ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

# Analysis of the Design of Helical Compression Spring to Study the Behaviour of Steel and Composites Used as Spring Materials

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## Abstract

Presently the automobile manufacturers are facing challenges of improvements in the quality and performance of the components together with the reduction in weight and cost of manufacturing. Efforts are directed towards the use of alternative materials in design which results in increase of strength to weight ratio. The use of composite materials is increasing in the design of automobile components due to their light weight and costs. The present work attempts to study the feasibility of select composite materials in the design of helical compression spring used in automobile suspension systems. The design of helical compression spring is first analysed for the conventional steel material (IS 4454 Grade 3) and then compared with that of for the composites used as spring materials study their behaviours at the two loading conditions of 1500N(normal loads) and 3000N (overload). Composite materials considered for the present study are Eglasss/Epoxy and Carbon/Epoxy. The modeling of the helical spring has been done using CREO 2.0 and simulation were performed using ANSYS v 14.5 to predict the stresses, deflections and strain energies at the stated loads. It was observed that the stresses developed in composite material helical compression spring is lower as compared to the stresses developed in conventional steel (IS 4454 Grade 3)helical compression spring. Also the deflection and strain energies are observed to be higher for composite materials. The results indicate that composite materials are feasible option at normal loading conditions which will also reduce the manufacturing and maintenance costs

**Keywords**: Helical compression spring, Composite materials, E-glass/Epoxy, Carbon/Epoxy and Finite Element Analysis.

## Introduction

Helical compression springs are generally used to absorb the energy due to the impacts and to form a flexible link which deflects under loading and restore the objects to the normal position where the disturbing forces are removed .These springs mostly in the suspension system of two wheelers(motor bikes) may fail due to overloading which occurs in Indian conditions .Automobile manufacturers today are facing challenges to reduce the manufacturing and maintenance costswithout confirming the qualityand functionality of parts.Helical compression springs contribute majorly in the total costs and weight of the suspension system and are therefore liable for modification improvement in design.

The present work attempt to analyse the design of a spring used in a two wheeler vehicle with the objectives of comparing the behaviour of steel material and composites used as spring materials.

## Literature review

The primary factor considered in the design of a spring is the strain energy of a material.

The specific strain energy in the material is expressed as $U = \frac{\sigma^2}{2 \times \rho \times E}$ [1]

Here it can be concluded that a material having lower Young's modulus(E) and density ($\rho$) will be having relatively higher specific strain energy under the same stress condition.

H.A. AI-Qureshi compared the performance of GFRP and multi leaf steel spring for a compact car 'jeep' wherein design and analysis was performed on a single leaf variable thickness spring of glass fibre reinforced plastic having similar properties as the multi leaf steel spring[2].

Beardmore P and Johnson CF. have concluded that the functional requirements of ride quality defined in terms of noise, vibration and ride harshness can be attained by using composite materials in primary

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structural areas of vehicle in addition to the fundamental requirements of energy absorption and fatigue resistance[3].

Beardmore P. described several examples of composite automotive structures and also discussed about the potential fabrication methods for composites used in automotive applications[4].

CJ Moris, demonstrated the viability and potential of fibre reinforced composites in automotive suspension systems.The results of the study for composite integrated rear suspension showed reduction in weight and good ride (Noise Vibrations and Harshness NVH) characteristics[5].

A Corvi presented a program for the preliminary design of composite beams based on composite mechanics and the finite element method and the feasibility of the programs a tool for developing preliminary designs was demonstrated by applying it to an automotive leaf spring [6].

L. Del LIano-Vizcaya et al have applied the multiaxial fatigue criteria to the analysis of helical compression springs wherein fatigue experimental lives are compared with the multiaxial fatigue criteria predictions performed on 'ncode'.The location of the most damaged zone was identified by the numerical analysis [7].

Chang Hsuan Chiu et al conducted study on four different types of helical compression springs made of unidirectional laminates(AU),rubber core unidirectional laminates (UR),unidirectional laminates with a braided outer layer(BU), rubber core unidirectional laminates with a braided outer layer(BUR) respectively. The results indicates that the helical composite springs with a rubber core has 12% more load bearing capacity while for the spring with BUR failure load in compression to 18% along with the improvement of 16% in spring constant [8].

Mehdi Bakhshesh and Majid bakshesh conducted study on the steel helical spring used in a light vehicle suspension system. The effect of uniform loading has been studied using finite element analysis for the steel and composite materials (E-glass/Epoxy, Carbon/Epoxy and Kevlar/Epoxy).The results indicate that the stress is lesser for the composite helical spring and is maximum for it when fibre is oriented in direction of loading .The longitudinal displacements in compression is also higher as compared to steel helical spring.[9]

## Problem definition and related data

The present work attempts to analyze the design of a helical compression spring (as shown in fig 1) used in the suspension system of a two wheeler (motor-bike) currently used in Indian roads.

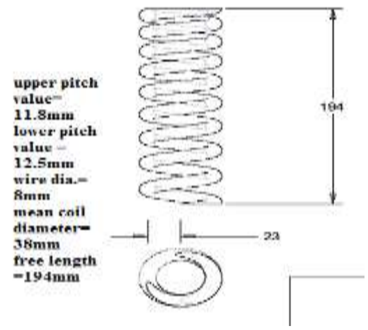


***Fig.1 Design details of helical compression spring***

The helical compression spring is made up of spring steel graded as IS4454 Grade 3[10].The specifications of existing Helical Compression Spring are listed in the Table 1 .

***TABLE No.1 Specifications and material properties of Existing Helical Compression Spring***

| Sr. No. | Specification | Value |
|---|---|---|
| 1 | Free length (mm) | 194 mm |
| 2 | Upper side pitch value | 12.5mm |
| 3 | Lower side pitch value (mm) | 11.8 mm |
| 4 | Spring wire diameter (mm) | 8 mm |
| 5 | Mean coil diameter (mm) | 38 mm |
| 6 | Number of turns | 09 |
| 7 | Actual no. of turns (mm) | 11 |
| 8 | Material Grade | IS 4454 Grade3 |
| 9 | Young's Modulus (MPa) | $\mathbf{2.1 \times 10^5}$ |
| 10 | Poisson's Ratio | 0.3 |
| 11 | Ultimate Tensile Strength (MPa) | 1500 |
| 12 | Yield Tensile Strength (MPa) | 1100 |
| 13 | Density (kg/mm$^3$) | 0.00000785 |
| 14 | Coefficient of thermal expansion(/$^0$ C) | $\mathbf{12 \times 10^{-6}}$ |

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The behaviour of helical compression spring is studied for two different loading conditions of 1500N and 3000N for the conventional steel spring and composite material springs made of Eglass/Epoxy and Carbon/Epoxy,The properties of the composite materials are presented in Table below

***TABLE No.2 Specifications of Composite Materials [11,12,13]***

| Sr. No. | Specification | EGlass/ Epoxy | Carbon/ Epoxy |
|---|---|---|---|
| 1 | Tensile Modulus in X-direction (MPa) | $4.3 \times 10^4$ | $1.77 \times 10^5$ |
| 2 | Tensile Modulus in Y-Direction (MPa) | $6.5 \times 10^3$ | $1.06 \times 10^4$ |
| 3 | Tensile Modulus in Z-Direction (MPa) | $6.5 \times 10^3$ | $1.06 \times 10^4$ |
| 4 | Tensile Strength (MPa) | 900 | 700 |
| 5 | Compressive Strength (MPa) | 450 | 520 |
| 6 | Shear Modulus in XY-Direction (MPa) | 4500 | 7600 |
| 7 | Shear Modulus in YZ-Direction (MPa) | 2500 | 2500 |
| 8 | Shear Modulus in ZX-Direction (MPa) | 2500 | 2500 |
| 9 | Poisson's ratio in X-Direction | 0.27 | 0.27 |
| 10 | Poisson's ratio in Y-Direction | 0.06 | 0.02 |
| 11 | Poisson's ratio in Z-Direction | 0.06 | 0.02 |
| 12 | Density (kg/mm$^3$) | 0.000002 | 0.0000016 |
| 13 | Coefficient of thermal expansion ($/^0$ C) | $1.96 \times 10^{-5}$ | $9 \times 10^{-7}$ |
| 14 | Behavior | Orthotropic | Orthotropic |

## Analysis of design [1,14,15,16]

Figure 2 shows the spring deflecting under the action of axial compressive loads F

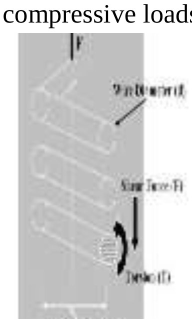

***Fig.2 helical compression spring under axial loading***

Shear stress is estimated as

Shear stress $\tau = \frac{K \times 8 \times F \times D}{\pi \times d^3}$

$$\tau = \frac{K \times 8 \times F \times C}{\pi \times d^2} \qquad [14]$$

Where K is Wahl's factor (here the spring index is less than 6 so the curvature effect is considered)

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$$

$$K = \frac{4 \times 4.75 - 1}{4 \times 4.75 - 4} + \frac{0.615}{4.75}$$

K= 1.33

Now shear stress induced in the spring

$$\tau = \frac{K \times 8 \times F \times C}{\pi \times d^2}$$

$$\tau = \frac{1.33 \times 8 \times 3000 \times 4.75}{\pi \times 8^2}$$

$$\boldsymbol{\tau = 754.47 \ N/mm^2}$$

For safe design, the design shear stress of spring should be greater than the working shear stress of the spring.

Here design shear stress $\tau_d = \frac{0.67 \times \sigma_{ut}}{F.O.S} = \frac{\mathbf{0.67 \times 1500}}{\mathbf{1.25}}$

$$\boldsymbol{\tau_d = 805 \text{ MPa}}$$

Since design shear stress $\boldsymbol{\tau_d} > \tau$ shear stress induced therefore the design of spring is safe

Now the deflection in the spring is estimated as

Deflection $(\delta) = \frac{8 \times F \times D^3 \times n}{G \times d^4}$ [14]

Deflection$(\delta) = \frac{8 \times F \times C^3 \times n}{G \times d} = \frac{8 \times 3000 \times 4.75^3 \times 9}{110 \times 10^3 \times 8}$

$\boldsymbol{\delta = 26.30}$ **mm**

The Spring rate is estimated from

$$F = k \times \delta \qquad [1]$$

Where F is the compressive force applied (3000N),k is the spring rate and $\delta$ is the deflection in spring (26.30 mm).

$$k = {}^{3000}/_{26.30}$$

$$\mathbf{k = 114} \ \boldsymbol{N/mm}$$

Since the ends of springs are considered as squared and grounded then

$$n' = n + 2$$

$$n' = 9 + 2 = 11 \text{ mm}$$

Solid length $L_s = n' \times d$

Solid length $L_s = 11 \times 8$

$$\mathbf{L_s} = 11 \times 8 = \mathbf{88mm}$$

Free length $L_f = n' \times d + \delta_{max} + 0.15 \times \delta_{allowance}$ $(\boldsymbol{\delta_{allowance} = 0.15 \ \delta_{max}})$

$$L_f = n' \times d + \delta_{max} + 0.15 \times \delta_{max}$$

$$194 = 11 \times 8 + \delta_{max} + 0.15 \times \delta_{max}$$

Maximum possible deflection $\delta_{max} = \mathbf{92.17 \ mm}$

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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Strain energy absorbed by spring is estimated as

$$U = \frac{1}{2} \times F \times \delta$$
$$U = \frac{1}{2} \times 3000 \times 26.30$$
$$U = 39450\ N - mm$$
$$\mathbf{U = 39.450\ N - m}$$

**Check for buckling**:

We know that for steel,

$$L_f < 2.57 \times {}^{D}/_{C_e} \qquad [15]$$

Here, for the given spring seat configuration,column factor $C_e$ = 0.5 (for both end fixed)

If the spring is likely to buckle then a guide rod passing through the center of the spring axis is to be used.

$$L_f < 2.57 \times {}^{38}/_{0.5} = \mathbf{195.32mm}$$

Since the free length of the spring, 194 mm is less than the critical length for buckling, 195.32mm. Therefore the design is safe**.**

**Check for critical frequency**:

The fundamental frequency of the spring (for both ends within flat plates),

$$f = \frac{1}{2} \times \sqrt{{}^{k \times g}/_{W_s}} \qquad [16]$$

$$f = \frac{1}{2} \times \sqrt{{}^{114 \times 10^3 \times 9.81}/_{11.433}}$$

$$\boldsymbol{f} = \mathbf{156.379\ Hertz}$$

Safe loading frequency should be at least 20 times less than the fundamental frequency to avoid spring surging. Therefore, the loading frequency for should be around 7.81 Hz**.**

## CAD modeling and simulations

The CAD models as shown in fig of the helical compression spring are developed by using CREO 2.0 and the simulations were carried out using in ANSYS 14.5 Software. Axial displacements and Von-Mises stresses have been compared with analytical results.

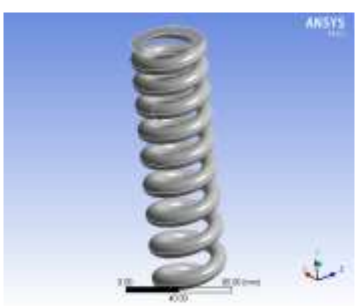


*Fig. 3 CAD model of helical compression spring used in suspension system*

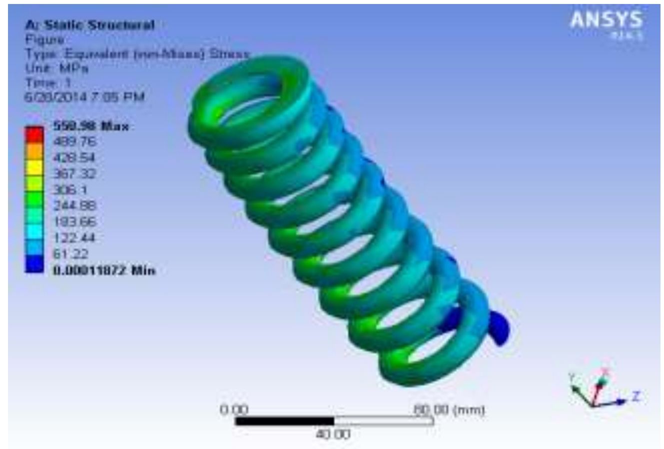


***Fig.4a)Equivalent Von Mises Stress induced in the IS4454 Grade 3 material helical compression spring subjected to a load of 1500N.***

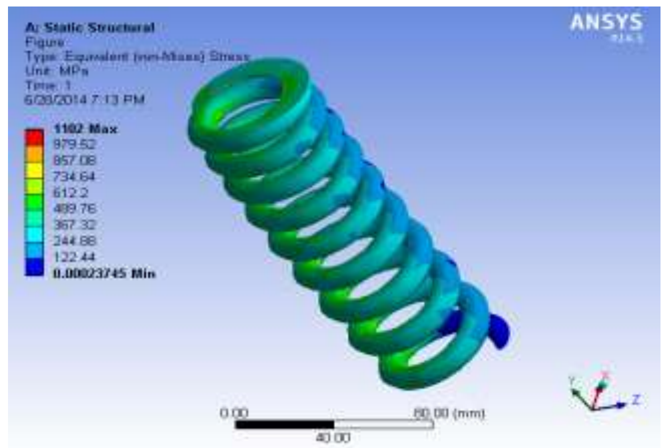


***Fig.4b)Equivalent Von Mises Stress induced in the IS4454 Grade 3 material helical compression spring subjected to a load of 3000N***.

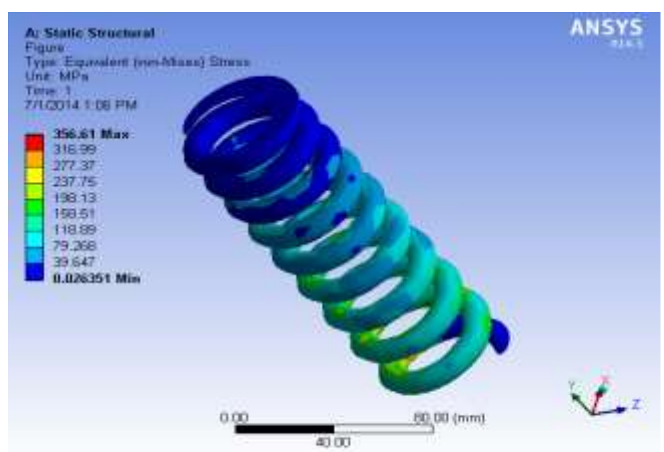


***Fig.5a)Equivalent Von Mises Stress induced in the Carbon/Epoxy material helical compression spring subjected to a load of 1500N***

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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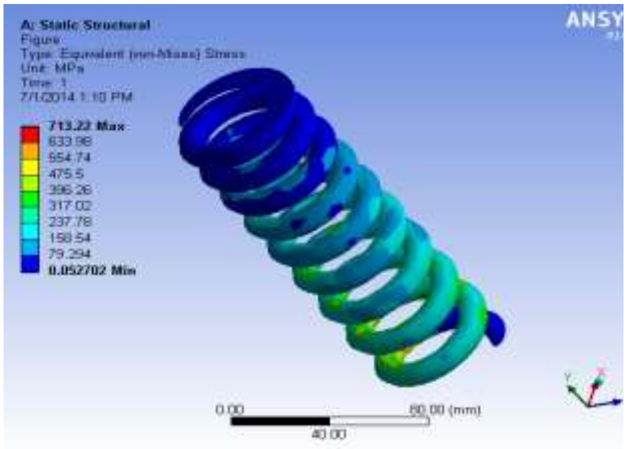


*Fig.5a)Equivalent Von Mises Stress induced in the Carbon/Epoxy material helical compression spring subjected to a load of 3000N*

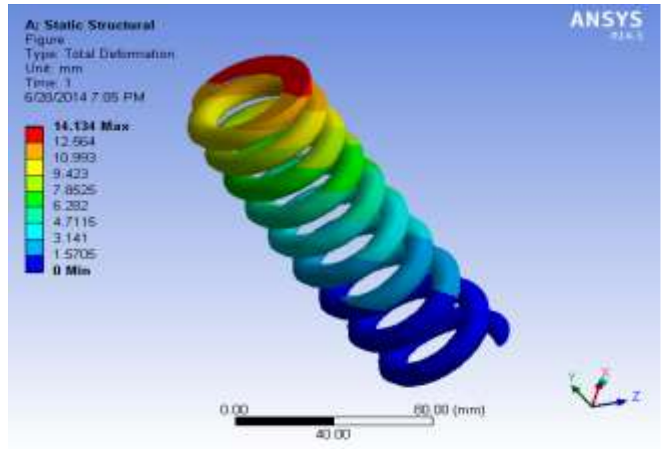


*Fig.7a) Total Deformation obtained from the IS4454 Grade 3 Material Helical Compression Spring subjected to a load of 1500N*

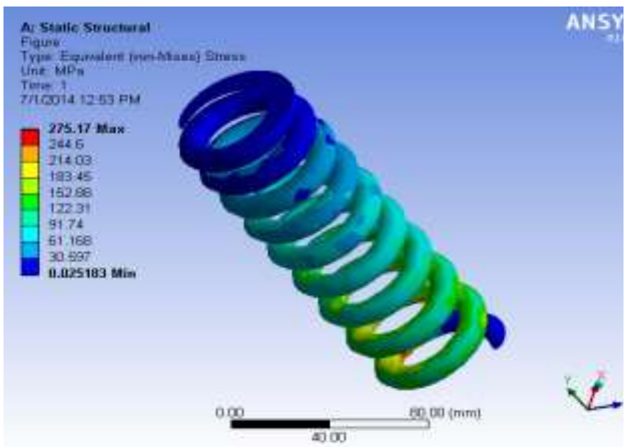


*Fig.6a)Equivalent Von Mises Stress induced in the Eglass/Epoxy material helical compression spring subjected to a load of 1500N*

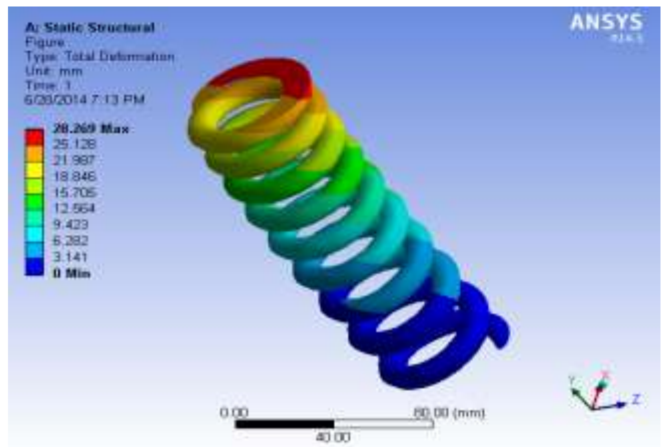


*Fig.7b) Total Deformation in IS4454 Grade 3 Material Helical Compression Spring subjected to a load of 3000N*

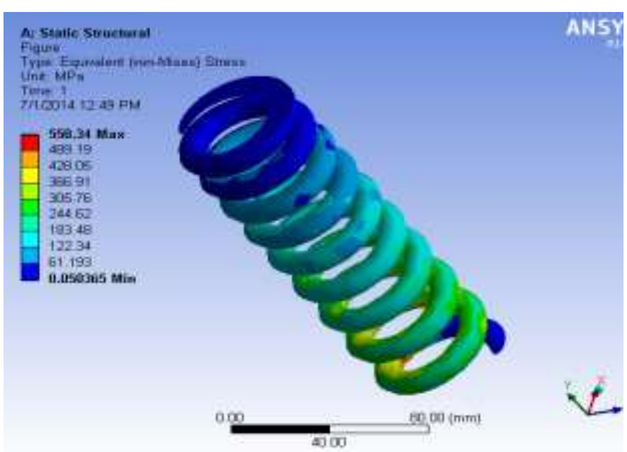


*Fig.6b) Equivalent Von Mises Stress induced in the Eglass/Epoxy material helical compression spring subjected to a load of 3000N*

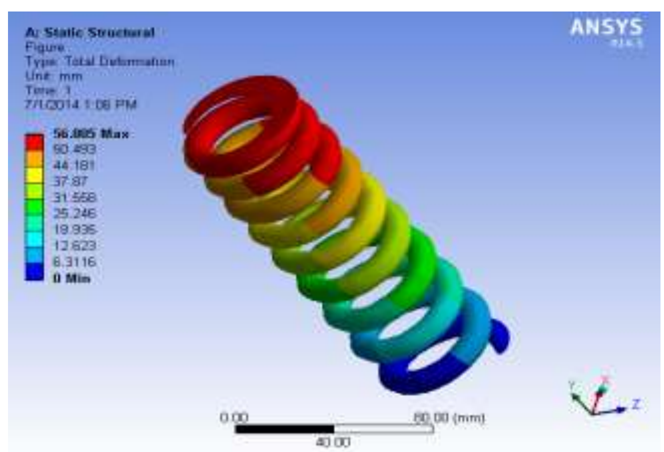


*Fig.8a)Total Deformation in carbon/Epoxy Material Helical Compression Spring subjected to a load of 1500N*

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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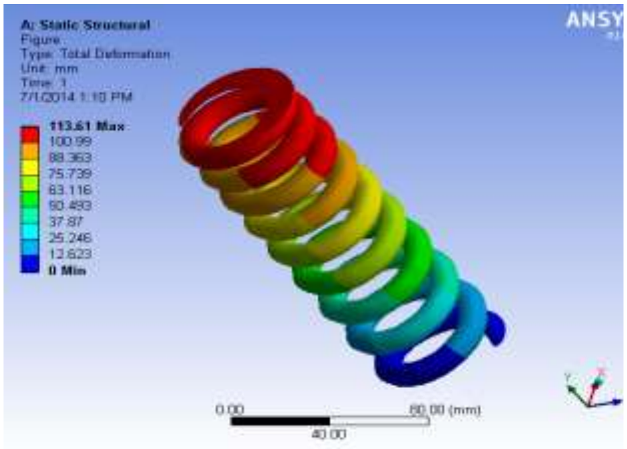


*Fig.8b)Total Deformation in Carbon/Epoxy Material Helical Compression Spring subjected to a load of 3000N*

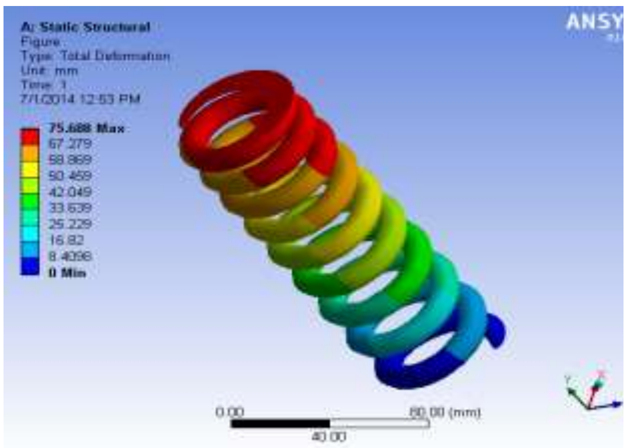


*Fig.9a)Total Deformation in Eglass/Epoxy Material Helical Compression Spring subjected to a load of 1500N*

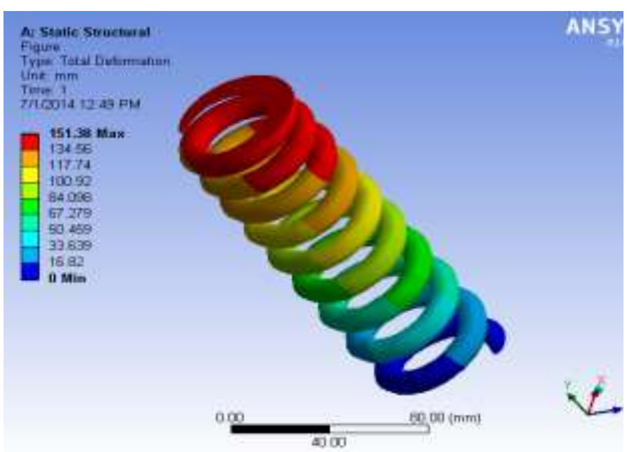


*Fig.9b)Total Deformation in Eglass/Epoxy Material Helical Compression Spring subjected to a load of 1500N*

## Results and discussions

### Stress Analysis

***TABLE No.3 (a) Stress Analysis using FEA Software***

| Load | Isotropic Material (IS 4454 Grade3 material) | Orthotropic Materials | |
|---|---|---|---|
| | | Carbon/ Epoxy material | Eglass/ Epoxy material |
| 1500 | 550.98 | 356.61 | 275.17 |
| 3000 | 1102 | 713.22 | 550.34 |

Interpretation of results for stress

It is seen that the stresses induced in the composite material (Carbon/Epoxy, E-glass/Epoxy) much lower than that of Spring Steel, due to that its load bearing capacity is more as compared to the materials specified in the present work

### Total Deformation Analysis

***TABLE No. 3 (b) Total Deformation Analysis using FEA Software***

| Load | Isotropic Material | Orthotropic Materials | |
|---|---|---|---|
| | | Carbon/ Epoxy material | Eglass/ Epoxy material |
| 1500 | 14.134 | 56.805 | 75.688 |
| 3000 | 28.269 | 113.61 | 151.38 |

Interpretation of results for deformation

It is seen that the total deformation occur in the Composite Material Helical Compression Spring is much greater than that of Conventional Steel ( IS4454 Grade 3 ) Helical Compression Spring due to its lower stiffness as compared to the conventional steel materials under studied.

***Table No.4 Comparison of the weight of conventional steel helical compression spring with orthotropic material helical compression spring***

| S.No | Material | Weight of spring (N) | Weight saving (%) |
|---|---|---|---|
| 1 | IS4454 Grade 3 Material Helical Compression Spring | 14.33 | NIL |
| 2 | Carbon/Epoxy Material Helical Compression Spring | 0.2912 | 97.96 |
| 3 | E-glass/Epoxy Material Helical Compression Spring | 2.3302 | 83.73 |

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

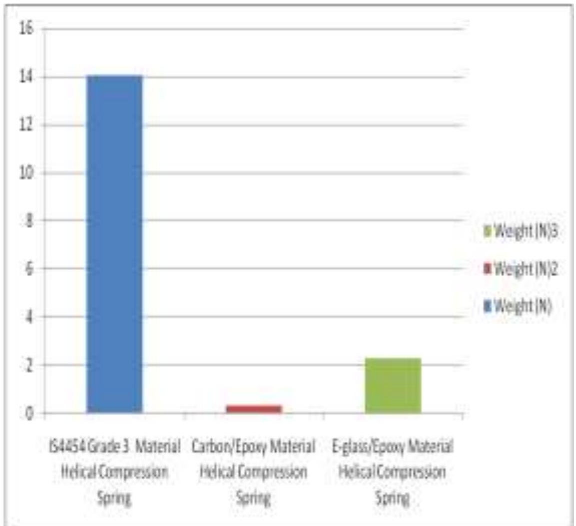


***Fig.10 Comparison of the weight of conventional steel helical compression spring with orthotropic material helical compression spring***

## Conclusions

1. It was found that the weight of conventional steel helical compression spring (IS4454 Grade 3) was 1.433 kg, whereas E-glass/Epoxy and Carbon/Epoxy composite material helical compression springs weighs only 0.233 kg and 0.02912 kg, respectively with weight saving of 83.74 % and 97.96% respectively for composites as compared to conventional steel (IS4454 Grade 3) helical compression spring.
2. It was also found that stresses induced in the composite material helical compression spring were much lower than conventional steel (IS4454 Grade 3) helical compression spring .
3. It was also seen that the deflection of the composite material helical compression spring was much higher than the conventional steel (IS4454 Grade 3) helical compression spring, hence the suspension system seems to be less rigid and ensure the smooth riding of the vehicle with less jerks.
4. It was observed that the deformation in the composite materials springs at the load of 3000N(severe overloading conditions) was greater than the maximum allowable deflection whereas it was within the safe limit at the normal loading conditions of 1500N.Hence the use of composite materials may not be recommended for severe overloading conditions.

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ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

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