Design and Analysis of Leaf Spring by using Composite Material

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Abstract - *Composite materials are extensively used in many engineering applications due to high strength and stiffness to weight ratio. The objective is to compare the stresses, deformations 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) 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 Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, the composite materials has high strength to weight ratio, good corrosion resistance. In this paper, the design and analysis a composite leaf spring and compared with a standard steel leaf spring. The materials selected are Epoxy glass, Epoxy carbon, Aluminum Alloy, Titanium Alloy is used against conventional steel leaf spring. The design parameters are selected and analyzed with the objective of comparing Stress, Deformation, Elastic Strain and Weight of the composite leaf spring as compared to conventional steel leaf spring. The leaf spring was modeled in CATIA and the analysis was done in ANSYS software.*

Key words **- Steel Leaf Spring, Composite, Epoxy, Automobile, Composite Leaf Spring.**

1. INTRODUCTION

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. The advantage of leaf spring over helical spring is that the end of the springs may be guided along a definite path. Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason manufacturers have experimented with mono-leaf springs.

Figure – 1.1: A traditional leaf spring arrangement.

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 springness.There were a variety of leaf springs, usually employing the word "elliptical". "Elliptical" or "full elliptical" leaf springs referred to two circular arcs linked at their tips. This was joined to the frame at the top center of the upper arc; the bottom center was joined to the "live" suspension components, such as a solid front axle. Additional suspension components, such as trailing arms, would be needed for this design, but not for "semi-elliptical" leaf springs as used in the Hotchkiss drive. That employed the lower arc, hence its name. "Quarter-elliptic" springs often had the thickest part of the stack of leaves stuck into the rear end of the side pieces of a short ladder frame, with the free end attached to the differential, as in the Austin Seven of the 1920s. As an example of non-elliptic leaf springs, the Ford Model T had multiple leaf springs over its differential that was curved in the shape of a yoke. As a substitute for dampers (shock absorbers), some manufacturers laid non-metallic sheets in between the metal leaves, such as wood.

2. LITERATURE REVIEW

M. M. Patunkar, et al. Vinkel Arora, et al.[1] in their work has done design and analysis of conventional mono leaf spring standard eye end and casted eye end. CAD modeling was done in CATIA and analysis was done in ANSYS under similar loading conditions for parameters like deformation, von-mises stress, normal stress etc. They have concluded that for similar static load application, when standard eye is replaced with casted eye deflection was increased by 5.4%. von-mises stress was reduced by 3%. Normal stress was increased by 19.08% and minimum factor of safety reduced by 13.1%. Further they have concluded that CAE tools are economic and less time consuming with result variation in a specified range as compared to experimental testing.

Kumar Krishan, et al.[2] in their work has done design and finite element analysis of conventional SUP9 steel multi leaf spring including two full length leaves in which one is with eyed ends and seven graduated length leaves. Finite element modeling was carried out in CATIA V5 R17and was imported in ANSYS11 for finite element analysis. Bending stress and deflection observed from the finite element analysis was compared with the experimental results under full and half load application. They have observed 0.632% variation in deflection and 10.11% variation in bending stress under full load application and 0.632% variation in deflection and 17.95% variation in bending stress under half load application which is negligible. They have concluded that CAE tools give batter results with negligible variation and the design was safe from failure under given load conditions.

Mahmood M. shokrieh and Davood Rezaei[3] presented work on design, analysis and optimization of leaf spring .The aim of this review paper was steel leaf spring was replaced with an optimized composite one. Main objective of this paper was to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. Here the work is carried out of a four-leaf steel spring which used in the rear suspension system of light vehicles & heavy duty vehicles. The four-leaf steel spring is analyzed by using ANSYS V5.4 software. The finite element results showing stresses and deflections verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, 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. In this study stress and displacements were used as design constraint. The experimental results are verified with the analytical data and the finite element solutions for the same dimensions. Result shows that stresses in the composite leaf spring are much lower than that of the steel leaf spring. Compared to the steel leaf spring the optimized composite leaf spring without eye units weights nearly 80% less than the steel spring. The natural frequency of composite leaf spring is higher than that of the steel leaf spring and is far enough from the road frequency to avoid the resonance.

E. Mahdi a, O.M.S. Alkoles[4] etc presented work on light composite elliptic springs for vehicle suspension. They worked on based study marries between an elliptical configuration and the woven roving composites. In this paper, the influence of ellipticity ratio on performance of woven roving wrapped composite elliptical springs has been investigated both experimentally and numerically. A series of experiments was conducted for composite elliptical springs with ellipticity ratios (a/b) ranging from one to two. Here they were also presented history of their failure mechanism. Both spring rate and maximum failure increase with increasing wall thickness. In general, this present investigation demonstrated that composites elliptical spring can be used for light and heavy trucks and meet the requirements, together with substantial weight saving. The results showed that the ellipticity ratio significantly influenced the spring rate and failure loads Composite elliptic spring with ellipticity ratios of a/b 2.0 displayed the highest spring rate.

Mr.Abdul Rahim Abu Talib, Aidy Ali, G. Goudah, Nur Azida Che Lah and A.F. Golestaneh[5] worked on developing a composite based elliptic spring for automotive applications. After that using this conclusion they have change steel leaf spring by composite material and analyze it with same loading condition. They concluded that composite elliptical springs have superior fatigue performance than steel. They consider light and heavy trucks with steel elliptic spring for analysis of fatigue performance and weight reduction by using ANSYS software. The objective is to compare the load carrying capacity, fatigue performance and weight savings of composite leaf spring with that of steel leaf spring. Also they have compared the finite element result of fatigue life and weight reduction with existing analytical and experimental result.

The conventional steel leaf spring and weight reduction ratio is achieved Dev dutt Dwivedi and V.K.Jain[6] had done Design and analysis of composite leaf spring. ANSYS14.5 has been used to conduct the analysis. Static structural tool has been used of ANSYS. A three layer composite leaf spring with full length leave. E-Glass/epoxy composite material has been used. Conventional steel leaf spring results have been compared with the results obtained for composite leaf spring. E glass/epoxy material is better in strength and lighter in weight as contrast with conventional steel leaf spring. A wide amount of study has been conducted in his paper to investigate the design and analysis of leaf spring and leaf spring fatigue life. Results demonstrate that composite leaf spring deflection for a particular load is less compared to conventional leaf spring. Stress generated in the E-Glass/Epoxy leaf spring is lower than steel leaf spring.

N.P. Doshi, et al.[7] has proposed design modification in existing leaf spring with dynamic load effect consideration by implementing analytical and finite element method. Stress and deflection analysis has been carried out by using ANSYS 11.0. They have concluded that on reducing number of leaf spring from 17 to 13 weights reduced by 6 kg and cost reduced b20%.

G. Goudha, et al.[8] has developed finite element models to optimize geometry and material of composite elliptical leaf spring by considering spring rate, shear stress and log life as working design constraints. Effect of ellipticity ratio on the performance of composite elliptical leaf spring was investigated both experimentally & numerically. They have concluded that the composite elliptical leaf spring can be used for both light & heavy commercial vehicles with significant weight saving. Composite elliptical leaf spring with ellipticity ratio of a/b=2 showed optimum results.

3. DESIGN OF LEAF SPRING

The design of the leaf spring is done in CATIA V5 R20. 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 surface 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 leaf spring.

3.1 Design specifications of leaf spring

1	total length of the spring(eye to eye)	1120 mm
2	free camber	180 mm
3	no of full length leaves	2
4	no of graduated leaves	8
5	thickness of the leaf	6 mm
6	width of the leaf	50 mm
7	young's modulus of the steel	210 gpa
8	poisson ratio	0.3

Table -3.1.1: Design specifications of leaf spring.

3.2 CATIA drawing of leaf spring

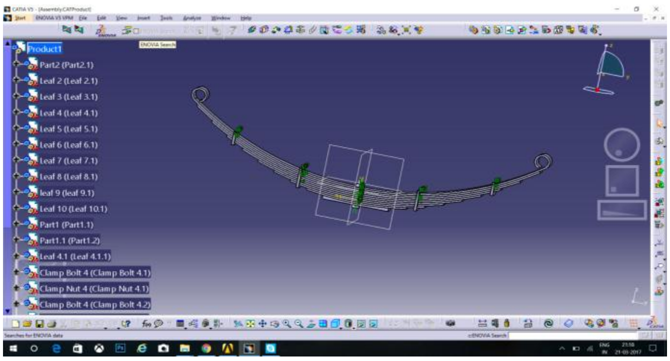

Figure –3.2.1: Assembled diagram of Leaf spring in CATIA

3.3: Materials Properties of leaf spring

In Analysis of Leaf spring, the authors are considered different materials to compare the conventional steel leaf spring. The selected materials are Epoxy glass, Epoxy carbon, Aluminum Alloy, and Titanium Alloy. The following are the material properties of selected materials are compared with the steel properties.

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.

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.

3) Epoxy Carbon:

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

4) Aluminum Alloy:

Aluminum is a very desirable metal because it is more malleable and elastic, corrosion resistant and less denser.

5) Titanium Alloy:

Titanium's material is a combination of high strength, stiffness, toughness, low density and good corrosion resistance provided by various titanium alloys. It is the most useful strongest metal available.

4: ANALYSIS PROCEDURE OF 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, Aluminum Alloy, Titanium Alloy. 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.

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.

5) Obtain solution and generate results:

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

4.1 Analysis of leaf spring

Now, let us check the results obtained in Ansys for stress, deformation, elastic strain and weight for the specified materials.

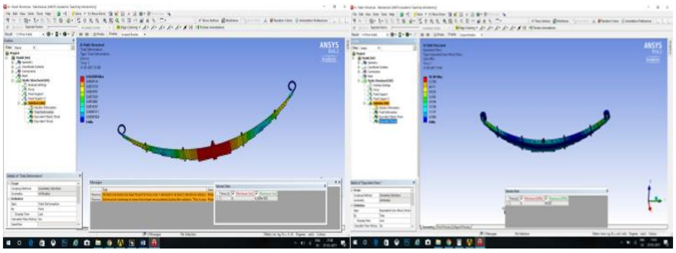

Figure – 4.1: Steel material

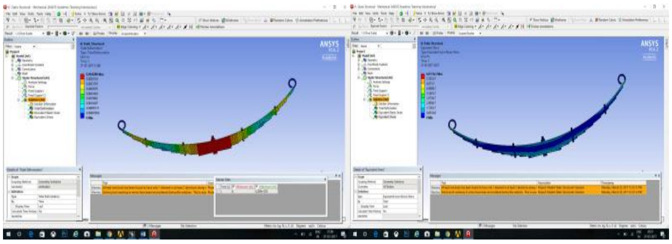

Figure -4.2: E-Glass/Epoxy

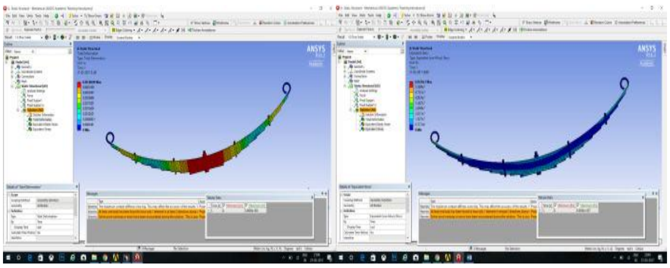

Figure – 4.3: Epoxy Carbon

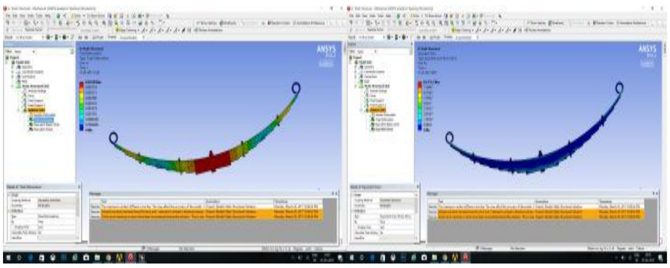

Figure – 4.4: Aluminum Alloy

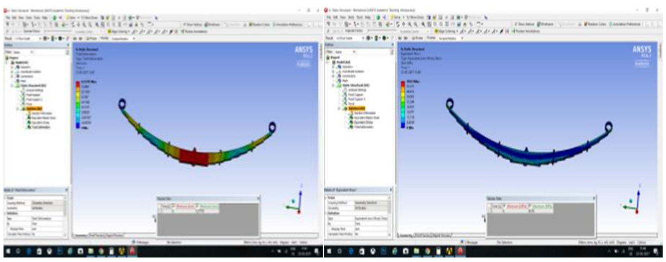

Figure - 10: Titanium Alloy

4.2 Comparison of theoretical and analysis result

Comparison of theoretical stress, deformation and weight with that of the results obtained from the Ansys software:

Table -4.2.1: Comparison of Stress

sr. no.	material	theoretical((n/mm2)	ansys (n/mm2)
1	steel	60	59.36
2	e-glass/epoxy	60	69.11
3	epoxy carbon	60	63.14
4	alluminium alloy	60	59.62
5	titanium alloy	60	59.91

Table-4.2.1 shows the comparison of stress in theoretical and computational for the steel and other composite materials, the theoretical stress is 60 N/mm^2, where as the stress values obtained using Ansys for different materials are nearly to 60 N/mm2.

Table –4.2.2: Comparison of Deformation at 3200N

Sr.no.	material	theoretical((mm)	anysys (mm)
1	steel	0.143	0.133
2	e-glass/epoxy	3.56	3.36
3	epoxy carbon	2.85	3.11
4	alluminium alloy	0.39	0.373
5	titanium alloy	0.297	0.275

Table-4.2.2 shows the comparison of the theoretical and Ansys results of deformation for various materials. The Ansys values are close to the theoretical values.

Table -4.2.3: Comparison of Weight

sr.no.	material	theoretical	anysys
1	steel	16.65	18.4
2	e-glass/epoxy	4.25	3.61
3	epoxy carbon	3.16	3.57
4	alluminium alloy	5.93	6.63
5	titanium alloy	9.85	13

Table 3 shows the comparison of the theoretical and Ansys results of weight of the leaf spring for different materials. The ANSYS values are close to that of the theoretical leaf spring weight.

5. CONCLUSIONS & FUTURE SCOPE

1. Static analysis of leaf spring for different material combination under similar loading condition has been done for all design cases.
2. Results for selected parameters are obtained for all design cases of leaf spring.
3. Total deformation, equivalent elastic strain, equivalent (Von-Mises) stress, strain energy and mass results have been analyzed for different

material combination in different design cases of leaf spring.
4. Results are studied for above five parameters. It has been concluded that design case D2 is optimum for total deformation, equivalent elastic strain, equivalent (Von-Mises) stress, strain energy and mass optimization.
5. CAE tool Creo 2.0 is used for 3d modeling of leaf spring. This method is more cost effective less time consuming then other methods of modeling.
6. Leaf spring assembly file in IGES file format is exported to ANSYS 14.0 for analysis.
7. ANSYS 14.0 is used for meshing and analysis of leaf spring. This method of analysis is more cost effective, efficient and less time consuming than other methods of solution.

5.1 Future Scope:

1. Spring can be modeled with different dimensions and static analysis could be done on different loading.
2. Dynamic analysis of leaf spring may be done and obtained results could be compared with software and experimental results.
3. Experimental analysis may be conducted and obtained results could be compared with software results.
4. Composite materials may be used for leaf spring for light weight and more efficiency.

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