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MODELLING & ANALYSIS OF HELICAL COIL SPRING UNDER DIFFERENT LOAD CONDITION BY USING FEM

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ABSTRACT

Currently, the automobile industries have challenges of improvements in their product quality and its performance together with the weight reduction and cost reduction. Automobile industries directed their efforts towards the use of alternative materials which results in increase of strength to weight ratio. The use of composite materials is new trend in the design of automobile components due to their light weight and costs. The present work attempts to check the feasibility of select composite materials in the design of helical coil spring used in automobile suspension systems. The design of helical coil spring is first analysed for SAE 9254 material and then compared with that of for the composite – Carbon Fiber Reinforced Plastics material. The modelling of the helical spring has been done using Solidworks 2013 and simulations were performed using ANSYS R16.1 to find the stresses, deflections at the stated loads. It was observed that the stresses developed in CFRP material helical coil spring is lower as compared to the stresses developed in SAE 9254 material helical coil spring. The results indicate that composite materials are feasible option at normal loading conditions.
KEYWORDS: Suspension, helical coil spring, FEM, Stress analysis, strength to weight ratio.

I. INTRODUCTION

Coil springs are generally used in automobile suspension system and industrial applications. Springs are crucial suspension elements and these are necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride.

Metal coils springs can be replaced by composite springs because of weight reduction and corrosion resistance. Composite coil springs can be manufactured using carbon/graphite/glass fibers and resin impregnation. These composite coil springs, compared to standard metal coil springs reduces weight.

This current study attempts to analyze the design of a spring used in passenger car vehicle with the objective of comparing the behaviour of SAE 9254 material and composite – Carbon Fiber Reinforced Plastics material used as spring materials.

II. LITERATURE REVIEW

In following literature review, author has explained about replacement of steel material coil spring by composite material coil spring.

J. C. Hendry and C. Probert [1] explained about replacement of steel coil spring used in the suspension system of a passenger car by a coil spring in fiber reinforced plastics. Author proposed CFRP (Carbon Fiber Reinforced Plastics) spring design which gives more than 50% saving in weight against the steel coil spring. This could have been achieved but gives a slight relaxation in volume of coil spring specification to allow a bigger coil diameter. Author also found that cost of the final carbon fiber spring is three times than that of the steel coil spring.

Chang Hsuan Chiu et al [2] explained about four types of helical compression 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 respectively. The results indicates that the helical

composite coil springs with a rubber core has 12% more load carrying capacity while for the spring with BUR has 18% more load carrying capacity along with the improvement of 16% in spring constant.
P. K. Mallick [3] has suggested the concept of fiber reinforced composite elliptic springs for automotive suspension system. Due to higher strength-to-weight ratio for unidirectional fiber reinforced plastics, the composite elliptic springs can be saved approximately 50 percent weight over steel coil springs.
C. J. Morris [4] has explained that design, fabrication, weight analysis and testing of a composite integrated rear suspension in a production car vehicle. The results of the study for composite integrated rear suspension showed reduction in weight and good ride (Noise, Vibrations and Harshness NVH) characteristics.

III. OBJECTIVE

As composite materials have high strength to weight ratio automobile industries has great interest for replacement of steel components by composite parts. Carbon fiber composite parts gives significant weight saving and increase in stiffness also. High manufacturing cost of carbon fiber components prohibiting their implementation.
The objective of this paper is to design new coil spring with
• Optimized weight for same loading
• Higher strength to weight ratio for same dimensions.

IV. COIL SPRING DESIGN PARAMETERS

To design coil spring the terms like wire diameter (d), coil diameter (D), spring index (ω), free length (L), solid length (Lc), number of active coils (n), total number of coils (nt) are used and these parameters are termed design parameters. Figure 1 shows coil spring design parameters.

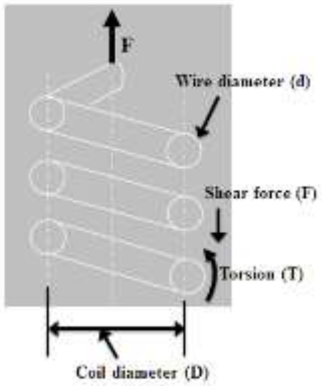

Figure 1: Coil Spring parameters

Existing Coil Spring: SAE 9254
Table 1 and 2 shows material properties and mechanical properties of SAE 9254 respectively.

Table 1: Material properties of SAE 9254……. [5]

Material	C %	Si %	Mn %	P %	S %	Cr %
SAE 9254	0.56	1.37	0.7	0.01	0.01	0.59

Table 2: Mechanical properties of SAE 9254…… [6]

Quantity	**Value**	**Unit**
Young's modulus	200	GPa
Tensile strength	2055	MPa

Proposed Coil Spring: Carbon Fiber Reinforced Plastic
Mechanical properties of CFRP material are shown in Table 3.

Table 3: Mechanical properties of CFRP…… [7]

Quantity	**Value**	**Unit**
Young's modulus	70	GPa
Tensile strength	2550	MPa

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V. DESIGN OF COIL SPRING

A. Parameters for Existing helical coil spring (SAE 9254)

The following dimensions of helical coil spring (SAE 9254) are considered for the analysis.
Wire diameter, d = 10.4 mm
Coil diameter, D = 100 mm
Total number of coils, $n_t = 6.8$
Active number of coils, n = 5.3
Free length, L = 317 mm
Spring Index, $\omega = D/d = 100/10.4 = 9.62$
Wahl's stress concentration factor,
$k = [(4*\omega -1) / (4*\omega -4)] + [0.615/\omega] = 1.15$
Shear modulus, G = 79.3 GPa
Density, $\rho = 7850$ Kg/m^3

B. Parameters for Proposed helical coil spring (Carbon Fiber Reinforced Plastic, CFRP)

The following dimensions of helical coil spring (CFRP) are considered for maintaining same stiffness.
Wire diameter, d = 13 mm
Coil diameter, D = 100 mm
Total number of coils, $n_t = 6.8$
Active number of coils, n = 5.3
Free length, L = 325 mm
Spring Index, $\omega = D/d = 100/13 = 7.69$
Wahl's stress concentration factor,
$k = [(4*\omega -1) / (4*\omega -4)] + [0.615/\omega] = 1.19$
Shear modulus, G = 31.8 GPa
Density, $\rho = 1510$ Kg/m^3

C. Calculations

Loading conditions for analysis are considered as shown in Table 4.
For both coil springs (SAE 9254 & CFRP) deflection, shear stress, stiffness is calculated using below formulae…... [8]
Deflection, s (mm) = $(8*F*D^3*n) / (G*d^4)$
Shear Stress, τ (Kg/mm^2) = $(k*8*F*D) / (\pi*d^3)$
Stiffness or Spring Rate, R (Kg/mm) = F / s
Table 4 shows deflection, shear stress comparison for both types of coil springs.

Table 4: Deflection & Shear Stress comparison between SAE 9254 & CFRP by Analytical Calculation

	Spring Load (F) Kg	**Deflection, s (mm)**		**Shear Stress, τ (Kg/mm2)**	
Condition		**SAE 9254**	**CFRP**	**SAE 9254**	**CFRP**
Unladen	163	73.2	74.7	43	23
Load	263	118	120.5	69	36
Bump	413	185.2	189.2	108	57
Peak Load	427	191.5	195.6	111	59

Stiffness, R (Kg/mm)
For SAE 9254, R= 2.23 Kg/mm
For CFRP, R= 2.18 Kg/mm
Weight, $W = (\pi*d^2/4)*(\pi*d*n_t)*\rho$

Table 5: Strength to Weight ratio comparison between SAE 9254 & CFRP coil spring

Parameters	**SAE 9254**	**CFRP**
Weight (Kg)	1.42	0.42
Strength to Weight ratio	76	135.7

From above calculations it is observed that Carbon Fiber Reinforced Plastics (CFRP) spring with defined parameters gives almost same deflection and same stiffness. Also stress level is getting reduced in CFRP spring with modified parameters.

VI. CAD MODELLING OF COIL SPRING

The solid modeling of the compression helical spring is done using Solidworks 2013 parametric software. The characteristic parameter of the helical spring affects their behavior. The important dimension used for modeling the spring are wire diameter (d) and mean coil diameter (D), total number of coils (n_t) and Free length (L). These are the parameters affects the behaviour of the spring.

Figure 2: Modeling of helical coil spring (SAE 9254)

VII. ANALYSIS OF COIL SPRING

The analysis of above mentioned design models has been carried out in Ansys R16.1 tool. The analysis of existing coil spring SAE 9254 is completed by using structural steel as material and the analysis using Carbon fiber reinforced plastic material has been carried out in proposed coil spring.

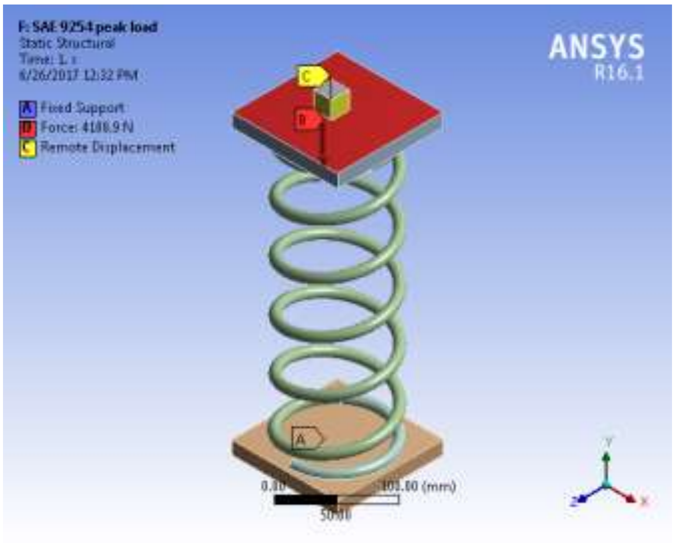

Figure 3: Coil spring (SAE 9254) with loading conditions

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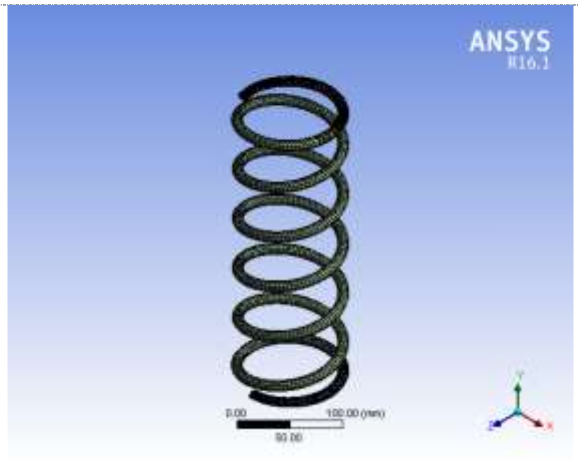

Figure 4: Meshing of coil spring (SAE 9254)

The CAD model of coil spring is fixed at its bottom end and load is applied vertically downwards as shown in figure 3. Coil spring is meshed into 9809 nodes as shown in figure 4.
Under peak load loading condition of both coil spring deflections and shear stresses are plotted and shown in figure 5 to 8. Similarly, for other conditions deflections & shear stresses are plotted and tabulated in Table 6.

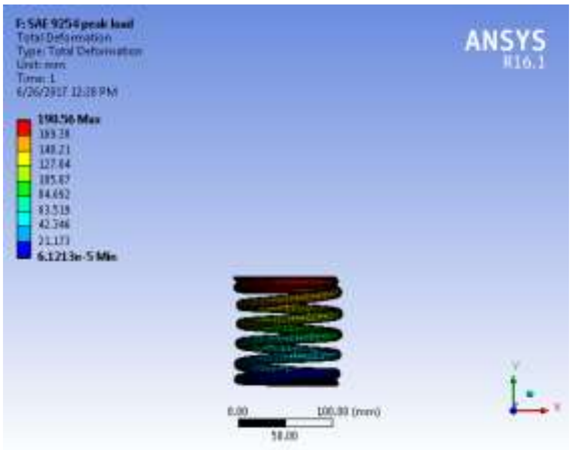

Figure 5: Deflection of existing coil spring (SAE 9254) at Peak Load

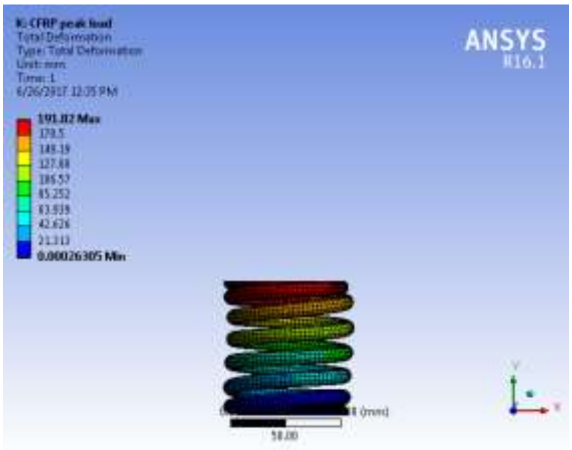

Figure 6: Deflection of proposed coil spring (CFRP) at Peak Load

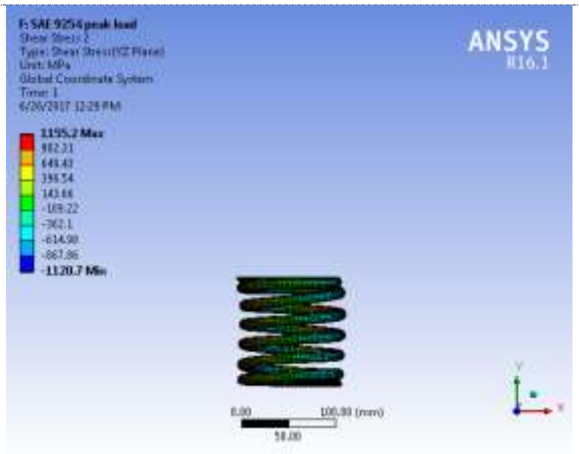

Figure 7: Shear stress of existing coil spring (SAE 9254) at Peak Load

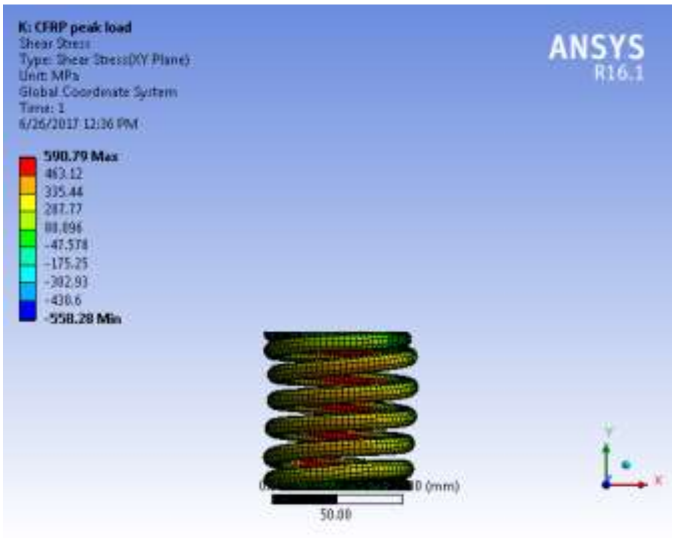

Figure 8: Shear stress of proposed coil spring (CFRP) at Peak Load

Table 6: Deflection & Shear Stress comparison between SAE 9254 & CFRP by Finite Element Analysis

	Spring Load (F) Kg	Deflection, s (mm)		Shear Stress, τ (Kg/mm2)	
Condition		**SAE 9254**	**CFRP**	**SAE 9254**	**CFRP**
Unladen	163	77.9	77.1	44.4	23
Load	263	122.2	123.1	72.2	37.9
Bump	413	185.1	186.3	114.2	58.5
Peak Load	427	190.6	191.8	117.8	60.2

VIII. RESULTS AND DISCUSSION

While designing CFRP coil spring, its stiffness is kept same that of existing SAE 9254 coil spring. This is done to take same load carrying capacity. For this, CFRP wire diameter is increased to 13 mm. This proposed CFRP coil spring with increased diameter gives almost same deflection and same stiffness as required with lesser stress level. The maximum shear stresses induced in CFRP coil spring are only 47% than that of the SAE 9254 coil spring. The proposed CFRP coil spring weighs (0.42 Kg) nearly 70% less than the SAE 9254 coil spring (1.42 Kg).

From table 4 and 6 it is clear that the results obtained for both coil springs by analytical calculation and FEA analysis were close together. Load vs. Deflection for both types of coil springs are plotted in figure 9.

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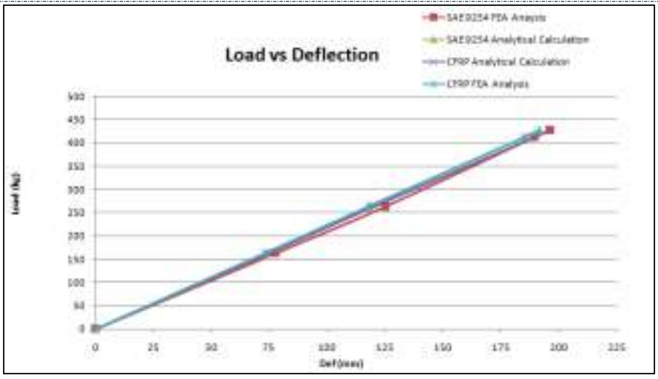

Figure 9: Load vs. Deflection graph for SAE 9254 & CFRP coil spring

IX. CONCLUSION

The SAE 9254 coil spring is replaced by proposed CFRP coil spring. In order to increase the stiffness of the spring the dimensions of the CFRP coil spring is increased which in turn increases the weight of the spring. Application of the CFRP coil spring can be limited to light vehicles, which requires less spring stiffness. Manufacturing cost of CFRP components can be reduced for mass production.

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