Analysis of Mono Composite Leaf Spring for Light Commercial Vehicle Using Finite Element Method

Mr. Kumbhar Prafull Mahadeo[1] Prof. Patil Yuvraj R.[2]
[1]Student [2]Professor
[1,2]Department of Mechanical Engineering
[1,2]Dr. J. J. Magdum College of Engineering, Jaysingpur, India

Abstract— Leaf springs probably are the oldest automobile suspension gadgets still in active use. Weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. In this dissertation work the material of the leaf spring is changed. The new Leaf spring is used which is made of composite material and high weight reduction is achieved. The main objective of research work is to carry out Sensation analysis of composite leaf spring with nonlinear parameters. Here free and forced Sensational Analysis of Composite Leaf Spring is done and compared with Steel Leaf Spring. The nonlinear Sensation analysis is carried out. So, to achieve this, CATIA and ANSYS software's are used for three dimensional modeling and analysis respectively. The simulated results are compared with experimental results. The result shows good Agreement between experimental results and numerical results.

Keywords: ANSYS, Composite, FFT, Layup, Leaf spring, Metal Matrix Composite, Mode Shapes, Von- Misses Stress

I. Introduction

Inside the automotive Industrial Sectors, increasing competition and innovation seek to alter Current goods or replacing old with new goods and creative Material items. The mechanism of suspension for automobiles it is also an area where these inventions are carried out on a daily basis. Further attempts are made to enhance the comfort of the customer. A simple requirement is the required combination of comfort riding characteristics and economy in leaf spring manufacturing. Many changes have occurred over time to strengthen the suspension mechanism. Many of these recent changes to suspension structures are developments the use of composite materials for these springs in parabolic leaf springs [1].

A typical type of steel spring, typically used in suspension system for automobiles, is a mono/multiple leaf spring. To absorb sensations caused during the motion of the vehicle, it uses a leaf spring, which is an automotive component. Leaf springs are long and thin plates mounted above or below the vehicle axle mostly on chassis of a vehicle. Based on the application needed, Single leaf springs and multi-leaf springs are used. Leading to the weight of the vehicle and payload, it also serves as a frame to allow vertical loading. The behavior of the spring of the leaf is complex under operating conditions because of its impact on clamping and interleaf communication, His research is therefore essential to predict mode frequency and displacement [2].

II. History of Leaf Spring

We know that, since the middle Ages, Wheeled cars were used with springs. In fact, although the early models were primitive, they were used as the first spring type. In early cars and trucks, springs were using elliptical leaf. They experienced innovations, in importantly adding additional leaves to cover the journey even further and remained popular in cars for several decades. This changed with the introduction of front wheel drive automobiles in the 1970s. The coil springs took over at that point. In large commercial vehicles, you can often find leaf springs today; some SUVs still use them on the rear axle as well. A more recent discovery is the parabolic leaf spring. This greatly enhances the efficiency of the journey, and can usually be seen on buses. The spring connects to the frame at either end. The rear axle resets and is attached to the middle of the spring by "U" nuts, on one side or another. As an option, the ride is smooth and the springs connect directly to the frame at one end, leaf springs are fitted, but the other end is retained by a shackle to the frame, allowing for further movement. Leaf springs on classic vehicles: Most people can only find leaf springs if they are interested in older vehicles. That said, a new type of plastic leaf spring is used by the Corvette, and still they live in a number of S.U.V.s.

A. *Leaf Spring Prerequisite*

1) Mainly used for vehicle suspension, the leaf spring is
2) Leaf spring can withstand vertical sensations and impacts the Sensations caused by load disturbances in the spring deflection indicate that P.E. is retained at springs as strain energy and then release a leaf spring's steadily rising energy stored capacity to ensure a more complaint suspension system.
3) To support position, stabilize and shock resists the axle and is attached to the underside of the vehicle in both directions.
4) Leaf springs are typically more capable than ordinary coil-type springs of uniformly spreading the weight of a heavy load.
5) Some road shocks are absorbed by them and serve as dampers.
6) The lateral sensations are constrained.
7) Any amount of accelerating and braking torque is decreased.

B. *Need for a Spring Composite Leaf*

In recent years, Car makers have sought to minimize car weight to satisfy the topic criteria about natural resources and the energy market. The suspension spring is one of the most significant automotive systems that decrease jerk, sensations and shock absorption while driving. For many applications, the production of solid polymers with fibers has been attributed for weight savings. Such benefits of using fiber-reinforced polymers rather than steel are:

1) Because of the high damping factor the risk of decreasing noise, sensation & moving rigidity.

2) Lack of problems with corrosion, that means less maintenance costs; & the lack of problems in corrosion, that means less maintenance costs;
3) The positive effect on the cost of production is due to decreased prices for tooling.

Springs are critical suspension components in vehicles, due to road regularities, essential to reduce vertical shocks, impacts and bumps. Due to composite design and production, the roles of suspension springs in the automotive sector must preserve good control stability and improve riding comfort; issues have emerged, for example, in the transition from comparatively homographic-isotropic steel alloys to anisotropic plastic for homogeneous fiber enhancement. The action of Leaf Spring (Steel) is non-linear and relatively high, and shifts in the solid axle angle due to the weight shift, in particular, during cornering of a car. This can result in steering and lateral instability when a driver has a very difficult time handling the vehicle.

Although there are different ways of classifying materials, they can be categorized as natural and synthetic or man-made in the simplest and broadest sense.

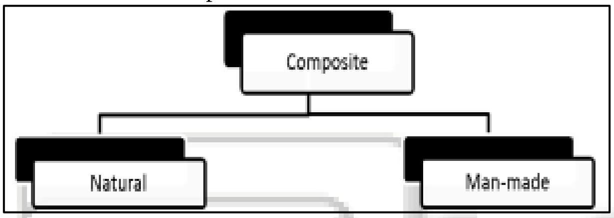


Fig. 2.1: Composite Grouping

The in-kind composites are considered naturally occurring composites. Human or animal bodies, even rocks or Wood and minerals are common examples of such composites. Examples of natural composite are also the human tissue of the bones is composed by two parts: organic inorganic seas and elephant tusks. Bones of bone are composites themselves. A lot like the composite of today materials are man-made. The man-made composite classification is shown in [fig 1.10.2].

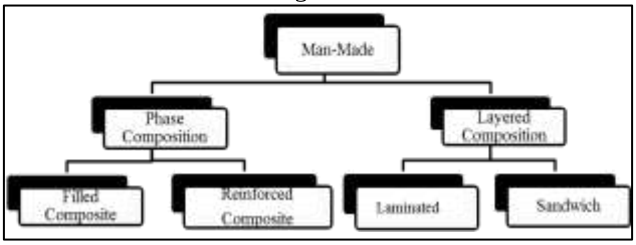


Fig. 2.2: Man-made of Grouping

Two distinct materials are typically composed of composites. Just two methods can be used to combine the two components:
1) By linking one substance to another
2) Layer by layer link.

The former structure type is the layered phase of the latter step type. The structure of the phase is normally visualized at the microscopic level and at the microscopic level they layered the composition.

The substance obtaining the insert in the phase composition is of a continuous nature and is called the matrix. The insert is discreet and can be referred to as a reinforcement or filler. If the cost reduction is the primary feature for the insert process then the filled composite is called the resulting material. Some common instances of Carbon Black natural coated rubber, cement concrete, Portland cement, and cement reinforced concrete are filled with resin. In order to improve the mechanical properties, the insert is mainly called a strengthened composite.

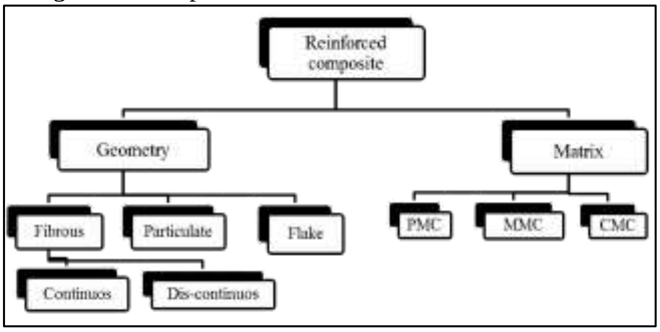


Fig. 2.3: Reinforced Composite of Grouping.

The improved composite can be categorized in two different ways,
1) Centered on the used matrix
2) Based on the strengthening geometry.

III. THEORETICAL ANALYSIS

The subsequent analysis of the balance of powers and moments generates

Governing equation of motion differential,

$$\frac{\partial 2}{\partial x2}\left\{EI(x)\frac{\partial 2y}{\partial x2}\right\}+m(x)\frac{\partial 2y}{\partial t2} = f(x,t) \qquad (3.1)$$

The eq (1) above can be modified as follows by adding viscous damping per unit length c:

$$\frac{\partial 2}{\partial x2}\left\{EI(x)\frac{\partial 2y}{\partial x2}\right\}+m(x)\frac{\partial 2y}{\partial t2}+C(x)\frac{\partial y}{\partial t} = f(x,t) \qquad (3.2)$$

The continuous framework of linear behavior, an elegant method called "mode superposition" technique, remains. The method is explored in depth in a summary. The normal frequencies and the required mode forms first have to be understood to apply the overlay technique.

A. *Normal Frequencies and Shapes of Mode*

The standard In terms of the homogeneous beam sensations equation solution, frequencies and mode shapes are obtained. The undemanded mode for the beam bending sensations with clear sectional property is considered. Let f (x, t) = 0 if there are free sensations and take the answer, Y (x, t) = Φ(x) sin ωt. In which Φ (x) the mode form is a function, and al is the standard circular frequency.

Consider a beam; it is filled by a point P, such that the beam is diverted through a curve. When the P power of a displaced beam is extracted, it returns to its first shape. However, the inertia of the beam may allow its original location to vibrate. The beam is the equation,

$$\frac{\boldsymbol{EI}}{\boldsymbol{\rho A}}\frac{\boldsymbol{\partial^4 y}}{\boldsymbol{\partial x^4}}+\frac{\boldsymbol{\partial^2 w}}{\boldsymbol{\partial t^2}}=\boldsymbol{0} \qquad 3.3$$

Where, ρ is the density of mass and A is the beam cross-sectional area.

$$\mathbf{c^2\frac{\partial^4 y}{\partial x^4}+\frac{\partial^2 y}{\partial t^2}=0} \qquad 3.4$$

Where,

$$\mathbf{C} = \sqrt{\frac{\mathbf{EI}}{\boldsymbol{\rho}\mathbf{A}}}$$

Equation approaches 3.2 are for the factors to be divided, one based on location and the other on time.

$$\mathbf{y} = \mathbf{W(x)T(t)} \qquad 3.5$$

By including Equation 3.4 in Equation 3.5, and simplifying, the Equation is:

$$\frac{\mathbf{C^2}}{\mathbf{w(x)}}\frac{\partial^4 \mathbf{y}}{\partial \mathbf{x^4}} = -\frac{\mathbf{1}}{\mathbf{T(t)}}\frac{\partial^2 \mathbf{T(t)}}{\partial \mathbf{t^2}} \qquad 3.6$$

The Eq. (3.6) Two Differential Equation can be written as,

$$\frac{\partial^4 \mathbf{w}}{\partial \mathbf{x^4}} - \boldsymbol{\beta}^2\ \mathbf{W(x)} = \mathbf{0} \qquad 3.7\ a$$

$$\frac{\partial^2 \mathbf{T}}{\partial \mathbf{t^2}} + \boldsymbol{\omega}^2\ \mathbf{T(t)} = \mathbf{0} \qquad 3.7\ b$$

Where,

$$\boldsymbol{\beta}^4 = \frac{\boldsymbol{\omega}^2}{\mathbf{c^2}} = \frac{\boldsymbol{\rho}\mathbf{A}\boldsymbol{\omega}^2}{\mathbf{EI}}$$

To find out the solution of Eq. 3.7 a, consider the Eq.

$$\mathbf{W(x)} = \mathbf{C_1 \cos h\beta x + C_2 \sin h\beta x + C_3 \cos h\beta x\, h + C_4\ \sin h\beta x} \qquad 3.8$$

In order to solve eq. 3.8 the following boundary conditions for cantilever beam are needed:

1. At x = 0 → W = 0
2. At x = 0 → W I= 0
3. At x = L→ W II= 0
4. At x = L→ W III= 0

By substituting boundary conditions to WI, WII, WIII. We obtain the following values of C1, C2, C3, and C4:

$$[\mathbf{\sin h\beta l - \sin \beta l}]\mathbf{C_3}\ + [\mathbf{\cos h\beta l + \cos \beta l}]\mathbf{C_4} = \mathbf{0} \qquad 3.9$$

We can write Eq. 3.8 in matrix form as,

$$\begin{bmatrix} \mathbf{\cos h\beta l\ +} & \mathbf{\cos \beta l +} & \mathbf{\sin h\beta l + \sin \beta l} \\ \mathbf{\sin h\beta l\ -} & \mathbf{\sin \beta l\ -} & \mathbf{\cos h\beta l + \cos \beta l} \end{bmatrix} \begin{bmatrix} \mathbf{C_3} \\ \mathbf{C_4} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \end{bmatrix} \qquad 3.10$$

For solving matrix of Eq. 3.10, we get determinant,

$$(\mathbf{\cos h\beta l + \cos \beta l})^2 - (\mathbf{\sin h\beta l + \sin \beta l})(\mathbf{\sin h\beta l - \sin \beta l}) = \mathbf{0}$$

$$\mathbf{\cos h^2\ \beta l + 2\cos h\beta l + \cos^2\ \beta l - \sin h^2\ \beta l + \sin^2 \beta l} = \mathbf{0}$$

It is known however that,

$$\mathbf{\cos h^2\ \beta l - \sin h^2\ \beta l = 1}$$

That is why we are,

$$\mathbf{\cos \beta l\ \ \cos h\beta l = 1} \qquad 3.11$$

This essential equation has a variety of solutions,

$$\boldsymbol{\beta}\mathbf{i} = \mathbf{1, 2, 3 \ldots n.}$$

This offers an unlimited range of natural frequencies,

$$\boldsymbol{\omega}_1 = (\boldsymbol{\beta}_1\, \mathbf{l})^2\sqrt{\frac{\mathbf{EI}}{\boldsymbol{\rho}\mathbf{Al^4}}} \qquad 3.12$$

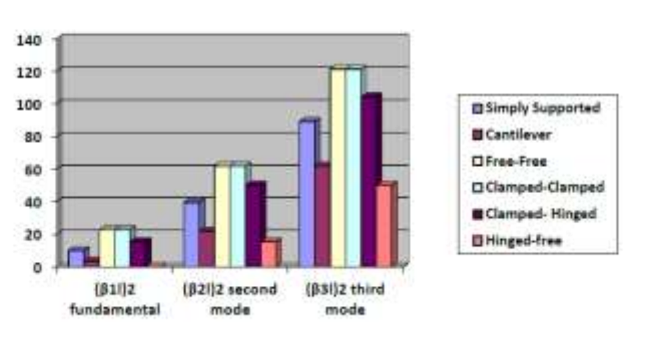
The first 5 roots of Eq. (3.12) are shown in Table 3.1.1

Root	$ß_n$ l
1	4.73
2	7.85
3	10.99
4	14.13

Table 3.1.1: Value of Roots

Beam Condition	$(\beta_1 l)^2$ fundamental	$(\beta_2 l)^2$ second mode	$(\beta_3 l)^2$ third mode
Simply Supported	9.87	39.5	88.9
Cantilever	3.52	22.0	61.7
Free-Free	22.4	61.7	121.0
Clamped-Clamped	22.4	61.7	121.0
Clamped-Hinged	15.4	50.0	104.0
Hinged-Free	0	15.4	50.0

Table 3.1.2: Value of $(Bnl)^2$ for different End Conditions



In this dissertation, the proportions and material constants for a Leaf Spring (Steel) and Leaf Spring Composite are studied in Table 3.1.3 and Table 3.1.4 respectively.

Parameter	Symbol	Value
Total Effective Length	L	1.17 m
Width	B	0.2 m
Moment of Inertia	I	$624 \times 10^{-3} m^4$
Young's Modulus	E	$2.1 \times 10^{11} N/m^2$
Mass Density	ρ	$7830\ kg/m^3$

Table 3.1.3: Experimental Parameters for Steel Leaf Spring

Parameter	Symbol	Value
Total Effective Length	L	1.17 m
Width	B	0.022 m
Moment of Inertia	I	$918 \times 10^{-6} m^4$
Young's Modulus (Ex)	E	$7.3 \times 10^{10} N/m^2$
Mass Density	ρ	$1400\ kg/m^3$

Table 3.1.4: Experimental Parameters for Composite Leaf Spring

Euler's Beam Principle for Continuous Structure

The normal frequency of both the Leaf Spring (Steel) and Leaf Spring Composite is numerically determined by.

The Euler's Equation for natural frequency is given as,

$$F = (1/2\boldsymbol{\pi})\ (Bnl)^2\ (EI/\boldsymbol{\rho}Al^4)^{1/2}$$

Where,

$(Bnl)^2$= constant depending on end conditions.

I = Moment of inertia of system.

ρ = Density of Material.

A = Area of cross section.

L = Length of spring.

The end conditions for system are same as that of suspension connected to vehicle body. Both ends are fixed.

The values of different parameters for Conventional Leaf Spring are,

$(Bnl)^2$ = 22.4., 61.7, 121.

E = $210 \times 10^3\ N/mm^2$

I = $624 \times 10^6\ mm^4$

ρ = 7.41×10^{-7}

$A = 156 \times 10^3$ mm^2
L = 1170 mm

By substituting these values in above equation we get natural frequencies for Steel Leaf Spring are,
The Fundamental Natural frequency equals 26.12 Hz.
The Second Natural frequency equals 83.23 Hz.
The Third Natural frequency equals 142.18 Hz.

The values of different parameters for Composite Leaf Spring are,
$(Bnl)^2 = 22.4, 61.7, 212.$
$E = 73 \times 10^9$ N/mm^2
$I = 918 \times 10^3$ mm^4
$\rho = 3.193 \times 10^{-4}$
$A = 156 \times 10^3$ mm^2
L = 1170 mm

We obtain natural frequencies by replacing these values in the above equation for Leaf Spring Composite are,
The simple natural frequency is equal to 45.61 Hz.
The 2nd natural frequency equals 125.64 Hz.
The 3rd natural frequency equals 246.39 Hz.

Mode	Steel Leaf Spring	Composite Leaf Spring
1st Mode	26.74	45.61
2nd Mode	73.66	125.64
3rd Mode	142.18	246.39

Table 3.1.5: Natural Frequencies of Steel and Composite Leaf Spring

B. *Theoretical research to work out the Composites and Leaf Spring (Steel) stresses*

1) *Leaf Spring Composite bent test to work out the Stress.*

Length of beam = (l) = 250mm
Thickness of beam = (t) = 10mm
Width of beam = (b) = 25.4mm
Modulus of elasticity for mild steel = (E) =205 Gpa

$$\text{Stress} = \sigma_{max} = M/Z$$

Where,
M =Max. Bending moment for cantilever beam.
Z =Section modulus for rectangular beam.
M = Load (N) × Length of cantilever (mm)/4
= 910 × 250/4
= 0.0568×10^6 N. mm

$Z = 1/6 \times b.t^2$
$= 1/6 \times 25.4 \times 10^2$
$Z = 423.33$ mm^3

Stress = $(\sigma_{max})_{Th.} = M/Z$
$= 0.0568 \times 10^6 / 423.33$
$= 134.17$ N/mm^2

2) *Bending test of Steel leaf spring to find out the stress.*

Length of beam = (l) = 250mm
Thickness of beam = (t) = 10mm
Width of beam = (b) = 25.4mm
Modulus of elasticity for mild steel = (E) =205 Gpa

$$\text{Stress} = \sigma_{max} = M/Z$$

Where,
M =Max. Bending moment for cantilever beam.
Z =Section modulus for rectangular beam.
M = Load (N) × Length of cantilever (mm)/4
= 910 × 250/4
= 0.0568×10^6 N. mm

$Z = 1/6 \times b.t^2$
$= 1/6 \times 25.4 \times 10^2$
$Z = 423.33$ mm^3

Stress = $(\sigma_{max})_{Th.} = M/Z$
$= 0.0568 \times 10^6 / 423.33$
$= 134.17$ N/mm^2

Sr. No.	Bending Stress for Steel Leaf Spring	Bending Stress for Composite Leaf Spring
1	134.17 N/mm^2	134.17 N/mm^2

Table 3.2.1: Bending Stresses of Steel and Composite Leaf Springs.

C. *The Chapter's Conclusion*

It may be inferred from the above findings that the theory results are in reasonable a marginal mistake arrangement agreement that can be attributed to the truncation. Certain assumptions are made during the theoretical study that will not take into account nonlinearities present in the system. The findings obtained from theoretical analysis are not true because of this. Non - linearity is considered in experimental science such that outcomes in real life are the results produced from experimental research. Experimental analysis should also be conducted for accurate analysis of the steel and Leaf Spring Composite.

REFERENCES

[1] Jaydeep J. Patil, Dr. S. A. Patil. "Design and Analysis of Composite Leaf Spring using Finite Element Methods,"- A Review, International Journal of Advanced Engineering Technology, Volume V, Issue II, 2014.
[2] Mohansing R. Pardeshi, Dr. (Prof.) P. K. Sharma, Prof. Amit Singh "Sensation Analysis of E-Glass Fibre Resin Mono Leaf Spring used in LMV," International Journal of Advanced Technology in Engineering and Science,Volume No.02, Issue No. 05, May 2014.
[3] A. L. Aishwarya, A. Eswara Kumar, V. Balakrishna Murthy, "Free Sensation Analysis of Composite Leaf 1Springs," International Journal of Research in Mechanical Engineering and Technology, Volume 4, April 2014.
[4] Ranjeet Mithari, "Analysis of Composite Leaf Spring by using Analytical and FEA," International Journal of Engineering Science and Technology (IJEST), ISSN: 0975-5462, Volume 4, December 2012.
[5] Hiroyuki Sugiyama, Ahmed A. Shabana, Mohamed A. Omar, Wei-Yi Loh. "Development of Nonlinear Elastic Leaf Spring Model for Multibody Vehicle Systems," Computer Methods in Applied Mechanics and Engineering, February 2005.
[6] M. M. Patunkar, D. R. Dolas. "Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by Using FEA," International Journal of Mechanical and Industrial Engineering, Volume 1, Issue 1, 2011.
[7] K. K. Jadhao, Dr. R.S Dalu. "Experimental Investigation & Numerical Analysis of Composite Leaf Spring," International Journal of Engineering Science and Technology (IJEST), Volume 3, June 2011.

[8] Kumar Krishan and Aggarwal M.L., “A Finite Element Approach for Analysis of a Multi Leaf Spring using CAE Tools”, Research Journal of Recent Sciences, Vol. 1 (2), 2012, pp 92-96. (2)
[9] Dhoshi N.P., Ingole N.K. and Gulhane U.D., “Analysis and Modification of Leaf Spring of Tractor Trailer Using Analytical and Finite Element Method”, International Journal of Modern Engineering Research (IJMER), Vol.1 (2), pp 719-722.
[10] Mahmood M. Shokrieh andDavoodRezaei, “Analysis and optimization of a composite leaf spring”, Journal of Composite Structures, Elsevier,Vol. 60, 2003, pp 317–325.
[11] PerttuKainulainen, “Analysis of Parabolic Leaf Spring Failure”, Thesis, B.Tech, Savonia University of Applied Sciences, 2011.
[12] WieslawKrason, JózefWysocki, “Analysis of Sensations of the Simplified Model of the Suspension System With a Double Spring and a Fluid Damper”, Journal of KONES Powertrain and Transport, Vol. 18 (1), 2011, pp 311-316.
[13] M.Venkatesanand D.HelmenDevaraj, “Design and Analysis ofComposite Leaf Spring in Light Vehicle”, International Journal of Modern Engineering Research (IJMER), Vol.2 (1), 2012, pp 213-218.
[14] Muhammad AshiqurRahman, Muhammad TareqSiddiqui and Muhammad ArefinKowser, “Design and Non-Linear Analysis of A Parabolic Leaf Spring”,Journal of Mechanical Engineering, Transaction of the Mech. Eng. Div., The Institution of Engineers, Bangladesh, Vol. ME37, 2007, pp 47-51.
[15] Gulur Siddaramanna Shiva Shankar, SambagamVijayarangan, “Mono Composite Leaf Spring for Light Weight Vehicle - Design, End Joint Analysis and Testing’, Materials Science (Medžiagotyra). Vol. 12 (3), 2006, pp 1392–1320.
[16] Y. N. V. Santhosh Kumar, M. Vimal Teja, “Design and Analysis of Composite Leaf Spring,” International Journal of Mechanical and Industrial Engineering (IJMIE), ISSN No. 2231-6477, Vol-2, Issue-1, 2012.
[17] Ganesh. K, Gembiram. M, Elayaraja. R, Saravanan. R, Murali .K. “Design and Analysis of Multi Leaf Springs Using Composite Materials,” IJRASET, Vol. 2 Issue IV, April 2014.
[18] Vivek Rai, Gaurav Saxena. “Development of a Composite Leaf Spring for a Light Commercial Vehicle (Tata Magic),” Research Article at Int. Journal of Engineering Research and Applications, Volume 3, Issue 5,pp.110-114, October 2013.
[19] Mr. Akshay Kumar, Mr. V. J. Shinde, Mr. S. S. Chavan, “Design, Analysis, Manufacturing and Testing of Mono Composite Leaf Spring Using UD E-Glass Fiber/Epoxy”, International Journal of Advanced Technology in Engineering and Science (IJATES),Volume No.02, Issue No. 12, December 2014 ,ISSN (online): 2348 – 7550.
[20] Rajagopal D. et. Al, “Automobile Leaf Spring from Composite Materials”, International Journal of Engineering and Advanced Technology (IJEAT), ISSN: 2249 – 8958, Volume-4, Issue-1, October 2014.

