International Journal of Advance Research in Science and Engineering
Volume No. 12, Issue No. 12, December 2023
www.ijarse.com
IJARSE
ISSN 2319 - 8354

Mechanical Assessment of Helical Springs: Comparative Finite Element Analysis between Steel and Composites

Kailas Pathade[1], Mohan Futane[2], Basavaraj Karoshi[3],

Krishnakumar Jere[4], Iragouda Patil[5], Srinath Ingale[6], Amar Navalihalkar[7]

[1]*Assistant Professor, Department of Mechanical Engineering, VSMSRKIT, Nipani, India.*
[2]*Assistant Professor, Department of Mechanical Engineering, HIT, Nidasoshi, India.*
[3,4,5,6,7]*Assistant Professor, Department of Mechanical Engineering, VSMSRKIT, Nipani, India.*

ABSTRACT

Helical or coiled springs serve a crucial role in automotive suspension systems, mitigating shocks from uneven road surfaces to enhance passenger comfort. The utilization of composite materials in spring manufacturing holds promise for optimizing suspension performance by facilitating weight reduction and enhancing resistance to corrosion, durability, and overall lifespan. This research explores the suitability of three materials—Structural Steel, S-Glass Epoxy Composite, and Epoxy-Carbon Prepreg Composite—as potential candidates for automobile suspension springs. ANSYS analyses were conducted to assess the deformation under various loads and the stiffness of each type of spring. While composite springs exhibited a lower load-carrying capacity than their steel counterparts, their strength-to-weight ratio demonstrated a significant improvement. Composite springs were found to be approximately 75-80% lighter than steel springs. The finite element technique employed was validated against theoretical models, with deformation and stress variations well within the acceptable limit of 5%.

Key Words: *ANSYS, Composite Materials, Deflection, Helical Springs, Stiffness,.*

I. INTRODUCTION

Springs, characterized by their ability to distort under load and regain their original shape upon load removal, constitute essential components in automotive suspension systems [2]. Their primary function is to mitigate vertical vibrations, impacts, and bumps resulting from irregularities in road surfaces, ultimately contributing to a smoother and more comfortable ride for passengers. Consequently, optimizing springs plays a crucial role in enhancing car dynamics [6].

Traditionally, high-carbon steels have been the predominant choice for manufacturing springs in automobile suspensions. The fabrication process involves coiling pre-heated stock over metal dies for smaller springs, while larger ones are similarly coiled using annealed steel and subsequently hardened. The affordability, widespread availability, and simplicity of manufacturing contribute to the popularity of steel springs. However, their limitations include unsuitability for extreme temperatures and vulnerability to shock or impact loading [1].

Helical springs, distinguished by closely coiled and open coiled varieties, exhibit varying helix angles and induce shear stresses during loading. The efficiency of automobile design is a key consideration, focusing on emission gas regulations and fuel efficiency. The incorporation of composite materials, such as resin-impregnated carbon or glass fiber composites, offers significant weight reduction and improved NVH (Noise, Vibration & Harshness) properties compared to conventional materials like steel [3].

Typically crafted from a single length of metal rod, coil springs are heated and wound on a cylindrical die to achieve their desired shape. Factors influencing spring rate or load-carrying capacity include wire diameter, mean diameter, cross-section, and coil pitch. Helical springs often fail due to high cyclic fatigue, necessitating stress levels below the yield strength and considerations of material properties [4].

While composite springs present an opportunity for enhanced weight reduction and corrosion resistance, their anisotropic nature makes fabrication challenging and expensive. Metal springs, in contrast, offer versatility in size and stiffness across a broad range. Despite the potential advantages of composite springs, their utilization in manufacturing remains uncommon [5].

This study focuses on investigating the mechanical behavior of helical springs made from structural steel, S-Glass Epoxy, and Epoxy-Carbon prepreg materials under axial loading. Simulation results for stiffness and deformation are compared with theoretical expectations to provide insights into the performance of these materials in the context of automotive suspension systems.

II. LITERATURE REVIEW

Several researchers have delved into the exploration of composite springs for automobile applications, emphasizing the potential for weight reduction through the adoption of composite materials. The optimization of production processes for these springs has also been a focal point in these studies. Noteworthy contributions from various researchers in this domain are outlined below.

D.A. Budan et al emphasized the significance of strain energy in the design of springs, expressing specific strain energy (U) as

$$U = \sigma^2/\rho E \tag{1}$$

Where a material with lower Young's modulus (E) or density (ρ) exhibits greater specific strain energy under the same stress (σ) conditions. This underscores the advantage of composite materials, which offer both high strength and reduced weight.

Harshal Rajurakar et al conducted a study on helical coil springs made of hard carbon steel and chrome vanadium spring steel with circular and rectangular cross-sections. Utilizing Finite Element Analysis (FEA), they obtained shear stress and deflection values for comparison between the two materials across different cross-sectional shapes.

T.S Manjunatha et al explored the feasibility of using fiber-reinforced plastic materials in springs, specifically designing and fabricating coiled springs with glass fiber, carbon fiber, and glass/carbon fiber in a +45 degrees' orientation. Their experiments focused on studying the mechanical behavior of these composite springs, with an emphasis on their potential application in automobile suspensions.

Sagar N.K. et al conducted a comparative study involving Hard-Drawn Spring Steel, Oil Tempered Carbon Steel, Vanadium Chrome Steel, and Epoxy materials in helical springs. They employed FEA analysis using ANSYS software to evaluate stress and deflection values, aiming to identify the optimal material for suspension springs in two-wheelers.

In light of the literature reviewed, it is evident that this work will leverage ANSYS to simulate the loading of helical springs, enabling the observation of deformation patterns and stress induction in the chosen materials. This approach aligns with the broader trend in the literature, where computational tools are employed to enhance the understanding of composite spring behavior under various conditions.

III. METHODOLOGY

The methodology for the conducted work is outlined in Figure 1 below. The initial step involved defining the problem, which focused on comparing the mechanical properties of helical springs made from different materials. Subsequently, a comprehensive literature review was undertaken to examine similar studies conducted by researchers in the field.

The selection of appropriate materials was a crucial aspect of this comparative study, given the specific aim to assess the mechanical properties of both steel and composite material helical springs for potential application in automobile suspensions. Once the materials were identified, the next steps in the methodology unfolded as follows:

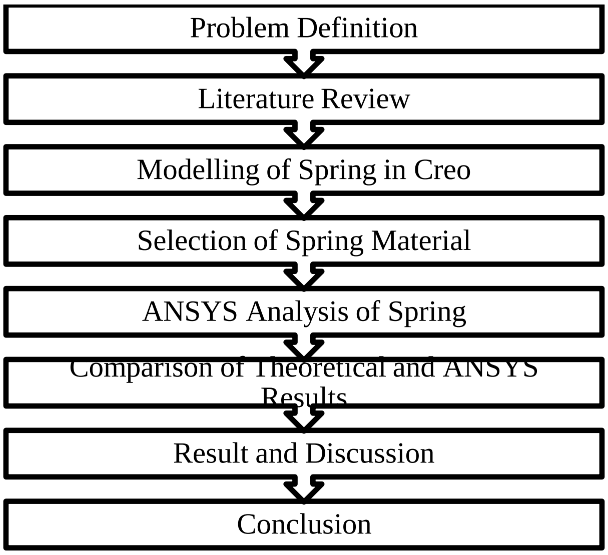

Fig. 1. Methodology

1. Problem Definition: Clearly define the objective of the study, which is to compare the mechanical properties of helical springs made from different materials.
2. Literature Review: Conduct a thorough review of existing literature to understand the background and context of similar studies in the field.
3. Modelling of Spring in Creo: Utilize Creo software to create a model of the helical spring based on the defined problem.
4. Selection of Spring Material: Carefully choose the materials for the helical springs, considering the specific focus on comparing steel and composite materials.
5. ANSYS Analysis of Spring: Employ ANSYS software to simulate the loading conditions of the helical springs made from different materials.
6. Comparison of Theoretical and ANSYS Results: Tabulate and compare the deformation and stress values obtained from the ANSYS simulations with theoretical results.
7. Result and Discussion: Present the findings from the analysis and engage in a discussion of the results, considering their implications and significance.
8. Conclusion: Summarize the key findings, draw conclusions based on the results, and potentially suggest areas for further research or improvement.

This structured methodology ensures a systematic approach to the comparison of helical springs, combining theoretical analysis with simulation results for a comprehensive understanding of their mechanical properties.

IV. MODELING OF HELICAL SPRING

Figure 2 illustrates the spring created using CREO software. The design of the linear spring draws inspiration from typical helical suspension springs commonly observed in compact sedan cars. The spring-seat, highlighted in royal blue within figure 2, provides support to both the top and bottom ends of the spring.

In Table 1 below, the dimensions of the spring employed in this investigation are presented. These dimensions are derived from widely used suspension springs found in compact cars.

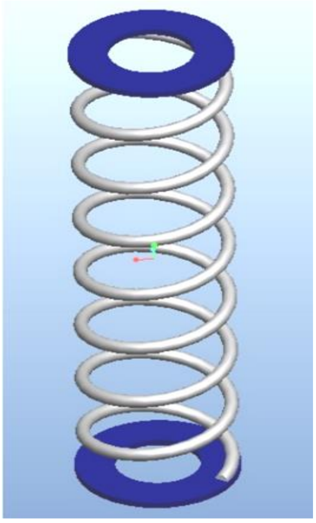

Fig. 2. Helical Spring

Table 1. Spring Dimensions

Sl. No.	Description	Values
1	Pitch (mm)	50
2	Wire Diameter (mm)	10
3	Mean Diameter (mm)	104
4	Free Length (mm)	380
5	Number of Coils (Turns)	7
6	Spring Seat Thickness (mm)	5

V. ANSYS SIMULATION

This study involved simulating the loading of three distinct material springs in ANSYS. The model was imported into ANSYS WORKBENCH, meticulously meshed to enhance accuracy, and subjected to varying levels of loading. The outcomes, specifically the deformation and Von-Mises stress, were carefully observed and documented.

1. Structural Steel

Deformation and stress induction in the steel spring under a 100N load are depicted in Figures 3 and 4. The corresponding values for deformation and stress can be found in Table 2.

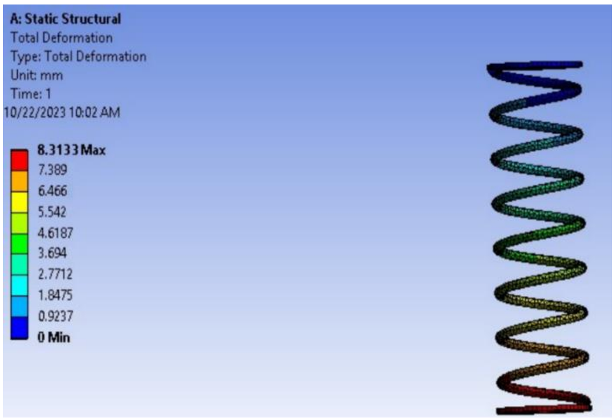

Fig. 3.Total Deformation for Structural Steel at 100N Load

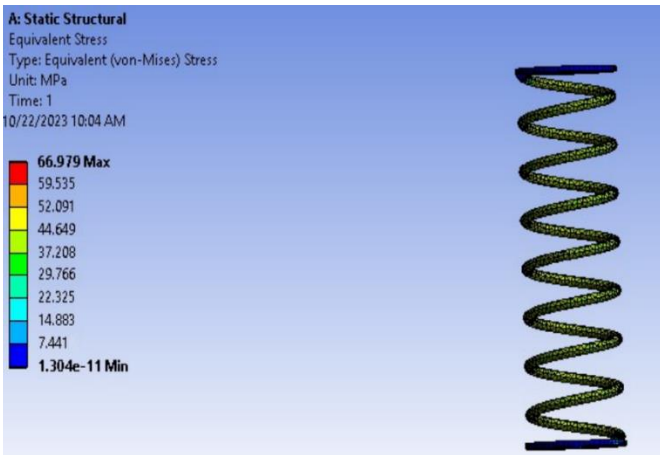

Fig. 4. Von-Mises Stress for Structural Steel at 100N Load

Table 2. Stress and Deformation at varying loads for Structural Steel

Load (N)	Total Deformation (mm)	Von-Mises Stress (MPa)
100	8.31	66.98
200	16.75	134.85
300	24.94	202.74

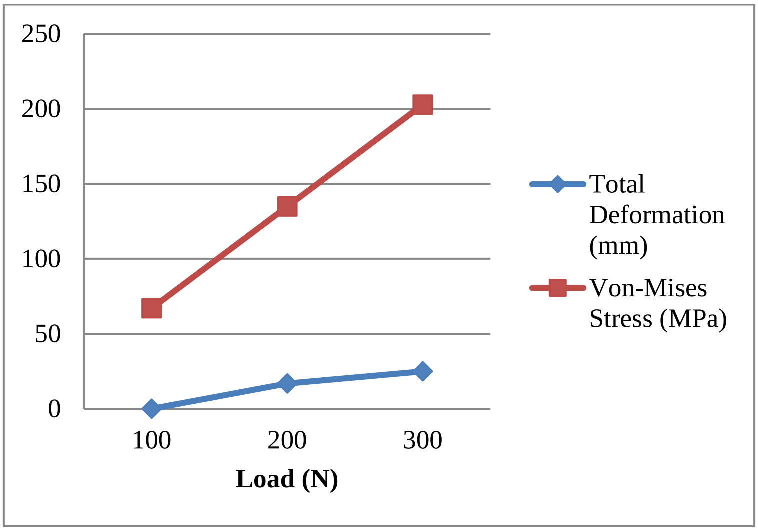

Fig. 5. Graph of variation in stress and deformation by varying load

By examining Table 2 and referring to Figure 5, we can infer that as the load increases, both the deformation and stress exhibit a linear growth pattern.

2. Glass Fiber Reinforced Plastic

The images presented in Figures 6 and 7 illustrate the deformation and Von-Mises stress observed in an S-Glass Epoxy composite material subjected to a 100N load. The corresponding values can be found in Table 3. It is worth noting that the deformation in this composite material is greater when compared to a steel spring with identical dimensions.

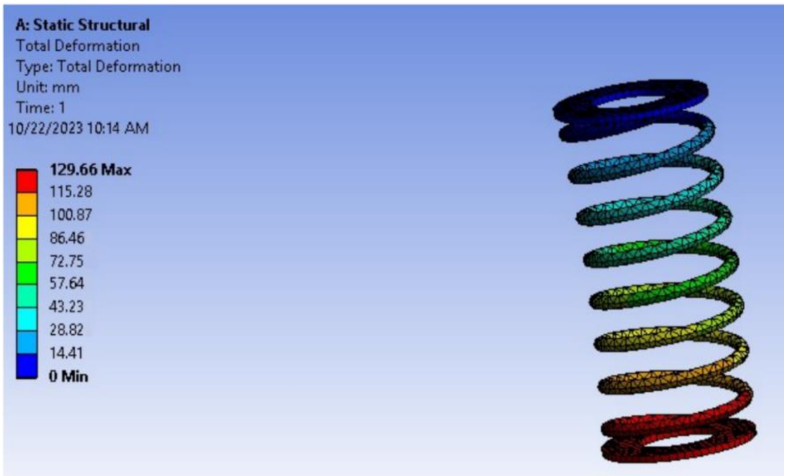
A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
10/22/2023 10:14 AM

Fig. 6. Total Deformation for S-Glass Epoxy Composite at 100N Load

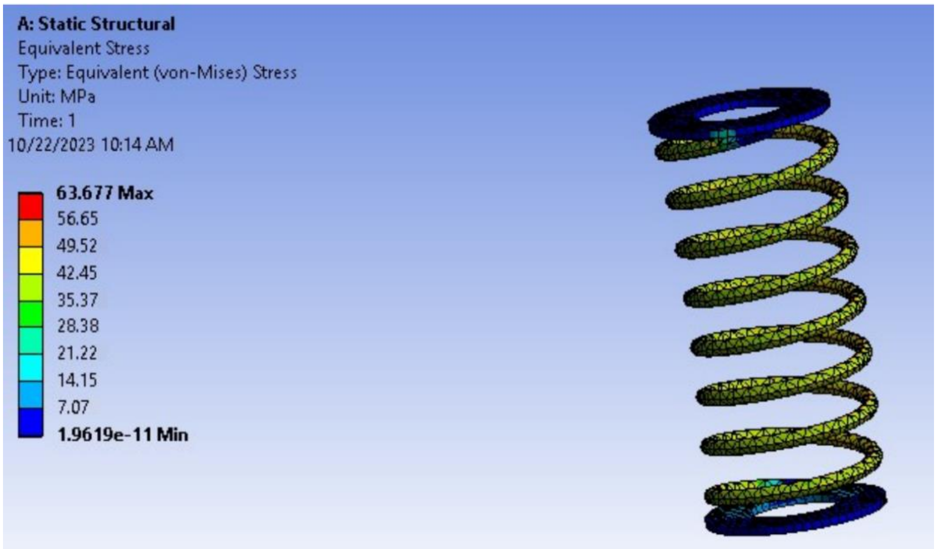

Fig. 7. Von-Mises Stress for S-Glass Epoxy Composite at 100N Load

Table 3. Stress and Total Deformation at varying loads for S-Glass Epoxy

Load (N)	Total Deformation (mm)	Von-Mises Stress (MPa)
100	129.66	63.677
200	262.42	125.44
300	387.67	193.66

Based on the information presented in Table 3 and Figure 8, we can conclude that the S-Glass Epoxy material exhibits maximum deformation and is unable to withstand loads exceeding 200N before failure

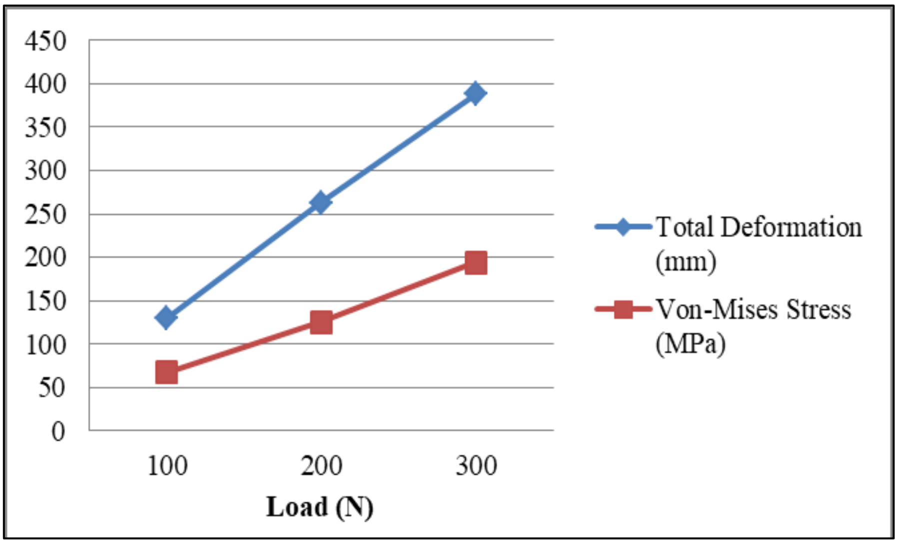

Fig. 8. Graph of variation in stress and deformation by varying load

3. Carbon Fiber Reinforced Plastic

Figures 9 and 10 illustrate the deformation and Von-Mises stress in an Epoxy-Carbon composite material under a 100N load. The corresponding values can be found in Table 4. While the deformation surpasses that of a steel spring with identical dimensions, it is comparable to that observed in S-Glass Epoxy material.

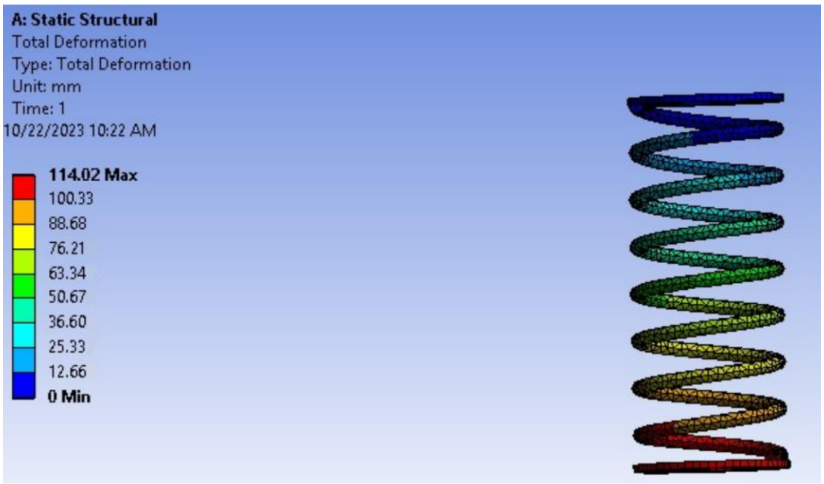
A: Static Structural
Total Deformation
Type: Total Deformation
Unit: mm
Time: 1
10/22/2023 10:22 AM

Fig. 9. Total Deformation for Epoxy-Carbon at 100N Load

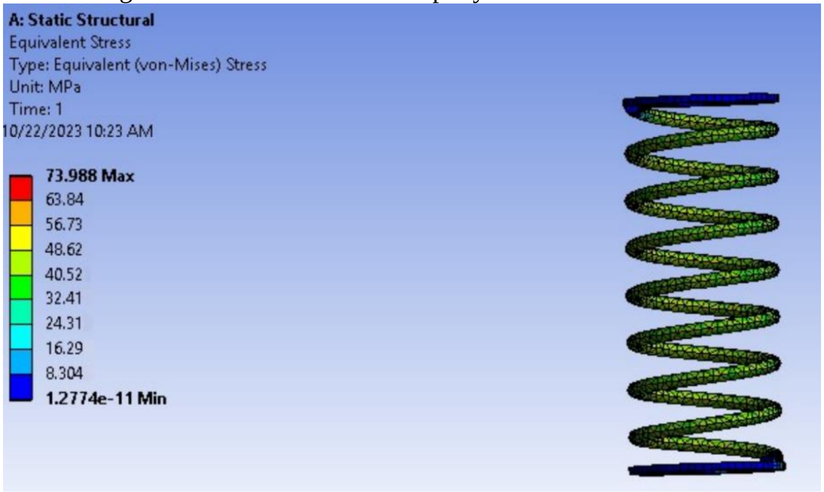
A: Static Structural
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1
10/22/2023 10:23 AM

Fig. 10. Von-Mises Stress for Epoxy-Carbon at 100N Load

Table 4. Stress and Deformation at varying loads for Epoxy-Carbon

Load (N)	Total Deformation (mm)	Von-Mises Stress (MPa)
100	114.02	73.988
200	264.98	127.66
300	386.47	195.85

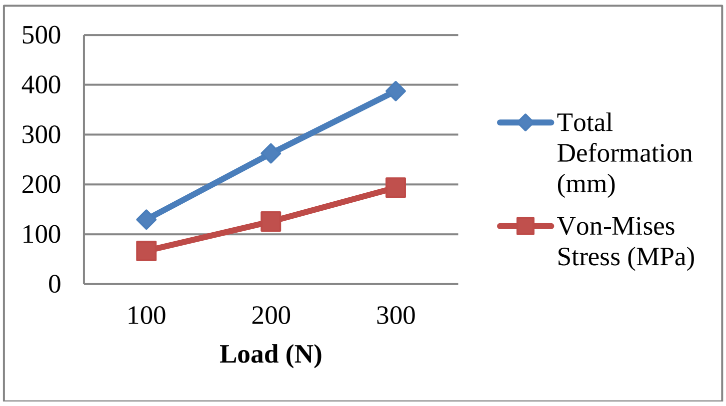

Fig. 11. Graph of variation in stress and deformation by varying load

Based on the information presented in Table 4 and Figure 11, we can conclude that the Epoxy-Carbon material exhibits maximum deformation and is unable to withstand loads exceeding 200N before failure

VI. RESULT AND DISCUSSION

Table 5. – Material properties, Weight, ANSYS and Theoretical stiffness for different material

Material	Material Properties	Weight of Spring (kg)	Load (N)	Total Deformation (mm)	Shear Modulus, G (N/mm^2)	Stiffness (N/mm)	Stiffness Theoretical (N/mm)
Structural Steel	E=200GPa μ = 0.3	1.39	100	8.31	76900	12.03	12.56
S-Glass Epoxy	E=50GPa μ = 0.3	0.35	100	129.66	5000	0.77	0.81
Epoxy-Carbon	E=209GPa μ = 0.27	0.27	100	114.02	5500	0.87	0.89

Table 5 presents the properties of materials under consideration in this study, including Young’s Modulus (E) and Poisson’s Ratio (μ), the applied load, observed deformation, maximum stress values, and the calculated stiffness based on the observed deformation and load conditions.

The table 5 highlights a significant reduction in weight for composite materials compared to a given size of a spring, particularly advantageous for applications in the automotive industry.

The stiffness of a spring can be theoretically determined using Castigliano’s theorem, with the final equation for Spring Stiffness given by:

$$k = \frac{F}{y} = \frac{G.d}{8C^3N} = \frac{G.d^4}{8D^3N} \quad (2)$$

In this equation,

k = Stiffness of spring.
F = Force or Load
y = Deflection.
G = Shear modulus for the material.
d = Wire diameter spring.
D = Mean diameter of the spring coil.
N = Number of active coils.

Theoretical stiffness values were calculated using the above equation and compared with ANSYS data. The results, as recorded in the subsequent table, reveal a negligible deviation between the stiffness values calculated using ANSYS results and theoretical calculations, well within the allowable limit.

Considering the equation 2, F is the load acting on the spring and y is the deformation due to the applied load, and knowing that F=100N, the theoretical stiffness values from the table were employed to calculate deflection values, as tabulated below.

Table 6. Comparison of theoretical and simulation deformation values for different material springs

Material	Deformation from simulation (mm)	Theoretical Deformation (mm)

Structural Steel	8.31	8.02
S-Glass Epoxy	129.66	124.45
Epoxy-Carbon	114.02	112.65

Upon comparing the theoretical stiffness values above with the simulation results, it is evident that the variation falls within acceptable limits.

Table 7. Specific Strength of Different Springs

Material	Density (kg/m^3)	Specific Strength [(N/mm^2)/kg]
Structural Steel	7850	48.17
S-Glass Epoxy	2000	181.91
Epoxy-Carbon	1540	270.11

Specific Strength is defined as the ratio of Max. Stress to the weight of the spring, expressed by the equation:

$$\text{Specific Strength} = \frac{\text{Max.Stress}}{\text{Weight of the spring}} \tag{3}$$

The unit of Specific Strength is (N/mm^2)/kg. Examining the specific strength values presented in Table 7, it is evident that composites demonstrate superior strength-to-weight ratios in comparison to steel material. This characteristic is a crucial criterion in the selection of materials for mechanical components.

VII. CONCLUSION

Maximum Stress Values: Observations indicate that the maximum stress values for all three chosen materials are comparable under similar load conditions.

Specific Strength Comparison: Considering specific strength values (max stress to weight ratio), it is evident that both Epoxy-Carbon Prepreg and S-Glass Epoxy composite materials exhibit higher specific strength compared to Structural Steel springs.

Composite Stiffness and Specific Strength: Despite the lower stiffness of composite springs in comparison to structural steel, the specific strength is maximized, emphasizing the advantageous trade-off between stiffness and specific strength in composite materials.

Consistency between Mathematical Models and ANSYS Simulation: Stiffness values calculated using mathematical models closely match those observed during simulation in ANSYS, with a minimal variation of approximately 5%.

Comparative Study of Stiffness and Deflections: The comparative analysis of stiffness and deflections obtained through simulation and theoretical models reveals a close correspondence, with a variation of about 5%, well within the acceptable limit. This supports the validation that composites excel in weight reduction and specific strength considerations.

Limitations in Load Carrying Capacity: Despite the advantages in weight reduction and specific strength, it is noteworthy that the load-carrying capacity or spring rate of composite springs is significantly lower than that of steel springs. This limitation raises questions about their applicability in automobile suspensions.

REFERENCES

[1] Harshal Rajurakar, M.C. Swami, “Analysis of Helical Compression Spring for Two Wheeler Automotive Rear Suspension”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume no: 13, Mar-Apr 2016, pp.29-33

[2] Sagar Namdev Khurd, Prasad P Kulkarni, Samir D Katekar, Arvind M Chavan, “Analysis of two wheeler suspension spring by using FEA for different materials”, International Research Journal of Engineering and Technology (IRJET), Volume no: 3, Jan 2016, pp.833-839

[3] Dr. D. Abdul Budan, T.S. Manjunatha, “Carbon Fibre Reinforced Composite Coil Springs”, Pro. Of International Conference on Advances in Industrial and Production Engineering, Volume no: 2, 2011, pp.17-21

[4] N. Lavanya, P. Sampath Rao, M. Pramod Reddy, “Design and Analysis of a Suspension Coil Spring for Automotive vehicle”, International Journal of Engineering Research and Applications, Volume no: 4, Sep 2014, pp.151-157

[5] D.A.Budan, T.S.Manjunatha, “Investigation on the Feasibility of Composite Coil Spring for Automotive Applications”, International Journal of Aerospace, Industrial, Mechatronic and Manufacturing Engineering, Volume no: 4, 2010, pp.1035-1039

[6] A.M. Wahl, “Mechanical Springs”, McGraw Hill Book, Edition 2, 1963.