IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
PP 23-38

Design And Analysis of Composite Parabolic Leaf Spring for Light Vehicles

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Abstract: *Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this paper we describe design and analysis of composite leaf spring. The objective is to compare the stresses and weight saving of composite leaf spring with that of steel leaf spring. The design constraint is stiffness. The Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials has high strength to weight ratio, good corrosion resistance. The material selected was glass fiber reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. The design parameters were selected and analyzed with the objective of minimizing weight of the composite leaf spring as compared to the steel leaf spring. The leaf spring was modeled in PRO-E and the analysis was done using ANSYS.12 software.*

I. Introduction

A spring is defined as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. Leaf springs absorb the vehicle vibrations, shocks and bump loads induced due to road irregularities by means of spring deflections, so that the potential energy is stored in the leaf spring and then relieved slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Semi-elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension. The spring consists of a number of leaves called blades.

The blades are varying in length. The blades are us usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining blades are called graduated leaves. All the blades are bound together by means of steel straps. The spring is mounted on the axle of the vehicle.

The entire vehicle load rests on the leaf spring. The front end of the spring is connected to the frame with a simple pin joint, while the rear end of the spring is connected with a shackle. Shackle is the flexible link which connects between leaf spring rear eye and frame. When the vehicle comes across a projection on the road surface, the wheel moves up, leading to deflection of the spring. This changes the length between the spring eyes. If both the ends are fixed, the spring will not be able to accommodate this change of length. So, to accommodate this change in length shackle is provided at one end, which gives a flexible connection.

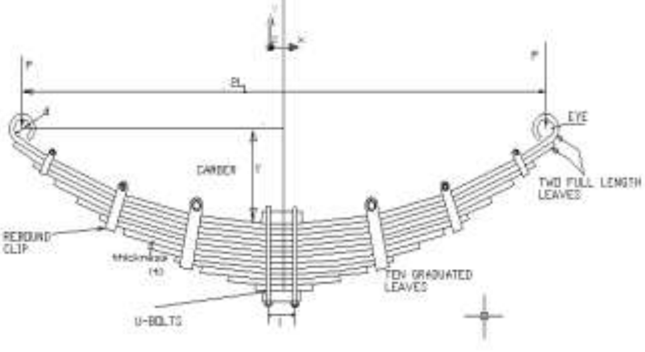


Figure: 1.1 Leaf spring

The entire vehicle load rests on the leaf spring. The front end of the spring is connected to the frame with a simple pin joint, while the rear end of the spring is connected with a shackle. Shackle is the flexible link which connects between leaf spring rear eye and frame. When the vehicle comes across a projection on the road surface, the wheel moves up, leading to deflection of the spring. This changes the length between the spring eyes. If both the ends are fixed, the spring will not be able to accommodate this change of length. So, to accommodate this change in length shackle is provided at one end, which gives a flexible connection.

The front eye of the leaf spring is constrained in all the directions, whereas rear eye is not constrained in X-direction. This rare eye is connected to the shackle. During loading the spring deflects and moves in the direction perpendicular to the load applied. When the leaf spring deflects, the upper side of each leaf tips slides or rubs against the lower side of the leaf above it. This produces some damping which reduces spring vibrations, but since this available damping may change with time, it is preferred not to avail of the same. Moreover, it produces squeaking sound. Further if moisture is also present, such inter-leaf friction will cause fretting corrosion which decreases the fatigue Strength of the spring, phosphate paint may reduce this problem fairly. The elements of leaf spring are shown in Figure 1. Where t is the thickness of the plate, b is the width of the plate and L is the length of plate or distance of the load W from the cantilever end.

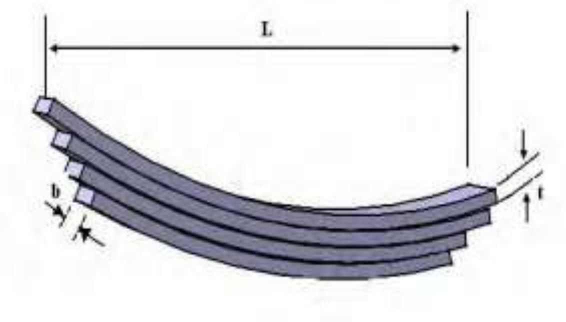


Figure:1. 2 Design Parameters of Leaf Spring.

The vehicles need a good suspension system that can deliver a good ride and handling. At the same time, the component must have an excellent fatigue life. Fatigue is one of the major issues in automotive components. It must withstand numerous numbers of cycles before it can fail, or never fail at all during the service period. Leaf spring is widely used in automobiles and one of the components of suspension system. It consists of one or more leaves. As a general rule, the leaf spring must be regarded as a safety component as failure could lead to severe accidents.

The leaf springs may carry loads, brake torque, driving torque, etc. in addition to shocks. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. The leaf springs bend and slide on each other allowing suspension movement. Fatigue failure is the predominant mode of in-service failure of many automobile components. This is due to the fact that the automobile components are subjected to variety of fatigue loads like shocks caused due to road irregularities traced by the road wheels, the

Sudden loads due to the wheel travelling over the bumps etc. The leaf springs are more affected due to fatigue loads, as they are a part of the unstrung mass of the automobile. The aim of the project undertaken was to increase the load carrying capacity and life cycles by modifying the existing multi-leaf spring of a light commercial vehicle (LCV). In this paper, only the work of the modified ten-leaf steel spring is presented.

1.2 Merits Of Composite Leaf Spring

- Reduced weight.
- Due to laminate structure and reduced thickness of the mono composite leaf spring, the overall weight would be less.
- Due to weight reduction, fuel consumption would be reduced.
- They have high damping capacity; hence produce less vibration and noise.
- They have good corrosion resistance.
- They have high specific modulus and strength.
- Longer fatigue life.

II. Literature Review

Miravete.A, Castejon. L, Bielsa.J, Bernal.E – ‘Analysis and Predicti on of large composite Structures’ [1990]. Material properties and design of composite structures are reported in many literatures. Very little information is available in connection with finite element analysis of leaf spring in the literature, than too in 2D analysis of leaf spring. At the same time, the literature available regarding experimental stress analysis more. The experimental procedures are described in national and international standards. Recent emphasis on mass reduction and developments in materials synthesis and processing technology has led to proven production worthy vehicle equipment[1].

H.J. Aguilar , J.A. Rodrıguez ‘Premature fracture in automobile leaf springs’Volume 12 Issue 7, 21-30, 2012 The origin of premature fracture in leaf springs used in Venezuelan buses is studied. To this end, common failure analysis procedures, including examining the leaf spring history, visual inspection of fractured specimens, characterization of various properties and simulation tests on real components, were used.

It is concluded that fracture occurred by a mechanism of mechanical fatigue, initiated at the region of the central hole, which suffered the highest tensile stress levels. Several factors (poor design, low quality material and defected fabrication) have combined to facilitate failure. Preventive measures to lengthen the service life of leaf springs are suggested

F.N.Ahmad Refngah, S.Abdullah, ‘Life Assessment of a Parabolic Spring under Cyclic Strain Loading’ Vol 3 Issue 1, pp.155-162, March 2013,

The variable amplitude loading for the fatigue life analysis. Service loading of parabolic spring has been collected using data acquisition system. The finite element method (FEM) was performed on the spring model to observe the distribution stress and damage. The experimental works has been done in order to validate the FEM result [5].

III. Methodology For Leaf Spring

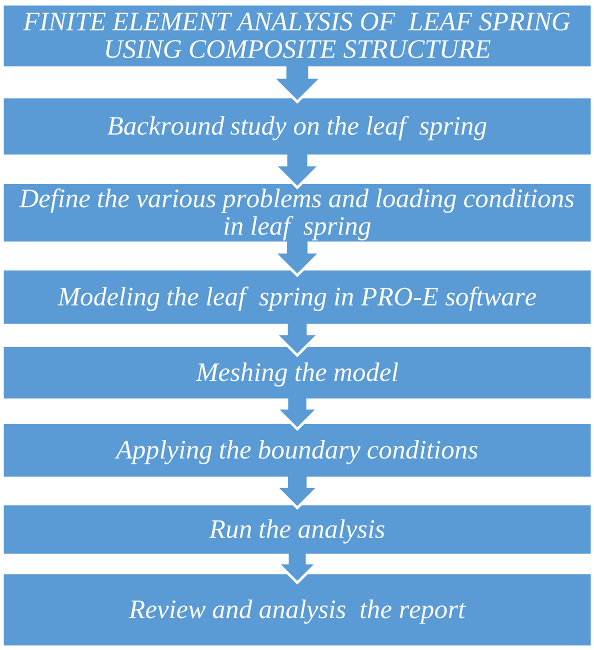


Figure: 3.1 Methodology

IV. Leaf Spring Materials

4.1materials For Leaf Spring

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

4.2carbon/Graphite Fibers:

Their advantages include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance and high electrical conductivity.

4.3glass Fibers:

The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties. The disadvantages are low elastic modulus poor adhesion to polymers, low fatigue strength and high density, which increase leaf spring weight and size. Also crack detection becomes difficult.

4.4. Material Properties

Table: 4. 1 Material properties

PROPERTIES OF COMPOSITES					
S.No	**Properties**	**E-glass/epoxy**	**Carbon epoxy**	**Graphite epoxy**	
1	Yield strength:	4500(MPa)	3450(MPa)	4900(MPa)	
2	Tensile strength	900(MPa)	900(MPa)	790(MPa)	
3	Elastic modulus	6500(MPa)	10600 (MPa)	6400(MPa)	
4	Shear modulus	2433(MPa)	7600 (MPa)	3000(MPa)	
5	Density	0.000002(kg/mm³)	0.0000016(kg/mm³)	0.00000159(kg/mm³)	
6	Poisson's ratio:	0.27	0.27	0.023	

4.5 Design Data Details

Here Weight and initial measurements of Mahindra Model - 650 light vehicle are taken

- Gross vehicle weight = 2150 kg
- Un sprung weight = 240 kg
- Total sprung weight = 1910 kg
- Taking factor of safety (FS) = 1.4
- Acceleration due to gravity (g) = 10 m/s²
- There for; Total Weight (W) = 1910*10*1.4 = 26740 N

4.**6 Design Parameters Of Leaf Spring**

Leaf no.	Full leaf length (mm) 2L	Half leaf length (mm) L	Radius of curvature (mm) R
1	1120	560	961.11
2	1120	560	961.11
3	1007	503.5	973.11
4	894	447	979.11
5	780	390	985.11
6	667	333.5	991.11
7	554	277	997.11
8	440	220	1003.11
9	327	163.5	1009.11
10	214	107	1015.11

Table: 4. 2 Design parameters of leaf spring

V. Composite Material

5.1 Composite Material Characteristics

A composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Typical composite materials are composed of inclusions suspended in a matrix. The constituents retain their identities in the composite. Normally the components can be physically identified and there is an interface between them. Many composite materials offer a combination of strength and modulus that are either comparable to or better than any traditional metallic materials. Because of their low specific gravities, the strength weight-ratio and modulus weight-ratios of these composite materials are markedly superior to those of metallic materials.

The fatigue strength weight ratios as well as fatigue damage tolerances of many composite laminates excellent. For these reasons, fiber composite have emerged as a major class of structural material and are either used or being considered as substitutions for metal in many weight-critical components in aerospace, automotive and other industries. Another unique characteristic of many fiber reinforced composites is their high internal damping.

This leads to better vibration energy absorption within the material and results in reduced transmission of noise and vibration to neighboring structures. High damping capacity of composite materials can be beneficial in many automotive applications in which noise, vibration, and hardness is a critical issue for passenger comfort. Among the other environmental factors that may cause degradation in the mechanical properties of some polymeric matrix composites are elevated temperatures, corrosive fluids, and ultraviolet rays. In many metal matrix composites, oxidation of the matrix well as adverse chemical reaction between fibers and matrix are of great concern at high temperature applications.

5.2 Applications:

Commercial and industrial applications of composite s are so varied that it is impossible to list them all. The major structural application areas, which include aircraft, space, automotive, sporting goods, and marine engineering. A potential for weight saving with composites exists in many engineering field. The first major structural application of composite is the corvette rear leaf spring in 1981. A uni-leaf E-glass – reinforced epoxy has been used to replace a ten-leaf steel spring with nearly an 80 % weight savings. Other structural chassis components, such as drive shafts and road wheels, have been successfully tested in the laboratories and are currently being developed for future cars and vans.

The metal matrix composites containing either continuous or discontinuous fiber reinforcements, the latter being in the form of whiskers that are approximately 0.1-0.5 μm in diameter and have a length to diameter ratio up to 200. Particulate-reinforced metal matrix composites containing either particles or platelet that ranges in size from 0.5 to 100 μm.

Dispersion-strengthened metal matrix composites containing particles that are less than 0.1 μm in diameter. And metal matrix composites are such as directionally solidified eutectic alloys.

5.3 Benefits:

- Weight reduction,
- High strength,
- Corrosiveness,
- Low specific gravity.

VI. Solid Model Of Leaf Spring Created In Pro-E Soft Ware

Figure: 6.1 Leaf spring

Material	Half length (mm)	Width (mm)	Thickness (mm)	Radius of Curvature(mm)
Carbon/ epoxy	560	50	14	961.11
Graphite/epoxy	560	50	12	961.11

6.1 Leaf Springs:

Leaf springs also known as flat spring are made out of flat plates. Leaf springs are designed two ways: multi-leaf and mono-leaf. The leaf springs may carry loads, brake torque, driving torque, etc. In addition to shocks. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. The leaf springs bend and slide on each other allowing suspension movement.

6.2 Construction Of Leaf Spring:

The leaves are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaves are held together by means of band shrunk around them at the center or by a bolt passing through center. Since, the band exerts stiffening and strengthening effect, therefore effective length of the spring for bending will be overall length of the spring minus width of the band.

In case of a center bolt, two-third distance between centers of U-bolt should be subtracted from the overall length of the spring in order to find effective length. The spring is clamped to the axle housing by means of U-bolts. The longest leaf known as main leaf or master leaf has its ends formed in the Shape of an eye through which the bolts are passed to secure the spring to its supports.

The other leaves of the spring are known as graduated leaves. In order to prevent digging in the adjacent leaves, the ends of the graduated leaves are trimmed in various forms. Rebound clips are located at intermediate positions in the length of the spring, so that the graduated leaves also share the stress induced in the full length leaves when the spring rebounds.

6. 3 Design Selection:

The leaf spring behaves like a simply supported beam and the flexural analysis is done considering it as a simply supported beam. The simply supported beam is subjected to both bending stress and transverse shear stress. Flexural rigidity is an important parameter in the leaf spring design and test out to increase from two ends to the center.

6.4 Constant Thickness, Varying Width Design:

In this design the thickness is kept constant over the entire length of the leaf spring while the width varies from a minimum at the two ends to a maximum at the center.

6.5 Constant Width, Varying Thickness Design:

In this design the width is kept constant over the entire length of the leaf spring while the thickness varies from a minimum at the two ends to a maximum at the center

6.6 Constant Cross-Selection Design:

In this design both thickness and width are varied throughout the leaf spring such that the cross-section area remains constant along the length of the leaf spring. Out of the above mentioned design concepts. The constant cross-section design method is selected due to the following reasons Due to its capability for mass production and accommodation of continuous reinforcement of fibers.

VII. Finite Element Analysis

7.1introduction

Finite Element analysis tools offer the tremendous advantage of enabling design teams to consider virtually any molding option without incurring the expense associated with manufacturing and machine time. The Ability to try new designs or concepts on the computer gives the opportunity to eliminate problems before beginning production. Additionally, designers can quickly and easily determine the sensitivity of specific molding Parameters on the quality and production of the final part.

The leaf spring model is created by modeling software like pro-E, Caria and it is imported in to the analysis software and the loading, boundary conditions are given to the imported model and result are evaluated by post processor The different comparative results of steel leaf spring and composite leaf spring are obtained to predict the advantages of composite leaf spring for a vehicle

A stress-deflection analysis is performed using finite element analysis (FEA). The complete procedure of analysis has been done using ANSYS-12. To conduct finite element analysis, the general process of FEA is divided into three main phases, preprocessor, solution, and postprocessor.

7.2preprocessor:

The preprocessor is a program that processes the input data to produce the output that is used as input to the subsequent phase (solution). Following are the input data that needs to be given to the preprocessor: I. Type of analysis ii. Element type iii. Real constants iv. Material properties v. Geometric model vi. Meshed model vii. Loading and boundary conditions.

7.3 Solution

Solution phase is completely automatic. The FEA software generates the element matrices, computes nodal values and derivatives, and stores the result data in files. These files are further used by the subsequent phase (postprocessor) to review and analyze the results through the graphic display and tabular listings.

7.4postprocessor:

The output from the solution phase is in the numerical form and consists of nodal values of the field variable and its derivatives. For example, in structural analysis, the output is nodal displacement and stress in the elements. The postprocessor processes the result data and displays them in graphical form to check or analyze the result. The graphical output gives the detailed information about the required result data.

7.5 Methodology

In all of these approaches the same basic procedure is followed.

During preprocessing

- The geometry (physical bounds) of the problem is defined.
- The volume occupied by the fluid is divided into discrete cells (the mesh).
- The mesh may be uniform or non-uniform.
- Boundary conditions are defined. This involves specifying the fluid behavior and properties at the boundaries of the problem. For transient problems, the initial conditions are also defined.
- The simulation is started and the equations are solved iteratively as a steady-state or transient.
- Finally a postprocessor is used for the analysis and visualization of the resulting solution.

7.6 Meshed Model Of Leaf Spring

Figure: 7. 1 Mesh model of composite leaf spring

7.7 MESHING

Meshing involves division of the entire of model into small pieces called elements. This is done by meshing. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is solid 72. The element edge length is taken as 15 and is refined the area of Centre bolt to 2. Fig 6 shows the meshed model of the leaf spring.

VIII. Result And Discussion

8.1deformation Of The Leaf Spring

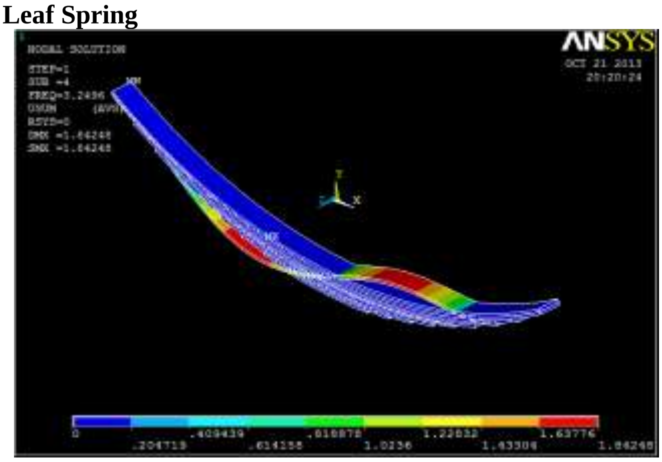
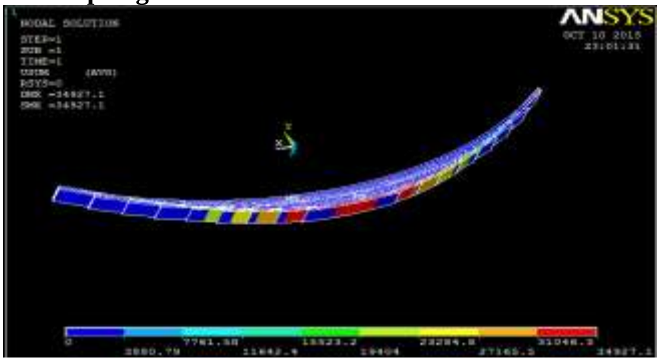


Figure: 8. 1 Fourth mode shape of deformation

The above figure 8.1 shows the first mode shape of deformation of the load 6000N is act totally on the leaf spring, the maximum translation experience 1.824mm by one ends of the leaf spring.

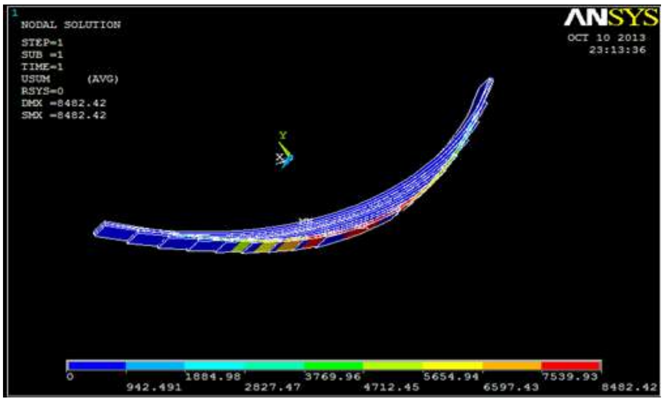
8.2 Displacement Of The Leaf Spring



[redacted]

Figure: 8.2 Displacement pattern for Carbon/Epoxy composite leaf spring Load 6000N

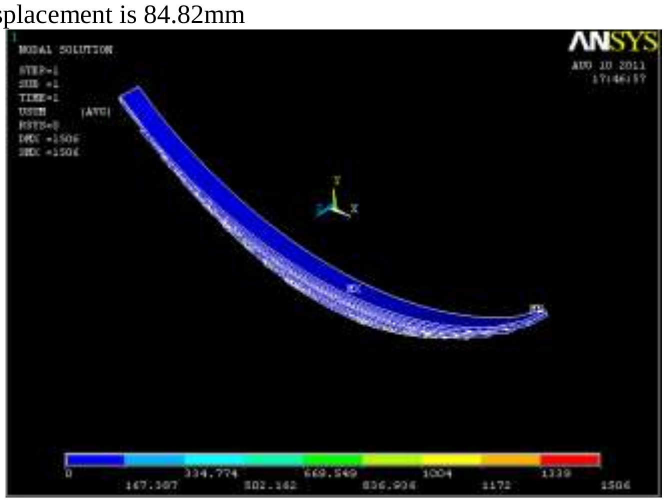
The above figure 8.2 shows the displacement of the pattern for Carbon/Epoxy composite leaf spring Load 6000N.The maximum displacement is 349.73mm



[redacted]

Figure: 8.3 Displacement pattern for E glass /Epoxy composite leaf spring Load 6000N

The above figure 8.3 shows the displacement of the pattern for E glass /Epoxy composite leaf spring Load 6000N.The maximum displacement is 84.82mm



[redacted]

Figure: 8.4 Displacement pattern for graphite epoxy composite leaf spring Load 6000N

The above figure 8.4 shows the displacement of the pattern for graphite epoxy composite leaf spring Load 6000N.The maximum displacement is 1506 mm

8.3 Strain Analysis Of The Leaf Spring

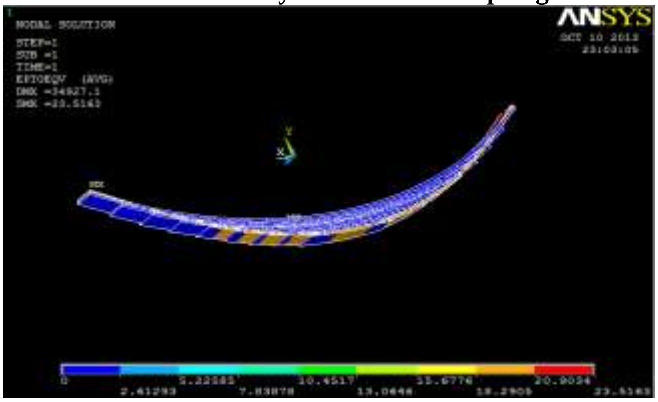


Figure:8.5 Strain distribution for Carbon/Epoxy composite leaf spring load 6000N

The above figure 8.5 shows the Strain distribution for Carbon/Epoxy composite leaf spring load 6000N. The maximum Strain distribution 23.51

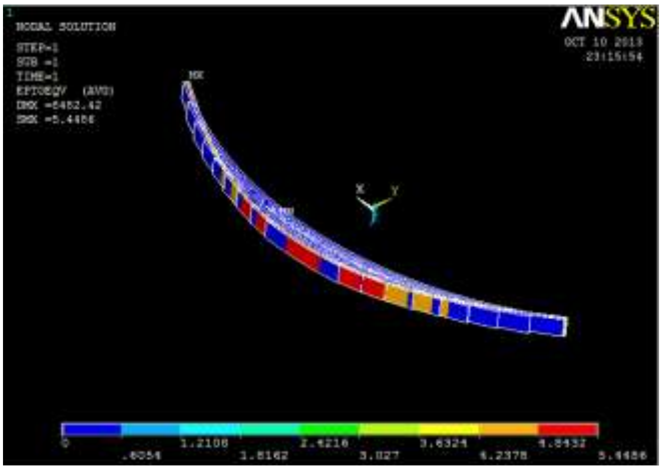


Figure: 8.6 Strain distribution for E glass /Epoxy composite leaf spring load 6000N

The above figure 8.6 shows the Strain distribution for E glass /Epoxy composite leaf spring load 6000N. The maximum Strain distribution 5.44

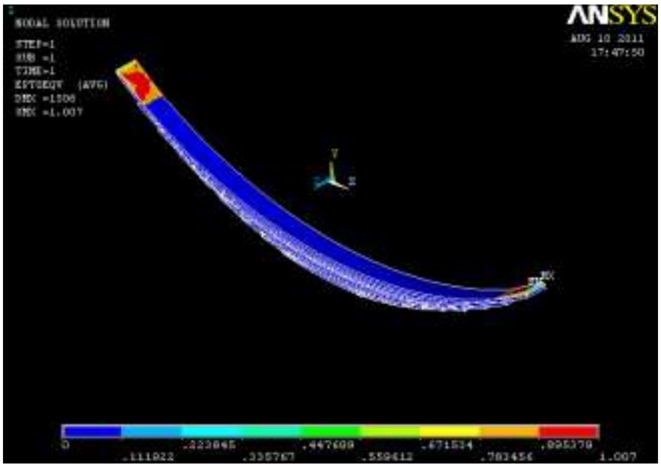


Figure: 8.7 Strain distribution for graphite epoxy composite leaf spring load 6000N

The above figure 8.7 shows the Strain distribution for graphite epoxy composite leaf spring load 6000N. The maximum Strain distribution 1.007.

8.4 Stress Analysis Of The Leaf Spring

Stress analysis of multi leaf spring were considered, when the spring is subjected to maximum load of 6000N to determine the stress distribution and critical region of high stresses which could cause failure to the spring. Von Mises stresses on each leaf from first to fifth were calculated for different radii of curvature. In all above groups the radii of curvature varies from 1250mm to 3000mm. The relationship between radius of curvature(R) and angle of curvature(θ) are inversely proportional as shown in Fig(3),this is because when distance (b) remain constant then the radius of curvature increased when the angle of curvature decreasing depending on equation θ = tan-1(b/R). On each leaf it is noted that the leaf have two sides, the upper side at internal curvature and the lower side at external curvature. In all (24) cases it was found that the stresses at lower side of leaves is more than the upper sides for the first four leaves as shown in fig(4) and

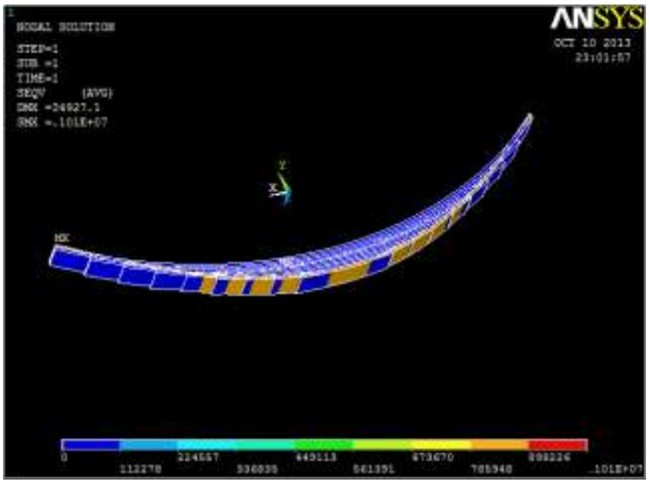


Figure:8.8 Stress distribution for Carbon/Epoxy composite leaf spring Load 6000N

The above figure 8.8 shows the Stress distribution for Carbon/Epoxy composite leaf spring load 6000N. The maximum Stress distribution $1x10^6$N/mm^2

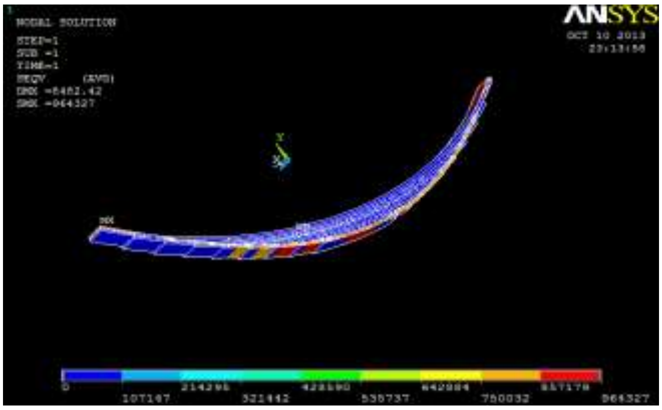


Figure:8.9 Stress distribution for E glass /Epoxy composite leaf spring Load 6000N

The above figure 8.9 shows the Stress distribution for E glass /Epoxy composite leaf spring load 6000N. The maximum Stress distribution 964327N/mm^2

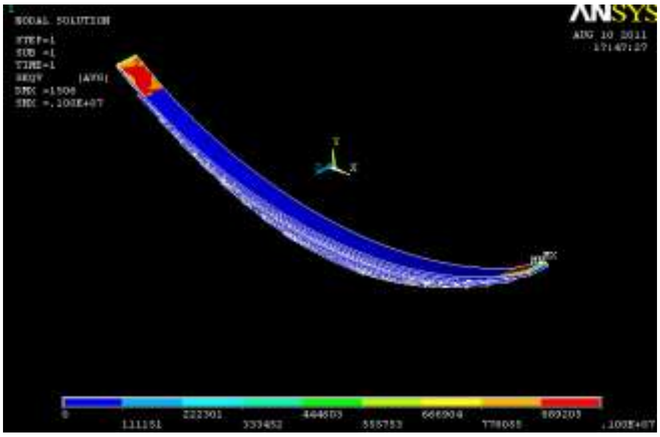


Figure:8.10 Stress distribution for graphite epoxy composite leaf spring Load 6000N

The above figure 8.10 shows the Stress distribution for graphite epoxy composite leaf spring load 6000N. The maximum Stress distribution $1x10^7 N/mm^2$

8.5 Experimental Results Tables

Table: 8.1& 8.2 the table shows the comparative result composite leaf spring

Load (N)	Deformation (mm)		Displacement (mm)		
	E glass / Epoxy	Carbon/ Epoxy	E glass /Epoxy	Carbon/ Epoxy	graphite epoxy
1500	1.605	3.45	12.7661	87.3178	2120.6
3000	1.606	7.08	25.5323	174.636	4241.2
4500	1.716	10.63	63.6181	261.953	1130
6000	1.824	14.72	84.8242	349.273	1506

Load (N)	Strain (MJ)			Stress (N/mm^2)		
	E glass / Epoxy	Carbon/ Epoxy	graphite epoxy	E glass /Epoxy	Carbon/ Epoxy	graphite epoxy
1500	0.80	5.879	1.36	238052	252626	241082
3000	1.61	11.75	2.73	476103	505252	482163
4500	4.08	17.63	0.755	723245	757878	750267
6000	5.44	23.51	1.007	964327	$1x10^6$	$1x10^7$

8.6 Result Comparison Table

Deformation

Table: 8.3 The table shows the comparative result for deformation Re Design leaf spring and Normal leaf spring

Load (N)	Deformation Re Design leaf spring (mm)		Deformation Normal leaf spring (mm)	
	E glass / Epoxy	Carbon/Ep oxy	E glass / Epoxy	Carbon/Ep oxy
1500	1.605	3.45	1.872	3.983
3000	1.606	7.08	1.923	7.571
4500	1.716	10.63	2.471	11.340
6000	1.824	14.72	2.613	15.782

8.7 Displacement

Table: 8.4 The table shows the comparative result for displacement Re Design leaf spring and Normal leaf spring

Load (N)	Displacement Re Design leaf spring (mm)			Displacement Normal leaf spring(mm)		
	E glass / Epoxy	Carbon/Epoxy	Graphite epoxy	E glass / Epoxy	Carbon/Epoxy	Graphite epoxy
1500	12.7661	87.3178	2120.6	12.9860	87.9280	2140.78
3000	25.5323	174.636	4241.2	25.9002	175.1223	4598.08
4500	63.6181	261.953	1130	64.2119	261.8012	1398
6000	84.8242	349.273	1506	85.7623	359.2981	1669

8.8 strain

Table: 8.5 The table shows the comparative result for strain Re Design leaf spring and Normal leaf spring

Load (N)	Strain Re Design leaf spring (MJ)		Strain Normal leaf spring (MJ)	
	E glass / Epoxy	Carbon/Epoxy	E glass / Epoxy	Carbon/Epoxy
1500	0.80	5.879	1.03	6.14
3000	1.61	11.75	1.87	11.79
4500	4.08	17.63	4.64	17.74
6000	5.44	23.51	6.01	23.89

8.9 Stress

Table: 8.6 The table shows the comparative result for stress Re Design leaf spring and Normal leaf spring

Load (N)	Stress (N/mm^2) Re Design leaf spring		Stress (N/mm^2) Normal leaf spring	
	E glass / Epoxy	Carbon/Epoxy	E glass / Epoxy	Carbon/Epoxy
1500	238052	252626	245780	257812
3000	476103	505252	477231	515359
4500	723245	757878	724310	769802
6000	964327	$1x10^6$	964410	$1.2 x10^6$

8.10 Graphs For Deformation

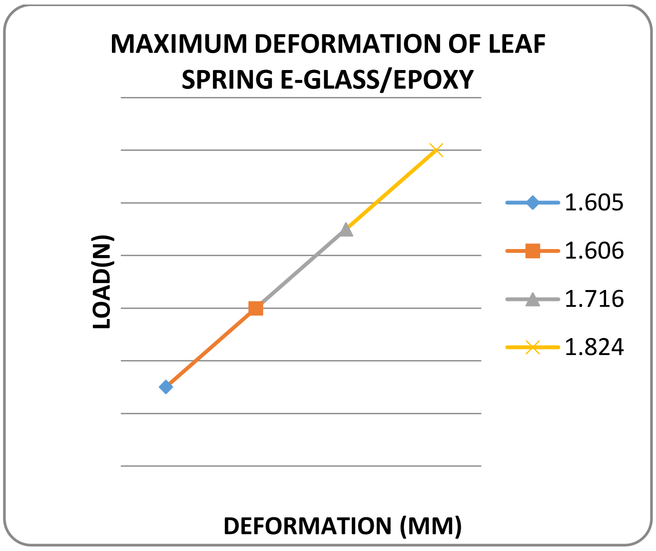


Figure: 8.11 Maximum deformation of leaf spring E-glass/Epoxy

The mode shape as can be seen from figure 8.11 natural frequency increase slightly with load increase to maximum value load at 6000N.the deformation curve constant value at all load condition but minimum variations at all load.the result shows when load increses the natural frequency increased

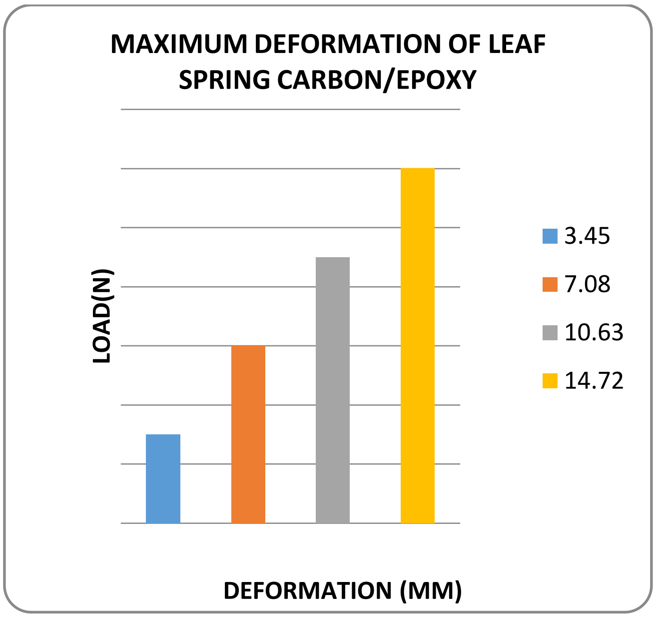


Figure: 8.12 Maximum deformation of leaf spring Carbon /Epoxy

The mode shape as can be seen from figure 8.12 natural frequency increase slightly with load increase to maximum value load at6000 N.the deformation curve constant value at all load condition but minimum variations at all load.the result shows when load increses the natural frequency increase

8.11 Graphs For Displacement

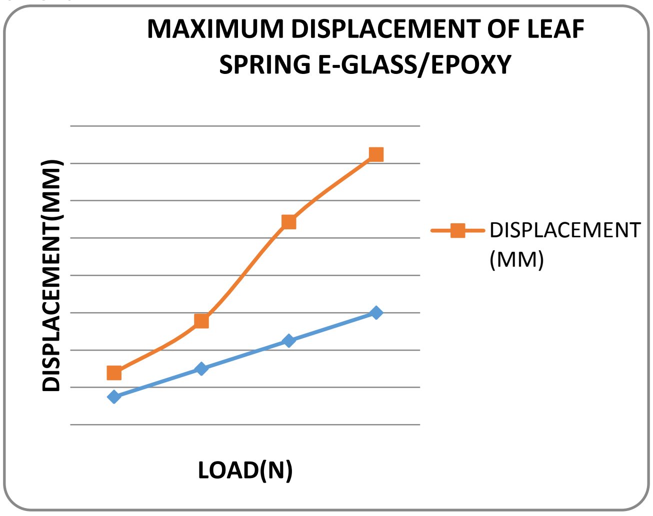


Figure: 8.13 Maximum displacement of leaf spring E-glass/Epoxy

The maximum displacement of the leaf spring to compare load and maximum displacement as can be seen from figure 8.13 load slightly with increase to maximum value load at 6000N.the displacement curve minimum increase at all load condition but minimum variations at all load.the result shows the when load increses the displacement increased.

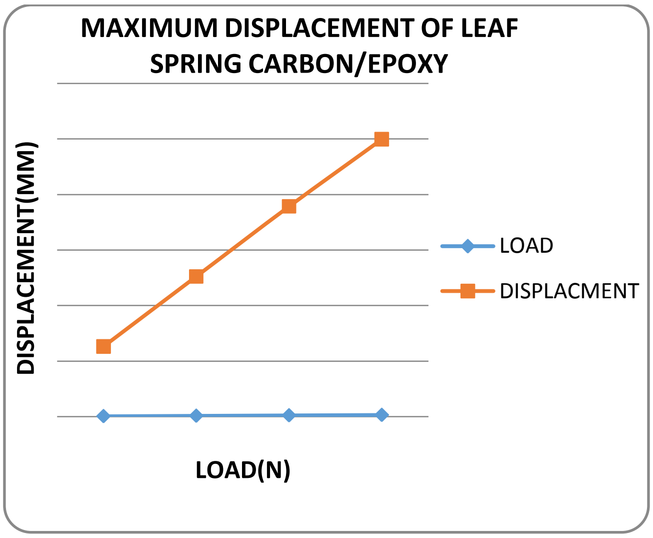


Figure: 8.14 Maximum displacement of leaf spring Carbon /Epoxy

The maximum displacement of the leaf spring to compare load and maximum displacement as can be seen from figure 8.14 load slightly with increase to maximum value load at 6000N.the displacement curve minimum increase at all load condition but minimum variations at all load.the result shows the when load increses the displacement increased.

8.12 Graphs For Strain

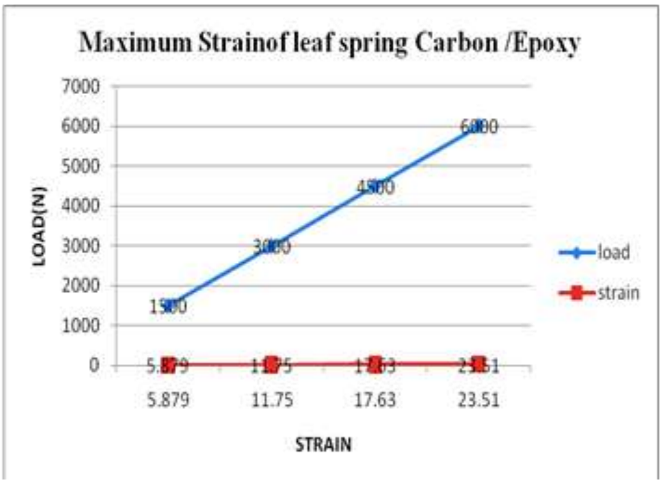


Figure:8.15 Maximum strain of leaf spring E-glass/Epoxy

The maximum strain of the leaf spring to compare load and maximum strain as can be seen from figure 8.15 load slightly with increase to maximum value load at 6000 N.the strain curve minimum increase at all load condition but minimum variations at all load.the result shows the when load increses strain curve.The maximum stress of the leaf spring to compare load and maximum stress as can be seen from figure 8.17 and 8.18 load slightly with increase to maximum value load at 6000N.the stress curve minimum increase at all load condition but minimum variations at all load.the result shows the when load increses stress curve.

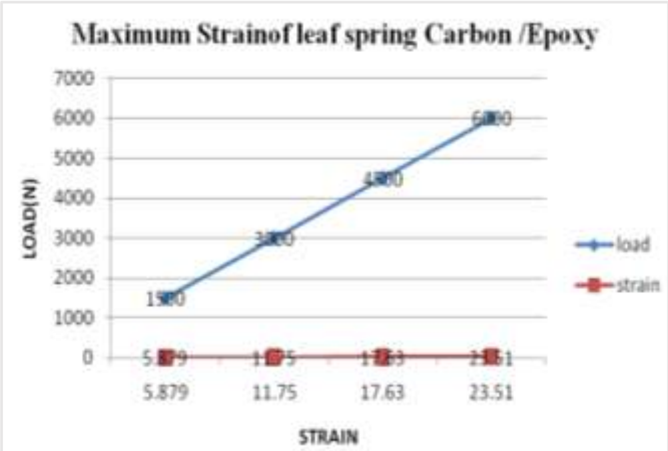


Figure:8.16 Maximum strain of leaf spring Carbon /Epoxy

The maximum strain of the leaf spring to compare load and maximum strain as can be seen from figure 8.16 load slightly with increase to maximum value load at 6000 N.the strain curve minimum increase at all load condition but minimum variations at all load.the result shows the when load increses strain curve

8.13 GRAPHS FOR STRESS

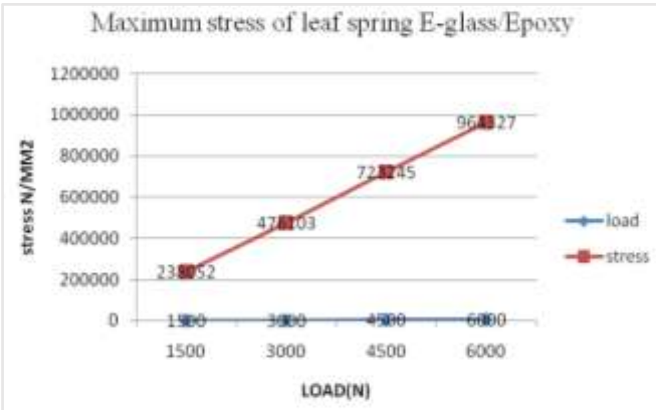


Figure:8.17 Maximum stress of leaf spring E-glass/Epoxy

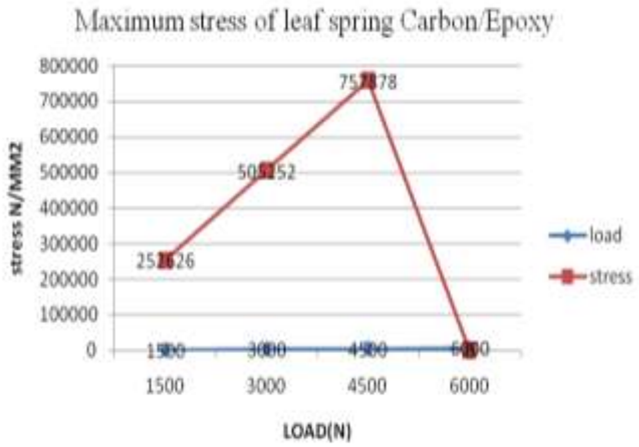


Figure: 8.18 Maximum stress of leaf spring Carbon /Epoxy

IX. Conclusion

- As reducing weight and increasing strength of products are high research demands in the world, composite materials are getting to be up to the mark of satisfying these demands.
- In this paper reducing weight of vehicles and increasing 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 composite leaf spring is designed and it is shown that the resulting design and simulation stresses are much below the strength properties of the material satisfying the maximum stress failure criterion.
- From the static analysis results it is found that there is a maximum displacement of E-glass / epoxy, and carbon/epoxy is 84.8.mm, and 349.273mm. And all the values are below the camber length for a given uniformly distributed load 67 N/mm over the ineffective length.
- From the static analysis results, we see that the von-mises stress in E glass/ epoxy, and Carbon/epoxy is 964327N/mm^{2}and 1x10^{6}N/mm^{2}and respectively. Among the two composite leaf springs, only Carbon/epoxy composite leaf spring has higher stresses than the steel leaf spring.
- Carbon/epoxy composite leaf spring can be suggested for replacing the E-glass/epoxy leaf spring from stress and stiffness point of view.
- A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight by 81.22% for E-Glass/Epoxy, and 90.51 % for Carbon/Epoxy over conventional leaf spring.

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