Performance analysis of fiber reinforced composite spring Embedded with steel wire

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Abstract— Helical spring is the most common element that has been used in many automobile suspension systems. In this work, hybrid spring are fabricated using the composite material and steel wire as a core material, helical spring related to light vehicle suspension system under the effect of a uniform loading has been studied and finite element model has been developed to compare with analytical solution. In the present work three different types of hybrid helical springs using cross-vowen glass fiber, cross- vowen carbon fiber and combined glass and carbon fiber along with a steel wire as a core material have been fabricated. Tests were conducted on these specimens to study their mechanical behavior. The spring rate and deflection with respect to various loading condition have been evaluated. The results of these parameters with respect to the above three specimen have been compared with one another. The present study is an attempt to observe the feasibility of replacing composite coil spring in place of conventional steel spring. It is concluded that through a modification in the cross-section design of coil spring and with a proper material combination, it is possible to improve the properties of composite coil springs.

Keywords— Composite material, helical spring, glass fibre, steel wire, spring constant, spring deflection, filament winding.

INTRODUCTION

Springs are crucial suspension elements on automobiles which are necessary to minimize the vertical vibrations impacts and bumps due to road irregularities and create a comfortable ride. Coil springs are commonly used for automobile suspension and industrial applications. Presently the automobile production companies are showing an interest for replacement of conventional steel helical spring with composite helical spring due to their high strength to weight ratio property. The replacement of steel parts by composite materials yields, significant weight savings. But as with many new materials, design and manufacturing problems arise. The composite materials made it possible to reduce the weight of the springs without any reduction of load carrying capacity and stiffness. Studies were conducted on the application of the composite spring for automobiles and then compared to steel spring efficiency. Hybrid springs are also adopted for replacing the conventional spring to increase the efficiency of hybrid springs they are manufactured by combining the different material in different composition. The effect of hybridization on hybrid springs with standard cross-section was investigated and optimum hybrid spring was determined according to cost and maximum loading capacity, it is determined that carbon/epoxy plies are used for outer layers and are more advantageous. But the outer ply subjected to force was damaged thus this layer should be particularly reinforced.

The main factor to be considered in the design of the spring is the strain energy of the material. The type of stresses acting in the compression loading of the spring is the direct shear and torsion. The stiffness of the spring is also very important property which is obtained by load divided by deflection. For the purpose of saving energy and improving the performance of the shock absorbers, with light weight and high quality, composite materials have to be used for to present vehicles. With more number of electric vehicles and hybrid vehicles are entering into the market in the present-days.

In this study spring for two wheelers is taken for replacement, Glass fiber and carbon fiber is used to manufacture the composite hybrid helical spring. But as with many new materials, design and fabrication problems arise. The main reason is that fiber reinforced plastic composites are anisotropic materials, which are quite different from traditional materials. Hence the applications of composites in the manufacture of springs are not yet popular. Fiber reinforced polymers have been developed for many applications, mainly because of the potential weight savings, the possibility of reducing noise, vibrations and ride harshness due to their high damping factors, the absence of corrosion problems, which lowers maintenance costs, which has favorable impact on the manufacturing costs. However, due to the availability and cost limitation, the present work was restricted to the study of helical spring made from glass fiber and carbon fiber cross vowen. It presents advantages over graphite/ epoxy such as lower sensitivity to cracks, impact and wear damage.

Several papers were devoted to the application of composite materials for automobiles. I Rajendran studied the applications of composite structures for automobiles and design optimization of a composite leaf spring. Chang-Hsuan et al. (2007) have investigated the mechanical behaviors of helical composite springs. They have developed four different types of springs made of unidirectional laminates, rubber core unidirectional laminates, unidirectional laminates with a braided outer layer and rubber core unidirectional laminates with a braided outer layer. Faruk (2009) investigated the dynamic behavior of composite coil springs of arbitrary shape. Abdul et al. (2010) have investigated the influence of ellipticity ratio on the performances of woven roving wrapped composite elliptical springs both experimentally and numerically. Many more researchers have been investigated on elliptical springs, leaf springs and C springs. Research on fiber reinforced composite helical spring is not popular due to manufacturing difficulties. This paper discusses the feasibility of using fiber reinforced composite helical spring for automobile suspension. It is well documented in the literature that the energy storage capacity of rectangular spring is more: also found that less amount of work is carried out on this variety of springs. Hence for the experimentation rectangular cross section is chosen

MATERIALS AND METHODS

Materials

The fibers chosen for the spring design are cross-vowen glass fiber and cross-vowen carbon fiber with steel wire as a core material for fabrication, In order to facilitate the wetting of fibers; epoxy resin is selected. L-12/K-6 Lapox epoxy system for laminating applications is used. The properties of the material are given in Table1.

Table 1: Properties of E-glass/ Epoxy Resin

Properties	E-Glass/Epoxy
Young's modulus in fiber direction,E_1(GPa)	53.8
Young's modulus in transverse direction,E_1(GPa)	17.9
Shear modulus,G_{12}(GPa)	8.96
Major Poisson's ratio,ν_{12}	0.25
Minor Poisson's ratio, ν_{21}	0.08
Strength in fiber direction,X_1 (MPa)	$1.03*10^3$
Strength in transverse direction,X_2 (MPa)	27.58
Shear strength, S (MPa)	41.37

Design of Composite hybrid helical spring	**Design of conventional spring**
• Outer diameter : 60mm	1. Outer Diameter : 55mm
• Mean diameter : 48mm	2. Mean Diameter : 50mm
• Width of wire : 12mm	3. Diameter of wire : 10mm
• Thickness of wire : 10mm	

Calculation of the width and thickness of the rectangular spring

The stress in the rectangular section spring. The axial deflection in the rectangular section spring.

$$\tau_{max} = KFD\,\frac{1.5h+0.96b}{b^2}\,h^2$$

Where $K = \frac{4C-1}{4c-4} + \frac{0.615}{c} = \frac{b}{h}$

b= width of the spring and h= Thickness of the spring in mm.

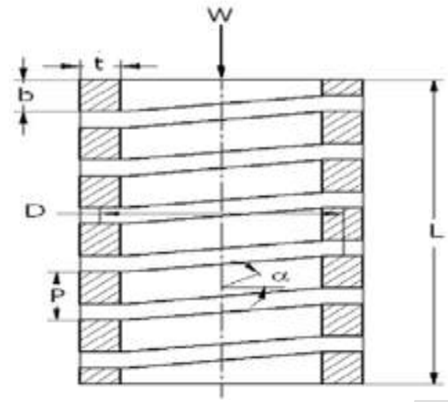

Fig 1: Spring with rectangular cross-section

Fig 2: Helical groove cutting process.

Fabrication

The manufacturing process followed in this work is a variation of filament winding process. In this method a mandrel as shown in Figure 2 is prepared with Mild steel or any other material.

In this, the mandrel having a shape of the spring profile is fixed between the centers of the lathe. A mould release agent silicone-gel/grease is applied on the mandrel. Since the load acting on the compression is shear, the fiber is cut in 90 degree orientation as shown in Fig 4. In order to form the hybrid helical spring the stainless steel strip is used in between the fibers at the center of the spring thickness.

The measured quantity of Epoxy resin matrix material is taken. The fiber tape with steel strip after dipping in the epoxy resin is wound on the mandrel. This process of winding the tape on the mandrel is continued till the thickness of the spring is obtained on the mandrel. After the completion of winding, the shrink tape is wound on the mandrel as shown in Fig 3.The mandrel with the fibers kept for curing in atmospheric temperature for 48 hours. After curing the spring is removed from the mandrel by turning operation in a lathe is as shown in the Fig 3(a). The cured spring has the dimension of L=180mm, D_0=60mm, D=48mm, b=12mm, t=10mm and n=9. The same procedure is followed for glass and carbon fiber springs. And for glass/carbon fiber springs, one layer of carbon fiber and one layer of glass fibers are to be bonded with resin for winding on the mandrel. Fabricated springs are shown in the Fig 5.

Fig 3: Tube strip wound on mandrel

Fig 3(a): Tube strip is removed from mandrel

Fig 4: Fiber and steel strip with 90^0 orientations

Fig 5: Models of the helical spring

Experimental Methods

The main parameters to be considered in the application of spring stiffness, failure load, maximum compression and physical dimensions. There is no deviation obtained in the physical dimension of the fabricated spring. Experiments were conducted as per ASTM standards and the results are shown in table 2.

Table 2: Details of composite and conventional steel spring

Properties	Composite spring	Conventional spring
Spring constant (N/mm)	4	5
Maximum Compression (mm)	80	85
Load at Max compression (N)	175	6461.52
Failure Load (N)	1000	7000
Shear stress (N/mm^2)	15.185	82.270
Weight of spring (g)	260	560
Pitch (mm)	22	24

RESULTS AND DISCUSSION

The main objective of this study is to find the feasibility of replacing metal coil spring with the composite hybrid spring for automotive suspension and to study their mechanical properties. In order to improve reliability of the Experimental results for three sets of springs were fabricated and tests were conducted on these springs. Experimental results are compared with theoretical results by graphical representation Fig 6.

Load-Displacement curve for Hybrid Spring Models

The load-deflection or stiffness test results for three different springs are obtained automatically from the Universal testing machine manually operating which generates the load-deflection.

The load-deflection curves for the three types of springs are shown in Fig 6. A linear cure is obtained for all the three types of springs. A small variation is observed in the curves of the specimens are observed in the three spring. This variation is due to the dimensional variations in the fabrication process. The values of the load and the deflection of all the three springs are given in Table 3 and the corresponding curves are shown in Figure 6.

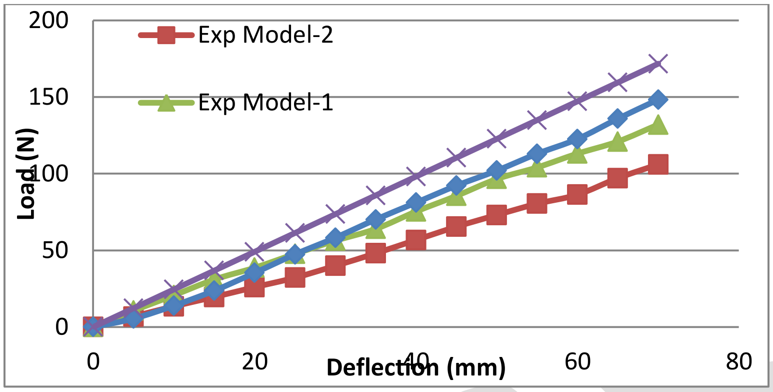

Fig 6: Load- deflection plots for Theoretical and Experimental spring models

Table 3: The values of Load and Deflection of Three spring models

Displacement (mm)	Composite Hybrid Spring			Theoretical
	Model-1	Model-2	Model-3	Spring
	Load (N)	Load (N)	Load (N)	Load(N)
0	0	0	0	0
5	10.693	6.867	5.494	12.265
10	20.699	13.534	13.931	24.531
15	30.999	19.62	23.741	36.797
20	38.652	25.996	35.316	49.063
25	47.676	32.176	47.383	61.329
30	56.309	39.926	58.272	73.595
35	63.961	48.069	70.142	85.861
40	75.341	56.80	81.128	98.127
45	85.543	65.433	92.214	110.394
50	96.531	73.085	102.024	122.659
55	104.084	80.442	113.012	134.925
60	113.109	86.328	122.625	147.191
65	120.957	97.119	135.869	159.457
70	132.043	106.046	148.323	171.723

Load-Stiffness plot for composite Hybrid spring Models

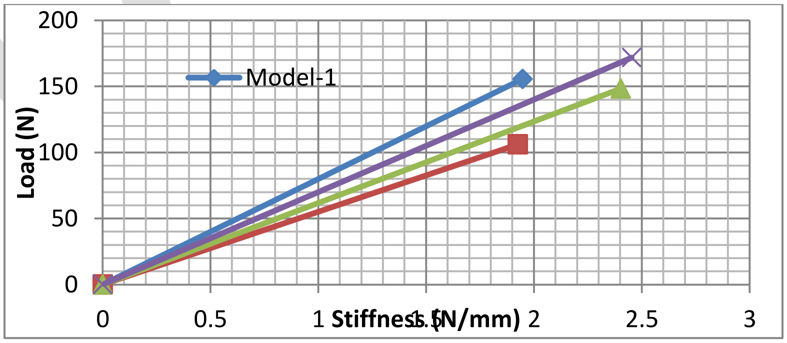

Fig 7: Load-Stiffness plot for Composite hybrid spring

The load- stiffness for composite hybrid spring is as shown in the above fig 7. It is clearly observed from the above graph that the stiffness of the spring model-3 is very close to the theoretical spring model than the remaining models 2 & 3.

Load-Deflection Curve for conventional steel spring over composite hybrid spring

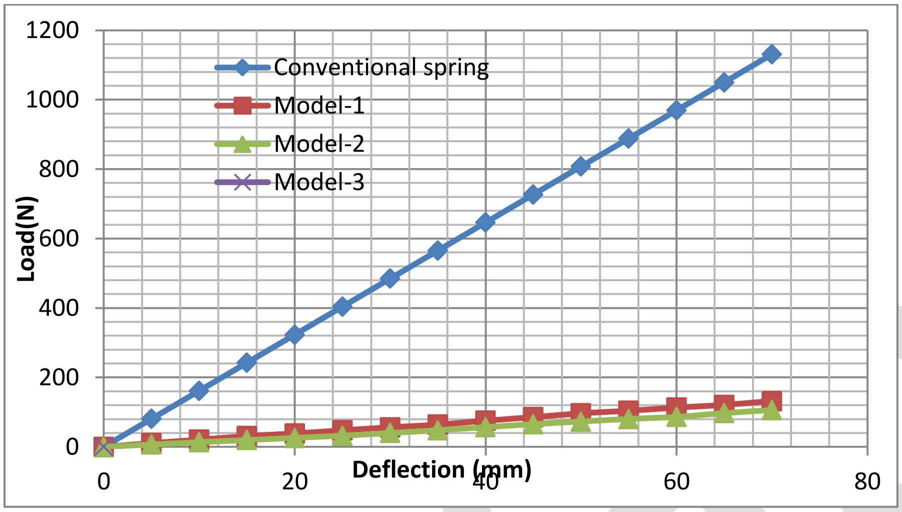

Fig 8: Load-Deflection plot for conventional spring over composite spring

The above graph shows the comparison of the conventional steel spring with composite hybrid helical spring. It is observed that the conventional steel spring having more load carrying capacity over the composite hybrid spring, among the composite hybrid spring the model-3 has more load carrying capacity than the model 1 & 2.

Weight of composite hybrid helical spring

The weight of the composite helical compression spring is obtained theoretically by considering the area and length of the rectangular wire and density of the composite material. The fiber volume fraction and mass matrix volume fraction is calculated by using the rule of mixture method

Table 4: Weight of the spring obtained

Spring number	Fiber volume fraction	Theoretical Weight (grams)	Fiber mass fraction	Experimental Weight (grams)	Difference in weight (grams)
Model-1	0.55	283	0.726	246	37
Model-2	0.60	293.72	0.765	256	37.72
Model-3	0.70	313.92	0.835	260	53.92

The theoretical weight of the conventional steel helical spring is 548 grams. The average experimental weight of the composite material hybrid spring is 254grams, in which the spring contains of steel strip of weight 40grams. As compared to the weight of the metal spring and experimental weight of the composite hybrid spring 53.65% of weight reduction is achieved.

CONCLUSION

Composite hybrid springs with different combination were subjected to different test under different loading condition. The test results have drawn the following conclusions.

- Load deflection results for hybrid helical spring shows large variations in deformations up to 171.723N. Subsequently the variations in deformations reduced as there is lesser gap between the coils
- On comparing the deflection values of hybrid composite helical springs with that of conventional steel spring, it is observed that 60% of the load that is required for steel spring is sufficient for the full compression of hybrid composite spring.

- For a set of specific design parameters of the helical compression spring on comparing with the conventional steel helical spring for the similar set of parameters the weight of the hybrid composite spring is 54% less than the conventional steel spring.
- The axial stress computed on the steel spring is about 945.9MPa, whereas the stress on composite helical spring is 19.523MPa.

In order to achieve better stiffness results on hybrid composite helical springs it is required to incorporate certain modification in the design parameters and material combination.

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