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DEVELOPMENT OF HIGH STRENGTH HELICAL COILED SPRINGS USING CARBON PRE-PEG EPOXY BASED COMPOSITE

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ABSTRACT

The best way to increase the fuel efficiency is to reduce the weight of the automobiles by employing composite materials in the structure of the automobiles. Metal coil springs can be replaced by composite springs because of high strain energy, less weight and high corrosion resistance. Carbon pre-peg epoxy based composite spring is the best alternate to metallic springs and E-glass epoxy based composite springs. A helical compression spring of rectangular cross section is designed for a payload of 1400N and deflection of 30mm.The deflections and axial stresses are the design constraints for the selection of fiber orientations in carbon pre-peg epoxy based composites. Finite element analysis predicts the structural behavior of metallic and composites of varied orientations. A composite helical spring is developed using Tape winding technology and experimental validations are carried out on Carbon pre-peg epoxy based spring. The results indicate that carbon pre-peg springs are superior in structural parameters compared to metallic springs.

KEYWORDS : Composite Springs, Helical Springs, Suspension System

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. The fuel efficiency and emission gas regulations of automobiles are two important issues in these days. The best way to increase the fuel efficiency is to reduce the weight of the automobiles by employing composite materials in the structure of the automobiles. Metal coil springs can be replaced by composite springs because of weight reduction and corrosion resistance. Metal coil springs cannot withstand high temperature. At high temperature where it is required to operate composite springs are used. Since the composite materials are anisotropic in nature, the design and manufacture of composite springs are difficult. Therefore the application of composite materials in springs is not yet popular. However they are used in the suspension system of the automobiles. 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 today's vehicles. With the more no of electric vehicles and hybrid vehicles are entering into the market in the present scenario, it has become essential to go for the light components for improving the efficiency. Because composite springs have some advantages over the metal springs, many researchers are actively involved in the study of composite springs (Norton, 2005).

MATERIALS AND METHODS

Composites coil springs have many advantages over the conventional ones: they are light and have better performance in fatigue and dynamic response. In addition to the structural benefits, composite springs can be designed to render the optimal mechanical properties by tailoring the orientations and content of reinforcing fibers. They have been typically manufactured by the filament winding (F/W) process. Although this process can be cost-effective, the reinforcing fibers may be limited in the longitudinal direction for small composite springs, which results in low strength and stiffness in the transverse direction. Also, due to the limitation of reinforcing direction, optimized structure is hardly achieved in the Filament Winding process.

Three different types of springs were selected glass fiber, carbon fiber and combination of glass fiber and carbon fiber. Properties of three spring materials are given in table1.The objective of the study is to reduce the weight of the spring. According to the experimental results the spring rate of the carbon fiber spring is 34% more than the glass fiber spring and 45% more than the glass fiber/carbon fiber spring. The weight of the carbon fiber spring is 18% less than the glass fiber spring, 15% less than the Glass fiber/carbon fiber spring and 80% less than the steel spring.

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Design of a Helical Compression Spring for Rectangular Cross Section

Design of a Helical Compression Spring for Rectangular Cross Section involves findings of stresses, axial deflections, spring deflections in the rectangular section spring, number of active coils, total number of coils, and total weight of the spring (Figure 1).

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

$$\tau 1 = KFD \frac{1.5h + 0.96b}{b2} h2$$

$$Where\ K = \left(4C - \frac{1}{4C} - 4\right)$$

$$= (0.615/C), m = b/h$$

The axial deflection in the rectangular section spring,

$$y = 2.83IFD3\ (b2\ + h2)/b3\ h3\ G$$

$$= €D3\ F/b2\ h2\ G$$

Spring deflection (mm) = $I = b2\ h2\ G/€F0\ D3$

Where € =elasticity (resilience) coefficient and depends on Number of active coils

Total no. of coils = I + 2

Total weight of the spring (wt) $= \pi 2 * d * 2D * Nt * \delta/4$

In the current study helical compression springs for a 500kgf mechanical component systems is designed. The mechanical component systems requires four helical springs.

Assumptions

1.Maximum deflection of the springs =30mm

2. Length of the spring = 150mm

3. Mean diameter of the coil (D) =52mm

Table1: Properties of Three Spring Materials

Properties	Glass fiber	Carbon fiber	Glass/ carbon fiber
Spring Constant (N/mm)	4.83	6.36	5.75
Maximum Compression(mm)	83	80	77
Load at Max Compression(N)	388.8	511.75	459.76
Failure Load (N)	1000	1500	1200
Shear Stress (N/mm2)	83	79.67	95.49
Fiber Volume Fraction (%)	60.20	69.23	62.46
Weight of Spring (g)	237.46	200.50	224.59

Load factors

1. Load on each spring = 5000/4 = 1250N

2. Considering dynamic load factor = 1.12

3. Total load on each spring = 1250*1.12 = 1400N

Calculation of Width & Thickness of the Spring

Load applied (w) =1400N $_c$=D/t

$$\tau = kWD\ (1.5t - 0.9b)/b2t2$$

b= width of the spring in mm,

t=thickness of the spring in mm.

Where k= (4c-1/4c-4) + (0.615/c)

Helix angle=tanα =*p/πD* (Where p= pitch)

Based on the above calculations, (Table, 2) shows the carbon/epoxy material is found to have high shear strength

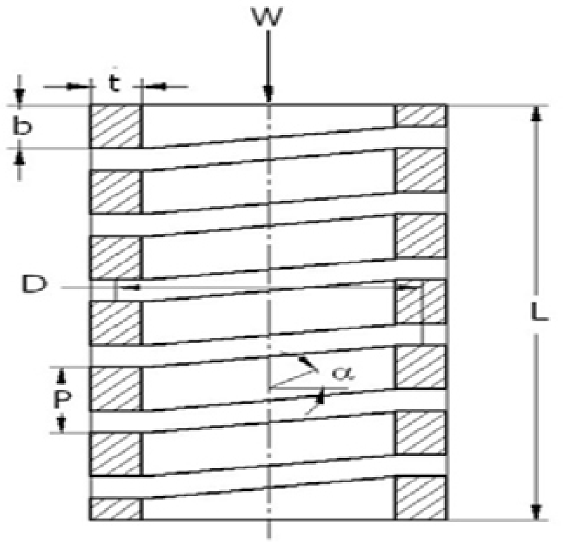

Figure 1: Spring with rectangular cross-section

Material selection

Carbon /Epoxy is selected as spring material. A composite spring of rectangular cross section for a payload of 1400N and 30mm deflection is designed. A rectangular helical spring of 12mm thickness and 20mm Width is considered for the current study.

Material properties

The Carbon/Epoxy exhibits good mechanical properties which were used in the spring design as well as analyses and are given in Table,3.

Table 2: Calculation of Width of the Spring for Different Materials

Material	Shear stress(τ) N/mm^2	Thickness(t) mm	Width(b) mm
Glass fiber	80	12	20
Carbon fiber	60	12	24
Glass/carbon fiber	40	12	31

Table3 :Material Properties for Carbon Fabric Composite

Stiffness			
E_1	66,000	M-Pa	Young's modulus along fiber
E_2	67,000	M-Pa	Young's modulus across fiber
G_{12}	3500	M-Pa	In-plane shear modulus
υ_{12}	0.23	-	Poisson's ratio
υ_{23}	0.30	-	Poisson's ratio
ρ	1400	Kg/m^3	Density of composite
Strength			
$\sigma_1^{tension}$	500	M-Pa	Tension strength
$\sigma_1^{compression}$	690	M-Pa	Compressive strength
$\sigma_2^{tension}$	520	M-Pa	Tension strength
$\sigma_2^{compression}$	700	M-Pa	Compressive strength
τ_{12}	110	M-Pa	In-plane shear strength
τ_{23}	110	M-Pa	Out-of-plane shear strength

Finite Element Analysis:

The static analysis of the helical compression spring is performed using ANSYS.A composite helical spring of 150mm in length and stiffness of 46N/mm is designed based on the helical compression spring concepts.

The composite casing has been analyzed with 3D modeling using ANSYS. Linear analyses was carried out with layered-46 element for composite whereas solid-45 element for isotropic materials. Load of 1400 N is applied on the free end of spring and other end is fixed as shown in (Figure,2)

The structural analysis was performed by Finite element method for both metallic spring and composite helical springs. Different orientations of the plies are considered to optimize the dimensions of the cross section of the spring for maximum deflection and minimum stress parameters. The comparison of deflections and stresses of metallic spring and composite springs are shown in (Figure, 3 to Figure, 10) and results were tabulated in (Table, 4). (Chang et al. 2007 and Morries, 1986).

Development of composite helical spring

A mandrel of length 200mm and diameter 64mm, with grooves of helix angle 10 degrees, width 20mm and thickness 12mm is used for the development of helical composite spring. Carbon Pre-peg Fiber is cut in 45degree orientation with dimensions of width 20mm, thickness 0.5mm and then wounded on spool. Composite carbon pre-peg fiber is passed through the payout eye to the first groove of the mandrel. The mandrel continuously rotates at a low speed of 10-20 rpm. The fiber is wounded on all the grooves

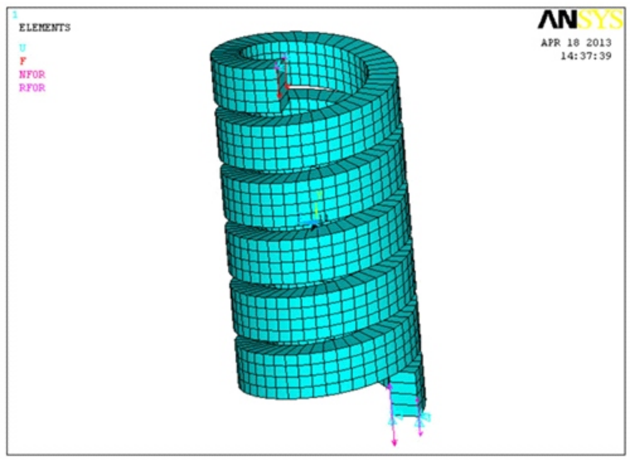

Figure 2: FE model of Helical Spring with loading and boundary conditions

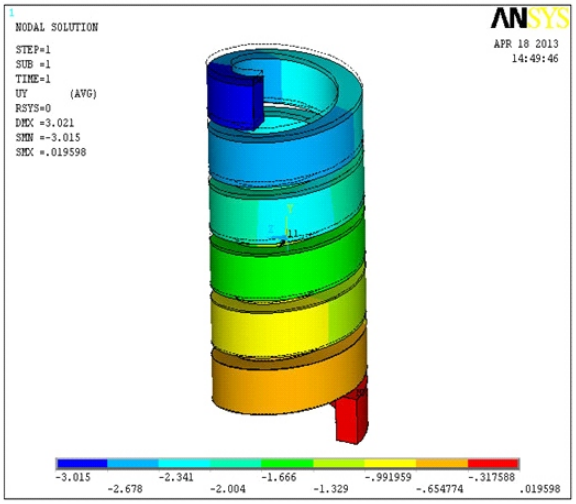

Figure 3: Axial Deformation of Metallic spring in mm

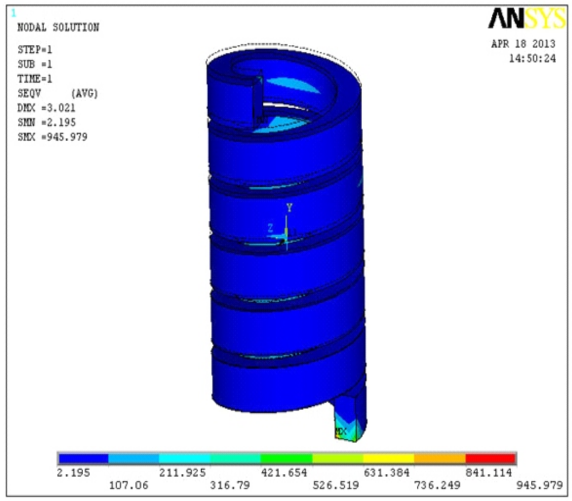

Figure 4: Axial Stress of Metallic Spring in MPa

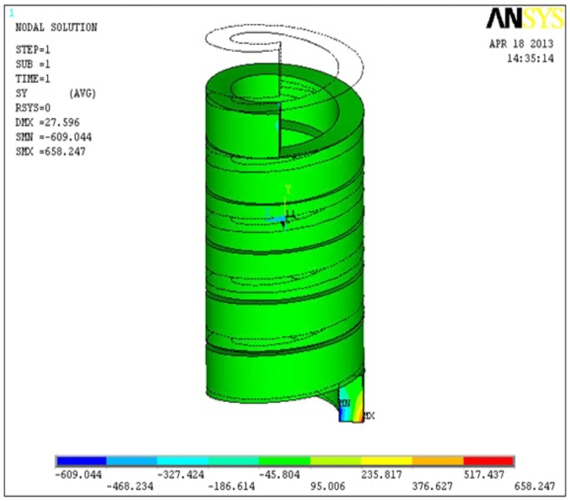

Figure 5: Axial deformation of Composite helical spring with ±30° orientation in mm

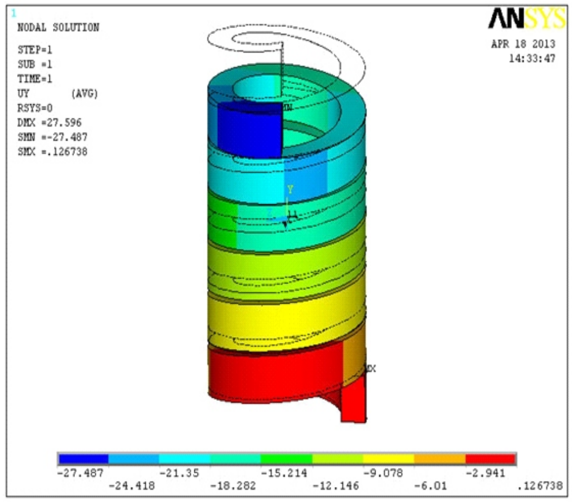

Figure 6: Axial stress of Composite spring with ±30° orientation in MPa

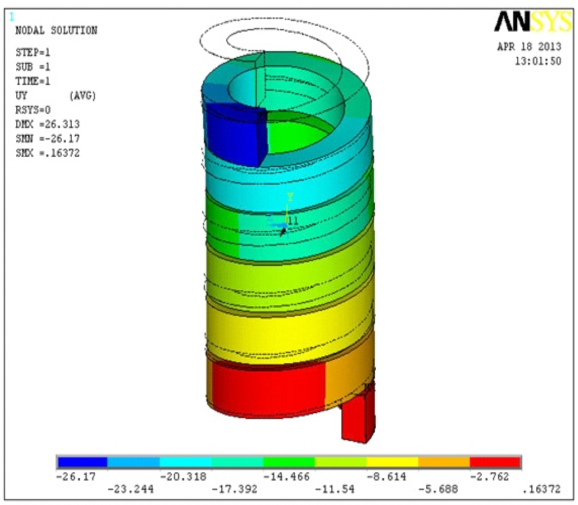

Figure 7: Axial deformation of Composite helical spring with ±45° orientation in mm

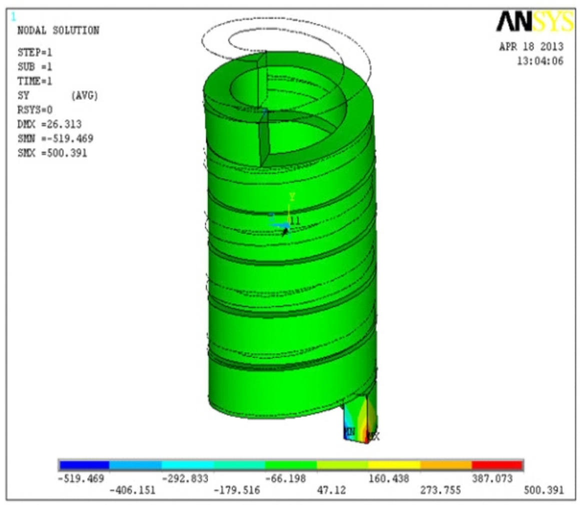

Figure 8: Axial stress of Composite spring with ±45° orientation in MPa

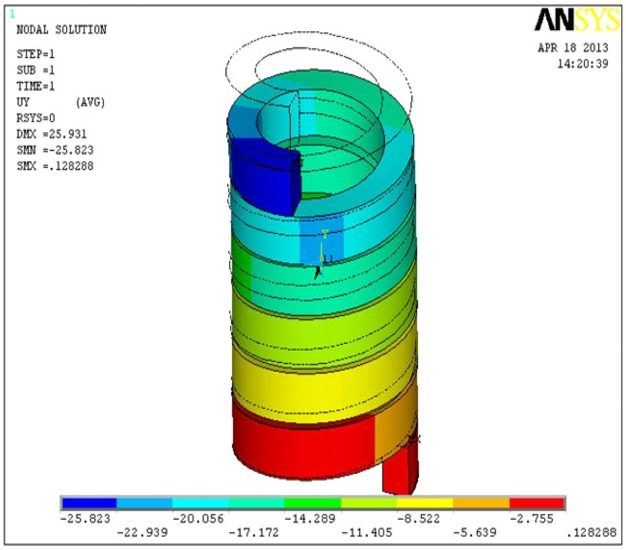

Figure 9: Axial deformation of Composite helical spring with $\pm 60^o$ orientation in mm

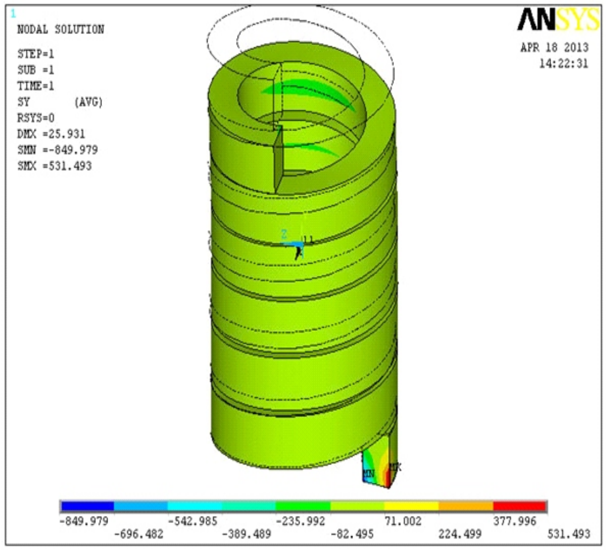

Figure 10: Axial stress of Composite spring with $\pm 60^o$ orientation in MPa

Figure 11: Composite Helical Spring

of the mandrel till the first layer is completed and it is cut at end. The process is continued till the required thickness is obtained. It is observed that the total number of layers required for the thickness is 24. The helical spring developed by tape winding technology is shown in (Figure,11).

RESULTS AND DISCUSSION

The helical spring developed by tape winding technology is tested on Universal Testing Machine as shown in (Figure, 12) to determine deflections for variable loads. The variable loads applied on helical compression spring and respective deflections were tabulated in table 5. (Hendry and Pobert, 1986).

The load vs. Deflection for composite spring is shown in (Figure,7). By observing the values determined analytically and experimentally are having a standard deviation of 6.7 %. (Mallick, 1987).

Table 4: Deflection and Axial Stresses of Metallic and Composite Springs

HELICAL SPRING MATERIAL	DEFLECTION(mm)	AXIAL STRESS(MPa)
Metallic	3.02	946
Carbon/Epoxy with 30 degrees orientation	27.4	609
Carbon/Epoxy with 45 degrees orientation	26	519
Carbon/Epoxy with 60 degrees orientation	25.2	849

Figure 12 : Static Testing of Composite Spring on UTM

CONCLUSION

1. Composite Spring is manufactured using carbon fiber in ±45 degree orientation. Tests were conducted on the spring to study the mechanical behavior.
2. Load deflection results shows large variations in deformations up-to 600N.Subsequently the variations in deformations reduced as there is lesser gap between the coils.
3. Experimental results indicate 27.5mm deflection in the composite helical spring for 1400N and 6.7 % deviation is observed from the design value.
4. Axial stress computed on the steel spring is about 945.9MPa,whereas the stress on composite helical spring is 519MPa.
5. A stiffness value of 50N/mm is obtained through experimental result.

Due to high Strain energy capacity and high corrosive resistance, composite helical springs may be used for high strength engineering applications.

Table 5: The experimental results of Composite helical spring with ±45^0 orientations

LOAD (N)	DEFLECTION(mm)	
	Experimental	FEA
0	0	0
200	5.3	5.1
400	14.9	13.5
600	22.3	21.7
800	23.1	22.6
1000	25.2	24.9
1200	26.5	25.1
1400	27.5	26.3

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