

Chapter 74

Modeling and Analysis of Composite Helical Compression Spring



Akhileshwar Nirala, A. K. Richhariya, N. Kumar, V. K. Dwivedi and Manohar Singh

Abstract The challenges for the automobile manufacturers are to improve the quality along with the performance of the components and reduction in weight and manufacturing cost. Therefore, the investigation is going for alternative materials to design automobile parts and improves the strength to weight ratio, which is fuel-efficient. As alternative materials, composites are used widely. The use of composite material produces in mass level which reduces the manufacturing cost and higher strength. The present work is keen to study the feasibility of composite helical compression spring used in suspension systems. The comparative study was done with conventional steel IS4544 Grade 3 (Tata Indica Vista) helical compression spring to the composites helical spring in the present study on a load of 4542.3 N. EGlass/Epoxy and IS4544 Grade 3 are used as the composite constituent, in which EGlass/Epoxy is used inner or outer layer and IS4544 Grade 3 vice versa. Composite helical spring has found better mechanical properties than conventional. Solid works 2013 is used for the modeling of helical compression spring, and commercially available ANSYS 14.5 software is used for the static and modal analysis. It is observed from the study that stresses and deformation generated in the composite material helical compression spring are reduced, and strain energies stored by the composite material helical compression spring are increased.

Keywords Spring · Composite materials · EGlass/Epoxy · Mechanical properties · FEM

74.1 Introduction

To absorb the energy due to the impacts, helical compression springs are commonly used to form a flexible link. The link deflects when loading has done and restored the objects after that the disturbing forces are removed. That is why these springs

A. Nirala (✉) · A. K. Richhariya · N. Kumar · V. K. Dwivedi · M. Singh
Department of Mechanical Engineering, Galgotias College of Engineering and Technology,
Greater Noida 201310, India

are used in the suspension system. S. S. Bhatia et al. designed helical compression spring which was fabricated by conventional steel material (IS 4454 Grade 3) and then analyzed comparative study at the two loading conditions of 1500 N (normal loads) and 3000 N (overload). They have done modeling and analysis of the helical spring using CREO 2.0 and ANSYS 14.5 to predict the stresses, deflections and strain energies. They have found that weight of conventional steel helical compression spring (IS4454 Grade 3) was 1.433 kg; whereas, EGlass/Epoxy and Carbon/Epoxy composite material helical compression springs weigh only 0.233 kg and 0.02912 kg, respectively, and weight saving of 83.74% and 97.96%, respectively, for composites as compared to conventional steel (IS4454 Grade3) helical compression spring. Authors also found that stresses induced in the composite helical compression spring were much lower than conventional steel (IS4454 Grade 3) spring and higher deflection than the conventional steel (IS4454 Grade 3) helical compression spring. Therefore, the suspension system seems to be less rigid and ensures the smooth riding of the vehicle with fewer jerks. They have observed that the deformation in the composite materials springs at a load of 3000 N (severe overloading conditions) was greater than the maximum allowable deflection; whereas, it was within the safe limit at the normal loading conditions of 1500 N. Hence, the use of composite materials may not be recommended for severe overloading conditions [1]. M. Bakhshesh et al. have compared experimentally to FEM analysis for uniform loading in the light vehicle suspension system and found good agreement. They have replaced conventional spring materials to these composite materials such as EGlass/Epoxy, Carbon/Epoxy and Kevlar/Epoxy. It has been investigated that the orientation of fiber in composite influenced the stress value in compression spring [2]. Some other authors have analyzed the shock-absorbing capacity of bikes for varying the wire diameter of spring. They have done modeling and analysis of shock absorber for 160 cc bike in proE and ANSYS software, and it has been designed for a modified shock absorber by reducing the wire diameter [3]. D. A. Budan and T. S. Manjunatha established the practicability of composite coil spring at the place of metal coil spring. They have fabricated three different composite springs as carbon fiber, glass fiber and combination of carbon and glass fiber. Composite compression spring has a lower weight and higher corrosion resistance than conventional materials used for spring, and it is fuel-efficient for any automobile. Composite spring can be used at a higher temperature and higher load condition, but design and manufacturing are difficult, that is why it is not popular [4]. T. M. Mulla et al. analyzed the mechanical properties of helical compression spring for a three-wheeled vehicle which is used for public transport and carrying freight as well. To design this kind of spring, they have considered elastic characteristics and fatigue strength. To maintain elastic characteristics along with weight reduction is a big task for researchers, and they have done in a well manner. They have considered structural reliability and done finite element analysis for stress distribution in spring [5]. Niranjan Singh has been widely applied in the suspension system of flexible leaf springs fixed in the four corners in a horse-drawn carriage and relate with complex control algorithms of the recent automobile. The design objective of the suspension system is to isolate the vehicle mass to the uneven road and keep up contact with the wheel and

road surface. The author has used numerical as well as an experimental method to analyze and calculate fatigue strength and shear stress by the finite element method [6]. Suresh. G et al. have designed and experimented analysis of fiber-reinforced polymer and epoxy resin reinforced with nano-clay composite helical spring. Epoxy resin reinforced with nano-clay composite helical spring showed improved mechanical and tribological properties and high corrosion resistance and has a high factor of safety at low weight; therefore, it is economical. Authors have studied comparative study between steel helical spring and composite helical spring and found better properties such as load-carrying capacity, stiffness and weight savings in composite helical spring. The study was done by authors to consider conventional steel spring dimensions and fabricate the same composite spring in their study [7]. B. Praveen et al. have investigated to reduce the spontaneous failure and enhance working life by design optimization with the variation of wire diameter of helical compression spring. Their research indicates that by increasing the wire diameter of spring von Mises stresses decreases. Therefore, the spring rate increases by reducing deflection, and hence, premature failure reduces [8]. Authors studied to take four different laminate composites such as unidirectional laminates (UL), rubber core (RC) UL, UL with the braided outer layer (BOL) and RC UL with BOL. And they incorporated the mechanical properties of UL, RCUL, UL with BOL and RC UL with BOL [9]. S. Patter et al. have also analyzed disparity in deformation value as well as maximum shear stress value by analytical and FEM with the varying load on that [10].

The present study is showing better mechanical properties than reported research data which is helpful for further research work to design and fabricate new composite compression spring for the automobile sector.

74.2 Materials Selection and Design Equation

This chapter incorporates the governing equation used in the design of helical compression spring. Moreover, material selection along with is also discussed in the latter part of the chapter. Strain energy (U) considered first as

$$U = (\sigma^2)/(2 \times \rho \times E) \quad (74.1)$$

Here, under the same stress (σ) condition, specific strain energy will be higher when Young's modulus (E) and density (ρ) will be lower. If we consider a helical compression spring with the axial load, then shear stress can be determined as follows:

$$\tau = (K \times 8 \times F \times D) / (\pi \times d^3) \quad (74.2)$$

where τ = shear stress, F = load on the spring, D = inside diameter of helical compression spring, and d = wire diameter of helical compression spring.

Equation 74.2 shows that shear stress increases by increasing the Wahl’s factor (K), and we can calculate K by using Eq. 74.3 as follows:

$$K = (4C - 1)/(4C - 4) + 0.615/C \tag{74.3}$$

Here, C is the spring index which is given by ($C = Dd$), and the deflection in the spring is estimated by

$$\delta = (8 \times F \times n \times D^3)/(G \times d^4) \tag{74.4}$$

where δ = deflection, and n = number of active coil.

Steel and its variants are the conventional choices for the manufacturing of spring used for the automobile industry as well as other industrial machinery. The steel offers a better combination of mechanical properties such as strength, ductility, hardness and toughness. Presently, steel graded as IS4454 is used for making automotive helical compression spring. Tables 74.1 and 74.2 show the mechanical property of IS4454 Grade 3 steel and EGlass/Epoxy, respectively.

For the boundary condition and load calculation, a helical compression spring of Tata Indica V2 has been considered which has some specification weight of the vehicle 1145 kg. The present study is considered for five persons in car/vehicle of weight ($80 \times 5 = 400$) 400 kg, and the total weight of the vehicle is = 155 kg. Total load of the vehicle when car is fully filled = $545 \times 9.8 = 15,141$ N. In these type of cars, 60% load is carried by front wheels so the load on a single wheel is = $15,41 \times 60,100 \times 12 = 4542.3$ N after using Eqs. (74.1)–(74.4) we have got as the value of

Table 74.1 Mechanical properties of IS4454 Grade 3

S. No.	Specification	Value
1.	Density	0.00785 kg/cm ³
2.	Young’s modulus	2.1×10^5 MPa
3.	Poisson’s ratio	0.3
4.	Ultimate tensile strength (UTS)	1500 MPa
5.	Yield tensile strength	1100 MPa
6.	Coefficient of thermal expansion (/°C)	12×10^{-6}

Table 74.2 Material properties of EGlass/Epoxy

S. No.	Specification of EGlass/Epoxy	Value (MPa)
1.	Tensile modulus (along X-axis)	4.3×10^4
2.	Tensile modulus (along Y-axis)	6.5×10^3
3.	Tensile modulus (along Z-axis)	6.5×10^3
4.	Tensile strength	900
5.	Compressive strength	450

C is 10.17 and K is 1.14, shear stress on the helical compression spring 931.75 MPa and deflection of the spring 188.22 mm.

74.3 Modeling and Analysis

Figure 74.1a is the reference design of the helical spring of Tata Indica V2 2008, and the dimensions of helical compression spring are measured by vernier calipers. The first model of Tata Indica was introduced in 1999 by Tata Motors. In Tata Indica V2, MacPherson strut suspension system has been used to absorb the shock and to provide better driver comfort while the vehicle is moving.

This is used in the front wheel of the vehicle. The helical compression spring of conventional steel IS4544 Grade 3 is designed on the Solid Works 2013. The coil is designed according to Tables 74.3 and 74.4, while for the composite helical compression spring the assembly is made in the Solid Works 2013. The composite spring is made with steel and EGlass/Epoxy, steel is taken inside which has 8 mm diameter, and composite is taken outside which has 4 mm diameter Fig. 74.1 (a) Helical compression spring of Tata Indica (b) shows the CAD model of helical compression spring made of conventional steel of IS4454 Grade 3 and (c) shows the CAD model of same helical compression spring made of composite materials. In the composite helical compression spring, the spring is made of steel and EGlass/Epoxy.

Fig. 74.1 a Helical compression spring of Tata Indica, b CAD model of helical compression spring of conventional steel of IS4454 Grade 3 and c CAD model of same helical compression spring of composite materials

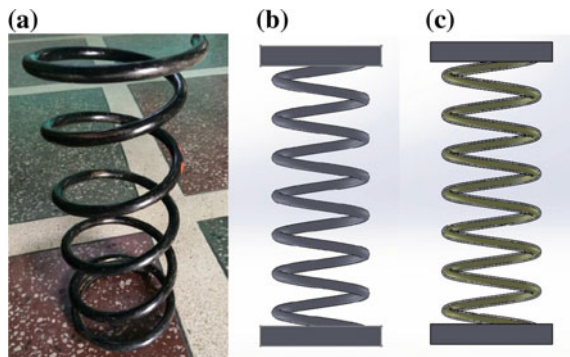


Table 74.3 Dimension of helical coil spring

S. No.	Dimensions	Size in mm
1.	Free length (Helical coil spring)	340
2.	Diameter (Spring wire)	12
3.	Diameter (Mean coil)	122
4.	Number of actual turns	8
5.	Number of active turns	6.5

Table 74.4 Detail specification of helical compression spring under analysis

Parameter numerical	Value
Total weight of vehicle	1545 kg
Total load on vehicle	15,141 N
Load on the single coil spring	4542.3 N
Type of spring	Helical compression
Spring wire diameter	12 mm
Spring free length	340 mm
Spring turns	6.5

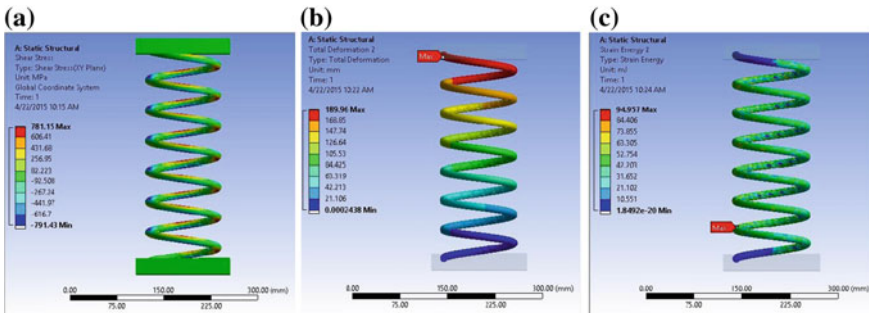


Fig. 74.2 a Shear stress on the IS 4544 Grade 3 material helical compression spring, b Total deformation on the IS 4544 Grade 3 material helical compression spring and c Strain energy in the IS 4544 Grade 3 material helical compression spring

74.3.1 FEM Analysis

74.3.1.1 In the Case of IS 4544 Grade 3 Helical Compression Spring

Figure 74.2a–c shows shear stress, strain energy and maximum deformation in FEM Analysis of IS 4544 Grade 3 helical compression spring. It shows the maximum shear stress, strain energy and maximum deformation. When the load is 4542.3, the maximum shear stress is 781.15 MPa, the maximum deformation is 189.96 mm, and the strain energy absorbed by the coil spring is 94.95 mJ.

74.3.1.2 In the Case of IS 4544 Grade 3 and EGlass/Epoxy When EGlass/Epoxy Is Inner Material and IS4544 Grade 3 Steel Is Outside Material (6E-12S)

Figure 74.3a–c shows shear stress, deformation and strain energy in FEM of hybrid helical compression spring. This case study consists of first 6 mm EGlass/Epoxy inner material and an outer 6 mm overlay IS 4544 Grade 3 steel. Hybrid helical compression

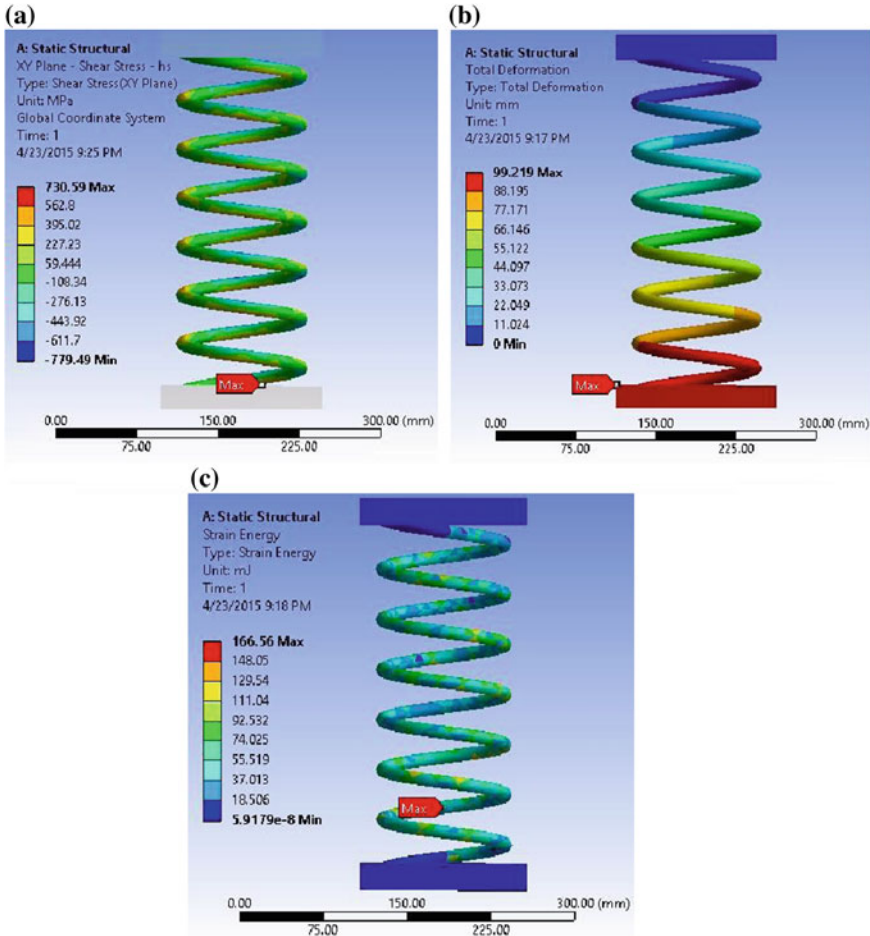


Fig. 74.3 **a** Shear stress on the inner and outer material is approximate similar, **b** Total deformation on composite helical spring and **c** Strain energy on the composite material

spring is subjected to the same loading and boundary condition as that of IS4544 Grade 3 conventional steel. The maximum shear stress in the helical compression spring is 650–730.59 MPa on the inner composite material, the maximum shear stress on the outer steel material is 600–695.8 MPa, the maximum total deformation is 99.219 mm, the strain energy is 166.56 mJ, and the results are shown in Fig. 74.3.

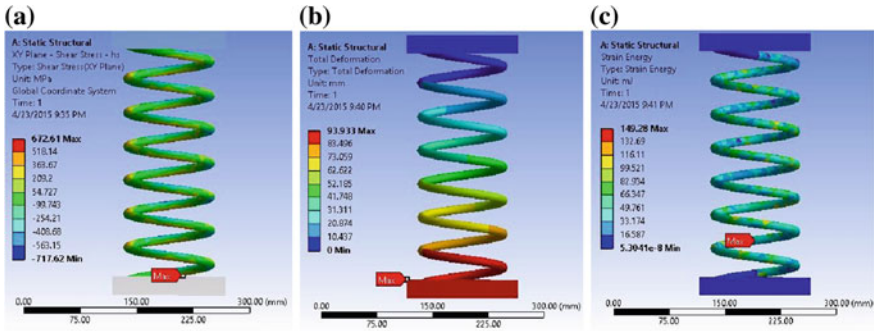


Fig. 74.4 a Shear stress on the outer material (EGlass/Epoxy) b Total deformation in the helical compression spring (6S-12E) and c Strain energy stored by (6S-12S)

74.3.1.3 In the Case of IS 4544 Grade 3 and EGlass/Epoxy When IS4544 Grade 3 Steel Is Inner Material and EGlass/Epoxy Is Outside Material (6S-12E)

Figure 74.4a–c shows shear stress, deformation and strain energy in FEM of hybrid helical compression spring. In this case, the steel is taken as inner material, and EGlass/Epoxy is taken as outer material. In this case, the results are better when steel is outer material and EGlass/Epoxy is inner material. When steel of IS4544 Grade 3 is taken as inner material and EGlass/Epoxy is taken as outer material maximum, shear stress on the helical compression spring is 711.22 MPa (inner IS4544 grade 3 material) and 672.61 MPa (outer EGlass/Epoxy material), the maximum total deformation is 93.933 mm, and strain energy stored by the helical compression spring is 149.28 mJ. So from all the above results, it is clear that the results are better when steel is taken as inner material and composite overlay is as outside material.

74.4 Conclusion

In the case of IS 4544 Grade 3 helical compression spring at load 4542.3 N, the maximum shear stress is 781.15 MPa, the maximum deformation is 189.96 mm, and the strain energy absorbed by the coil spring is 94.95 mJ. In the second case as hybrid helical compression spring study which consists of first 6 mm EGlass/Epoxy inner material and an outer 6 mm overlay IS 4544 Grade 3 steel, the maximum shear stress in the helical compression spring is 650–730.59 MPa on the inner composite material, the maximum shear stress on the outer steel material is 600–695.8 MPa, the maximum total deformation is 99.219 mm, and the strain energy is 166.56 mJ. Further when steel is taken as inner material and EGlass/Epoxy is taken as outer material, then maximum shear stress on the helical compression spring is 711.22 MPa (inner IS4544 grade 3 material) and 672.61 MPa (outer EGlass/Epoxy material), the maximum total

deformation is 93.933 mm, and strain energy stored by the helical compression spring is 149.28 mJ. So from all the above results, it is clear that the strain energy is better when steel is taken as outer material in the composite. Total deformation reduces 50%, and strain energy enhanced by 43% compared to conventional compression spring.

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