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Design and Material Optimization of Helical Coil Suspension

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Abstract - *With increasing fuel prices and dem, and to reduce vehicle weight, automobile manufacturers are looking for lighter suspensions without compromising in strength. This research investigates structural steel material for helical coil suspension using the finite element method by ANSYS software and later subjected to design optimization using response surface optimization considering coil diameter and coil means radius as optimization parameters. Sensitivities of both input parameters are plotted for equivalent stress and deformation. Considerable weight reduction of helical coil suspension is achieved using the response surface method.*

Keywords — *Helical Coil Suspension, Finite Element Analysis, Response Surface Method*

I. INTRODUCTION

Vehicles generate vibration while passing through irregularities or bumps on roads, which are absorbed by suspensions. The vehicles must have a good suspension system that can deliver a good ride and good human comfort. The suspension system separates the axle from the vehicle chassis so that any road irregularities are not transmitted directly to the driver and the load on the vehicle. To reduce damage to vehicles and shocks to passengers, it becomes imperative to improve suspension systems. The suspension system isolates vehicle structure and occupants from vibrations caused due to uneven road surface. This is achieved by the elasticity property of helical coil suspension, which is made up of a spiral wire coil with constant cross-section diameter and pitch. Suspension systems are made from both compressions as well as tension spring.

Figure 1: Helical Coil Suspension

II. LITERATURE REVIEW

Anil Antony Sequeira, Ram Kishan Singh, and Ganesh K Shettiet al [1] have conducted the static structural analysis to study the behavior of carbon hod and Kevlar composite helical suspension, and comparison is made from steel helical spring using ANSYS software. The properties investigated are load carrying capacity, stiffness, along weight reduction using FRP composite spring. The optimization design parameters are inner coil diameters, pitch length, height. Their researches show that the specific modulus (young's modulus (E) upon the mass density of the material (ρ)) of CFRP composite spring is the highest, and Kevlar FRP (KFRP) is lowest. Load and deflection characteristics of steel spring have been found better than composite ones. However, the mass of the KFRP helical spring has been determined less than CFRP and steel ones. A good percentage of weight reduction is achieved using CFRP against steel suspension.

Nijssen, R.P.L et al. [2] has investigated the effect of fiber volume fraction on the properties of composite materials used in the analysis of helical coil suspension. A schematic of variation in fiber-reinforced composite with the amount of fiber volume fraction is shown in figure 2-1. Typically, fiber shares 30% to 75% of the volume of composites. At low fiber volume fraction, matrix properties are dominant, while at high fiber volume percentage, the behavior of composite is controlled by the fiber properties. Tensile strength increases with an increase in the fiber content while compressive strength is high at low fiber contents and decreases with increasing fiber volume fraction.

Mehdi Bakhshesh et al. [3] conducted a comparative study using steel spring with composite helical spring, and results have shown that composite helical spring is found to have lower stresses and performs best when fiber position has been considered to be in the direction of loading. The spring weight is also reduced by changing the fiber percentage of Carbon/Epoxy composite.

PR Jadhav, NP. Doshi and UD. Gulhane et al. [4], in this research, steel coil spring is replaced by three different composite materials. The results obtained from the numerical method are in close agreement with results from the analytical method. The stress generated in composite helical coil spring is found to be lower as compared to steel suspensions, and considerable weight reduction is also achieved by changing fiber percentage.

III. PROPOSED WORK

The objective of this research is to optimize the design of helical coil suspension to reduce weight using response surface methodology. The material used for analysis is structural steel material, and sensitivities of input parameters (coil diameter and coil radius) are determined along with response surfaces.

IV. METHODOLOGY

In this stage, the CAD model is developed using ANSYS software. ANSYS design modeler is a specific tool used for designing and editing operations. The model is meshed using tetra elements of appropriate size and shape. After meshing, appropriate loads and boundary conditions are assigned.

Table 1: Dimensions of Helical Coil Suspension [5]

Free Length (lf)	256mm
Mean dia. (D)	48mm
Wire Dia (d)	8mm
No. of turns (n)	16
Pitch (p)	16mm
Spring index (D/d)	6

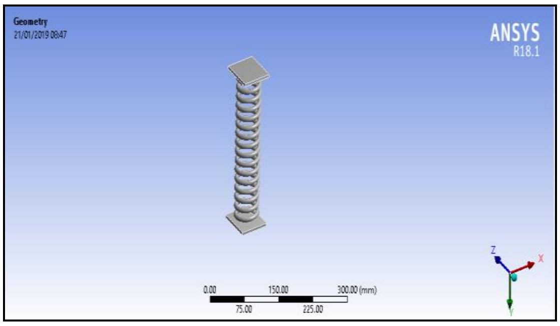

Figure 2: CAD modeling of helical coil suspension

The CAD model, as shown in figure 2 above, is developed in ANSYS. The helical sweep and sketch tools are used to develop a CAD model of leaf spring.

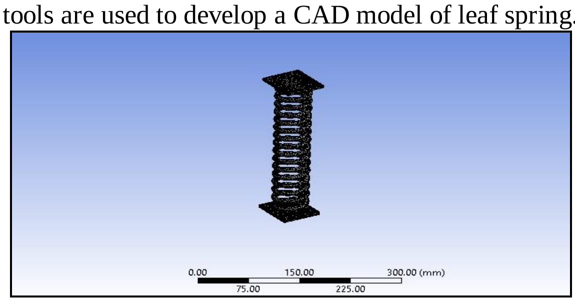

Figure 3: Meshed model of helical coil suspension

The CAD model is meshed using tetrahedral elements and fine sizing with curvature effects. The number of elements generated is 17431, and the number of nodes generated is 34996 as shown in figure 3 above. The element shape of the tetrahedral element is shown in figure 3 below. It consists of 4 nodes connected to each other by tetrahedral shape. CAD model of suspension after being meshed is applied with appropriate loads and boundary conditions.

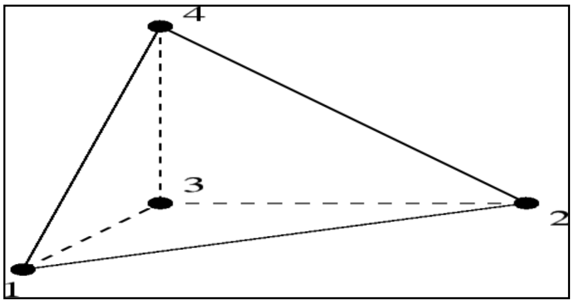

Figure 4: Tetrahedral element

The bottom face of suspension is kept fixed, and the top face is applied with the force of 1356.4N in the downward direction.

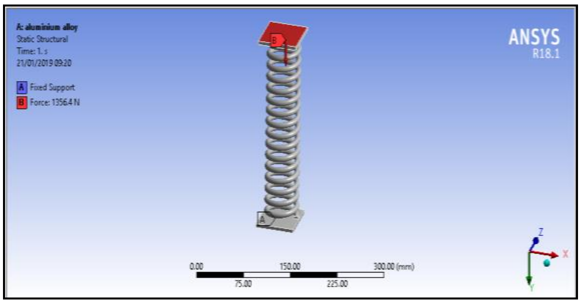

Figure 5: Loads and Boundary conditions

The vehicle has a mass of 300kg. The suspension system has a spring constant (spring rate) of 46714.2N/m, and here we consider a damping ratio of ξ =0.5. The road surface varies with an amplitude of Y = 50mm.Calculation made for 1km/hr to 40 km/hr& deflection & stresses value determine at various speed. The frequency ω of the base excitation can be found by dividing the vehicle speed v km/hr by the Length of one cycle of road roughness.
or 3Km/hr

$\omega = 2\pi f = 2\pi$ (V × 1000) /3600×(1/1)=1.74 v rad/s
ω = 1.74 × 3 = 5.22 rad/s

The natural frequency of the vehicle is given by
$\omega n=\sqrt{k/m}=\sqrt{46714.2/300}=12.4$rad/s

Frequency ratio:-r = $\omega / \omega n$ = 5.22 /12.4 = 0.42
Amplitude ratio:-(Displacement transmissibility)
X/Y={1 + (2ξr)2 / (1 + r2)2+ (2ξr)2 }1/2
X/Y={1+(2×0.5×0.42)2/(1+0.422)2+(2×0.5×0.42)2 } 1/2

X/+Y = 1.17

Thus the displacement of the vehicle at 3 km/hr is given by
X= 1.17 × Y = 1.07 × 0.05 = 0.0586 m = 58.6 mm
This indicates that a 50mm bump in the road is transmitted as a 58.6mm deflection to the chassis.

Forces (F) = $\frac{\delta G\, d^4}{8\, d^3 n}$ = (58.6×42×103 × 84) / (8×483 ×6)
F= 1356.4 N

Stresses(τ) = K $\frac{8FD}{\Pi d^3}$
τ = (1.25 × 8 × 1356.4×48) / (π ×8^3)
τ = 404.8 N

V. RESULTS AND DISCUSSION

The static structural analysis is performed using techniques of the Finite Element Method used by ANSYS software. The problem is formulated into a spring matrix damper system; as discussed in the previous chapter, the force and stresses are determined analytically.

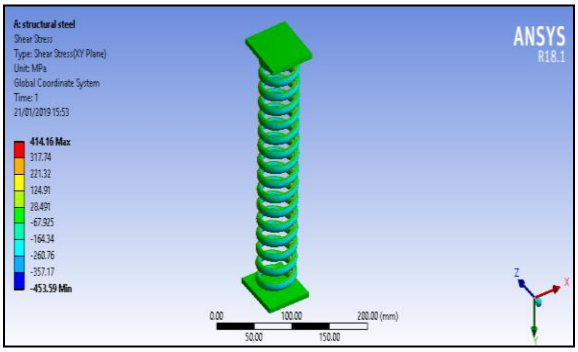

Figure 5: Shear stress generated

Maximum Shear stress generated is denoted by the red color shown in figure 5 above with a magnitude of 414.16MPa. The maximum shear stress is developed on the inner surface of the coil, with a value of 248.49MPa.

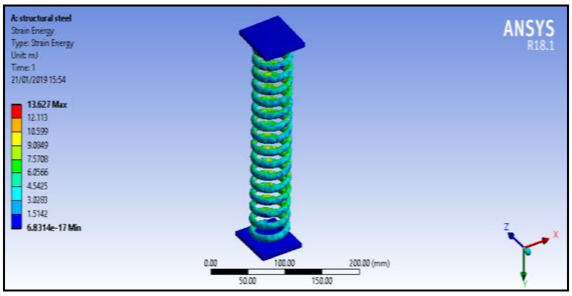

Figure 6: Strain energy

The maximum amount of strain energy developed is 13.62 mJ. Similar to shear stress, this strain energy is developed on the inner face of the coil, shown by a dark red color. After the conduction of Finite Element Analysis and determination of stresses, on the basis of input variables for optimization, i.e., coil radius and mean diameter, design points are generated using the design of experiments.

1	Name	P1 - radius (mm)	P2 - coil_dia (mm)	P3 - Shear Stress Maximum (MPa)	P10 - Strain Energy Maximum (mJ)	P11 - Solid Mass (kg)
2	1 DP 0	24	8	414.16	13.627	1.2769
3	2	21.6	8	373.08	10.842	1.1824
4	3	26.4	8	426.96	11.196	1.3717
5	4	24	7.2	533.05	19.415	1.0977
6	5	24	8.8	309.49	9.3533	1.4746
7	6	21.6	7.2	495.54	18.479	1.0211
8	7	26.4	7.2	591.9	18.975	1.1745
9	8	21.6	8.8	280.91	6.8492	1.3604
10	9	26.4	8.8	331.07	8.8115	1.5894

Figure 7: Design Points

These design points are generated on the basis of the 2nd order polynomial function. On the basis of these design points, the software calculates a response, i.e., shear stress and strain energy. On the basis of the design of experiments, the maximum value and minimum value of output parameters are shown in figure 8 below.

	A	B	C	D
1	Name	Calculated Minimum	Calculated Maximum	Maximum Predicted Error
2	P3 - Shear Stress Maximum (MPa)	279.83	591.9	9.7704
3	P10 - Strain Energy Maximum (mJ)	6.8492	19.579	0.46107
4	P11 - Solid Mass (kg)	1.0211	1.5894	1.9819E-05

Figure 8: Maximum , and Minimum Values

Figure 8 above shows the maximum and minimum values of shear stress and strain energy obtained from response surface optimization. The maximum value of shear stress is 591.9MPa, and strain energy is 198.38mJ, while the minimum values of shear stress are 279.83MPa, and strain energy maximum is 19.57mJ while minimum strain energy is 6.849mJ.

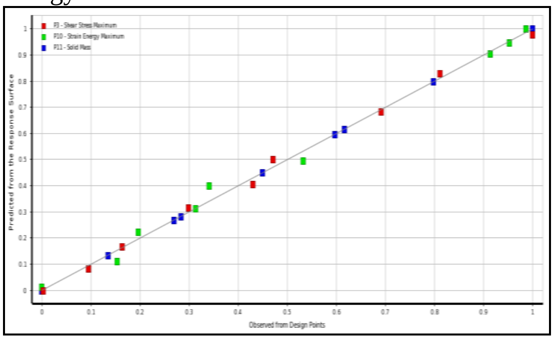

Figure 9: Goodness of Fit Curve

The goodness of fit curve plotted in figure 9 above shows the deviation between observed values and expected values of shear stress and strain energy. The curve above shows a considerable deviation of observed values of shear stress and strain energy from expected values.

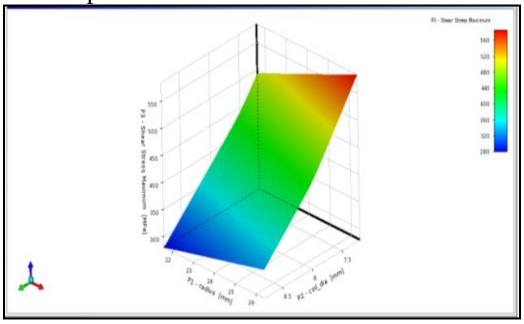

Figure 10: Response Surface for shear stress using Structural Steel material

The response surface plot of shear stress is shown in figure 10 above. The plot shows the maximum value of shear stress of 560MPa for coil mean diameter less than 7.5mm and coil radius more than 25mm. The minimum value of shear stress is near to 280MPa for coil radius less than 22mm and coil mean diameter greater than 8.5mm.

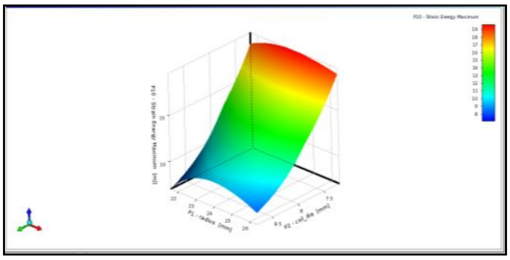

Figure 11: Response Surface for strain energy using Structural Steel material

The response surface plot for strain energy is shown in figure 11 above. The maximum value of strain energy is near 19mJ for coil mean diameter less than 7.5mm and coil radius greater than 26mm. The minimum value of strain energy is neat to 8mJ for coil mean diameter less than 22mm, and coil means diameter greater than 8.5mm.

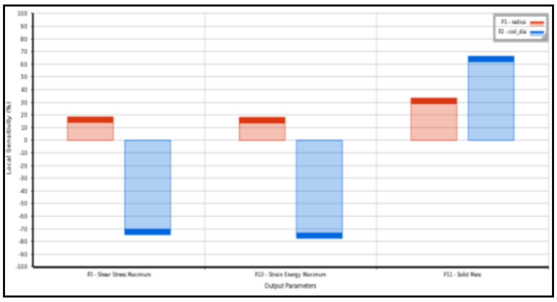

Figure 12: Sensitivity plot for different input parameters on shear stress, strain energy, and mass

The local sensitivity plot of responses (shear stress and strain energy) is for input variables (coil radius and coil mean diameter) is shown in figure 12. The coil radius positive sensitivity for both shear stress and strain energy while coil means diameter shows negative sensitivity for both shear stress and strain energy. This means if coil radius increases, the shear stress decreases with a sensitivity value of 18.43% for shear stress and 18.08% for strain energy. The increase of coil means diameter decreases shear stress with a sensitivity percentage of -74.60% for shear stress and -77.51% for strain energy. After conducting FEA analysis using chrome vanadium material, shear stresses, deformation, and strain energy plots are generated, as shown below.

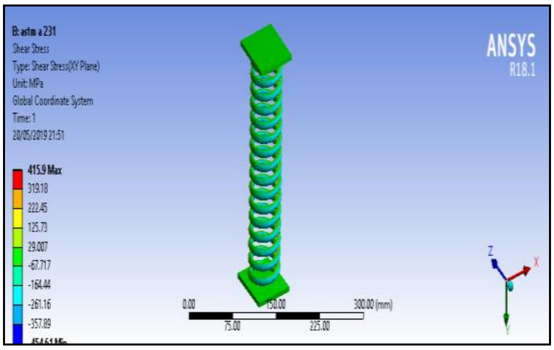

Figure 13: Shear stress using chrome vanadium

The maximum shear stress generated is on the inner portion coil with a magnitude of 415.9 MPa and reduces on the outer portion of the coil with a magnitude of 29MPa.

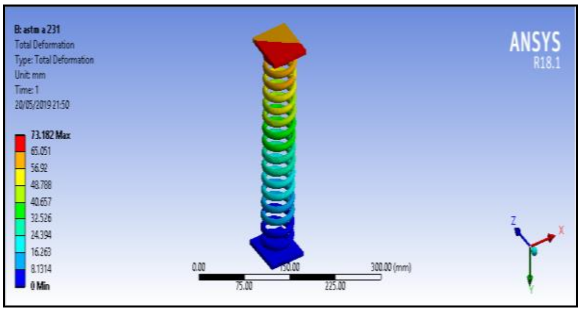

Figure 14: Total deformation using chrome vanadium

The maximum deformation is observed on the top flat portion of the coil with a magnitude of 73.18mm, and minimum deformation is at the bottom portion of the coil. The deformation reduces moving from top to bottom of the coil, as shown in figure 14 above.

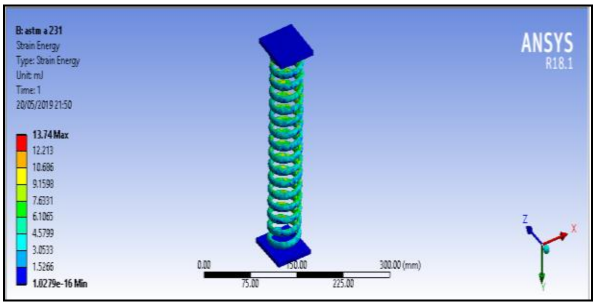

Figure 15: Strain energy using chrome vanadium

The maximum strain energy observed using chrome vanadium material is observed at discrete portions with a magnitude of 13.74mJ, and the minimum strain energy is 1.52mJ. After conducting FEA analysis using SAE 1025, material shear stresses, deformation, and strain energy plots are generated, as shown below.

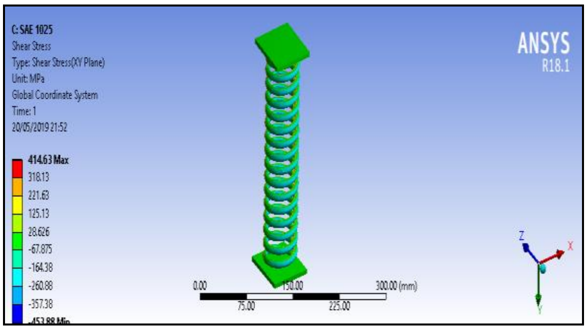

Figure 16: Strain energy using SAE 1025

The maximum shear stress generated is on the inner portion coil with a magnitude of 414.63 MPa and reduces on the outer portion of the coil with a magnitude of 28.62MPa.

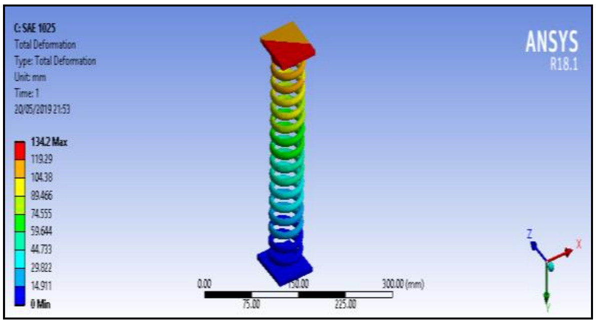

Figure 17: Total deformation using SAE 1025

The maximum deformation is observed on the top flat portion of the coil with a magnitude of 134.2mm, and minimum deformation is at the bottom portion of coil. The deformation reduces moving from top to bottom of the coil, as shown in figure 17 above.

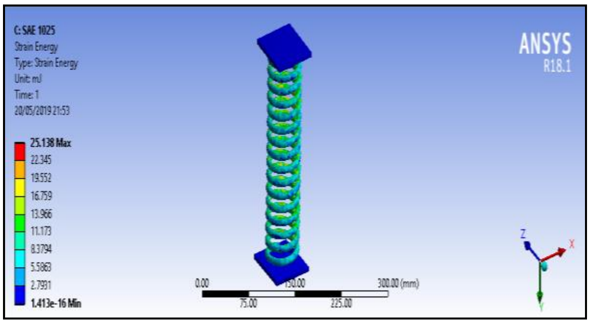

Figure 18: Strain energy using SAE 1025

The maximum strain energy observed using SAE 1025 material is observed at discrete portions with a magnitude of 25.13mJ, and the minimum strain energy is 2.79mJ.

Table 1: Result Comparison using different materials

Material Name	Aluminium Alloy	Structural Steel	Chrome Vanadium	SAE 1025
Deformation (mm)	207.87	72.86	73.18	134.2
Shear Stress (MPa)	404.23	414.16	415.9	414.63
Strain energy (mJ)	69.15	13.62	13.74	25.13

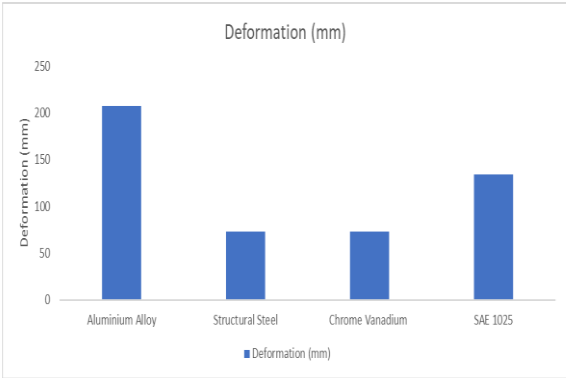

Figure 19: Deformation comparison using different materials

From figure 19, it is evident that deformation is highest using aluminum alloy material and minimum using structural steel material.

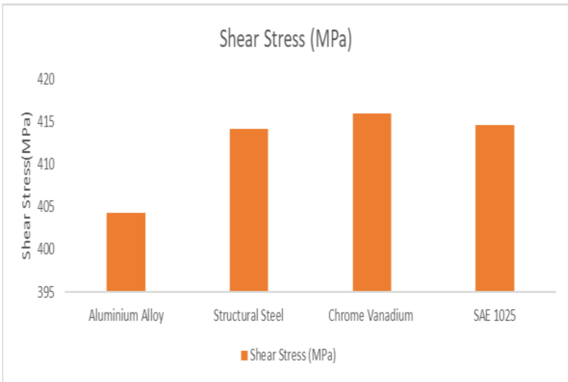

Figure 20: Shear stress comparison using different materials

From figure 20, it is evident that shear stress is highest using chrome vanadium alloy material and minimum using aluminum material.

VI. CONCLUSIONS

FEA analysis of helical coil suspension is conducted, and equivalent stresses and deformation are determined using ANSYS software. The FEA analysis is conducted using Structural Steel material and Aluminium Alloy material. After conducting FEA analysis design optimization of helical coil suspension is performed using Response Surface Method using both materials, and optimized mass is determined. The details of the findings are:

1> The maximum shear stress generated using Aluminium alloy material is 404.23Mpa, which is near to stress calculated from the analytical method against 414.16Mpa obtained for structural steel. Thereby the stress generated using Aluminium alloy material is lower than structural steel material.

2> The maximum amount of strain energy generated using Aluminium alloy material is 69.15mJ, which shows good energy absorption characteristics, whereas the maximum strain energy generated using structural steel is 13.627mJ. Therefore Aluminium alloy absorbs more strain energy as compared to structural steel material

3> The design optimization of helical coil suspension using coil diameter and coil mean radius is performed using the design of experiments for both structural steel material and aluminum alloy material, and sensitivities and responses of different input parameters are plotted.

4> From the sensitivity analysis of aluminum alloy coil, radius shows the positive response of 25.5% for shear stress, and coil means diameter shows a negative response of -79.61% for shear stress. The positive response of the coil radius signifies increase of shear stress with an increase of coil radius, while the negative response of strain energy signifies a decrease in shear stress with an increase of coil mean diameter.

5> From the sensitivity analysis of structural steel, the coil radius positive sensitivity for both shear stress, and strain energy, while coil means diameter shows negative sensitivity for both shear stress and strain energy. This means if coil radius increases, the shear stress decreases with sensitivity value of 18.43% for shear stress and 18.08% for strain energy. The increase of coil means diameter decreases shear stress with a sensitivity percentage of -74.60% for shear stress and -77.51% for strain energy.

6> The maximum weight of helical coil suspension using the response surface method for aluminum alloy material obtained is .56Kg, and the minimum mass obtained is .36Kg. Therefore, the optimized mass of helical coil suspension using Aluminium alloy is much lighter than made from structural steel. The maximum weight of helical coil suspension using the response surface method for structural steel is 1.58Kg, and the minimum mass obtained is 1.021Kg. Therefore, we can say that more than 50% weight reduction is possible by using Aluminium Alloy material.

7> The maximum strain energy is obtained at different design points obtained from the design of experiments. For all design points, the strain energy obtained using aluminum alloy has shown lower values as compared to structural steel material.

8> The comparative studies of steel, aluminum alloy, chrome vanadium, and SAE 1025 show the best material in the application of helical coil suspension is aluminum alloy, which is light in weight and has better energy absorption characteristics.

REFERENCES

[1] Anil Antony Sequeira, Ram Kishan Singh, and Ganesh K Shetti, "Comparative Analysis of Helical Steel Springs with Composite Springs using Finite element method," St Joseph Engineering College-Vamanjoor, Mangaluru, pp. 63-70, 2016.

[2] R. Nijssen, "Fatigue Life Prediction, and Strength Degradation of Wind Turbine Rotor Blade Composites," TU Delft, Netherl, and, 2006.

[3] Mehdi Bakhshesh, and Majid Bakhshesh, "Optimization of Steel Helical Spring by composite spring," International Journal Of Multidisciplinary Sciences, and Engineering, Vol. 3, No. No.6, Pp. 47-51 June 2012.

[4] PR Jadhav, NP. Doshi and UD. Gulhane, "Analysis of Helical Spring in Dual Suspension System Used in Motorcycle," International Journal of Research in Advent Technology, vol. 2 October 2014.

[5] Anil Agarwal, Vaibhav Jain, "Design, and Analysis of Helical Spring in Two Wheeler Suspension System using Finite Element Method" International Research Journal of Engineering, and Technology (IRJET), Volume: 04 Issue: 09 | Sep -2017

[6] D.Pravin, B.Adesh, Suresh Vellingiri, "Design & Analysis of Coil Spring using Different Material" SSRG International Journal of Mechanical Engineering 5.12 (2018): 1-2.

[7] Settey Thriveni, G. Ranjith Kumar, Dr.G. Harinath Gowd (2014), "Design, Evaluation & Optimization of A Two-Wheeler Suspension System," International Journal of Emerging Technology, and Advanced Engineering, August 2014, Volume 4, Issue 8, pp 370-374.

[8] Niranjan Singh (2013), "General Review of Mechanical Springs used in Automobile Suspension System," International Journal of Advanced Engineering Research, and Studies, October-December 2013, Volume 3, Issue 1, pp 115-122.