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Comparative Study of Helical Compression Suspension Spring for Different Materials

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***Abstract* - One of the major problems faced by automobile industries in few decades is the fuel efficiency which is related to the weight of the vehicle. This has led to more research in light weight materials with same mechanical properties as that of conventional materials. The composite materials are serving this need. In this study the helical compression steel springs are replaced with that of composite materials. The composite materials used are E-glass/Epoxy and Carbon fiber/Epoxy. Spring analysis is done with FEA and results are compared with steel spring. The springs are manufactured and the experimental deflections are also measured. The study shows that the weight reduction achieved with composite spring. Thus, indicating that the composite material springs can be effectively used as replacement for heavy steel springs.**
***Keywords*: composite, helical springs**

I.INTRODUCTION

Helical compression springs are used in the suspension system of automobiles. The main function of these springs is to absorb the shock and vibrations and provide comfort to the driver. Current research work in automobile industries is largely focused in use of alternative materials in place of conventional materials. Composite materials are used in number of components of automobiles as alternative materials. Composite materials are the mixture of two or more materials. The implementation of composite materials reduces the weight of components but showing the same mechanical properties compared to the conventional materials. This leads to solve the major problem of weight reduction faced in few decades by the automobile manufactures. The suspension springs are one of those components where the composite material can be implemented. The present work showcases the effective implementation of composite materials for helical compression spring in automobiles in place of steel spring. The performance characteristics of the composite helical spring are compared with a randomly selected steel spring of a two wheeler vehicle.

II.COMPOSITE MATERIALS

Composite material consists of two parts one matrix and the other reinforcement (Fibers). Thus the properties of composite are mixture of the two constituents. According to lamina the properties and behavior of composite changes. For unidirectional lamina the behavior is anisotropic [2] [3]. E-Glass/Epoxy and Carbon fiber/Epoxy (Where epoxy is matrix and E-glass, carbon are fibers) are two selected composites for helical spring with uni-directional lamina. The main parameters considered for selection are Mechanical properties, cost of materials and availability of material. The properties of the selected material prove to be appropriate for the selected application and the materials are available readily. Due to these factors these materials are selected.

III. DESIGN OF SPRING

For particular application many number of springs can be designed by changing the three parameters i.e. mean coil diameter (D), wire diameter (d) and number of active turns. Thus design is done with trial and error method by varying the above parameters to get the final design with same results as that of reference steel spring. The parameters were selected by inserting various values of d, D and N in the following equations.

$$\delta = \frac{8PD^3 N}{Gd^4}$$

$$\tau = K\left(\frac{8PD}{\pi d^3}\right)$$

For Steel spring-
Considered Force (P) = 1000 N for design purpose,
Wire diameter (d) = 7.5 mm, Mean diameter (D) = 42.5 mm, S_{ut} = 1000 N/mm^2,
Spring index (C) = $\frac{D}{d} = \frac{42.5}{7.5}$ = 5.66
The permissible stress is given by,
$\tau = 0.5S_{ut} = 0.5\,(1000) = 500$ N/mm^2

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4\times5.66-1}{4\times5.66-4} + \frac{0.615}{5.66} = 1.26960145$$

$$\tau = K\left(\frac{8PD}{\pi d^3}\right) = 1.269\left(\frac{8\times1000\times\times42.5}{\pi\times7.5^3}\right) = 325.4780107 \text{ N/mm}^2$$

Deflection

$$\delta = \frac{8PD^3 N}{Gd^4} = \frac{8\times1000\times42.5^3\times17}{87500\times7.5^4} = 37.70965785 \text{ mm}$$

$$\text{Stiffness} = \frac{\text{load}}{\text{deflection}} = \frac{1000}{37.709} = 26.51841 \text{ N/mm}$$

For E-glass/epoxy spring-
Spring Index (C) =4.5 Wire diameter (d) = 15 mm, Mean diameter (D) = 67.5 mm Number of active turns (N) = 3
Now,

$$\text{Deflection } (\delta) = \frac{8PD^3 N}{Gd^4} = \frac{8\times1000\times67.5^3\times3}{3700\times15^4} = 39.48 \text{ mm}$$

Shear stress $\tau = K\left(\frac{8PD}{\pi d^3}\right)$

Here $K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4\times4.5-1}{4\times4.5-4} + \frac{0.615}{4.5} = 1.26$

$\tau = 1.3105(\frac{8\times1000\times67.5}{\pi\times15^3})$ = 68.83 N /mm^2

The design is safe as design stress is lower than permissible and the deflection results are satisfactory for the application thus, this design is selected.

For carbon/ epoxy spring

G = 3900 N/mm^2 , S_{ut} = 1149 N/mm^2

Assume

Spring Index (C) =4.5, Wire diameter (d) = 15 mm, Mean diameter (D) = 67.5 mm, Number of active turns (N) = 3

Now,

Deflection $(\delta) = \frac{8PD^3N}{Gd^4} = \frac{8\times1000\times67.5^3\times3}{3900\times15^4}$ =37.38 mm

Shear stress $\tau = K\left(\frac{8PD}{\pi d^3}\right)$

Here $K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = \frac{4\times4.5-1}{4\times4.5-4} + \frac{0.615}{4.5}$ =1.26

$\tau = 1.3105\ (\frac{8\times1000\times67.5}{\pi\times15^3})$ = 68.83 N /mm^2

The design is safe as design stress is lower than permissible and the deflection results are satisfactory for the application .Thus, this design is selected.

TABLE-1 SELECTED VALUES FOR SPRINGS

Specification	E-Glass Epoxy	Carbon Epoxy
Coil diameter(d) mm	15	15
Mean Diameter(D) mm	67.5	67.5
Spring constant(C)	4.5	4.5
Number of turns(N)	3	3
Total number of turns(Nt)	5	5
Length(L) mm	170	170
Pitch(p) mm	42.5	42.5
Shear modulus(G) N/mm^2	3704	3940

IV. FINITE ELEMENT ANALYSIS

Modelling

The modeling of spring is carried in CATIA V5. In CATIA Wireframe feature is used for modeling the spring of desired dimensions. The selected reference steel spring had square and grounded ends thus the model is created accordingly to insure proper axial loading. The surface of the spring which are seated are considered as inactive coils as they do not contribute to the deflection and rest coils are considered as active coils. The model is created as per the dimensions in Table.

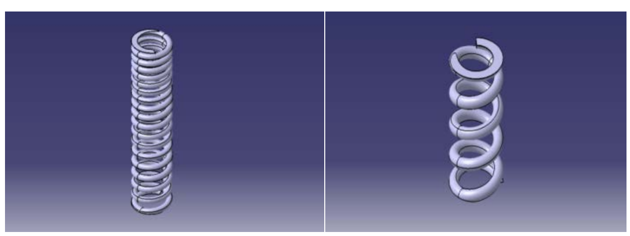

Fig.1 Catia Models of Steel and Composite Springs

Material properties

The material properties of composites are not present in default material list of ANSYS, hence the properties have to be entered in the directory.

Meshing and loading conditions

After entering the material properties the model is loaded in ANSYS WORKBENCH. The mesh is generated. Then effect of mesh refinement is also seen on the results. After meshing the loading and boundary conditions are applied. The ends which are seated in the suspension system of helical spring are fixed and at the other end axial load are applied. As the spring is considered for two wheelers the loads are calculated accordingly. The average kerb weight of two-wheeler is 130kg and along with two passengers the total weight becomes 270kg (130+2*70, 70kg per person). The front suspension carries 30% while rare suspension 70% approximately. And again the load is distributed between two struts at rare side. Thus approximately 100kg load will act upon each strut. Hence the analysis is carried for 500N, 750N and 1000N load.

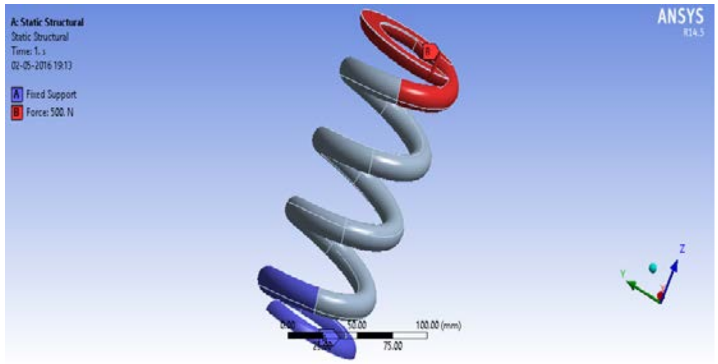

Fig.2 Loading Condition Of The Spring

Static analysis

The linear static analysis is carried out to determine the total deformation and shear stress. The deformation and stress analysis is carried for each 500N, 750N and 1000N load. The results are recorded accordingly. The results are within the permissible limit which indicated that the design is safe. The 1000N results are represented here.

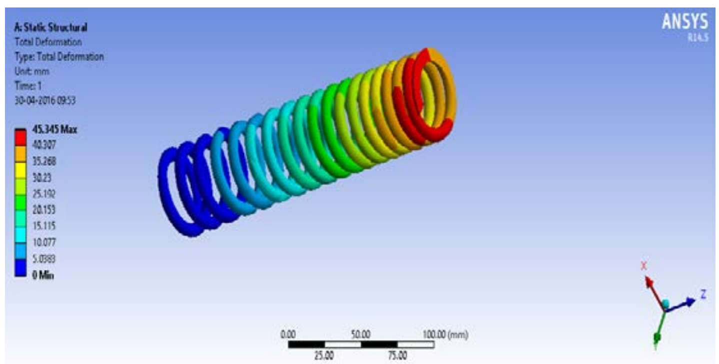

Fig.3 Deflection of steel spring for 1000N load

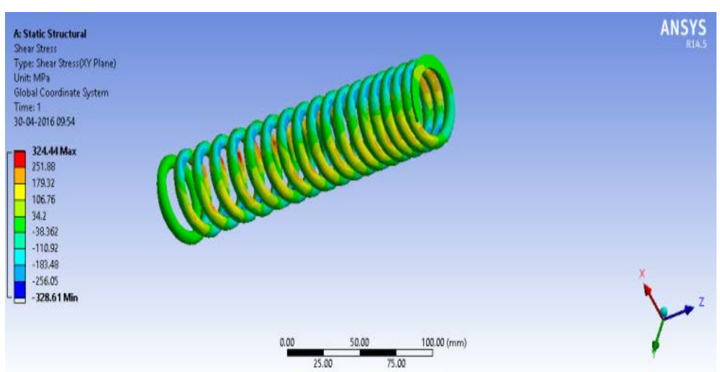

Fig.4 Shear Stress of Steel Spring for 1000N Load

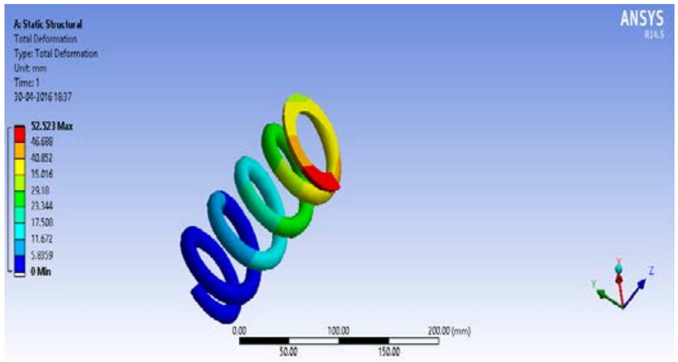

Fig.5 Deflection of E-glass/Epoxy Spring for 1000N load

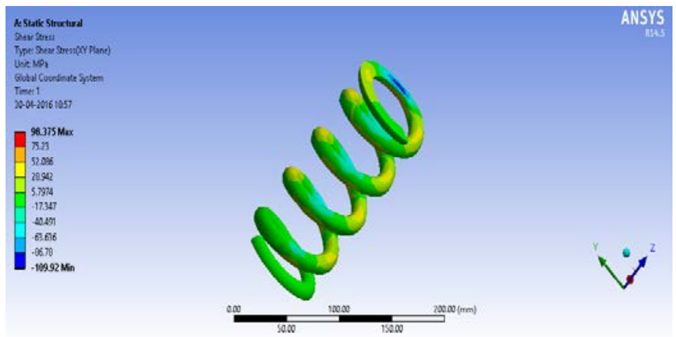

Fig.6 Shear stress of E-glass/Epoxy spring for 1000N load

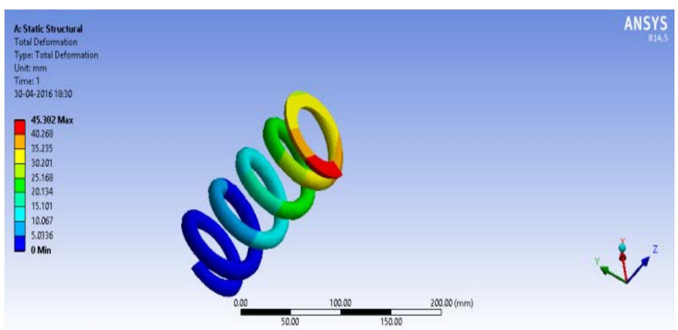

Fig.7 Deflection of Carbon/Epoxy spring for 1000N load

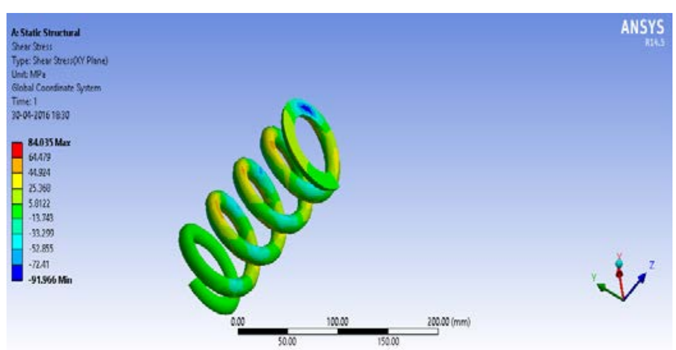

Fig.8 Shear stress of Carbon/Epoxy spring for 1000N

V. MANUFACTURING

The manufacturing process of composite material helical spring is completely different from that of steel springs. The conventional methods of steel spring manufacturing cannot be applied to the composite materials. The attained volume fraction of E-glass/ epoxy and Carbon/epoxy springs are 0.6 & 0.5 respectively with coil diameters 19mm and 17mm respectively [2].

Fig.9 Manufactured springs

VI. EXPERIMENTAL ANALYSIS

The Experiment analysis is carried to observe the experimental deflection properties of the springs. For the purpose of deflection measurement a test rig with similar structure of compression testing machine is prepared.

Fig.10 Test rig prepared for deflection testing

For measuring the deflection of the spring under different loads, first the spring is placed between the two plates. Initially no load is applied on the plate. The top plate weighs 6.5kg. At this condition the distance between plates is observed with help of measuring scale, this indicated the no load condition on the spring. After recording the initial condition the loads are applied in gradually increasing manner. The loads applied are 40, 60 and 100kgs. The deflections are measured with the measuring scale at the respective loads. The same process is repeated for the other springs.

Fig.11 Applied loads for testing

VII. RESULTS AND ANALYSIS

Deflection Results

TABLE 2 THEORETICAL DEFLECTIONS

Load in N	Deflection in mm		
	Steel	E-glass/Epoxy	Carbon/Epoxy
500	18.78	19.72	18.69
750	28.18	29.55	28.03
1000	37.17	39.05	37.38

TABLE 3 FEA DEFLECTIONS

Load in N	Deflection in mm		
	Steel	E-glass/Epoxy	Carbon/Epoxy
500	22.673	26.262	22.651
750	34.009	39.393	33.976
1000	45.34	52.523	45.302

The ANSYS results of deflection indicated that the deflection for load 500N, 750N and 1000N are almost near for all the three springs, i.e., Steel spring, E-glass/Epoxy spring and Carbon/Epoxy. On an average the deflection of carbon/Epoxy spring is lowest and that of E-glass/Epoxy is highest.

TABLE 4 EXPERIMENTAL DEFLECTIONS

Load in N	Deflection in mm	
	E-glass/Epoxy spring with 19mm coil diameter	Carbon/Epoxy spring with 17 mm coil diameter
465	20	35
665	30	45
1065	41	57

The Experimental results of deflection of manufactured spring have bit difference in the values of deflection because of different dimension. The E-glass/Epoxy spring with coil diameter 19mm has lower values of deflection than that of Carbon/Epoxy spring with 17mm coil diameter.

TABLE 5 THEORETICAL SHEAR STRESS VALUES

Load in N	Shear stress in N/mm^2		
	Steel	E-glass/Epoxy	Carbon/Epoxy
500	162.73	34.41	34.41
750	244.10	51.62	51.62
1000	325.47	68.83	68.83

TABLE 6 FEA SHEAR STRESS RESULTS

Load in N	Shear Stress in N/mm^2		
	Steel	E-glass/Epoxy	Carbon/Epoxy
500	162.22	49.187	42.017
750	243.33	73.781	63.026
1000	324.44	98.375	84.035

The Shear stress results of ANSYS show the variation with materials. The shear stress induced in steel spring is too high as that of composite spring. The shear stress values for both composite springs are almost equal.

TABLE 7 STIFFNESS RESULTS

	Stiffness in N/mm		
	Steel	E-glass/Epoxy	Carbon/Epoxy
Theoretical	26.62	25.35	26.75
FEA	22.05	19.03	22.07

The stiffness results shows that the steel and carbon/epoxy springs are the stiffest with almost same stiffness while the E-glass/Epoxy has the lower stiffness value.

TABLE 8 WEIGHT RESULTS

Steel (Average)	E-glass/Epoxy	Carbon/Epoxy
900 grams	444 grams	236 grams

The weight of composite spring is very small as compared of steel spring. The E-glass/Epoxy spring with 444 gram weight is almost 50% lighter than steel spring while carbon/Epoxy spring with 236 gram is almost 70% lighter.

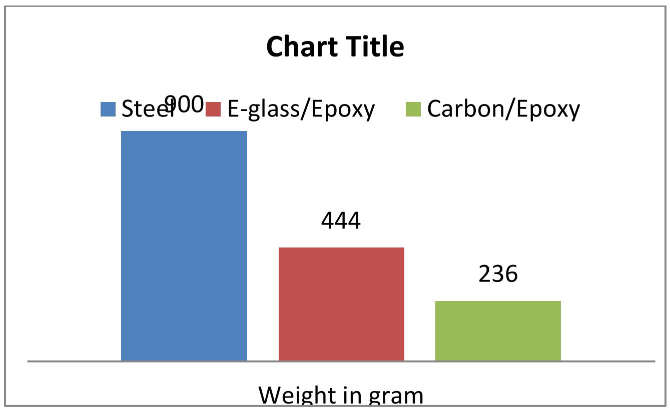

Fig.12 Weight comparison of the springs

The theoretical, FEA and experimental results have deviations within the allowable range. The deviation in FEA and actual value is due to errors in manufacturing.

VIII.CONCLUSION

The composite helical springs can be effectively used in automobiles without affecting the performance of the suspension system of the vehicles. They provide around 50-7-% weight reduction as compared to that of steel spring. The percentage cost of E-glass/Epoxy spring increases by 20% as that of steel spring but 50% lighter with the same performance results. The cost of Carbon/Epoxy spring increase by 5 times of steel spring but a significant reduction in the weight.The stiffness of the composite spring is almost same as that of the steel springs. Successful implementation of the composite springs can be achieved for the suspension systems.

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