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Experimental comparison of Static, Dynamic Analysis of Steel, Composite Mono Leaf Spring for Shifting Natural Frequency to Reduce the Vibrations

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ABSTRACT

The objective is to present experimentation, modeling and analysis of steel, composite mono leaf spring for Static, Dynamic analysis and compare its results. Experimentation is carried out using computerized UTM (Universal testing machine) and FFT (Fast Fourier Transform) analyzer for static and dynamic analysis respectively. Analysis is carried out by using ANSYS 14.0 software for better understanding. From the study, it is seen that the Composite leaf spring (BASALT FIBRE/E-POXY) weight is 2.7 times less as compared to steel leaf spring for same stiffness (same load carrying capacity).Composite leaf spring (BASALT FIBRE/E-POXY) natural frequency is 1.93 times more as compared to steel leaf spring for same stiffness, Though the Basalt fiber spring sets offer a higher degree of vertical direction deflection, while this is a small concern in terms of static deformation, the overall reduction in dynamic displacements combined with increased vibration damping ratio offer superior ride comfort.

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I. INTRODUCTION

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. More efforts are taken in order to increase the comfort of user. Appropriate balance of comfort riding qualities and economy in manufacturing of leaf spring becomes an obvious necessity. To improve the suspension system many modification have taken place over the time. Inventions of parabolic leaf spring, use of composite materials for these springs are some of these latest modifications in suspension systems [00]. This project is mainly focused on the implementation of composite materials by replacing steel in conventional leaf springs of a suspension system. A spring is defined as an elastic body, whose function is to distort when loaded and to recovers its original shape when the load is removed. Semi-elliptic mono leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension.

II. DESIGN OF BASALT FIBRE/E-POXY MONO-LEAF SPRING

Considering several types of vehicles that have leaf springs and different loading on them, various kinds of composite leaf spring have been developed. In multi-leaf composite leaf spring, the interleaf spring friction plays a spoil spot in damage tolerance. It has to be studied carefully.

The following cross-sections of mono-leaf composite leaf spring for manufacturing easiness are considered.

1. Constant thickness, constant width design.
2. Constant thickness, varying width design.
3. Varying width, varying thickness design.

In this paper, only a mono-leaf composite leaf spring with varying width and varying thickness is designed and manufactured. Computer algorithm using C-language has been used for the design of constant cross-section leaf spring. The results showed that a spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat The design parameters for composite leaf spring are shown in table I. The material properties of Basalt fiber/Epoxy are listed in Table II.

A. *Dimensions of Composite Leaf Spring*

Table I. Design Parameter for composite leaf spring

Sr. No.	Parameters	Dimensions (mm)
1	Length of leaf spring	560
2	Thickness of leaf spring	5
3	Width of leaf spring	36

Table II. Material properties of Basalt fiber/E-Poxy

Sr. No.	Parameter	Descriptions
1	Material	Basalt
2	Young's Modulus E	$1.1x10^5$ N/mm^2
3	Density ρ	$2.65X10^{-6}$ kg/mm^3
4	Poisson's ration	0.4
5	Yield stress	2100 N/mm^2

B. *Design of Steel Mono-Leaf Spring*

1) *Materials of Steel leaf spring*

The material used for leaf spring is usually a plain Basalt steel having 0.90 to 1.0% Basalt. The leaves are heat treated after the forming process. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

According to Indian standards, the recommended materials are:

1. For automobiles : 50 Cr 1, 50 Cr 1 V 23, and 55 Si 2 Mn 90 all used in hardened and tempered state.
2. For rail road springs: C 55 (water-hardened), C 75 (oil-hardened), 40 Si 2 Mn 90 (water-hardened) and 55 Si 2 Mn 90 (oil-hardened) [00].

Table III. The material properties for steel leaf springs

Sr. No.	Parameter	Descriptions
1	Material	SiMn Steel
2	Young's Modulus E	$2.1x10^5$ N/mm^2
3	Density ρ	$7.86X10^{-6}$ kg/mm^3
4	Poisson's ration	0.3
5	Yield stress	1680 N/mm^2

Table IV. Design Parameters for steel leaf spring

Sr. No.	Parameters	Dimensions (mm)
1	Length of leaf spring	560
2	Thickness of leaf spring	5
3	Width of leaf spring	36

III. THREE-DIMENSIONALFINITE ELEMENT ANALYSIS OF SPRING

Modeling is done using Pro-E (Wild Fire) 4.0 and Analysis is carried out by using ANSYS 14.0 software for better understanding. The element is defined by 10 nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible elastoplastic materials, and fully incompressible hyperelastic materials. The MPC184 rigid link/beam element can be used to model a rigid constraint between two deformable bodies or as a rigid component used to transmit forces and moments in engineering applications. This element is well suited for linear, large rotation, and/or large strain nonlinear applications [00].

Analysis is carried out for composite leaf spring and the results were compared with steel leaf spring Figure 2. and 3. represent FEA results for steel and mono composite leaf spring (Basalt Fiber/Epoxy). The load, deflection for Basalt Fiber/Epoxy and for steel were measured and plotted with the help of Ansys 14.0 as shown in Figure 2. and 3.

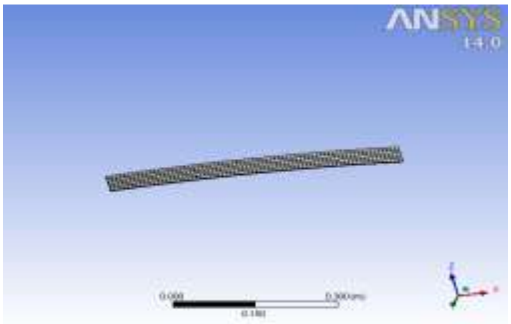

Figure 1. Meshed Model

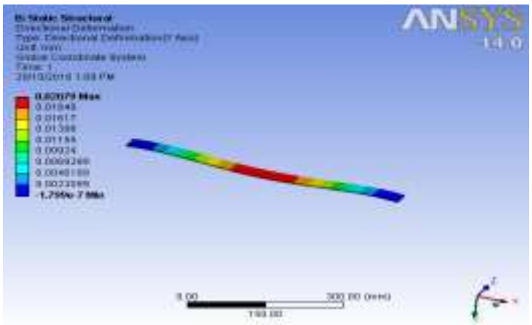

Figure 2. Load Applied 50 N on composite spring

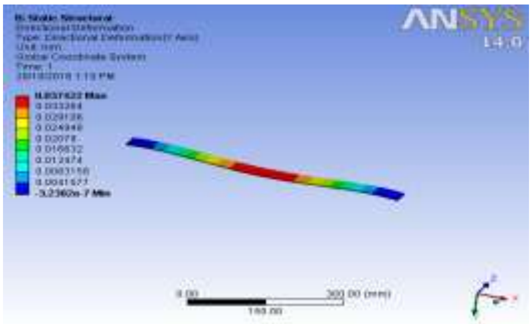

Figure 3. Load Applied 90 N on steel spring

The composite and steel leap spring is loaded with different value of load varies from 50N to 360N. and their corresponding deflection in as given below. The more the deflection, more the quality of shock absorbing capacity. These values are find out with the help of Ansys 14.0 design software which allow to know the deflection of the leaf spring with the corresponding load applied on it.

Table V. The load, deflection of Composite spring.

Sr. No.	Load	Deflection
1	0	0
2	50	3.45
3	90	13.25
4	180	23.05
5	270	28.5
6	320	37.5
7	360	42.25

Table VI. The load, deflection of Steel spring.

Sr. No.	Load	Deflection
1	0	0
2	50	0.34
3	90	1.54
4	180	3.75
5	270	5.79
6	320	6.56
7	360	7.90

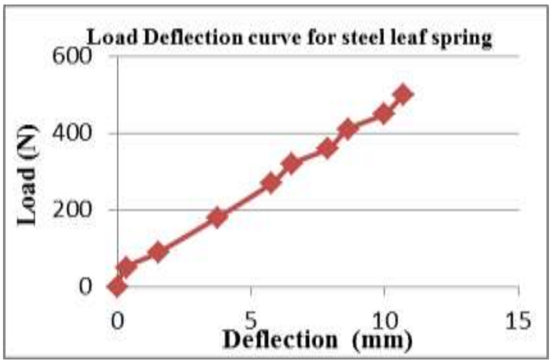

Fig. 4. Load Deflection curve for steel leaf spring.

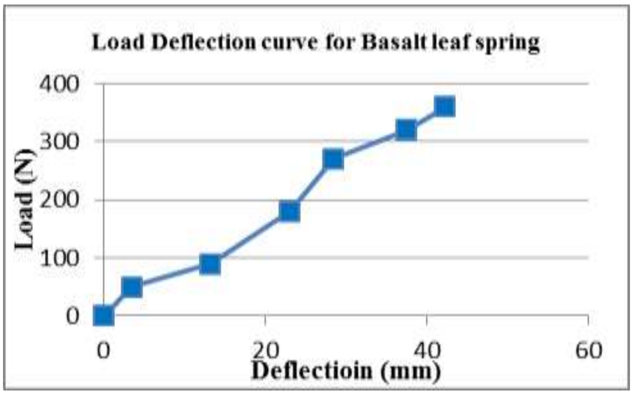

Fig. 5. Load Deflection curve for steel leaf spring**.**

The comparison of both leaf springs in graph is as shown in fig. it shows the reliable result towards basalt fibre.

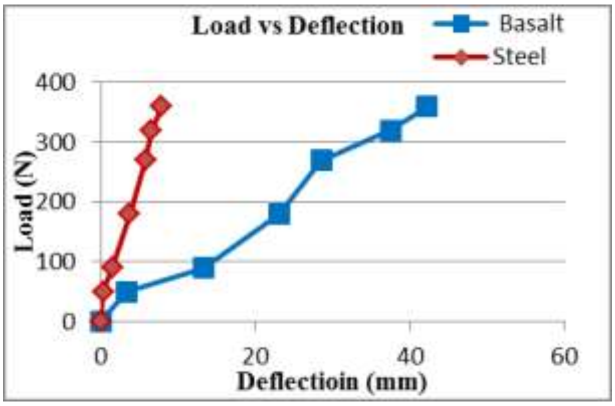

Fig.6. Comparison of Load Deflection curve for steel & Basalt fiber/epoxy leaf spring

Stiffness of both spring is calculated by taking the slope of the graph of load vs. Deflection which are listed in table 8.

IV. DYNAMIC ANALYSIS

When elastic bodies such as a spring, a beam and a shaft are displaced from the equilibrium position by the application of external forces, and then released, they execute a vibratory motion. This is due to the reason that, when a body is displaced, the internal forces in the form of elastic or strain energy are present in the body. At release, these forces bring the body to its original position. When the body reaches the equilibrium position, the whole of the elastic or strain energy is converted into kinetic energy due to which the body continues to move in the opposite direction. The whole of the kinetic energy is again converted into strain energy due to which the body again returns to the equilibrium position. In this way, the vibratory motion is repeated indefinitely.

There are two general cases of vibrations called free and forced vibrations. Free vibrations, takes place when a system oscillates under the action of forces inherent in the system itself, and when external impressed forces are absent. The system under free vibration will vibrate at one or more of its natural frequencies, which are properties of the dynamical system established by its mass and stiffness distribution.

Vibration taking place under the excitations of external forces is called forced vibration. When the excitation is oscillatory, the system is forced to vibrate at the excitation frequency. If the frequency of the excitation coincides with one of the natural frequencies of the system, the condition of resonance is encountered, and large oscillations may result. The failure of major structures, such as bridges, buildings or airplane wings, is an awesome possibility under resonance. Thus, the calculations of natural frequencies are very important [00].

V. EXPERIMENTAL APPROACH FOR DYNAMIC ANALYSIS WITH THE HELP OF FFT

The FFT mean Fast Fourier Transformation is used to determine the natural frequencies and also with the help of accelerometer we can measure deflection with corresponding that frequency.

Figure shows the steel and basalt leaf spring kept on exciter to give some excitation and this excitation is measured with the help of accelerometer the deflection with corresponding that frequency.

Figure 7. Experimental Setup for Dynamic Analysis of Steel Leaf Spring

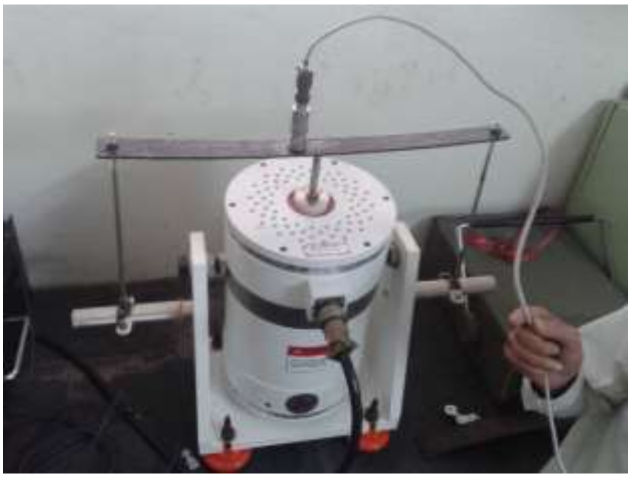

Figure.8. Experimental Setup for Dynamic Analysis of Steel &Composite Leaf Spring

*B. **Experimental set-up***

The leaf spring is attached with some fixture; whole arrangement is fixed by side angle with the help of nuts and bolts. The exciter is kept exactly below the center of leaf spring. Tip of exciter is touched to the leaf spring. Accelerometer is attached above the leaf spring and at the center.

The forced excitation is given to the leaf spring with the help of exciter, provided with control panel. The forced excitation is given in the range of 2 Hz from 24 Hz to 36 Hz.

FFT (Fast Fourier Transform) analyzer plots the Displacement time graph. Peak value for particular frequency is noted. Displacement vs. Frequency curves is plotted and shown below.

A.CALCULATING NATURAL FREQUENCY WITH FFT ANALYSER TH

1. Observations:

The natural frequencies of the both composite and steel leaf spring are calculated with the help of FFT. The result shows that the natural frequency of basalt leaf spring is more than the steel leaf spring, which means that the shock absorbing capacity of composite leaf spring is more than the steel leaf spring.

Following figure shows the FFT result of composite leaf spring and steel leaf spring.

Figure.9 Output of FFT analyzer (steel leaf spring) first natural frequency

Figure.10 Output of FFT analyzer (Basalt fiber /Epoxy) first natural frequency

Figure.11 Output of FFT analyzer (steel leaf spring) second natural frequency

Figure. 12 Output of FFT analyzer (Basalt fiber /Epoxy) second natural frequency.

Figure.13 Output of FFT analyzer (steel leaf spring) third natural frequency

Figure.14 Output of FFT analyzer (Basalt fiber /Epoxy) third natural frequency.

The FFT experiment conclude that the natural frequency of composite leaf spring is more than the steel leaf spring, which means that for the suspension purpose the composite leaf spring is more efficient than the steel leaf spring.

B. Experimental Results of FFT analyzer:

Table VII: - Results of FFT analyzer

	Steel	Basalt fibre/Epoxy
1st Natural Frequency	94 Hz	150 Hz
2nd Natural Frequency	482 Hz	350 Hz
3rd Natural Frequency	672 Hz	740 Hz

VI. RESULTS AND DISCUSSIONS

The objective of this project was to evaluate the applicability of a composite leaf spring in automobiles by considering riding comfort. The comparison between steel leaf spring and composite leaf spring is made for the same stiffness and loading conditions. The comparison is based on four major aspects such as weight, riding comfort, cost and strength.

A. Comparison of Weight

The total weight of composite leaf spring is 0.145 kg. The weight of a convectional steel spring assembly is around 1.118 kg. So, around 82.27 % of weight reduction is achieved. Thus the objective of reducing the unsprung mass is achieved to a larger extent.

B. Comparison Based on Riding Qualities

The leaf spring of light passenger vehicles has to be designed in such a way that its natural frequency is maintained to avoid resonance condition with respect to road frequency to provide good ride comfort. The road irregularities usually have the maximum frequency of 55 Hz. Therefore the leaf spring should be designed to have a natural frequency, which is away from 55 Hz to avoid the resonance (poor ride comfort zone). It is found that the first natural frequency of composite leaf spring is nearly 2-3 times the maximum road frequency and therefore resonance will not occur. Therefore it is obvious that composite leaf spring provides improved ride comfort. The weight reduction of unsprung mass of an automobile will improve the riding quality. The suspension leaf contributes 10% - 20% of the unsprung mass. The weight of the composite leaf spring is 2.7 times less than steel leaf spring. Hence the riding comfort of an automobile is increased due to the replacement of the steel leaf spring by composite leaf spring. Also damping ratio of composite leaf spring is far more than conventional leaf spring, which will provide increased riding comfort.

C. Comparison of Natural Frequency

Composite leaf spring (BASALT FIBRE/E-POXY) natural frequency is 1.92 times more as compared to steel leaf spring for same stiffness. As the natural frequency of composite leaf spring is more than the steel leaf spring, the comfort and the performance regarding of the composite leaf spring is much better than steel leaf spring.

D. cost comparison

The cost estimation of composite leaf spring provides a clear economic viability of the product in comparison to that of a convectional leaf spring.

VII. CONCLUSIONS

The conclusions drawn from the analysis carried out are as follows:

- The 3-D modeling of both steel and composite leaf spring is done and analyzed using ANSYS v14.0;
- Composite leaf spring can be used on smooth roads & also on rough road with very high performance.
- The study demonstrated that composites can be used for leaf springs for light weight vehicles for improved ride comfort.
- A comparative study has been made between composite and steel leaf spring with respect to weight, Natural frequency and Damping ratio.
- From the results, it is observed that the composite leaf spring is lighter and more efficient than the conventional steel spring with similar stiffness.

VIII. FUTURE SCOPE

After carrying out the work, it is found that following things can be added as an extension to this work.

- As experimental work is carried out on small scale model because of limitations of exciter capacity, one can go for full scale model using shaker for dynamic analysis.
- Experimental work is carried out in laboratory condition; one can go for actual road condition test.

- Static analysis is done only for calculating stiffness, by using strain gauges one can find out stresses developed in both leaf spring.

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