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# Comparison of Experimental and Numerical Investigation of Mono-Composite and Metal Leaf Spring

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## Abstract

*The automotive industry is increasingly focused on reducing vehicle weight, leading to the widespread adoption of composite materials with high strength-to-weight ratios in both aviation and automotive sectors. These materials are gradually replacing traditional options like steel. Leaf springs, one of the oldest and most common suspension components, continue to be widely used in vehicles. This study aims to replace conventional multi-leaf steel springs with mono-composite leaf springs while preserving the same load-carrying capacity and stiffness. Composite materials, such as glass fiber and epoxy resin, provide advantages including higher elastic strain energy storage, superior strength-to-weight ratios, and enhanced corrosion resistance compared to steel. Consequently, the weight of leaf springs can be reduced without sacrificing performance. The steel and mono-composite leaf springs were modeled using Catia software, and their performance was evaluated using ANSYS 15.0 software.*

**Keywords:** *Ansys, Epoxy Resin and Glass Fiber, Finite Element Analysis (FEA), Leaf Spring, Mono Composite Materials, Suspension*

## 1.0 Introduction

### 1.1 Origin of Study

Multi-leaf springs are integral components in the suspension systems of cars, trucks, and railway wagons, providing support, stability, and comfort. These springs, commonly found in automobiles, feature a semi-elliptical shape that efficiently distributes weight and absorbs shock from road irregularities. The design and construction of

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multi-leaf springs play a crucial role in their functionality and durability. A typical leaf spring consists of several layers, or leaves, of steel plates stacked together. These leaves are initially curved, or cambered, which allows them to straighten when a load is applied. This cambering process ensures that the spring can absorb and distribute the load effectively, preventing sudden jolts and providing a smoother ride[1-3].

The leaves are held together by two U-clips and a center bolt. The U-clips wrap around the leaves, securing them in place, while the center bolt runs through the middle, holding the assembly together. Rebound clips are strategically placed along the length of the spring to maintain alignment and prevent lateral shifting of the plates during operation. These clips ensure that the leaves remain properly aligned, enhancing the spring's overall stability and performance. The longest leaf in the assembly is known as the master leaf. This leaf is unique because it is bent at both ends to form the spring eye, which is the point of attachment to the vehicle's chassis. The spring eye allows for pivotal movement, enabling the suspension to flex and adapt to varying road conditions. The master leaf is also the primary load-bearing component, providing the necessary strength and support to the suspension system.

At the centre of the spring, the assembly is fixed to the vehicle's axle. This central attachment point is crucial as it distributes the weight evenly across the axle, ensuring balanced support for the vehicle. The connection between the leaf spring and the axle allows for controlled movement, absorbing shocks and vibrations from the road surface, thus enhancing the ride quality[3].

In addition to the master leaf, multi-leaf springs often include one or two extra full-length leaves. These additional leaves are stacked between the master leaf and the graduated-length leaves, which are progressively shorter. Including extra full-length leaves provides additional support, particularly for the transverse shear force, which is the force acting perpendicular to the axis of the spring. This reinforcement is essential for heavy-duty vehicles, such as trucks and railway wagons, which carry substantial loads and require enhanced durability and strength. The graduated-length leaves, which taper in size from the master leaf downwards, distribute the load more evenly across the spring. This graduation in length ensures that the stress is spread out, reducing the likelihood of any single leaf bearing too much weight and potentially failing. The combination of the master leaf, extra full-length leaves, and graduated-length leaves creates a robust and efficient spring assembly capable of handling various load conditions.

Overall, the design of multi-leaf springs is a testament to engineering ingenuity. Their ability to provide consistent support, absorb shocks, and maintain alignment under varying loads makes them indispensable in the automotive and transportation industries. By understanding the intricacies of their construction and functionality, one can appreciate the vital role these springs play in ensuring a smooth and stable ride for vehicles of all types[1-3].

The longest leaf, referred to as the master leaf, has ends that are shaped like eyes that are used to slide bolts through to fasten the spring to its supports. Typically, bushings or an anti-friction substance like rubber or bronze are installed in the eyes, which are used to

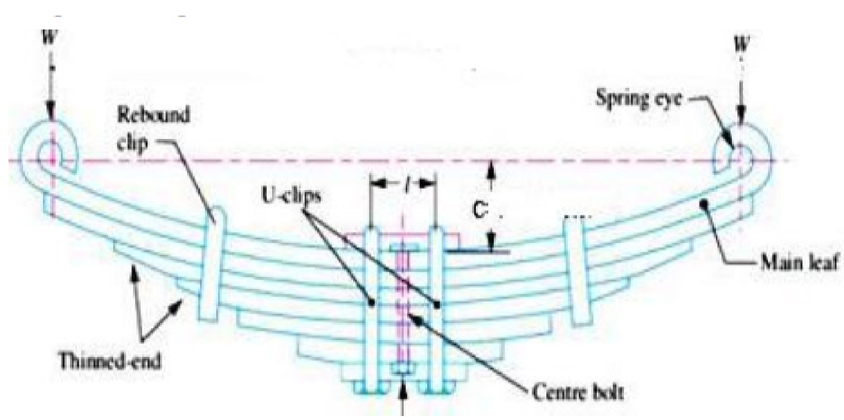


**Figure 1.** Conventional steel leaf spring[2].

connect the spring to the hanger or shackle. Graduated leaves are the other springtime leaves. It is customary to offer full-length leaves and the remaining graduated leaves since the master leaf must bear stresses induced by loads resulting from sideways of the vehicle, twisting, and vertical bending[1-3]. Major disadvantages of steel leaf springs are: The weight of the leaf spring is more also stresses developed in steel leaf springs are high. Steel leaf springs are corroded because of this life of steel leaf spring is reduced. Also, steel leaf springs make more noise. Because of this nowadays in the automobile sector steel leaf springs are replaced by composite leaf springs

### 1.2 Scope

A few advantages of composite materials are improved strength, stiffness, resistance to corrosion, resistance to wear, and fatigue life. They can also reduce weight, improve attractiveness, and better thermal and acoustic insulation. Fiber-Reinforced Polymers (FRPs) have been extensively developed due to their potential for significant weight savings. Compared to steel, FRPs provide several advantages: They reduce noise, vibrations, and ride harshness because of their high damping properties, eliminate corrosion issues leading to lower maintenance costs, and reduce tooling expenses, which lowers overall manufacturing costs.

When comparing composite leaf springs to conventional steel leaf springs, several key advantages emerge:

**1. Reduced Weight**: The laminate structure and thinner design of mono-composite leaf springs result in a lower overall weight.

**2. Fuel Efficiency**: The reduction in weight leads to decreased fuel consumption.

**3. Enhanced Damping**: Composite leaf springs have a high damping capacity, which minimizes vibrations and noise during operation.

These benefits make composite leaf springs a superior choice for applications requiring lightweight and high-performance components.

### 1.3 Objective of the Study

The use of composite materials has enabled a significant reduction in the weight of leaf springs while maintaining their load-carrying capacity and stiffness. As reducing weight is a key priority for automobile manufacturers today, replacing traditional steel with optimally designed composite leaf springs can achieve up to an 80% weight reduction. Additionally, composite leaf springs experience lower stress levels compared to their steel counterparts. These advancements contribute to fuel savings, which in turn can enhance energy independence by reducing the need for fuel production.

## 2. Review of Literature

The integration of composite materials into automotive design, particularly for leaf springs, marks a significant advancement in vehicle technology, optimizing both performance and efficiency. This detailed study leverages Finite Element Analysis (FEA) to explore and enhance the design of composite leaf springs made from fiberglass and epoxy resin. The goal is to achieve minimal weight while ensuring adequate load-bearing capacity and overall performance.

### 2.1 Finite Element Analysis (FEA) and Optimization

The research began with a thorough analysis of a traditional steel leaf spring used in a car's rear suspension system. FEA was employed to simulate and assess the performance of this steel component, providing a baseline for comparison with composite alternatives. The analytical methods were validated through experimental testing, confirming the FEA results and ensuring the accuracy of the findings.

The team went on to construct and optimize a fiberglass and epoxy resin composite leaf spring using these verified results. To reduce the weight of the composite leaf spring and still achieve the required load requirements, the geometry of the spring was optimized. Natural frequency and the distribution of stress were important optimization parameters. The composite leaf spring was created to have a greater natural frequency and lower stress levels than its steel equivalent by modifying the design specifications. This was essential to prevent road resonance and guarantee the spring's ability to withstand static external stresses without breaking[4,5].

### 2.2 Performance and Comparative Analysis

The study revealed that the optimized composite leaf spring achieved a remarkable 80% reduction in weight compared to the steel spring. This significant weight reduction is attributed to the inherent properties of composite materials, which offer high strength-to-weight ratios. In addition to weight reduction, the composite leaf spring demonstrated a 6105% decrease in stress, a 64.95% increase in stiffness, and a 126.98% increase in natural frequency compared to the steel spring. These improvements contribute to enhanced vehicle performance and efficiency[6-7].

Further comparative studies showed that composite leaf springs, including those made from E-glass or epoxy, graphite or epoxy, and carbon or epoxy, all outperformed traditional steel springs in various aspects. For instance, the stiffness of E-glass or epoxy composite leaf springs was found to be 36.72 N/mm, while graphite or epoxy and carbon or epoxy composites exhibited even higher stiffness levels at 39.92 N/mm and 41.06 N/mm, respectively[8]. Notably, the composite leaf springs showed substantial weight reductions, with E-glass or epoxy reducing weight by 85%, graphite or epoxy by 94.18%, and carbon or epoxy by 92.94% compared to conventional steel leaf springs[9-11].

The study also addressed the fatigue life of the leaf springs. It was determined that composite leaf springs have a longer fatigue life compared to steel springs, highlighting their durability and suitability for various vehicle applications. The improved fatigue resistance is attributed to the composite materials' ability to distribute stresses more evenly and withstand repeated loading cycles more effectively[11].

## 2.3 Design Considerations and Practical Implementation

The design of the composite leaf spring involved creating a model with a constant cross-sectional area and variable thickness and width. The use of adhesive bonding for end joints, as opposed to bolted joints, was found to enhance the performance of the composite leaf spring by reducing issues related to delamination and stress concentration at the ends[12-15].

The study also explored the implementation of parabolic leaf springs as a potential replacement for traditional mono-leaf springs in vehicles. Through modelling and analysis, it was demonstrated that composite leaf springs can achieve up to 78% reduction in maximum total deflection, a 30% reduction in Von Mises stress, and an 80% weight reduction when compared to steel springs. These improvements are critical for optimizing vehicle suspension systems and enhancing ride quality[13-15].

Static and fatigue life predictions for various composite materials, including E-glass or epoxy, graphite or epoxy, and carbon or epoxy, were carried out using FEA. The results showed that composite leaf springs could be designed to achieve significant weight reductions up to 84.94% compared to steel springs without sacrificing performance. These materials exhibited higher elastic strain energy storage capacity and strength-to-weight ratios compared to steel, contributing to their superior performance[16-18].

The above study highlights the considerable advantages of using composite materials for leaf springs in vehicles. The optimized composite leaf spring not only achieves significant weight reduction but also demonstrates lower stress levels, higher stiffness, and better natural frequency compared to traditional steel springs. These enhancements lead to improved vehicle efficiency, performance, and comfort. The findings suggest that composite leaf springs, particularly those made from E-glass or epoxy, graphite or epoxy, and carbon or epoxy, offer substantial benefits over conventional steel springs. They provide a viable alternative for reducing vehicle weight, enhancing suspension performance, and achieving better fuel efficiency. As automotive technology continues to evolve, the adoption of advanced composite materials in suspension systems will likely play a crucial role in shaping the future of vehicle design, delivering both environmental and performance benefits. Kurhade *et al.,* conducted numerical simulations on Phase Change Material (PCM) cooling for smartphones and thermal performance[19-21]. Anant *et al.* utilized PCM to minimize chip temperatures[22-24]. Shital *et al.*, provided comprehensive reviews on heat transfer and its enhancement in tubular heat exchangers using jet impingement[25-27]. Rahul Khot *et al.*, investigated the impact of laser welding parameters on the strength of TRIP steel[28-33]. Gadekar T.D. *et al.*, conducted experimental studies on gear EP lubricants mixed with $Al_2O_3/SiO_2/ZrO_2$ composite additives to develop a predictive system[34-36]. Patil, P *et al.,* employed a water-based $Al_2O_3$ nanofluid for material grinding due to its excellent convective heat transfer and thermal conductivity properties[37]. Rahul Y *et al.*, employed a comparison of the effect of the process on the surface roughness of Copper and Mild Steel and the welding process for steel with used in BIW structures in vehicles[38-40].

## 3.0 Experimental Test Procedure

In the realm of fiber reinforcement materials, commonly used options include cotton, glass, and kevlar. Glass fiber is often selected due to its favorable balance of cost and strength. Among the various types of glass fibers, C-glass, S-glass, S+R glass, and E-glass, each serves distinct purposes. C-glass is primarily used to enhance surface finish, while S-glass provides exceptionally high strength, making it suitable for specialized applications in the aeronautical industry.

For the fabrication of Fiber-Reinforced Plastics (FRP), a variety of thermoset resins such as polyester, vinyl ester, and epoxy are utilized. Among these, epoxy resins are particularly notable for their superior interlaminar shear strength and excellent mechanical properties, which make them ideal for demanding applications. Consequently, epoxy is often chosen as the resin of choice for this application.

The polycondensation of epichlorohydrin with polyphenols produces epoxy resins. When making epoxy resins, bisphenol-A is frequently utilized as the polyphenol. Based on their mechanical characteristics, different hardener combinations and epoxy resin grades are categorized. This classification helps in selecting the most suitable resin and hardener combination for specific applications, ensuring optimal performance and durability in the final product.

### 3.1 Material Selection

The materials used in this process include coarsely woven E-glass fiber with a density of 400 gsm and glass fiber chopped strand mat ranging from 175 to 450 gsm. These materials are chosen for their high tensile strength, toughness, and cost-effectiveness. The selection of resin plays a critical role in determining the overall cost of the leaf spring. In this case, Dobeckot 520 F resin is used, paired with hardener 758, in a mass ratio of 10:1. This ratio is crucial for optimizing the cost and performance of the composite. The resin-to-hardener ratio is calculated for each weight percentage of the composite, based on factors such as the mould size, desired thickness, and the density of the fiber and epoxy. Each weight percentage is mixed in separate jars. To ensure effective wetting of the fibers and epoxy resin, a pot life of 2 hours is selected, allowing adequate time for proper mixing and application before the mixture begins to set[14].

### 3.2 Selection of Cross Section

For the manufacturing of mono-leaf springs, three cross-sectional designs are considered to facilitate the production process:

**1. Constant Thickness, Varying Width Design:** This design maintains a uniform thickness throughout the leaf spring while allowing the width to vary.

**2. Varying Width, Varying Thickness Design:** In this design, both the width and thickness of the leaf spring change along its length.

**3. Constant Thickness, Constant Width Design:** This design features both a consistent thickness and width throughout the entire length of the leaf spring.

In the present work, the constant thickness, constant width design has been chosen. This selection is driven by its advantages in mass production and the ease of incorporating continuous fiber reinforcement. Since the cross-sectional area remains uniform throughout the leaf spring, it allows for a consistent application of reinforcement fibers and resin during manufacturing. This uniformity simplifies the production process and ensures the effective distribution of materials, which is crucial for maintaining the structural integrity and performance of the leaf spring.

### 3.3 Manufacturing of spring

The Hand Lay-up process for manufacturing a mono-composite leaf spring involves several steps:

**1. Pattern Making:** Create a pattern based on the dimensions of a conventional steel leaf spring, considering cross-sections for ease of manufacturing as shown in Figure 2.

**2. Mould Making:** Fabricated a mold according to the pattern as shown in Figure 3.

**3. Fibers Cutting:** Cut glass fibers to the required lengths for layer-by-layer deposition as shown in Figure 4.

**4. Surface Finishing:** Place tissue mats on the top and bottom of the spring for a smooth finish.

**Figure 2.** Pattern of mono-composite leaf spring.

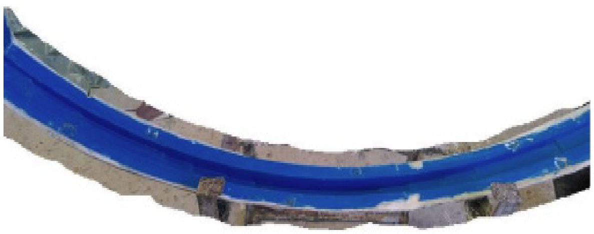

**Figure 3.** Mould of mono-composite leaf spring.

**5. Release Agent Application:** Apply a releasing agent to the mould.
**6. Epoxy Application:** Coat the tissue mat and glass fibers with epoxy resin, applying additional layers as needed while removing trapped air with a brush.
**7. Layering:** Continue layering until desired dimensions are achieved, ensuring no Fiber distortion.
**8. Curing:** The process continues until the desired dimensions are achieved as shown in Figure 5. Each layer must be carefully laid up to avoid fiber distortion, which could reduce the spring's strength and rigidity. The entire procedure can take up to 30 minutes. Afterward, the mould is left to cure at room temperature for 4-5 days[2].

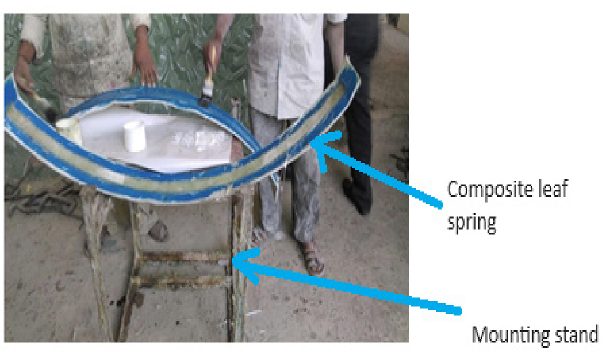


**Figure 4.** Glass fiber and epoxy resin layer by layer application.

**Figure 5.** Mono-composite leaf spring.

## 4.0 Experimental Results

### 4.1 Experimental Test with Leaf Spring Test

In this part, we address the load and deflection of leaf spring when it comes under different loading conditions (*i.e.* Tensile).

To test the mono-composite leaf spring, a computerized Universal Testing Machine (UTM) is employed. The process begins by securing a C-channel on the UTM to ensure proper sliding of the leaf spring. The leaf spring is then mounted on the UTM, as depicted in Figure 6. An initial load is applied at the centre of the leaf spring from the underside, and the data is recorded using the computer software. The UTM operates at a testing speed of 20 mm/min.

The load range is selected from 0 N to 4000 N. Then gradually load is increased on leaf spring and analysis of load and deflection is seen on computer display. The load and deflection curve is also stored in the computer memory. The load is applied until the leaf spring breaks. The data of gradually applied load and corresponding deflection of leaf spring with respect to time is also stored in the computer. The computer software generates the load *vs* deformation curve under different loading conditions. Initially, as the load on the mono-composite leaf spring increases the deformation of the mono-composite leaf spring also increases. The failure of the leaf spring occurs suddenly. Changes in cross-sectional area. The failure of

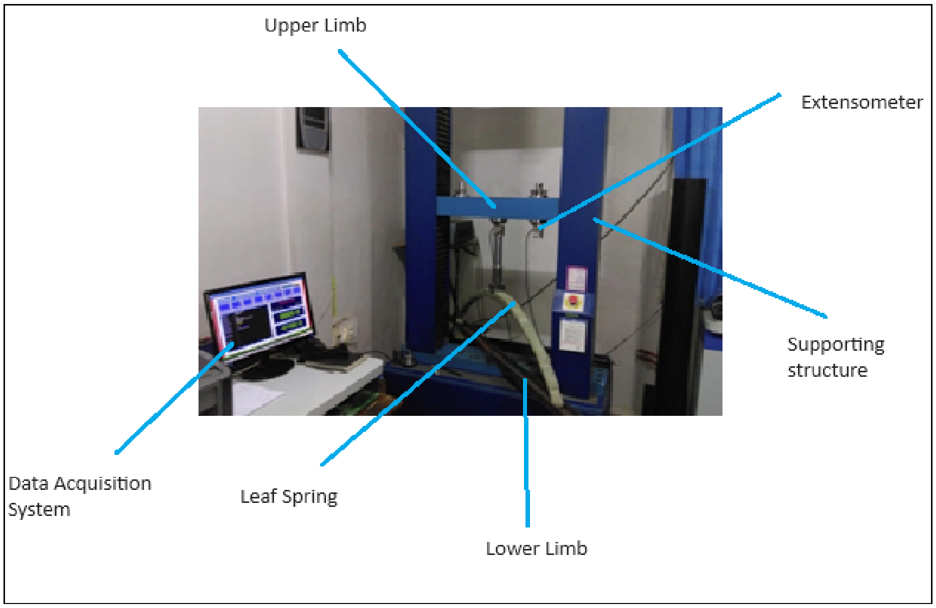


**Figure 6.** Experimental test set-up for testing of leaf spring.

**Figure 7.** Failure of mono-composite leaf spring.

the mono-composite leaf spring occurs at 2597.98 N load. Figure 7 shows the failure of the mono-composite leaf spring.

## 4.2 Finite Element Analysis

For linear analysis where the induced stresses are within the yielding of material and for less memory usage of computer 8 node brick element is better than other types of element. The 8-node brick element was selected for these analyses. This type of element is used for static loading with small deformation which fulfils the requirements of this analysis. 8 node Solid 185 hexahedral element is used for preparing the finite element model. A total of 1,23,557 nodes and 67,235 elements are there in the steel model and 1,12,432 nodes and 56,442 elements are in the composite leaf spring. As far as boundary conditions are concerned, one end of the eye of leaf spring is connected to the fixed axle and it rotates in one direction only, so at this end remote displacement is used in which these ends are allowed to rotate in one direction only and remaining are constrained.

At the other end the eye is not only rotated but also moves axially in one direction so, at this end remote

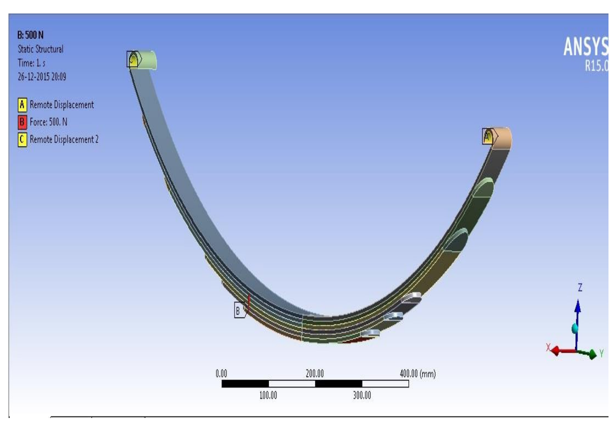


**Figure 7.** Boundary conditions used for analysis of leaf spring.

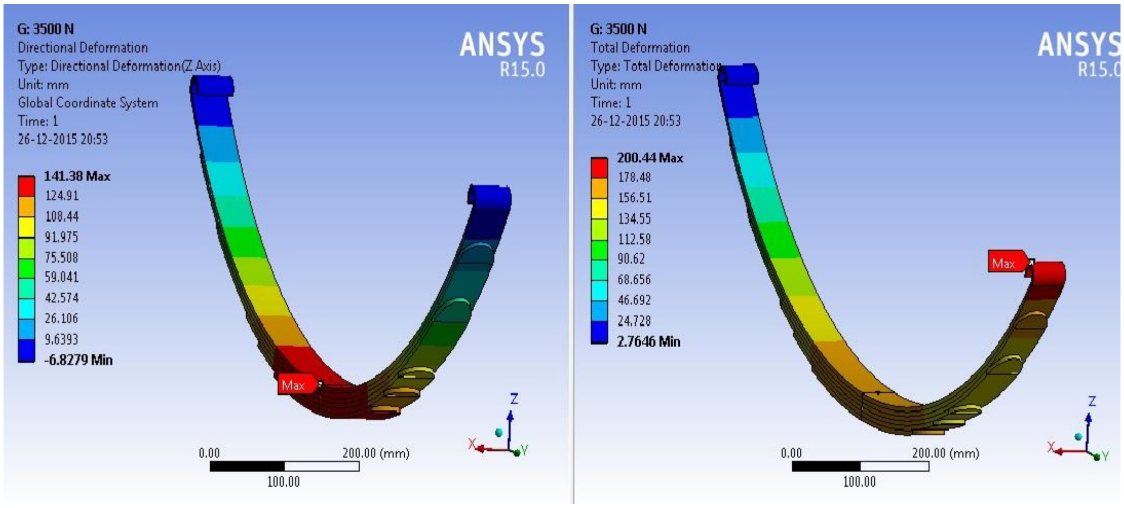


**Figure 9.** Analysis results of deflection for conventional steel leaf spring at load 3500 N.

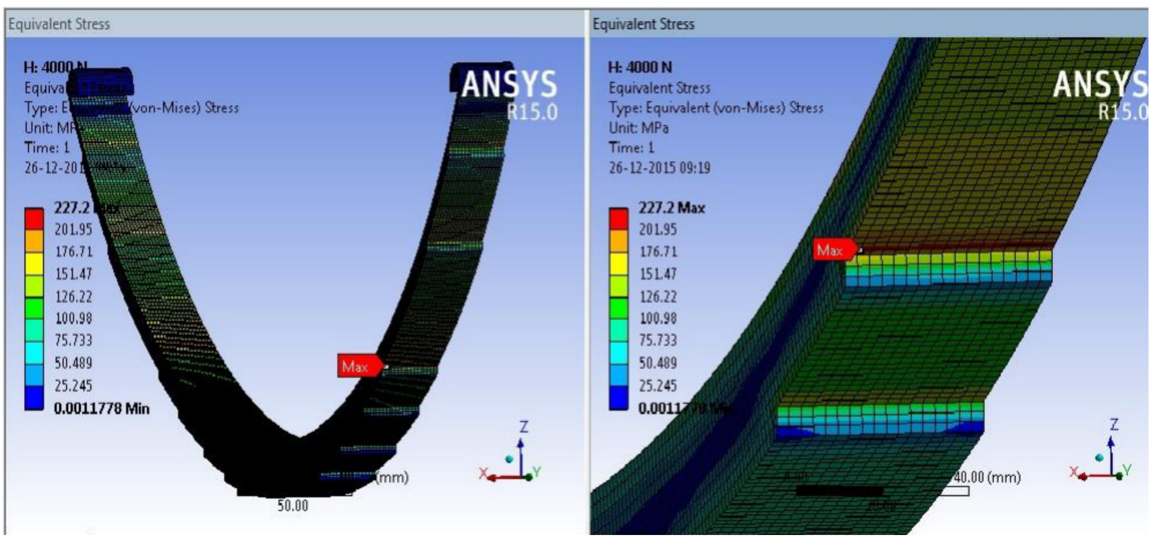


**Figure 10.** Analysis results of stress for mono-composite leaf spring at load 4000 N.

displacement is used in which it is free to rotate and allowed to move in one direction and remaining are constrained. The force is applied at the small leaf plate in vertically upward direction. The overall process and results are shown in Figure 8 to Figure 11.

In the analysis of the leaf spring system, fixed supports are placed at both ends of the leaf spring, as depicted in Figure 8. A load is applied at the center of the spring, and its magnitude varies from 500 N to 4000 N in predefined intervals.

Figure 9 illustrates the resulting directional and total deformation of the leaf spring. Notably, when the load reaches 3500 N, the middle section and one end of the spring are highlighted in red, indicating significant deformation in these areas. Additionally, Figure 10 details the Equivalent Von-Mises stress distribution across the leaf spring. At the maximum load of 4000 N, the Von-Mises stress reaches a peak value of 227.5 MPa, providing insight into the stress conditions experienced by the spring under maximum loading conditions. This data helps in understanding the performance and structural

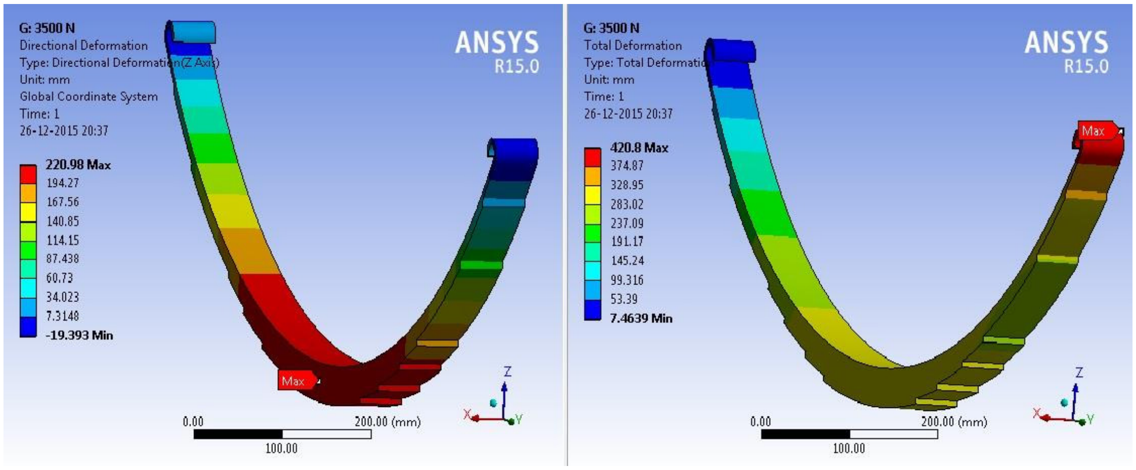


**Figure 11.** Analysis results of deflection for mono-composite leaf spring at load 4000 N.

integrity of the leaf spring under varying load scenarios. Figure 11 presents results similar to those in Figure 9, with the loading condition adjusted from 3500 N to 4000 N. Under this new load, the directional deformation increases from 141.38 mm to 220.98 mm, while the total deformation ranges from 200.44 mm to 420.8 mm.

## 5.0 Result and Discussion

A conventional steel leaf spring is designed according to the standard design procedure and analysed using ANSYS 15.0 software. In design, we calculated the deflection and bending stress developed in the leaf spring under a 500 N to 4000 N load.

Figure 12 shows a graphical representation of the load *vs.* deflection of conventional steel leaf springs for the analytical result and the Finite Element Analysis (FEA) result. The deflection of conventional steel leaf springs increases linearly with load.

Figure 13 shows graphical representation of the Load *vs* Stress of conventional steel spring for analytical result and Finite Element Analysis (FEA) result. The results obtained from analytical and FEA are almost the same.

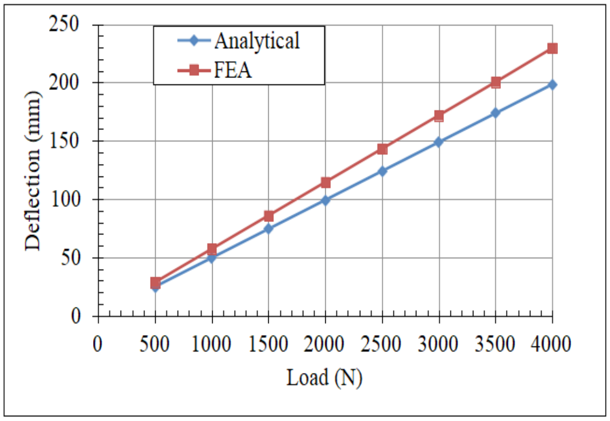


**Figure 12.** Graph load vs deflection for conventional steel leaf spring.

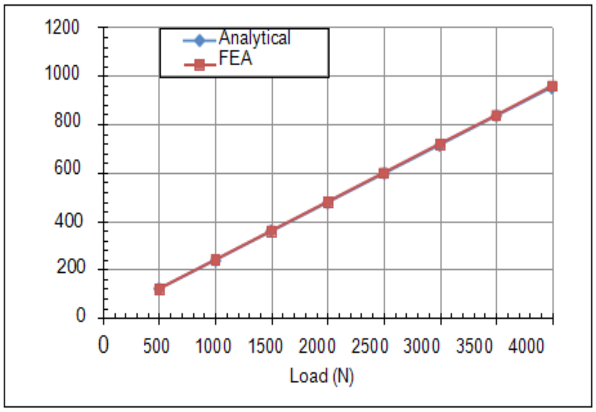


**Figure 13.** Graph load vs stress for conventional steel leaf spring.

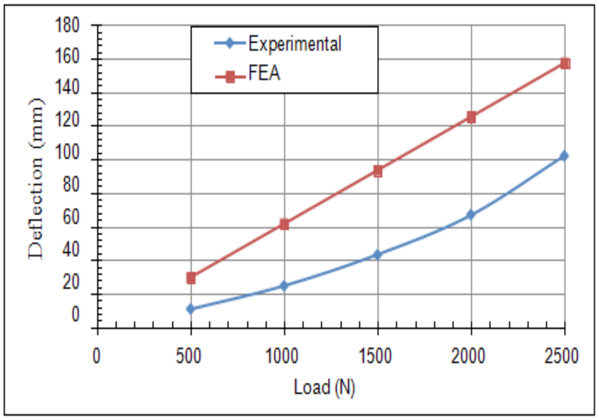


**Figure 14.** Graph load vs deflection for mono-composite leaf spring.

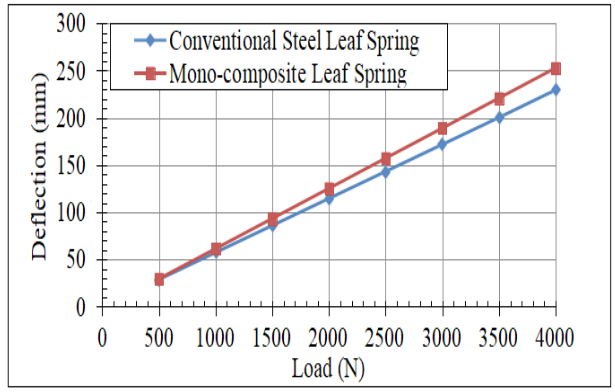


**Figure 16.** Graph of load vs deflection of conventional steel leaf spring and mono- composite leaf spring for Finite Element Analysis (FEA) result.

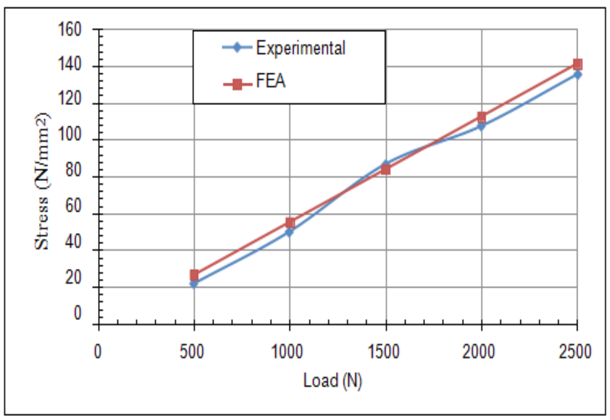


**Figure 15.** Graph load vs stress for mono-composite leaf spring.

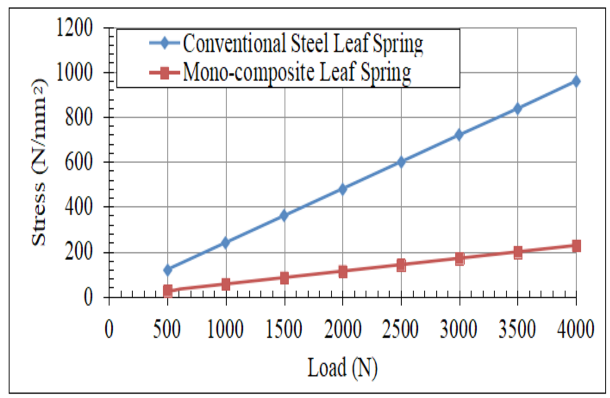


**Figure 17.** Graph of load vs stress of conventional steel leaf spring and mono-composite leaf spring for Finite Element Analysis (FEA) result.

Figure 14 shows a graphical representation of load vs. deflection of mono-composite leaf spring for Finite Element Analysis (FEA) and experimental result. The deflection of the mono-composite leaf spring increases linearly with load.

Figure 15 shows a graphical representation of the load vs stress of a mono-composite leaf spring for Finite Element Analysis (FEA) and experimental result. The stresses developed in the mono-composite leaf spring increase linearly with the load.

Figure 16 shows graphical representation of load *vs* deflection of conventional steel leaf spring and mono-composite leaf spring for Finite Element Analysis (FEA) result. The deflection of mono-composite leaf spring is more as compared to conventional steel spring under the same loading condition.

Figure 17 shows graphical representation of load *vs* stress of conventional steel leaf spring and mono-composite leaf spring for Finite Element Analysis (FEA) result. The stresses in mono-composite leaf spring are less as compared to conventional steel spring under the same loading condition.

Figure 18 shows a graph of experimental testing of mono-composite leaf springs. The graph shows relation

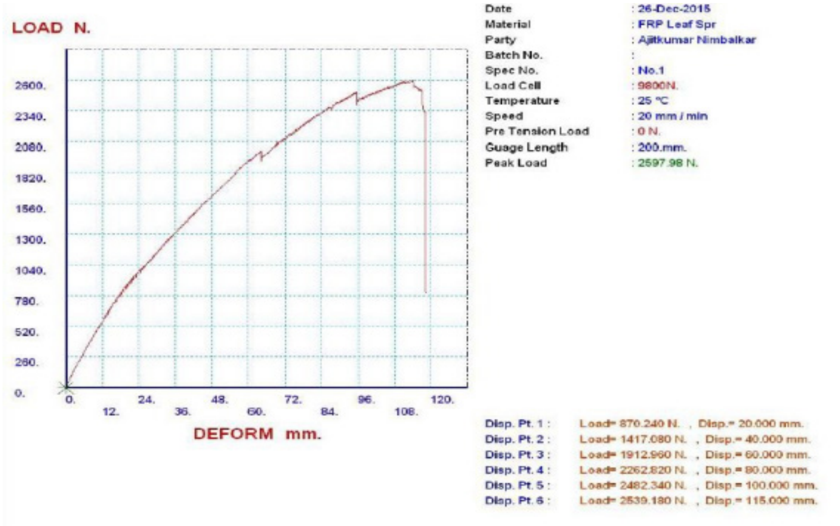


**Figure 18.** Graph of load vs stress of conventional steel leaf spring and mono-composite leaf spring for Finite Element Analysis (FEA) result.

between load and deflection under different loading conditions. The deflection in mono-composite leaf spring goes on increasing as the load applied on mono-composite spring increases. The mono-composite leaf spring fails at load 2579.98 N.

## 6.0 Conclusion

In response to the growing global demand for lighter and stronger products, composite materials are increasingly meeting these needs. This study compares the performance of steel leaf springs with E-glass or epoxy mono composite leaf springs under identical static load conditions. Both types of leaf springs were analysed, focusing on deflection and stress characteristics. The comparison revealed that mono-composite leaf springs experience failure at points where there are abrupt changes in cross-sectional area, with a failure load of approximately 2597.98 N. This failure is attributed to stress concentration resulting from these abrupt changes. Despite this, composite materials offer advantages such as corrosion resistance, lightweight properties, and high strain energy capacity. These benefits make composites a valuable option for leaf springs, as they contribute to reduced vehicle weight and lower fuel consumption.

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