FINITE ELEMENT ANALYSIS AND COMPARISON OF LEAF SPRING

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

MASTER IN TECHNOLOGY

(COMPUTATIONAL DESIGN)

TO

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CERTIFICATE

This is to certify that this thesis report entitled, "Finite Element :analysis and comparision of Leaf Spring" being submitted by Pr avin Kumar Roll No. 2k13/cdn/11 at Delhi Technological university. Delhi for the award of the Degree of Master of Technology as per academic curriculum. It is a record of bonafide research work carried out by student under my supervision and guidance. towards partial fulfillment of the requirement for the award of Master of Technology degree in Computational Design. The work is original as it has not been submitted earlier in part or full for any purpose before.

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ABSTRACT

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. This helps in achieving vehicle improved riding qualities. The springs are designed to absorb, store and release energy. Therefore, the strain energy of the material becomes a major factor in designing the springs. In every automobile, leaf spring is one of the main components that provides a good suspension and plays a vital role in supporting- lateral loads, shock loads. brake torque. and driving torque. Advantages of leaf' spring over helical spring are that the ends of the springs are guided along a definite path so as to act as a structural member in addition to shock absorbing device.

A Leaf spring is as an elastic body, whose function is to distort when loaded and to recover its original shape when the load is removed. Leaf spring absorbs the vehicle vibrations, shocks and bump loads (induced due to road irregularities) by means of spring deflections. This deflection generates potential energy in the leaf spring and which is then relieved slowly. Ability to stoic and absorb more amount of strain energy ensures a comfortable suspension system. Semi-elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. There are also other types of leaf springs like Parabolic, Bogie Suspensions. Bell crank Suspensions etc. Leaf spring consists of a number of leaves. The leaves are varying in length. The leaves are usually given an initial curvature or camber so that they will tend to straighten when loaded. The leaf spring design is based upon the theory of a beam of uniform strength.

TABLE OF CONTENTS

List of Tables

CHAPTER- 1

INTRODUCTION

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The longest leaf has eyes on its ends. This leaf is called main or master leaf, the remaining leaves are called graduated leaves. All the leaves 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 the leaf spring rear eye and the vehicle frame.

Leaf 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. 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. 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. 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, they also act as structural member. The multi-leaf spring is made of several steel plates of different lengths stacked together. The leaf springs bend and slide on each other allowing suspension movement.

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 centre 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.. The spring is clamped to the axle housing by means of U-bolts. The longes tleaf 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.

Parts of a leaf spring

Master leaf-They have the advantage of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point. 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.

Graduated leaves- 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. The leaves are usually given an initial curvature or cambered so that they will tend to straighten under the load.

Rebound Clip-It is used for binding master and graduated leaves together. 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 spring rebounds.

Center Bolt-It is used for fixing each leaf together on center hole. The leaves are held together by means of band shrunk around them at the centre 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.

Nipping in leaf spring

The master leaf of a laminated spring is hinged to the supports. The support forces induce, stresses due to longitudinal forces and stresses arising due to possible twist. Hence, the master leaf is more stressed compared to other the graduated leaves. Methods to reduce additional stresses could be

1 Master leaf is made of stronger material than the other leaves.

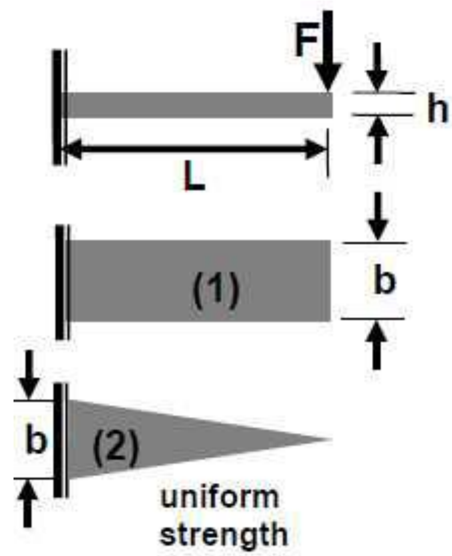
2 Master leaf is made thinner than the other leaves. This will reduce the bending stress as evident from stress equation.

3 Another common practice is to increase the radius of curvature of the master leaf than the next leaf.

The master leaf has a larger radius of curvature compared to the additional leaf that is placed below so obviously a gap will be created between the two leaves. Now an initial bent is created during assembly by tightening the central bolt. Therefore, some amount of compressive stress will be produced at the inside curvature of the master leaf. Similarly, at the outside curvature of the master leaf tensile stress will be produced. Both these stresses are initial stresses in the master leaf. However, by such operation of tightening the central bolt, the additional leaf that is placed beneath the master leaf has a tendency to flatten out and as a result the stress pattern of the additional leaf will be reverse of that of the master leaf, tensile stress is produced at the inner curvature and compressive stress is produced at the outer curvature. Hence when the spring is loaded, for both the master leaf and the additional leaf, tensile stress will be produced at the inner curvature and compressive stress will be produced at the outer curvature. Therefore, due to opposite nature of initial stress and loading stress, the master leaf will experience lesser stress on both the surfaces. However, due to same nature of initial stress and loading stress, the additional leaf is stressed more compared to the master leaf. But, it is to be noted that the higher stress on the additional leaf is actually shared between all other leaves than the master leaf. This practice of stress relief in the master leaf is known as nipping of leaf spring. As a matter of fact, all the leaves of a laminated leaf spring do have certain amount of nipping, so that there will be gaps between the leaves, as a result the stresses will be uniformly distributed and accumulated dusts can also be cleaned.

Stress and deflection analysis

In order to have an idea of working principle of a leaf spring, let us think of the diving board in a swimming pool. The diving board is a cantilever with a load, the diver, at its free end. The diver initiates a to and fro swing of the board at the free end and utilizes the spring action of the board for jumping. The diving board basically is a leaf spring.



The leaf springs are widely used in suspension system of railway carriages and automobiles. But the form in which it is normally seen is laminated leaf spring. A simple cantilever type leaf spring is shown in the Fig below. In the cantilever beam type leaf spring, for the same leaf thickness, h, leaf of uniform width, b (case 1) and, leaf of width, which is uniformly reducing from b (case 2) is considered. From the basic equations of bending stress and deflection, the maximum stress σmax and tip deflection δmax, can be derived.

For case 1(uniform width)

$$\sigma_{max} = \frac{6FL}{bh^2}$$

$$\delta_{max} = \frac{4FL^3}{Ebh^3}$$

Where, E is the Elastic modulus of the spring material.

For case 2(non uniform width)

$$\boldsymbol{\sigma_{max}} = \frac{\boldsymbol{6FL}}{\boldsymbol{bh^2}}$$

$$\boldsymbol{\delta_{max}} = \frac{\boldsymbol{6FL^3}}{\boldsymbol{Ebh^3}}$$

In the second case it is observed that instead of uniform width leaf, if a leaf of varying width (triangular one as shown in the figure) is used, the bending stress at any cross section is same and equal to $\boldsymbol{\sigma_{max}}$. This is called as leaf of a uniform strength. Moreover, the tip deflection being more, comparatively, it has greater resilience than its uniform width counterpart. Resilience, as we know, is the capacity to absorb potential energy during deformation. However, one should keep in mind that in order to withstand the shear force the tip has to have some width. This is shown as a red zone in the figure. In one way non uniform width leaf is a better design than a uniform width leaf.

Figure 1.4: Cantilever plate [3]

The spring is assumed to be a double cantilever beam, even though the leaf spring is simply supported at the ends. Also, this spring is geometrically and materially symmetrical so that only one half is considered with cantilever beam boundary conditions for the analysis to save the calculation time. The spring is assumed to be a double cantilever beam, even though the leaf spring is simply supported at the ends. Also, this spring is geometrically and materially symmetrical so that only one half is considered with cantilever beam boundary conditions for the analysis to save the calculation time.

Introduction to FEA

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. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition. 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. Within each of these modeling schemes, the programmer can insert numerous algorithms (functions) which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally do not take into account plastic deformation. Non-linear systems do account for plastic deformation, and many also are capable of testing a material all the way to fracture. 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. The mesh acts like a spider web in that from each node, there extends a mesh element to each of the adjacent nodes. This web of vectors is what carries the material properties to the object, creating many elements. A Finite Element Analysis consists of three separated stages;

Preprocessing, processing, and postprocessing. A complete finite element analysis is a logical interaction of these three stages.

1.4.1. Preprocessing

As the name indicates, preprocessing is something which is done before processing your analysis. The Preprocessing involves the preparations of data, such as nodal coordinates, connectivity, boundary conditions and loading and material information. The preparation of data require considerable effort if all data are to be handled manually. If the model is small, the user can often just write a text file and feed it into the processor, but as the complexity of the model grows and the number of elements increases, writing the data manually can be very time consuming and error-prone. Therefore it is necessary with a computer preprocessor which help with mesh plotting and boundary conditions plotting. We can change loads, boundary conditions, mesh and element properties and material. All this is done graphically to minimize the chance of error. The only limitation is that you cannot draw your own geometry; you have to select one of the pregenerated geometries.

1.4.2. Processing

The processing stage involves stiffness generation, stiffness modification, and solution of equations, resulting in the evaluation of nodal variables. This is a typical "black box"-operation, as the user will see little of what is going on. We feed data from the preprocessor, and get data out.

1.4.3. Postprocessing

The postprocessing stage deals with the representation of results. Typically, the deformed configuration and stress distribution are computed and displayed at this stage.

CHAPTER- 2

LITERATURE REVIEW

Erol Sancaktar, Mathieu Gratton [1] have proposed Design and manufacture of a functional composite spring for a solar powered light vehicle is described. The objective is to provide an understanding of the manufacture, use, and capabilities of composite leaf springs produced by using unidirectional Eglass impregnated by an epoxy resin for light vehicle applications where the vehicle weight is of primary concern. and conclude that The spring can be sanded down on its convex side to achieve the desired spring rate. This method proved to be very effective in reducing the spring rate.

H.A.Qureshi [2] Present the general study on design ,analysis and fabrication of composite leaf spring and conclude that composite can be used for leaf spring for light truck and meet requirement with weight saving.(2001).

Mahmood M. Shokrieh, Davood Rezaei [3] used A four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software.and finally 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.(2003).

M.A. Osipenko, R.N. Rudakov [4] Take the leaves have the same widths and different lengths (the lengths decrease upwards).and Each leaf has one end clamped and the other free.for that they gave loading is applied (upwards) to the lower leaf. and finding the densities of the forces of interaction between the leaves and investigation of the interaction of spring leaves under joint bending allows one to understand the bending of two straight uniform leaves in full.(2003).

Gulur Siddaramanna Shiva Shankar, Sambagam Vijayarangan [5] have present a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. Also, general study on the analysis and design. A single leaf with variable thickness and width for constant cross sectional area of unidirectional glass fiber reinforced plastic with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested. Computer algorithm using C-language has been used for the design of constant cross-section leaf spring. and conclude that a spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat. The finite element results using ANSYS software showing stresses and deflections were verified with analytical and experimental results. The design constraints were stresses and displacement. Compared to the steel spring, the composite spring has stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85% lower with bonded end joint and with complete eye unit.(2006).

J.P. Hou, J.Y. Cherruault, I. Nairne, R.M. Mayer[6] present the design evolution process of a composite leaf spring for freight rail applications. Three designs of eye-end attachment for composite leaf springs are described. The material used is glass fiber reinforced polyester. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. Load–deflection curves and strain measurement as a function of load for the three designs tested have been plotted for comparison with FEA predicted values and conclude Three eye-end designs of a double GRP leaf suspension have been evaluated by finite element analysis and static and fatigue testing. FEA and static test results show that the stress concentration at the tip of the fibers coming back along the leaf body.

Shiva Shankar and Vijayarangan;- manufactured a composite mono leaf spring with an integral eye and tested under static load conditions. Also fatigue life prediction was also done to ensure a reliable number of life cycles of a leaf spring.

Niklas philipson and Modelan;- modeled a leaf spring in conventional way and simulated for the kinematic and dynamic comparatives.

Zhi'an Yang and et al. studied the cyclic creep and cyclic deformation. Efforts were taken for Finite Element Analysis of multi leaf springs. These springs were simulated and analyzed by using ANSYS [5].

C.K. Clarke and G.E. Borowski ;- evaluated the failure of leaf spring at different static load conditions and *J.J. Fuentes et al.* studied the effect of premature fracture in Automobile Leaf Springs.

Mouleeswaran et al;- describes static and fatigue analysis of steel leaf springs and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. The dimensions of existing conventional steel leaf springs of a light commercial vehicle are taken and are verified by design calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1and compared with experimental results.

H. A. Al-Qureshi;- has described a single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf steel spring, was designed, fabricated and tested.

J.J.Fuentes et al.;- in this work, the origin of premature 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.

RajendranI, S. Vijayarangan;- A formulation and solution technique using genetic algorithms (GA) for design optimization of composite leaf springs is presented here.

J.P. Hou et al.;- explained the design evolution process of a composite leaf spring for freight rail application.

A.strzat and T.Paszek;- performed a three dimensional contact analysis of the car leaf spring. They considered static three dimensional contact problem of the leaf car spring and the solution is obtained by finite element method performed in ADINA 7.5 professional system. The maximum displacement of car spring is chosen as reliability criterion. Different types of mathematical model were considered starting from the easiest beam model and ending on complicated three dimensional non-linear model which takes into consideration large displacements and contact effects between subsequent spring leaves. The static characteristics of the car spring was obtained for different models and later on, it is compared with one obtained from experimental investigations.

Fu-Cheng Wang;- performed a detailed study on leaf springs. Classical network theory is applied to analyze the behavior of a leaf spring in an active suspension system.

I.Rajendran and S.Vijayarangan;- performed a finite element analysis on a typical leaf spring of a passenger car. Finite element analysis has been carried out to determine natural frequencies and mode shapes of the leaf spring by considering a simple road surface model.

AL-Qureshi presented a general study on the analysis, design and fabrication of composite leaf springs. The suspension spring of compact car (jeep) was selected as a prototype. A single leaf with variable thickness spring of glass fiber reinforced plastic was designed, fabricated and tested. The testing was performed experimentally in the laboratory and was followed by a road test. Comparison between GFRP and Steel multi leaf spring was done.

Shokrieh et al. compared the steel and composite leaf spring to obtain a spring with minimum weight that is capable of carrying given static external forces without failure. The design constraints were stresses (Tsai–Wu failure criterion) and displacements. The results showed that an optimum spring width decreases hyperbolically and the thickness increases linearly from the spring eyes towards the axle seat. Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

Shankar *et al.* presented a low cost fabrication of complete mono composite leaf spring and mono composite leaf spring with bonded end joints. A single leaf with variable thickness and width of constant cross sectional area of unidirectional glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multileaf spring, was designed, fabricated and tested. Computer algorithm using C-language has been used for the design of constant crosssection leaf spring. The results showed that spring width decreases hyperbolically and thickness increases linearly from the spring eyes towards the axle seat. The finite element results using ANSYS software showing stresses and deflections were verified with analytical and experimental results. The design constraints were stresses (Tsai-Wu failure criterion) and displacement. Compared to the steel spring, the composite spring has stresses that are much lower, the natural frequency is higher and the spring weight is nearly 85 % lower with bonded end joint and with complete eye unit.

Hou *et al.* presented the design evolution process of a composite leaf spring for freight rail applications. Three designs of eye-end attachment for composite leaf springs were described. The material used was glass fibre reinforced polyester. Static testing and finite element analysis had been carried out to obtain the characteristics of the spring. Load–deflection curves and strain measurement as a function of load for the three designs tested had been plotted for comparison with FEA predicted values. The main concern associated with the first design was the delamination failure at the interface of the fibres that have passed around the eye and the spring body, even though the design can withstand 150 kN static proof load and one million cycles fatigue load. FEA results confirmed that there is a high interlaminar shear stress concentration in that region. The second design feature is an additional transverse bandage around the region prone to delamination. Delamination was contained but not completely prevented. The third design overcomes the problem by ending the fibres at the end of the eye section.

Abdullah *et al*. (2009) analyzed and evaluated the capability of parabolic spring to replace the multi leaf in suspension system. Finite element analysis had been performed to analyze the stress distribution and behavior for both type of springs. Finally, comparison between simulation and experimental result had been made for validating purpose. Multi leaf can hold much more load then parabolic spring, but in terms of material usage and space requirement, parabolic spring has the advantages. For multi-leaf, the stress was concentrated at the center part, while for parabolic, stress was distributed well at the both side of the part.

Kothari *et al.* studied static and fatigue life analysis of conventional leaf springs made of respectively SUP 9 & EN 45. Comparison for maximum stress, deflection and stiffness as well as fatigue life was done. The CAD models were prepared in CATIA and analyzed by using ANSYS 12.1. Computer algorithm using C++ language had been used in calculating maximum stress, deflection and stiffness. Calculated results were compared with FEA result. SUP 9 springs has lower value of maximum stress, deflection and stiffness in compare to EN45 spring.

Raghavedra *et al.* (2012) compared laminated composite leaf spring and steel leaf spring with respect to weight, stiffness and strength. By employing a composite leaf spring for the same load carrying capacity, there was a reduction in weight of 73%-80%**,** natural frequency of composite leaf springs are 27%~67% higher than steel leaf spring and 23~65% stiffer than the steel spring**.** Based on the results, it was inferred that carbon/epoxy laminated composite mono leaf spring has superior strength and stiffness and lesser in weight compared to steel and other composite materials considered in this investigation. From the results, it is observed that the laminated composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications.

CHAPTER- 3

PROBLEM INDENTIFICATION AND METHODOLOGY

Increasing competition in automobile sector tends to modify the existing products or replacing old products by new and advance materials. The suspension leaf spring is one of the potential items for weight reduction in automobile vehicles. The automobile industry has shown great interest in replacement of steel parts with composite materials. The advantages of using composite material include high strength to weight ratio. In the present work, a geometric model of multi leaf spring consisting of nine leaf was created in solid works and finite element analysis was carried out in ANSYS 14.5.

The objective of the present work is to

1.Comparision between stress and deflection of leaf spring made of steel and composite leaf spring.

2. Determine the effect of fiber orientation on stresses and deflection induced in leaf springs

3.1. Design methodology

1. Modeling of mutli-leaf spring was done in SOLID WORKS.

2. Geometric Model of the multi leaf spring is imported in ANSYS 14.5.

3. Stresses and deflections are obtained from finite element analysis are compared and conclusions are drawn.

SPECIFIC DESIGN DATA

Here Weight and initial measurements of four wheeler Light commercial vehicle is taken.

Weight of vehicle= 700 kg
Maximum load carrying capacity= 1000 kg
Total weight= 700 + 1000 = 1700 kg;
Taking factor of safety (FS) = 2

Acceleration due to gravity (g) = 9.81 m/s2

Therefore; Total Weight = 1700*9.81 = 16677

Since the vehicle is 4-wheeler, a single leaf spring corresponding to one of the wheels takes up one 4th of the total weight.

∴ 16677/4 = 4169 N,

But 2F = 4169 N. ∴ F = 2084 N.

Span length, 2L = 860 mm, ∴ L= 430mm.

Now the Maximum Bending stress of a leaf spring is given by the formula

Bending Stress, $\boldsymbol{\sigma_{max}}$= 6FL/bh^3

= (6*2084*430) / (3*60*8^2) = 466.84 Mpa

The Total Deflection of the leaf spring is given by

Δ_{max} = 6FL^3/ Ebh^3

= (6*2084*4303) / (2.1*105*3*60*8^3) = 51.38 mm

SELECTION OF COMPOSITE MATERIAL

The ability to absorb and store more amount of energy ensures the comfortable operation of a suspension system. However, the problem of heavy weight of spring is still persistent. This can be remedied by introducing composite material, in place of steel in the conventional leaf spring. From several studies it is found that the E-glass/Epoxy is better material for replacing the conventional steel as per strength and cost factor. The E-glass fiber is a high quality glass, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. The material select is E-Glass/Epoxy material.

Table:- Orthotropic Properties of E-Glass/Epoxy material

Properties	**value**
Tensile modulus along X-direction (E_X), MPa	34000
Tensile modulus along Y-direction (E_Y), MPa	6530
Tensile modulus along Z-direction (E_Z), Mpa	6530
Shear modulus along XY-direction (G_{XY}),MPa	2433
Shear modulus along YZ-direction (G_{YZ}),MPa	1698
Shear modulus along ZX-direction (G_{ZX}),MPa	2433
Poisson ratio along XY-direction (NU_{XY})	0.217
Poisson ratio along YZ-direction (NU_{YZ})	0.366
Poisson ratio along ZX-direction (NU_{ZX})	0.217
Mass density of the material (ρ), kg/mm^3	$2.6x10^6$
Tensile strength of the material, Mpa	900
Compressive strength of the material, Mpa	450
Flexural modulus of the material, MPa	40000
Flexural strength of the material, Mpa	1200

Procedure for Testing

1. The spring to be tested is examined for any defects like cracks, surface finishing, etc.

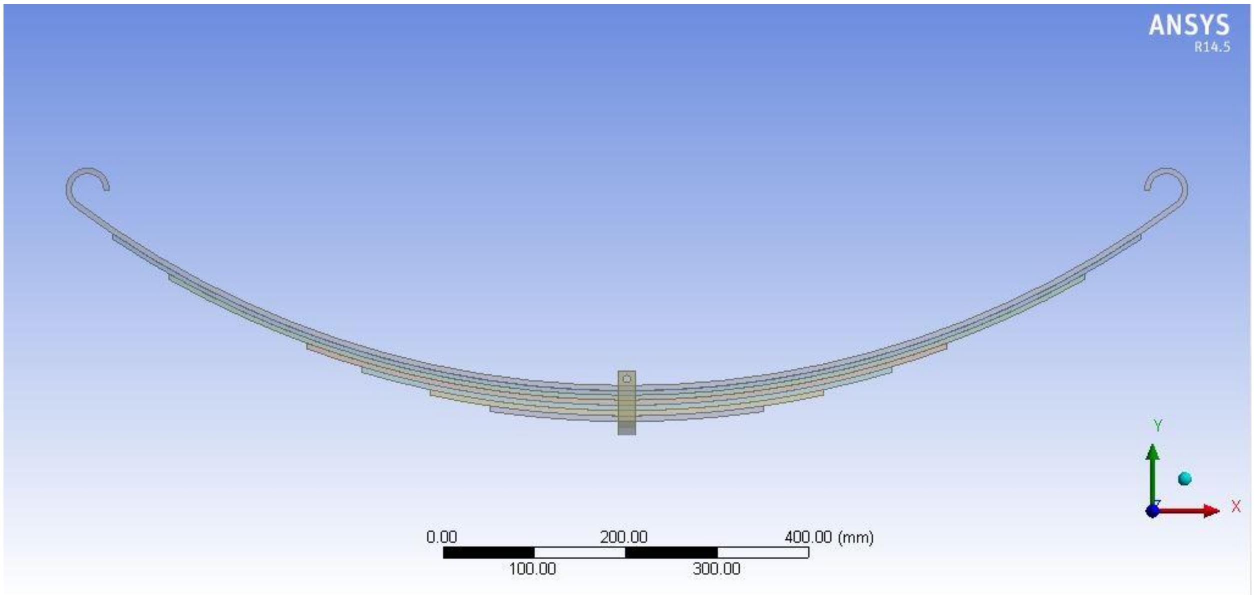
2. Move the plunger up to desired height so that we can fix the fixture and leaf spring for test.

3. Fix the position of fixture. On the fixture place the specimen.

4. The load is applied at the centre of spring, the vertical deflection of the spring centre is recorded at desired interval.

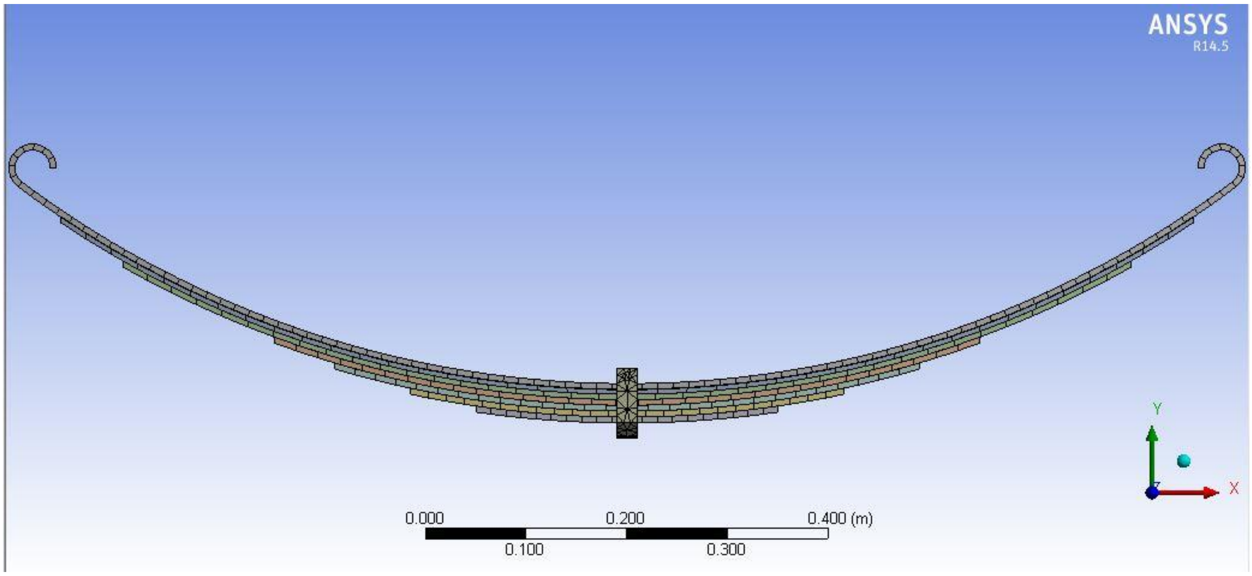
3.4. CAD modeling of multi leaf spring

CAD modeling software is dedicated for the specialized job of 3D-modeling. The model of the multi leaf spring structures also includes many complicated parts. Modeling of multi leaf spring is done in SOLID WORKS. All the seven leaves are modeled separately in the part module of solidworks and assembled in assembly module. The multi leaf spring is modeled in a position having maximum deflection i.e. all leaves are in flat position and then load is applied in the reverse direction to attain its original shape i.e. semi-elliptical. The modeling process is same for steel as well as composite leaf spring. First of all 2-D geometry was created in sketch of part module and it is then extruded to get the required 3-D geometry. These steps are repeated for all the seven leaves followed by assembly in the assembly module.



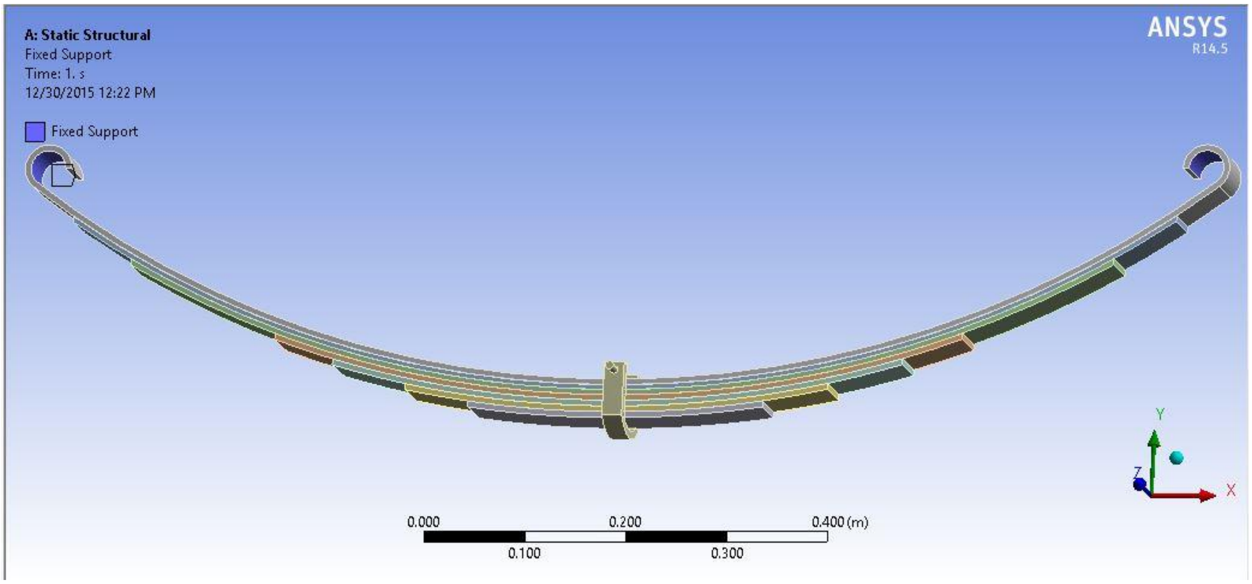
Meshing

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.



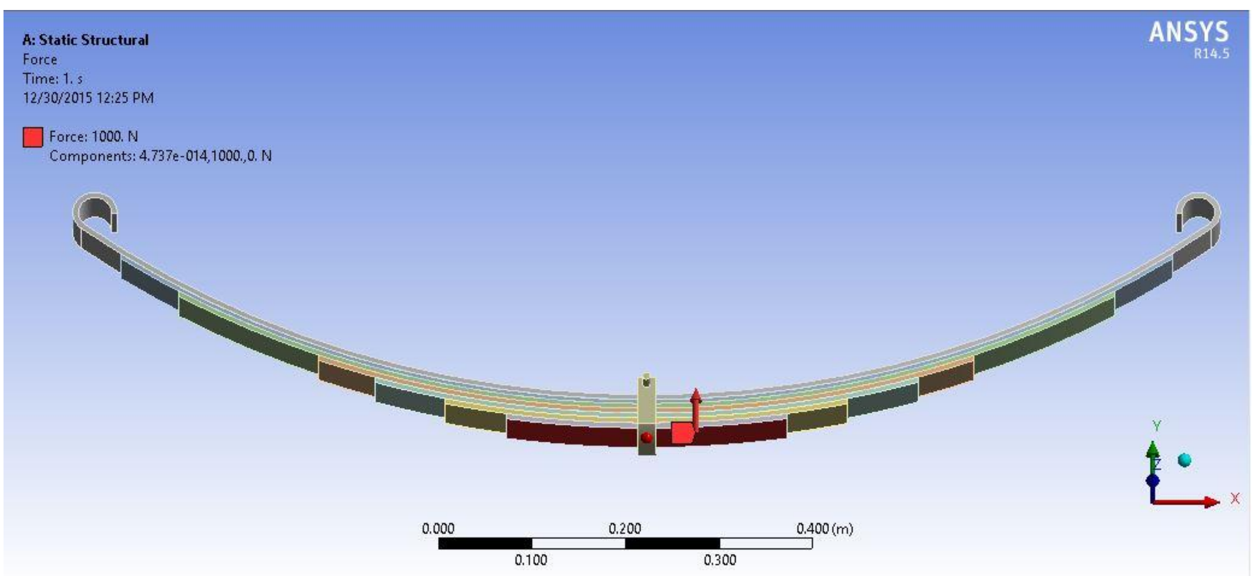
Boundary Conditions

The leaf spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the leaf spring. The ends of the leaf spring are formed in the shape of an eye. The front eye of the leaf spring is coupled directly with a pin to the frame so that the eye can rotate freely about the pin but no translation can occur. The rear eye of the spring is connected to the shackle which is a flexible link; the other end of the shackle is connected to the frame of the vehicle. The rear eyes of the leaf spring have the flexibility to slide along the X-direction when load applied on the spring and also it can rotate about the pin. The link oscillates during load applied and removed. The degree of freedom of both eyes is arrested in this research work i.e. a fixed support is used on both the eyes.



Loads Applied

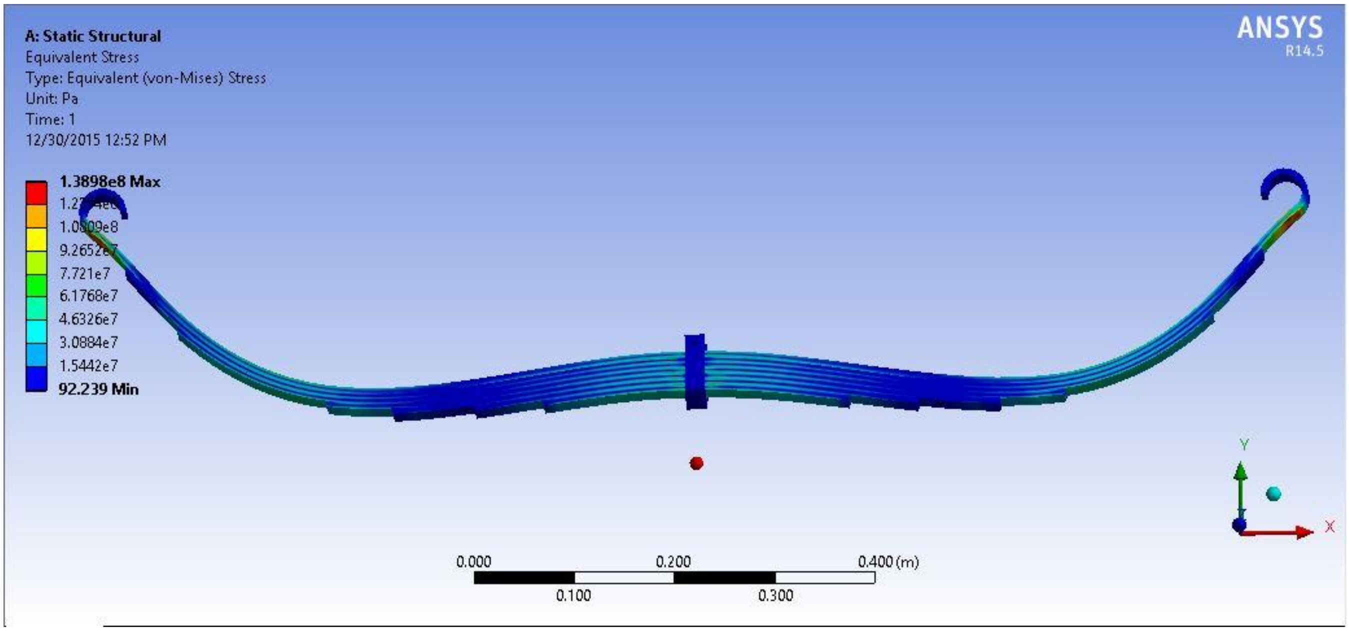
The load is applied in downward direction on the surface of the last leaf



RESULTS AND DISCUSSION

From the results of static analysis of steel leaf spring, it is seen the displacement of leaf spring is 53.159 mm which is well below the camber length of leaf spring shown in fig.4. It is seen that the maximum bending stress is about 450.73MPa, which is less than the yield strength of the material shown in fig.3. The FEA results are compared with the theoretical results and found that the theoretical result and FEA result are nearer to each other.

The deformed shape of the leaf spring is shown in Figure and the Table gives the Von-Mises stress at various loads.



Load N	Von-mises Stress N/mm2
1000	139.628
2000	282.615
3000	426.152
4000	568.83
5000	712.642
6000	852.345
7000	993.515
8000	1136.106
9000	1277.672
10000	1420.076

Static analysis is performed to find the Von-Mises stress by using ansys software and these results are compared with bending stresses calculated in mathematical analysis at various loads and is shown in Table.

Table:- Comparison between Analytical and ANSYS results of conventional steel leaf spring

Parameter	**Analytical Results for steel leaf spring**	**FEA Results for steel leaf spring**	**Variation**
Load, N	4169	4169	NIL
Bending Stress, MPa	466.84	450.73	3.04 %
Total Deflection, mm	51.24	53.159	3.06 %

After that the multi leaf spring with E-Glass/Epoxy material is analyzed in ANSYS-14.5 with same dimension and same boundary condition as that of conventional leaf spring, showing bending stress and deflection under load

The comparison between steel leaf spring and composite leaf spring for deflection and bending stress results from the ANSYS is shown in the Table

Parameter	**FEA Results for steel leaf spring**	**FEA Results for composite leaf spring**	**Percentage variation**
Load, N	4169	4169	NIL
Bending Stress, MPa	450.73	338.03	- 25.05 %
Total Deflection, mm	53.159	34.676	- 34.76 %

By the comparison of results between steel leaf spring and the composite leaf spring from ANSYS-14.5 the deflection is decreased by 34.76 % in composite leaf spring that is within the camber range. The bending stresses are decreased by 25.05% in composite leaf spring means less stress induced with same load carrying conditions. The conventional multi leaf spring weights about 10.27kg whereas the E-glass/Epoxy multi leaf spring weighs only 3.26 kg. Thus the weight reduction of 67.88% is achieved. By the reduction of weight and the less stresses, the fatigue life of composite leaf spring is to be higher than that of steel leaf spring. Totally it is found that the composite leaf spring is the better that of steel leaf spring.

Table:- Percent saving of weight by using composites

Materials	**Weights**	**% weight saving**
Conventional Steel	10.27 kg	-----
E-glass/epoxy	3.26 kg	67.88%

CONCLUSION AND FUTURE SCOPE

- It is concluded that for the given specifications of the leaf spring, the maximum safe load is 8000N.
- The conventional multi leaf spring weights about 10.27kg whereas the E-glass/Epoxy multi leaf spring weighs only 3.26 kg.
- It is observed that the maximum stress is developed at the inner side of the eye sections, so care must be taken in eye design and fabrication and material selection.
- the deflection is decreased by 34.76 % in composite leaf spring that is within the camber range.

In future lot of work needed to be done :

- The FEA results can be compared with the results obtained from the mathematical models which consider micromechanics of leaves.
- Replacing the each leave of multi leaf spring made of steel with different composite material.

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