Design and Analysis of Composite Leaf Spring

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Abstract— **A leaf spring is a simple form spring commonly used for suspension in wheel vehicles. The automobile industry has shown keen interest for replacement of steel leaf spring with that of composite leaf spring. Since the composite material has high strength to weight ratio, good corrosion resistance and other thermal properties. The steel material is replaced with the composite material. A spring with constant width and thickness was fabricated by hand lay – up technique which was very simple and economical. The numerical analysis is carried via finite element analysis using ANSYS software. Stress, deflection and strain energy results for both steel and composite leaf spring material were obtained.**

The design and FEA analysis is of composite leaf spring made of glass fiber reinforced polymer. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken for evaluation of results.

Index Terms— **Finite element Analysis, Static Analysis, Modal Analysis, Leaf Spring**

I. INTRODUCTION

In automobile car out of many components one of the components of automobile which can be easily replaced is leaf spring. A leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. The suspension of leaf spring is the area which needs to focus improve the suspensions of the vehicle for comfort ride. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for 10 to 20% of un spring weight.

It is well known that springs are designed to absorb shocks. So the strain energy of the material becomes a major factor in designing the springs. The introduction of composite material will make it possible to reduce the weight of the leaf spring without reduction in load carrying capacity and stiffness. Since the composite material have high strength to weight ratio and have more elastic strain energy storage capacity as compared with steel.

The relationship of specific strain energy can be expressed as

$$U=\frac{1}{2}*\frac{\sigma^2}{\rho E}$$

It can be easily observed that material having lower density and modulus will have a greater specific strain energy capacity. Thus composite material offer high strength and light weight. In this work, leaf springs of automobile vehicle are force India cruiser passenger car is considers for further investigation.

The suspension quality can be improved by minimizing the vertical vibrations, impacts and bumps due to road irregularities which create the comfortable ride.

TYPES OF SPRING

1) Helical springs
2) Conical and volute springs
3) Torsion springs
4) Disc or Belleville springs
5) Special purpose springs
6) Laminated or leaf springs

LEAF SPRING

Leaf spring (also known as flat springs) is made out of flat plate. The advantage in leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition the energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. Single plate fixed at one end and loaded at the other end as shown in figure 1. This plate may be used as a flat spring.

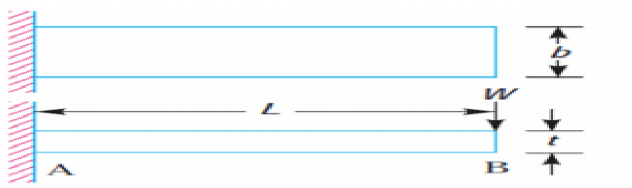

Figure: 1.1Flat spring cantilever type

Bending stress in spring

$$\sigma_b=\frac{6*W*L}{b*t2}$$

The bending stress & deflection of this flat plate is calculated using following equation.

Deflection of spring

$$Y=\frac{4*w*L^3}{E*b*t^3}$$

In the bending moment, top fiber will be in tension and bottom fibers in compression, but the shear stress is zero at the extreme fibers and maximum at the center. Bending stress zero at the centre, where shear stress maximum at the center as shown in figure .2.

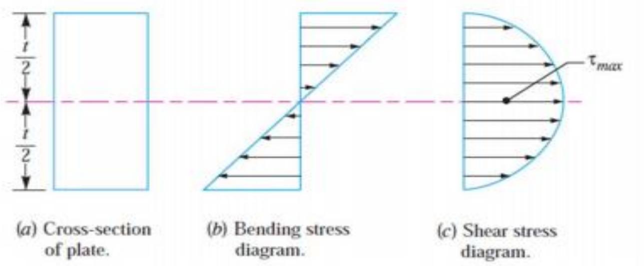

Figure:1.2:(a)Cross-section of plate (b) Bending stress (c) Shear stress diagram

If the spring is consider as simply supported beam the length is 2L and load 2W as shown in figure 3.The bending stress & deflection of this at plate is calculated using following equation.

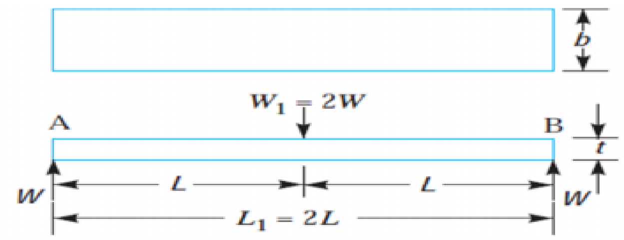

Figure:1.3.Flat spring simply supported beam type

CONSTRUCTION OF LEAF SPRING

A leaf spring commonly used in automobiles is of semi-elliptical form as shown in figure 1.6.It is built up of a number of plates (known as leaves). 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 a band shrunk around them at the centre or by a bolt passing through the centre. In case of a centre 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. The spring is clamped to the axle housing by means of U-bolts.

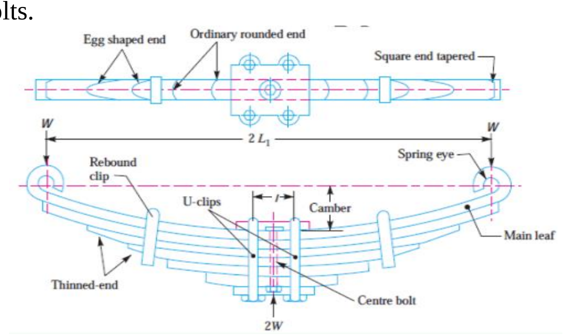

Figure:1.4 Semi elliptical leaf spring

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. Usually the eyes, through which the spring is attached to the hanger or shackle, are provided with bushings of some antifriction material such as bronze or rubber. 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 as shown in figure 4.Since the master leaf has to with stand vertical bending loads as well as loads due to sideways of the vehicle and twisting, therefore due to the presence of stresses caused by these loads, it is usual to provide two full length leaves and the rest graduated leaves as shown in figure 4.Rebound clip are located at intermediate positions in the length of the spring, so that the graduated leaves also share the stresses induced in the full length leaves when the spring rebounds.

STANDARD SIZES OF SUSPENSION LEAF SPRING

- Standard nominal widths are:
  32,40,45,55,60,65,70,75,80,90,100 and 125 mm.
- Standard nominal thickness are:
  3.2,4.5,5,6,6.5,7,7.5,8,9,10,11,12,14 and 16 mm.
- At the eye, the following bore diameter commended:
  19,20,22,23,25,27,28,
  30,32, 35,38,50,55 mm.

APPLICATIONS OF LEAF SPRING

- To cushion, absorb or control energy due to either shock or vibration as in car springs, railway buffers, air-craft landing gears, shock absorbers and vibration dampers.
- To apply forces, as in brakes, clutches and spring loaded valves.
- The leaf spring acts as a linkage for holding the axle in position and Thus separate linkage are not necessary. It makes the construction of the suspension simple and strong.

MATERIAL FOR LEAF SPRING

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties. Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and the performance of the vehicle. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite materials have been selected for leaf spring design.

The material of the spring should have high fatigue strength, high ductility, high resilience and it should be creep resistant. It largely depends upon the service for which they are used i.e. severe service, average service or light service. Severe service means rapid continuous loading where the ratio of minimum to maximum load (or stress) is one-half or less, as in automotive valve springs. Average service includes the same stress range as in severe service but with only intermittent operation, as in engine governor springs and automobile suspension springs. Light service includes springs subjected to loads that are static or very infrequently varied, as in safety valve springs.

MATERIAL FOR COMPOSITE LEAF SPRING

Over the last thirty years composite materials, plastics and ceramics have been the dominant emerging materials. The volume and number of applications of composite materials have grown steadily, penetrating and conquering new markets relentlessly. Modern composite materials constitute a significant proportion of the engineered materials market ranging from everyday products to sophisticated niche applications. While composites have already proven their worth as weight-saving materials, the current challenge is to make them cost effective. The efforts to produce economically attractive composite components have resulted in several innovative manufacturing techniques currently being used in the composite industry. It is obvious, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is essential that there be an integrated effort in design, material, process, tooling assurance, manufacturing and even program management for composites to become competitive with metals.

Further, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock

& vibration. Composites are now extensively being used for rehabilitation/ strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity.

Unlike conventional materials (e.g. steel), the properties of the composite material can be designed considering the structural aspects. The design of a structural component using composites involves both material and structural design. Composite are properties (e.g. stiffness) can be varied continuously over a broad range of values under the control of the designer. Careful selection of reinforcement type enables finished product characteristics to be tailored to almost any specific engineering requirement. Whilst the use of composites will be a clear choice in many instances, material selection in others will depend on factors such as working lifetime requirements, number of items to be produced (run length), complexity of product shape, possible savings in assembly costs and on the experience & skills the designer in tapping the optimum potential of composites. In some instances, best results may be achieved through the use of composites in conjunction with traditional materials.

II. DESIGN CALCULATION OF LEAF SPRING

Conventional design methods of leaf springs are largely based on the application of empirical and semi-empirical rules along with the use of available information in the existing literature. The functions of springs are absorbing energy and release this energy according to the desired functions to be performed. So leaf springs design depends on load carrying capacity and deflection.

Hence the Force Motors Taxi Cruiser is considering for design of leaf spring.

Step (1): Material of leaf spring:

- Material selected steel :50Cr1V23
- Composition of material: 0.45% C, 0.1- 0.3% Si, 0.6-0.%Mn, 0.9-1.2% Cr,

Step (2): Basic data of Force Motors Taxi Cruiser leaf spring:

- Total length of the spring (Eye to Eye) = 1250mm
- No. of full length leaves (n_f) = 01
- Thickness of leaf (t) = 10mm
- Width of the leaf spring (b) = 70 mm
- Young's modulus (E)= $2x10^5$ N/mm^2
- Tensile strength (t) = 1900-2400 N/mm^2
- Yield strength (y) = 1800 N/mm^2
- Total load = 2500 N
- BHN = 500 – 580 HB with hardened and tempered

Step (3): Basic requirement of load:

Maximum capacity = 500 Kg
= 5000 x 10
= 5000 N

Step (4): Calculation of the load and effective length of leaf spring:

- Consider the leaf spring is cantilever beam. So the load acting on the leaf spring is acted on the two ends of the leaf spring. Load acted on the leaf spring is divided by the two because of consideration of the cantilever beam.

2*W = 5000N
W = 5000/2
W = 2500 N

- Effective Length of the spring L= 729 mm

Step (5): Calculations of the stress generated in the leaf spring are as under:

- Material of the leaf spring is 50 Cr 1 V 23
- Property of the material are as under:

Tensile strength (t) = 190–240Kgf/mm^2
=1900–2400N/mm^2 Yield strength (y) = 180Kgf/mm^2= 1800 N/mm^2
Modulus of elasticity (E) = 200000N/mm^2
BHN = 500 – 580 HB with hardened and tempered

- By considering the factor of safety for the safety purpose of the leaf spring is 1.5 for automobile leaf spring [20]. So the allowable stress for the leaf spring is as under :

Tensile strength (σ_t) = 1900/1.5Kgf/mm^2
= 1266.66N/mm^2
Yield strength (σ_y) = 180Kgf/mm^2
= 1800 N/mm^2
= 1200 N/mm^2

Bending stress generated in the leaf spring is as under:

σ_b=6*W*L / n*b*t^2
σ_b=6*1250*729/1*70*(10)^2
= 78107 N/mm2

So, the stress generated in the leaf spring is lower than the allowable design stress. So design is safe.

Deflection generated in the leaf spring is as under:

Y=6*W*L^3/n*b*t^3
Y=6*1250*(729)^3/2*10^5*70*100
y = 207.546mm

III. MODELING AND ANALYSIS OF STEEL LEAF SPRING

INTRODUCTION OF CATIA

Based on the dimensions obtained from the conventional design of leaf spring, the model of the leaf spring was created with the help of the 3-D modeling CAD software CATIA. CATIA is modeling software for modeling various mechanical designs for performing related design and manufacturing operations. The system uses a 3D solid modeling system as the core, and applies the feature base parametric modeling method. In short CATIA is a feature based parametric solid modeling system with many extended design and manufacturing applications. Some of the features of CATIA are as below:

MODELING OF LEAF SPRING

Modeling of leaf spring is performed in CATIA. Procedure of modeling leaf spring is as following.

Create sketch with the help of leaf spring length and camber. Divide leaf spring length and camber into equal division and draw a line which passes through intersection of camber and length division. 2) Extrude above sketch to leaf spring width to create one leaf.

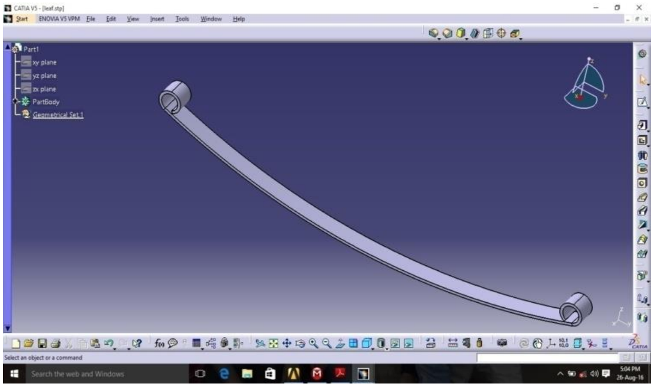

Figure:3.13D model of master leaf

INTRODOCTION OF ANSYS

ANSYS is a finite element analysis (FEA) software package. It uses a preprocessor software engine to create geometry. Then it uses a solution routine to apply loads to the meshed geometry. Finally it outputs desired results in post-processing. FEA is used throughout almost all engineering design including mechanical systems and civil engineering structures. In most structural analysis applications it is necessary to compute displacements and stresses at various points of interest. The finite element method is a very valuable tool for studying the behavior of structures. In the finite element method, the finite element model is created by dividing the structure in to a number of finite elements. Each element is interconnected by nodes. The selection of elements for modeling the structure depends upon the behavior and geometry of the structure being analyzed. The modeling pattern, which is generally called mesh for the finite element method, is a very important part of the modeling process. The results obtained from the analysis depend upon the selection of the finite elements and the mesh size. Although the finite element model does not behave exactly like the actual structure, it is possible to obtain sufficiently accurate results for most practical applications.

The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. These tools have the benefit of being highly automated along with having a moderate to high degree of user control.

❖ Advantages of FEA:

- Visualization increases
- Design cycle time reduces
- No. of prototypes reduces
- Testing reduces
- Optimum design

The process of performing ANSYS can be broken down into three main steps

.1) Pre- processing
2) Solver
3) Post-processing

- Pre-processing:

This step is most important in analysis of leaf spring. Any modeling software can be used for modeling of geometry and can be shifted to other simulation software for analysis purpose. After mesh generation (grid generation) is the process of subdividing a region to be modeled into a set of small elements. Meshing is the method to define and breaking up the model into small elements. In general a finite element model is defined by a mesh network, which is made up of the geometric arrangement of elements and nodes. Nodes represent points at which features such as displacements are calculated. Elements are bounded by set of nodes, and define localized mass and stiffness properties of the model. Elements are also defined by the number of mesh, which allowed reference to be made to corresponding deflections, stresses at specific model location. The common type of mesh element used in ANSYS solver is hexahedral, tetrahedral and brick.

- Solver: During preprocessing user has to work hard while solution step is the computer to do the job. User has to just click on solve icon & enjoy a cup of tea! Internally software carries out matrix formations, inversion, multiplication& solution for unknown. e.g. displacement & then find strain & stress for static analysis
- Post-processing:

The final step in ANSYS is Post-processing, during which the ANSYS results are analyzed. However, the real value of ANSYS simulation is frequently found in its ability to provide accurate predictions of integrated quantities such as find displacement and stresses.

❖ Assumptions :

- Software to be used for ANSYS
- Model simplification for FEA.
- Meshing size is limited to computer compatibilities.
- Static analysis is considered.
- Material used for steel leaf spring analysis is isotropic.

Properties of steel material

Parameter	Values
Material selected	50Cr1v23
Young's modulus	$2*10^5$ MPa
Passion's ratio	0.3
BHN	534-601
Tensile strength ultimate	2000 MPa
Tensile strength yield	1800 MPa
Density	7850 Kg/m^3

Table:3.1 Properties of steel material

STATIC ANALYSIS OF STEEL LEAF SPRING

1) After creating Catia model of steel leaf spring in Catia 2014. Save that model in STEP format.
2) Import above 3D model in ANSYS Workbench static structural module for static analysis.
3) Create leaf spring material 50Cr1V23.

Provide material properties as per table in the ANSYS Workbench.

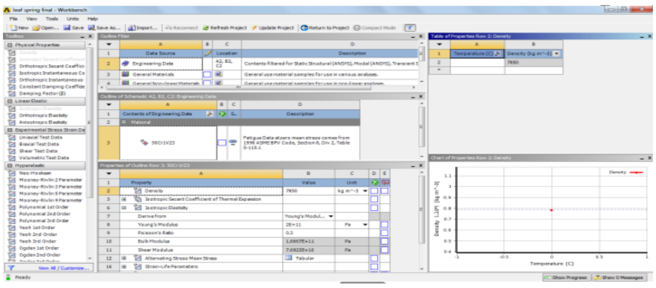

Figure: 3.2Define materials in ANSYS Workbench

4) Create meshing of leaf spring.

Meshing is the process in which your geometry is spatially discredited into elements and nodes. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure. The mesh has been generated automatically. The default element size is determined based on a number of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. As shown in figure 4.1 Number of elements used are 2352 & and number of nodes used are 19346.

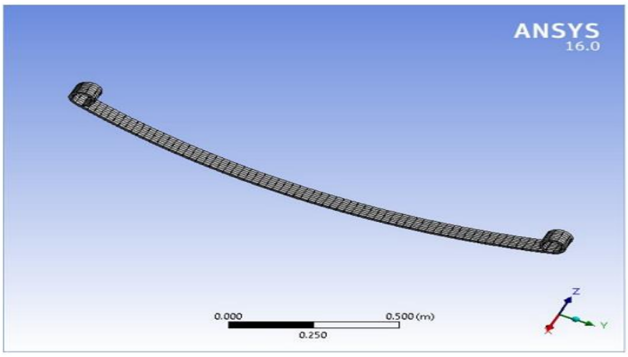

Figure: 3.3 Meshed model of leaf spring

5) Apply boundary condition

Boundary condition one end remote displacement for component X free, Y and Z fixed and rotation Z free, X and Y fixed and other end remote displacement for component X, Y and Z fixed and rotation Z free, X and Y fixed. Loading conditions involves applying a load upper side at the centre of the bottom leaf spring.

- **Define force**

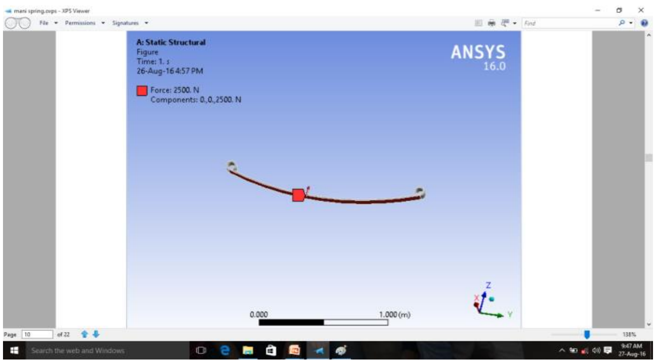

Figure: 3.4 Define force

6) Run the analysis.
7) Get the results.

RESULT ANALYSIS OF STEEL LEAF SPRING

Static structural analysis for deflection, strain energy and von-misses stress as shown in figure 4.4, 4.5 and 4.6 respectively.

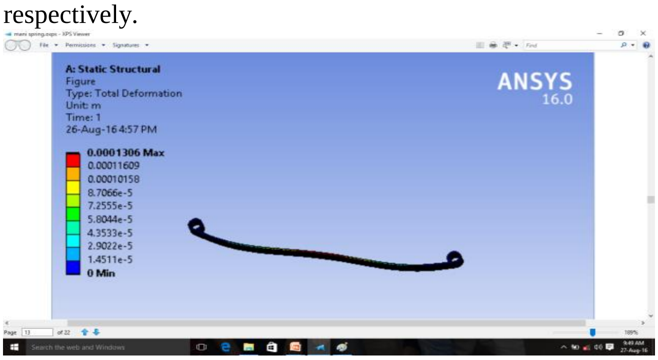

Figure: 3.5Maximum deflection contours

- Maximum strain energy

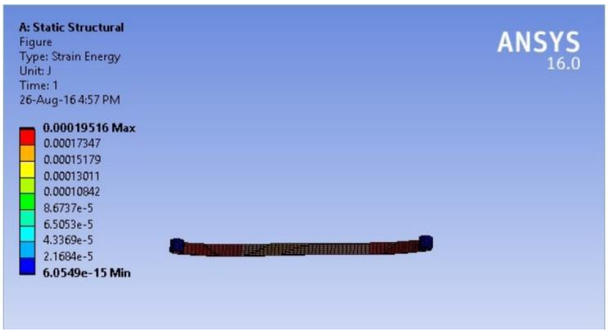

Figure: 3.6 strain energy of steel leaf spring

- Von-misses stress contour

Figure:3.7 von-misses stress of steel Leaf spring

Result table for analytical and analysis of steel leaf spring

Below table shows that static analysis fairly matches with the analytical results but it also shows that static analytical results underestimate the results. For the optimization of leaf spring, accurate prediction of stress and deflection is necessary for that reason we have to perform model and transient analysis of leaf spring Parameters Analytical results Static analysis results Percentage variation

Table 4.2 Comparison of analytical and analysis result for steel leaf spring

Parameter	Analytical results	Static analysis results	Percentage variation
Von-misses stress (MPa)	78107	63407	1.231
Maximum deflection (mm)	207.54	195.16	1.06

IV. ANALYSIS OF COMPOSITE LEAF SPRING

As mentioned earlier, 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. Research has indicated that the results of E-glass/epoxy, Carbon epoxy and Graphite epoxy were found with good characteristics for storing strain energy. So, a virtual model of leaf spring was created in CATIA. Model is imported in ANSYS and then material is assigned to the model. These results can be used for comparison with the steel leaf spring.

❖ Assumptions :

- Software to be used for ANSYS 12.1

- Model simplification for FEA.
- Meshing size is limited to computer compatibilities.
- Static analysis is considered.
- Material used for steel leaf spring analysis is isotropic.

❖ Properties of composite mate

Table4.1 Properties of composite material

Sr.no	Properties	E-glass/Epoxy
1	E_X (MPa)	43000
2	E_Y(MPa)	6500
3	E_Z(MPa)	6500
4	PR_{XY}	0.27
5	PR_{YZ}	0.06
6	PR_{ZX}	0.06
7	G_{XY}(MPa)	4500
8	Gyz(MPa)	2500
9	G_{zx}(MPa)	2500
10	ṗ(Kg/mm^3)	0.000002

STATIC ANALYSIS OF COMPOSITE LEAF SPRING

1) After creating solid model of steel leaf spring in CATIA. Save that model in STEPED format.
2) Import above 3D model in ANSYS Workbench static structural module for static analysis.
3) Create leaf spring material in E-glass/epoxy.
   - Provide material properties as per table 5.1 in the ANSYS Workbench.

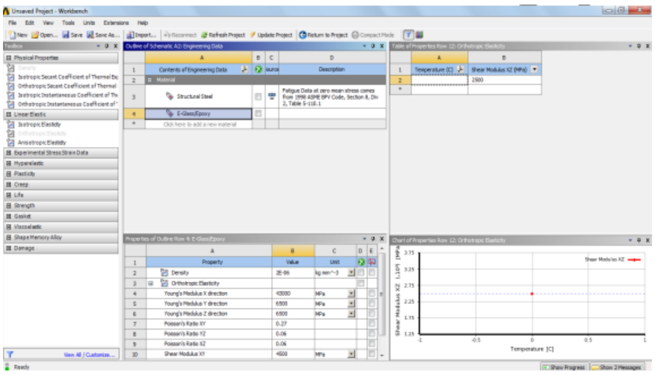

Figure 4.1 Define materials in ANSYS Workbench

4) Create meshing of leaf spring.

This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure. The mesh has been generated automatically. As shown in figure 5.4 Number of elements used are 90 & and number of nodes used are 798.

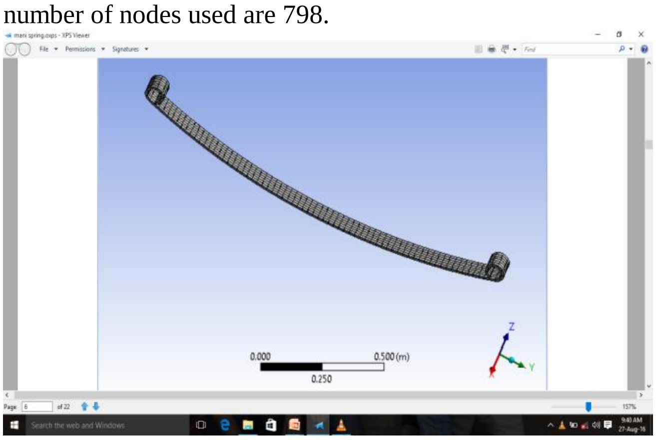

Figure 4.2 Meshed model of leaf spring

5) Apply boundary condition

Boundary condition one end remote displacement for component X free, Y and Z fixed and rotation Z free, X and Y fixed and other end remote displacement for component X, Y and Z fixed and rotation Z free, X and Y fixed. Loading conditions involves applying a load upper side at the centre of the bottom leaf spring.

- Define force.

Figure 4.3Define

Define displacement constrain.

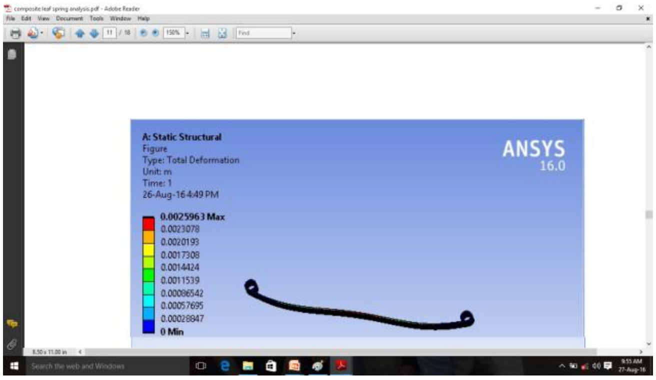

Figure 4.4 Displacement of composite leaf spring

6) Run analysis.
7) Get results.
   - Von-misses stress contour

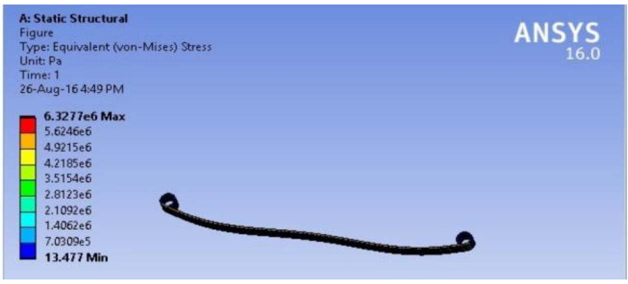

Figure 5.5 Von misses stress contour of E-glass/epoxy leaf spring

COMPARISON OF STEEL AND COMPOSITE LEAF SPRING ANALYSIS DATA

Table 5.2 Comparison of analysis result for steel and composite leaf spring

Material	Displacement(mm)	Stress(MPa)	Weight (Kg)
Steel	0.11609	6.3407	0.1951
E-glass/epoxy	0.04902	1.509	3.73327

Here, from comparison of steel leaf spring with composite leaf spring as shown in table 5.2, it can be see that the maximum deflection 0.11609 mm on steel leaf spring and corresponding deflection in E-glass/epoxy is 0.04902 mm. Also the von-misses stress in the steel leaf spring 6.3407 MPa while in E-glass/epoxy the von-misses stress is 61.509MPa. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight by 84.98% for E-glass/epoxy over steel leaf spring.

V. CONCLUSION

The design and static structural analysis of steel leaf spring and composite leaf spring has been carried out. Comparison has been made between composite leaf spring with steel leaf spring having same design and same load carrying capacity. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite leaf spring reduces the weight by 84.98% for E-glass/epoxy over steel leaf spring. The size optimization has been carried out for further mass reduction of composite leaf spring.

Material	Displacement(mm)	Stress(MPa)	Weight (KG)
Steel	0.11609	6.3407	0.1951
E-glass/epoxy	0.04902	1.509	3.73327

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