Malaga. Anil Kumar, T.N.Charyulu, Ch.Ramesh / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 6, November- December 2012, pp.759-765

Design Optimization Of Leaf Spring

Malaga. Anil Kumar [1], T.N.Charyulu[2], Ch.Ramesh [3]

1. Student, 10a01d0407, M.Tech (Cad/Cam), Nova College Of Engineering & Technology, Jangareddy Gudem,
2. Associate Professor, Department Of Mechanical Engineering, Nova College Of Engineering & Technology, Jangareddy Gudem,
3. Assistant Professor, Department Of Mechanical Engineering, Pace Institute Of Technology & Sciences, Ongole,

Abstract

The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio. This work deals with the replacement of multi-leaf steel spring with mono composite leaf spring. Suspension system in an automobile determines the riding comfort of passengers and the amount of damage to the vehicle. The main function of leaf spring assembly as suspension element is not only to support vertical load, but also to isolate road-induced vibrations. The behavior of leaf spring is complicated due to its clamping effects and inter-leaf contact etc.

The objective of this paper is to replace the multi-leaf steel spring by mono composite leaf spring for the same load carrying capacity and stiffness. Since the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. It is possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness. The design constraints were limiting stresses and displacement. Modeling and analysis of both the steel and composite leaf springs have been done using ANSYS software.

1. Introduction

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturer. 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 unsprung weight. Hence, the strain energy of the material becomes a major factor in designing the springs.

The introduction of 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 composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. The introduction of fiber reinforced plastics (FRP) made it possible to reduce the weight of a machine element without any reduction of the load carrying capacity.

Because of FRP materials high elastic strain energy storage capacity and high strength-to-weight ratio compared with those

Of steel, multi-leaf steel springs are being replaced by mono leaf FRP springs.

2. Model Preparation And Formulation

Solid modeling is the first step for doing any 3D analysis and testing and it gives 3D physical picture for new products. FE models can easily be created from solid models by the process of meshing.

2.1 Solid Modeling

In the present work, multi-leaf steel spring and mono-composite leaf spring are modeled. For modeling the steel spring, the dimensions of a conventional leaf spring of a light weight commercial vehicle are chosen. Since the leaf spring is symmetrical about the neutral axis only half of the leaf spring is modeled by considering it as a cantilever beam. Load is applied at the base of the leaf spring in the middle in the upward direction.

2.2 Specifications for Steel Leaf Spring

Model	: cdr 650md 2wd
Suspension	: rear leaf
Span length	: 1120 mm
Width	: 50 mm
Thickness	: 6 mm
Outer eye dia	: 50 mm
Dia .of centre bolt	: 8 mm
Camber	: 180 mm
Ineffective length	: 100 mm
Total no. Of leaves	: 10
No. of full length leaves	: 2
No. of graduated leaves	: 8
Vehicle weight	: 1910 kg

2.3 Geometric Properties of leaf spring

Camber = 180 mm
Span = 1120 mm
Thickness = 6 mm
Width = 50 mm
Number of full length leaves $n_F = 2$

Number of graduated leaves $n_G = 8$
Total Number of leaves n = 10

Table: 1 Design Parameters of Steel leaf spring

Leaf number	Full leaf Length (mm)	Half leaf Length (mm)	Radius of Curvature (mm)	Half rotational Angle (Deg)
1	1153.33	576.66	961.11	34.37
2	1153.33	576.66	967.11	34.37
3	1047.97	523.98	973.11	30.84
4	942.64	471.32	979.11	27.57
5	837.31	418.65	985.11	24.34
6	731.98	365.99	991.11	21.15
7	626.65	313.32	997.11	18.00
8	521.32	260.66	1003.11	14.88
9	415.99	207.99	1009.11	11.80
10	310.66	155.33	1015.11	8.76

2.4 Modeling Procedure for Leaf Spring

1. First create the key point100 at origin ,i.e. x ,y, z=(0,0,0)
2. Create the another key point200 at some arbitrary distance in Z-direction, say x, y, z = (0, 0, 200)
3. Join the above two key points 100 and 200 to get the reference axis.
4. By using data from mathematical analysis create the key point1 with a distance of radius of curvature R_1 in vertically down-ward direction, i.e x, y, z = (0, $-R_1$, 0).
5. Similarly key points 2 and 3 correspond to R_2, i.e. x, y, z = (0,$-R_2$,0), key points 4 and 5 corresponds to R_3, i.e. x, y, z = (0, $-R_3$, 0), Key point 20 corresponds to R_{11}. i.e x, y, z = (0, -R11, 0)
6. Join the pair of key points sequentially as follows:

   Key points 1 and 2, 2 and 3, 3 and 4...and 19 and 20.
7. Then line1 formed by the key points 1 and 2, line2 formed by the key points 2 and 3 and line10 formed by the key points 19 and 20.
8. Extrude the above lines with respect to reference axis stated in step3 as Follows:

   Extrude line1 with an angle Φ_1, will get area1

   Extrude line2 with an angle Φ_2, will get area2 …and

   Extrude line10 with an angle Φ_{10}, will get area10.
9. After extruding all the lines, the semi area of the spring without eye will form on XY- plane with significant degeneracy.
10. To avoid degeneracy, extend the right side line of smallest area i.e. area 10 to some extent such that it cross the top most area i.e. area1.Now divide area by line. For this, select the areas left to extended line1 and divide with that line. Similarly, extend the right side line of second smallest area i.e. area9 to some extent such that it cross the top most area i.e. area1. Again divide area by line. For this select the areas left to extended line2 and divide with that line.
11. The above process is to be done up to extension of line of area9 and divide area by extension line9.
12. To get the full area of the leaf spring. Shift the origin to the top left most area key point i.e. key point1. Reflect the entire area with respect to YZ –plane.
13. To get the solid model of the leaf spring Extrude the area by Z -offset to a length equal to the width of the leaf spring.

Fig.1 shows the model of the steel leaf spring. Figures 2, 3, 4 represent the mono-composite leaf springs modeled by using the above procedure. Table.2. gives the geometric properties of mono composite leaf spring where the thickness are calculated basing on the same stiffness and are shown in annexure-1

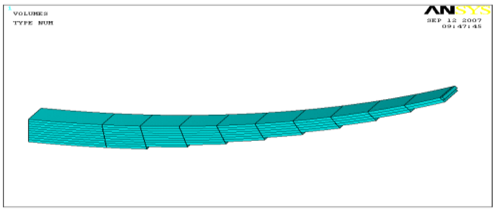

FIG.1 Solid Model of Steel Leaf Spring

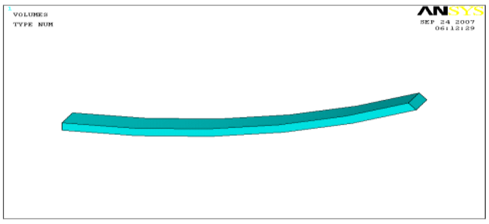

FIG.2 Solid Model of E-Glass/Epoxy Mono Composite Leaf Spring

Fig.3 Solid Model Of Graphite / Epoxy Mono Composite Leaf Spring

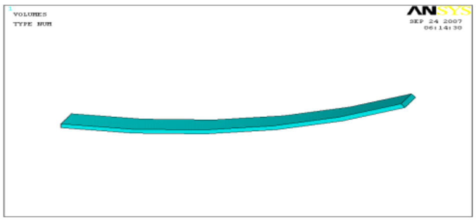

FIG.4 Solid Model of Carbon/Epoxy Composite Leaf Spring

Table: 2. Geometric Properties of Mono Composite leaf spring

Material	Half Length (mm)	Width (mm)	Thickness (mm)	Radius of curvature (mm)	Half rotational Angle (Deg)
Carbon/ epoxy	576.66	50	13.68	961.11	34.37
Graphite/ epoxy	576.66	50	11.55	961.11	34.37
E-Glass/epoxy	576.66	50	21.50	961.11	34.37

3. Analysis of Steel Leaf Spring

3.1Material Properties:

Material selected is Manganese Silicon Steel (Steel 55Si2Mn90)
Young's Modulus E = 2.1E5 N/mm^2
Density = 7.86E-6 kg/mm^3
Poisson's ratio = 0.3
Tensile stress = 1962 N/mm^2
Yield stress = 1470 N/mm^2

3.2 Element type

- SOLID45- 3-D Structural Solid
- CONTA174 - 3-D 8-Node Surface-to-Surface Contact

3.2.1 SOLID 45- 3-D Structural Solid

SOLID 45 is used for the 3-D modeling of solid structures.
The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions

3.2.2 CONTA174/170 - 3-D 8-Node Surface-to-Surface Contact

CONTA174 is an 8-node element that is intended for general rigid-flexible and flexible-flexible contact analysis. CONTA174 is surface-to-surface contact element . CONTA174 is applicable to 3-D geometries. It may be applied for contact between solid bodies or shells.

3.3 Static Analysis

The fig.5 shows the contact pressure in the leaf spring and it varies from 0 to 19.989MPa

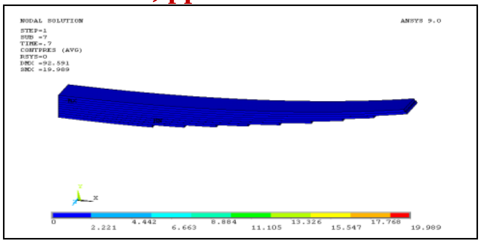

FIG.5 Plot of Contact Pressure in Steel Leaf Spring

The following fig. 6 shows the contact total stress whose value is 19.991MPa

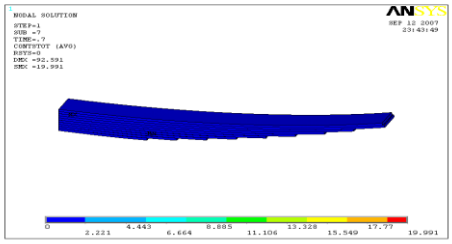

FIG.6 Plot of Contact Total Stress in Steel Leaf Spring

The fig. 7 shows the contact gap distance along the length of the leaf and it is -0.888E-15

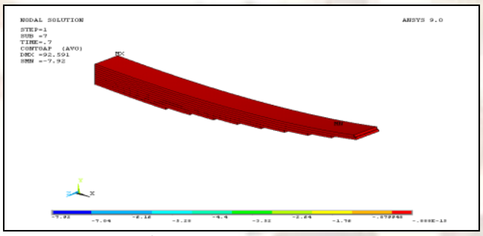

FIG.7 Plot of Contact Gap Distance in Steel Leaf Spring

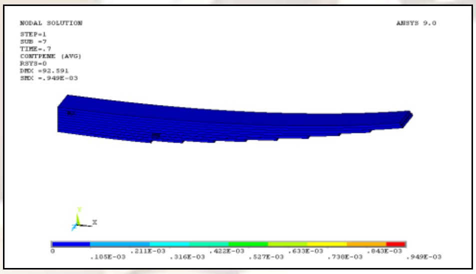

FIG.8 Plot of Contact Penetration in Steel Leaf Spring

3.4 Modal Analysis

Modal analysis is carried out to determine the natural frequencies and mode shapes of the leaf spring. Modal analysis need only boundary conditions, it is not associated with the loads applied, because natural frequencies are resulted from the free vibrations. The boundary conditions are same as in the case of static analysis.
From the modal analysis results, the natural frequencies of the steel leaf spring are found to be

2.847Hz, 19.443Hz, 21.523Hz, 55.91Hz, and 56.627Hz

4. Analysis of Mono Composite leaf spring

The aim of the analysis is to study the mono composite leaf spring and verification of the results to be within the desirable limits. Three different composite materials have been selected .They are E-Glass / Epoxy, Graphite / Epoxy and Carbon/ epoxy composite materials. Analysis is done using ANSYS.

4.1. Analysis of E-Glass /Epoxy Composite Leaf Spring

4.1.1 FEM Model details

Mechanical properties:

Extensional Elastic Modulus	E_1	= 43E+3 MPa
Transverse Elastic Modulus	E_2	= 9E+3 MPa
In-plane Shear Modulus	G_{12}	= 4.5E+3 MPa
Major Poisson's Ratio	ν_{12}	= 0.27
Minor Poisson's Ratio	ν_{21}	= 0.06
Density	ρ	= 2000kg/m^3
Yield strength	S_y	= 2000MPa

4.1.2 Element type

The element used in descretization of the solid model is 8 noded brick element (SOLID 45) which has 3 translational degrees of freedom in x, y and z direction.

4.1.3 Stress Analysis

FE analysis for stress and deformation are carried out. For this load of 3330N is applied at the base of leaf spring in the middle. The constraints are, the front eye is constrained as UY, UZ and the nodes at the middle are constrained as UX, UZ.

The fig: 9 shows the von-mises stress at different positions of the leaf spring and it varies from 0.1147MPa to 475.606Mpa

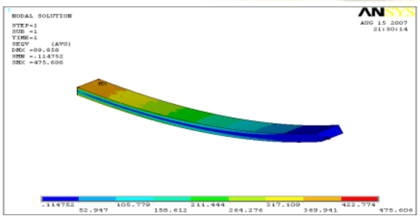

FIG.9 Von-Mises Stress Plot of E-Glass/Epoxy Composite Leaf Spring

4.1.4 Modal Analysis

Modal analysis is performed to determine the natural frequencies and mode shapes of the leaf spring.

After the post processing, from solution options, new analysis is selected as modal. The analysis can be performed by Block Lancos method or Subspace method. The subspace method is selected. In the next step select the no. of modes to extract and expand are taken as 5. From the modal analysis results, it is found that the first five natural frequencies of E-Glass / epoxy mono composite leaf spring are 1.244Hz, 10.244 Hz, 15.231 Hz, 27.902 Hz, and 46.612 Hz

The fig.10 shows the mode shape at a natural frequency of 1.209Hz and the displacement is 1.244mm

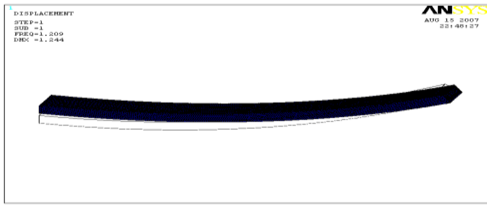

FIG.10 Total Deformation Plot for 1st Natural Frequency

4.2 Analysis of Graphite / Epoxy Composite Leaf Spring

4.2.1 FEM Model details

Mechanical Properties:

Extensional Elastic Modulus	E_1	=294E+3MPa
Transverse Elastic Modulus	E_2	=6.4E+3 MPa
In-plane Shear Modulus	G_{12}	=4.9E+3 MPa
Major Poisson's Ratio	ν_{12}	= 0.23
Minor Poisson's Ratio	ν_{21}	= 0.01
Density	ρ	= 1590kg/m^3
Yield Strength	S_y	= 2067Mpa

4.2.2 Element Type

The element used in descretization of the solid model is 8 noded brick element (SOLID 45) which has 3 translational degrees of freedom in x, y and z direction.

4.2.3 Stress Analysis

FE analysis for stress and deformation are carried out. For this load of 3330N is applied at the base of leaf spring in the middle. The constraints are, the front eye is constrained as UY, UZ and the nodes at the middle are constrained as UX, UZ. From the results it is found that displacement is 80.369mm and maximum stress is 1573 Mpa.

The fig: 11 shows the deformed shape of the leaf spring with respect to undeformed shape for the load of 3300N

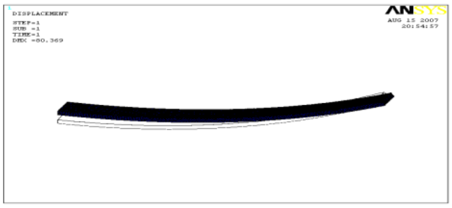

FIG.11 Deformed & Undeformed Plot of Mono Composite Leaf Spring

The fig: 12 shows the von-mises stress at different positions of the leaf spring and it varies from 2.36MPa to 1573MPa

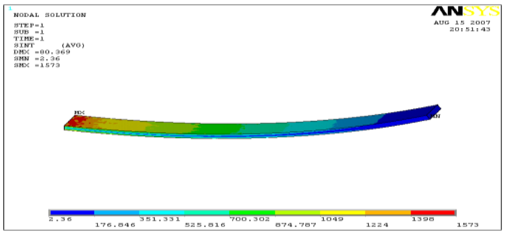

FIG.12 Von-Mises Stress Plot of Graphite /Epoxy Composite Leaf Spring

4.2.4 Modal Analysis

Modal analysis is performed to determine the natural frequencies and mode shapes of the leaf spring.

After the model is created, select the analysis as modal analysis. The analysis can be performed by Block Lancos method or Subspace method. The subspace method is selected. In the next step select the no. of modes to extract and expand as 5. Then the problem is solved. From the modal analysis results, it is found that the first five natural frequencies are 1.924Hz, 16.868 Hz, 42.56 Hz, 46.337 Hz, and 90.172 Hz

The fig.13 shows the mode shape at a natural frequency of 1.985Hz and the displacement is 1.924mm

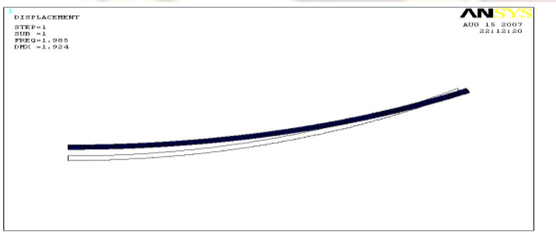

FIG.13 Total Deformation Plot for 1st Natural Frequency

4.3 Analysis of Carbon / Epoxy Composite Leaf Spring

4.3.1 FEM Model details

Mechanical Properties:

Extensional Elastic Modulus E_1 = 177E+3 MPa
Transverse Elastic Modulus E_2 = 10.6E+3 MPa
In-plane Shear Modulus G_{12} = 7.6E+3 MPa
Major Poisson's Ratio ν_{12} = 0.27
Minor Poisson's Ratio ν_{21} = 0.02
Density ρ = 1600kg/m^3
Yield strength Sy= 1900MPa

4.3.2 Element type

The element used in descretization of the solid model is 8 noded brick element (SOLID 45) which has 3 translational degrees of freedom in x, y and z direction.

4.3.4 Stress Analysis

FE analysis for stress and deformation are carried out. For this load of 3330N is applied at the base of leaf spring in the middle. The constraints are, the front eye is constrained as UY, UZ and the nodes at the middle are constrained as UX, UZ. We can obtain the stresses and displacement by performing this analysis. From the results it is found that the maximum stress is 1061Mpa and displacement is 82.662mm

The fig: 14 shows the deformed shape of the leaf spring with respect to undeformed shape for the load of 3300N

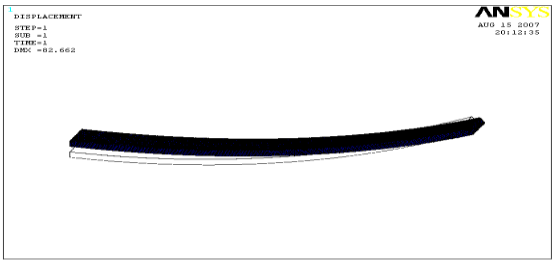

FIG.14 Deformed & Undeformed Plot of Mono Composite Leaf Spring

The fig: 15 shows the von-mises stress at different positions of the leaf spring and it varies from 1.006MPa to 1061MPa

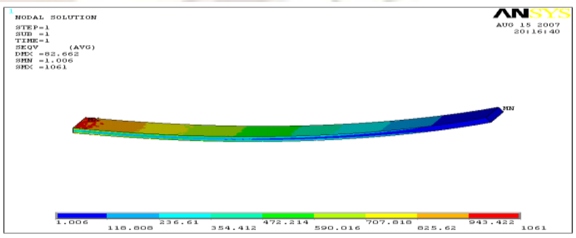

FIG.15 Von-Mises Stress Plot of Carbon/Epoxy Composite Leaf Spring

4.3.5 Modal Analysis

Modal analysis is performed to determine the natural frequencies and mode shapes of the leaf spring.

After the model is created, select the analysis as modal analysis. The analysis can be performed by Block Lancos method or Subspace method. The subspace method is selected. In the next step select the no. of modes to extract and expand as 5. Then the problem is solved. From the modal analysis results, it is found that the first five natural frequencies are 1.784Hz, 15.155 Hz, 33.443 Hz, 41.586 Hz, and 80.744 Hz

The fig.166 shows the mode shape at a natural frequency of 1.784Hz and the displacement is 1.761mm

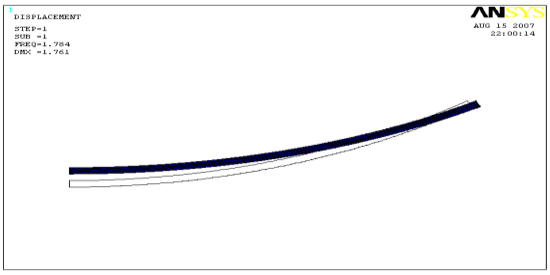

FIG16. Total Deformation Plot for 1st Natural Frequency

5. Results And Discussions

From the results of static analysis of steel leaf spring, it is seen the displacement of leaf spring is 92.591mm which is well below the camber length of leaf spring (i.e. 180mm). Therefore from the static analysis, the stiffness of the leaf spring is found to be 35.60mm. It is seen that the maximum Von-Mises stress is about 596.047Mpa, which is less than the yield strength of the material. The FEA results are compared with the theoretical results.

From the modal analysis, the first five natural frequencies are found to be are found to be 2.847Hz, 19.443Hz, 21.523Hz, 55.91Hz, and 56.627Hz.

Static analysis has been done for three different mono composite leaf springs of different materials. They are E-glass/epoxy, carbon/epoxy, graphite/epoxy. From the results of static analysis of mono composite leaf spring, the displacements of the E- glass /epoxy, carbon/epoxy, graphite/epoxy are 89.858mm, 82.662mm and 80.369mm. And the corresponding stiffness is 36.72N/mm, 39.92N/mm and 41.06N/mm.

TABLE: 3 Displacement and Stiffness Results

Material	Displacement (Theoretical)	Displacement (Ansys)	Stiffness (Theoretical)	Stiffness (Ansys)
Steel	102.20	92.591	32.28	35.60
E-Glass/epoxy	108.48	89.858	30.42	36.72
Carbon/epoxy	102.20	82.662	32.28	39.92
Graphite/epoxy	102.20	80.369	32.28	41.06

From the table, when compared with the stiffness of steel leaf spring, the stiffness of all the mono composite leaf springs is higher.

TABLE: 4 Theoretical and Ansys Results

Material	Theoretical Stress (MPa)	Von-Mises Stress (MPa)
Steel	621.60	596.05
E-glass/epoxy	479.74	475.60
Carbon /epoxy	1184.00	1061.00
Graphite/epoxy	1662.00	1573.00

The following table shows the first five natural frequencies of the three mono-composite leaf springs which are obtained by modal analysis:

TABLE: 5 Modal Analysis Results

SET	E-Glass/Epoxy	Carbon/Epoxy	Graphite/Epoxy
1	1.209	1.784	`1.985
2	10.244	15.155	16.868
3	15.231	33.443	42.560
4	27.902	41.586	46.337
5	46.612	80.744	90.172

The following table shows the weight reduction due to replacement of steel leaf spring with mono-composite leaf spring.

TABLE: 6 Results Showing the % Weight Reduction

Material	Weight(N)	% weight reduction
Steel	88.290	-
E-glass / epoxy	12.528	85.00
Carbon / epoxy	5.133	92.94
Graphite / epoxy	6.233	94.18

Composite mono leaf spring reduces the weight by 85 % for E-Glass/Epoxy, 94.18% for Graphite/Epoxy, and 92.94 % for Carbon/Epoxy over conventional leaf spring.

6. CONCLUSIONS

In the present work, a steel leaf spring was replaced by a mono composite leaf spring due to high strength to weight ratio for the same load carrying capacity and stiffness. The dimensions of a leaf spring of a light weight vehicle are chosen and modeled using ANSYS 9.0. As the leaf spring is symmetrical about the axis, only half part of the spring is modeled by considering it as a cantilever beam. Analysis has been performed by using ANSYS by applying the boundary conditions and the load. The boundary conditions are UY, UZ at the front eye end and UX, UZ in the middle. A load of 3300N was applied at the base in the middle of the leaf spring in the Y-direction. Later a mono composite leaf spring of uniform thickness and width was modeled so as to obtain the same displacement and hence same stiffness as that of steel leaf spring. Three different composite materials have been used for analysis of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. Static and model analysis has been performed.

1. From the static analysis results it is found that there is a maximum displacement of 92.591mm in the steel leaf spring and the corresponding displacements in E-glass / epoxy, graphite/epoxy, and carbon/epoxy are 89.858mm, 80.369mm and 82.662mm. And all the values are nearly equal and are below the camber length for a given load of 3300N.
2. From the static analysis results, we see that the von-mises stress in the steel is 596.047MPa. And the von-mises stress in E-glass/epoxy, Graphite /epoxy and Carbon/epoxy is 475.606MPa, 1556MPa and 1061MPa. Among the three composite leaf springs, only E-glass/epoxy composite leaf spring has lower stresses than the steel leaf spring.
3. All the FEA results are compared with the theoretical results and it is found that they are within the allowable limits and nearly equal to the theoretical results.
4. The composite leaf spring is modeled for the same stiffness as that of the steel leaf spring. It is found that the stiffness of all the composite leaf springs is more when compared with that of the steel leaf spring. The stiffness of steel leaf spring is 35.60N/mm and similarly stiffness of E-glass/epoxy, graphite/epoxy and carbon/epoxy composite leaf springs are 36.72N/mm, 39.92N/mm and 41.06N/mm respectively.
5. E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring both from stiffness and stress point of view.
6. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite mono leaf spring reduces the weight by 85% for E-Glass/Epoxy, 94.18% for Graphite/Epoxy, and 92.94 % for Carbon/Epoxy over conventional leaf spring.
7. For the modal analysis, same boundary conditions are applied and the load need not be applied. The natural frequencies and the mode shapes are important parameters in the design of a structure for dynamic loading conditions.
8. From the modal analysis results, the natural frequencies of the steel leaf spring are found to be 2.847Hz, 19.443Hz, 21.523Hz, 55.91Hz, and 56.627Hz.
9. The first five natural frequencies of E-Glass / epoxy mono composite leaf spring are 1.244Hz, 10.244 Hz, 15.231 Hz, 27.902 Hz, and 46.612 Hz.
10. The first five natural frequencies of Graphite / epoxy composite leaf spring are 1.924Hz, 16.868 Hz, 42.56 Hz, 46.337 Hz, and 90.172 Hz.
11. It is found that the first five natural frequencies of carbon/epoxy are 1.784Hz, 15.155 Hz, 33.443 Hz, 41.586 Hz, and 80.744 Hz

REFERNCES

[1] Gary Leevy and Khoa Cao, 2004 “Evaluation of a Multi-Leaf Hybrid Springs for Automotive Suspensions” SAE paper series, 2004-01-0782

[2] Mouleeswaran SENTHIL KUMAR, Sabapathy VIJAYARANGAN, “ Analytical and Experimental studies on Fatigue Life Prediction of steel and composite Multi-leaf spring for Light Passenger Vehicles using Life Data Analysis” Materials science . vol.13.No.2.2007

[3] Erdogan KILIC “Analysis of composite leaf springs” 2006, http:// www.elsevier.com

[4] C.K. Clarke and G.E. Borowski “ Evaluation of a leaf spring failure” ASM International 1547-7029

[5] Thimmegowda RANGASWAMY., Sabapathy VIJAYARANGAN, Optimal Sizing and Stacking Sequence of Composite Drive Shafts MATERIALS SCIENCE Vol. 11, No. 2. 2005

[6] Tirupathi R. Chandrupatla & Ashok D.Belegundu, “Introduction to Finite Elements in Engineering”. Third Edition- Pearson Education Pvt. Ltd- 2002.

[7] S.S.Rao, “The Finite Element Method in Engineering”. Third Edition- Butterworth Heinemann Publications-2001.

[8] T.V.S.Sundarajamoorthy, N.Shanmugam “ Machine Design”- Eighth Edition- Published by M.Sethuraaman, Anuradha Agencies- 2000

[9] O.P.Khanna, “Material science and metallurgy”-First edition –Dhanapati Rai Publications-1999.

[10] Autar. K.Kaw, “ Mechanics of Composite materials” CRC Press-1999

[11] Gummadi Sanjay, Akula Jagadeesh Kumar “Optimum design and analysis of a composite drive shaft for an automobile” Masters Degree Thesis.