iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: VII Month of publication: July 2022

DOI: https://doi.org/10.22214/ijraset.2022.45425

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VII July 2022- Available at www.ijraset.com

Design Analysis and Weight Optimization of Mono Leaf Spring by Using ANSYS and Validation with Practical Testing

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Abstract: The present paper having a work on Design and analysis of composite leaf spring. The analysis has been conducted by using ANSYS-14.5 workbench software with the help of static structural tool. Two composite leaf springs with full length leave made of E-Glass fiber and Carbon fiber composite material has been used. The results of Conventional steel leaf spring have been compared with the present results obtained for composite leaf spring. Carbon fiber material is better in strength and lighter in weight as compared to the conventional steel leaf spring as well as Glass fiber leaf spring. We worked on different loading condition to validated UTM result with hand calculation and ANSYS result.
Keywords: Leaf spring, Glass Fiber, Carbon Fiber, Weight optimization.

I. INTRODUCTION

In order to conserve natural resources and economize energy, weight reduction has been the main focus of Automobile manufacturer in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the un sprung weight. This helps in achieving the vehicle with improved riding qualities. It is well known that springs, are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major factor in designing the springs. The relationship of the specific strain energy can be expressed as

$$U = \frac{\sigma^2}{\rho E},$$

The introduction of composite materials has made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Since; Materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. Several papers were devoted to the application of composite materials for automobiles, Rajendran studied the application of composite structures for automobiles and design optimization of a composite leaf spring. Great effort has been made by the automotive industries in the application of leaf springs made from composite materials S.Vijayarangan showed the introduction of fiber reinforced plastics (FRP) made it possible to reduce the weight of a machine element without any reduction of the load carrying capacity. Because of FRP materials high elastic strain energy storage capacity and high strength-to-weight ratio compared with those of steel, multi-leaf steel springs are being replaced by mono leaf FRP springs. In every automobile, i.e., four wheelers and railways, the leaf spring is one of the main components and it provides a good suspension and it plays a vital role in automobile application. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. The geometry of the Steel leaf spring is shown in Fig. 1

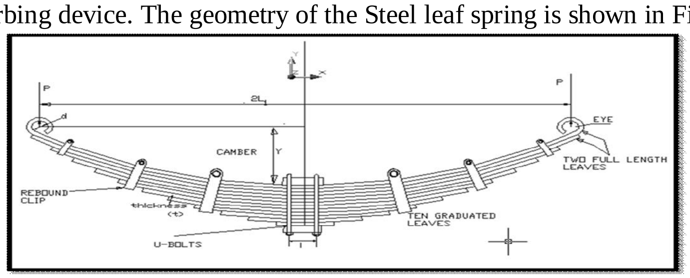

Fig. 1 Leaf Spring.

A. Composite Material

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Typical composite materials are composed of inclusions suspended in a matrix. The constituents retain their identities in the composite. Normally the components can be physically identified and there is an interface between them. Many composite materials offer a combination of strength and modulus that are either comparable to or better than any traditional metallic materials. Because of their low specific gravities, the strength weight-ratio and modulus weight-ratios of these composite materials are markedly superior to those of metallic materials. The fatigue strength weight ratios as well as fatigue damage tolerances of many composite laminates excellent. For these reasons, fiber composite have emerged as a major class of structural material and are either used or being considered as substitutions for metal in many weight-critical components in aerospace, automotive and other industries. Another unique characteristic of many fiber reinforced composites is their high internal damping. This leads to better vibration energy absorption within the material and results in reduced transmission of noise and vibration to neighbouring structures. High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort. Among the other environmental factors that may cause degradation in the mechanical properties of some polymeric matrix composites are elevated temperatures, corrosive fluids, and ultraviolet rays. In many metal matrix composites, oxidation of the matrix as well as adverse chemical reaction between fibers and matrix are of great concern at high temperature.

B. Applications

Commercial and industrial applications of composites are so varied that it is impossible to list them all. The major structural application areas, which include aircraft, space automotive, sporting goods, and marine engineering. A potential for weight saving with composites exists in many engineering field. The first major structural application of composite is the corvette rear leaf spring in 1981. A uni-leaf E-glass – reinforced epoxy has been used to replace a ten-leaf steel spring with nearly an 80 % weight savings. Other structural chassis components, such as drive shafts and road wheels, have been successfully tested in the laboratories and are currently being developed for future cars and vans. The metal matrix composites containing either continuous or discontinuous fiber reinforcements, the latter being in the form of whiskers that are approximately 0.1-0.5 μm in diameter and have a length to diameter ratio up to 200. Particulate-reinforced metal matrix composites containing either particles or platelet that ranges in size from 0.5 to 100 μm. Dispersion-strengthened metal matrix composites containing particles that are less than 0.1 μm in diameter. And metal matrix composites are such as directionally solidified eutectic alloys.

C. Selection of Material

Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and the performance of the vehicle. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite materials have been selected for leaf spring design.

D. Fibre Selection

The commonly used fibers are carbon, glass, keviar, etc. Among these, the glass fiber has been selected based on the cost factor and strength. The types of glass fibers are C-glass, S-glass and E-glass. The C-glass fiber is designed to give improved surface finish.S-glass fiber is design to give very high modular, which is used particularly in aeronautic industries. The E-glass fiber is a high-quality glass, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. Thus, E-glass fiber was found appropriate for this application.

E. Resins Selection

In a FRP leaf spring, the inter laminar shear strengths is controlled by the matrix system used. Since these are reinforcement fibers in the thickness direction, fiber do not influence inter laminar shear strength. Therefore, the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermo set resins such as polyester, vinyl ester, epoxy resin are being used for fiber reinforcement plastics (FRP) fabrication. Among these resin systems, epoxies show better inter laminar shear strength and good mechanical properties. Hence, epoxy is found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classifieds, based on the mechanical properties. Among these grades, the grade of epoxy resin selected is Dobeckot 520 F and the grade of hardener used for this application is 758.

Dobeckot 520 F is a solvent less epoxy resin. Which in combination with hardener 758 cures into hard resins Hardener 758 is a low viscosity polyamine. Dobeckot 520 F, hardener 758 combination is characterized by curing at room temperature.

II. METHODOLOGY

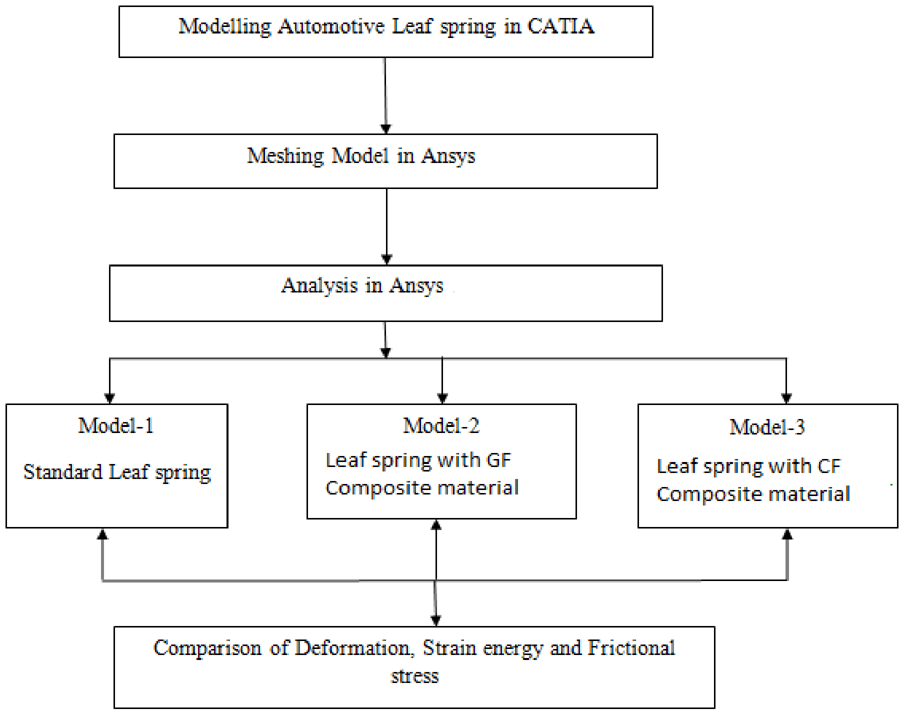

Fig.2. Methodology for leaf spring weight optimization

III.MATERIALS FOR LEAF SPRING

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel products greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

1) *Carbon Fibers:* Their advantages include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance and high electrical conductivity.
2) *Glass Fibers:* The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties. The disadvantages are low elastic modulus, poor adhesion to polymers, low fatigue strength and high density, which increase leaf spring weight and size. Also crack detection becomes difficult.

Properties	Values	Unit
Young's modulus	210000	Mpa
Tensile strength	650-880	Mpa
Elongation	8-25	%
Fatigue	275	Mpa
Yield strength	350-550	Mpa
Density	7700	Kg/m^3

Table 1 Mechanical Properties of EN 47 Steel (Original Leaf Spring)

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ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VII July 2022- Available at www.ijraset.com

Sr.No	Properties	E-glass/epoxy	Carbon epoxy
1	EX(MPa)	43000	177000
2	EY(MPa)	6500	10600
3	EZ(MPa)	6500	10600
4	PRXY	.27	.27
5	PRYZ	.06	.02
6	PRZX	.06	.02
7	GX (MPa)	4500	7600
8	GY(MPa)	2500	2500
9	GY(MPa)	2500	2500
10	ρ (kg/mm³)	.000002	.0000016

Table 2 Mechanical Properties of E-glass/epoxy and Carbon epoxy

IV. ANALYSIS

A. *Original Leaf Spring.*

Deformation Stress

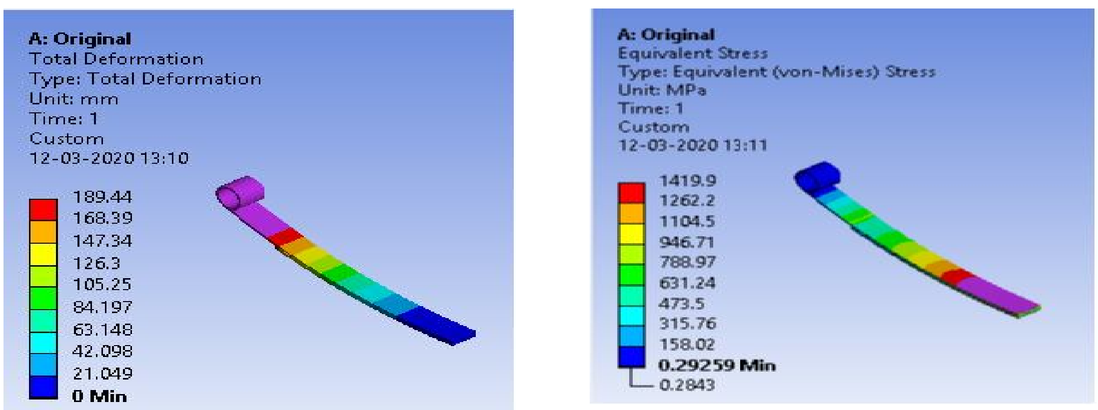


FIG.3. DEFORMATION AND STRESS FOR 2697.5N LOAD.

B. *Glass Fiber*

Deformation Stress

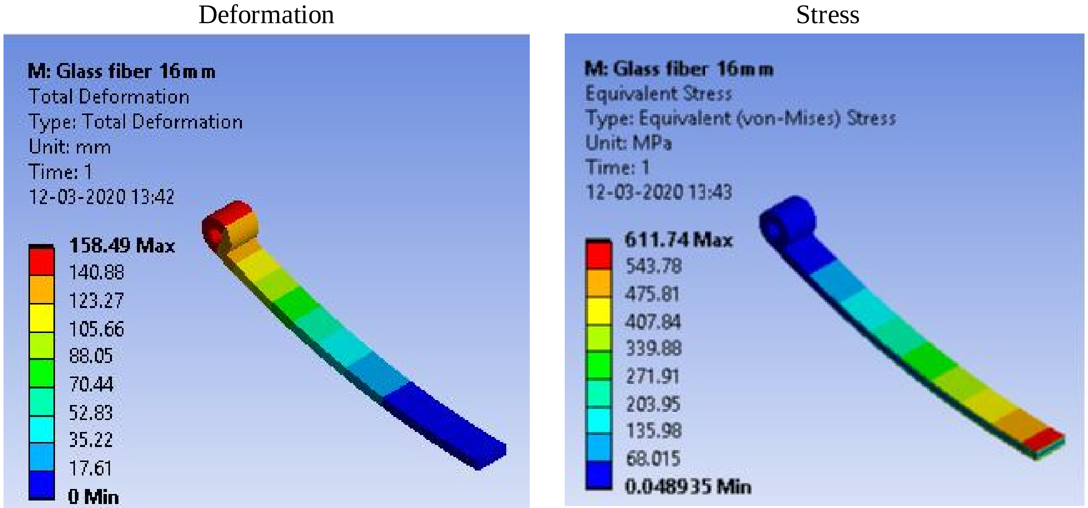
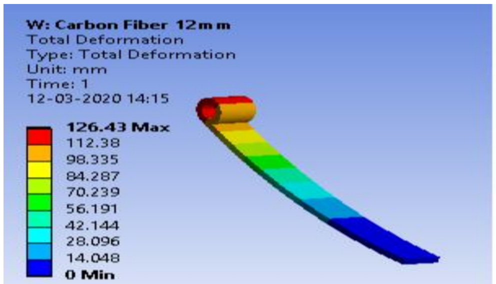


FIG.4. DEFORMATION AND STRESS FOR GLASS FIBER.

C. Carbon Fiber

Deformation



Stress

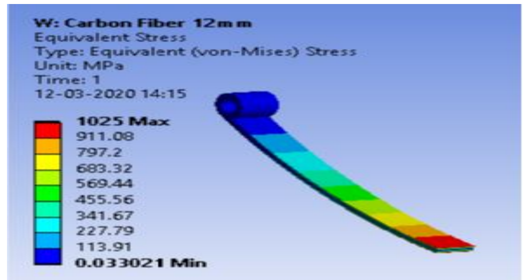


Fig.5. Deformation and stress for CARBON FIBER.

V. RESULT

Comparison of the three above materials on basis of DEFORMATION, STRESS and Weight by Theoretical calculations :

A. On Basis of Deformation

ANSYS Result

Theoretical Result

	Original	
Load	Hand	ANSYS
1000	57.2	29.069
2000	114.4	58.13
3000	171.6	87.2
4000	228.8	116.28
5000	286	145.35
6000	343.2	174.45

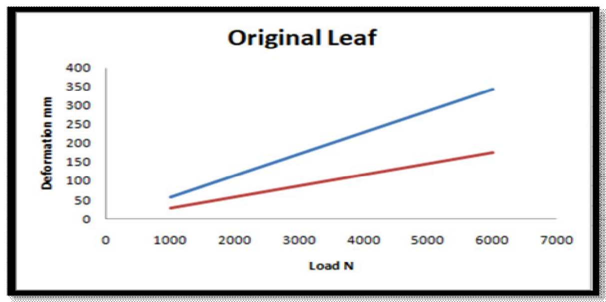


Fig 6.Graph of Deformation for Original Leaf Spring

	Glass Fiber	
Load	Hand	ANSYS
1000	50.89	58.73
2000	101.79	117.5
3000	152.69	176.21
4000	203.59	234.94
5000	254.49	293.68
6000	305.39	352.41

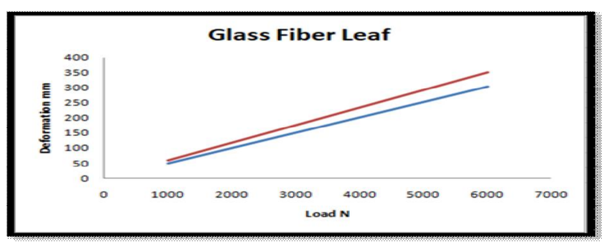


Fig 7. Graph of Deformation for Glass Fiber leaf spring

	Carbon Fiber	
Load	Hand	ANSYS
1000	41.87	46.86
2000	83.74	93.72
3000	125.61	140.59
4000	167.48	187.46
5000	209.36	234.32
6000	251.23	281.19

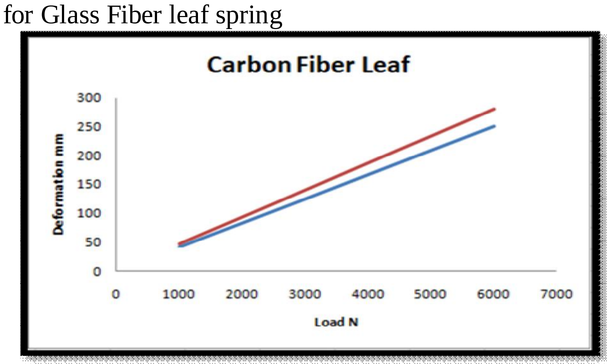


Fig 8. Graph of Deformation for Carbon Fiber Leaf Spring

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Volume 10 Issue VII July 2022- Available at www.ijraset.com

B. On Basis of Stress

	Original	
Load	Hand	ANSYS
1000	438.75	398.6
2000	877.5	797.41
3000	1316.25	1196.1
4000	1755	1594.4
5000	2193.75	1993.5
6000	2632.5	2392.2

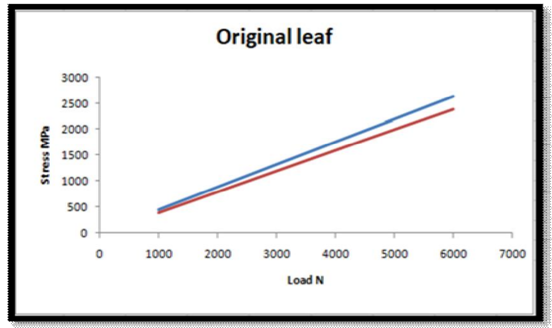


FIG 9 GRAPH OF STRESS FOR ORIGINAL LEAF SPRING

	Glass Fiber	
Load	Hand	ANSYS
1000	219.375	216.35
2000	438.75	453.51
3000	658.125	649.09
4000	877.5	865.38
5000	1096.875	1081.47
6000	1316.25	1298.1

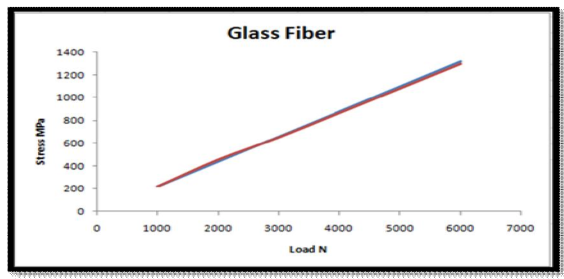


FIG 10. GRAPH OF STRESS FOR GLASS FIBER LEAF SPRING

	Carbon Fiber	
Load	Hand	ANSYS
1000	390	379.92
2000	780	759.85
3000	1170	1139.8
4000	1560	1519.17
5000	1950	1899.6
6000	2340	2279.5

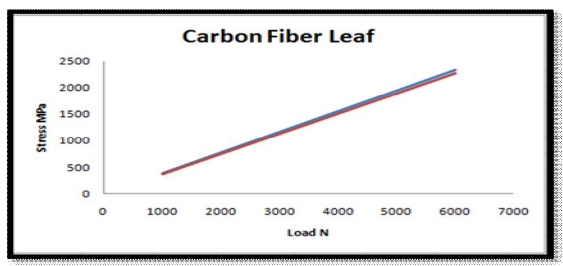
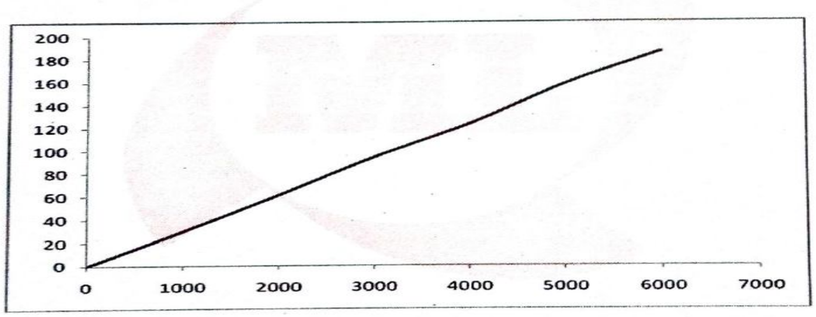


FIG 11. GRAPH OF STRESS FOR CARBON FIBER LEAF SPRING

C. Testing Result

Sample Description : Steel Leaf Spring , **Sample Code** - 01 , **Material** - M.S.

The above samples has been tested and result are as below.



Deformation Vs Load Graph

Fig. 12 UTM Testing result graph for original leaf spring

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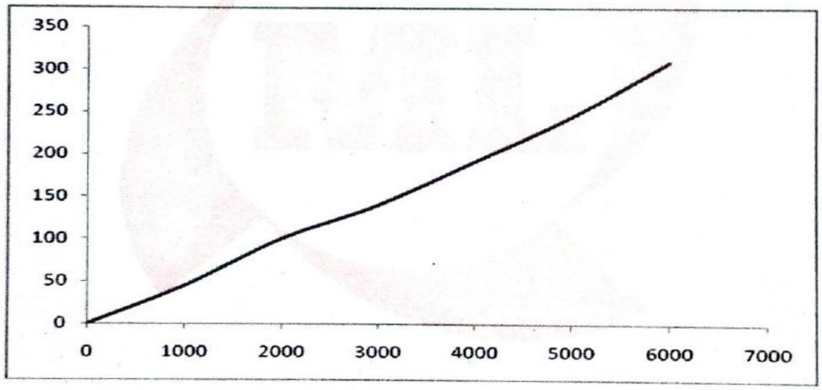
Volume 10 Issue VII July 2022- Available at www.ijraset.com

Sample Description : Carbon Fiber Leaf Spring , **Sample Code** - 01 , **Material** - Carbon Fiber

The above samples has been tested and result are as below.



Deformation Vs Load Graph

Fig. 12 UTM Testing result graph for carbon fiber leaf spring

VI. CONCLUSIONS

Reducing weight and increasing strength of products have high demands in the automobile world. Composite materials can satisfy these demands considerably. The present work involves the static analysis of conventional steel spring and composite spring. Model is prepared in CATIA V5R20 and then analysis is performed through ANSYS 14.0. A comparative study has been made between steel and composite leaf spring to find out material having high strength to weight ratio. From The results obtained it is concluded that,

1) Bending stress and deflection occurred in the composite leaf spring is less as compared to conventional steel spring.
2) Results obtained through ANSYS are got validation from Theoretical calculations and Testing.
3) The natural frequency of composite leaf springs is higher than the steel leaf spring and it's far enough from the road frequency to avoid resonance.
4) Composite E-glass epoxy spring has 30 %and carbon fibre has 55 % less weight than conventional steel spring. So composites can be suggested for mono leaf spring.

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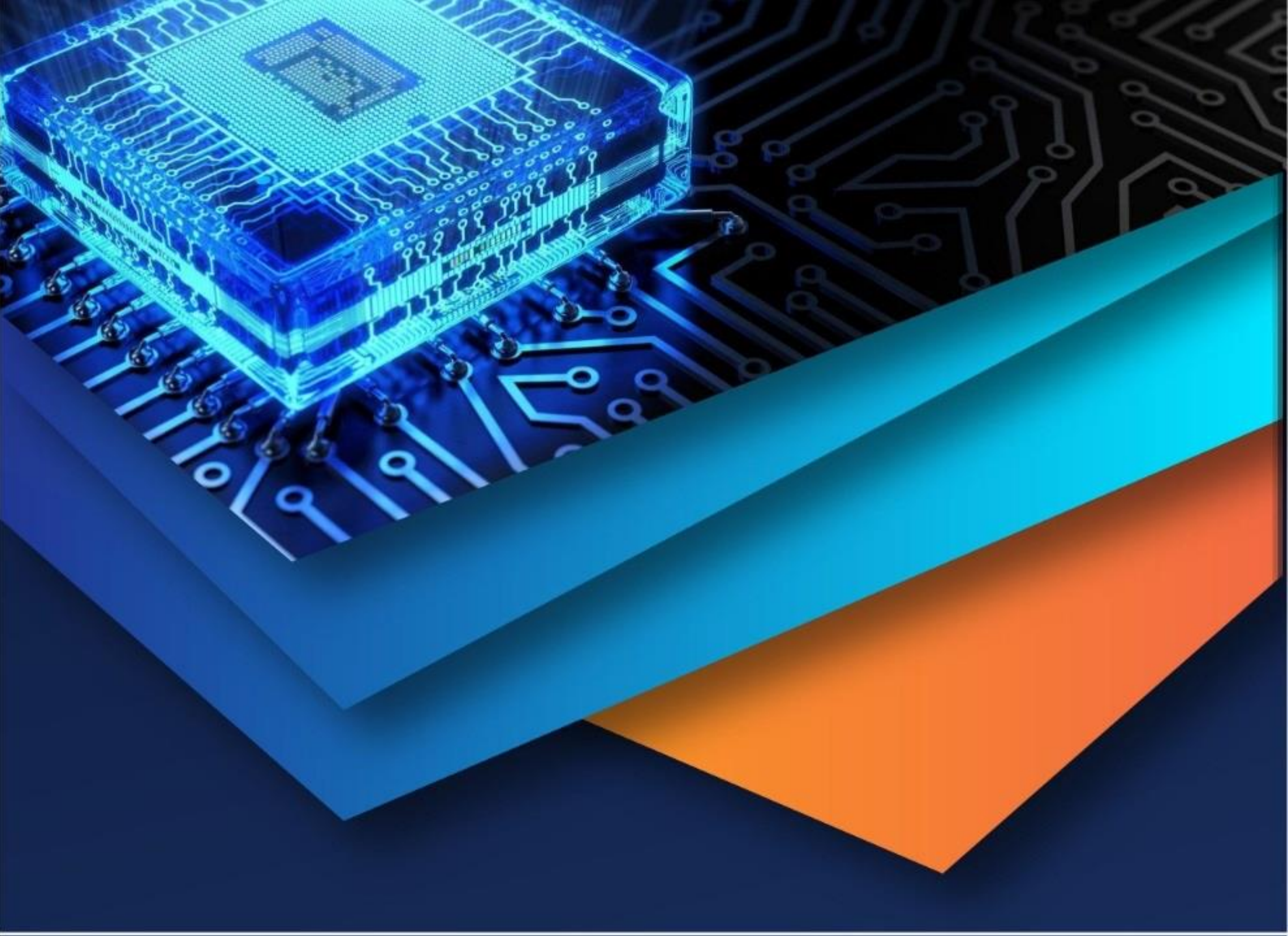

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