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Dynamic synthesis of composite based leaf springs for automotive applications

G. Hemanth, A. Babul Reddy, M. Pavan Kalyan, V. Tanishka Varma, K.V.V. Sai Kalyan, A. Suresh
Department of Mechanical Engineering, CVR College of Engineering, Hyderabad, 501510.

Abstract – *The proposed work is about the dynamic analysis and response against the loads on the leaf springs using the composite leaf springs. The response against the operating conditions of the leaf springs is analyzed using the Abacus software and the results are compared with the standard numerical tests including the finite element analysis. In this work the composite based leaf type springs are emphasized with a visco-elastic material cores that can withstand the fatigue stress and repeated and fluctuating loads. Usually it is a customary requirement to maintain the more strength to the less weight ratio for the spring to operate in a real time working environment. But due to the versatility in the application of loads on the conventional springs that are made up of steel are to be replaced with a much stronger, low weight and high strength material. In the current work a composite based leaf type springs were considered with the visc-elastic leaf springs to withstand impact loads, static loads and vibrations. The addition of visco-elatic material has promoted the high strain energy and subsequently it has shown a significant difference in the performance of spring.*

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I. Introduction

Leaf springs are essential elements used in the automobile sector for the effective transformation of the energy from one component to the other component. Usually leaf springs used for the storing and retrieval of energy obtained from the tires / roads to the vehicle body [1]. These leaf acts as a suspension system and provide comfort the vehicle and passengers or goods against the impact and fluctuating loads. At the outset these leaf springs are used to provide safety and good working ambience to the vehicle for the long durability and smooth operation [2].

Conventionally these leaf springs are made by the steels that provide more strength to weight ratio but the proposed work has introduced the adoptability of the composite leaf springs in place of conventional steel springs for the enhanced strength to weight ratio and also to provide the long lasting life against the fatigue and fluctuating loads [3]. Efforts are made to cope up the gap between the performance and material aspects to enhance the efficiency and effectiveness [4].

It is also important aspect to be considered for the performance point of view of composite based leaf springs. Further the addition of visco-elastic cores and its impact in against static and dynamic loading is to be assessed [5]. The performance testing and analysis is made using the Abacus software and the results are further compared with the conventional numerical methods including the finite element analysis [6]. The width and geometrical features of the leaf spring are considered for the optimal functioning of the leaf springs. The carbon / glass epoxy composite materials are used in the present work as an alternative to the existing steel leaf springs [7]. The addition of multi featured materials into the existing model of leaf springs the anisometric properties have improved to uplift the multi facet properties. Then the addition of the visco-elastic materials are improved the performance with respect to impact loads and dynamic performance [8].

II. Defining the objective function

In the present work the static response and the dynamic response of composite based leaf type springs were analyzed. The analysis is carried out in two phases in the first phase the composite based leaf type spring along with visco-elastic core was considered in the later one the composite leaf springs without leaf springs are used. The visco-elastic core is made as a layer by layer and subsequent modeling is performed [9].

The loads during the analysis are static and impact, with the inclusion of both the loads the static and dynamic response is analyzed for the assessment of adoptability of these materials. The strength to weight ratio is often a serious concern in developing the leaf springs to tackle the loads and shocks of the automobile [10]. In the present work analysis of the leaf springs made from the composite materials are analyzed with and without visco-elastic cores. The static and dynamic analysis is made using the Abacus software and numerical analysis using the finite element methods is analyzed [11]. At the end the results are compared for the usage of leaf springs.

III. Methodology and Material Selection

The selection of the material is made by considering the material properties and their impact in the performance of the leaf springs [12]. As the present work is confined for using the composite materials, in the present analysis the carbon / glass epoxy composite materials are considered. The modeling of the leaf springs is made by the carbon reinforced epoxy composite material and also the glass epoxy reinforced composites.

The advantages of the both the cases are critically analyzed for the application in the leaf springs. In addition the fatigue and impact loads effects are also taken for consideration while making the analysis. The following flow chart will make the complete understanding of the analysis of leaf springs.

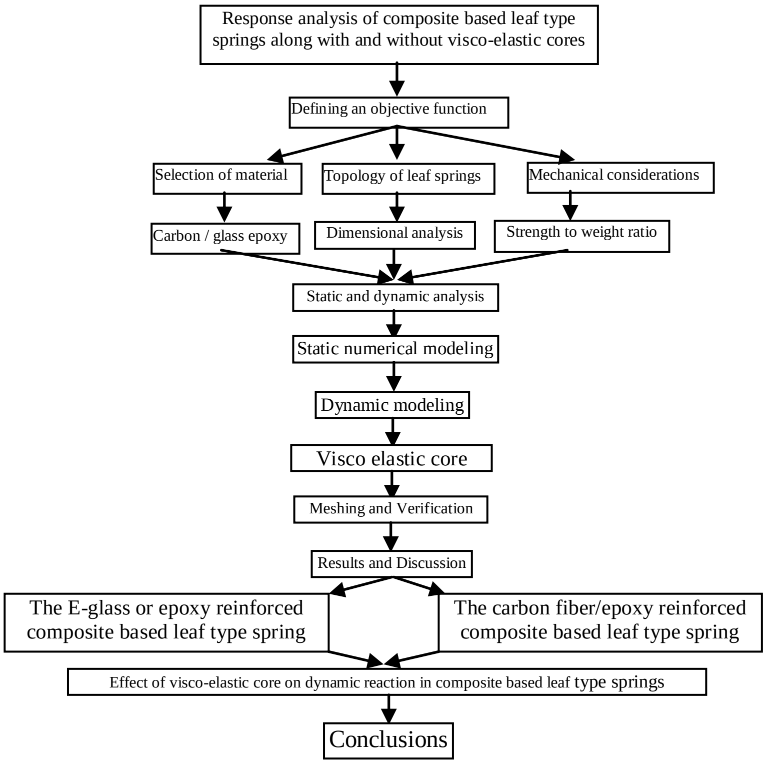

Figure 1. Detailed flow chart showing the response analysis of composite based leaf type springs with & without visco-elastic cores

IV. Numerical Modeling

The numerical modeling of the leaf springs analysis is aimed at finding the equivalent stiffness at the operating loads. The numerical modeling is subdivided into the two parts one is static modeling and the other is dynamic modeling [13]. In the static modeling the leaf springs made from composite materials are loaded with steady and static loads. The static load applied is considered as the point load and that is applied at ten different points along span of the leaf spring. The load applied is 425N and the maximum deflection (static) is assumed as 130mm. To evaluate the topological features such as width and thickness the leaf type spring is pondered as the cantilever type beam at an instance. The width is denoted with B and thickness is denoted with H. In the Figure 2 the modeled leafs spring in the form of cantilever beam is shown.

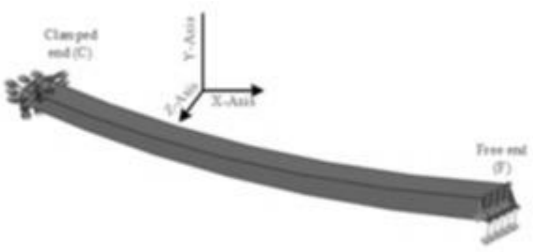

Figure 2: The composite based leaf type spring designed as cantilever type beam

In below figure 3 the topological features such as width and thickness are shown. And at the end of the beam point load applied is shown with symbol F. The length of the beam is considered as L.

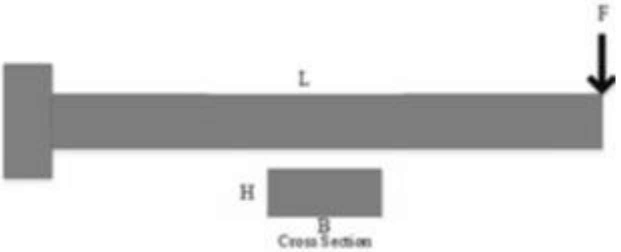

Figure 3: Topological details of the leaf spring

The width B and thickness H are calculated using the following formulae.

$$H = \frac{2 * \sigma_{max} * \left(\frac{L}{2}\right)^2}{3 * E_1 * \delta_{max}} \qquad (1)$$

$$B = \frac{6 * F * (\frac{L}{2})}{\sigma_{max} * H^2} \qquad (2)$$

In the above equations E_1 is modulus of elasticity and σ is the stress and δ is deflection the suffix max indicates the maximum value of the given quantity [14]. By applying the Abacus software the initial values of the width and thickness are calculated by evaluating the values of stress and deflection. Then the optimal values of width and thickness are found [15].

Then after the Visco-elastic core is introduced into the leaf spring. Then the optimal values of leaf spring width and thickness are calculated with and without of Visco-elastic core [16]. To do this activity the trial and error method is applied. By doing so the optimal values of the width and thickness are calculated. In the current analysis the thickness of leaf springs are considered as 2mm, 4mm and 6mm.

V. Dynamic designing

After design of composite based leaf type springs along with-and-without of visco-elastic core, in two cases the spring is subjected to the impact type of loads for taking into the account of effect of road and bump alterations and irregularities. With the increase of energy carrying ability characteristic of the composite based leaf springs, they will absorb the wider spectrum of the vertical impacts and vibrations, shielding the comfort of passenger ushering to a joyful and convenient ride. Hence, in the current work, the objective is to dilate this discriminating characteristic (energy reposting ability) with the addition of a visco-elastic veneer in the quintessential composite based leaf type spring [17].

During the analysis of dynamic application of load, the frontier contexts are analogous to the real time road test frontiers. The composite based leaf type spring is inferred to cantilever shaped beam along with the one end fixed and other end free that deflects in the y- direction only. In the present occurrences, stress & deflection developed in composite based leaf type spring are quite lower than that of conditions of static load that fulfills criteria of design. The conditions of load and amplitude of the vibrations were detailed in the Figure 3.

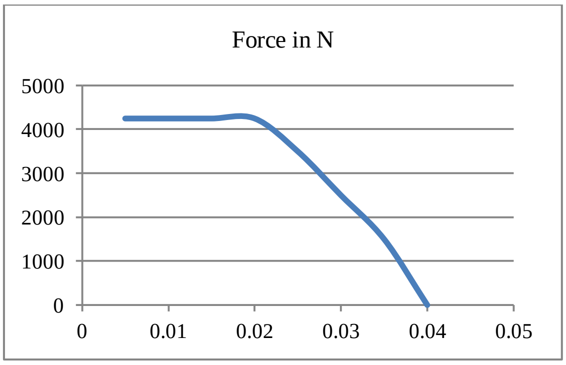

Figure 4: Profile of Impact load

It must be identified that overall force comprises of two important parts: they are static load (weight) of the spring structure & load of impact on it. For the comparison of damping level both of composite based leaf springs with and without the visco-elastic layer, ratio of damping (n) is found. The ratio of damping can be calculated by

$$\zeta = \frac{\delta}{(4*\Pi^2 + \delta^2)^{1/2}} \qquad (3)$$

In the above equation δ is decrement of logarithmic.

$$\delta = \ln \frac{X_1}{X_2} \qquad (4)$$

The modulus of shear for the linear visco-elastic type materials the domain of frequency form is considered as:

$$G^* = G' + G'' = G'(1+i\eta_G) \qquad (5)$$

Where η_G is factor of loss for the visco-elastic materials and G' and G'' are loss moduli and storage for the shear in the visco-elastic materials correspondingly.

Visco-elastic based materials are represented in the form of permutations of the viscus and the elastic materials such as the dashpots and springs. Researchers are presented in many models depend on basic variations expressed by the Voigt-Kelvin and Maxwell cases. Proposed model for the Tschoegl in that the shear modulus of complex may be expressed for the N words in the form of the domain of frequency (Mosallam, A.2018).

$$G^* = G_0 - G_0 \sum_{n=1}^{N} g_n + \sum_{n=1}^{N} \frac{G_0 g_n \tau_n s}{1 + \tau_n s} \qquad (6)$$

In the equation (6) s = iω and ω are the terms of frequency. Equation term in the series is termed as the term of N_{th} of series of Prony in the domain of frequency. g_n and τ_n are the material variables & G_0 the instantaneous modulus of shear. The below table 1 represents the Prony's series of expressions.

Table 1: Expressions of prony's series

N	g_n	τ_n (s^{-1})
1	0.003104	0.6069
2	0.0071	0.1521
3	0.01221	0.0307
4	0.034987	0.008741
5	0.06645	0.001822
6	0.1544	0.00049
7	0.2617	0.000025
8	0.455	0.000004

To corroborate the tendered model, natural frequencies of a composite based leaf type springs along with visco-elastic core is contrasted with a composite type sandwich made beams along with a visco-elastic core. Material and their topological characteristics of a sandwich type beam are tabulated in Table 2.

Table 2: Configuration and Materials of sandwich benchmark beam for verifying the nominated model.

	Faces materials	Vicsco-elastic core
Thickness mm	1.51	0.126
Length mm	177.9	177.9
Width mm	12.6	12.6
Density kg/m^3	2819	969.7
E in GPa	67	-
Poisson's ratio	0.3	-
G in GPa	-	0.00069
Loss factor	0	0.1,0.3,0.4,0.6,1,1.4

Table 3: Composite based sandwich beam Natural frequency

Model			Present study	Mace	Mead and Markus	JKR method	Fasana and Marchesiello	Arikoglu and ozkoi
Natural frequency Hz	Loss factor	0.1	62.49	60.2	63.771	64.3	63.22	63.88
		0.3	62.55	61.3	61.33	64.5	-	62.99
		0.4	62.61	61.5	65.11	64.5	-	63.99
		0.6	64.77	62.8	64.71	65.7	-	64.28
		1	66.03	64.8	66.99	67.1	-	64.5

		1.4	68.32	70.1	70.10	70.1	69.25	64.6

Table 4: Contrasting the ratio of damping and natural frequency pertaining to composite based sandwich type beam

		1	2	3
Natural frequency in Hz	Present Study	12.08	65.49	181.06
	Filho and Felippe study	11.29	64.11	176.11
Ratio of Damping	Present Study	0.0499	0.0489	0.0442
	Filho and Felippe study	0.0498	0.0491	0.0437

In the above table 3 and table 4 the results of the present investigation and other studies investigations are compared and contrasted. Furthermore, Finite Element Analysis outcomes (in current study) of composite based leaf spring is contrasted along with an another analytical outcome Felippe Filho for the beam along with 2 elastic covers & a visco-elastic cover to validate the precision of yielded dynamic outcomes.

VI. Results and Discussion

E-glass based reinforced epoxy based composite made leaf type spring

At first, the composite based leaf type spring excluding the visco-elastic core is considered for analysis. In the contemplate the E type glass based reinforced epoxy based composite based leaf type spring is analyzed under impact & static loading, sequentially. It is then, contrasted with the E type glass based epoxy reinforced composite based leaf type spring with visco-elastic core. Initial width and thickness of the composite based leaf type spring as the cantilever type beam possessing the functionality factor of number 2 is found by:

$$\sigma_{max} = \frac{X_{1t}}{n} = \frac{1035}{2} = 517\text{MPa}$$

The width and thickness, vouchsafing to equations. (1) and (2), were 29 & 40 mm correspondingly. Then after finding the embryonic numeral of cantilever oriented beam topological dimension, composite based leaf spring is the one in this the chamber and length are 135 and1300 mm is made. Hence the dimensions are prepared for cantilever oriented beam, the values should be altered for composite based leaf spring (Guo, Y. 2018). Hence, as detailed above, the width escalated until a specified quantities that fulfill the criteria of design. The outcomes are tabulated in Table 5.

Table 5: Delineated E type glass based epoxy reinforced composite based leaf type spring

Material used	E-glass epoxy
W in kg	3.15
B in mm	35
L in mm	1300
H in mm	30
F in Hz	40
Load in N	4200

The below figures shows the analytical outcomes of the e type glass made epoxy with and with-out the use of visco-elastic core in terms of stress distribution contour and vertical displacement contour.

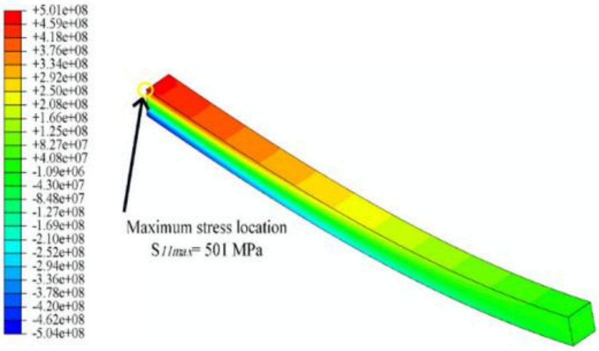

Figure 8: Stress distribution contour without use of Visco-elastic contour

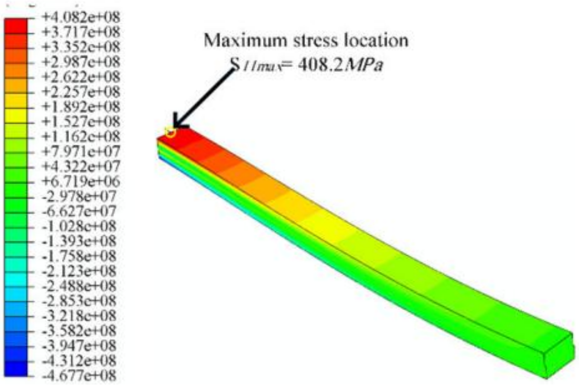

Figure 9: Stress distribution contour with use of Visco-elastic contour

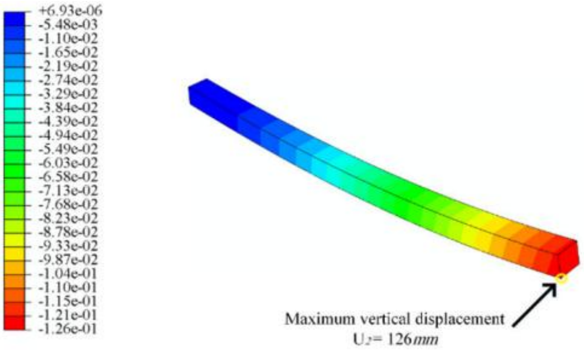

Figure 10: Vertical displacement contour without use of Visco-elastic contour

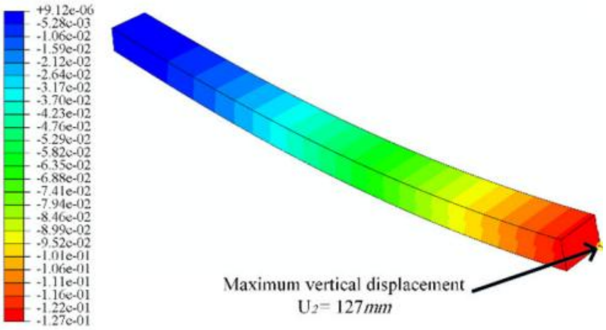

Figure 11: Vertical displacement contour with use of Visco-elastic contour

Dynamic response of the composite based leaf springs without use of visco-elastic core. Results of the analysis shows that stress induced in the orientation of the fibers is about 84 MPa, that is much lower than the quantity of static rule due to the altering conditions of boundary in the context of dynamic analysis. During this situation of dynamic environed, the factor of reliability is about 4.5 depend upon the maximum stress failure criteria. During the response of Impact that another important critical hallmark of the composite based leaf type springs, that is contemplated in current work. The Figures below elaborate the kinetic energy, deflection-time and strain energy curve, correspondingly, with respect to the free end of the leaf type spring. Similarly they elucidate the deflection vs time analogy curve in vertical orientation. This comparative graph depicts after the application of the impact loading and accordingly maximum deflection of the amplitude is archived to be 13.89 mm, then deflection of the spring beam converges rounded to 4 mm. In continuation the ratio of damping is found. According to the equations below the values of ratio of damping is determined by:

$$\delta = \ln \frac{X_1}{X_2} = \ln \frac{0.01389}{0.00622} = 0.803644$$

$$\xi = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}} = 0.12693$$

Carbon fiber based reinforced epoxy based composite made leaf type spring

The maiden measurements of the carbon epoxy / fiber made composite based leaf type spring is found. The gist for calculating topological measurements are same as that of the E type glass made epoxy reinforced composite made leaf type spring. At first, the maximum quantity of stress holds with composite leaf spring is found as:

$$\sigma_{\max} = \frac{X_{1t}}{n} = \frac{1003}{2} = 515Mpa$$

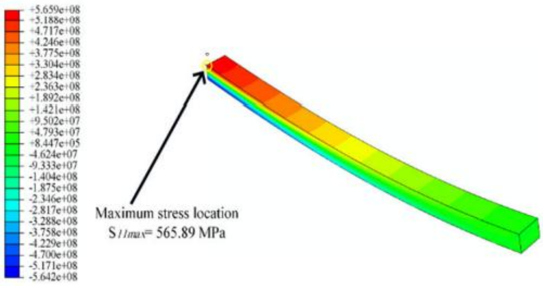

Figure 16: Stress distribution contour without use of Visco-elastic contour

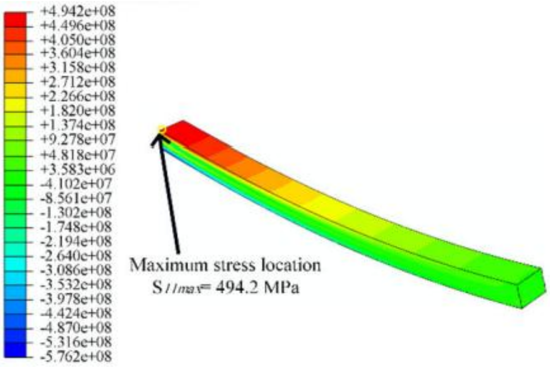

Figure 17: Stress distribution contour with use of Visco-elastic contour

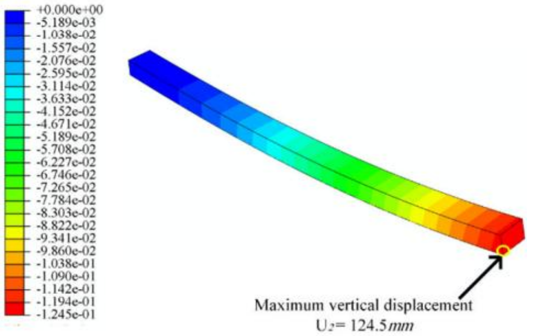

Figure 18: Vertical displacement contour without use of Visco-elastic contour

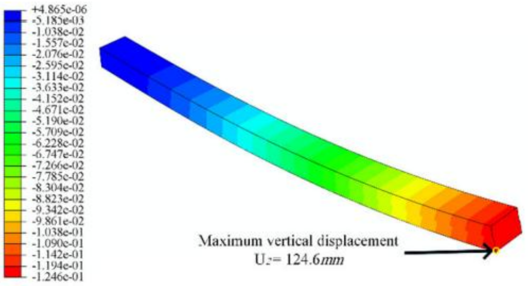

Figure 19: Vertical displacement contour with use of Visco-elastic contour

The below table depicts the designed E-glass and carbon epoxy based epoxy reinforced composite based leaf type spring. The comparison of the E type glass and carbon are well made and contrasted for the utilization of the type of composite material to be used for the application in the leaf springs.

Table 6: Comparison of designed composite leaf spring

Composite material	L mm	H composite	H Visco-elastic	B mm	F Hz	ζ
E-glass epoxy	1300	30	0	35	40	0.12693
	1300	15	2	50	25	0.04560
	1300	16	4	50	30	0.05502
	1300	17	6	50	31	0.05824
Carbon fiber epoxy	1300	25	0	35	40	0.09834
	1300	14	2	50	25	0.07479
	1300	15	4	50	30	0.07990
	1300	16	6	50	31	0.08591

Repercussions of visco-elastic based core over dynamic retaliation in a composite based leaf type springs:

In a current work to obtain the much better discernment of visco-elastic veneer's ramification, the dynamic retaliation of delineated E type glass based epoxy reinforced composite made leaf type spring is outlined the graph given in the above discussions. All the design outcomes, for instance the ratio of damping for a E type glass based epoxy reinforced composite made leaf type spring for 3 disparate visco-elastic core object thicknesses were tabulated in the Table 6.

In accordance to the Table 6, the ratio of damping of all the E type glass based epoxy reinforced composite made leaf type springs is quite lower than 1 that is $d < 1$, hence the designed system is considered as under-damped. Additionally, in the present situation of $d < 1$, the ratio of damping reduces and the traveler feels a quite smooth travel or ride, along with that the spring of the system will absorb the vibration and shocks that may impact.

VI. Denouements

In the current swatting, a 3 Dimensional FE analysis enlisting Abaqus software is made to find out the impact of coping the visco-elastic core over the leaf type spring post-impact and response of the composite based leaf type spring. Outcomes of the present work are stated as follows. Contriving of a composite based leaf type spring along with the visco-elastic made core reduces the ratio of damping of composite based leaf type spring system in this outcomes in a comfortable ride as the system of spring attracts the vibrations and shocks. Composite based leaf springs along with the visco-elastic material core are stockpiled high energy of strain that is a noteworthy characteristic for composite based leaf type spring.

Composite based leaf type springs along with the visco-elastic made core of thickness about 2 mm were found to be optimum for the leaf springs viewed from strain energy point of view and the capacity spectrum for both verities of composite based leaf type spring. E type glass based epoxy reinforced composite made leaf type springs along with the visco-elastic core of a 2 mm thickness that are of higher strain energy with capacity that of other types of composite based leaf type springs.

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