COMPOSITE LEAF SPRING

Sandeep Bhattacharjee[1], Suyog Kanitkar[2], Naveen Kalasapur[3], Vivek Patel[4]

[1,2,3,4] *Department of Mechanical Engineering, KLE Institute of Technology, Hubli, Karnataka, India.*

Abstract: *The Automobile Industry has shown keen interest for replacement of steel leaf spring with that of fiber composite leaf spring, since the composite material has high strength to weight ratio, good corrosion resistance and tailor-able properties. They are found to be the potential materials for replacing these conventional metallic leaf springs without giving up the strength and by reducing the structural weight substantially. Therefore, analysis of the composite material becomes equally important to study the behavior of Composite Leaf Spring. The aim is to review the paper about fabrication and analysis of composite leaf spring. The numerical analysis is carried via finite element analysis using ANSYS software.*

Key Words: Composite material, Leaf Spring, High strength to weight ratio, Optimum cost, Stress in leaf spring

1. INTRODUCTION

In the present scenario, to optimize the utilization of energy, weight reduction became one of the main focuses of automobile manufacturers. Weight reduction can be achieved by the introduction of better material. Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. They carry lateral loads, brake torque, driving torque in addition to shock absorbing. Leaf springs are having an advantage that the ends of the spring may be guided along a definite path as it deflects. The use of composite materials for suspension leaf spring reduces the weight of conventional multi leaf steel leaf spring by nearly 75%.This achieves the vehicle with more fuel efficiency and improved riding qualities. For more compliant suspension system (i.e. energy storage capability), 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. A material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. The composite materials have more elastic strain energy storage capacity, excellent corrosion resistance, high strength to weight ratio as compared with those of steel. Conventional Multi-leaf steel springs are being replaced by mono-leaf composite springs.

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 travelling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile.

In the present work comparative study is been carried out to understand the working principle of multi-leaf steel spring used in passenger cars. The multi-leaf steel spring is replaced with a composite single leaf spring made of E glass/ epoxy and Jute-Glass fiber composite. The stresses for both steel leaf spring and composite leaf springs are considered for the study. The primary objective is to compare their load carrying capacity, stiffness and weight savings of composite leaf spring. Finally, Natural frequencies and fatigue life of Natural Faber reinforced composite leaf spring is also predicted using life data.

2. LITERATURE SURVEY

2.1 Preceding Studies:

1. V.K. Aher et. al. “Fatigue Life Prediction of Multi Leaf Spring used in the Suspension System of Light Commercial Vehicle”, International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME), 2012.

The purpose of this paper is to predict the fatigue life of steel leaf spring along with analytical stress and deflection calculations. This present work describes static and fatigue analysis of a steel leaf spring of a light commercial vehicle (LCV).The non-linear static analysis of 2D model of the leaf spring is performed using NASTRAN solver and compared with analytical results. The pre-processing of the model is done by using HYPERMESH software. The stiffness of the leaf spring is studied by plotting load versus deflection curve for various load applications. The simulation results are compared with analytical results. The fatigue life of the leaf spring is predicted using MSC Fatigue software.

2. Ravi Kumar V. et. al. “Analysis of Natural Fibre Composite Leaf Spring”, International Journal of Latest Trends in Engineering and Technology (IJL^{2}TET) September 2013

The aim of present work is to compare the Glass-Fiber-Reinforced - Composite (GFRC) leaf spring with a Natural-Fiber-Reinforced Composite/Jute-Fiber – Reinforced – Composite (NFRC/JFRC) leaf spring. Fabrication is carried by hand lay-up technique and tested. The present work carries analytical and simulated results comparison of both types of composite leaf springs. The testing was performed experimentally with the help of Universal Testing Machine (UTM) and by Finite Element Analysis (FEA) using ANSYS. Stresses and Deflection were verified with analytical and experimental results. Compared to the GFRC leaf spring, the NFRC Composite material spring has stresses much lower to steel and the spring weight is also reduced nearly to 60-70%.The

3. T.N.V. Ashok Kumar at. al. "Design and Material Optimization of Heavy Vehicle Leaf Spring", International Journal of Research in Mechanical Engineering & Technology, Nov 2013 - April 2014

The paper describes static and dynamic analysis of steel leaf spring and laminated composite Multi leaf spring. The objective is to compare displacement, frequencies, deflections and weight savings of composite leaf spring with that of steel leaf spring. Static and Dynamic Analysis of 3-D model of conventional leaf spring is performed using ANSYS 10.0. Same dimensions are used in composite multi leaf spring using S2 Glass/Epoxy and Kevlar/Epoxy unidirectional laminates. Analysis is done by layer stacking method for composites by changing reinforcement angles for 3 layers, 5 layers and 11 layers. The weight of composite leaf spring is compared with that of steel leaf spring. The design constraints are stresses and deflection. A weight reduction of 27.5 % is achieved by using composite leaf spring.

3. APPLICATIONS

A leaf spring is a simple form of spring commonly use for the suspension in wheeled vehicles. Originally called a laminated or carriage spring, and sometimes referred to as a semi-elliptical spring or cart spring, it is one of the oldest forms of springing, dating back to medieval times.

A leaf spring takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason some manufacturers have used mono-leaf springs.

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swivelling member.

3.1 Contents

3.1.1 History
3.1.2 Characteristics.
3.1.3 Manufacturing Process

3.1.1 History

There were a variety of leaf springs, usually employing the word "elliptical". "Elliptical" or "full elliptical" leaf springs referred to two circular arcs linked at their tips. This was joined to the frame at the top center of the upper arc, the bottom center was joined to the "live" suspension components, such as a solid front axle. Additional suspension components, such as trailing arms, would usually be needed for this design, but not for "semi-elliptical" leaf springs as used in the Hotchkiss drive. That employed the lower arc, hence its name. "Quarter-elliptic" springs often had the thickest part of the stack of leaves stuck into the rear end of the side pieces of a short ladder frame, with the free end attached to the differential, as in the Austin Seven of the 1920s. As an example of non-elliptic leaf springs, the Ford Model T had multiple leaf springs over its differential that were curved in the shape of a yoke. As a substitute for dampers (shock absorbers), some manufacturers laid non-metallic sheets in between the metal leaves, such as wood.

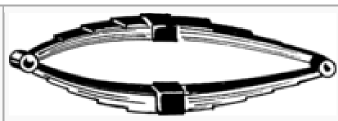
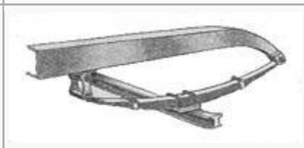
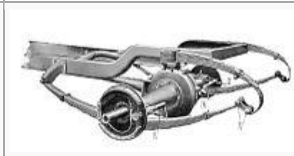
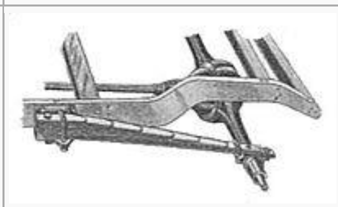
Elliptic	
Semi-elliptic	
Three quarter-elliptic	
Quarter-elliptic	
Transverse	

Fig.3.1 Varieties of Leaf Springs

Leaf springs were very common on automobiles, right up to the 1970s in Europe and Japan and late '70s in America when the move to front-wheel drive, and more sophisticated suspension designs saw automobile manufacturers use coil springs instead. Today leaf springs are still used in heavy commercial vehicles such as vans and trucks, SUVs, and railway carriages. For heavy vehicles, they have the advantage of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point. A further advantage of a leaf spring over a helical spring is that the end of the leaf spring may be guided along a definite path.

A more modern implementation is the parabolic leaf spring. This design is characterized by fewer leaves whose thickness varies from center to ends following a parabolic curve. In this design, inter-leaf friction is unwanted, and therefore there is only contact between the springs at the ends and at the center where the axle is connected. Aside from a weight saving, the main advantage of parabolic springs is their greater flexibility, which translates into vehicle ride quality that approaches that of coil springs. It is widely used on buses for better comfort. A further development by the British GKN company and by Chevrolet with the Corvette amongst others, is the move to composite plastic leaf springs.

Typically when used in automobile suspension the leaf both supports an axle and locates/ partially locates the axle. This can lead to handling issues (such as 'axle tramp'), as the flexible nature of the spring makes precise control of the unsprung mass of the axle difficult. Some suspension designs use a Watts link (or a Panhard rod) and radius arms to locate the axle and do not have this drawback. Such designs can use softer springs, resulting in better ride. The various Austin-Healey 3000's and Fiat 128's rear suspension are examples.

3.1.2 Characteristics

1. The leaf spring acts as a linkage for holding the axle in position and thus separate linkage are not necessary. It makes the construction of the suspension simple and strong.

2. As the positioning of the axle is carried out by the leaf springs so it makes it disadvantageous to use soft springs i.e. a spring with low spring constant.

3. Therefore, this type of suspension does not provide good riding comfort. The inter-leaf friction between the leaf springs affects the riding comfort.

4. Acceleration and braking torque cause wind-up and vibration. Also wind-up causes rear-end squat and nose-diving.

5. The inter-leaf friction damps the spring's motion and reduces rebound, which until shock absorbers were widely adopted was a great advantage over helical springs.

3.1.3 Manufacturing Process

Multi-leaf springs are made as follows:

1. Shearing of flat bar
2. Center hole punching / Drilling
3. End Heating process forming (hot & cold process)
    1. Eye Forming / Wrapper Forming
    2. Diamond cutting / end trimming / width cutting / end tapering
    3. End punching / end grooving / end bending / end forging / eye grinding
    4. Center hole punching / Drilling / nibbing
4. Heat Treatment
    1. Heating
    2. Camber forming
    3. Hardening
    4. Quenching
    5. Tempering
5. Surface preparation
    1. Shot peening / stress peening
    2. Primary painting
6. Eye bush preparation process
    1. Eye reaming / eye boring
    2. Bush insertion
    3. Bush reaming

4. DESIGN OF LEAF SPRING

The relationship of the specific strain energy can be expressed as it is well known that springs, are designed to absorb and store energy and then release it slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system.

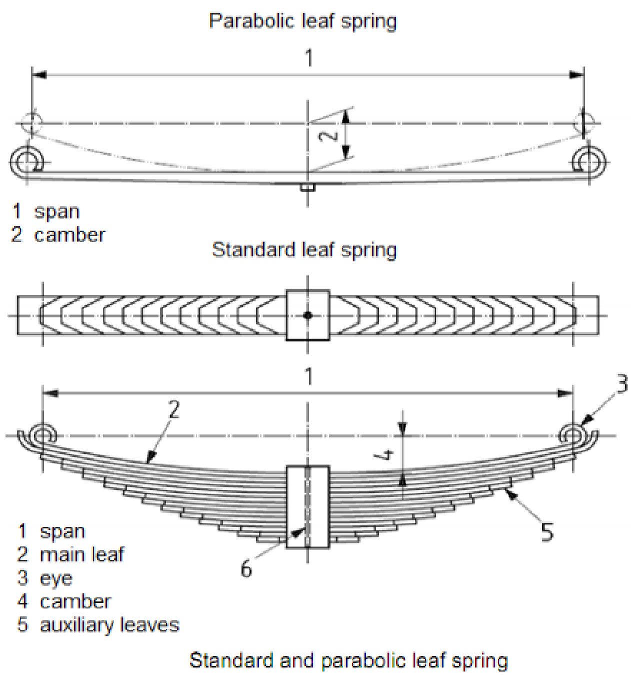


Fig 4.1 Standard and Parabolic Leaf Spring

4.1 Terms Involved:

1. Span: Horizontal Distance between the Eyes of spring.

2. Main Leaf: The Long leaf fastened to the supports is called main leaf or master leaf.

3. Eye: Main leaf ends are bent to form the Eyes.

4. Camber: Distance b/w horizontal axis joining 2 eyes and main leaf.

5. Auxiliary Leaves: Other leaves below main spring are called Graduated leaves.

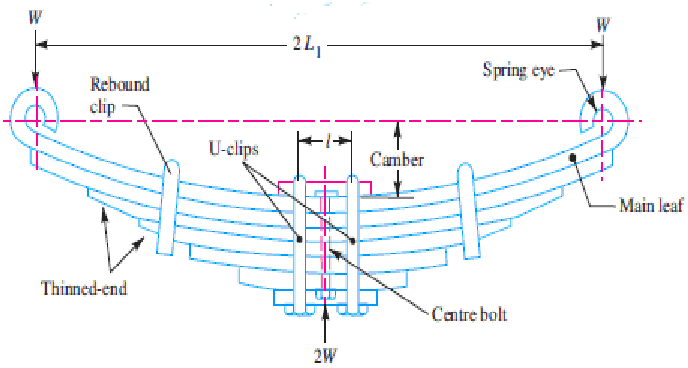


Fig 4.2 Laminated Leaf Spring

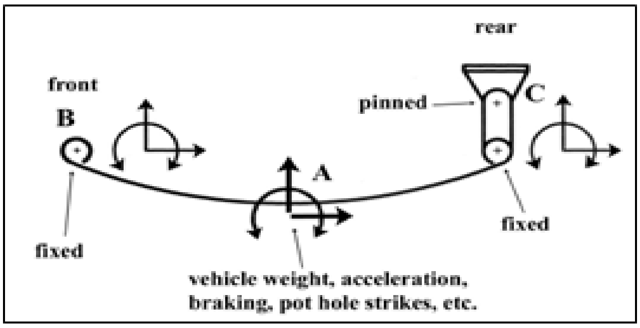


Fig 4.3 Reaction forces on the spring eyes in the vehicle

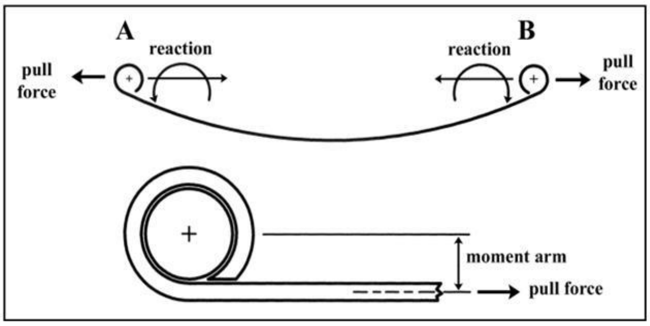


Fig 4.4 Active and Reactive Forces on spring

The relationship of the specific strain energy can be expressed as,

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

Where,
σ is the strength, ρ is the density
E is Young's Modulus of the spring material.

From the above equation, the material which is having low density and low Young's modulus will have high strain energy storage capacity. This purpose will be served by Composites.

4.2 DEMERITS OF CONVENTIONAL LEAF SPRING

1. They have less specific modulus and strength.

2. Increased weight.

3. Conventional leaf springs are usually manufactured and assembled by using number of leafs made of steel and hence the weight is more.

4. Its corrosion resistance is less compared to composite materials.

5. Steel leaf springs have less damping capacity.

4.3 SELECTION OF COMPOSITE MATERIAL

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Composites are combinations of two materials in which one of the material is called the "matrix phase" is in the form of fibres, sheets, or particles and is embedded in the other material called the "reinforcing phase". Many composite materials offer a combination of strength and modulus that are either comparable to or better than any tradional metallic metals. Because of their low specific gravities, the strength to weight-ratio and modulus to weight-ratios of these composite materials are markedly superior to those of metallic materials. The fatigue strength weight ratios as well as fatigue damage tolerances of many composite laminates are excellent. For these reasons, fibre composite have emerged as a major class of structural material and are either used or being considered as substitutions for metal in many weight-critical components in aerospace, automotive and other industries. Another unique characteristic of many fibre reinforced composites is their high internal damping capacity. This leads to better vibration energy absorption within the material and results in reduced transmission of noise to neighbouring structures. High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort.

The ability to absorb and store more amount of energy ensures the comfortable operation of a suspension system. However, the problem of heavy weight of spring is still persistent when using steel leaf spring. This can be remedied by introducing composite material instead of steel which is normally used in the conventional leaf spring. 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.

It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. Research has indicated that E-Glass/Epoxy has good characteristics for storing specific strain energy. Hence, E Glass/Epoxy is selected as the composite material.

5. CASE STUDY

5.1 Modelling and Analysis of Laminated Composite Leaf Spring under the Static Load Conditions by using FEA

In the present work, the dimensions of an existing mono steel leaf spring of a Maruti 800 passenger vehicle is taken for modelling and analysis of a 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 have been modelled 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 ANSYS 10.0. 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[1].

Table 5.1 shows the specifications of a mono leaf steel spring of a maruti 800 passenger vehicle. The typical chemical composition of the material is 0.565C, 1.8% Si, 0.7%Mn, 0.045%P and 0.045% S.

Table 5.1: Specifications of Mono Leaf Steel Spring

Sl. No.	Parameters	Value
1	Total length of the spring(Eye to Eye)	965mm
2	Free camber (At no load condition)	6mm
3	No. of full length leave (Master Leaf)	01
4	Thickness of leaf	10mm
5	Width of leaf spring	50mm
6	Maximum load given on spring	794.54N
7	Young's Modulus of leaf spring	2.1e5 N/mm²

Deflection of leaf spring:

$$\delta = \frac{12 * W * L^3}{E * b * t^2 (2n_G + 3n_F)} \quad [1]$$

Where,

W- Maximum load on leaf spring
L- Total length of the spring (Eye to Eye)
E- Young's Modulus of leaf spring
b- Width of leaf spring
t- Thickness of leaf
n_G – number of graduated leaves
n_F -- number of full length leaves

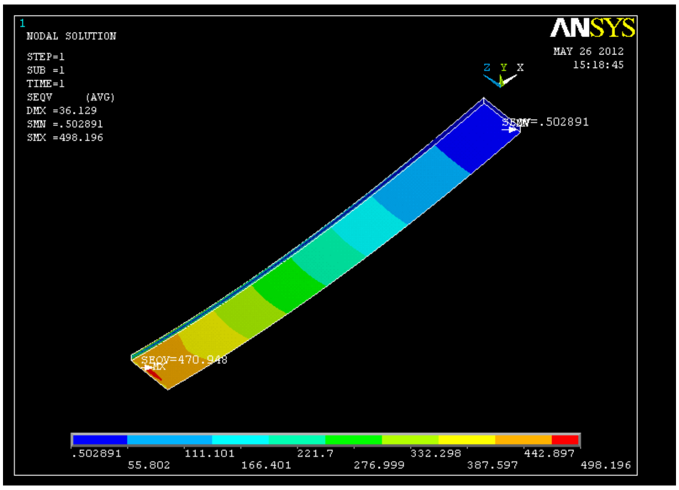


Fig 5.1 Stress distribution for steel leaf spring

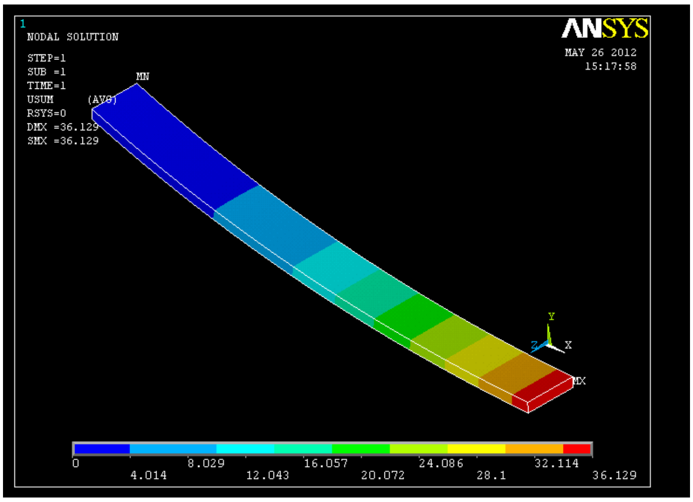


Fig 5.2 Displacement pattern for steel leaf spring

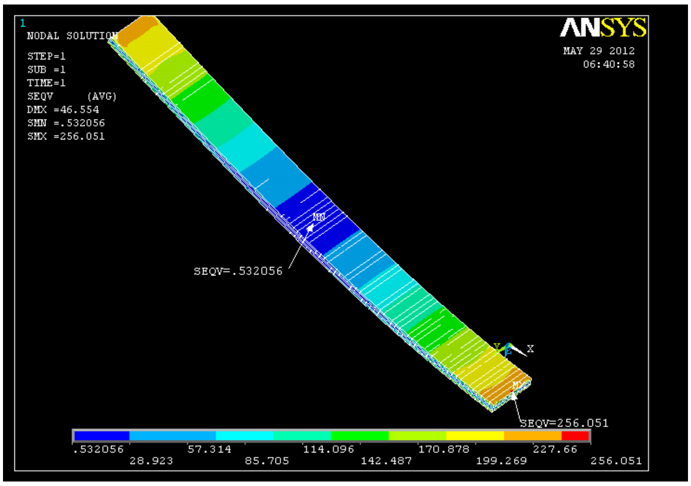


Fig 5.3 Stress distribution for E-glass/epoxy laminated composite leaf spring

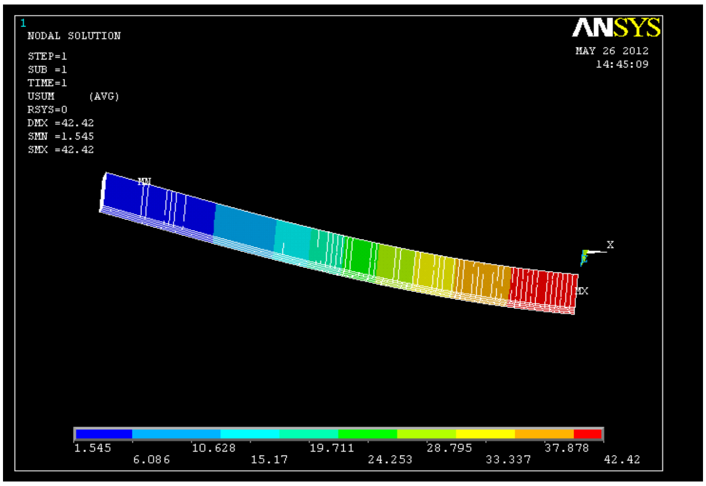


Fig 5.6 Displacement pattern for S-glass/epoxy laminated composite leaf spring

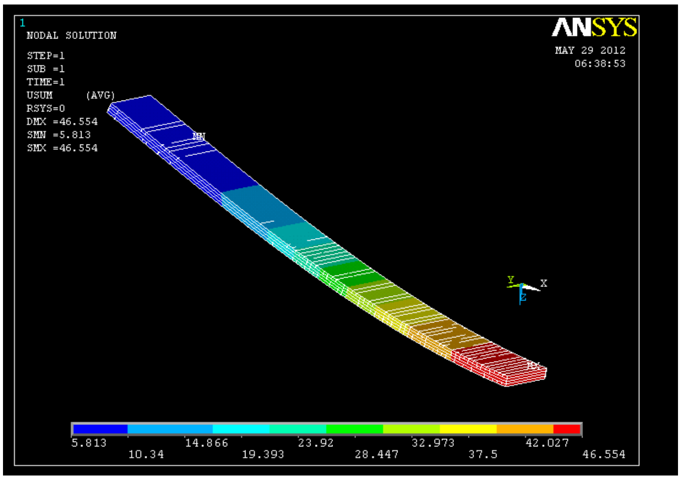


Fig 5.4 Displacement pattern for E-glass/epoxy laminated composite leaf spring

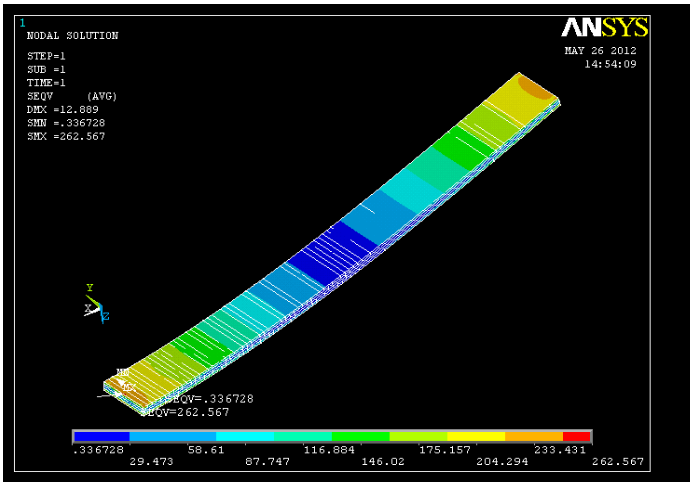


Fig 5.7 Stress distribution for carbon/epoxy laminated composite leaf spring

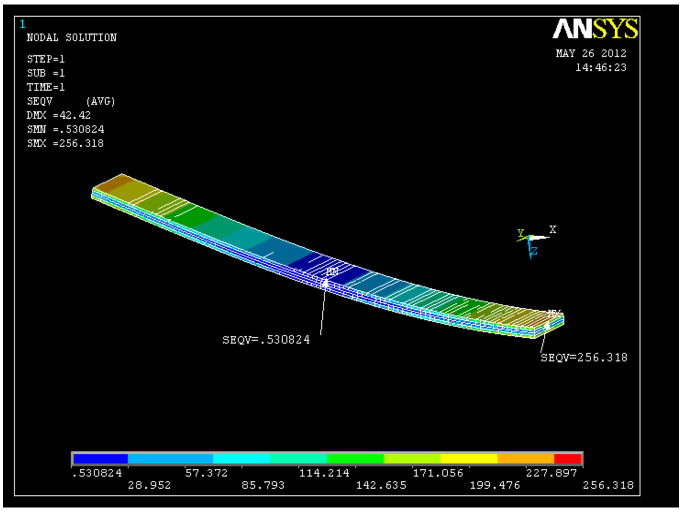


Fig 5.5 Stress distribution for S-glass/epoxy laminated composite leaf spring

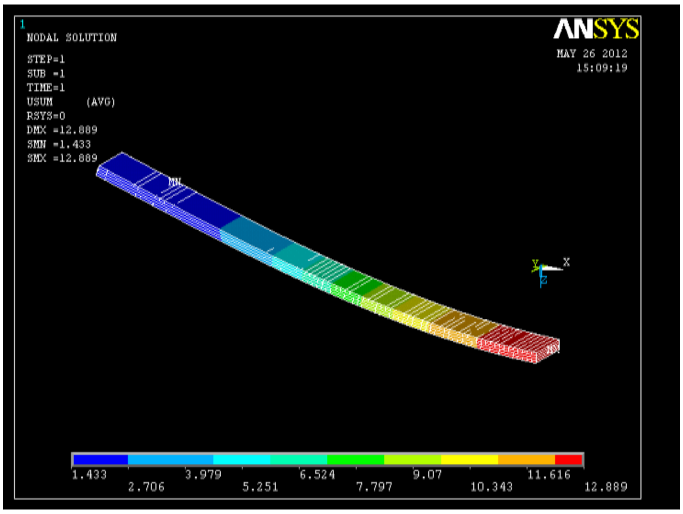


Fig 5.8 Displacement pattern for carbon/epoxy laminated composite leaf spring

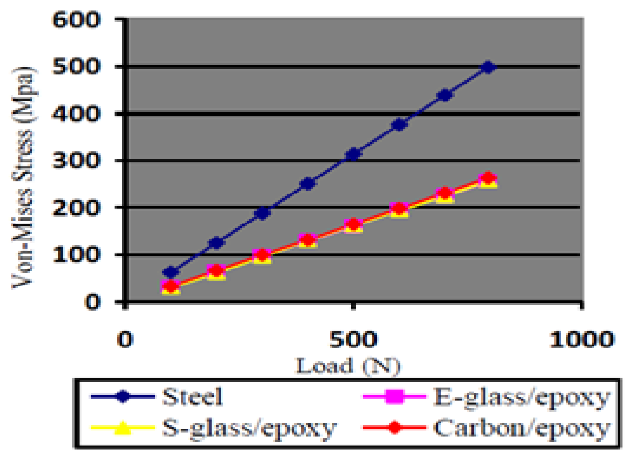


Fig 5.9 Load and Von-Mises Stress for Steel and Laminated Composite Leaf Spring

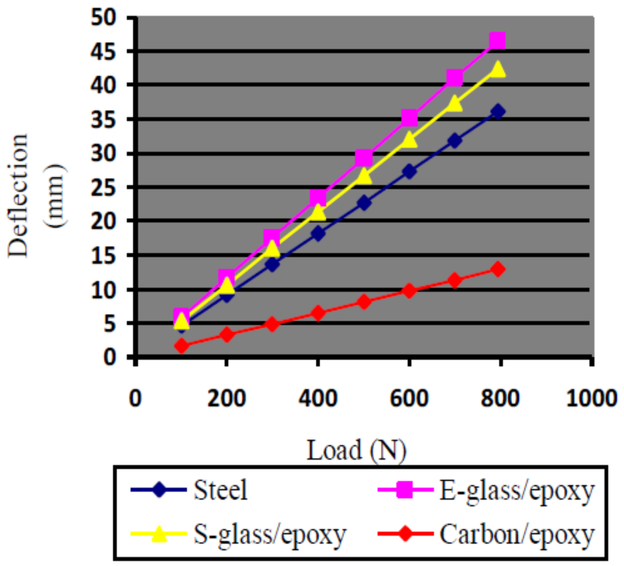


Fig 5.10 Load- Deflection Curves for Steel and Laminated Composite Leaf Spring

Table 5.2: Comparative Analysis of Mono Leaf Steel Spring and Laminated Composite Leaf Spring

Sl. No	Parameters	Steel Spring	Laminated Composite Leaf Spring		
			Comp1	Comp2	Comp3
1	Weight (kg)	3.79	1.01	0.965	0.762
2	Stress (N/mm^2)	498.19	256.05	256.320	262.56 0

5.2 MERITS OF COMPOSITE LEAF SPRING

1. Reduced weight.
2. Due to laminate structure and reduced thickness of the mono composite leaf spring, the overall weight would be less.
3. Due to weight reduction, fuel consumption would be reduced.
4. They have high damping capacity; hence produce less vibration and noise.
5. They have good corrosion resistance [5].

6. CONCLUSION

A comparative study has been made between laminated composite leaf spring and steel leaf spring with respect to weight, stiffness and strength. By employing a composite leaf spring for the same load carrying capacity, there is a reduction in weight of 73%~80%, natural frequency of composite leaf springs are 27%~67% higher than steel leaf spring and 23~65% stiffer than the steel spring. Based on the results, it was inferred that carbon/epoxy laminated composite mono leaf spring has superior strength and stiffness and lesser in weight compared to steel and other composite materials considered in this investigation.

From the results, it is observed that the laminated composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications [1]

The composite leaf spring is lighter than conventional steel leaf spring with similar design specifications but not always is cost- effective over their steel counterparts. Composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel. Therefore, it is concluded that composite leaf spring is an effective replacement for the existing steel leaf spring in automobile.

7. REFERENCES

1. M. Raghavedra et. al. “Modelling and Analysis of Laminated Composite Leaf under the Static Load Condition by using FEA”, International Journal of Modern Engineering Research (IJMER) Vol.2, Issue.4, July-Aug. 2012 pp-1875-1879

2. V.K. Aher et. al. “Fatigue Life Prediction of Multi Leaf Spring used in the Suspension System of Light Commercial Vehicle”, International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME), 2012.

3. Ravi Kumar V. et. al. “Analysis of Natural Fibre Composite Leaf Spring”, International Journal of Latest Trends in Engineering and Technology (IJL^2TET) September 2013

4. T.N.V. Ashok Kumar at. al. “Design and Material Optimization of Heavy Vehicle Leaf Spring”, International Journal of Research in Mechanical Engineering & Technology, Nov 2013 - April 2014

5. Pankaj Saini et. al. "DESIGN AND ANALYSIS OF COMPOSITE LEAF SPRING FOR LIGHT VEHICLES", International Journal of Innovative Research in Science, Engineering and Technology. Vol. 2, Issue 5, May 2013

6. Baviskar A. C. et. al. "Design and Analysis of a Leaf Spring for automobile suspension system: A Review", International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal, Volume 3, Issue 6, June 2013)

7. Ravi Kumar V. et. al. "Analysis of Natural Fiber Composite Leaf Spring", International Journal of Latest Trends in Engineering and Technology (IJLTET) Vol. 3 Issue 1 September 2013

8. V Sampath et. al. "ANALYSIS OF LEAF SPRING WITH VARIABLE THICKNESS FOR COMPOSITE MATERIALS", International Journal For Technological Research In Engineering Volume 1, Issue 9, May-2014