

Performance Analysis of Composite Leaf Spring

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Abstract: Increasing competition and innovation in automobile sector tends to modify the existing products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. Leaf springs are one of the oldest suspension components that are being still used widely in automobiles. Weight reduction is also given due to importance by automobile manufacturers. The automobile industry has shown increased interest in the use of composite leaf spring in the place of conventional steel leaf spring due to its high strength to weight ratio. This work deals with replacement of conventional steel leaf spring of a light commercial vehicle with composite leaf spring using Carbon/Epoxy. Dimensions of the composite leaf spring are to be taken as same dimensions of the conventional leaf spring. The objective is to compare the load carrying capacity, stresses, deflection and weight savings of composite leaf spring with that of steel leaf spring.

Keywords: Laminated Composite leaf spring (LCLS); Static analysis; Carbon/epoxy.

1. INTRODUCTION

In order to conserve natural resources, economize energy, increasing competition and innovations in automobile sector weight reduction has been the main focus of automobile manufacturer in the present scenario. A suspension system of vehicle is also an area where these innovations are carried out regularly. 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 [1]. The conventional steel leaf spring has some problems such as due to continuous running of the vehicle there is a decrease in the level of comfort provided by the spring. It is observed that the leaf springs tend to break and weaken at the eye end portion which is very close to the shackle and at the centre. The conventional steel leaf spring has higher weight, which also affect the fuel efficiency. Substituting composite structures for conventional metallic structures has many advantages, which helps in achieving the vehicle with more fuel efficiency and improved riding qualities [2]. 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 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. The introduction of composite

materials was made it possible to reduce the weight of the 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 to those of steel. Composite has received attention largely from the automotive industry due to their superior mechanical properties and relative ease of processing. The use of a thermoset matrix gives the molder the ability to modify and enhance the properties of the resin by blending additives, fillers and fire retardants depending upon the nature of the application [3].

This project is mainly focused on design and analysis of laminated mono composite leaf spring with uni-directional fiber orientation angle 0° is considered. The implementation of Carbon/Epoxy composite materials for leaf springs of a suspension system can replace steel in conventional spring to reduce the weight, deflection, stresses, product development cost and increase the comfort.

2. LITERATURE REVIEW

The Several papers were devoted to the application of composite materials for automobiles, to present and discuss the various methodologies and strategies that are adopted by researchers in order to predict the performance of composite leaf spring. The review mainly focuses on replacement of steel leaf spring with the composite leaf spring made of glass fiber reinforced polymer (GFRP) and majority of the published work applies to them.

GSS Shankar et al. had presented a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. Also, general study on the analysis and design. A single leaf with variable thickness and width for constant cross sectional area of

unidirectional glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested. Computer algorithm using C-language has been used for the design of constant cross-section leaf spring. And conclude that a spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the composite spring has stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85% lower with bonded end joint and with complete eye unit. [1]

Amare et al. worked on design simulation and prototyping of single composite leaf spring for light weight vehicle, reducing weight of vehicles and increasing or maintaining the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single E-glass/Epoxy leaf spring is designed and simulated the design rules of the composite materials considering static loading only. It showed the resulting design and simulation stresses are much below the strength properties of the material, satisfying the maximum stress failure criterion. The designed composite leaf spring has also achieved its acceptable fatigue life. [2]

Amrute et al worked on design and assessment of multi leaf spring. A semi-elliptical multi leaf spring is designed for a four wheel automobile and replaced with a composite multi leaf spring made of E-glass/epoxy composites. Under the same static load conditions the stresses and the deflection in leaf springs are found with great difference. Stresses and deflection in composite leaf springs is found out to be less as compared to the conventional steel leaf springs. All the FEA results are compared with the theoretical results and it is found that they are within the allowable limits and nearly equal to the theoretical results.[3]

Ghodake et al. worked on analysis of steel and composite leaf spring for vehicle. The 3-D modeling of both steel and composite leaf spring is done and analyzed A comparative study has been made between composite and steel leaf spring with respect to Deflection, strain energy and stresses. 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.[4]

Qureshi et al had described a single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested.[5]

Koppula et al, worked on static analysis of composite mono leaf spring. The development of a composite mono leaf spring having constant cross sectional area, where the stress level at any station in the leaf spring is considered constant due to the parabolic type of the thickness of the spring, has proved to be very effective; The study

demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings.[6]

Raghavedra et al. worked on modeling and analysis of laminated composite leaf spring under the static load condition by using FEA. The work carried out on laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, S-glass/Epoxy and Carbon/Epoxy subjected to the same load as that of a steel spring. The design constraints were stresses and deflections. The three different composite mono leaf springs had modeled by considering uniform cross-section, with unidirectional fiber orientation angle for each lamina of a laminate. Static analysis of a 3-D model has been performed using FEA software. Compared to mono steel leaf spring the laminated composite mono leaf spring is found to have 47% lesser stresses, 25%~65% higher stiffness, 27%~67% higher frequency and weight reduction of 73%~80% is achieved[7].

Bhandari et al. worked on Parametric Analysis of Composite Leaf Spring. The conclusion of the work is to minimize stress and deformation in C-Glass/Epoxy composite leaf spring compared to steel leaf spring for automobile suspension system. This is done to achieve the comparison that the bending stress induced in the C-Glass/Epoxy composite leaf spring is 64% less than the conventional steel leaf spring for the same load carrying capacity. This design helps in the replacement of conventional steel leaf springs with composite mono-leaf spring with better ride quality. To achieve weight reduction in the suspension system by replacing steel leaf spring with mono composite leaf spring. [8]

The objective of this work is, to analyze the comparative performance of carbon/ epoxy composite leaf spring with respect to conventional steel leaf spring to reduce the weight, product development cost and increase the comfort. By analyzing performance, conventional steel leaf spring can be replaced by carbon epoxy composite leaf spring.

2.1. Objective function

The objective is to minimize the weight of leaf spring with prescribed strength and stiffness. The objective function identified for the leaf spring problem is given below:

$$W=\rho Lbt \quad (1)$$

Where ρ is the material density, t , the thickness at centre, b , the width at centre and L , the length of the leaf spring.

3. DESIGN OF COMPOSITE LEAF SPRING

The design of composite leaf spring aims that the replacement of steel leaf spring of an automobile with mono-leaf composite spring. The design requirements are taken to be identical to that of the steel leaf spring Material selection Materials constitute nearly 60%-70% of the

vehicle cost and contribute to the quality and the performance of the vehicle. [8] 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 have been selected for leaf spring design.

3.1.1. Fiber selection

The designer or material specialist has a wide range of fibers from which to make a selection. Often a fiber is selected because of physical properties. Fiber selection should also consider mechanical and thermal properties. The silent mechanical properties are modulus and strength. Those for thermal properties include coefficient of thermal expansion and thermal conductivity.

Vertical vibrations and impacts are buffered by 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. The material used directly affects the quantity of storable energy in the leaf spring. The specific strain energy can be written as Eq. (2)

$$U = \frac{\sigma^2}{2\rho E} \quad (2)$$

The material with maximum strength and minimum modulus of elasticity is the most suitable material for the leaf spring application.[8]

Table 3.1 strain energy stored by material (KJ/Kg) [8]

| Sr. No. | Material | Strain energy stored by material (KJ/Kg) |
|---------|---------------|--|
| 1 | EN47 | 0.3285 |
| 2 | Carbon/epoxy | 2.45 |
| 3 | E-glass/epoxy | 4.5814 |
| 4 | C-glass/epoxy | 18.76 |
| 5 | S-glass/epoxy | 32.77 |

The commonly used fibers are carbon, glass, Kevlar etc. Among these, the carbon fiber has been selected based on the strength and stiffness. Although carbon fibers have better mechanical properties than other fibers, and their advantageous include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. This is used as standard reinforcement fiber for all mechanical property requirements. Thus, Carbon fiber was found appropriate for this application.[9]

3.1.2. Resin 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, epoxies are found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classified based on the mechanical properties which in combination with hardener 758 cures into hard resin.

It is characterized by

- Good mechanical and electrical properties.
- Faster curing at room temperature.
- Good chemical resistance properties.

Matrix materials or resins in case of polymer matrix composites can be classified according to their chemical base i.e. thermoplastic or thermo sets. Thermoplastics have excellent toughness, resilience and corrosion resistance but have fundamental disadvantage compared to thermosetting resins, in that they have to be molded at elevated temperature. Thermosetting plastics or thermo sets are formed with a network molecular structure of primary covalent bonds. Some thermo sets are cross-linked by heat or a combination of heat and pressure. Others may be cross-linked by chemical reaction, which occurs at room temperature. At present, epoxy resins are widely used in various engineering and structural applications such as aircraft, aerospace engineering, sporting goods, automotive, and military aircrafts industries. In order to improve their processing and product performances and to reduce cost, various fillers are introduced into the resins during processing. Epoxy resins are the most commonly used thermo sets plastic in polymer matrix composites. Hence from the above listed advantages of epoxy resin it has been selected for the study. [9]

3.1. Design selection

The leaf spring behaves like a simply supported beam and the flexural analysis is done considering it as a simply supported beam. The simply supported beam is subjected to both bending stress and transverse shear stress. Flexural rigidity is an important parameter in the leaf spring design and test out to increase from two ends to the center. [4]

3.2.1. Constant Thickness, Varying Width Design

In this design the thickness is kept constant over the entire length of the leaf spring while the width varies from a minimum at the two ends to a maximum at the center. [4]

3.2.2. Constant Width, Varying Thickness Design

In this design the width is kept constant over the entire length of the leaf spring while the thickness varies from a minimum at the two ends to a maximum at the center. [4]

3.2.3. Constant Cross Section- Selection Design

In this design both thickness and width are varied throughout the leaf spring such that the cross section area

remains constant along the length of the leaf spring. Out of the above mentioned design concepts, the constant cross section design method is selected due to the following reasons:-

- Due to its capability for mass production and accommodation of continuous reinforcement of fibers.
- Since the cross section area is constant throughout the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacture.[4]

4. ANALYTICAL DESIGN

4.1. Specific design data

Here weight and initial measurement of four wheeler “Maruti 800 ” light vehicle are taken.

Weight of vehicle= 920Kg
 Maximum load carrying capacity= 5x100=500Kg
 Total weight=920+500=1420Kg
 Acceleration due to gravity (g) =9.81 m/s²
 Therefore,
 Total Weight (W’) = 1420x9.81=13931N
 Since the vehicle is 4-wheeler, a single leaf spring corresponding to one of the wheel takes up one fourth of the total weight.
 Load on each wheel is,
 W=13931/4=3483N.
 Load on each eye of spring is 1742N.

4.2. Design data for Leaf spring

Since the leaf spring is fixed with the axle at its centre, only half of it is considered for analysis purpose.

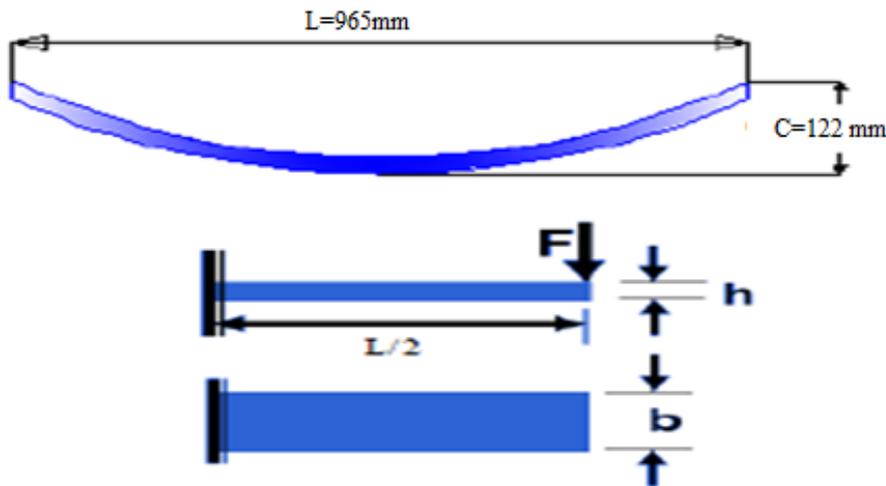


Fig. 4.1 Dimensions and free body diagram to analyze half of the leaf spring

Since we consider half of the leaf spring we substitute ‘L/2’ instead of ‘L’ to calculate ‘t’ and ‘b’. As the end of leaf spring is hinged, the entire leaf spring will only be loaded under tension. Therefore, we consider only the longitudinal properties. [10]

capacity of storing strain energy in the longitudinal direction of the fibers.

We have to find t=? And b=?

$$\sigma_{max} = \frac{6WL}{bt^2} \quad (3)$$

$$\delta_{max} = \frac{4Wl^3}{Ebt^3} \quad (4)$$

$$t = \frac{\sigma_{max}L^2}{E\delta_{max}} \quad (5)$$

4.3. Design for Carbon/Epoxy Composite Leaf spring

From the material point of view a unidirectional Carbon/Epoxy composite material is selected. It is selected due to its relative advantages stated in the literature review above, mainly high strength to weight ratio and high

Table 4.1 Material properties of carbon/epoxy

| Sr. No. | Parameter | Value |
|---------|---|--------|
| 1 | Tensile modulus along X direction Ex, MPa | 123000 |
| 2 | Tensile modulus along Y direction Ey, MPa | 7.7 |
| 3 | Tensile modulus along Z direction Ez, MPa | 4.2 |
| 4 | Tensile strength of material, MPa | 1841 |
| 5 | Compressive strength of material, MPa | 920 |
| 6 | Poisons ratio | 0.282 |
| 7 | Density Kg/m ³ | 1400 |

Maximum stress (σ_{max})=920 MPa

Maximum deflection (δ_{max})=112 mm

Measured data of the above stated light weight 4-wheeler vehicle

Straight length of the leaf spring (L) = 965mm

The equation (5) will be written as:

$$t = \frac{\sigma_{max}(L/2)^2}{E\delta_{max}}$$

$$t = \frac{920 \times 550^2}{123000 \times 112} = 20.2 \text{mm} \approx 20 \text{mm}$$

Rearranging the equation (3) and solving for the width 'b'

$$\sigma_{max} = \frac{6W(L/2)}{bt^2}$$

$$b = \frac{6W(L/2)}{\sigma_{max} t^2} = \frac{6 \times 3483 \times 550}{920 \times 20^2}$$

$$b = 32 \text{mm}$$

Table 4.2 Specification of Composite leaf spring

| Parameter | Value mm |
|------------------------------|----------|
| Straight length | 965 |
| Leaf thickness at the centre | 20 |
| Leaf thickness at the end | 12 |
| Leaf width at the centre | 32 |
| Leaf width at the end | 50 |
| Camber | 112 |

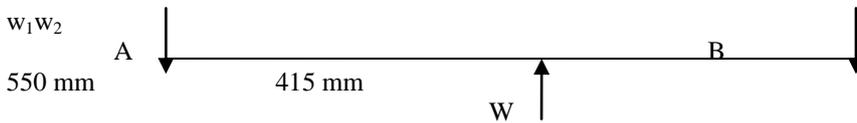


Fig. 4.2 FBD for Carbon/Epoxy composite leaf spring

W=central load, (N)

w₁ and w₂= cantilever load, N.

Taking moment at point B,

$$965 \times w_1 = 415 \times W$$

$$w_1 = 0.4301 \times W$$

$$\sigma = 0.2578 \times w_1$$

4.3.2. Deflection of composite leaf spring.

$$\delta = \frac{WL^3}{3EI}$$

$$= \frac{2\sigma L^2}{3Et}$$

$$= (2 \times \sigma \times 550^2) / (3 \times 123000 \times 20)$$

$$\delta = 0.0819 \times \sigma$$

4.3.1. Bending stress of composite leaf spring.

$$\sigma = \frac{M}{Z} = \frac{6w_1L}{bt^2}$$

$$\sigma = \frac{6 \times w_1 \times 550}{32 \times 20^2}$$

4.4. Design for steel (EN 47) Leaf spring

Table 4.3 specification of existing steel leaf spring

| Parameter | Value mm |
|-----------------|----------|
| Straight length | 965 |
| Leaf thickness | 10 |
| Leaf width | 50 |
| Camber | 112 |

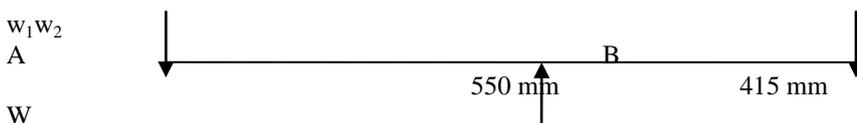


Fig. 4.3 FBD for Steel leaf spring

W=central load, (N)

w₁ and w₂= cantilever load, N.

Taking moment at point B,

$$965 \times w_1 = 415 \times W$$

$$w_1 = 0.4301 \times W$$

$$\sigma = \frac{6 \times w_1 \times 550}{50 \times 10^2}$$

$$\sigma = 0.66 \times w_1$$

4.4.2. Deflection of steel leaf spring

$$\delta = \frac{WL^3}{3EI} = \frac{2\sigma L^2}{3Et}$$

$$\delta = (2 \times \sigma \times 550^2) / (3 \times 2.07 \times 10^5 \times 10)$$

$$\delta = 0.09742 \times \sigma$$

4.4.1. Bending stress of steel leaf spring.

$$\sigma = \frac{M}{Z} = \frac{6w_1L}{bt^2}$$

Table 4.4 comparisons of results for carbon/epoxy and EN 47 leaf spring

| Sr. No. | Central load W (N) | Cantilever load w_1 (N) | Carbon/Epoxy | | EN 47 | |
|---------|--------------------|---------------------------|-------------------------------|--------------------------|-------------------------------|--------------------------|
| | | | Bending stress σ (MPa) | Deflection δ (mm) | Bending stress σ (MPa) | Deflection δ (mm) |
| 1 | 100 | 43.01 | 11.08 | 0.90 | 28.39 | 2.77 |
| 2 | 500 | 215.05 | 55.43 | 4.54 | 141.93 | 13.83 |
| 3 | 1000 | 430.1 | 110.88 | 9.08 | 283.87 | 27.65 |
| 4 | 1500 | 645.15 | 166.31 | 13.62 | 425.80 | 41.48 |
| 5 | 2000 | 680.2 | 175.35 | 14.36 | 448.93 | 43.73 |
| 6 | 3000 | 1290.3 | 332.63 | 27.24 | 851.60 | 82.96 |
| 7 | 3483 | 1498.03 | 386.19 | 31.63 | 988.69 | 96.31 |

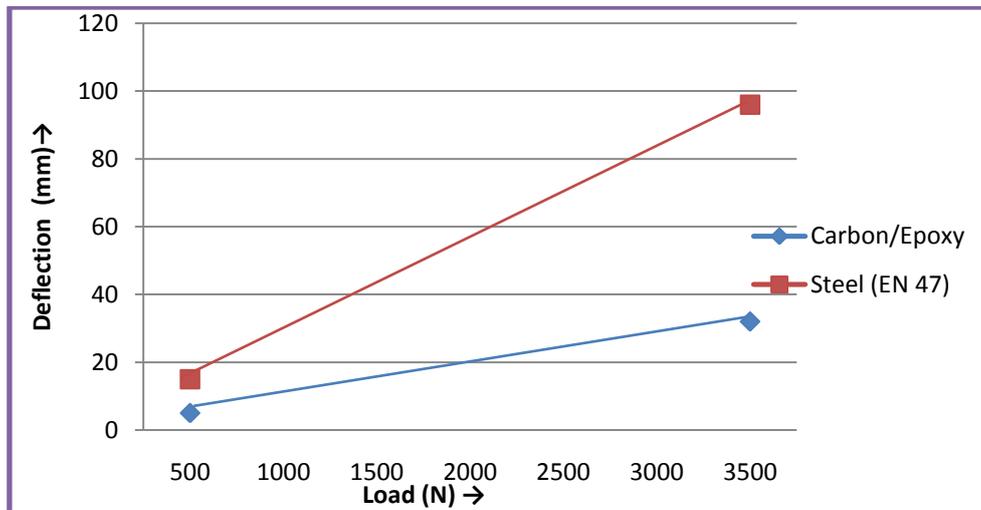


Fig. 4.4 Graph of Load Verses Deflection

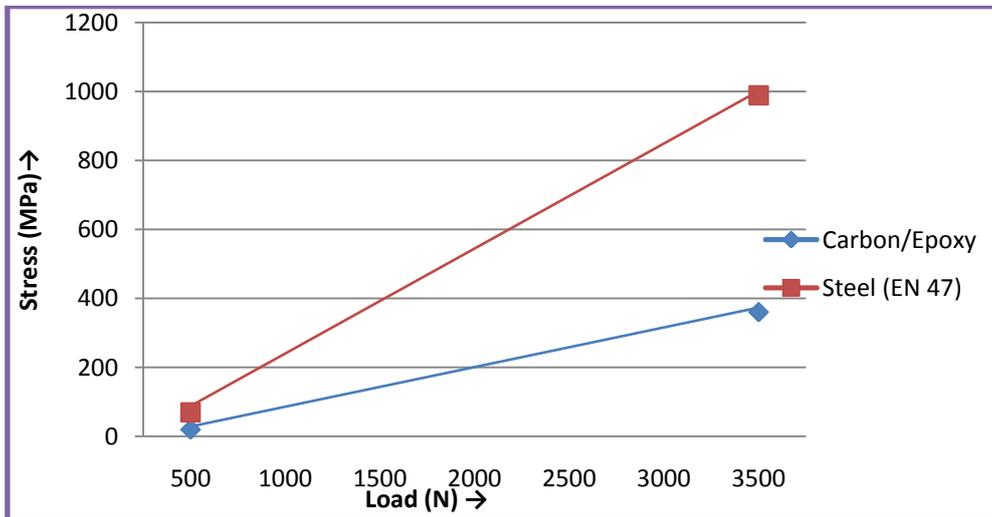


Fig. 4.5 Graph of Load Verses Stress

5. CONCLUSION

The conclusion of work is to minimize stress and deformation in Carbon/Epoxy composite leaf spring compared to steel leaf spring for automobile suspension system. This is done to achieve the following- It can be observed from the comparison that the deflection and bending stress induced in the Carbon/Epoxy

composite leaf spring is less than the conventional steel leaf spring for the same load carrying capacity.

- This design helps in the replacement of conventional steel leaf springs with Carbon/Epoxy mono composite leaf spring with better ride quality.
- To achieve weight reduction in the suspension system by replacing steel leaf spring with mono composite leaf spring.

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