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Structural and Modal Analysis of Composite Leaf Spring

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ABSTRACT

The suspension system is one of the imperative parts of an automobile and is responsible for the ride comfort and handling of the vehicle. In suspension system, two types of springs are used helical spring and leaf spring. In addition to energy absorbing device, the ends of a leaf spring behave as a guided along a definite path as it deflects act as a structural member, this behaviour of leaf spring proves to be an advantage over helical spring. In the present work, fabricated mono-leaf spring comprises of steel and unidirectional glass fiber reinforced composite. To analyze the behavior of the fabricated steel and composite leaf spring, experimental modal testing and FEA has been carried out with free-free boundary condition. For FEA, ANSYS workbench environment has been used. By FEA it is found that natural frequencies of steel leaf spring are greater than natural frequencies of composite leaf spring and it has been also noticed that the experimental modal testing results showed a similar trend.

Keywords: Mono leaf spring, Metal leaf spring, Experimental modal analysis, Harmonic analysis

I. INTRODUCTION

Leaf spring is a simple form of a spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of springing, dating back to medieval times. An advantage of a leaf spring over a helical spring is that the end of the leaf spring may be guided along a definite path. Sometimes referred to as a semi elliptical spring or cart spring it takes the form of as lender 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.

This project mainly focused on modal analysis of laminated mono composite leaf spring with unidirectional fiber with an orientation of (0°/90°/45°/−45°/−45°/45°/90°/0°). The probability Glass fiber/ Epoxy composite material for leaf springs of a suspension system to interchange in conventional spring to increase the deflection, stresses, gain the comfort is studied.

Shokrieh*et al.* [1] determine stresses and deflection in the leaf spring utilized in back suspension of vehicles by FEA. As the width decreases, the thickness increases linearly from spring eye towards the axel seat.

Abdul Rahim Abu Talib*et al.*[2] studied the fabric material and geometry of the composite curved spring was optimized utilizing FEM by considering versatility properties of a/b = 2 of composite elliptic springs had an ideal spring parameter and it can be utilized for all trucks.

Karditsas*et al.* [3]designed two parabolic leaf spring for front axles of heavy duty vehicles was done using finite element methods. The permissible stress weredetermined using Wohler curve. The results shown that the stress limitations or exceeded and nearly uniform stress distribution were achieved along the length of the two leaves.

Kong et *al.*[4] worked on failure assessment of a leaf spring eye design under various load cases. They presented a transient dynamic multibody simulation of a truck leaf spring and suspension module. They analyzed the various leaf spring eye design extreme load condition such as cornering, breaking and striking

Stephan Krall *et al.* [5] this work carried out experimental modular investigation (impact test and shaker test) for examining energetic quality of CFRP cantilever leaf springs. Classical lamination theory of composite was utilized in arriving at the measurements. The results obtained by Euler Bernoulli beam hypothesis were compared the experimental results.

N Suprith*et al.*[6] FEM analysis of three multi leaf springs made up of three distinctive materials viz. 65Si7, composite leaf spring, and hybrid leaf spring. Structural analysis was carried out for these leaf springs and they found that under the same static conditions the stresses in leaf springs were with great contrast.

R M Patil*et al.*[7] found that the conventional metallic leaf springs include significant static weight to the vehicles and diminishes their fuel productivity. Hand lay-up vacuum bagging process using fabrication of composite leaf spring. Experimental tests were performed to load carrying capacity and stiffness of composite leaf spring compare to metallic.

II. METHODS AND MATERIAL

In leaf springs made of strong materials, the energy is stored as elastic strain energy. Further, since a portion of the spring's mass is associated with vertical motion of the wheel, it is desirable to reduce its mass as well as other contributing unsprung mass to increase vehicle control. Therefore the spring setup and fabric material of construction should be chosen to maximize the strain energy storage capacity per unit mass without outstanding stress horizontal surface with reliable long life method.

Steel leaf spring

The material used for leaf springs is generally pure carbon steel having 0.90%to 1.0% carbon. The leaves are warm treated after the making process. Greater range of deflection and better fatigue properties.

Table 1. Measurements of steel leaf spring

Parameter	Value mm
Straight length	985
Camber	112
Leaf width	50
Leaf thickness	8

Mechanical properties of steel leaf spring

Table 2

Sr. No	Properties	value
1	Hardness	BHn 388-461
2	Tensile strength	1300-1700MPa
3	Yield Strength	1170-1550MPa
4	Density of material	7800kg/m^3

A. Finite Element Analysis

Finite Element Analysis of steel leaf spring. It can be used to calculate deflection, natural frequency, and many other phenomena.

The modeling of metal leaf spring is done with CATIA V5. For the finite element analysis, ANSYS is selected due to its simplicity and quick results.For modelling the steel spring, the dimensions of a conventional leaf spring are chosen.

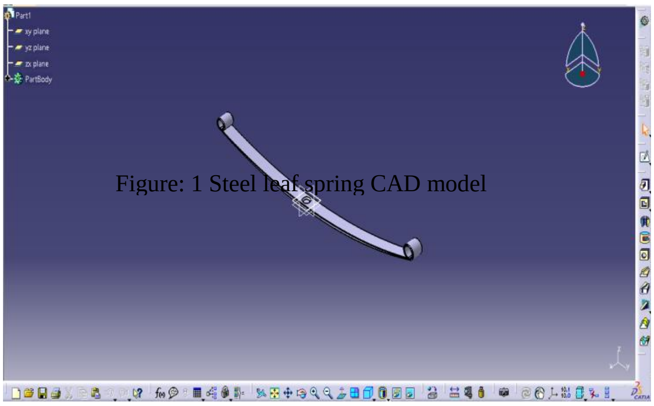

Figure 1. Steel leaf spring CAD model

Vehicle specifications:-

Here weight and initial dimension of four wheeler "Maruti Suzuki Omni" vehicle are taken.

- Max. load carrying capacity = 5*70= 350kg
- Weight of vehicle = 785kg
- Acceleration due to gravity (g) = 9.81m/s^2
- Total weight = 785+350 = 1135kg
- Total weight = 11135.34N
- Load on each eye of spring is 2784N
- Load on each wheel is = 1392 N

Since the vehicle is 4-wheeler, a single leaf spring comparing to one of the wheel takes up one fourth of the overall weight.

Composite Leaf Spring

The capacity to absorb and store more expanse of energy ensures the comfortable operation of a suspension system. In any case, the problem of heavy weight of spring is still determined. This can be cured by presenting composite material, in place of the conventional leaf spring. From several studies, it is found that the E-glass/Epoxy is better material for replacing the conventional steel as per strength.

MATERIAL PROPERTIES OF E-GLASS EPOXY

Table 3

Sr. No	Properties	Value
1	Young's modulus Y-direction (Ey)	8060 MPa
2	Young's modulus X-direction (Ex)	52060 MPa
3	Young's modulus Z-direction (Ez)	8060 MPa
4	Shear modulus XY-direction (Gxy)	4500 MPa
5	Shear modulus ZX-direction (Gyz)	4500MPa
6	Shear modulus YZ-direction (Gzx)	3846.2 MPa
7	Poisson ratio XY-direction (NUxy)	0.26
8	Poisson ratio ZX-direction (NUyz)	0.4
9	Poisson ratio YZ-direction (NUzx)	0.26
10	Density of material	1800kg/mm^3

Table 4. Measurements of composite leaf spring

Parameter	Value (mm)
Straight length	985
Leaf thickness at the end	08
Leaf thickness at the centre	20
Leaf width at the centre	32
Camber	112
Leaf width at the end	50

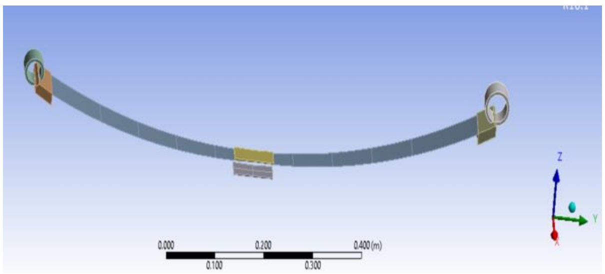

Figure 2.composite leaf spring shell model

The shell model of composite leaf spring is shown in figure 2 is developed in ANSYS Composite PRE-POST. To create layers for different thickness and different width of composite leaf spring and connected metal parts to shell bounded contact.

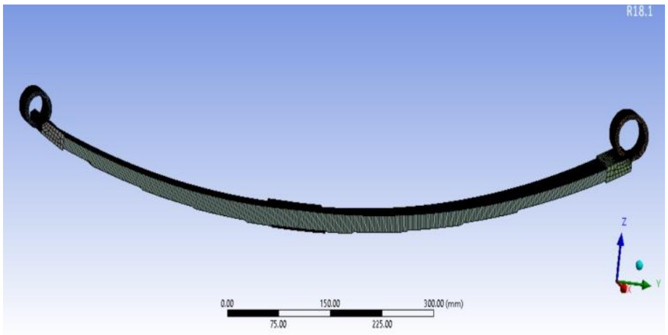

Figure 3. Meshed model of composite leaf spring

The meshed model of composite leaf spring is shown in Figure 3 is a hexahedral mesh consists of 108176 elements with an element size 5mm.

Simulation is carried out for free-free boundary condition to determined natural frequency and deflection of composite leaf spring.

B. Experimental modal testing

The leaf spring is suspended by two elastic strips within a designed setup, to make it hang a free-free condition. When the leaf spring is excited at resonant frequencies, it causes to vibrate and gives special shapes called mode shapes. By understanding the modal parameters or "mode shapes", all possible type of vibration can be predicted. The excitation is applied by the impact roving hammer and the input force is measured by the force measuring transducer. The accelerometer is mounted on specified point to measure the frequency response at several points on the leaf spring and data acquisition system computes the frequency response function (FRF) and output is measured.

To perform an impact test the following equipment's are required:

1. An impact hammer
2. An accelerometer
3. A 8 channel FFT data analyser
4. Post-processing software

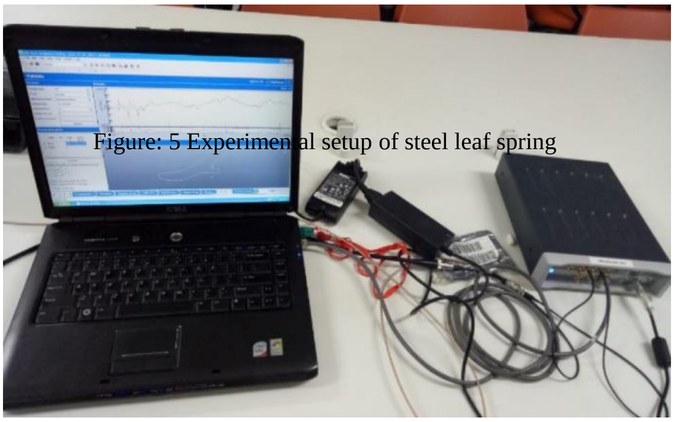

Figure 4. Actual impact testing Experimental setup

Generally, experimental modal analysis is used to solve a dynamic problem. Most of vibration and acoustic problems are function of both initial conditions and inherent characteristics of a system which described by the modal analysis. Thus, it helps to understand the various mode of vibration response of any structure.

Figure 5. Experimental setup of steel leaf spring

III. RESULTS AND DISCUSSION

A. Numerical Results of Steel Leaf Spring

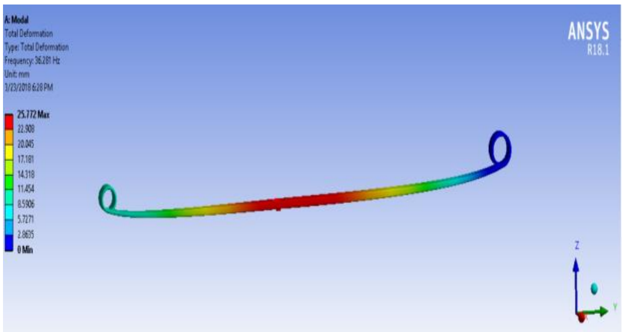

Figure7. Steel leaf spring 1st Mode shape

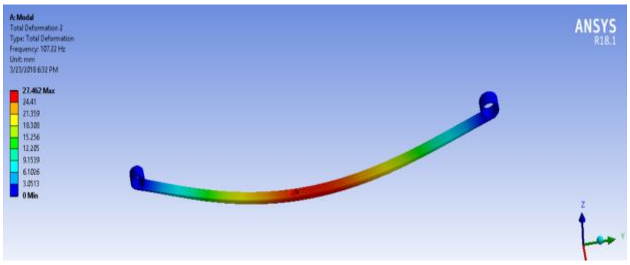

Figure 8. Steel leaf spring 2nd Mode shape

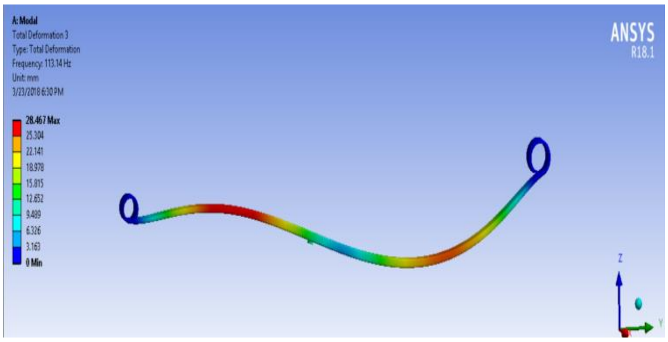

Figure 9. Steel leaf spring 3rd Mode shape

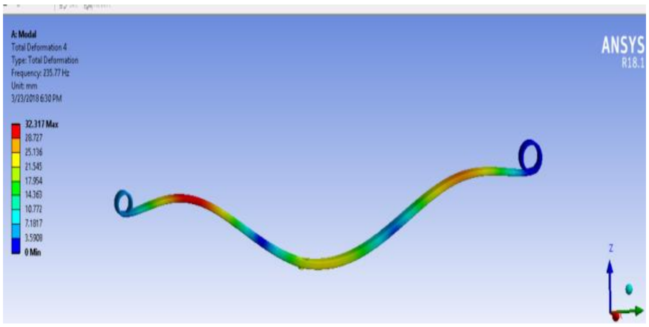

Figure 10. Steel leaf spring 4th Mode shape

B. Numerical Results of composite Leaf Spring

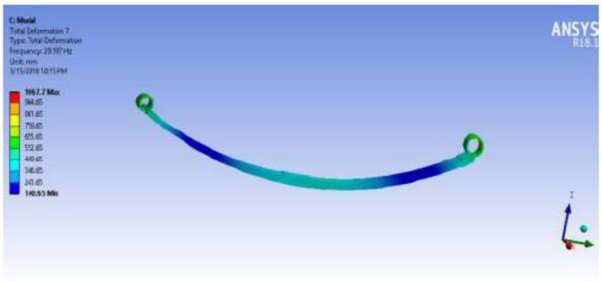

Figure 11. Composite leaf spring 1st Mode shape

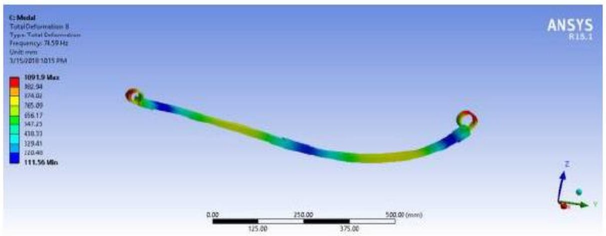

Figure 12. Composite leaf spring 2nd Mode shape

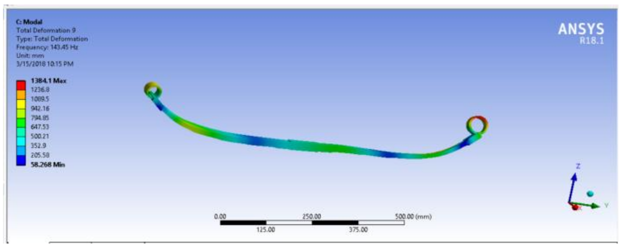

Figure 13. Composite leaf spring 3rd Mode shape

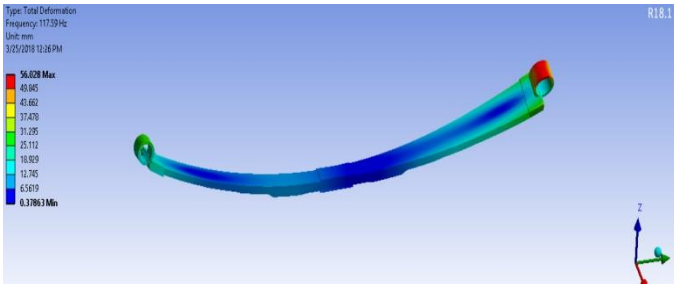

Figure 14.composite leaf spring 4th Mode shape

Table 4. Natural frequency of Steel Leaf Spring

Modes	Experimental Results (Hz)	FEA Results (Hz)
1	32.08	36.28
2	75.30	107.22
3	150.13	113.14
4	225.73	235.77

Table 5. Natural frequency of Composite Leaf Spring

Modes	Experimental Results (Hz)	Numerical Results (Hz)
1	26.09	29.18
2	79.10	74.43
3	89.74	98.35
4	116.91	119.20

From Above results, it is observed that there is good agreement between experimental and simulated natural frequencies of both steel and composite leaf spring.

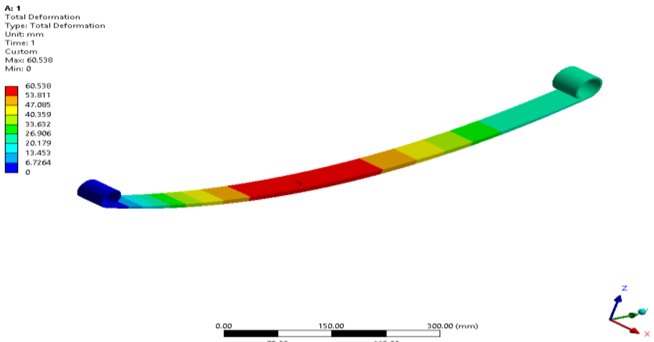

Figure15. Deformation of steel leaf spring 60.53mm

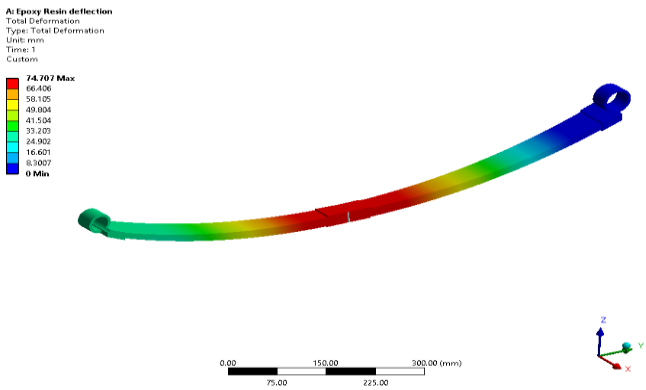

Figure16. Deformation of composite leaf spring 74.70mm

Deflection of composite and steel leaf spring obtained from simulation is 74.70 mm and 60.53 mm is same load carrying capacity respectively.

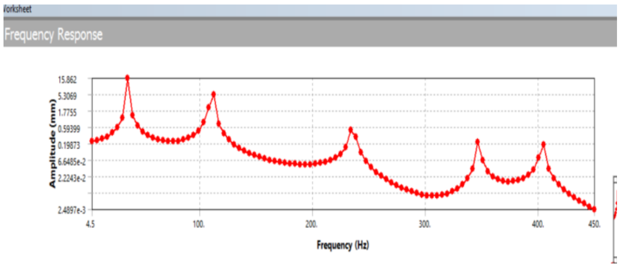

Figure 17. FRF of Steel leaf spring

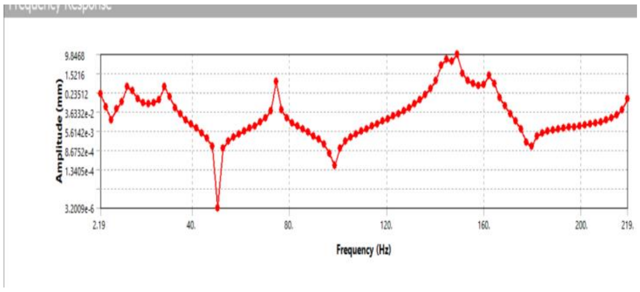

Figure 18. FRF of Composite leaf spring

Figure 17 and figure 18 shows the response analysis of composite leaf spring and steel leaf spring. This technique exploits the Frequency Response Function (FRF) of the structure, which represents the relation between the excitation and the vibrational response of the structure. Resonance frequencies appear as peaks in the measured frequency response functions.

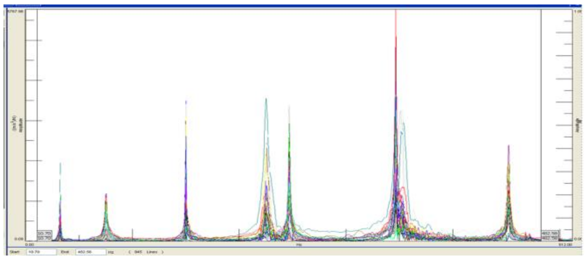

Figure 19. Experimental FRF of Steel leaf spring

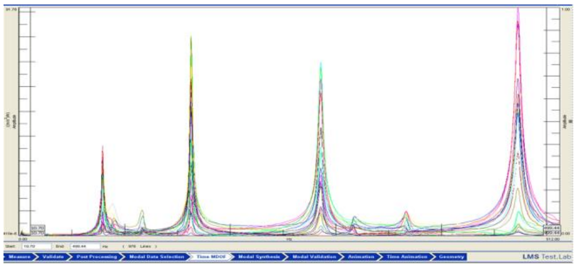

Figure 20. Experimental FRF of Composite leaf spring

Figure 19 and figure 20 shows the experimental response analysis of composite leaf spring and steel leaf spring good agreement with numerical results.

IV. CONCLUSIONS

This work is to compare load and deformation in Glass/Epoxy composite leaf spring compared to steel leaf spring for automobile suspension system.

It can be observed from the comparison that the deflection and load induced in the Glass/Epoxy composite leaf spring is higher than the conventional steel leaf spring for the same load carrying capacity.

This design helps in the replacement of conventional steel leaf springs with Glass/Epoxy mono composite leaf spring with better ride quality.

Comparative modal analysis of mono composite Leaf spring has been carried out.

The mode shapes and frequencies are carried out of both steel leaf spring and composite leaf spring. The numerical results from Finite Element Analysis showed in general a good agreement with the experimental results.

Totally it is found that the composite leaf spring is the better that of steel leaf spring. Therefore, it is concluded that composite mono leaf spring is an effective replacement for the existing steel leaf spring in vehicles.

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