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Performance Analysis of Composite Leaf Spring

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ABSTRACT

Increasing competition and innovation in automobile sector tends to modify the existing products by new and advanced material products. A suspension system of vehicle is also an area where these innovations are carried out regularly. The Leaf springs are one of the oldest suspension components that are being still used widely in automobiles. Weight reduction is also given due to importance by automobile manufacturers. The conventional steel leaf spring has higher weight which also affects the fuel efficiency. Substituting composite structures for conventional metallic structures has many advantages.

The main objective of this paper is the use of carbon-epoxy composite leaf spring in the place of conventional steel leaf spring and provides low cost fabrication. The Carbon-epoxy composite materials are having lower density which results into reduction in the weight of leaf spring significantly with adequate improvement of mechanical properties. The structural analysis of Carbon/Epoxy composite leaf spring has performed using FEA software (Ansys14). The result of FEA is also verified experimentally by using Microprocessor based Universal Testing Machine (UTM).

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I. INTRODUCTION

In order to conserve natural resources, economize energy, increasing competition and innovations in automobile sector weight reduction has been the main focus of automobile manufacturer in the present scenario. A suspension system of vehicle is also an area where these innovations are carried out regularly. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the un-sprung weight [1]. The conventional steel leaf spring has higher weight, which also affect the fuel efficiency. Substituting composite structures for conventional metallic structures has many advantages, which helps in achieving the vehicle with more fuel efficiency [2]. It is well known that springs, are designed to absorb and store energy and then release it. Hence, the strain energy of the material becomes a major factor in designing the springs. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential Energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. Fortunately, composites have these characteristics [3, 4]. The introduction of carbon-epoxy composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. Since; the carbon-epoxy composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel [5, 6].Composite has received attention largely from the automotive industry due to their superior mechanical properties and relative ease of processing. The use of a thermo set matrix gives the molder the ability to modify and enhance the properties of the resin by blending additives, fillers and fire retardants depending upon the nature of the application [7].

This project is mainly focused on design analysis and fabrication of laminated carbon-epoxy composite leaf spring with uni-directional fiber orientation angle 0^0 is considered using hand-layup technique. This is an alternative efficient economical method over a wet filament winding technique. By analysing performance, the conventional steel leaf spring can be replaced by carbon-epoxy composite leaf spring.

A. Objective of The Work

1) To Reduce product development cost
2) To reduce the weight

Increase the comfort

II. Literature Review

This chapter provides a review of relevant literature on fiber reinforced polymer. The Several papers were devoted to the application of composite materials for automobiles, to present and discuss the various methodologies and strategies that are adopted by researchers in order to predict the performance of composite leaf spring..

GSS Shankar et al. worked on mono composite leaf spring for light weight vehicle, design, end joint analysis and testing. They concluded that, compared to the steel spring, the composite leaf spring has stresses that are much lower, comparative study has been made between composite and steel leaf spring with respect to weight, cost and strength. Composite mono leaf spring reduces the weight by 85% for E-glass/Epoxy, 91% for Graphite/Epoxy, and 90% for Carbon/Epoxy over conventional leaf spring [1].

Amare et al. worked on design simulation and prototyping of single composite leaf spring for light weight vehicle, reducing weight of vehicles and increasing or maintaining the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single E-glass/ Epoxy leaf spring is designed and simulated considering static loading only. They showed that the resulting design and simulation stresses are much below the strength properties of the material, satisfying the maximum stress failure criterion [2].

Amrute et al. worked on design and assessment of multi leaf spring, In their work, a steel leaf spring was replaced by a composite leaf spring due to high strength to weight ratio for the same load carrying capacity and stiffness with same dimension as that of steel leaf spring. Totally it is found that the composite leaf spring is the better that of steel leaf spring. Therefore, it is concluded that composite multi leaf spring is an effective replacement for the existing steel leaf spring in vehicles [3].

Venkatesan et al. worked on design and analysis of composite leaf spring in light vehicle. The study demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings. It is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications. Composite leaf spring reduces the weight by 85 % for E-Glass/Epoxy, over conventional leaf spring [4].

Ghodake et al. worked on analysis of steel and composite leaf spring for vehicle. The 3-D modeling of both steel and composite leaf spring is done and analyzed A comparative study has been made between composite and steel leaf spring with respect to Deflection , strain energy and stresses. From the results, It is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications [5].

Shokrieh et al. work on analysis and optimization of composite leaf spring . They said compared to the steel leaf spring (9.2 kg) the optimization composite leaf spring without eye units weights nearly 80% less than the steel spring. For this material is selected is E-glass/Epoxy resin on the basis of cost and strength comparison. A steel leaf spring used in the rear suspension of light passenger cars was analyzed by two analytical and finite element methods [6].

Zoman et al. worked on performance analysis of two mono leaf spring used for maruti 800 vehicle. In that paper they looked on the suitability of composite leaf spring on vehicles and their advantages. Efforts have been made to reduce the cost of composite leaf spring to that of steel leaf spring. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very replacement material for convectional steel.[7].

Kumar et al. worked on design optimization of leaf spring, international journal of engineering research and applications. They said three different composite materials have been used for analysis of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring both from stiffness and stress point of view [8].

Patunkar et al. worked on modeling and analysis of composite leaf spring under the static load condition by using FEA. Conventional steel leaf spring was found to weigh 23 Kg. whereas E-glass / Epoxy mono leaf spring weighs only 3.59 Kg composite leaf spring can be used on smooth roads with very high performance expectations [9].

Aher et al. describes to predict the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations. This work describes static and fatigue analysis of a modified steel leaf spring of a light commercial vehicle. The non-linear static analysis of 2D model of the leaf spring is performed using solver and compared with analytical results. The pre processing of the modified model is done by using FEA software [10].

Qureshi et al. describes a single leaf spring with variable thickness of glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi leaf steel spring was designed, fabricated and tested. This study demonstrated that composite can be used for leaf spring for light trucks (jeeps) and meet the requirement, together with substantial weight saving [11].

Koppula et al, worked on static analysis of composite mono leaf spring. The development of a composite mono leaf spring having constant cross sectional area, where the stress level at any station in the leaf spring is considered constant due to the parabolic type of the thickness of the spring, has proved to be very effective; The study demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight savings [12].

Raghavedra et al. worked on modeling and analysis of laminated composite leaf spring under the static load condition by using FEA. The analysis of laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, S-glass/Epoxy and Carbon/Epoxy subjected to the same load as that of a steel spring [13].

From the review of above papers it is seen that many people had work in design and analysis of glass-epoxy composite leaf spring. In this paper experimental investigations regarding performance of carbon-epoxy composite leaf spring have done. By analysing performance, the conventional steel leaf spring can be replaced by carbon-epoxy composite leaf spring.

III. THEORY

A. Materials for Steel Leaf Spring

Many industries are manufactured steel leaf spring by EN45, EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7 and 50CrMoCV4 etc. These materials are widely used for production of parabolic leaf spring and conventional multi leaf spring. [3].

TABLE I
MECHANICAL PROPERTIES OF EN 47 STEEL LEAF SPRING [16]

Sr. No.	Parameter	Value
1	Density (x 1000 kg/m^3)	7800
2	Poisson's Ratio	0.30
3	Elastic Modulus (Gpa)	207
4	Tensile Strength (Mpa)	1962
5	Yield Strength (Mpa)	1470
6	Hardness (HB)	335

B. Material for Composite Leaf Spring

1) Fibre selection: The designer or material specialist has a wide range of fibres from which to make a selection. Fibre selection should also consider mechanical and thermal properties. Vertical vibrations and impacts are buffered by variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. The specific strain energy can be written as Eq. (1)

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

The material with maximum strength and minimum modulus of elasticity is the most suitable material for the leaf spring application. [8]

TABLE II
STRAIN ENERGY STORED BY MATERIAL (KJ/KG) [8]

Sr. No.	Material	Strain energy stored by material(KJ/Kg)
1	EN47	0.3285
2	Carbon/epoxy	2.45
3	E-glass/epoxy	4.5814
4	C-glass/epoxy	18.76
5	S-glass/epoxy	32.77

Among these, the carbon fiber has been selected based on the strength and stiffness.

2) Resin selection: In a FRP leaf spring, the inter laminar shear strengths is controlled by the matrix system used. Since these are reinforcement fibers in the thickness direction, fiber do not influence inter laminar shear strength. Therefore, the matrix system should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber [9].

C. Design Selection

1) The following cross-section of composite leaf spring for manufacturing easiness is considered.
1) Constant Thickness, Varying Width Design
2) Constant Width, Varying Thickness Design
3) Constant Cross Section- Selection Design

D. Fabrication of Composite Leaf Spring

Hand Lay-up Technique

Hand layup technique is suitable for manufacturing of composite leaf spring with suitable effective properties. In this process a mould cavity made up with the help of green sand mould, after manufacturing cavity of suitable size optical gel coating of suitable thickness layer is made in the boundary of cavity then after this resin in liquid form is poured in that cavity and for getting require shape the consolidation roller rolls over the two layer of resin and dry reinforcement fabric layer of given thickness, same procedure repeated to achieve desired thickness [7].

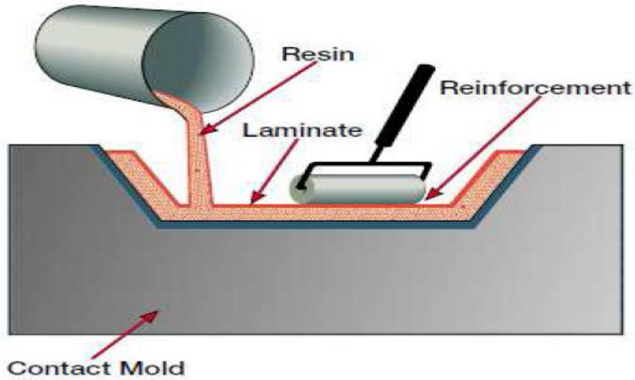

Fig 1 Processing of Composite Laminates By Hand Lay-Up [7]

E. Optimum Volume of Fibre and Matrix in Composite

Rules of Mixture is method of approach to approximate estimation of composite material properties, based on an assumption that a composite property is the volume weigh average of phases properties

According to rule of mixtures properties of composite materials are estimated as follows

1) Density
dc=dm*Vm+df*Vf
Where,
dc= Density of the composite
dm= Density of the matrix
df = Density of the fiber
Vm=Volume of fraction of the Matrix
Vf= Volume of fraction of the fiber

2) Modulus of Elasticity

Modulus of Elasticity in longitudinal direction
Ecl=Em*Vm+Ef*Vf
Modulus of Elasticity in transverse direction
1/Ect=Vm/Em+Vf/Ef

3) Tensile Strength

Tensile strength of fibre rein forced composite in longitudinal direction
σc= σm*Vm+ σf*Vf
Where,
σc= tensile strength of the composite
σm= tensile strength of the matrix
σf= tensile strength of the fiber

4) Poisson's ratio

µ12=Vfµf+Vmµm
Where,
µf= Poisson's ratio of fiber material
µm= Poisson's ratio of matrix material

TABLE III
PROPERTIES OF CARBON FIBRE AND EPOXY RESIN MATERIAL[12,13]

Material	Carbon fibre	Epoxy Resin
Elastic modulus (GPa)	240	3.7
Tensile Strength (MPa)	2000	82
Compressive strength (MPa)	1500	102
Density (Kg/m^3)	1.7	1.2
Poisson's ratio	0.15	0.30

TABLE IV
OPTIMUM VOLUME OF FIBER AND MATRIX IN COMPOSITE

V_f %	V_m %	Modulus of elasticity	Longitudinal tensile strength	Remark
70	30	162000 MPa	1500 MPa	High value of elasticity
60	40	145000 MPa	1240 MPa	Optimum value
50	50	121000 MPa	1041 MPa	Strength is very low

Above comparison shows that the optimum volume fraction of fiber phase selected to be 60% and for the matrix phase it is 40%.

TABLE V
PROPERTIES OF CARBON EPOXY COMPOSITE MATERIAL

Sr. No.	Parameter	Value
1	Tensile modulus, MPa	145000
2	Tensile strength of material, MPa	1240
3	Compressive strength, MPa	940
4	Poisons ratio	0.21
5	Density Kg/m^3	1500

IV. ANALYTICAL ANALYSIS

This Chapter deals with the analytical calculations for design of Carbon-epoxy composite leaf spring for Maruti 800 Vehicle and determination of mechanical properties stresses and deflection.

A. Analytical Design

Let,
t= thickness of plate
b= width of plate
L= length of plate or distance of the load W from the Cantilever end
E=Young's modulus of elasticity
The bending stress is

$$\sigma_{max}=\frac{M}{Z}=\frac{6WL}{bt^2}$$

We know that the maximum deflection for a cantilever with
Concentrated load at free end is given by

$$\delta_{max}=\frac{WL^3}{3EI}$$

1) For Carbon-epoxy Leaf Spring
Maximum stress (σ_{max}) =940 MPa
Maximum deflection (δ_{max})=112 mm
Straight length of the leaf spring (L) = 965mm
Above equation will be written as:

$$t=\frac{\sigma_{max}(L/2)^2}{E\delta_{max}}=\frac{940x550^2}{145000X\,112}$$

t =17.5mm ≈ 18mm
Rearranging above equation and solving for the width 'b'

$$\sigma_{max}=\frac{6W(L/2)}{bt^2}$$

$$b=\frac{6W(L/2)}{\sigma_{max}t^2}=\frac{6x3483x550}{940x18^2}$$

b =30mm

TABLE VI
STEEL (EN47) LEAF SPRING SPECIFICATION

Parameter	Value mm
Straight length	965
Leaf thickness	10
Leaf width	50
Camber	112

TABLE VII
CARBON-EPOXY COMPOSITE LEAF SPRING SPECIFICATION

Parameter	Value mm
Straight length	965
Leaf thickness at the centre	18
Leaf thickness at the end	10
Leaf width at the centre	30
Camber	112

Thickness of plate, t =18mm
Width of plate, b =30mm
Length of plate or distance of load w from the Cantilever end, L=415mm
Young's modulus of elasticity, E=145000 MPa
Yield tensile strength, S_{yt}=1240MPa
Density=1500 Kg/m^3
W=central load, (N)
Taking moment at point B,
$965xw_1 = 415xW$
$w_{1=} 0.4301xW$
$\sigma = 0.2562 \times w_1$
$\delta = 0.0439x\sigma$

TABLE VIII
ANALYTICAL RESULTS FOR COMPOSITE LEAF SPRING

Sr. No.	Central load (W)	Carbon/Epoxy	
		Bending stress (σ)	Deflection (δ)
1	100	11.01	0.4833
2	500	55.09	2.41
3	1000	110.19	4.83
4	2000	220.37	9.67
5	3000	330.56	14.5
6	3500	385.52	16.92

2) For Steel Leaf Spring
Thickness of plate, t=10mm
Width of plate, b=50mm
Length of plate or distance of load w from the cantilever end, L=415mm
Youngs modulus of elasticity, E=2.07x10^5 MPa
Yield tensile strength, S_{yt}=1034MPa
Density=7800 Kg/m^3
W=central load, (N)
Taking moment at point B,
$965xw_1 = 415xW$
$w_{1=} 0.4301xW$
$\sigma = 0.498 \times w_1$
$\delta = 0.05546x\ \sigma$

TABLE IX
ANALYTICAL RESULTS FOR STEEL LEAF SPRING

Sr.No.	Central load (W)	EN 47	
		Bending stress (σ)	Deflection (δ)
1	100	21.41	1.187
2	500	107.09	5.93
3	1000	214.18	11.87
4	2000	428.36	23.73
5	3000	642.54	36.21
6	3500	749.63	42.53

V. FINITE ELEMENT ANALYSIS

FEA of leaf spring is done by Ansys workbench 2014. To perform analysis of leaf spring, 3-dimensional model is created using Pro-E. Meshing of the prepared model is done. Meshing is nothing but the descritization of object into small parts called as element.

A. Loading and Boundary Conditions

Fixed support has restriction to move in X and Y direction as well as rotation about that particular point. For the leaf spring analysis one end of leaf spring is fixed to the chassis of vehicle. All degree of freedom are restricted for one end and at the other end of leaf spring, force is applied.

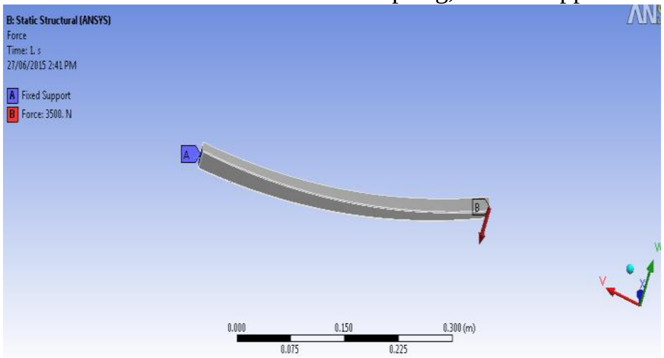

Fig. 2 Boundary condition for FEA model

B. Total Deflection

Fig. 3 and fig.4 shows the deflection of steel and composite leaf spring under the application of 3500N load. The deflection values are 90.667 mm and 26.87 mm respectively.

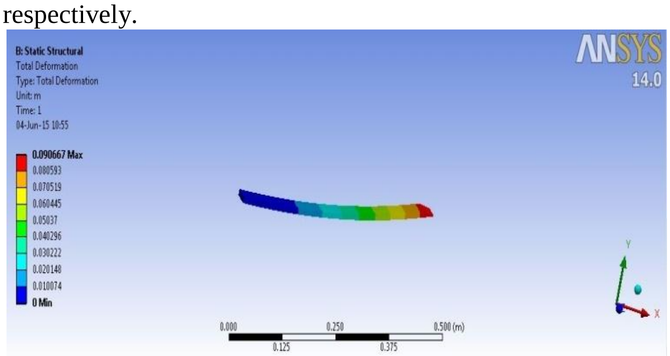

Fig. 3 Displacement pattern for steel leaf spring

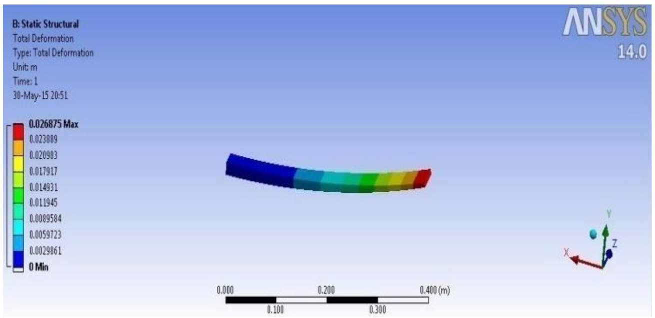

Fig. 4 Displacement pattern for steel leaf spring

C. Stresses Induced in Leaf Spring

Fig.5 and fig.6 shows the equivalent Von-Mises stress induced in steel and composite leaf spring under the action of 3500N load. The stress values are 892.6 N/mm^2 and 286.32 N/mm^2 respectively.

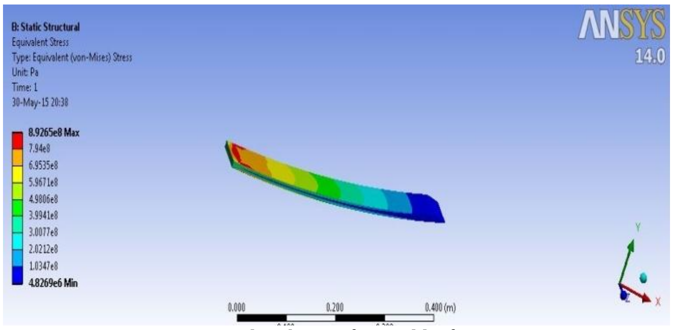

Fig. 5 Stress distribution for steel leaf spring

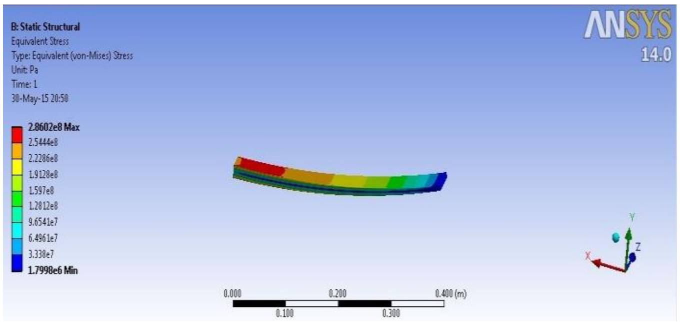

Fig. 6 Stress distribution for carbon/epoxy leaf spring

TABLE X
FEA RESULTS FOR STEEL LEAF SPRING

Sr. No.	Central load (W)	Steel Leaf Spring (EN 47)	
		Bending stress (σ) (MPa)	Deflection (δ) (mm)
1	100	25.629	2.603
2	500	128.145	13.015
3	1000	256.29	26.03
4	2000	513.435	52.06
5	3000	770.03	78.09
6	3500	892.65	90.667

TABLE XI
FEA RESULTS FOR CARBON/EPOXY COMPOSITE LEAF SPRING

Sr. No.	Central load (W)	Carbon/Epoxy	
		Bending stress (σ) (MPa)	Deflection (δ) (mm)
1	100	8.21	0.771
2	500	41.05	3.855
3	1000	82.2	7.71
4	2000	164.3	15.42
5	3000	246.4	23.13
6	3500	286.02	26.985

VI. EXPERIMENTAL ANALYSIS

The deflection and stresses of both the spring for comparative study is taken on the Universal Testing Machine (UTM). In the experimental analysis the comparative testing of composite leaf spring and the steel leaf spring are taken.

A. Procedure for Testing

The spring to be tested is examined for any defects like cracks, surface finishing, etc. Move the plunger up to desired height so that we can fix the fixture and leaf spring for test. Fix the position of fixture. On the fixture place the specimen.

The load is applied at the centre of spring; the vertical deflection of the spring centre is recorded at desired interval.

B. Strain gauge locations for steel and composite leaf spring.

First Strain gauge location	L1	100 mm
Second Strain gauge location	L2	230 mm
Third Strain gauge location (From center of leaf spring)	L3	300 Mm

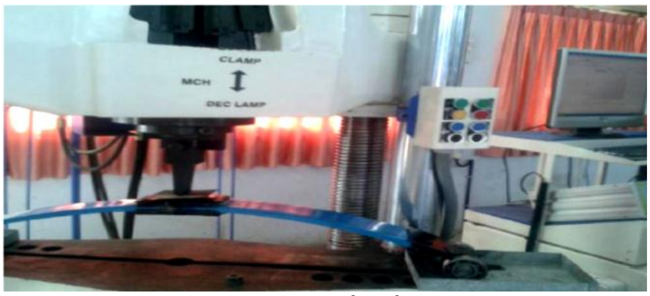

Fig. 7 Testing of Leaf Spring

1) Test Report of Steel Leaf Spring

Following are the readings for Steel Leaf Spring of EN47 material

TABLE XII
EXPERIMENTAL READING OF STEEL LEAF SPRING

Sr. No.	Load (N)	Deflection (mm)	Strain Meter Reading		
			L1	L2	L3
1	100	2.68	83	95	70
2	500	13.32	401	477	387
3	1000	26.62	795	957	781
4	2000	52.66	1580	1917	1569
5	3000	78.94	2364	2877	2357
6	3500	92.46	2692	3288	2698

Sample calculation for bending stress

ε= 83

Now, by using Hooke's law

Stress/Strain=Young's Modulus

Stress=83 x 0.207=17.18 N/mm^2

Bending Stress = 17.18 N/mm^2

TABLE XIII
EXPERIMENTAL RESULTS FOR STEEL LEAF SPRING

Sr. No.	Load (N)	Deflection (mm)	Von-Mises stresses for Steel of Material (EN47)		
			L1	L2	L3
1	100	2.68	17.181	19.665	14.49
2	500	13.32	83.007	98.739	80.109
3	1000	26.62	164.565	198.099	161.667
4	2000	52.66	327.06	396.819	324.78
5	3000	78.94	489.348	595.539	487.899
6	3500	92.46	557.244	680.616	558.486

2) Test Report of Carbon-Epoxy Composite Leaf Spring

Following are the readings for Leaf Spring of Carbon/Epoxy material.

TABLE XIV
EXPERIMENTAL READING OF CARBON-EPOXY LEAF SPRING

Sr. No.	Load (N)	Deflection (mm)	Strain Meter Reading		
			L1	L2	L3
1	100	0.68	81	87	41
2	500	3.675	409	431	201
3	1000	7.395	819	861	401
4	2000	14.835	1636	1711	801
5	3000	22.275	2429	2461	1221
6	3500	25.99	2850	3011	1411

Sample calculation for bending stress

$\varepsilon = 81$

Now, by using Hooke's law

Stress/Strain=Young's Modulus

Stress=81 x 0.103=8.343 N/mm^2

Bending Stress = 8.343 N/mm^2

TABLE XV
EXPERIMENTAL RESULTS FOR CARBON-EPOXY LEAF SPRING

Sr. No.	Load (N)	Deflection (mm)	Von-Mises Stresses for Carbon-Epoxy Leaf Spring		
			L1	L2	L3
1	100	0.68	8.343	8.961	4.223
2	500	3.675	42.127	44.393	20.703
3	1000	7.395	84.357	88.683	41.303
4	2000	14.835	168.508	176.233	82.503
5	3000	22.275	250.187	263.783	125.763
6	3500	25.99	290.55	310.133	145.333

VII. RESULT AND DISCUSSION

The Overall result for all the three methods is compared in the fig.8, fig.9 and fig.10. It can be observed from the comparison that the bending stresses induced in the Carbon-Epoxy composite leaf spring are 60% less than the conventional steel leaf spring. The deflection of carbon-epoxy is less than that of steel for the same load carrying capacity and lesser in weight as compared to steel

TABLE XVI
COMPARISON OF RESULTS FOR STEEL AND CARBON-EPOXY COMPOSITE LEAF SPRING

Parameter		Load (N)	Deflection (mm)	Bending stress (N/mm^2)
Analytical Value	Steel (EN47)	3500	42.53	749.63
	Carbon/ Epoxy		16.92	385.52
FEA Value	Steel (EN47)		90.667	892.65
	Carbon/ Epoxy		26.98	286.02
Expt. Value	Steel (EN47)		92.46	680.61
	Carbon/ Epoxy		25.99	310.13

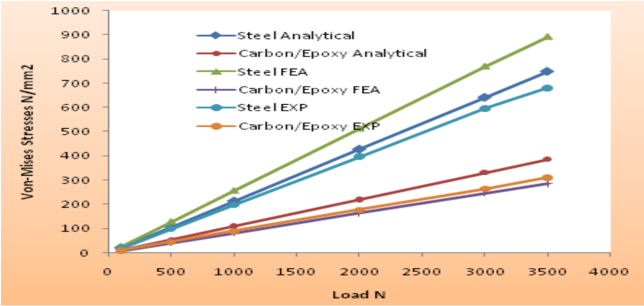

Fig. 8 Load vs. Bending stress curve for steel and composite leaf spring

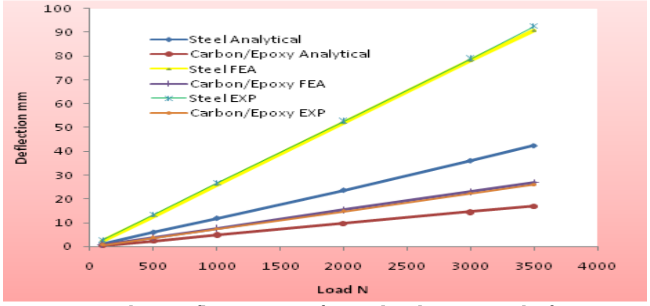

Fig. 9 Load vs. Deflection curve for steel and composite leaf spring

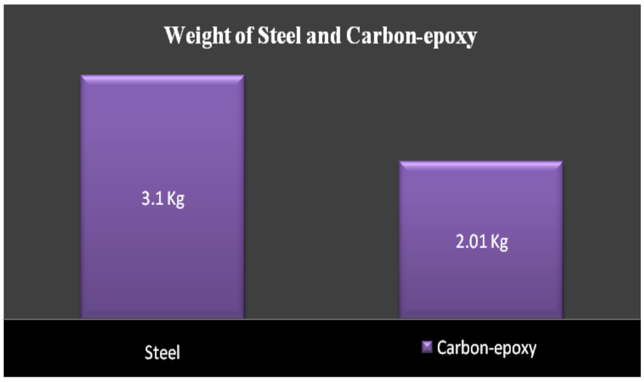

Fig. 10 Comparison of Weight for Steel and Carbon-epoxy Composite

VII. CONCLUSION.

1) The stresses induced in the Carbon/Epoxy composite leaf spring are nearly 60% less than that of the steel spring.
2) The finite element solutions show the good correlation for total deformation with analytical & Experimental results.
3) A steel leaf spring used in the rear suspension of light passenger cars was analyzed by analytical, Experimental and finite element methods.
4) Study demonstrates that the composite can be used for leaf spring for the light vehicle and meet the requirement, together with the sustainable weight reduction.
5) A weight reduction achieved in mono composite leaf spring is about 35%.

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REFERENCES

[1] GSS Shankar, Sambagam V, "Mono composite leaf spring for light weight vehicle, Design, End joint analysis and Testing" ISSN: 1392-1320 Materials science, vol.12, Issue 3-2006,pp-220-225.

[2] Shishay Amare Gebremeskel "Design, Simulation, and Prototyping of Single Composite Leaf Spring for Light Weight Vehicle" Global Journals Inc. (USA) Online ISSN: 2249-4596 Print ISSN:0975-5861.

[3] Ashish V. Amrute1, Edward Nikhil2,R K Rathore "Design And Assesment of Multi Leaf Spring" ISSN (Online): 2321-3051 International Journal Of Research In Aeronautical And Mechanical Engineering.

[4] M.Venkatesan [1], D.Helmen Devaraj [2], "Design And Analysis Of Composite Leaf Spring In Light Vehicle". International Journal of Modern Engineering Research (IJMER) ISSN: 2249-6645 Vol.2, Issue.1, Jan-Feb 2012 pp-213-218

[5] Ghodake A. P., Patil K.N. "Analysis of Steel and Composite Leaf Spring for Vehicle" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278 1684 Volume 5, Issue 4 (Jan. - Feb. 2013), PP 68-76.

[6] Mahmood M. Shokrieh *, Davood Rezaei, "Analysis and optimization Of Composite Leaf Spring" Composite Structures 60 (2003) 317–325.

[7] Jadhav Mahesh V, Zoman Digamber B, Y R Kharde, r R Kharde, "Performance Analysis of Two Mono Leaf Spring Used For Maruti 800 Vehicle". International Journal Of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278- 3075, Vol.2, Issue 1, December 2012

[8] H.A. Al-Qureshi "Automobile Leaf Springs From Composite Materials" Journal of Material Processing Technology 118(2001) 58-61.

[9] Supriya Koppula1 G.S.R.Sunand2 and R.Vijaya Prakash3 "Static Analysis Of Composite Mono Leaf Spring" International eJournal of Mathematics and Engineering 146 (2012) 1331 – 1337.

[10] M. Raghavedra[1], Syed Altaf Hussain[2], V. Pandurangadu[3], K. PalaniKumar[4], "Modeling and Analysis of Laminated Composite Leaf Spring under the Static Load Condition by using FEA" International Journal Of Modern Engineering Research, ISSN: 2249-6645, Vol.2, Issue 4, July-Aug.2012,pp1875-1879.

[11] Bhaumik A. Bhandari, Bhavesh C. Patel "Parametric Analysis Of Composite Leaf Spring" IJSTE– International Journal of Science Technology & Engineering| Vol. 1, Issue 1, July 2014| ISSN(online): 2349-784X

[12] R. M. Jones, "Mechanics Of Composite Materials". 2e, McGraw-Hill Book Company, 1990.

[13] Autar K. Kaw, "Mechanics of composite material", second edition Taylor & Francis Group, 2006

[14] R. S. Khurmi, J. K. Kupta. "A Text Book of Machine Design", 2000,Chapter 23, pp. 866-874.Third Edition-Tata McGraw Hill Education Privet Limited-2010.

[15] S.S. Rao,"Finite Element Method in Engineering". Third Edition Butterworth Heinemann Publications-2001

[16] Pro-E wildfire and ANSYS release help manual 2010

[17] www.alloysteel.com