# Design and Analysis of Composite Leaf Spring

**Yogesh V. Shinde[1], Abhijeet B. Atpadkar[2]**
[1]Dept of Mechanical Engineering
[2]Asst. Professor, Dept of Mechanical Engineering
[1, 2] YSPM's Yashoda Technical Campus, Satara.

***Abstract-*** *Reducing weight while improving vibration characteristics of leaf spring is highly important research issue in this modern world to avoid vibration fatigue in leaf spring, Composite materials are being solutions of this issue. In this paper we did design and modal analysis of conventional steel leaf spring and composite leaf spring. The main objectives are to compare the Natural frequencies for different mode and weight of composite leaf spring with the steel leaf spring.*

*The Automobile Industry wanted replace of conventional steel leaf spring by composite leaf spring, because the composite materials has high strength to weight ratio, minimum modulus of elasticity in the longitudinal direction, minimum weight & vibration reduction, improved packaging, improved strain energy capacity, good corrosion resistance, improved durability & fatigue life. S2-Glass material is selected and used against conventional steel. The leaf spring was modeled in Creo 6.0 and the analysis was done by using ANSYS 14.5 software.*

***Keywords***- Stiffness, Composite leaf spring, Conventional steel leaf spring, ANSYS 18.2,Creo6.0, S2 Glass.

## I. INTRODUCTION

In the present scenario, the main focus of automobile manufacturers is to conserve natural resources and economize energy, weight reduction. Weight reduction can be achieved mainly by using better material, by doing design optimization and by better manufacturing processes. The suspension Leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unsprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities.

The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel; multi-leaf steel springs are being replaced by mono-leaf composite springs.

The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. Fortunately, composites have these characteristics.

Vibration Fatigue failure is the predominant mode of in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel traveling over the bumps etc. the leaf springs are more affected due to fatigue loads, as they are a part of the unsprung mass of the automobile.

The composite materials offer the various advantages like maximum strength, minimum modulus of elasticity in the longitudinal direction, weight & vibration reduction, improved packaging, strain energy capacity, improved durability & fatigue life and cost reduction due to the use of glass fibers intends of carbon fibers over the conventional composites materials.

However, literature survey indicates that study of the composite based multi leaf spring is at superficial level and very detailed work is required to understand the functioning of composites leaf spring. In this regard, the main objective of present work is to design, prepare and analyze the composite material spring based conventional steel leaf springs.

## II. OBJECTIVES

In the suspension, leaf spring is one of the potential items for weight reduction in automobiles. This project work focuses on using composite material for the leaf spring of automobiles for weight reduction with Improving Vibration Characteristics.

1. Selecting proper composite material for Composite leaf spring.
2. To construct Solid models of Conventional steel and Composite leaf spring for LCV using modeling software.
3. To Carry out Modal analysis of Conventional steel and Composite leaf spring in FEA software like ANSYS software.
4. To compare Conventional Leaf Spring and Composite leaf spring with respect to Weight and Natural Frequency

## III. LITERATURE REVIEW

**W. J. Yu and H. C. Kim[01]**have introduced Double Tapered FRP Beam for Automotive Suspension Leaf Spring. Fundamental properties of the dimensioning of the double tapered FRP leaf spring were investigated. The optimal taper ratio was shown 0.5.Prototype longitudinal type double tapered leaf springs replace four leaf steel springs from glass fiber and epoxy. Prototype of GRP leaf springs shows superior endurance and fail-safe characteristics, and the device or vehicle attachment was proved to have a sufficient strength.

**ErolSancaktar and Mathieu Gratton[02]** The objective is to provide an understanding of the manufacture, use, and capabilities of composite leaf springs produced by using unidirectional E glass roving impregnated by an epoxy resin for light vehicle applications where the vehicle weight is of primary concern.

**I. Rajendra and S. Vijayarangam[03]** have investigated optimal design of a composite leaf spring using genetic algorithms. The suspension system in automobile significantly affects the behavior of the vehicle i.e. vibration characteristics including ride comfort, directional stability, etc. Leaf springs are commonly used in suspensions systems of automobile and subjected to millions of varying stress cycles leading to fatigue failure. If the unsprung wait is reduced, then the fatigue stress induced in the leaf spring is also reduced. A composite material offers minimum weigh. A reduction of 75.8% weight is achieved when several steel leaf springs is replaced with a mono-leaf composite spring.

**H. A. Al-Qureshi [04]** has introduced Automobile leaf spring from composite materials. A single leaf variable thickness spring of glass fiber reinforced plastic with similar mechanical and geometric properties to the multi leaf steel spring.

**Mahmood M. Shokrieh and DavoodRezaei[05**] have investigated Analysis and optimization of a composite leaf spring. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions of Composite Spring. The results showed that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the optimized composite spring has much lower stresses, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

**Senthilkumar Mouleeswaran [06]** has investigated Design, Manufacturing and Testing of Polymer Composite Multi-Leaf Spring for Light Passenger Automobiles - A Review**.** Design and experimental analysis of composite multi leaf spring using glass fiber reinforced polymer are carried out. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. The conventional multi leaf spring weighs about 13.5 kg whereas the E-glass/Epoxy multi leaf spring weighs only 4.3 kg. Thus the weight reduction of 68.15% is achieved. Besides the reduction of weight, the performance of the leaf spring is also increased. Compared to the steel leaf spring (13.5 kg), the optimized composite leaf spring weighs nearly 76.4% less than the steel spring. Ride comfort and life of CLS are also more when compared to SLS. Therefore, it is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in light passenger vehicles.

**V. K. Aher and P. M. Sonawane [07]** have conducted Static and Fatigue Analysis of Multi Leaf Spring used in the Suspension system of LCV. The leaf spring is widely used in automobiles and one of the components of suspension system. It needs to have excellent fatigue life. As a general rule, the leaf spring must be regarded as a safety component as failure could lead to severe accidents. The purpose of this paper is to predict the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations. This present work describes static and fatigue analysis of a modified steel leaf spring of a light commercial vehicle (LCV). The dimensions of a modified leaf spring of a and are verified by design calculations. The non-linear static analysis of 2D model of the leaf spring is performed using NASTRAN solver and compared with analytical results. The preprocessing of the modified model is done by using HYPERMESH software. The stiffness of the modified leaf spring is studied by plotting load versus deflection curve for working range loads. The simulation results are compared with analytical results. The fatigue life of the leaf spring is also predicted using MSC Fatigue software.

**B. Vijaya Lakshmi1 I. Satyanarayana[08]**have investigated Static and Dynamic Analysis on Composite Leaf Spring in

Heavy Vehicle. The objective of this paper is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. The design constraints are stresses and deflections. The dimensions of an existing conventional steel leaf spring of a Heavy commercial vehicle are taken Same dimensions of conventional leaf spring are used to fabricate a composite multi leaf spring using E-Glass/Epoxy, C- Glass/Epoxy, S- Glass/Epoxy unidirectional laminates. Pro/Engineer software is used for modeling and COSMOS is used for analysis.

**PankajSaini, AshishGoel, Dushyant Kumar [09]**have investigated Design and analysis of composite leaf spring for light vehicles. Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this paper we describe design and analysis of composite leaf spring. The objective is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. The design constraint is stiffness. The material selected was glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. The design parameters were selected and analyzed.

**Manjunath H.N, Manjunath.K, T.Rangaswamy [10]**have investigated Static Analysis and Fatigue Life prediction of Composite Leaf Spring for a Light Commercial Vehicle (TATA ACE). In this research work an attempt has been made to check the suitability of composite materials like EGlass/Epoxy, Graphite/Epoxy, Boron/Aluminum, Carbon/Epoxy and Kevlar/Epoxy for light commercial vehicle leaf spring. First the static analysis is carried out for steel and different composite leaf spring using ANSYS V10.The obtained results are compared with theoretical values and observed that they have good agreement with each other. The fatigue life of various composite leaf springs is calculated using Hwang and Han relation. From the results it can be concluded that Boron/Aluminum and Graphite/Epoxy are best suitable composite material for leaf spring**.**

**GulurSiddaramanna, Shiva Shankar, Sambagam Vijayarangan[11]**In this paper a single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested. Three-dimensional finite element analysis is used for verification of result obtained from experiment. For the fabrication of mono composite leaf spring of E-glass /epoxy hand layup technique is used. It is observed that composite leaf spring is more superior than steel with a large weight reduction.

## IV. COMPOSITE MATERIAL

A Composite Materials is defined as a Material composed of two or more constituents on a macroscopic scale and chemical bonds. Typical composite Materials are composed of inclusion suspended in a matrix. The constituents retain their identities in the composite. Normally the component can be physically identified and there is an interface between them.

Many composite materials (carbon fiber/e-glass fiber/S-glass fiber/e-graphite fiber.) offer a combination of strength and modulus that are either comfortable to or better than any traditional metallic materials. Because of their low specific gravities, the strength weight-ratio and modulus weight-ratio of these composite materials are markedly superior to those of metallic materials. The fatigue strength weight ratios as well as fatigue damage tolerance of many composite laminates excellent. For these reasons, fiber composite have emerged as major class of structural material and are either used or being considered as substitution for metal in many weight critical components in aerospace, automotive and other industrials. Another unique characteristic of many fiber reinforced composite is their high internal damping. This leads to better vibration energy absorption within the materials and result in reduces transmission of noise and vibration to neighboring structures.

### 4.1 Material selection

The material used directly affects the quantity of storable energy in the leaf spring. The specific strain energy can be written as Eq.

$$s = \frac{1}{2} * \frac{\sigma_t^2}{\rho E}$$

Where

$\sigma_t$ = the allowable stress,
E = the modulus of elasticity
P = the density.

The specific strain energy of steel spring and some composites are compared in Fig., when the ultimate static strength is used for $\sigma_t$. The S2-Glass/epoxy value is set to 1 and other values are expressed as their relative percentages to it. Regarding the dynamic nature of loading on spring, the hatched regions identify the quantity of specific strain energy in dynamic loading when the fatigue strength is used for $\sigma_t$.

Compared to carbon fibers, glass fibers have lower strength and stiffness, higher density, better corrosion resistance, higher impact strength and lower cost. A good combination between the material properties and the cost is obtained with the glass fibers.

Glass fibers consist of two major types E and S2. As S2 fibers have better mechanical properties than E fibers so in the present work the S2 glass is selected as the spring material.

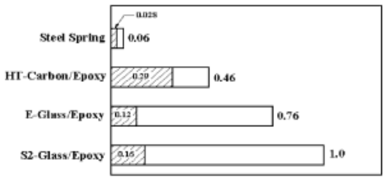



Fig. Specific Strain Energies of spring Materials

Material Properties of S2 Glass/Epoxy

| Sr. No. | Parameter | Value |
|---|---|---|
| 1 | Material | S2 Glass/Epoxy |
| 2 | Young's Modulus (Mpa) | 59000 |
| 3 | Poisson's Ratio | 0.28 |
| 4 | Bulk modulus (Mpa) | 4.4697 x $10^4$ |
| 5 | Shear Modulus (Mpa) | 2.3047 x $10^4$ |
| 6 | Density ($^{Kg}/_{m^3}$) | 2020 |

**4.2 Resins Selection:**

In a composite FRP leaf spring, the Inter laminar shear strengths are controlled by the matrix system used. Since these are composite reinforcement fibers in the thickness direction fiber do not influences Inter Laminar Shear strength. Therefore, the matrix system should have good interred laminar shear strength characteristics compatibility to the selected composite reinforcement fiber. Many thermo set resins such as polyester, vinyl ester, Epoxy resins, Lapox L-12, Dobeckot 50F are being used for composite fiber reinforcement plastics (FRP) fabrication. Among these resin systems, Lapox L-12 show better inter laminar shear strength and good mechanical properties. Hence, Lapox L-12 is found to be the best resins that would suit this application.

**4.3 Hardner Selection:**

Various hardeners' are available in market like Hardener 758, Lapox K-5, Lapox K-6. Here we use Lapox K-6 Harner with Lapox L-12 Rasin. 100 ml K-6 Harder is used with 1000 ml of Lapox L-12 Resin**.**

**V. DESIGN OF COMPOSITE MONO LEAF SPRING**

For Conventional Leaf Spring
Specification of spring

| Parameters | Value |
|---|---|
| The total length of the spring (Eye to Eye) | 980 mm |
| Free camber (At no-load condition) | 140 mm |
| Thickness of leaf (t) | 12 mm |
| No. of Full length leafs ($n_f$) | 02 |
| No. of gradual leafs ($n_g$) | 00 |
| Width of leaf spring (b) | 60 mm |

Maximum weight of Vehicle = 1670 kg
Acceleration due to gravity = 9.81 $^{m}/_{s^2}$
Hence Total Weight = 1670 x 9.81
= 16382.7 N
The Vehicleis4 wheeler, a single leaf spring corresponding to one of the wheel takes up $^1/_4$ th of total weight,
Hence Total Weight on single leaf spring = $\frac{16382.7}{4}$ N
= 4095.675 N
Now spring has two eye ends
Hence
2W = 4095.675 N
W= $\frac{4095.675}{2}$ N
W= 2047.8375 N
Taking FOS = 2.0
Hence W= 2047.8375*2.0 N
W= 4095.675 N

The table I below shows the specifications of conventional leaf spring.

| Sr. No. | Parameter | Value |
|---|---|---|
| 1 | Material | 55Si2Mn90 Steel |
| 2 | Young's Modulus (Mpa) | 2.1 x $10^5$ |
| 3 | Poisson's Ratio | 0.29 |
| 4 | Bulk modulus (Mpa) | 1.6667 x $10^5$ |
| 5 | Shear Modulus (Mpa) | 8.1395 x $10^4$ |
| 6 | Density ($^{Kg}/_{m^3}$) | 7850 |

$$\delta = \frac{12WL^3}{(2\,n_g + 3\,n_f)E \times b \times t^3}$$

$$\delta = \frac{12 \times 4095.675 \times (\frac{980}{2})^3}{(2 \times 0 + 3 \times 2) 2.1 \times 10^5 \times 60 \times 12}$$

$$\delta = 44.2618\ mm$$

For the manufacturing of composite leaf spring, we selected S2 glass composite material.

Now for Composite Spring

$$\delta = \frac{12WL^3}{(2\,n_g + 3\,n_f)E \times b \times t^3}$$

$$44.2618 = \frac{12 \times 4095.675 \times (\frac{980}{2})^3}{(2 \times 0 + 3 \times 1)\ 59000 \times 50 \times t^3}$$

$$t = 24.5306\ mm$$

Hence approximate value of 25 mm is selected.

Here W = Maximum Weight
L = Spam Length of spring
b = Width of Leaf spring
t = Depth / Thickness of spring
E = Young's Modulus

The following cross-sections of mono-leaf composite leaf spring for manufacturing easiness are considered.

1. Constant thickness, constant width design.
2. Constant thickness, varying width design.
3. Varying width, varying thickness design.

In this project, a mono-leaf composite leaf spring with varying width and varying thickness is designed and manufactured because to maintain stiffness of composite spring with thickness ratio 0.5 along the length. Spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat.The parameters of composite leaf spring are shown in Table.

| Parameter | At Center | At End |
|---|---|---|
| Breath in mm | 50 | 100 |
| Thickness in mm | 25 | 12.5 |

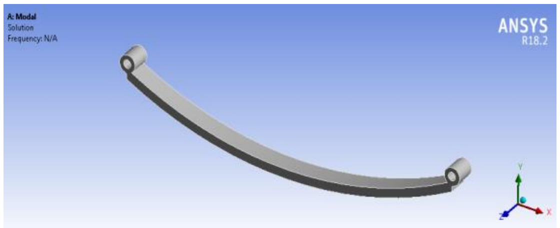
## VI. FINITE ELEMENT ANALYSIS

FEA tool is the mathematical idealization of real system. Is a computer based method that breaks geometry into element and link a series of equation to each, which are then solved simultaneously to evaluate the behavior of the entire system. It is useful for problem with complicated geometry, loading, and material properties where exact analytical solution are difficult to obtain. Most often used for structural, thermal, fluid analysis, but widely applicable for other type of analysis and simulation. For modal analysis of composite leaf spring Ansys Composite Pre Post (ACP) is used.

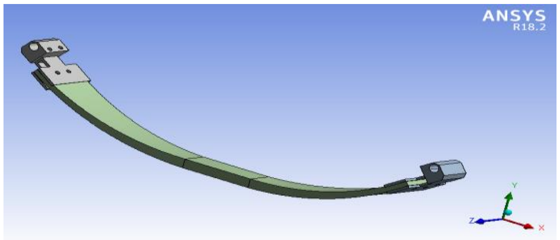
### 6.1 Preprocessing

**A. Solid Modeling:**

In the present work, steel spring and mono-composite leaf spring are modeled. For modeling the steel and & S2 Glass Composite spring, the dimensions of a conventional Steel leaf spring of a light weight commercial vehicle are Selected. Solid Model is created using Creo 6.0. This model produced in Creo 6.0 is imported into Ansys18.2.



Solid Model of steel leaf spring



Solid Model of composite leaf spring

**B. Element selection:**

SOLID187 element is a higher order 3-D, 10-node element. SOLID187 has a quadratic displacement behavior and is well suited to modeling irregular meshes.

The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyper elastic materials.

**C. Material properties:** Material properties are applied to the geometry.

| Sr. No. | Parameter | Value |
|---|---|---|
| 1 | Material | S2 Glass/Epoxy |
| 2 | Youngs Modulus (Mpa) | 59000 |
| 3 | Poisson's Ratio | 0.28 |
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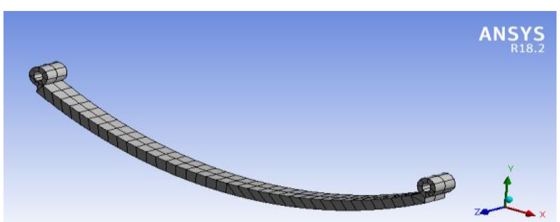
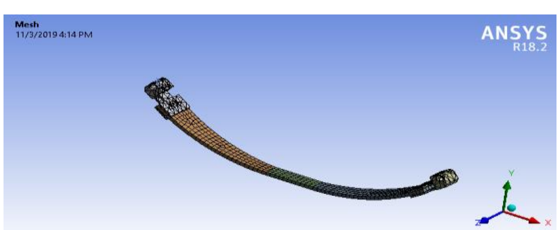
| 6 | Density ($Kg/m^3$) | 7850 |

**D. Meshing:**

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is SOLID 187 for Conventional leaf spring and composite leaf spring Fig shows the meshed models of leaf spring.




Mesh Model of steel leaf spring

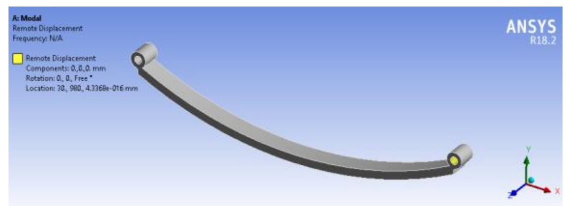



Mesh Model of composite leaf spring

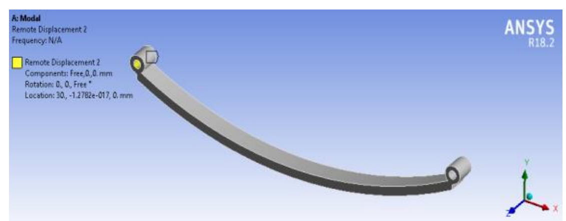
**E. Boundary conditions:**

The leaf spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the leaf spring. The ends of the leaf spring are formed in the shape of an eye. The front eye of the leaf spring is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation is occurred. The rear eye of the leaf spring is connected to the shackle, which is a flexible link; the other end of the shackle is connected to the frame of the vehicle. The rear eye of the leaf spring has the flexibility to slide along the X – direction when load applied on the spring and also it can rotate about the pin. The link oscillates during load applied on the spring and also it can rotate about the pin. The link oscillates during load applied and removed.

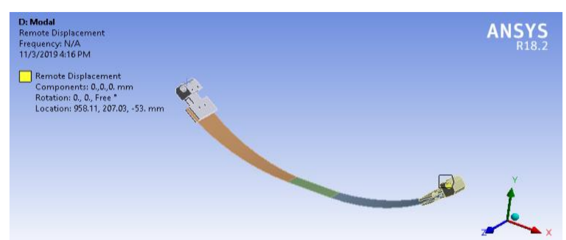
So the front eye is constrained as UX, UY, UZ, ROTX, ROTY and the nodes of rear eye is constrained as UY, UZ, ROTX, ROTY, .



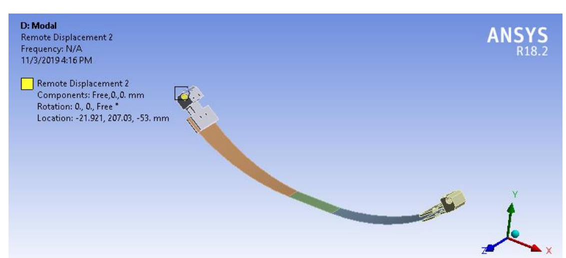

Boundary Conditions for front eye of steel leaf spring




Boundary Conditions for rear eye of steel leaf spring




Boundary Conditions for front eye of composite leaf spring



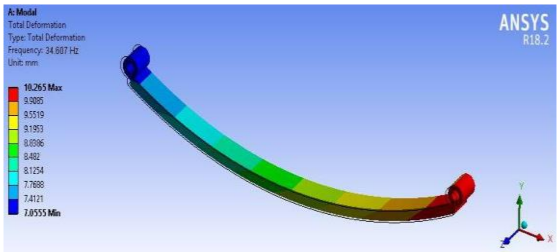

Boundary Conditions for rear eye of composite leaf spring

**6.2Processing**

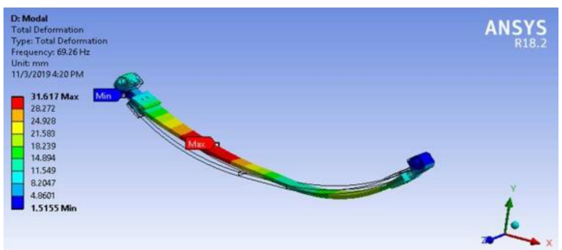
Modal analysis is carried out to determine the natural frequencies and mode shapes of the leaf spring. Modal analysis is performed for various parametric combinations of the leaf sprig. Modal analysis need only boundary conditions, it is not associated with the loads apply, because natural frequencies are resulted from the free vibrations.

### 6.3 Post processing

1. First Mode –

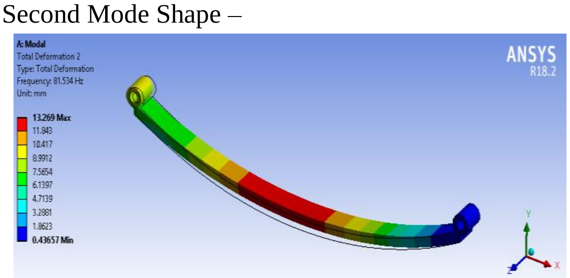


First mode of steel Leaf Spring

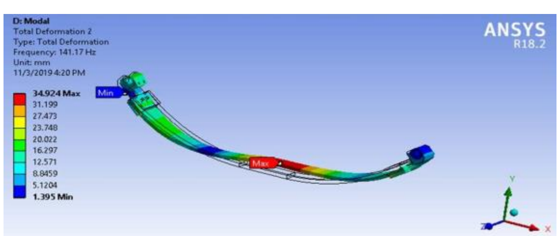


First mode of composite Leaf Spring

2. Second Mode Shape –

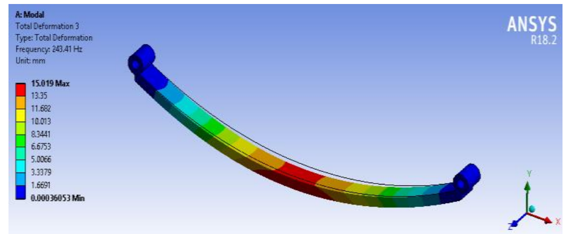


Second mode of steel Leaf Spring

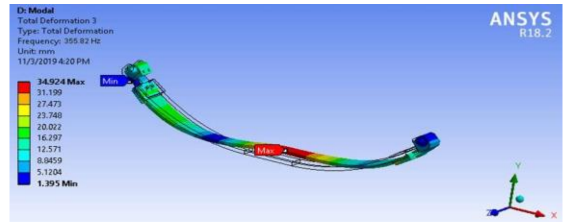


Second mode of composite Leaf Spring

3. Third Mode Shape –

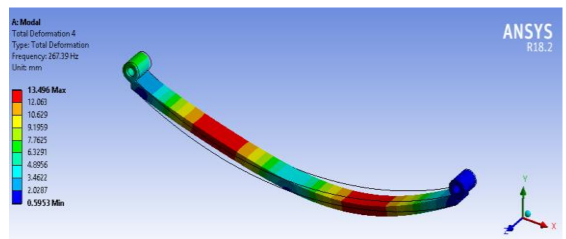


Third mode of steel Leaf Spring

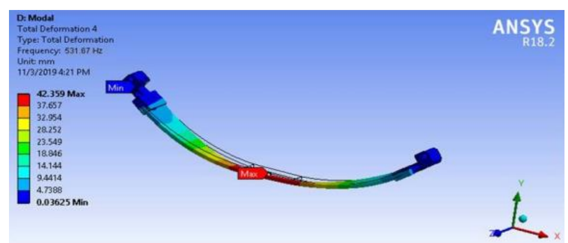


Third mode of composite Leaf Spring

4. Fourth Mode Shape –

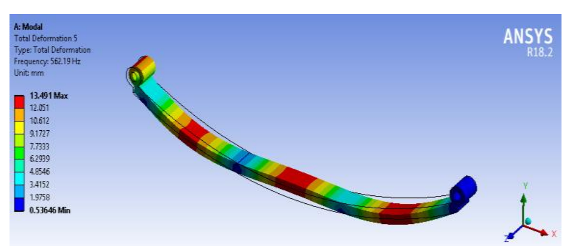


Fourth mode of steel Leaf Spring

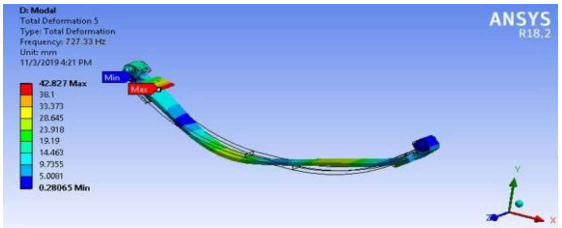


Fourth mode of composite Leaf Spring

5. Fifth Mode Shape –

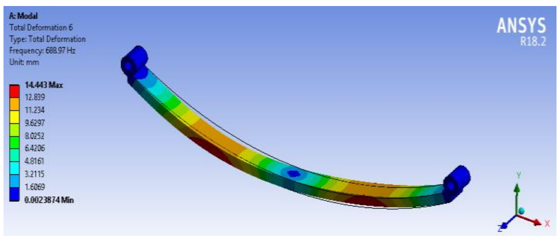


Fifth mode of steel Leaf Spring

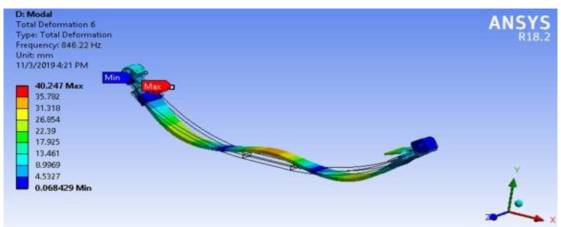


Fifth mode of composite Leaf Spring

6. Sixth Mode Shape –



Sixth mode of steel Leaf Spring



Sixth mode of composite Leaf Spring

Below table shows Natural Frequencies for Different Mode Shapes of conventional steel and composite leaf spring

| Sr. No. | Mode No. | Natural Frequency of Conventional Leaf Spring (Hz.) | Natural Frequency of S2 Glass Mono Leaf Spring (Hz.) |
|---|---|---|---|
| 1 | 1st | 34.607 | 69.26 |
| 2 | 2nd | 81.534 | 141.17 |
| 3 | 3rd | 243.41 | 355.82 |
| 4 | 4th | 267.39 | 531.67 |
| 5 | 5th | 562.19 | 727.33 |
| 6 | 6th | 688.97 | 846.22 |

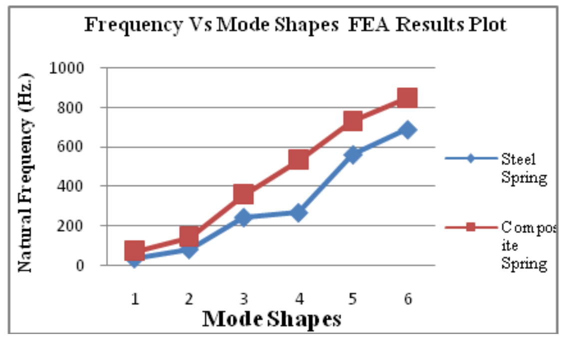
## VII. RESULTS AND DISCUSSION

### A. Comparison of Weight of conventional steel leaf spring with composite leaf spring

| Sr. No. | Leaf Spring | Mass (Kg) |
|---|---|---|
| 1 | Conventional Steel Leaf Spring | 11.6080 |
| 2 | Composite Leaf Spring | 2.0200 |
| 3 | Composite Leaf Spring with steel Eyes | 3.7800 |

### B. Comparison of FEA Results of conventional steel leaf spring with Composite leaf spring

| Sr. No. | Mode No. | Natural Frequency of Conventional Leaf Spring (Hz.) | Natural Frequency of S2 Glass Mono Leaf Spring (Hz.) |
|---|---|---|---|
| 1 | 1st | 34.607 | 69.26 |
| 2 | 2nd | 81.534 | 141.17 |
| 3 | 3rd | 243.41 | 355.82 |
| 4 | 4th | 267.39 | 531.67 |
| 5 | 5th | 562.19 | 727.33 |
| 6 | 6th | 688.97 | 846.22 |



**Plot of Frequency Vs Mode Shapes of FEA Results**

The steel leaf spring was replaced with a composite one. The objective was to obtain a spring with minimum weight which is capable of carrying given static external forces by constraints limiting stresses and displacements. The weight of the leaf spring is reduced considerably about 82.60 % by replacing steel leaf spring with composite leaf spring & about 67.44 % by replacing steel leaf spring with composite leaf spring with steel eyes. Thus, the objective of the unsprung mass is achieved to a larger extent.

Modal analysis has been done on Conventional steel as well as composite leaf spring to find the natural frequency. The six natural frequencies are listed in the table. The natural frequency composite leaf spring is higher than that of the Conventional steel leaf spring and is far enough from the road frequency to avoid the resonance.

## VIII. CONCLUSION

1. S2 Glass/Epoxy material is selected as a composite material for leaf spring.
2. The Solid model of both conventional steel and composite leaf spring is done in Creo 6.0
3. This model is analyzed by using Ansys Software.
4. A comparative study has been made between composite and Conventional steel leaf spring with respect to Weight & Modal Analysis.From the

results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications.

It is observed that the weight reduction of mono leaf spring is achieved up 82.60% in case of composite spring without Steel Eyes and 67.44% in case of composite spring with Steel Eyes than Conventional steel spring. Also from results, it is observed that natural Frequency for different modes of Composite Leaf spring is much more than that of Conventional Steel leaf Spring. Those are enough to avoid Resonance.

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