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A Review Paper on Design and Analysis of a Steel and Composite Leaf Spring

Mohiuddin Salahuddin Kamdod [a], Manjunath B T [b]

[a, b] Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru, India

ABSTRACT

This Research paper reviews the Design and Analysis of a steel and composite leaf spring. One of the first types of suspension parts, leaf springs are still widely utilized, especially in commercial vehicles. There is growing interest, according to the literature, in switching from steel to composite leaf springs. Vehicle behaviour, or vibration qualities such as ride comfort, stability, etc., are greatly influenced by the suspension system in the vehicle. Numerous studies have been conducted to enhance the functionality of leaf springs. Leaf springs can be made from a variety of materials. A lot of materials are used for leaf springs. But it is found that composite materials have better performance than compared to steel as they show less stress and deflection value and other characteristics like strength, lighter weight, and so on. In this paper, the review was done on a few papers and found out alternate composite materials for the better performance of leaf springs.

Keywords: Leaf spring, Composites Leaf Spring

1. Introduction

The leaf spring is one of the many parts of an automobile that may be changed with relative ease. Simple springs, such as leaf springs, are frequently employed in wheeled vehicles' suspension systems. The region where the vehicle's suspensions need to be improved for a comfortable ride is the leaf spring suspension. To absorb shock loads in autos like light motor vehicles, heavy-duty trucks, and rail systems, leaf springs are primarily employed in suspension systems. In addition to supporting vertical loads, leaf spring assemblies serve as suspension components that isolate vibrations brought on by the road. The clamping effects, inter-leaf contact, and other characteristics of leaf spring behavior make it difficult. Steel parts are increasingly frequently replaced by composite materials. The utilization of composite materials for automobiles was the subject of several articles.

The concept of spring is an elastic body that can deform when loaded and return to its original shape when the force is released. Springs are elastic bodies that can be forced to twist, pull, or stretch. When the force is withdrawn, they might revert to their previous shape. Flat plates are used to create leaf springs, commonly referred to as flat springs. A leaf spring has an advantage over a helical spring in that its ends can be directed along a predetermined path as it deflects, acting as a structural member in addition to an energy absorber. Thus, in addition to carrying shocks, leaf springs may also support lateral loads, brake torque, driving torque, etc. Figure 1. illustrates a single plate that is loaded at one end and fixed at the other. You might use this plate as a flat spring.

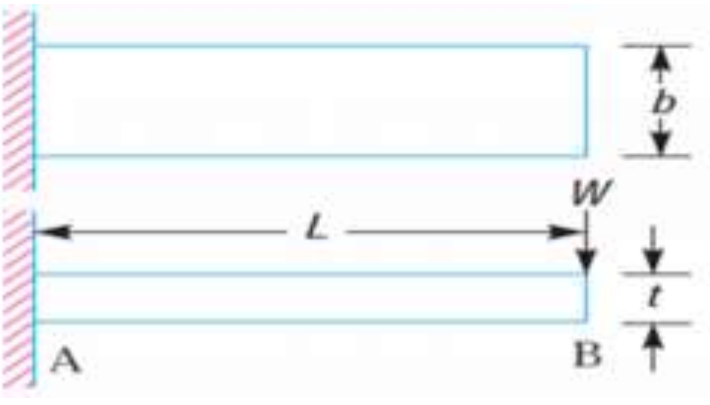

Fig. 1 – Flat spring cantilever type.

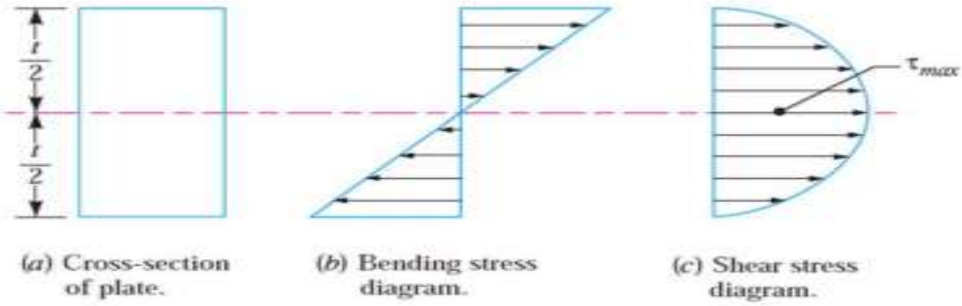

Fig. 2 – (a) Cross-section of plate (b) Bending stress (c) Shear stress diagram.

Top and bottom fibers will be in tension and compression, respectively, during the bending moment, while the shear stress is zero at the extreme fibers and maximal in the middle. According to figure 2, shear stress is at its highest near the middle, when bending tension is zero.

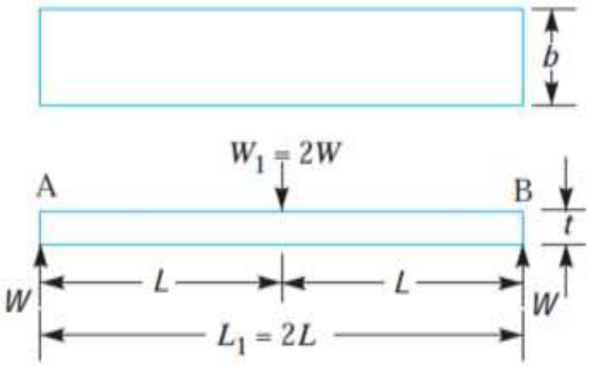

Fig. 3 – Flat spring simply supported beam type.

As illustrated in figure 3, the length and load of the spring are 2L and 2W, respectively. Using the following equation, the bending stress and deflection of this plate are determined.

The bending stress & deflection of this flat plate is calculated using the following equation.

Bending stress in spring; σ_b

Deflection of spring; y

$$\sigma_b = \frac{6 \times W \times L}{b \times t^2} \qquad (1)$$

$$y = \frac{4 \times W \times L^3}{E \times b \times t^3} \qquad (2)$$

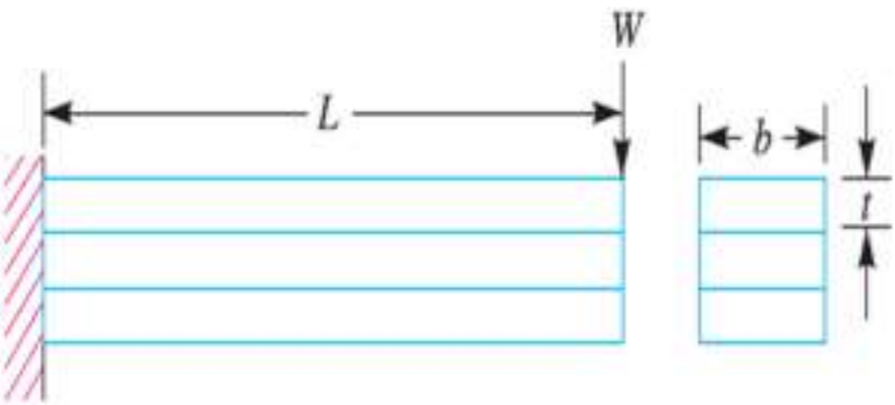

Fig. 4 – Flat spring simply supported beam type (n leaves).

If the spring is thought of as a cantilever beam with width b and thickness t as shown in figure 4, it will have n-strips. Using the following equation, the bending stress and deflection of this sort of spring are determined.

$$\sigma_b = \frac{6 \times W \times L}{n \times b \times t^2} \qquad (3)$$

$$y = \frac{4 \times W \times L^3}{n \times E \times b \times t^3} \qquad (4)$$

The aforementioned relationships determine the stress and deflection of a uniform cross-sectional spring. The support of such a spring experience the most stress. The stress will be uniformly distributed if the spring has a triangular plate, as shown in figure 5 (a). The bending stress and deflection of this triangle plate are computed using the following equation if the strips that make up the triangle plate are chopped into uniform-width pieces and stacked one on top of the other as illustrated in figure 5 (b).

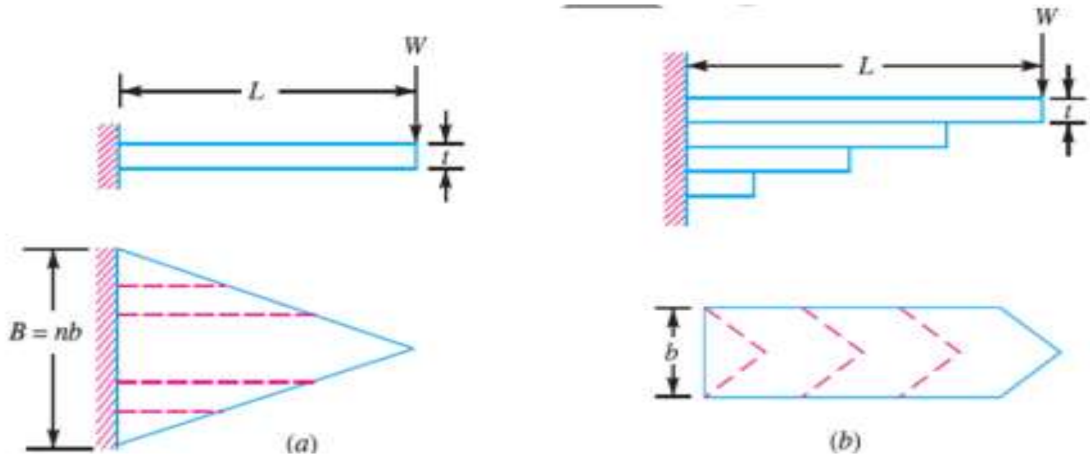

Fig. 5 – Laminated leaf spring.

$$\sigma_b = \frac{6 \times W \times L}{n \times b \times t^2} \qquad (5)$$

$$y = \frac{6 \times W \times L^3}{n \times E \times b \times t^3} \qquad (6)$$

A typical leaf spring found in cars has a semi-elliptical shape, as depicted in figure 6. It is made of several plates (known as leaves). To make the leaves more likely to straighten under pressure, they are typically given an initial curvature or camber. The bands or bolts that travel through the center of the leaves serve as a way of holding them together. The effective length of the spring for bending will be equal to the overall length of the spring minus the width of the band since the band has a stiffening and strengthening effect. In the event of a centre bolt, the effective length of the spring should be calculated by subtracting the two-thirds distance between the centres of the U-bolt from the total length of the spring. U-bolts are used to secure the spring to the axle housing.

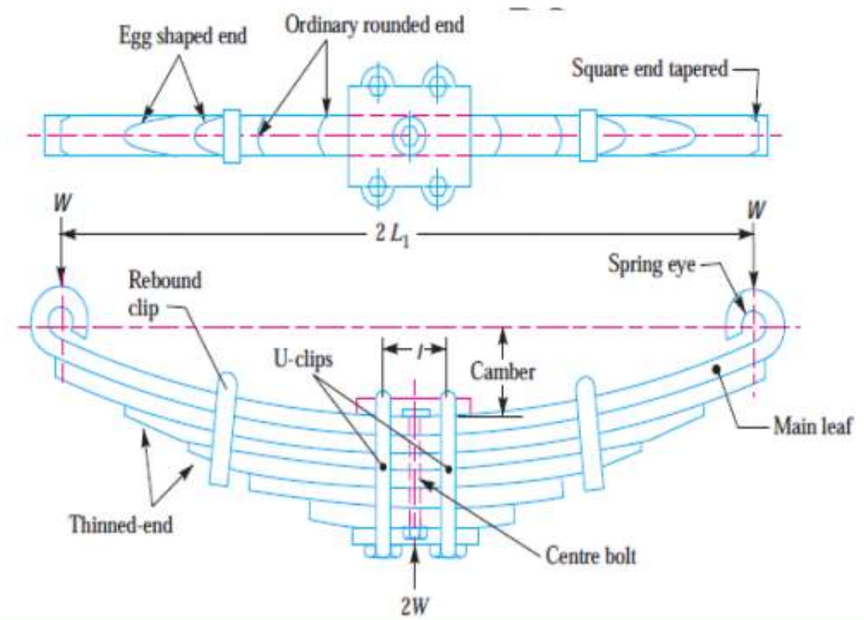

Fig. 6 – Semi elliptical leaf spring.

The main leaf often referred to as the master leaf, is the longest leaf. Its ends are designed with an eye through which bolts are inserted to fasten the spring to its supports. Typically, bushings made of an anti-friction substance like bronze or rubber are installed in the eye through which the spring is connected to the hanger or shackle. The additional springtime leaves are referred as graded leaves. The ends of the graded leaves are clipped in a variety of ways as indicated in figure 6 to prevent digging in the nearby leaves. It is customary to give two full-length leaves and the remaining graduated leaves as indicated in figure 6 because the master leaf must withstand loads that result from twisting, the sideways motion of the vehicle, and vertical bending. Rebound clips are positioned halfway down the spring's length so that the graduated leaves experience the same stresses as the full-length leaves when the spring rebounds. Standard dimensions Standard nominal widths are: 32, 40, 45, 55, 60, 65, 70, 75, 80, 90, 100 and 125 mm. Standard nominal thickness is: 3.2, 4.5, 5, 6, 6.5, 7, 7.5, 8, 9, 10, 11, 12, 14 and 16 mm. At the eye, the following bore diameter are recommended: 19, 20, 22, 23, 25, 27, 28, 30, 32, 35, 38, 50, 55 mm. Applications In vehicle springs, railway buffers, aircraft landing gear, shock absorbers, and vibration dampers, the purpose is to cushion, absorb, or control energy due to either shock or vibration. To exert force, as in the case of brakes, clutches, and spring-loaded valves. To maintain contact between two elements, as in cams and followers, to control motion. To measure forces, as in engine indications and spring balances. For energy storage, like in watches, action figures, etc.

Types of leaf springs

Multi-Leaf Spring: - For the suspension of automobiles, lorries, and railroad wagons, multi-leaf springs are frequently employed. A multi-leaf spring is made up of a number of flat, typically semi-elliptical, plates. The flat plates are referred to as spring leaves. The longest leaf is the one at the top. As you move from the top leaf to the lowest leaf, the length gradually gets shorter. The master leaf refers to the topmost, longest leaf.

Mono Leaf Spring: -Since they are not made for bigger vehicles, mono leaf springs are better suited to LCVs than HGVs. They have a construction that is similar to the multi-leaf system but without the additional plates, with a thicker center that gradually thins out toward the ends. Single leaf spring systems were once widely used, but they lost some of their appeals when they started to fail on bigger cars. Although not when the vehicle in question needs to be protected from a big load or the weight of the vehicle itself, it can still be seen and utilized.

Semi-elliptical Leaf Spring: -A multi-leaf spring typically takes on this shape, resembling the bow of a bow and arrow but lacking the string. Elliptical: An oval form can be made by combining two leaf springs that are facing away from one another. We call this elliptical.

Quarter-Elliptical Leaf Spring: - In earlier tiny cars like Chryslers, quarter-elliptical springs were employed. This sort of spring is attached to the frame with a bolt and only makes up a fraction of an entire elliptical spring.

Three-Quarter Elliptical Leaf Spring: - Semi-elliptical and quarter elliptical springs are combined to form a three-quarter elliptical spring. These springs were employed in vintage automobiles.

Full-elliptical leaf spring: - Two semi-elliptical springs are linked together in an opposite direction to form full elliptical springs. Older autos had springs of this type. They don't keep the axles properly aligned.

Transverse Leaf Spring: - Transverse springs have an inverted shape and are similar to semi-elliptical springs. The spring's other end is connected to the axle, and one end is shackled to the chassis frame. The bolts in the middle, it is also secured to the frame.

About the Composite Material:

Composite materials, polymers, and ceramics have dominated as emerging materials over the past thirty years. Composite materials have gradually increased in volume and number of uses, relentlessly entering and dominating new areas. Modern composite materials make up a large component of the engineered materials market, being used in everything from simple everyday items to complex specialist applications. Although composites have previously demonstrated their value as lightweight materials, the present problem is to make them affordable. The composites sector is currently using a number of cutting-edge production techniques as a result of efforts to develop economically appealing composite components. It is clear that, especially for composites, the cost barrier cannot be overcome by advancements in manufacturing technology alone. For composites to be competitive with metals, there must be an integrated effort in design, material, process, tooling quality assurance, manufacturing, and even systems integration. Further, the adoption of innovative and advanced materials that not only reduce dead weight but also absorb shock and vibration has been given significant priority due to the need for composite for lighter construction materials and more seismic resistant structures. In order to retrofit existing structures to make them seismically resistant or to repair damage from seismic activity, composites are increasingly widely employed for rehabilitation and strengthening. Contrary to conventional materials (like steel), the qualities of composite materials can be tailored while taking structural considerations into account. Both material and structural design go into the creation of a composite structural component. Under the designer's control, composite qualities, such as stiffness, can be continually changed throughout a wide range of values. The properties of the end product can be customised to practically any precise engineering need through careful reinforcing type selection. While using composites will often be a clear choice, other times material selection will depend on factors like the need for a long working lifetime, the quantity of items to be produced (run length), the complexity of the product shape, potential assembly cost savings, and the designer's experience and skills in utilizing composites to their fullest potential. In some circumstances, using composites in addition to conventional materials may produce the optimum results.

3. Literature Survey

Pankaj Saini, Ashish Goel, and Dushyant Kumar et. al [1] have worked on the design and analysis of composite leaf springs for light vehicles. This study examines passenger vehicles The goal is to contrast the stresses and weight savings between steel and composite leaf springs. E-glass/epoxy, carbon epoxy, and graphite epoxy were the materials chosen as an alternative to traditional steel. Steel leaf springs and composite leaf springs are thought to have the same size and leaf counts. They regarded strains and deflections as design limitations. According to the findings of the static analysis, the steel leaf spring has a maximum displacement of 10.16 mm, whereas the equivalent displacements for E-glass/epoxy, graphite epoxy, and carbon epoxy are 15 mm, 15.75 mm, and 16.21 mm. According to the results of the static study, the von-mises stress in steel is 453.92 MPa, while it was exiting at 163.22 MPa for e-glass epoxy, 653.68 MPa for graphite epoxy, and 300.30 MPa for carbon epoxy.

Mahmood M. Shokrieh and Davood Rezaei et. al [2] have worked on the analysis and optimization of a composite leaf spring. In this study, they use ANSYS software to analyse stress and deflection in a light car rear suspension system with four steel leaf springs. Additionally, they evaluated the stresses and deflection results using finite elements with the analytical and experimental solutions already in use. Following that, they replaced the steel leaf spring with a composite made of fiberglass and epoxy resin, and using the same loading conditions, they analysed it for stresses and deflection. Additionally, they adjusted the spring shape based on the analysis results and discovered that the spring thickness increased linearly from the spring eyes to the axle seat while the spring width decreased hyperbolically. Additionally, they came to the conclusion that the optimal composite leaf spring has significantly less stress than a steel spring.

M.Venkatesan and D.Helmen et. al [3] have worked on design and analysis of composite leaf spring in light vehicle. In this study, they use ANSYS software to analyse stress and deflection in passenger cars with seven-leaf steel springs. The comparison between steel and composite leaf springs' load-carrying capacity, stiffness, and weight reductions is the goal. They also compared the stresses and deflection results from finite elements with the results from previous analytical and experimental studies. They replaced the steel leaf spring with a composite made of E-glass and epoxy utilising that finding, and they analysed it under the identical loading conditions for stresses and deflection. Steel leaf springs and composite leaf springs are regarded as having the same size and leaf counts.

Gulur Siddaramanna Shiva Shankar and Sambagam Vijayarangan et. al [4] have worked on mono composite leaf spring for light weight vehicle – Design, end joint analysis and testing. In this study, they use the ANSYS software to analyse the stress and deflection of a light weight vehicle leaf spring. For both materials, the design limitations were stresses and deflection. Utilizing ANSYS software, 3-D modelling of both steel and composite leaf springs was completed, and analysis was performed utilising the same loading conditions and dimensions for both materials. The results of the ANSYS programme were confirmed by analytical and experimental data, and it was determined that the optimised composite spring had substantially lower stress, was about 85% lighter, and had a higher natural frequency than a steel leaf spring.

Mouleeswaran Senthil Kumar and Sabapathy Vijayarangan et. al [5] have done work on analytical and experimental studies on fatigue life prediction of steel and composite multi-leaf spring for light passenger vehicles using life data analysis. For the analysis, ANSYS software was used to determine the stress and deflection in a steel leaf spring. The goal is to evaluate the steel leaf spring's load carrying capacity, stiffness, fatigue life, and weight savings to that of the composite leaf spring. A light commercial vehicle's existing conventional steel leaf spring's dimensions are measured, and they are confirmed by design calculations. They also compared the stresses and deflection results from finite elements with the results from previous analytical and experimental studies. Glass fibre reinforced polymer unidirectional laminates are utilised to build a composite leaf spring with the same dimensions as a traditional leaf spring, and it is then examined for stresses and deflection under the same loading conditions.

K. K. Jadhao and DR. R.S. Dalu et. al [6] have worked on experimental investigation & numerical analysis of composite leaf springs. Using ANSYS software, they describe static analysis of steel leaf springs and composite multi-leaf springs. The main goal is to contrast the steel leaf spring with the composite leaf spring in terms of load carrying capacity, stiffness, and weight savings. Glass fibre reinforced plastic (GFRP) was the material chosen because it could be utilised more cheaply than other resins, which will lower the overall cost of a composite leaf spring. They have contrasted the analysis results with the outcomes of the experiments. They came to the conclusion that composite leaf springs had significantly lower stress and greater rigidity than those made of steel currently in use. Additionally, they found that the weight of the composite leaf spring was almost 85% less than the weight of the steel leaf spring.

Kumar Krisha and Aggarwal M.L et. al [7] have worked on Computer-aided FEA comparison of mono steel and mono GRP leaf spring. For the purpose of this paper's stress and deflection analysis utilising ANSYS software, SUP9 is used as the material for a mono steel leaf spring. Comparing composite leaf springs to steel leaf springs with regard to load carrying capability, rigidity, and weight savings is the goal. Additionally, they have contrasted the stresses and deflection results using the finite element method with the results from previous analytical and experimental studies. Following that, based on this finding, they replaced the steel leaf spring with a composite made of GRP (glass reinforced plastic) and analysed it under the same loading conditions for stresses and deflection.

N. P. Dhoshi, Prof. N. K. Ingole and Prof. U. D. Gulhane et. al [8] have worked on analysis and modification of composite leaf spring of tractor trailer using analytical and finite element method. This study uses ANSYS software to analyse stress and deflection on a tractor trailer with a seventeen-leaf steel spring. The goal is to evaluate the steel leaf spring's load carrying capacity, rigidity, and weight savings to that of the composite leaf spring. Additionally, they compared the stresses and deflection results from finite elements to previous analytical and experimental findings. Using this information, they replaced the steel leaf spring with a composite made of E-glass and epoxy and analysed it under the same loading conditions for stresses and deflection. Steel leaf springs and composite leaf springs are thought to have the same size and leaf counts. They regarded strains and deflections as design limitations. They came to the conclusion that the composite leaf spring had significantly lower stress and deflection than the steel leaf spring currently in use. Additionally, they found that the weight of the composite leaf spring was almost 80% lower than that of the steel leaf spring.

H.A. Al-Qureshi et. al [9] has worked on automobile leaf springs from composite materials. This essay's objective is to provide an overview of research on composite spring analysis, design, and production. Accordingly, the suspension spring of a little car called "a jeep" was used as a prototype. Glass fibre reinforced plastic (GFRP) was used to create a single leaf spring with variable thickness that has similar mechanical and geometrical characteristics to the multi-leaf steel spring. The testing was carried out experimentally in the lab, and then a road test was conducted. He came to the conclusion that steel springs had worse fatigue behaviour than composite leaf springs. Additionally, he discovered that the hybridization technology may be successfully applied to increase weight reduction and performance in the automotive sector.

J.P. Hou, J.Y. Cherruault, I. Nairne, G. Jeronimidis, and R.M. Mayer et. al [10] have worked on the Evolution of the eye-end design of a composite leaf spring for heavy axle loads. In this study, they use FEA to analyze stress and deflection in freight rail applications utilizing a two-leaf steel spring. Additionally, they evaluated the stresses and deflection results using finite elements with the analytical and experimental solutions already in use. They next replaced the steel leaf spring with a composite made of glass reinforced polyester (GRP) using this finding as a guide, and they analyzed it for stresses and deflection under identical loading conditions. They came to the conclusion that composite leaf springs are stiffer and have less stress than steel leaf springs. Additionally, they came to the conclusion that composite leaf springs have far better fatigue life than current steel leaf springs and reduce shear stresses in eye-end design.

So, from the above literature review, we can say that composite leaf springs are far better than steel leaf springs.

4. Conclusion

The literature analysis reveals that the goal was to create a spring with a minimal weight that could withstand specific static external forces by placing restrictions on stresses and displacements. For that reason, a composite leaf spring is used in place of the steel leaf spring. Steel leaf springs are inferior to composite leaf springs. Analytical and experimental findings were used to compare the performance of steel and composite leaf springs. FEA is used to forecast the overall life cycle and fatigue life of steel and composite leaf springs. Results reveal that composite leaf springs are lighter than traditional steel leaf springs with comparable design requirements, albeit they are not always more affordable than their steel counterparts. The stresses in the composite leaf spring are much lower than that of the steel spring, so it is concluded that the composite leaf spring is an effective replacement for the existing steel leaf spring in the automobile.

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