International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Design and Analysis of a Laminated Composite Leaf Spring

G Gopal[Ȧ*] and L Suresh Kumar[Ȧ]

[Ȧ]Mechanical Engineering Department, Ramanandatirtha Engineering College, Nalgonda, Telangana, India

Accepted 05 Nov 2014, Available online 01 Dec 2014, **Vol.4, No.6 (Dec 2014)**

Abstract

The paper deals with the basic design of a laminated leaf spring and analyzing the composite material values for different orientations of the fiber. For this purpose the laminated leaf springs are made of steel and composite material of unidirectional E-glass/ Epoxy, with the same dimensions. A static test rig is fabricated to conduct deformation test under various loading conditions for both the above materials. The deformations are compared for both the above materials. A three dimensional model of entire leaf spring is modeled using Solid Works. The static analysis is done using ANSYS. It is observed that the deflections in the Composite leaf spring are greater than the steel leaf spring for the same load. The stresses in the Composite leaf spring are less than the steel. And, the spring weight of the Composite leaf spring is observed to be 70% lower than the steel.

Keywords: *Laminated Leaf spring, E-glass/Epoxy, Lay-up technique, Fiber orientation, Nipping.*

1. Introduction

The leaf spring absorbs the vertical vibrations and impacts due to road irregularities by means of variations in its deflections and the potential energy is stored in as strain energy and is released slowly. Leaf springs carry lateral loads, brake torque, driving torque and shock absorption.
To meet these requirements, a material should have maximum strength and minimum modulus of elasticity in the longitudinal direction. The composite materials have more elastic strain energy, storage capacity and high strength to weight ratio as compared to steel. Also, the composite material helps in reduction of weight of the leaf springs without any reduction in the load carrying capacity and stiffness.

The leaf springs are made as i) Mono leaf spring or ii) Multi leaf spring. Multi leaf springs have steel plates stacked one over other. The leaves bend and slide on each other allowing suspension movement.

As of now, Plain Carbon Steel of 0.9 to 1% Carbon is used. The leaves are heated after the forming process. The heat treated steel will have greater strength and great load carrying capacity.

For automobile springs, the leaves are hardened and tempered. Rail road springs are either water hardened or oil hardened.

The suspension leaf spring is one of the potential items for weight reduction as it accounts for 10 to 20% of un sprung weight.

The rapid industrialization in the country requires lot of railway carriages for goods transport and growth of automotive industry is necessitating the study of the leaf springs with materials like composite materials. The reason being weight can be reduced which results in fuel savings.

The present paper considers the effect of the orientation of the fibers on the deflection and stresses due to loads.

2. Problem Formulation

A 2 Ton carrying capacity truck's leaf spring is to be designed, manufactured and analyzed. This is done using steel and E-glass/ Epoxy composite materials.

3. Parameters considered

A mono composite leaf spring is designed. The same design values are taken to manufacture steel and composite material leaf spring. A static test rig is fabricated to conduct deformation test under various loading conditions. The static test results of composite and steel are compared. A 3 D model of entire leaf spring is modeled using Solid Works. Finite Element Analysis is done to predict the behavior of both the steel and composite leaf springs. The effect of the orientation of fibers is studied.

3.1 Design of leaf spring

a) For Steel Leaf spring

Span length (eye to eye), 2L = 790mm
Full bump load, P = 3250 N
(Factor of safety is 1.5)
Camber height = 70mm
Thickness of each leaf, t = 6mm

*Corresponding author: **G Gopal** is working as Assistant Professor and **L Suresh Kumar** is working as Principal

Width of each leaf, b = 60mm
Design stress without considering sudden impact loads, f = 625 N/mm^2
Ineffective length, IL = 90mm
Effective length, EL = 2L-90 = 790-90 = 700mm
l = 350mm

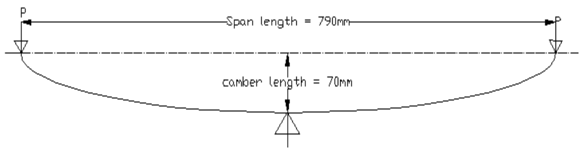

Fig. 1 2D Model of leaf spring

Calculation of number of leaves

$$f = \frac{6*P*l}{Z*b*t^2}$$

Number of leaves, Z = 5.83 (say) 6.

Calculation of deflection

$$\delta = \frac{12 * P * l^2}{E * b * t^2 * 2(Z*g + Z*f)} = 50.63\text{mm}$$

E, Modulus of Elasticity for steel = 2.1*10^3 N/mm^2

Length of each leaf

Small leaf = (EL/(Z-1)) + IL = 140 + 90 = 230mm
Next leaf = (EL/(Z-1)*2) + IL = 280+ 90 = 370mm
Next leaf = (EL/(Z-1)*3) + IL = 420+ 90 = 510mm
Next leaf = (EL/(Z-1)*4) + IL = 560+ 90 = 650mm
Next leaf = (EL/(Z-1)*5) + IL = 700+ 90 = 790mm

Master leaf = span length + allowance for the eyes
= 2L + π * (d+t) * 2 = 985mm
d – dia. of eye end = 25mm

Calculation of nipping

The radius of curvature decreases with shorter leaves. The initial gap between the extra full length leaf and the graduated length leaf before the assembly is called as nip.

$$\text{Nip, } C = \frac{2 * P * l^3}{E * Z * b * t^3} = 19.69\text{mm.}$$

b) For Composite material leaf spring

The dimensions are taken as that of the steel leaf spring.
Thickness of each composite leaf = 6mm
(Consists of 13 layers)
Width of each composite leaf = 60mm
(Consists of layer with width of 60mm)

3.2 Materials selected for composite spring

The material E-glass / Epoxy composite with 60% fiber volume is identified for Composite leaf spring.

E-Glass fibers are selected as they have low cost compared to either Carbon / Graphite fibers. It has high strength, high chemical resistance. But, the density is high compared to the other fibers.

Fibers – E-glass is a high quality glass fiber, which is used as a standard reinforcement and has good mechanical property requirements.

Resins– Epoxy resin, Dobeckot 520F, which is solvent less is used.

Hardener – Hardener 758 which is a low viscosity polyamine is selected.

Table 1 Properties of the E-glass / Epoxy composite

S No.	Properties	Values (MPa)
1	Tensile modulus along X direction, E_X	14000
2	Tensile modulus along Y direction, E_Y	6030
3	Tensile modulus along Z direction, E_Z	1530
4	Tensile strength of the composite	800
5	Compressive strength of the composite	450
6	Shear modulus along XY direction, G_{XY}	2433
7	Shear modulus along YZ direction, G_{YZ}	1600
8	Shear modulus along ZX direction, G_{ZX}	2433
9	Flexural modulus of the composite	40000
10	Flexural strength of the composite	1000
11	Poisson ratio along XY direction, NU_{XY}	0.217
12	Poisson ratio along YZ direction, NU_{YZ}	0.366
13	Poisson ratio along ZX direction, NU_{ZX}	0.217
14	Mass density of the composite, □ (kg/mm^3)	20000

3.3 Procedure

Lay up selection

Fabrication of leaf spring with hand lay-up technique is done. The lay-up is selected to be uni-directional along the longitudinal direction of the spring.
E-glass / Epoxy have good characteristics for storing strain energy in the direction of fibers.
100 grams of hardener is mixed with 1 kg of Epoxy resin. The mixture is applied on the wax polish and then a layer is placed on the mandrel and the resin is applied again. This is continued for 13 layers. After the lay-up is finished, it is kept undisturbed for 24 hrs at room temperature.

The composite leaf spring removed from the mandrel has the same dimensions of the steel leaf spring.
Sharp edges produced during the fabrication process are removed by using grinding machine.

3.4 Testing of leaf springs

a) Tensile test

Fig. 2 Tensile test

The springs are tested on Universal Testing Machine and the readings are noted. The leaf springs to be tested are to be examined for any defects like cracks, surface abnormalities, etc.

Table 2 Tensile test results

Tensile test results		
S No	Parameter	Value
1	Specimen type	Flat
2	Specimen width	12.85 mm
3	Specimen thickness	6 mm
4	Cross sectional area	94.57 mm^2
5	Original gauge length	50 mm
6	Final guage length	56.28 mm
7	Ultimate load	24.64 kN
8	Ultimate tensile strength	260.52 Mpa
9	Elongation	13.50%

b) Impact test

Charpy test and Izod impact tests are done and readings are noted.

Table 3 Impact test results

Impact test results			
S No	Parameter	Charpy - V	Izod - V
1	Notch depth	2.54	2.54
2	Notch angle	45^{0}	45^{0}
3	Specimen size	12.5 x 7.58 x 58	12.5 x 7.58 x 65
4	Observed value	14 Joules	12 Joules

c) Static load test

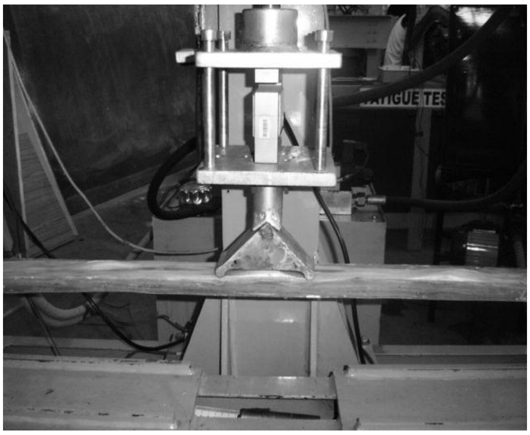

Fig. 3 Static load test

Table 4 Static load test results

Static load test results for Max. load deflection		
S No	Parameter	Value
1	Specimen type	Leaf spring
2	Specimen width	60 mm
3	Specimen thickness	6 mm
4	Cross sectional area	488.80 mm^2
5	Ultimate load	3.4 kN

3.5 Creating Solid model of the spring

A solid 3D model is created using Pro/E. Pro/E is a suite of programs that are used in the design, analysis and manufacturing of a virtually unlimited range of products.

Fig. 4 3D model of the leaf spring

3.6 FEA of the Solid model of the spring

Structural analysis of the spring is done using ANSYS. Modeling of the steel spring is done using 8 node 3D (Solid 45) brick element.
Modeling of the composite spring is done using Shell 99 element.

Loading and Boundary Conditions

The spring is symmetrical, half of the span length can be considered to save time.
One end of the spring is constrained as Uy = 0, Uz = 0 and Rotz = 0.
The load is applied on the free end of the leaf spring in steps of 2kg. Deformations and stresses under various loading conditions are computed.

ANSYS results

Fig. 5 Deflection of steel leaf spring for maximum load

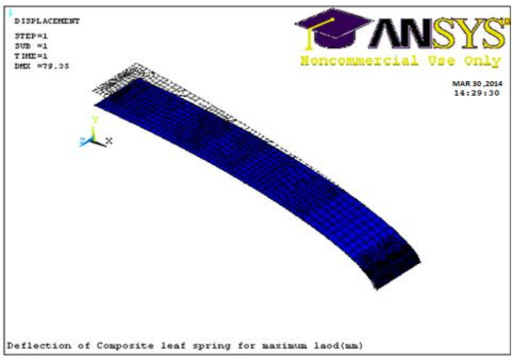

Fig.6 Deflection of composite leaf spring for maximum load

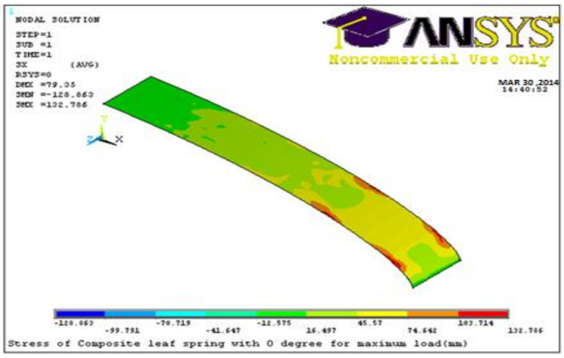

Fig. 7 Stress of composite leaf spring (0 Deg) for maximum load

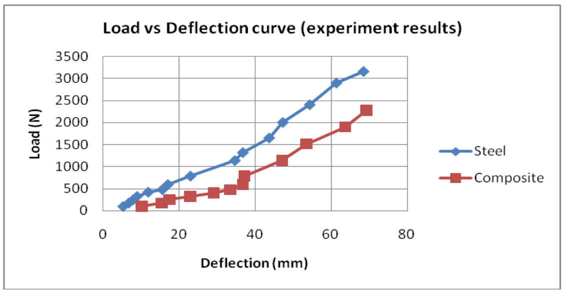

Fig. 8 Load Vs Deflection curve for Steel and Composite materials – Experimental results

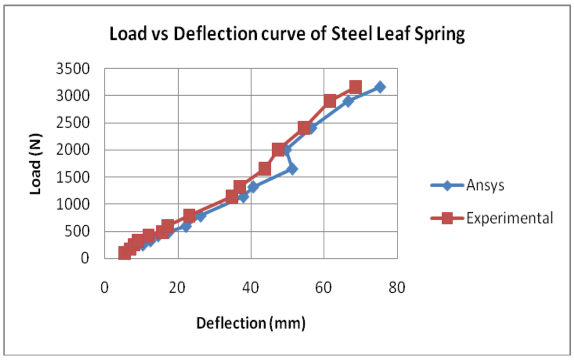

Fig. 9 Load Vs Deflection curve for Steel (ANSYS and Experimental results)

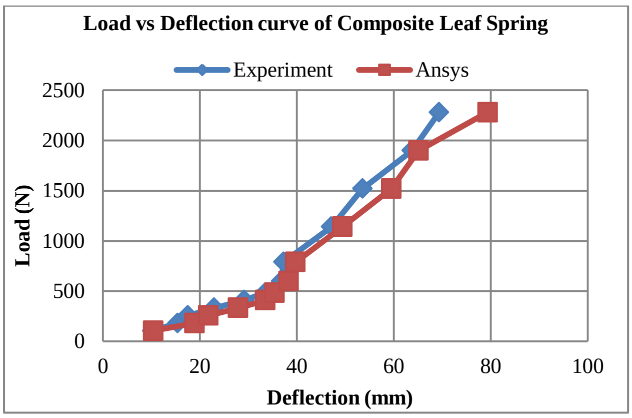

Fig. 10 Load Vs Deflection curve of Composite leaf spring

Table 5 Deflection values from experiment

S No	Load (N)	Deflection (mm)	
		Steel	Composite
1	105	5.31	10.18
2	180	6.79	15.43
3	250	7.98	17.54
4	333	8.98	22.94
5	426	11.90	29.14
6	485	15.63	33.47
7	599	17.08	36.82
8	789	23.02	37.25
9	1140	34.68	47.12
10	1320	36.78	53.54
11	1650	43.70	63.75
12	2000	47.30	69.36
13	2400	54.36	-
14	2890	61.40	-
15	3250	68.50	-

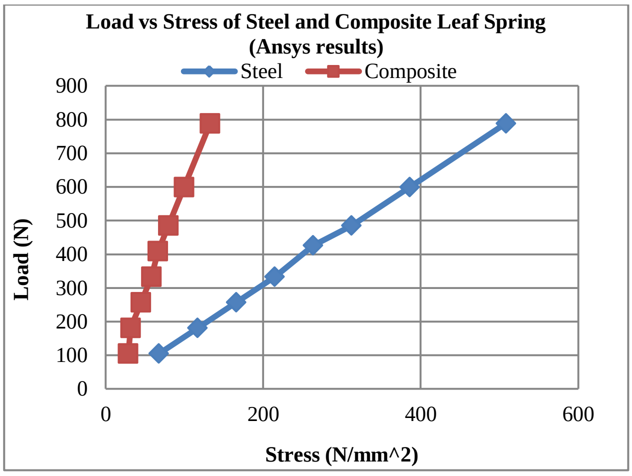

Fig. 11 Load Vs Stress of Steel and Composite leaf spring (ANSYS Results)

Table 6 Deflection values from ANSYS

S No	Load (N)	Deflection (mm)	
		Steel	Composite
1	105	5.92	10.37
2	180	7.27	18.91
3	250	10.30	21.72
4	333	12.40	27.90
5	426	14.50	33.50
6	485	17.30	35.40
7	599	22.10	38.30
8	789	26.10	39.70
9	1140	37.80	49.40
10	1320	40.50	59.50
11	1650	51.20	65.10
12	2000	49.50	79.35
13	2400	56.40	-
14	2890	66.50	-
15	3250	75.20	-

Table 7 Stress values from ANSYS

S No	Load (N)	Stress (N/mm^2)	
		Steel	Composite
1	105	67.66	28.66
2	180	116.76	31.65
3	250	165.73	44.93
4	333	214.70	58.22
5	426	263.60	66.39
6	485	312.36	79.67
7	599	386.11	99.59
8	789	508.50	132.78

Curves for different fiber orientations

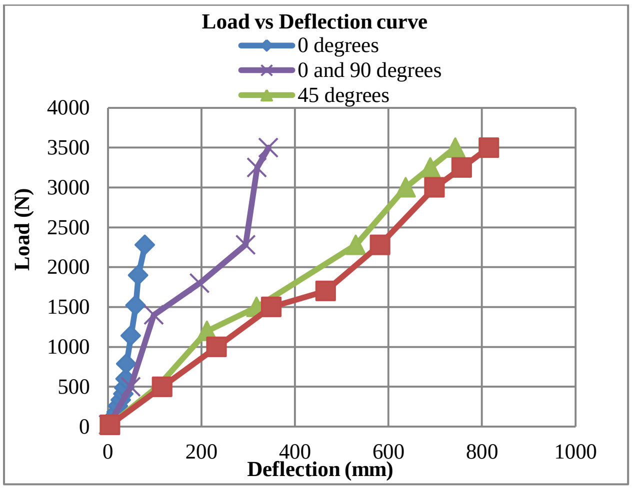

Fig. 1 Load Vs Deflection curves

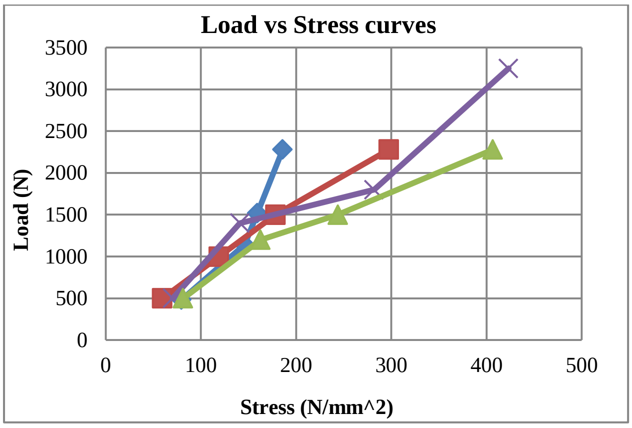

Fig. 2 Load Vs Stress curves

Conclusions

1) E-glass / epoxy mat is used as the material and epoxy resin is Dobeckot 520 F and the grade of hardener is 758. The composite leaf spring is fabricated using hand lay-up technique.
2) Testing of composite and steel leaf spring is done and the experimental results are obtained.
3) The analysis with the experimental values obtained is done using ANSYS.
4) The load vs deflection in composite leaf spring for different orientations in the fiber is studied. It is observed that 0^0 orientations have minimum deformation.
5) The fibers with an orientation of 0^0 has low deflection and stresses when compared with other orientations.
6) The maximum load capacity for the composite leaf spring is 2280 N whereas for the steel leaf spring it is 3150 N.
7) The load – deflection curve is non-linear for the composite material while it is linear for the steel leaf spring.
8) From the load vs stress graph, it is observed, that the stresses in the leaf spring with composite material is low and up to 200 N/mm^2. For the steel leaf spring, the stresses are maximum up to 600 N/mm^2.
9) Under the same static load conditions, deflection and stresses of composite and steel leaf springs are found to have great difference.
10) Composite leaf spring has to reduce the weight by 85% for E-glass / Epoxy. But, it is observed that the values are less due to property variation in the tapered system, improper bonding, improper curing, etc.
11) Composite leaf spring can be used on smooth roads with very high performance. Chipping resistance constrains their usage on poor roads.
12) In the experiment on Composite leaf spring, load is applied till the deformation value is same as that of the steel spring is obtained. Further loads are not applied.

Future Scope

1) Study can be done by replacing a complete set of steel leaf spring with a composite leaf spring for a vehicle.
2) Dynamic load test can be performed.
3) Doing analysis of composite leaf spring by designing and fabricating a variable width and thickness leaf spring.
4) The effect of impact on the composite leaf spring can be studied.
5) At higher loads, there is a considerable difference in the ANSYS and experimental values. Reasons for this can be studied.
6) Chipping resistance is a major disadvantage with the composites and the solution has to be found.

References

Manual on design and application of leaf springs (1990), *Spring design manual*, AE-11, Society of Automotive Engineer, Hs 788, 1990.

G S Shiva Shankar, S Vijaya Rangan (2006), *Mono Composite Leaf Spring for Light weight vehicle – Design, End Joint analysis and Testing*, Materials Science, Vol. 12, No. 3, P No. 220-225.

Tsai SW, Hahn HT (1980), *Introduction to composite materials, Technomic publishing.*

Ryan WE (1985), Method of making a molded fiber reinforced plastic leaf , *US Patent* 4,560,525.

Kumar Krishnan, Aggarwal M.L (2012), *A Finite Element approach for analysis of a multi leaf spring using CAE tools Research*, Journal of Recent Sciences, P No. 92-96.

R M Jones (1990), *Mechanics of Composite Materials*, 2e, Mc Graw Hill Book Company.

Deshmukh B.B, Dr S B Jaju (2011), *Design and Analysis of Glass Fiber Reinforced Polymer (GFRP) leaf spring*, Emerging trends in Engineering and Technology, P No. 82-87.

C K Clarke and G E Borowski, *Evaluation of Leaf spring failure, ASM International*, Journal of Failure Analysis and Prevention, Vol. 5 (6), P No. 54-63.

M M Shokrieh, D Rezaei (2003), *Composite Structures 60*, P No. 317-32.

R S Khurmi, J K Gupta (2000), *A text book of Machine Design*, P. No. 866-874.

V B Bhandari, *Design of Machine Elements, Springs*, Tata Mc Graw Hill, P No. 411-442.

Pankaj Saini, Ashish Goel, Dushyant Kumar (2013), Design and Analysis of Composite Leaf spring for light vehicles, IJIRSET, Vol 2 Iss 5, May, P No. 1-10

H A Al-Qureshi (2001), *Automobile Leaf springs from Composite materials*, Journal of Material Processing Technology, Vol-118, P. No. 58-61.

S Vijayarangan, I Rajendran (2002), *Design and Analysis of a Composite leaf spring*, Journal of Institute of Engineers India.