# Design and Analysis of Composite Leaf Spring: A Review

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**Abstract**
Automobile industry has shown increased interest in the replacement of conventional materials with composites due to its property of high strength to weight ratio. Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting the researchers and giving solutions for such issues. This paper presents literature review on: suitability of composite materials for leaf spring in automobile, compare its result with conventional steel leaf spring, design and analysis of composite leaf spring. Identify gaps in literature and present proposed research plan.

**Keywords**
Leaf Spring Glass Fiber Reinforced Material, Composite Material, FEA, ANSYS, Static and Fatigue Analysis

## I. Introduction

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. A composite is composed of a high-performance fibers such as carbon, Kevlar, graphite or glass in a matrix material that when combined provides better properties compared with the individual materials by themselves. The composite materials are used in structural application areas, such as in aircraft, space, automotive, for sporting goods, and marine engineering .The various type of glass fibers available are Carbon fiber, C-glass, S-glass and E-glass. However, carbon/epoxy material is better than other fibers but because of its high cost, it has limited applications. Favorable relation between cost and properties of a material can be obtained with E-glass fiber / epoxy.

Leaf spring is mainly used in suspension system to absorb shock loads in automobiles. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The various studies were conducted on the application of composites materials for automobile suspension system (B. P. Johnson 1986, Daugherty R. L. 1981)

The major step of composite in automotive business is extension of use in to truly structural application such as primary body structure and to chassis and suspension system. These are the area which has to sustain all major road load inputs and impact loads. 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. This helps in achieving the vehicle with improved riding qualities. These are widely used in light motor vehicles, heavy duty trucks and in rail systems to absorb shock loads and vibration. Generally, leaf springs have been classified as mono- leaf spring and multi-leaf spring and based on the spring's ends: they are double-eye leaf springs and open-eye leaf springs.

It is well known that springs are designed to absorb and store energy and then release it. It can be observed that material having lower modulus of elasticity and density will have a greater specific strain energy capacity. Thus, the introduction of Fiber Reinforced Plastics (FRP) made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. FRP material's have high elastic strain energy storage capacity, high strength-to-weight ratio, fatigue resistance.

## II. Literature Review

Literature has been classified into three categories: composite materials for leaf spring, design and optimization of composite leaf spring, and analysis of composite leaf spring. Each one is explained in brief below.

### A. Composite Materials for Leaf Spring

The composite material is having distinguishing characteristic such as, high strength to weight ratio, superior fatigue strength ,excellent corrosion resistance and higher natural frequency so it makes composite materials are excellent for leaf spring. (BeardmoreP,Johnson1986).Application of composite material reduces the weight of spring without reducing load carrying capacity and stiffness in automobile suspension system. The leaf spring should absorb vertical vibration due to irregularities by means of variation in the spring deflection so that potential energy is stored in the spring as strain energy and released slowly (Daugherty, 1981; Breadmore, 1986; Morris, 1986; Corvi, 1990; G. Siddaratha, 2006).Table1 shows various composite materials proposed by researchers for leaf spring.

Table 1: Composite Materials Proposed for Leaf Spring

| Sr No | Composite Materials | Researcher |
|---|---|---|
| 1 | (CFRP) Carbon Fiber Reinforced Plastic | P.Beardmore(1986) |
| 2 | S2-glass fiber/ Epoxy and E-glass/ Epoxy | W.J. Yu. Kim(1988) |
| 3 | Glass fiber, Carbon fibre | Andra Corvi(1990 |
| 4 | E-glass fibre with two layer of bidirectional fabric | Erol Sancatar (1999) |
| 5 | E-glass/Epoxy | Max. X.Sardou et.al (2000),M. Senthil (2007),Mahmood Shokrieh (2003), Dara Ashok (2012), Laxinarayana (2012), Asish Amrute(2013), Shishay Amare Gebremeskel(2012) |
| 6 | E-glass/Epoxy and carbon fiber/Epoxy | H.A.Al. Qureshi(2001) |
| 7 | E-glass/Epoxy and Woven roving/ Epoxy | G Gular Siddaramanna et.al(2006) |

| | | |
|---|---|---|
| 8 | Woven glass fiber baric | E.Mahdi et.al (2006); Abdul Rahim (2010 ) |
| 9 | 20% glass fiber reinforced polypropylene | C.Subhramian ,et.al (2011) |
| 10 | Glass/Epoxy, Graphite/Epoxy, arbon/Epoxy, Kelvar/ Epoxy, Boron /Aluminium | B.Ragu Kumar et.al (2013) |
| 11 | E-Glass/Epoxy, C-Glass/Epoxy, S-Glass /Epoxy | B.Vijaya Lakshmi1 I. Satyanarayana(2012) |
| 12 | Carbon/epoxy | Parkhe Ravindra and Sanjay Belkar (2014) |
| 13 | bidirectional carbon-glass reinforced plastic (C-GFRP) and bidirectional glass-carbon reinforced plastic (G-CFRP) | S.Rajesh1 and G.B.Bhaskare (2014) |
| 14 | C-glass/epoxy composite leaf spring | Mhaske Raman, Nimbalkar et.al (2014) |

### B. Design and Optimization of Composite Leaf Spring

Usually leaf spring in vehicle is assumed as a simply supported beam which is subjected to both bending stress and transverse shear stress. Usually, three design approaches have been tried to accessed: (i) constant thickness, varying width (ii) constant width, varying thickness and (iii) constant cross-section design. In 1981, a composite suspension of curved beam type was developed for family car (Daugherty 1981),in another design (Andrea Corrvi,1990) the thickness of spring was kept constant and the theoretical details of composite mono leaf spring were reported using a program tool. Over a period of time GFRP double tapered beam and spring with variable thickness were designed and optimized for automobile suspension assuming similar geometrical and mechanical properties as that of multi steel (Yu and Kim, 1988; H. A. Qureshi, 2001). From the better material utilization perspective and avoiding material wastage, spring designed was introduced in two stages. In first stage, using E- glass fiber/vinyl ester with two layer of bidirectional fabric layer was used and in second stage, leaves of spring in width and thickness direction were tapered. This produced even distribution of stress over the spring (Erol Sancaktar, 1999). An optimal spring width decreases hyperbolically and thickness increases linearly from spring end towards the axle seat but deflection of composite spring was lower than steel leaf spring (M.M.Shokrieh2003).

An optimized design of composite leaf spring is required to balance the weight and stiffness of composite leaf spring. The spring was preferred in certain shapes these included like C-type, Elliptical, parabolic and taper shape. The light and low cost composite compression C-spring was designed and tested for static, fatigue and road test (X.Sardou, et.al, 2000). Secondly parabolic taper leaf spring has been accepted for Tata Motors by (Sachin, et.al, 2005) and obtained the best compromise between stress induced and stiffness of spring. On the other hand, the high spring rate together with weight saving achieved with elliptical spring (E.Mahdi, O.M.Set et. al; G.Goudah, et. al 2006). But the influence of elliptical ratio as 0.5 and spring with open eye end reduces the problem of delamination in spring (J.P.Hou, 2007; Abdul Rahim, et.al, 2010). In another configuration of leaf spring a semielliptical multi- leaf steel leaf spring has been designed under same load carrying condition and the performance of both springs has to be studied and found that composite multi spring is an effective replacement for conventional steel leaf spring (Dara Ashok, et al 2012). Parabolic leaf spring plays a vital role in the suspension systems, since it has an effect on ride comfort and vehicle dynamics and suitable in terms of economy and light weight of spring (Mahammood Ashique et al., 2007).

Now a days popular technique namely formulation and solution techniques are used for weight optimization. The Genetic Algorithm (GA) approach was used for designing the composite leaf spring with constant cross sectional and it has been found with this technique that weight reduction of 93% is achieved in the spring(Shivashankar, Vijayarangan, et.al 2007).RecentlyParticle Swarm Optimization (PSO) and Simulated Annealing (SA) approaches are used for design optimization of composite Leaf Springs. It is helpful to determine the best combination of design variables like center width and thickness of composite spring. It is found that using Particle Swarm Optimization technique the composite spring produced less deflection ,stress & weigh nearly about 85%,and while with Simulated Annealing weight is 78.8 % compared to steel leaf spring (Simran Jeet Singh, Meenu Gupta 2013).

Researchers have employed a wide variety of methods and measures to investigate the performance parameters of composite leaf spring a brief summary are given below in table2.

Table 2: Performance Parameters of Composite Leaf Spring (1986-2014)

| Sr. No | Tested Performance parameters | Researchers |
|---|---|---|
| 1 | Noise Vibration and Harshness | C.J. Morries 1986 |
| 2 | Fatigue Life and Natural Frequency | Gulur Siddarmanna 2006, M. Senthil Kumar 2007 |
| 3 | Strain | J.P. Hou 2007 |
| 4 | Maimum Load, Stress, Deflection, Weight | I.Venkata Nag (2010), M.Venkata san(2012), B. Raghu Kumar et al. (2013 ) |
| 5 | Stiffness | Erol. Sancakart (1999), C. Maddan Mohan Reddy et.al (2013 ) |
| 6 | Vonmisses stress, Normal stress | Vinkel Arora 2011 |
| 7 | Endurance strength ,Maximum Load | C. Subbramanna 2011 |
| 8 | Load and Deflection | Parkhe Ravindra and Sanjay Belkar (2014) ,R. Pradeep, et.al (2013), Karthik Badugu, et.al (2013) |
| 9 | Principle stress | R. D. V. Prasad et.al (2013 ) |

### C. Analysis of Composite Leaf Spring

The primary goal of analysis is to obtain information about the relevant performance parameters of leaf spring under different

loading condition. These data can be of following: stresses, deflection, maximum and minimum stress induced, natural frequency and weight of spring. The leaf spring was analyzed by many researchers using analytical, numerical and experimental approach. In modern design, a wide range of software packages are being used, such as CATIA, PRO/Engineer, CAE, and ANSYS. The Analysis of composite leaf spring has become essential for comparative evaluation with conventional steel leaf spring.

The GFRP composite spring was subjected to static analysis to determine important attribute: deflection and bending stress. The result of analysis shows that impressive weight saving in leaf spring has been observed compared to conventional multi steel leaf spring ( H.A.Qureshi, 2001, Pozhilla Rosa T. 2013, Pankaj Saini et.al Karthik. Badugu1, et.al 2013)

A prediction of fatigue life based on finite element analysis was presented by F.N. Ahmad et al. (2009). The main factors that contribute for fatigue failure were observed to be number of load cycle experienced, range of stress and maximum stress experienced in each load cycle and presence of local concentration. Fatigue analysis were also carried out on constant cross section GFRP leaf spring (M.Senthil 2007, Vinkel Arora et.al 2011, Krishna Kumar2012, Dara Ashok 2012 M.Venkatashan et.al 2012 ; B.Ragu 2013, Keshav and Murthy 2013). As testing of leaf spring using regular procedure consumes a lot of time therefore sometimes standard SAE manual outlined procedure was used to conduct fatigue analysis on both composite and steel leaf spring. It was found that fatigue life of composite spring was higher than steel leaf spring (M.SenthilKumar, 2007). When hybrid composite elliptical spring was subjected to fatigue analysis, it indicates better fatigue behavior than conventional composite leaf and coil spring (E. Mahadi, et.al 2006). Makarand B.Shirk et.al (2012) found that life of composite leaf spring was109cycles as compared to 106 cycles for steel leaf-spring. The Behavior of seven steel and multi-composite leaf spring have been investigated using ANSYS tool (Joo -Teck Kuech,2012). The main center of attention was given to the effect of composite materials and orientation of fiber on the fatigue performance of spring. It is required that when spring is subjected to shock load the passenger seating in vehicle must get free form this vibration. In general, the road irregularities usually have maximum frequency of 12 Hz (Yu Kim, 1988). In order to provide comfort ride to the passengers in vehicle the leaf spring is designed in such a way that the natural frequency must be maintained within allowable limits to keep away from resonance. The natural frequency of composite leaf spring observed to be 1.2 times maximum road frequency and therefore resonance could not occurred(M. Senthil Kumaret.al 2007,Shokerich,2003,V. Laxmi Narayana, 2012).The modal analysis in structural mechanics was carried out to determine the natural mode shapes and frequencies of an object or structure during free vibration. In general, it is common to use the finite element method to perform this analysis because, like other calculations using the FEM, the object being analyzed can have arbitrary shape and the results of the calculations are acceptable. The natural frequency and mode shape of spring taking into consideration road surface model was determined for passenger car by means of finite element analysis (I. Rajendranan, et.al, 2002).Table 3. shows major work completed so far by researchers on analysis of Composite Leaf Spring.

The harmonic and shock analysis were carried out for two layered and five layered composite leaf spring. The change in amplitude of spring was observed for the both type of composite leaf spring. Furthermore during shock analysis, it has been observed that displacement of springs was changed as time progressed (K.A.Saianurag, 2012). It has been found that several papers were devoted to the study of behavior of spring through different analysis such as, static, fatigue, and modal which was projected only for unidirectional fiber orientation. Nevertheless, unidirectional fiber orientation may weaken joint area thus strengthening of the joint is required.

## III. GAPS in Litreture

1. Inadequate work has been done on modal analysis, creep analysis, and Impact analysis for composite leaf spring
2. Very Little work has been done on effect of different fibers reinforcement type, fiber orientation and stacking sequence on performance of composite leaf spring
3. Little work has been carried out on matrix cracking, delamination, and stress concentration at hole in composite leaf spring
4. Very less work has been carried out on Integral Eye design of composite leaf spring
5. Long term practical durability and effect of environmental parameters on composite leaf spring has not been studied
6. Torsional behavior of composite leaf spring was not much studied
7. Investigation required to improve fabrication process to reduce voids which are developed at surface of composite leaf spring
8. Less work has been carried out on problem like spring failure mode i.e. inter-laminar shear stress
9. Interleaf friction in multi-leaf spring has not been much studied

Table 3: Summary of Major Work on Analysis of Composite Leaf Spring

| S.No. | Research Objectives | Researchers |
|---|---|---|
| 01 | To study Fatigue life of spring | Hawang. W.(1986) |
| 02 | To Optimize geometry of composite leaf spring | Yu.Kim (1988), Erol Sancatar (1999), I. Raendran, S. Vijayarangan (2001) M.M. Shokrieh 2003),Shivshankar,V. (2007) |
| 03 | To evaluate design parameters of leaf spring | Andra Corvi(1990), Joo. Teck.(2012) |
| 04 | To design and analyse GFRP mono leaf spring | G Gular Siddaramanna et.al(2006) M. Senthil Kumar, S. Vijayarangan(2007) Jaydeep J. Patil,. S. A. Patil (2014) |
| 05 | Study performance of C- type leaf spring | Max. X.Sardou et.al(2000) |

| | | |
|---|---|---|
| 06 | To compare load carrying capacity, stiffness, strength and weight of spring | M.Senthil ( 2007), Vinkel Arora, et.al( 2011) M.Venkatashan, et.al, Krishna Kumar, Dara Ashok (2012) B.Ragu, Keshav (2013), Sorathiya Mehul, 2 Dhaval B. Shah, 3 Vipul Bhojawala (2013), T.N.Ashok Kumar et.al (2013) Pankaj Saini Kumar et.al (2013), Devebndra K. Domar, et.al (2013), B.Vijaya Lakshmi I.Satyanarayana (2012), D.N.Dubey, S.G.Mahakalkar (2013), K. Viswanatham, H. Raghavendra Rao (2013) Ganesh.K1, Gembiram. M2, Elayaraja.Saravanan. Murali.K (2014) |
| 07 | To improve eye end design of leaf spring | J.P.Hou (2007 ) |
| 08 | Investigate influence of ellipticity on leaf spring parameters | E.Mahdi et.al ( 2006) , Abdul Rahim (2010 ) |
| 09 | To reduce unsprung weight of suspension | I.Rajendra S. et.al (2001) |
| 11 | To suggest best composite for fabricating leaf spring | B.Ragu Kumar et.al (2013) , Mhaske Raman, et.al(2014) |
| 12 | To study behavior of two and five layered composite leaf spring | K.A. SaiAnurag , et.al ( 2012) |
| 13 | To evaluate joint strength of composite leaf spring under static and dynamic loading condition | C.Subhramian ,et.al (2011) |
| 14 | To increase the load carrying capacity and life cycles of a light commercial vehicle (LCV) | V. K. Aher , et.al(2012) Ganesh.K, Gembiram.M, (2014) |
| 15 | To compare the effect of material change on stresses and weight of assembly | Kumar Krishan* 2Aggarwal M.L(2012) |
| 16 | To reduce the overall weight of suspension system and improve load carrying capacity of the composite leaf spring | C.Madan Mohan Reddy, et.al (2013) Yogesh G. Nadargi1et.al Supriya. Koppula, Makarand B.Shirke,et.al (2012) P.B.Patole Jeevesh Kumar (2013) , Edward Nikhil Karlus,et.al(2014)) |
| 17 | To present a general study on the performance comparison of GFRP and conventional leaf spring | V.Pozhilarasu, T.Parameshwaran Pillai(2013) |
| 18 | To study the capability of composite leaf springs to reduce the weight of vehicle | R M PatilȦ,et.al (2014) |
| 19 | To perform FEM and static analysis of multi leaf springs of three different combinations | U. S. Ramakanth & K. Sowjany(2013) |
| 20 | To design, analyze, and testing of unidirectional Glass Fiber/Epoxy mono composite leaf spring with and without bonded end joints | U.S. Ramakanth, et.al(2014) |
| 21 | To design the Carbon/ Epoxy composite leaf spring for automobile suspension system and analyze it | Parkhe Ravindra, et.al (2014) |
| 22 | To estimate the deflection, stress and mode frequency induced in the leaf spring of an army jeep. | Y.Venu1, G.Diwakar (2013) |
| 23 | To give the idea about suitable composite materials, useful manufacturing techniques, advantages and limitations of composite leaf Spring over the steel leaf spring. | Dadasaheb Gaikwad et.al (2012) |
| 24 | To develop a new class of hybrid composite by combining natural fibers and synthetic fibers. | Avani B. Londhe (2013) |
| 25 | Optimization of material | N.Anu Radha1, C.Sailaja2, S.Prasad Kumar (2013) |

## V. Conclusion

This review paper provides a brief summary on the work carried out for material selection, design, analysis and optimization of composite leaf spring. All the above parameters on composite leaf spring were discussed and compared with existing steel leaf spring for vehicles. The composite mono leaf springs were modeled by considering constant and varying cross-section area, with unidirectional E-glass fiber /epoxy for each lamina of a laminate. The different analysis namely static analysis, fatigue analysis, modal and shock analysis were performed using analytical, numerical and experimental approaches on steel as well as composite leaf spring by many researchers. Sometimes apart from experimental method a wide range of software packages such as CATIA, PRO/Engineer, CAE, ANSYS were used. Finally from various research papers, it is concluded that compared to conventional mono and multi steel leaf spring for vehicle the composite leaf spring have lesser stresses, weight, noise, vibration, harshness characteristic and increasing in fatigue life, strength and comfort ride. Also, Past Research has indicated that the results of E-Glass/Epoxy were found with good characteristics for storing strain energy. As a result this indicates that composite leaf spring is lighter and more economical than the conventional steel spring. Therefore, it is concluded that composite leaf spring is an effective replacement for the existing steel leaf spring in light passenger vehicle.

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