. For carbon fabric the weight is 0.5 kg and for the Kevlar fabric/resin the weight is 0.6 kg. This drastic reduction of weight in helical spring can lead to very good stiffness to weight ratio which is the concluding factor in this project. The volume of the spring remains the same.

3.2. Stiffness to Weight Ratio or Specific Modulus

Stiffness to weight ratio is the ratio of young’s modulus in GPa by mass density of the material in g/cc. The specific modulus of steel spring is 25.47 and the specific modulus for composite spring i.e. carbon fiber fabric spring is 43.75 and for Kevlar fabric spring is 21.42. The unit of specific modulus is young’s modulus upon mass density of the material.

Table 2. Mass and Volume

Material Properties	Steel	Carbon Fibre	Kevlar Fibre
Volume (m^3)	3.8834×10^{-4}	3.8834×10^{-4}	3.8834×10^{-4}
Mass (kg)	3.0485	0.62135	0.54368

Table 3. Material Properties of Steel, Carbon Fiber Fabric and Kevlar Fabric Coil Spring

Material Properties	Steel	Carbon Fibre	Kevlar Fibre
DENSITY (kg/m^3)	7850	1600	1400
YOUNG'S MODULUS (Pa)	200×10^9	70×10^9	30×10^9
POISSON'S RATIO	0.3	0.1	0.2
BULK MODULUS (Pa)	1.6667×10^{11}	2.9167×10^{10}	1.6667×10^{10}
SHEAR MODULUS (Pa)	7.6923×10^{10}	3.1818×10^{10}	1.25×10^{10}
ULTIMATE COMPRESSIVE STRENGTH (Pa)	0	1.9×10^8	5.7×10^8
SPECIFIC MODULUS	25.47770701	43.75	21.42857143
STIFFNESS (N/m)	64860	26830	10540

Table 4. Analytical vs. FEA results of Steel, Carbon Fiber Fabric and Kevlar Fabric Coil Spring for Load Vs Deflection

Load (N)	Steel		Carbon		Kevlar	
	Analytical	FEA	Analytical	FEA	Analytical	FEA
0	0	0	0	0	0	0
500	7.71	6.6177	18.64	16.082	47.44	40.817
1000	15.42	13.235	37.27	32.163	94.87	81.633
1500	23.13	19.853	55.91	48.245	142.31	122.45
2000	30.83	26.471	74.54	64.326	189.75	163.27
2500	38.54	33.089	93.18	80.408	237.18	204.08
3000	46.25	39.706	111.81	96.489	284.62	244.9
3500	53.96	46.324	130.45	112.57	332.06	285.72
4000	61.67	52.942	149.09	128.65	379.49	326.53
4500	69.38	59.559	167.72	144.73	426.93	367.35
5000	77.08	66.177	186.36	160.82	474.37	408.17

Table 5. Stress vs Strain results of Steel, Carbon Fiber Fabric and Kevlar Fabric Coil Spring for Load Vs Deflection

Load (N)	Steel		Carbon Fibre		Kevlar Fibre	
	Stress	Strain	Stress	Strain	Stress	Strain
0	0	0	0	0	0	0
500	95.647	4.78E-04	96.672	1.38E-03	96.146	3.21E-03
1000	191.29	9.57E-04	193.34	2.76E-03	192.29	6.41E-03
1500	286.94	1.43E-03	290.02	4.14E-03	288.44	9.62E-03
2000	382.59	1.91E-03	386.69	5.52E-03	384.58	1.28E-02
2500	478.24	2.39E-03	483.36	6.91E-03	480.73	1.60E-02
3000	573.88	2.87E-03	580.03	8.29E-03	576.88	1.92E-02
3500	669.53	3.35E-03	676.71	9.67E-03	673.02	2.24E-02
4000	765.18	3.83E-03	773.38	1.11E-02	769.17	2.56E-02
4500	860.83	4.30E-03	870.05	1.24E-02	865.31	2.88E-02
5000	956.47	4.78E-03	966.72	1.38E-02	961.46	3.21E-02

4.Results and Discussion

The analysis of helical spring used in automobile was done on three different materials such as steel, carbon fiber fabric and Kevlar fabric. The mass of steel spring is 3.0 Kg as replaced with the composite materials the weight of the spring drastically reduces. Therefore the weight of the carbon fiber fabric spring is 0.6 Kg and the weight of Kevlar fabric spring is 0.5 Kg. Similarly the stiffness is 64860 N/m,26830 N/m and 10540 N/m for steel, carbon and Kevlar spring respectively. The analytical values for the spring deflection were calculated numerically and the FEA results for the spring deflection was obtained using ANSYS workbench. The results obtained by these two methods were close enough with only around 13% error. The specific modulus of steel, carbon and Kevlar material is found to be 25.47, 48.75 and 21.429

5. Conclusions

From the results obtained by the analytical calculations and the FEA results were compared. The results are found to be similar with just 13% error. The specific modulus for steel material was 25.47 and for the Kevlar material was 21.42 and for the carbon material it was 43.75. Thus carbon has high stiffness to weight ratio compared to the other materials which makes it a concluding factor in deciding the type of material to be used for the manufacturing of the spring. Since the weight of the carbon is very low compared to the steel spring it is very beneficial to use carbon spring instead of steel spring to reduce the overall weight of the vehicle when used in automotive industries.

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