Optimization of Heavy Vehicle Suspension System Using Composites

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Abstract

This paper describes design and experimental analysis of leaf spring made of Mild Steel and composite materials-S2 glass and Kevlar. The objective is to compare the load carrying capacity, strength and weight savings of composite leaf spring with that of mild steel leaf spring. The leaf spring is designed for Ashok Leyland Viking heavy vehicle for the load of 14087.5N. The design constraints are stresses and deflections. For validating the design FEA Structural Analysis and Modal Analysis are conducted. Pro/Engineer software is used for design and modeling, ANSYS 12.0 is used for analysis. The results show that the stresses in the composite leaf spring of the design are much lower than that of the allowable stress. The strength to weight ratio is higher for composite leaf spring than conventional steel spring with similar design. Weight of the composite spring by Kevlar composite material are 8times less than steel, S2 Glass epoxy composite material are 5 times less than steel. For less weight of the spring we can increase mechanical efficiency. It is concluded that leaf spring made of composite S2 Glass Epoxy is advantageous than mild steel.

Key words: *Composite Materials, Structural Analysis, Leaf Spring and Modal Analysis.*

1. Introduction

Suspension is the term given to the system of springs, shock absorbers and linkages that connects a vehicle to its wheels. Leaf spring originally called laminated or carriage spring, a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of springing, dating back to medieval times. A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swivelling member. A more modern implementation is the parabolic leaf spring.

Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi-leaf steel springs are being replaced by mono-leaf composite springs. The composite material offer opportunities for substantial weight saving but not always are cost-effective over their steel counter parts. 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. 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 apart of the unstrung mass of the automobile.

2. Literature Survey

Composite materials are now used extensively in the automotive industry to take the place of metal parts. Several papers were devoted to the application of composite materials for automobiles. Some of those papers are reviewed here, with emphasis on those papers that involve composite leaf springs. 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 [1]. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Many suspension systems work on the same principle including conventional leaf springs. However, for the same load and shock absorbing performance, conventional (steel) leaf springs use excess of material making them considerably heavy.

This can be improved by introducing composite materials in place of steel in the conventional spring. Studies and researches were carried out on the applications of the composite materials in leaf spring [2, 6]. A composite mono leaf spring with an integral eye was manufactured and tested for the static load conditions [3].

Fatigue life prediction was also done by authors so as to ensure a reliable number of life cycles of a leaf spring. Further, a leaf spring had been modelled in conventional way and simulated for the kinematic and dynamic comparatives [4]. Cyclic creep and cyclic deformation was also studied [5]. Efforts were taken for Finite Element Analysis of multi leaf springs. These springs were simulated and analyzed by using ANSYS 7.1 [2, 5]. Premature failure in leaf springs was also studied so as to suggest remedies on application of composite leaf springs. [4, 5].

3. Problem Formulation and Methodology

Present used material for leaf spring is steel, whose density is more thereby increasing the overall weight of the leaf spring. In this work, composite materials Kevlar and S2 Glass are replaced for leaf spring. The reason for using composites is that their densities are very much less than steel. So the overall weight of the leaf spring reduces thereby increasing its efficiency due to the reduction in mechanical losses [2].

The objective of the work is to design and model a leaf spring according to the loads applied. The leaf spring is designed for the materials Mild Steel and composites S2 glass and Kevlar. For validating the design FEA Structural Analysis is conducted for the leaf springs- Mild steel, S2 glass and Kevlar. Modal Analysis is also done. Pro/Engineer software is used for modeling and ANSYS software is used for analysis.

3.1. Design Selection

The leaf spring is designed for Ashok Leyland Viking heavy vehicle for the load of 14087.5N. This design is characterized by fewer leaves whose thickness varies from centre to ends following a parabolic curve. In this design, inter-leaf friction is unwanted, and therefore there is only contact between the springs at the ends and at the centre where the axle is connected. Spacers prevent contact at other points. Aside from a weight saving, the main advantage of parabolic springs is their greater flexibility, which translates into vehicle ride quality that approaches that of coil springs. There is a trade-off in the form of reduced load carrying capability, however. The characteristic of parabolic springs is better riding comfort and not as "stiff" as conventional "multi-leaf springs".

It is widely used on buses for better comfort. Typically when used in automobile suspension the leaf supports an axle and locates/ partially locates the axle. This can lead to handling issues (such as 'axle tramp'), as the flexible nature of the spring makes precise control of the unsprung mass of the axle difficult. Some suspension designs which use leaf springs do not use the leaf to locate the axle and do not have this drawback.

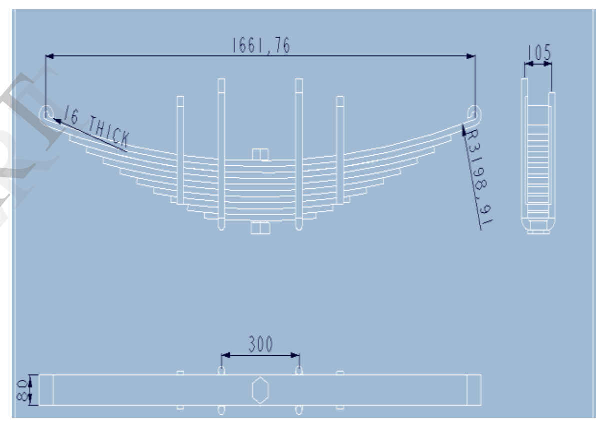

Figure No.1. Showing 2D Drawing of Leaf Spring Created in AutoCAD

The design is developed by mathematical calculations, using the mathematical formulas for determining the length, thickness and radius of curvature for the leaf spring. By considering the obtained values a 2D model is created in AutoCAD shown in Figure No 1. Using PRO/Engineer Tools, the Modeling of the Leaf Spring is carried out considering the values obtained from Mathematical calculations.

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Table No. 1. Material Properties and Boundary Conditions of the Materials Used.

Material	Element Type	Youngs Modulus (EX)	Poisson Ratio (PRXY)	Density	Pressure
MILD STEEL	Solid 20 node 95	205000N/mm^2	0.29	0.000007850 kg/mm^3	1.809 N/mm^2
KEVLAR	Solid 20 node 95	112000N/mm^2	0.36	0.00000144 kg/mm^3	1.809 N/mm^2
S2-GLASS	Solid 20 node 95	86900/mm^2	0.23	0.00000246 kg/mm^3	1.809 N/mm^2

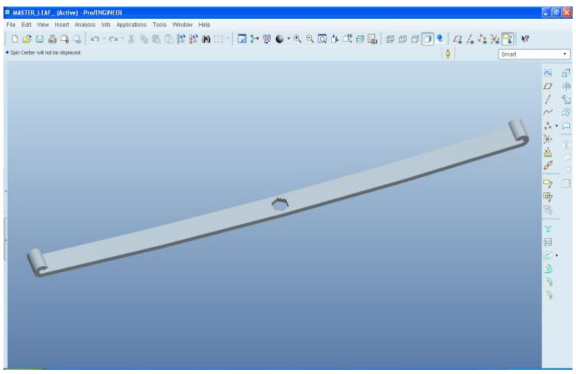

Figure No.2. Top View of the Leaf Spring Modeled

The Top View of the Leaf Spring and the Front View of the Assembled Leaf Spring Modeled using the tools available in PRO/Engineer are shown in Figure No 2 and Figure No 3.

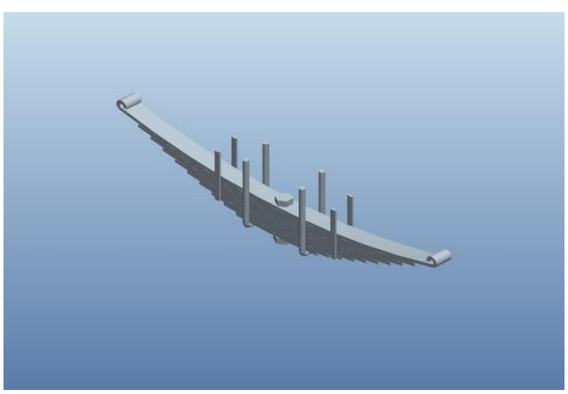

Figure No.3. Front View of Assembled Leaf Spring

3.1.1. Sample Calculation-Calculations for Lengths, Thickness and Radius of Leaves

Specifications of Ashok Leyland Viking
When n=10, Rear suspension
Number of leaf springs = 4
Width of leaves = 76.2 = 80mm

Overall length of the spring =2L_1=137.2cm
= 1372mm
Number of full length leaves = 2 = N_f
Number of graduated leaves = 8 = N_g
Number of springs = 10 (N_g+N_f)
Center load = 2W =115 tones = 11500kg
2W =11500 X 9.8 = 112700N
2W = 112700/4 = 28175N

$$2W = \frac{total\ load}{no\ of\ springs} = 28175N$$

W = 14087.5N
Material Used For Leaf Spring - Mild Steel
Bending stress σ_b = 21600 psi = 149 N/mm^2
Spring is simply supported beam
Width length = 2L
Central load =2W
Bending moment = M =W X L = 9664025
Section modulus Z = $bt^2/6$
b= width of leaves
t = thickness of leaves = $8Dt^2/6$

$$\text{Bending stress} = \sigma = \frac{M}{Z} = \frac{6wL}{nbt^2}$$

n = no of full length leaves and graduated leaves
L = 686mm; σ = 149 N/mm^2; n = 10

$$\sigma = \frac{6wL}{nbt^2}$$

$$149 = \frac{6 \times 14087.5 \times 686}{10 \times 80t^2} = \frac{57984150}{80t^2}$$

t^2 = 486.44 ; t = 20.133=22mm (approx.)
Deflection for both full length and graduated leaves

$$\delta = \frac{4WL^3}{n\epsilon b t^3} = \frac{4\times14087.5\times686^2}{10\times210\times10^2\times80\times22^3} = 10.169 \text{ mm}$$

Deflection for graduated leafs

$$\delta_G = \frac{6WL^3}{N_g \epsilon b t^3} = \frac{6\times14087.5\times686^2}{10\times210\times10^2\times80\times22^3} = 19.06\text{mm}$$

For same deflection in stress in uniform x- section leaves

$$\sigma_f = \frac{3}{2}\sigma_G$$

$$\text{Load for graduated leaves } W_G = \left(\frac{2N_g}{3N_f+2N_g}\right)$$

W = total load on the spring
W_G= Load taken up by graduated leaves
W_F= Load taken up by full length leaves
W_G=10245.45N
W_F=3842.05N
W = W_G + W_F

3.1.1.1. Bending Stress for Full Length Leaves

$\sigma_F = \frac{18WL}{bt^2\,(2N_g+3N_f)} = \frac{18\times14087.5\times686}{80\times22^2\times(2\times8+3\times2)}$ =204.20N/mm^2

$\sigma_G = \frac{12WL}{bt^2\,(2N_g+3N_f)} = \frac{12\times14087.5\times686}{80\times22^2\times(2\times8+3\times2)}$ =136.13N/mm^2

δ_F = Deflection of full length leaves

$\delta_F = \frac{12WL^3}{\epsilon bt^2\,(3N_f+2N_g)} = \frac{12\times14087.5\times686^3}{210\times10^3\times80\times22^2\times22}$=13.86mm

Equalized stress in spring leaves (nipping)

C = nip

C=$\frac{2WL^3}{n\epsilon b\,t^3}$; δ_F=$\frac{4L^3}{N_F\epsilon bt^3}\times\frac{W_b}{2}$; δ_G=$\frac{6L^3}{N_G\epsilon bt^3}\times\frac{W_b}{2}$

C=δ_G-δ_F=19.06-13.86=5.2mm

Load on clip bolts (W_b) required to close the gap is determined by fact that gap is equal to initial deflection.

$W_b = \frac{2N_f\times N_g\times W}{n(2N_g+3N_f)} = \frac{2\times2\times8\times14087.5}{10\times22}$ = 2049.09N/mm^2

Similarly the bending stress and deflection in stress is calculated for the other two composites and tabulated in Table no. 2, which are compared with the analytical results which are generated through software.

Table No. 2. Bending Stress and Deflection in Stress Values for the Materials

Parameters/ Material	Mild Steel	Kevlar	S2 Glass
Bending Stress (N/mm^2)	149	283.4146	283.4146
Deflection (mm)	10.169	74.42	95.923

3.1.1.2. Length of Leaf Springs

$2L_1$= overall length of spring

Ineffective length l = width of band/distance between centers of u-tubes

n_F = no. of full length leaves

n_G =no. of graduated leaves

Effective lengths 2L = $2L_1 - \frac{2l}{3}$ (when u bolts are used)

L_1=1372mm

l = 300 mm

2L=1372$-\frac{2\times300}{3}$=1172mm

It may be noted that when there is only one full length leaf (master leaf only) then the number of leaves to be cut will be n and when there are two full length leaves (including one master leaf) then the number of leaves to be cut will be (n-1) if a leaf spring has two full length leaves then the length of leaves is obtained as follows,

Length of smallest leaf

= $\frac{effective\ length}{n-1}$ + ineffective length

n= 10

= $\frac{1172}{9} + 300$ =430.22mm

Length of next leaf

=$\frac{effective\ length\ \times 2}{n-1}$ + Ineffective length

=$\frac{1172}{9}\times 2 + 300$ =560.44mm

Length of 3rd leaf = $\frac{1172}{9}\times 3 + 300$ =690.66mm

Similarly the length of remaining leafs for mild steel and other composite materials are calculated and tabulated in Table no 3.

The nth leaf will be the master leaf and it is of full length since the master leaf has eyes on both sides therefore

Length of master leaf = $2L_1$+π (d + t) × 2

d = Inside diameter of eye

t = thickness of master leaf

d =22mm

t = 1372+π (22+22) × 2 = 1648.46mm

Table No. 3. Lengths of leaf springs for the materials (All dimensions are in mm)

S. No	Mild Steel	Kevlar	S2 Glass
1	1648.46	1648.46	1648.46
2	1471.98	1471.98	1471.98
3	1341.76	1341.76	1341.76
4	1211.54	1211.54	1211.54
5	1081.32	1081.32	1081.32
6	951.1	951.1	951.1
7	820.88	820.88	820.88
8	690.66	690.66	690.66
9	560.44	560.44	560.44
10	430.22	430.22	430.22

3.1.1.3. Radius of curvature

The approximate relation between the radius of curvature (R) and camber (Y) of spring is given by

$$R = \frac{L_1^2}{2y}$$

L_1=half span of spring

Y = δ (the maximum deflection of spring is equal to camber(y) of spring)

L_1= $\frac{1372}{2}$ = 686mm; δ=10.169mm

$$R=\frac{686^2}{2\times10.169} = 23138.75\text{mm}$$

Similarly the radius of remaining leaf springs for mild steel and other composite materials are calculated and tabulated in Table no 4.

Table No. 4. Radius of leaf springs for the materials (All dimensions are in mm)

S. No	Mild Steel	Kevlar	S2 Glass
1	23336.75	3342.91	2644.91
2	23314.75	3326.91	2628.91
3	23292.75	3310.91	2612.91
4	23270.75	3294.91	2596.91
5	23248.75	3278.91	2580.91
6	23226.75	3262.91	2564.91
7	23204.75	3246.91	2548.91
8	23182.75	3230.91	2532.91
9	23160.75	3214.91	2516.91
10	23138.75	3198.91	2500.91

3.2 Finite Element Analysis

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. A company is able to verify a proposed design will be able to perform to the client's specifications prior to manufacturing or construction. There are generally two types of analysis that are used in industry: 2-D modeling, and 3-D modeling. While 2-D modeling conserves simplicity and allows the analysis to be run on a relatively normal computer, it tends to yield less accurate results. 3-D modeling, however, produces more accurate results while sacrificing the ability to run on all but the fastest computers effectively.

FEA uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which will receive large amounts of stress usually have a higher node density than those which experience little or no stress. Points of interest may consist of: fracture point of previously tested material, fillets, corners, complex detail, and high stress areas. To conduct the Structural and Frequency Analysis the Boundary Conditions and Material properties used are tabulated in above Table no1.

Using the mathematical values obtained after Calculation for Length, Span, Camber, Radius of Curvature, Thickness, those are used to create the model of Leaf Spring in Pro/Engineer Tools and Imported to Ansys to carry out the Analysis. Imported model of Leaf Spring from PRO/Engineer to conduct the Analysis for the Material Mild Steel is shown in Figure no. 4. Meshed Model of Leaf Spring is shown in Figure no. 5.

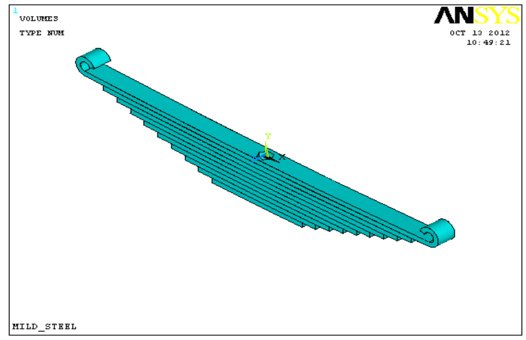

Figure No.4. Imported Model of Leaf Spring

The impact of boundary conditions on the leaf spring, the effect of boundary condition is shown in Figure no.6. For performing the structural and frequency analysis the boundary conditions and element types are required. Table no. 1 gives the material properties of the materials used.

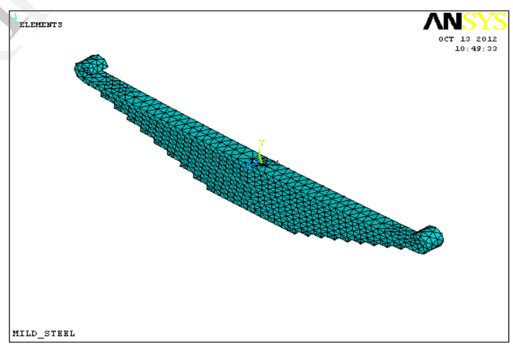

Figure No.5. Meshed Model of Leaf Spring

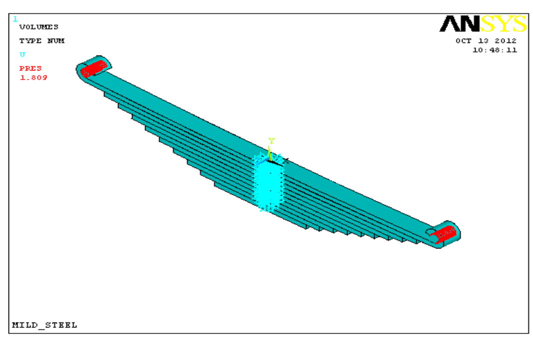

Figure No.6. Effect of Boundary conditions on Leaf Spring

4. Experimental Results and Discussion

The aim of the work is to compare the load carrying capacity, strength and weight savings of composites leaf spring with that of mild steel leaf spring. The design constraints are stresses and deflections. For validating the design FEA Structural and Modal Analysis are conducted on the leaf spring for the materials Mild Steel, Kevlar and S2 Glass, and plotted Displacement Vector Sum, Von Mistress Stress shown in Figure No.7 and Figure No.8. And three modes shape for corresponding materials, Mild Steel shown in Figure No. 9, Kevlar shown in Figure No. 10 and S2-Glass shown in Figure No. 11. The weight of the leaf spring when steel used is 141.225Kg, when Kevlar and S2 glass are used the weight is 18.79Kg and 32.25Kg respectively tabulated in Table no. 5. So the leaf spring is more lighter when composites are used thereby increasing its efficiency. Results of STRUCTURAL ANALYSIS performed for the materials are tabulated in the Table no. 6; the analyzed stress values for every material are less than their respective allowable stress value. Since using all these materials for leaf spring is safe under the load conditions. Results of MODAL ANALYSIS performed for the materials are tabulated in the Table no. 7; hence the obtained frequencies and deflections of leaf spring for every material are less compared to the values obtained through mathematical approach.

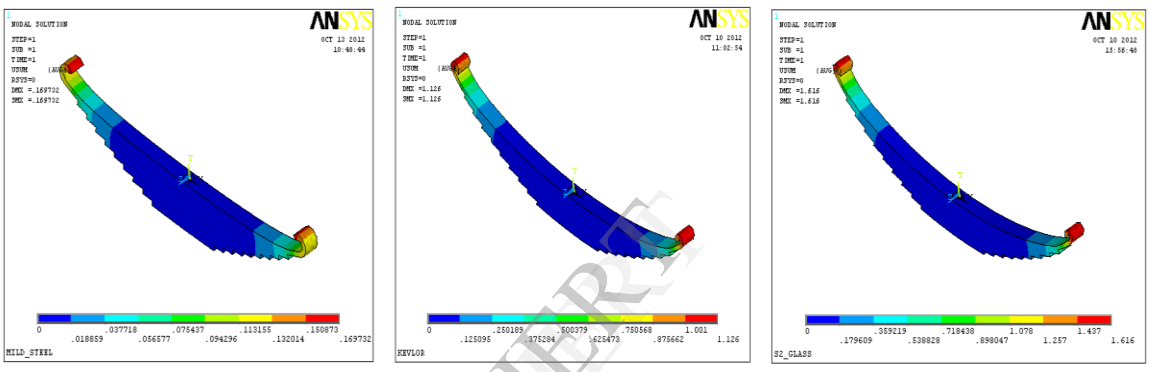

Figure No.7. Displacement Vector Sum of Leaf Spring of Mild Steel-Kevlar-S2Glass

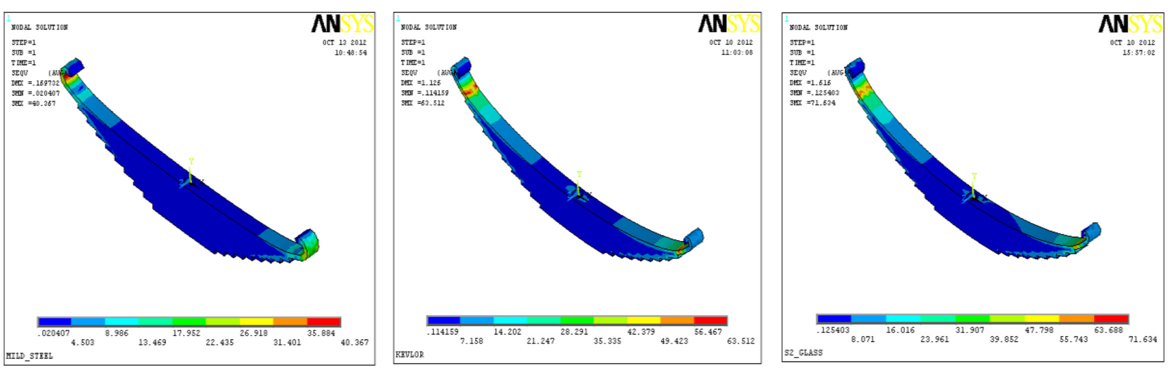

Figure No.8. Von Mistress Stress of Leaf Spring of Mild Steel-Kevlar-S2Glass

Table No. 5. Materials Weights after Analysis

Material	Weight (Kg)
MILD STEEL	141.225
KEVLAR	18.7959
S2 GLASS	32.25

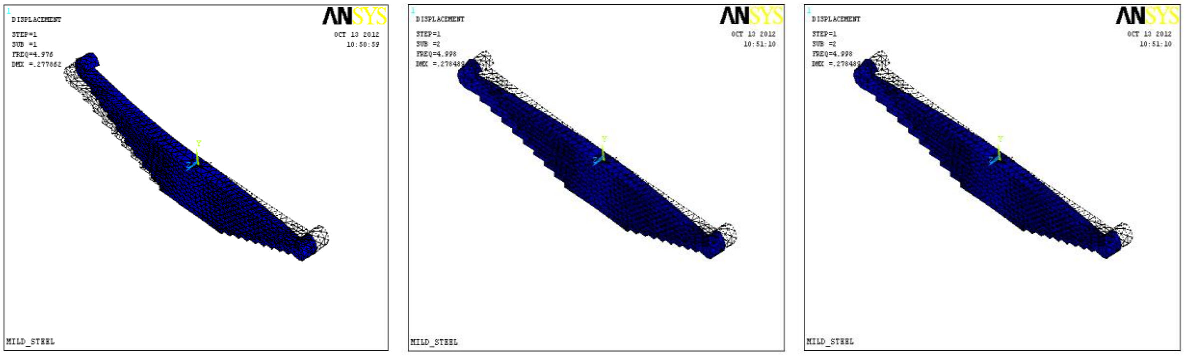

Figure No.9. Different Mode Shapes Plotted for Mild Steel material- MODE1, MODE2 and MODE3.

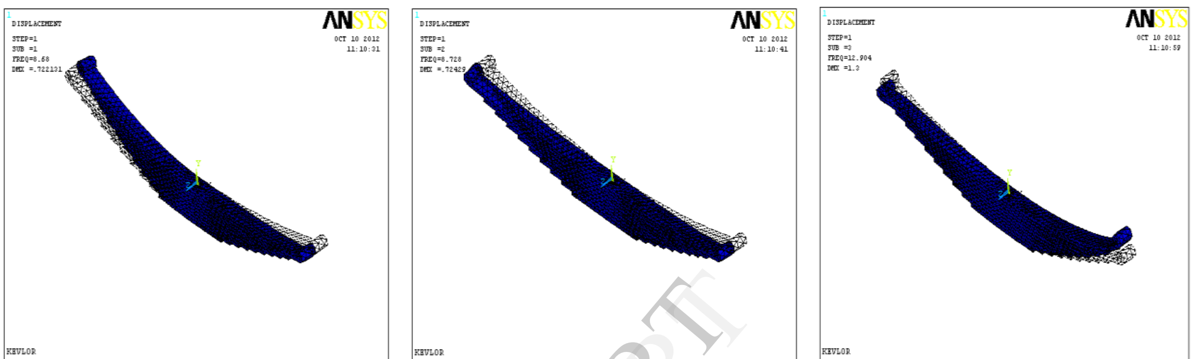

Figure No.10. Different Mode Shapes Plotted for Kevlar material- MODE1, MODE2 and MODE3

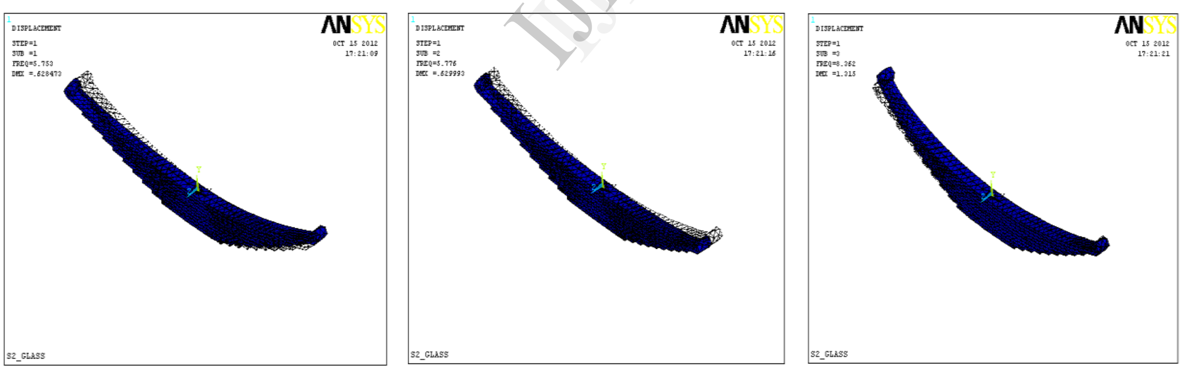

Figure No.11. Different Mode Shapes Plotted for S2 Glass material- MODE1, MODE2 and MODE3

Table No. 6. Results of Structural Analysis for the materials

	MILD STEEL	KEVLAR	S2 GLASS
Displacement (Mm)	0.169732	1.126	1.616
Stress (N/Mm^2)	40.367	63.512	71.634
Allowable Stress (N/Mm^2)	1600	3000	4890

Table No. 7. Results of modal analysis for the materials

		MILD STEEL	KEVLAR	S2 GLASS
MODE 1	Hz	4.976	8.68	5.753
	Deflection (mm)	0.27862	0.722131	0.628473
MODE 2	Hz	4.998	8.728	5.776
	Deflection (mm)	0.2764	0.72429	0.629993
MODE 3	Hz	9.436	12.904	8.362
	Deflection (mm)	0.5868	1.3	1.315

5. Conclusion

In the present work, a leaf spring is designed for Ashok Leyland Viking heavy vehicle for the load of 14087.5N. The data is collected from Internet for the specifications of the model. The calculations are performed for different materials of leaf spring by mathematical approach. Structural and modal analysis is made for mild steel, Kevlar, S2 glass Epoxy.
The results show:

1. The stresses in the composite leaf spring of the design are much lower than that of the allowable stress.
2. The strength to weight ratio is higher for composite leaf spring than conventional steel spring with similar design.
3. Weight of the composite spring by Kevlar composite material are 8times less than steel, by using material S2 Glass epoxy 5 times less than steel. For less weight of the spring we can increase mechanical efficiency.

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