Static Analysis and Fatigue Life Prediction of Composite Leaf Springs of Automotive Suspension System

Nithesh Naik, Dheeraj Gosangi, Revati Borkhade, Ritesh Bhat, Dasharathraj Shetty, Samuel Schumann

Abstract: ***Development of vehicles with the highest safety standards and lowest carbon emissions has been one of the primary goals of the automobile manufacturers. One of the methods of achieving higher fuel efficiency is by reducing vehicle weight by minimizing the unsprung weight without compromising strength and driver comfort. The study presents the behavior of the double-bolted-end joint semi-elliptical leaf spring that is generally used in the rear suspension of lightweight cars and commercial vehicles. 65si7 grade steel is conventionally used in the above leaf springs. The study evaluates the stress distribution, deflection and fatigue life assessment of leaf springs made up of glass epoxy (62% glass fiber), carbon epoxy (40% carbon fiber), and aluminum graphite (5% graphite). The results are compared with 65si7 steel leaf spring and analysed. The analysis performed showed a weight reduction of 76.4 %, 81.1%, 65.8% respectively. The first natural frequency was approximately 1.2 times greater than the road frequency. The simulated results for fatigue life cycles of leaf spring (10e5 cycles) was observed, whereas, for the conventional steel leaf spring (2e5 cycles) was observed. The results suggest the material aluminum graphite (5% graphite) will be the best replacement, considering the overall weight to strength ratio and cost.***

Keywords*: **Composite Leaf Spring, Fatigue life, Vehicle structures, Suspension.***

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I. INTRODUCTION

The rising cost of the energy resources and the global demand to reduce emission has obligated the automobile industry to emphasize on lightweight engineering with the balance of strength to weight ratio of the parts or assemblies [1, 2]. Driver comfort and weight reduction have been a non-negotiable demand for vehicle manufacturers. Driver ergonomics form the internal factors for driver comfort. The mechanical vibrations due to bums and road irregularities in the automobile vehicles are damped using suspension system. Hence, spring plays a key role to provide the ride comfort for the passengers [3-6]. The primary suspension system commonly used in heavy vehicles duty vehicles, which needs higher load bearing capabilities, and easier maintenance is leaf spring [7, 8]. The suspension leaf spring in automobiles contribute to 10%-20% of the unladen weight [4]. Excellent fatigue characteristics and fatigue behaviour of composites leaf springs have inclined the commercial manufacturers to replace steel with composite materials for the suspension system of the automobile [11-16].

The main objective of using a spring in the suspension system is to absorb the road shocks and to release them and hence the strain energy of the spring is of a major concern [5]. The specific strain energy (U) is given by the equation (1), where σ represent maximum allowable stress, E is modulus of elasticity, is density of the material.

$$U= \frac{\sigma^2}{\rho E} \qquad (1)$$

In this research, a leaf spring was developed for a lightweight vehicle from combined materials to be equal to a steel spring. The leaf springs are modeled by two-dimensional FEM for the considered case of steel and composite materials [7]. The deflections and stresses for steel and the other forms of structural fountains have also been measured. The deflection in the composite leaf springs is usually more than in the steel spring and is below the permitted value (the spring camber). The data reveal that EN45, EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7 and 50CrMoCV4 grades of steel are used to manufacture steel leaf springs [8, 9]. They are commonly used in parabolic leaf springs and traditional multi-leaf springs. The vehicle vibrations, shocks and the bump loads caused are absorbed by leaf spring deflections. The potential energy is stored and gradually released in the leaf spring [1].

II. MATERIALS AND METHODS

A. Design Concept and CAD Modelling

Design considerations of the spring with four leaves is shown in Table I.

Table- I: Parameters of Leaf Spring [5]

Parameter	Value (mm)
Overall length (2L)	1245
Front half (arc length between front eye and seat axle)	622.5
Height of the arc from axle seat	120.4
Arc radius of the leaf (R)	1669.45
Diameter of the eye (d)	75

This spring is symmetrical, i.e. the length of front are rear half are equal which is half the total length. The parameters of the design are elaborated in Fig. 1. The thickness and width of each leaf is 7 mm and 50 mm respectively [2]. The 3 dimensional model of the leaf spring was designed and assembled on Solidworks 2017.

B. Materials Used

A total of four materials were assigned to the design. The properties of the materials considered in the present study is shown in Table II.

a. Conventional steel

The most conventional material used to fabricate leaf springs is steel also known as structural steel in ANSYS 19.2 library.

b. Glass fibre reinforced polymer

A polymer matrix composite which is reinforced with S-glass fiber (68%) and matrix used is epoxy resin (32%). The properties of this material is calculated using the rule of mixtures [4].

$$Ec = EfVf + EmVm \qquad (2)$$

Equation (2). represents Ec, Ef, Em as Young's modulus of the composite, fiber or reinforcement and matrix respectively. Vf and Vm denotes the volume fraction of fiber or reinforcement and matrix respectively.

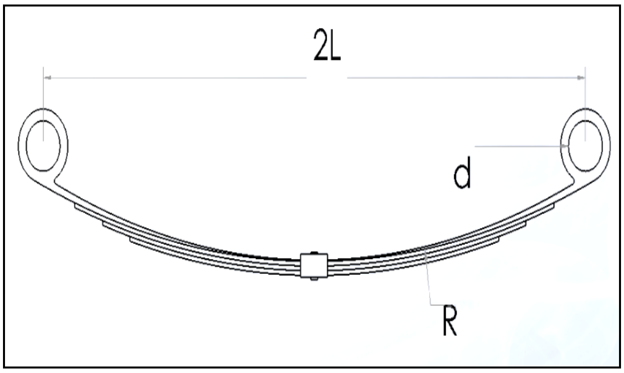

Fig. 1. Design parameters of leaf spring

a. Carbon fibre reinforced polymer

A polymer matrix composite which is reinforced with unidirectional Carbon fiber (40%) and matrix used is epoxy resin (60%). The properties of this material is calculated using the rule of mixtures [7].

Table- II: Properties of Materials Considered in the Study

Material	Density (kg m^{-3})	E (N/mm^2)	μ	Tensile yield strength (N/mm^2)	Compressive yield strength (N/mm^2)
Steel	7850	2e5	0.3	2.5e8	2.5e8
Glass epoxy	1850	0.35e5	0.23	7.8e8	4.8e8
Carbon epoxy	1480	0.92e5	0.23	8.29e8	4.39e8
Al -graphite	2678	0.67e5	0.23	2.56e8	2.56e8

b. Aluminium graphite (metal matrix composite)

This is a metal matrix composite, which is reinforced with Graphite (5%) and Aluminum (95%) [5]. The material properties for composites whose fibers are scattered randomly are calculated using Tsai-pin Hill theory, but when the L/D ratio of the fiber infinity, the equation gets reduced to the rule of mixtures.

2.1 Loads and boundary conditions

The experimental loading scenarios are considered while applying the boundary layer conditions. The modelled springs in the cambered condition subjected to full bump load condition are expected to go flat. Static structural analysis was conducted on the spring. The load applied was divided among the two eyes of the master leaf and these also tend to be the mounting points to the vehicle [3]. The bolt and the bolt holder were fixed and a load of 4660N was applied on the eyes of the master leaf along the negative 'Y' direction [2].

C. Mesh convergence test

The three dimensional finite element (FE) model is subjected to boundary conditions is analyzed for Von-mises stress. Leaf spring is modeled with beam mesh, which is a combination of triangular and quadrilateral elements, and the element size is decreased until the required convergence is achieved [7]

Table- III: Mesh Convergence Test

Element size (mm)	No. of nodes	No. of elements	Maximum Von-mises stress (MPa)
3	704491	97862	1095.6
5	177859	35090	631.51
7	70078	18374	633.86
9	41465	12132	552.54

The major role of mesh convergence is to establish the accuracy of the solution with minimum computation time and cost. The elaborated details of this test are mentioned in Table III. The test was conducted on structural steel.

The mesh size considered in the analysis is 3mm. Fig. 2 shows the finite element meshed model of leaf spring. Different element sizes for the mesh were considered to perform mesh convergence study. The study evaluates and determines the effect of mesh quality on the simulation results. All the layers of the spring were successively meshed by using size function as adaptive and varying the relevance centre to increasing element sizes as shown in Table 3. with the maximum load of 4660 N applied. The mesh size of 3 mm for the analysis for the composite leaf spring.

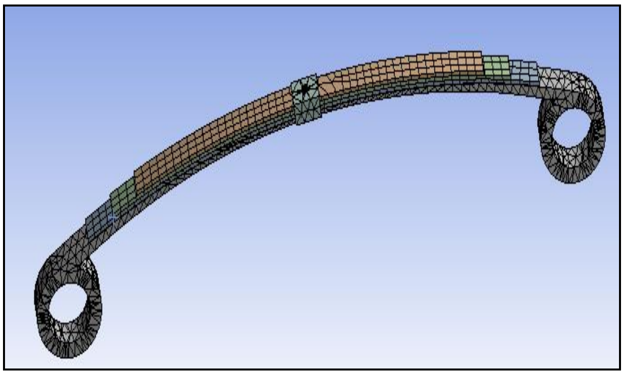

Fig. 2. Meshed model of composite leaf spring

III. RESULTS AND DISCUSSIONS

Static structural analysis on all the four materials were conducted and they were evaluated on the basis of ride comfort, von mises stress, von mises strain, total deformation, fatigue life cycles.

A. Ride Comfort

The leaf spring of suspension system is designed to provide a ride comfort to the passenger in the vehicle. The road frequency considered due to irregularities of the road is in range of 9 to 12 Hz [8]. Hence, natural frequency of the designed spring should have frequency away from the natural frequency to avoid resonance. The composite leaf spring has higher stiffness in comparison with conventional leaf spring and has lower weight. The first natural frequency evaluated for glass epoxy (62% glass fiber), carbon epoxy (40% carbon fiber), and aluminum graphite (5% graphite) was 14.1 Hz, 16.6 Hz, 15.3 Hz respectively when compared to that of conventional steel leaf spring to be 6.2 Hz. Hence, an improved ride comfort will be observed in composite leaf spring.

B. Stress Analysis

The composite leaf spring subjected to static load was analyzed for stress distribution in the member. The Von Mises stress distribution plot for conventional steel is shown in Fig. 3. The Von mises stress and strain values computed are tabulated in Table 4. The values shows that composite leaf spring is suitable and can sustain the loads in comparison with conventional steel leaf spring.

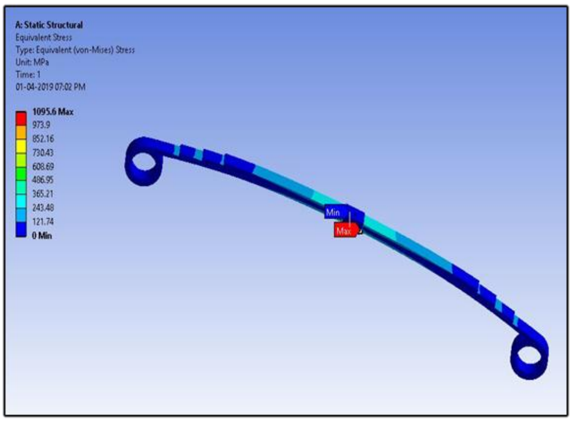

Fig. 3. Von mises stress distribution in leaf spring

C. Fatigue Analysis

The fatigue failures experienced by the leaf spring is contributed by factors like number of load cycles, range of stress, mean stress and local stress concentration [9, 10]. The fatigue tests were conducted on leaf spring design of conventional steel, glass epoxy (62% glass fiber), carbon epoxy (40% carbon fiber), and aluminum graphite (5% graphite) and compared. Fatigue life and fatigue damage cycles indicate the number of cyclic loads that spring can withstand without failure (Table IV).

Table IV: Weight, Stress Distribution, Strain, Fatigue life of Composite Leaf Spring

Material	Weight (kg)	Von mises stress (MPa)	Von mises strain	Total deformation (mm)	Fatigue life (cycles)
Steel	11.2	1095.6	0.05	18.6	2e5
Glass epoxy	2.64	850.49	0.05	92.24	10e5
Carbon epoxy	2.11	775.49	0.032	51.90	10e5
Aluminium graphite	3.82	1129.1	0.0173	55.79	10e5

IV. CONCLUSION

The analysis of composite leaf springs made up of glass epoxy (62% glass fiber), carbon epoxy (40% carbon fiber), aluminum graphite (5% graphite) and conventional steel are compared. The static analysis is performed to evaluate the weight to strength ratio, total deformation, Von mises stress and strains respectively. A weight reduction of 76.4 %, 81.1%, 65.8% respectively was also achieved by using composite leaf spring. Ride comfortness evaluation showed the percentage increase of 127.4%, 167.7% and 146.7% respectively. The first natural frequency was approximately 1.2 times greater than the road frequency.

The simulated results for fatigue life cycles of leaf spring (10e5 cycles) was observed, whereas, for the conventional steel leaf spring (2e5 cycles) was observed. The results thus obtained shows that the composite leaf spring can be a good replacement material with overall weight and cost reduction of the component. However when taken into consideration manufacturing aspects, aluminium graphite metal matrix leaf spring proves superior over other options considered in the study.

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