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A Paper Review on Finite Element Analysis with Fatigue Characteristics of Composite Multi-Leaf

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Abstract- *The aim of this review paper is to represent a general study on the design, analysis of leaf spring. In passenger vehicles ride comfort and load carrying capacity, rigidity is important considerations. Vehicle comfort depends upon the suspension system. Suspension system in automobile significantly affects the behaviour of vehicle. Leaf springs are perhaps the simplest and are less expensive compared to other suspension. Leaf spring is there-fore an important aspect in the suspension system design. Due to variation of load leaf springs are one of the most dynamically stressed components in automobile therefore quality of vehicle ride depends upon the leaf spring characteristics used in suspension unit, Performance measures of any leaf springs are its stiffness and fatigue life. This paper present analysis of leaf spring used in light commercial vehicle*

Keywords: *Composite Leaf Spring, Suspension, FEA, Fatigue Life.*

I. INTRODUCTION

In the present paper the main focus of automobile manufacturers is to improve life of the automobile. Fatigue failure is the predominant mode in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to several of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the sudden loads due to the wheel traveling over the bumps etc.Springs are crucial suspension elements on vehicles, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile. Performance measures of any leaf springs are its stiffness and fatigue life. Life of leaf spring can be achieved mainly by introducing the new material, changing design parameter and manufacturing processes. These springs are usually formed by stacking leafs of steel, in progressively longer lengths on top of each other, so that the spring is thick in the middle to resist bending and thin at the end where it attaches to the body. A leaf spring should support various kinds of external forces but the most important task is to resist the variable vertical forces.

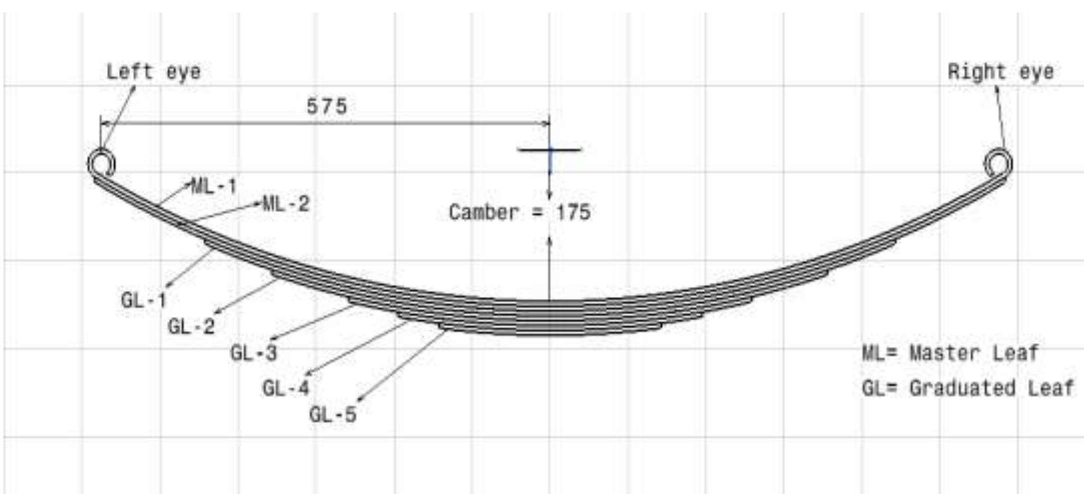

Figure 1 Multi Leaf spring

Composite materials are superior to all other known structure materials in specific strength and stiffness, high temperature strength, fatigue strength and other properties. The desired combination of properties can be tailored in advance and realized in the manufacture of a particular material. Moreover, the material can be shaped in this process as close as possible to the form of final products or even structural units. Composite materials are complex materials whose components differ strongly from each other in the properties, are mutually insoluble or only slightly soluble and divided by distinct boundaries.
Therefore analysis of composite material leaf springs has become essential in showing the comparative results with steel leaf spring. The past literature survey shows that leaf springs are designed as generalized force elements where the position, velocity and orientation of the axle mounting gives the reaction forces in the chassis attachment positions.

II. LITERATURE REVIEW

Many research papers have been published on the composite leaf spring and fatigue testing of leaf springs. A detailed review of some selected research papers is presented.
Mahmood M. Shokrieh, Davood Rezaei [1] a four-leaf steel spring used in the rear suspension system of light vehicles is analysed using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS. Main consideration is given to the optimization of the spring geometry. The objective was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. The results showed that the optimum spring width decreases hyperbolically and the thickness increases linearly from spring eye towards the axle seat. The stresses in the composite leaf spring are much lower than that of the steel spring. Compared to the steel leaf spring (9.2 kg) the optimized composite leaf spring without eye units weights nearly 80% less than the steel spring. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid the resonance. As shown in below table [1].

F (Hz)	**1**	**2**	**3**	**5**	**6**
Steel leaf spring	29.6	51.8	94.9	102.5	134.3
Composite leaf spring	33.3	57.6	173.1	248.9	464.2

Table [1]

Sabapathy Vijayarangan [2] this paper describes static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. Compared to steel spring, the composite leaf spring is found to have 67.35 % lesser stress, 64.95 % higher stiffness and 126.98 % higher natural frequency than that of existing steel leaf spring. A weight reduction of 68.15 % is also achieved by using composite leaf spring. It is also concluded that fatigue life of composite is more than that of steel leaf spring.

Syed Altaf Hussain [3] this paper show that design and analysis of composite multi leaf spring. Weight reduction is now the main issue in automobile industries. 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. 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.

Zheng Yinhuan, XueKa [4] this paper analyses the mechanics characteristic of a composite leaf spring made from glass fiber reinforced plastics using the ANSYS software. Considering interleaf contact, the stress distribution and deformation are obtained. Taking the single spring as an example, comparison between the performance of the GFRP and the steel spring is presented. The comparison results show that the composite spring has lower stresses and much lower weight. Then the automotive dead weight is reduced observably and stress of composite leaf spring is lower than steel spring and its resistance to fatigue ability is much stronger.

H.A. Al-Qureshi [5] work on The development of a GFRP single leaf spring having constant width, where the stress level at any station in the leaf spring is considered constant due to the parabolic tape of the thickness of the spring, has proved to be very effective. This study demonstrated that composites can be used for leaf springs for light trucks (jeeps) and meet the requirements, together with substantial weight saving. Other work has shown that composite leaf springs have better fatigue behaviour than steel springs. Needless to say, the hybridization technique can be used effectively to improve weight saving and performance in the automotive industry.

Shishay Amare Gebremeskel [6] 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 researchers and being solutions of such issue. In this project reducing weight of vehicles and increasing or maintaining the strength of their spare parts was considered. The fatigue life of the designed single E-glass/ Epoxy composite leaf spring is predicted and obtained as N= 221.16*103 cycles. This shows the acceptable life or good resistance of the material to failure under fatigue loading. Table [2] show us the comparison of the strength properties with the design and simulation results. When we compare the values, tabulated in Table [2] above both the design and simulation stress values are much less than that of strength properties of the material. Therefore the maximum stress failure criterion is satisfied, hence safe design of the product.

Strength properties and design and simulation results of E-glass/Epoxy single composite leaf spring					
Strength properties	**Design stresses**	**Design strains**	**Simulation stresses**	**Simulation strains**	**Simulation displacements(mm)**
Xt=1035MPa	Σ_1=470.35Mpa	ε_1= 8.7*10^{-3}	S_{11}=25MPa	E_{11}=4.5*10^{-4}	U_1= 0.65
Yt= 28 MPa	Σ_2=0.112 MPa	ε_2= 2.17*10^{-3}	S_{22}=1.8MPa	E_{22}= 1.3*10^{-4}	U_2= -2.68
S= 41 MPa	T_{12}= 3 MPa	γ_{12}=3.33*10^{-4}	S_{12}=1.3MPa	E_{12}= 1.5*10^{-4}	

Table [2]

Hanumanthraya R. [7] the unique and diverse characteristics of composite materials have increased in many folds. From feather weight rods to high performance aircraft parts, the use fibre reinforced materials have become a compelling asset due to their high strength to weight ratio and high strength to stiffness ratio combined with easy manufacturing methods In this study, the tensile, flexural and impact tests were carried out on E-glass/Epoxy composite to analyse the effect of different percentage of E-Glass/Epoxy on tensile, bending and impact strength. The tests were carried out for three different cases, namely 50:50%, 40:60% and 30:70% by volume of E-glass/Epoxy.

M. Venkatesan [8] this project describes design and experimental analysis of composite leaf spring made of glass fibre reinforced polymer. The objective is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. The design constraints are stresses and deflections. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. A weight reduction of 76.4% is achieved by using optimized composite leaf spring. From the results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications.

Predrag Borkovic, [9] stated that fatigue life of a component is a very important regarding safety and stability of any dynamically loaded systems. On the base of the fatigue simulations it is clear that the longest fatigue life of the mono-leaf spring is obtained by using the largest transition radius of 115 mm. With this transition radius, the mono-leaf spring may be able to endure at least 50 Million cycles, according to the S/N curve of the longitudinal oriented specimens. Also, by using different S/N curves for the perpendicular specimen orientation as well as for the notched specimens, the fatigue life is longer too.

Niklas Philipson [10] found the ease way to model leaf springs is to divide the spring into several rigid links. The models in this paper are designed as generalized force elements where the position, velocity and orientation of the axle mounting give the reaction forces in the chassis attachment positions. The shape of the Figure leaf spring will be determined by the rotations between each link.

Kaushal P. Khalokar, Shubham J. Alwat, [11] the automobile industries have shown interests in replacement of steel springs with composite leaf springs due to high strength to weight ratio. This work is carried out on multi leaf springs having nine leaves used by a commercial vehicle. This project describes design and experimental analysis of composite leaf spring made of glass fibre reinforced polymer. The objective is to compare the load carrying capacity. Stiffness and weight savings of composite leaf spring with that of steel leaf spring Finite element analysis with full load on 3-D model of composite multi leaf spring is done using ANSYS 14.5 and the analytical results are compared with experimental results. Compared to steel spring, the composite leaf spring is found to have 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. A weight reduction of 76.4% is achieved by using optimized composite leaf spring. Composite leaf spring reduces the weight by 85 % for E-Glass/Epoxy, over conventional leaf spring.

Type	**Minimum**	**Maximum**
Equivalent (von-Misses) Stress	2.8524e-006 MPa	1.8096e-002 MPa
Maximum Principal Stress	-8.6045e-003 MPa	2.2428e-002 MPa
Normal Stress	-1.9431e-002 MPa	1.5491e-002 MPa
Shear Stress	-8.1835e-003 MPa	7.787e-003 MPa
Total Deformation	0. mm	27937 mm

Table [3]

R. A. Claudio, J.M. Silva, C.M. Branco, J. Byrne [12] explained in paper Fatigue life calculated using total fatigue life predictive methods which are normally used for notched geometries, gave conservative results for almost all of the situations herein studied. These are found to be too pessimistic in predicting the shot peening effect. Results are much better if stress or strain energy density is averaged over a critical distance, when shot peening is considered.

Prof N.P.Dhoshi [13] the paper illustrated the importance of analytical and micro analysis. FEM analysis is done in ANSYS 11.0 and the project shows the importance of Stress analysis. On reducing the number of leaf spring from 17 to 13 will further reduce the weight by approximately 6kg and the production cost by nearly 20%.

Mr. V. K. Aher, Mr. P. M. Sonawane [14] the purpose of this paper is to predict the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations by using CAE tools. From the nonlinear static analysis, it is observed that for the leaf spring at 6 kN. Load, the max.von-Mises stress is 592.43 MPa and at 10 KN it is 1047.34 MPa.

Shiva Shankar [15] shows a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. A single leaf with variable thickness and width of constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested. Computer algorithm using C-language has been used for the design of constant cross-section leaf spring. The results showed that spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat. The finite element results using ANSYS software showing stresses and deflections were verified with analytical and experimental results. The design constraints were stresses (Tsai-Wu failure criterion) and displacement. Compared to the steel spring, the composite spring has stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85 % lower with bonded end joint and with complete eye unit.

E. Mahdi [16] the influence of ellipticity ratio on spring rate and load caring capacity.The influence of ellipticity ratio on performance of woven roving wrapped composite elliptical springs has been investigated both experimentally and numerically. A series of experiments was conducted for composite elliptical springs with ellipticity ratios (a/b) ranging from one to two. In general, this study demonstrated that composites elliptical spring can be used for light and heavy trucks and meet the requirements, together with substantial weight saving. The results showed that the ellipticity ratio significantly influenced the spring rate and failure loads. Composite elliptic spring with ellipticity ratios of a/b=2.0 displayed the highest spring rate.

S. Abdullah [17] analyzed and evaluated the capability of parabolic spring to replace the multi leaf in suspension system. Finite element analysis had been performed to analyze the stress distribution and behavior for both types of springs. Finally, comparison between simulation and experimental result had been made for validating purpose. Multi leaf can hold much more load then parabolic spring, but in terms of material usage and space requirement, parabolic spring has the advantages. For multi-leaf, the stress was concentrated at the center part, while for parabolic, stress was distributed well at the both side of the part.

Thippeswamy Ekbote [18] analyzed nine-leaf steel spring used in the rear suspension system of a light duty vehicle by finite element method using ANSYS software. The objective was to obtain a spring with minimum weight capable of carrying intended static external force without failure. The optimized spring will have its width decreasing and thickness increasing hyperbolically from the spring eye towards the axle seat. An approximate spring model was assumed and its analytical solution was also presented. Compared to steel spring, the optimized composite mono leaf spring has much lower stress and the spring weight without eye units is nearly 65% lower than steel spring.

R.B.Charde,Dr.D.V.Bhope [19] found for product quality it is necessary to find The stresses in various components in first approach the stress analysis is carried out by considering only the graduated leaves and in other approach the stress on master leaf is carried out by considering one extra full length leave. The Results of finite element analysis
for both approaches are verified experimentally by using strain gauges. The stress are evaluated at varies distances varying from 15mm to 345mm measured from support. So, length of graduated leaves plays a significant role in the stresses on master leaf. It is also observed from table that with the addition of extra full length leaf the stresses are reduced drastically. Thus to strengthen the leaf spring extra full length leave are recommended.

Dakshraj Kothari [20] studied static and fatigue life analysis of conventional leaf springs made of SUP-9 & EN-45.Comparison for maximum stress, deflection and stiffness as well as fatigue life was done. The CAD models were prepared in CATIA and analyzed by using ANSYS 12. Computer algorithm using C++ language had been used in calculating maximum stress, deflection and stiffness. Calculated results were compared with FEA result. SUP-9 springs has lower value of maximum stress, deflection and stiffness in compare to EN45 spring.

Abdul Rahim, Nur Azida Che Lah and A.F. Golestaneh [21] have worked on developing a composite based elliptic spring for automotive applications. They consider light and heavy trucks with steel elliptic spring for analysis of fatigue behaviour and weight reduction by using ANSYS software. The objective is to compare the load carrying capacity, fatigue behaviour and weight savings of composite leaf spring with that of steel leaf spring. Also they have compared the finite element result of fatigue life and weight reduction with existing analytical and experimental result. After that using this result they have replace steel leaf spring by composite material and analyse it with same loading condition. They concluded that composite elliptical springs have better fatigue behaviour than the conventional steel leaf spring and weight reduction ratio is achieved.

K. K. Jadhao, DR. R. S. Dalu [22] has worked on experimental investigation & numerical analysis of composite leaf spring. They describe static analysis of steel leaf spring and composite multi leaf spring by using ANSYS software. Primary objective is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. The material selected was glass fibre reinforced plastic (GFRP) and the polyester resin can be used which was more economical this will reduce total cost of composite leaf spring. They have compared the analysis results with experimental results. They concluded that, Composite leaf spring have much lower stress and higher stiffness than that of existing steel leaf spring. Also they concluded that weight of composite leaf spring was nearly reduced up to 85% compare to steel leaf spring.

Abdul Karim Selman, Arshed Abdul Hamed Mohammed [23] Leaf spring for light truck is investigated. Three groups of light truck are considered Simulation resembles to constrained condition when mounting on the vehicle, where each leaf in the system can be idealized in to a diamond shape. The finite element method was applied as a method of analysis to examine the stress distribution for each leaf. The number of cases studied equal 24 cases. He concluded the magnitude of stress in lower side surface for all leaves of spring is more than stress in upper side surface.

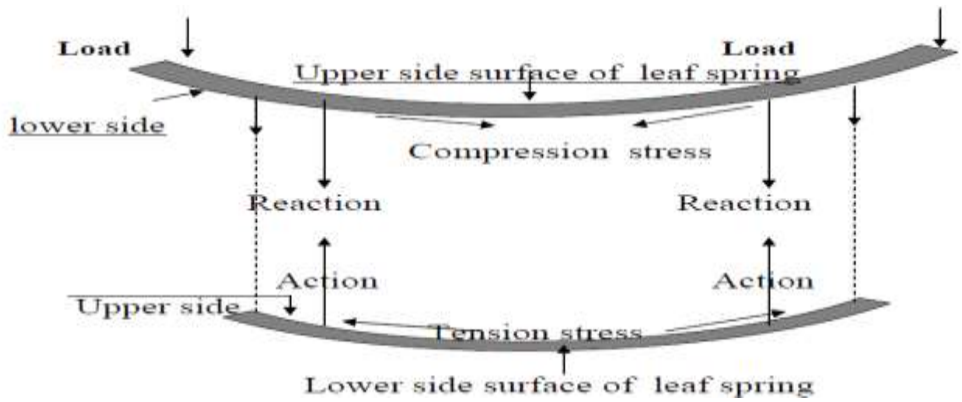

Figure 2 surfaces of leaf spring

Radha [24] she has studies optimization material of existing steel, carbon fiber and boron fibers were evaluated and optimized the best one in concern with their performance. The boron fiber composite material can be replaceable with existing steel for master leaf spring. The master leaf spring was modeled in Pro/E (Wild Fire) 5.0 and analysis was carried out by using ANSYS 13.0 for better understanding. The objective of this project was to present modeling, stress analysis and material optimization of master leaf spring and comparison of deformation and stress results between steel leaf spring and composite leaf springs under same conditions.

Makarand B. Shirke and Prof. V. D. Wakchaure [25] studied on performance association of static and fatigue behaviour of steel and glass epoxy composite leaf spring of light motor vehicle. They consider light motor vehicle steel leaf spring for analysis of stress and deflection by using ANSYS workbench 14.0 software. The objective is to reduce cost, weight that is capable of carrying given static external forces without failure. They have replaced steel leaf spring by composite material of Glass Epoxy and analyse it with same loading condition for stresses and deflection. From the analysis they concluded that, the composite leaf spring have 62.27 % lesser stress and lesser deflection compared to steel leaf spring. The predicted fatigue life of the steel leaf spring is 106 cycles and composite leaf spring is 109 cycles which are higher than that of exiting steel leaf spring. Composite leaf spring weight is reduced by 65.28 % as compare to steel leaf spring.

Suhas Jaimon D. Q., Vaishak N. L and Mahesh B. Davanageri [26] he has experimentally done investigation on E glass/Epoxy Resin hybrid composites lead to the following conclusions. For the compositions of 50:50%, 40:60%, 30:70% by volume of E-glass/Epoxy, 40:60% composition yielded maximum tensile strength, impact strength and flexural strength. The entire fabrication of composite leaf spring was done with 40:60% of E-Glass/Epoxy composition. A comparative study made between composite and steel leaf springs with respect to weight and strength showed that composite leaf spring has more load carrying capacity and is lighter compared to Steel leaf spring. The study demonstrated that composites can be used for leaf springs in light weight vehicles.

III. CONCLUSION

From the literature review it is seen that the objective was to obtain a spring with minimum weight that is capable of carrying given static external forces by constraints limiting stresses and displacements and the performance of steel leaf spring was compared with the composite leaf spring using analytical and experimental results. FEA are used for prediction about the total life cycle and fatigue life of composite and steel leaf spring. Results show that 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

Also observed that, the suspension system in a vehicle significantly affects the behaviour of vehicle that's vibration characteristics including ride comfort, stability etc. This research of papers is helpful in calculations of stress, strain, deflection and frequencies, bending moment of composite leaf spring. Comparative analysis of the performance of the system over experimental details Conclusion will be drawn on the basis of theoretical and experimental results of leaf spring.

A comparative study has been made between composite leaf spring and steel leaf spring with respect to stress and deflection. By looking all related research papers its observed that a composite leaf spring for the same load carrying capacity, 50-80% reduction in stresses and 20-40% reduction in deflection and reduction in weight about 60-8%.

This study will help to understand more the behaviour of the spring by using CAE and give information for the manufacturer to improve the fatigue life of the spring by changing design parameter. FEA is carried out by changing design parameter with conventional spring and modified spring and the results will compared with experimental results.

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