Design and Analysis of Parabolic Leaf Spring for Composite Materials

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Abstract - *The objective of this study is to perform experimental and numerical analysis of the static strength and fatigue life reliability of parabolic leaf springs in heavy commercial trucks. To achieve this objective, stress and displacements under static loading were analytically calculated. A computer-aided design model of a parabolic leaf spring was created. The stress and displacements were calculated by the finite element method. The spring was modeled and analysed using CATIA Part Design and ANSYS Workbench. The stress and displacement distributions on a three-layer parabolic leaf spring were obtained. The high-strength Steel EN 45 spring steel was used as sample parabolic leaf springs material, and heat treatments and shoot peening were applied to increase the material strength. Sample parabolic leaf springs were tested to obtain stress and displacement under static loading conditions. By comparing three methods, namely, the static analytical method, static finite elements method and static experimental method, it is observed that results of three methods are close to each other and all three methods are reliable for the design stage of the leaf spring. Similarly, sample parabolic leaf springs were tested to evaluate the fatigue life under working conditions. The reliability analysis of the obtained fatigue life test value was carried out. It was shown that both analytical model and finite element analysis are reliable methods for the evaluation of static strength and fatigue life behavior in parabolic leaf springs. In addition, it is determined by a reliability analysis based on rig test results of nine springs that the spring achieves its life cycle of 100,000 cycles with a 99% probability rate without breaking. Furthermore, the calculated fatigue life is 2.98% greater than experimentally obtained fatigue life mean and the leaf spring can be used safely and reliably during the service period in heavy trucks.*

***Key Words*: Parabolic leaf spring, Steel EN45, Catia, Ansys, E-Glass/Epoxy, Epoxy Carbon, kevlar/epoxy**

1. INTRODUCTION

Basically, a parabolic spring is a spring that consists of two or more leaves. The leaves touch only in the center where they are fixed to the axle and at the outer ends, they are fixed to the vehicle. In between those two points, the leaves do not touch each other as they do with conventional leaf springs. To increase the riding comfort, leaf springs are used widely. This paper mainly deals about the parabolic leaf spring. Comparing normal leaf spring, the number of leaves is less in parabolic leaf spring. This helps us in reducing the material which leads to less in cost. Also, the main advantage of using parabolic leaf spring is its load carrying capacity and energy absorption. This helps us in getting good suspension and good riding comfort

Leaf Spring is that part of the underbelly of the vehicle which is a slightly curved rod like contraption that is designed to keep the vehicle from wobbling. The leaf (or conventional) spring has one metal strip mounted on another and designed to absorb the shocks that a vehicle may be subjected to. The parabolic spring on the other hand, is carefully designed to do a similar function. A parabolic spring is lighter and thus helps in over all weight reduction of vehicle resulting in lower fuel consumption. This research work is based on a complete study and analysis of parabolic leaf spring and conventional leaf spring. Finite element model been deployed to optimize and different materials are used to analyze the behavior of parabolic and conventional leaf spring under different load conditions.

Fig 1.1 A 3D parabolic leaf spring

1.1 literature Review

J.P. Hou [1] work on Evolution of the eye- end design of a composite leaf spring for heavy axle loads and they concluded that Three eye-end designs of a double GRP leaf suspension have been evaluated by finite element analysis and static and fatigue testing. The first two designs consisted of integral eye ends where the skin tape layers went around the eye and along the leaf body. These layers were then maintained in place via a transverse wrap using woven GRP tape. The third design consisted of open eye ends. FEA and static test results show that the stress concentration at the tip of the fibres coming back along the leaf body for the first two designs led to a local delamination. However, this did not have any effect on the static proof loading of the suspension nor on its fatigue life.

Shubham Singh [2] they published paper titled as Parametric Analysis of Parabolic Leaf Spring for En45 /GFRP/Epoxy and they concluded that parabolic leaf spring made of epoxy materials shows less deformation which indicates large load bearing capability and Parabolic leaf spring shows same order of stress generated in all the materials considered epoxy,EN45 and GFRP.

A P Singh. [3] they researched on Numerical Investigation Of Parabolic Leaf Spring For Composite Materials Using Ansys and they concluded that the composite parabolic leaf spring is lighter and more economical than the conventional steel EN45 spring with similar design specifications.

Sachin Patil [4] they worked on Modelling and Analysis of Two Stage Parabolic Leaf Spring under the Static Load Condition by using FEA and they concluded that the objective was CAD Modelling and analysis of leaf for light commercial vehicle. The results obtained from this analysis are showing that the designed components are safe and well within limiting values.

D.N.Dubey [5] they have published paper on Stress Analysis of a Mono-parabolic Leaf Spring–A Review and they concluded that almost 65-70% of weight reduction could be achieved by using the carbon composites. At various loading conditions the composites under study show deflection as compared to conventional steel. The study has demonstrated that composite leaf springs would offer substantial weight savings.

1.2 Need of Parabolic leaf spring

The automobile industry has shown increased interest in the replacement of steel leaf spring with fibre glass reinforced polymers.

- To match Reduce the weight of the steel leaf spring by introducing composite material.
- With increase in the fatigue life of the spring.
- Increase the Stiffness of the leaf spring.
- A four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software.
- The finite element results showing stresses and deflections verified the existing analytical and experimental solutions.
- Using the results, a composite one made from fiberglass with epoxy resin is designed and optimized using ANSYS.
- Main consideration is given to the optimization of the spring geometry. The objective was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure.
- Parabolic leaf springs have replaced conventional leaf springs because they are lighter, cheaper, have better fatigue life and provide greater noise isolation.

2. Setup of Parabolic leaf spring

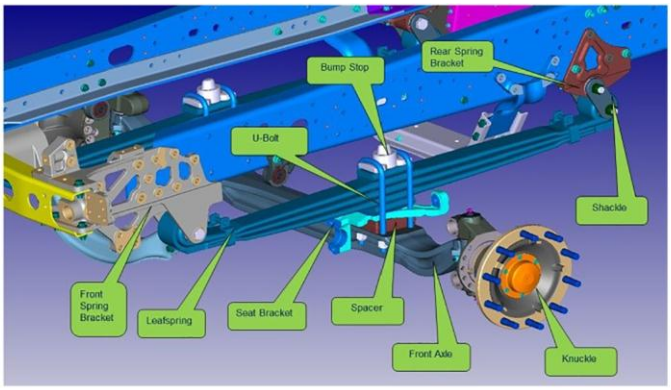


Fig 2.1 Setup of Parabolic leaf spring

The design of a three-layer parabolic leaf spring of a heavy commercial vehicle must include an investigation of its fatigue behavior, Assembly of the spring on the suspension system in a virtual environment is shown in figure.

2.1 Materials Properties of parabolic leaf spring:

1. STEEL

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 has greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

Properties	Value
Density(ρ) Kg/m3)	7860
Young's modulus, Mpa	2.1e5
Poisons ratio	0.266
Tensile strength (Mpa)	500
Tensile ultimate strength (Mpa)	800

2. E-Glass/Epoxy

The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties.

Properties	Value
Tensile Modulus(Mpa)	40000

Tensile strength , Mpa	900
Compressive Strength	450
Poisson Ratio	0.217
Mass Desnsity	2600

3. Epoxy Carbon

The advantages of Epoxy carbon include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength.

Properties	Value
Tensile modulus , Mpa	40000
Tensile strength of the material, Mpa	900
Compressive strength, Mpa	450
Poisson ratio	0.217
Mass density of the material (ρ),Kg/m3	2600

4. Kevlar/epoxy

In the case of Kevlar 49/epoxy composites, it has been found experimentally that compressive strengths are of the order of 275 MN/m 2, or only some 20% of the tensile strength of these unidirectional fibre composite.

Properties	Value
Shear modulus , Mpa	1860
Tensile strength of the material, Mpa	1240
Compressive strength,Mpa	275
Poisson ratio	0.34
Mass density of the material (ρ),Kg/m3	1402

Table 2..1 Design data of parabolic leaf spring

Length of the main leaf (L)	850mm
Length of the second leaf(L)	850.25 mm
Length of the third leaf(L)	757.89 mm
Length of the fourth leaf(L)	623.42 mm
Length of the fifth leaf(L)	508.52 mm
Length of the six leaf(L)	373.58 mm
Length of the seven leaf(L)	238.88 mm
Width of leaf (b)	7599 mm
Camber height (C)	74.828 mm
Tip inserts	25 mm dia
Thickness of leaves (t)	10.92 mm

3. DESIGN OF PARABOLIC LEAF SPRING

The design of the leaf spring is done in CATIA V5 R20 and ANSYS software. All the leaves, clamps and bolt are designed separately in the part drawing and are assembled in the assembly drawing section in CATIA. The leaves are assembled by giving surface contact between the bottom surfaces of one leaf to the top surface of the other leaf. In this way all the 10 leaves are assembled in the CATIA, after that the clamps and bolts are assembled in the parabolic leaf spring. Computer-aided design (CAD) modelling of a parabolic leaf spring was performed using CATIA V5 R20 in Part Design Workbench. It is essential to use the developed CAD model as a physical specimen prior to the production of a prototype.

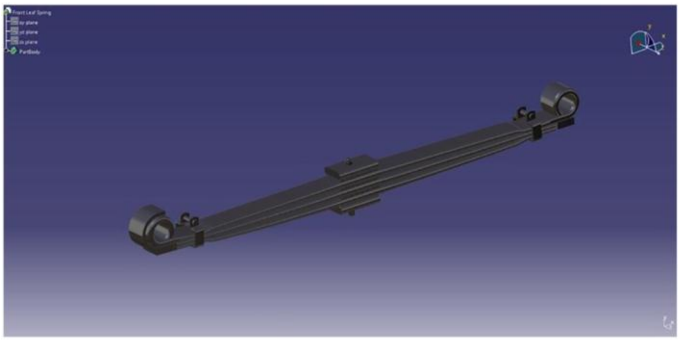


Fig 3.1 CAD model of parabolic Leaf spring

3.1 ANALYSIS PROCEDURE OF PARABOLIC LEAF SPRING

1. Geometry:

First generate the geometric model of the leaf spring from CATIA into Ansys software.

2. Define Materials:

Define a library of materials for Analysis. In this Analysis of leaf spring, selected materials are steel, Epoxy glass, Epoxy carbon, Kevlar epoxy these materials can be selected from the engineering data available in Ansys software.

3. Generate Mesh:

Now generate the mesh. This divides the drawing into finite number of pieces. It will show the number of nodes and elements present in the drawing after meshing is completed. Meshing is the process spatially discretize into elements and nodes. This mesh along with material stiffness and mass distribution of on a number of factors including the proximity of other topologies, body .If necessary, the fineness of the mesh (eight times for assembly) to achieve a successful mesh.

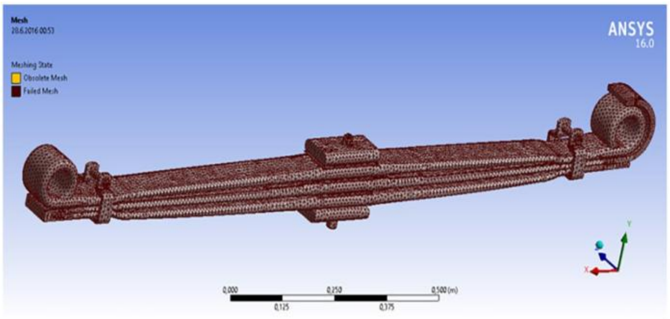


Fig 3.2 Mesh model of the parabolic leaf spring

4. Apply Boundary conditions

Simply supported boundary conditions are considered for the leaf spring. In this case both the ends of the leaf spring are given fixed support and the load on the leaf spring is applied at the bottom leaf in upwards direction. The parabolic leaf spring is placed on the axle of the vehicle; the frame of the vehicle is attached to the ends (by eyes) of the leaf spring. The ends of the parabolic leaf spring are produced in the form of an eye. The front eye of the parabolic leaf spring is attached straightly with a pin to the frame so that the eye can revolve without restraint about the pin but no translation is takes place. The backside eye of the spring is assembled with to the shackle which is a flexible link the next end of the shackle is linked to the frame of the vehicle. One eye of the leaf spring is reserved fixed. This leaf spring is being provided a cylindrical support. Whereas the other eye is given certain degree of rotation. This is done to allow the leaf spring to deflect by some amount along its length to meet the actual conditions for both the parabolic leaf spring (steel EN45 and composite) which is shown in Fig.5.1 .After load is applied of magnitude 4000 N in the upward direction at the centre of the parabolic leaf spring. This specific computation of load to be applied has been completed on the basis of Gross Vehicle Weight (GVW). This has been clearly shown the Fig.

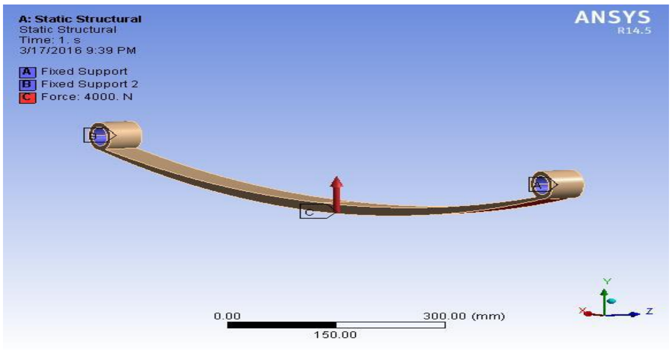


Fig 3.3 loading and boundary condition of parabolic leaf spring

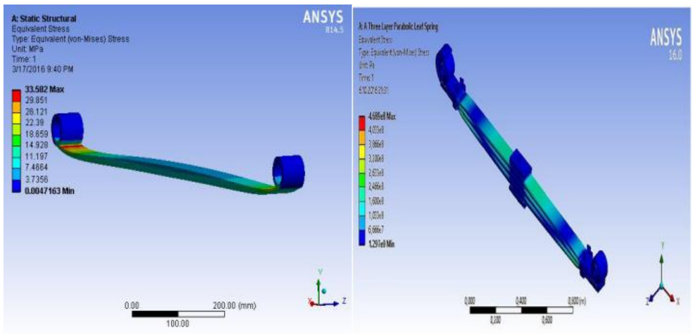
5. Obtain solution and generate results:

Now obtain the solution for the stress, deformation and elastic strain and generate the results.

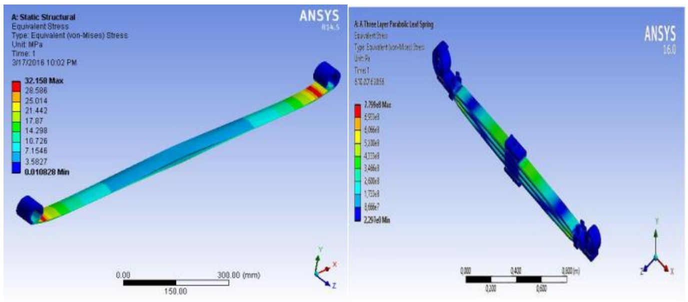
5. RESULT AND DISCUSSION

1] Equivalent Von-mises stress-

Using the ANSYS 16 Workbench software, the values of equivalent (Von-Misses) stress found along with the given boundary conditions and applied load from 2400 to 4750. The results of this static structural analysis shows that the equivalent (Von-Misses) stress of the laminated carbon/epoxy composite material leaf spring is the smallest one as compared to that of the E-glass/epoxy leaf spring under the same load and boundary conditions where as compared to steel it is little bit higher. This implies that laminated carbon/epoxy composite material leaf spring is less stressed, light weight and has a better performance.



Steel EN 45 Parabolic leaf spring E-glass/epoxy parabolic leaf spring

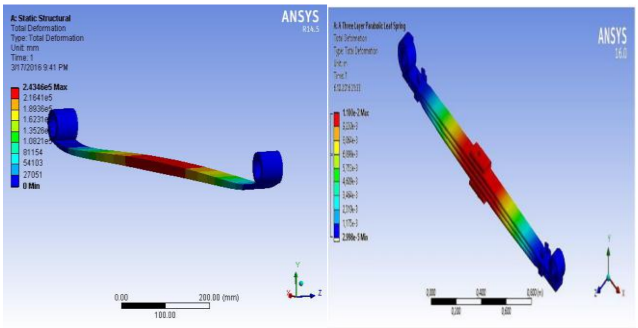


carbon/epoxy parabolic leaf spring kevlar/epoxy parabolic leaf spring

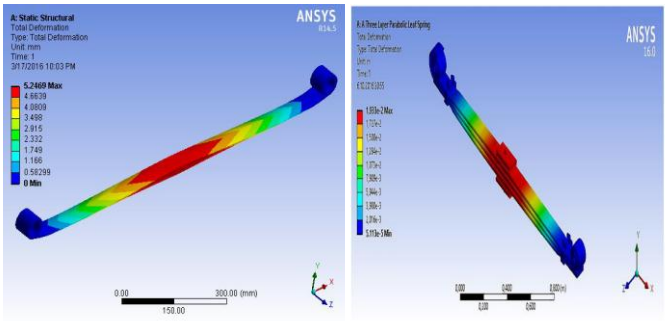
Fig 5.1 Estimated Von mises stresses for various material

2] Total deformation

From this static structural analysis ANSYS 16 workbench software, we show that, the maximum displacements of the laminated carbon/epoxy composite material leaf spring has the lowest deformation value compare with that of the current conventional steel leaf spring. When external loads applied to an elastic body, the body may deform or elongate according to the nature of the applied load. Then stress is defined as the average load per unit area that some particle of a body exerts on an adjacent particle, across an imaginary surface that separates them.



Steel EN 45 Parabolic leaf spring E-glass/epoxy parabolic leaf spring



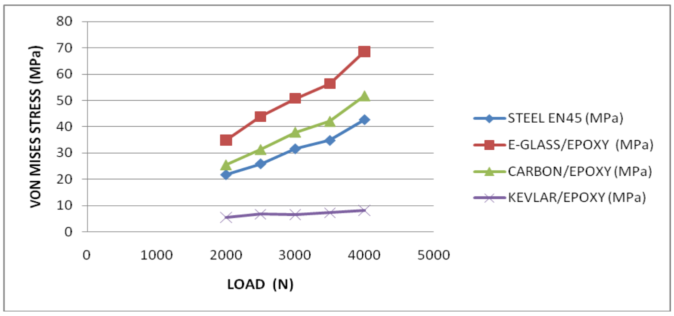
Carbon/epoxy parabolic leaf spring kevlar/epoxy parabolic leaf spring.

Fig 5.2 Estimated result of deformation for various material

5.2 STATIC ANALYSIS RESULTS

Table 5.1 Load Vs Von Mises Stress

		VON MISES STRESS			
Sr. No	LOAD	STEEL EN45 (MPa)	E-GLASS/EPOXY (MPa)	CARBON /EPOXY (MPa)	KEVLAR/ EPOXY (MPa)
1	2400	21.73	34.86	25.518	5.324
2	2900	25.85	43.816	31.316	6.56
3	3516.4	31.512	50.726	37.916	6.45
4	3900	34.690	56.35	42.01	7.12
5	4750	42.550	68.512	51.69	8.07

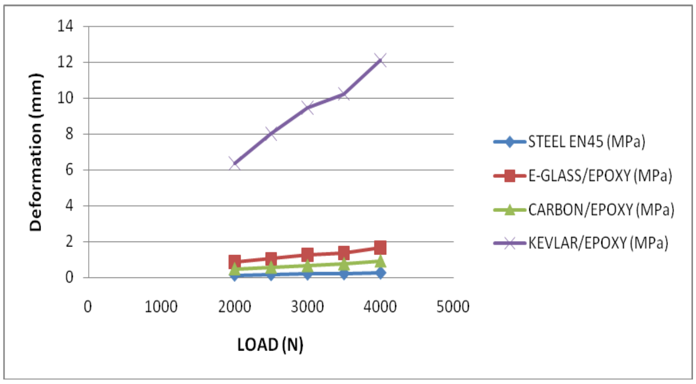


Graph 5.1 Load vs Von-mises Stresses graph for various materials

In analysis process we can see that von-mises stress is at maximum towards the fixed end of the parabolic leaf spring, and the value is less than yield point value of steel EN45 and composites. So the design of parabolic leaf spring is safe. Figure no- shows the comparison of load verses stress of both steel and composite leaf springs. It shows the load is taken on the x-axis. Whereas the stress for steel and composite material is taken on y-axis. Observation of the graph indicates the difference level of stress of four different materials. The variation of stress against the load applied for the material under consideration. It is observed that the stresses linearly increase with the applied load maximum

Table 5.2 Load Vs Deformation

DEFORMATION					
Sr. No	LOAD	STEEL EN45 (MPa)	E-GLASS/EPOXY (MPa)	CARBON /EPOXY (MPa)	KEVLAR/EPOXY (MPa)
1	2400	0.127	0.83	0.471	6.35
2	2900	0.153	1.01	0.565	8.001
3	3516.4	0.185	1.22	0.656	9.468
4	3900	0.20	1.35	0.767	10.22
5	4750	0.24	1.64	0.928	12.112



Graph 5.2 Load vs Displacement graph for various materials

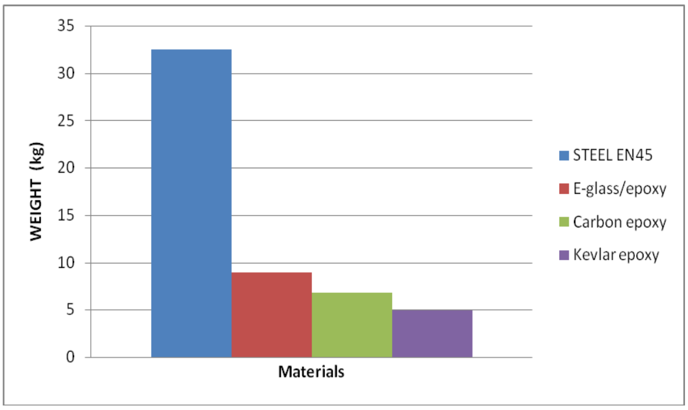
The rate of deformation is a function of the material properties, and the applied load depending on the magnitude of the applied stress and its duration. Figure-6.2 shows the comparison of applied load verses deformation of both conventional steel and composite leaf springs. It is found that the deformation in composite leaf springs is higher than steel leaf spring for the given loading conditions.

5.3 Comparison of weights

The bar chart have made below, which shows the comparisons in parabolic leaf spring weight in Kg by considering steel and composite material. Blue bar is the weight of steel EN45 leaf spring. From the comparison of bar chart, it is clearly observed that by using the different composite material, weight is reduced in parabolic leaf spring. For steel EN45 leaf spring, weight is 32.52kg and for composite leaf spring it is E-glass/epoxy weight is 8.90 kg, carbon epoxy weight is 6.75 kg, and Kevlar epoxy weight is 4.90kg. Table shows that using composites material instead off steel EN45 weight is saving.

Table 5.3 Percentage of weight savings for various materials

Sr. No	Material	Weight	% Weight Saving
1	Steel EN45	32.52	
2	E-glass/epoxy	8.90	72.63 %
3	Carbon epoxy	6.75	79.24%
4	Kevlar epoxy	4.90	84.93%



Graph 5.3 Percentage of weight saving graph for various materials

6. CONCLUSION

A comparative study has been made between composites and steel EN45 parabolic leaf spring for deflection and stresses. From the results, of static analysis we observed that the composite parabolic leaf spring is lighter and more economical than the conventional steel EN45 spring with similar design specifications. We observed that the weight of the composite parabolic leaf spring made of Kevlar/epoxy fibre, is reduced by 84.93% compared to spring made of steel EN45, by using material E-glass/epoxy fibre it is reduced by 72.63% compared to spring made of steelEN45.by using material carbon/epoxy fibre it is reduced by 79.24% compared to spring made of steelEN45. Without any reduction on load carrying capacity and stiffness the weight of the parabolic spring was being reduced because of introduction of composite material.

FUTURE SCOPE

For future work, we anticipate that the further reduction in weight is possible by means of applying the modern shape optimization techniques to achieve an effective shape of the leaf spring. Based on these investigations will be further performed and in future the shape optimization can lead us to a proper shape of the composite leaf spring.

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