

# MODELLING AND STRUCTURAL ANALYSIS OF LEAF SPRING USING FINITE ELEMENT METHOD

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**Abstract:** Leaf springs are used in suspension systems. The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio. The past literature survey shows that leaf springs are designed as generalized force elements where the position, velocity and orientation of the axle mounting gives the reaction forces in the chassis attachment positions. Therefore, analysis of the composite material becomes equally important to study the behaviour. The leaf springs are modeled with ANSYS Design Modeler and the analysis is carried out using ANSYS 15.0 FEA software to predict the behaviour. Then comparison of static analysis results for three materials and multi layered composite material leaf spring are done. Design of rear suspension is verified and validated successfully for ultimate load of 50000N, durability and handling by doing finite element analysis and testing. Deflection and Stresses results were verified for analytical results. Result shows that, the composite spring has stresses much lower than steel leaf spring and weight of composite leaf spring was reduced. By capturing the fundamentals of combining dissimilar materials and thus its equivalent modulus affects the overall stiffness characteristics of multi-leaf design.

**Key Words:** Keywords: FEM, ANSYS, Leaf spring, CAE.

## 1. INTRODUCTION

**1.1 Leaf springs:** A spring is defined as an elastic body, whose function is to distort when loaded and to recovers its original shape when the load is removed. Originally Leaf spring called laminated or carriage spring, a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems.

Semi- elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension. The spring consists of a number of leaves called blades. The blades are varying in length. The blades are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the

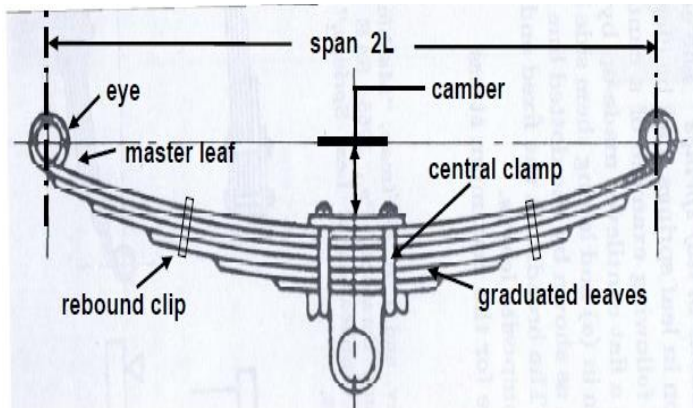
remaining blades are called graduated leaves. All the blades are bound together by means of steel straps. The introduction of composites helps in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability. In the design of springs, strain energy becomes the major factor. In the present scenario the main focus of automobile manufacturers is weight reduction of the automobile. Weight reduction can be achieved mainly by introducing the better material, design optimization and better manufacturing processes. In automobiles, leaf spring is one of the potential parts for weight reduction as it accounts for 10% - 20% of the unsprung weight.

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness.

The springs are initially cambered. More cambered leaf springs are having high stiffness, so that provides hard suspension. Use of longer springs gives a soft suspension, because when length increases the softness increases. Generally rear springs are kept longer than the front springs.

## 1.2 Construction of leaf spring

- Leaf springs used in automobiles is of Semi-Elliptical in form.
- It is built up of number of plates (known as leaf), which are of reducing lengths.
- The longest leaf is called main leaf or Master leaf, and the other leaves are called as graduated leaves.
- The spring is clamped to the axle by means of U-bolts.
- Rebound clips are used to hold the leaves together.
- Central clamp is used to fix the position of leaf spring to the wheel axle.



Leaf spring parts

### 1.3 ANSYS Workbench Overview

ANSYS Workbench is a new-generation solution from ANSYS that provides powerful methods for interacting with the ANSYS solver functionality. This environment provides a unique integration with CAD systems, and your design process, enabling the best CAE results.

ANSYS Workbench is comprised of five modules:

- Simulation for performing structural and thermal analyses using the ANSYS solver.
- CFX-Mesh for generating a CFX-Pre mesh for the CFX-5 solver.
- Design Modeler for creating and modifying CAD geometry to prepare the solid model for use in Simulation or CFX-Mesh.
- DesignXplorer and DesignXplorer VT for investigating the effect of variations input to the response of the system.
- FE Modeler for translating a Nastran mesh for use in ANSYS.

## 2. LITERATURE SURVEY

Leaf springs designing have involved engineering calculations, finite element simulations with extensive fatigue tests in reliability labs. In this section research papers are discussed related to the present work.

**M. Mahmood, e.tal [1]** presented work on design, analysis and optimization of leaf spring using fiber glass with epoxy resins. The steel leaf spring was replaced with an optimized composite one to obtain a spring with minimum weight that is capable of carrying given static external forces without failure.

**A. Strzat and T. Paszek [2]** performed a three-dimensional contact analysis of the car leaf spring by considering static three-dimensional contact problem of the leaf car spring. The static characteristics of the car spring obtained for

different models are compared with experimental investigations.

**Fu-cheng Wang [3]** performed a detailed study on leaf spring. The work mainly discusses the active suspension control of vehicle models in addition to passive suspension case.

**I. Rajendran and S. Vijayarangan [4]** 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 road surface mode.

**M.VENKATESAN e.tal [5]** performed design and experimental analysis of composite leaf spring made of glass fiber reinforced polymer & compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring.

**S. VENKATESH, [6]** research work describes about the development of porous Aluminium foam for making commercial vehicle leaf spring made of Aluminium. The Aluminium foamed leaf spring has stresses much lower than steel leaf spring and weight of aluminium foamed leaf spring was reduced upto 20%.

**G. HARINATH GOWD & E VENUGOPAL GOUD [7]** performs static analysis on leaf spring by using ANSYS software and it is concluded that for the given specifications of the leaf spring, the maximum safe load is 7700N. It is observed that the maximum stress is developed at the inner side of the eye sections.

## 3. DESIGN OF LEAF SPRING

The aim of this work is to develop a 3D modelling of leaf spring and to study the Leaf springs functionality, design parameters effecting on a automobile vehicle suspension system.

### 3.1 Design methodology

Leaf springs are made out of flat plates. The advantage of 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 to energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks.

Consider a single plate fixed at one end and loaded at the other end. This plate may be used as a flat spring.

Let  $t$  = Thickness of plate,

$b$  = Width of plate, and

$L$  = Length of plate or distance of the load  $W$  from the cantilever end.

$$\sigma = \frac{M}{Z} = \frac{W.L}{\frac{1}{6} \times b.t^2} = \frac{6WL}{b.t^2}$$

$$\delta = \frac{W.L^3}{3E.t} = \frac{W.L^3}{3E \times b.t^3/12} = \frac{4W.L^3}{Eb.t^3} = \frac{2\sigma L^2}{3E.t}$$

The above equations for bending stress  $\sigma$  and deflection  $\delta$  for cantilever beam as shown in fig-1

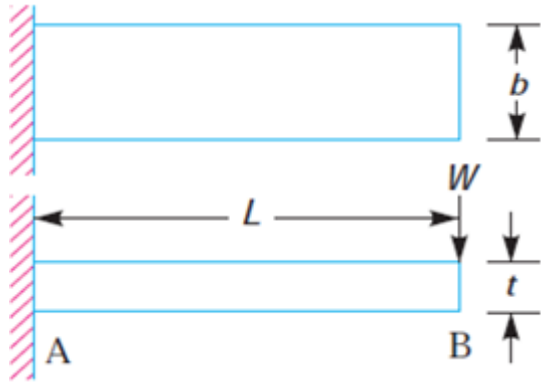


Fig-1.cantiliver beam

The following equations are for laminated plates as shown in Fig-2

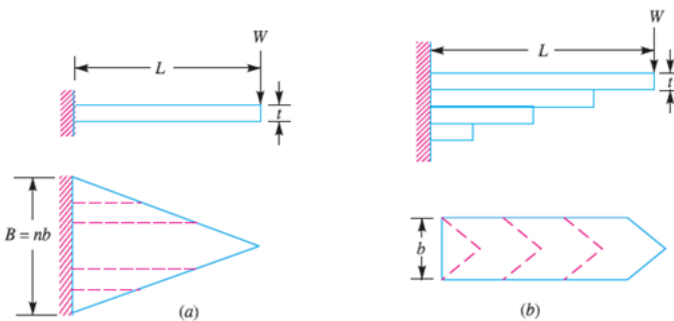


Fig-2 .Laminated plates

$$\sigma_{max} = \frac{pFL}{Nb_n h^2} \quad \text{and} \quad \delta_{max} = \frac{qFL^3}{ENb_n h^3}$$

Where, constants p and q are given as,

For simply supported beam: p= 3 & q= 3

For Cantilever beam: p= 6 & q= 6

N= Number of plates

### 3.2 Leaf spring modeling in Ansys Design modeler

**Dimensions:** Length of top layer=1050mm,

Bottom layer=100mm,

Decrease in length of each layer is 100mm,

Total layers=10.

Each layer thickness =20mm, width= 40mm

Graphics design can be done in many ways. It is always creativity how quick we can create graphics which represents leaf spring. The general procedure in ANSYS design modeller is explained in step by step

Step 1: Choose plane -YZ and draw sketch which represents the top layer of the spring

Step 2: Extrude in normal direction with depth = 40mm.you will get 3-Dimensional layer of leaf spring

Step 3: Draw sketches from the bottom of first layer simultaneously repeat the same procedure for all other 9-layers and extrude with the same width.

Step 4: Draw all other parts sketches and use 3D operation methods like extrude, revolve, pattern etc. to get complete assembly. The final drawing should looks like the fig-3 shown below.

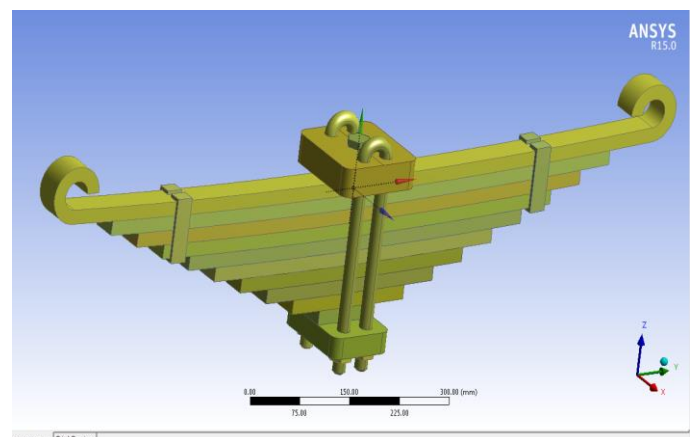


Fig 3. ANSYS model

### 3.3. Material selection of leaf spring

Three materials are considered for the analysis and results are compared with individual three materials and combination of each material.

Analysis 1:all layers with high carbon steel

Analysis 2: all layers with low carbon steel

Analysis 3: all layers with Inconel 600

Analysis 4: Top and bottom with High carbon steel and between Inconel and low carbon combination

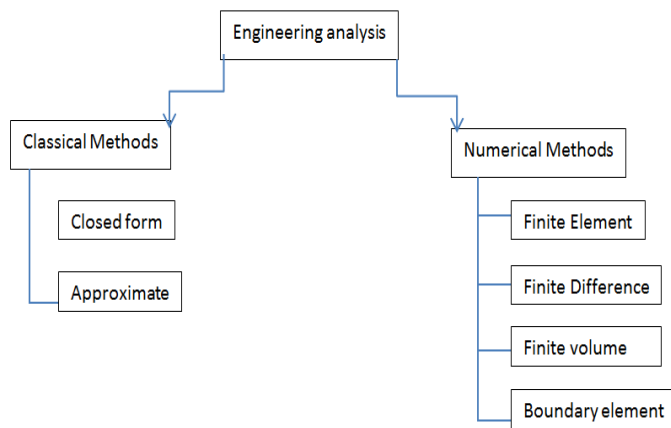
Material properties are given in Table -1

Material/Physical Properties	Hi carbon steel(SAE1074)	Low carbon steel(SAE1020)	Inconel(600)
Density	7840 Kg/m <sup>3</sup>	7700 Kg/m <sup>3</sup>	8500 Kg/m <sup>3</sup>
Young's Modulus	210Gpa	200Gpa	214Gpa
Shear modulus	79.3Gpa	70Gpa	75.8Gpa
Poisson's ratio	0.29	0.3	0.3
Thermal conductivity	49.8W/m K	46.7w/m K	14.8W/m K

Table1: Material Properties

#### 4. FINITE ELEMENT ANALYSIS OF A LEAF SPRING

Engineering analysis can be broadly divided into two categories: classical methods and numerical methods. Following tree diagram shows various methods for solving engineering problems. As shown below, the finite element method is one of several methods for solving engineering problems.



#### 4.1 Analysis Methods

- **Closed-form solutions** are available for simple problems such as bending of beams and torsion of prismatic bars
- **Approximate methods** using series solutions to governing differential equations are used to analyze more complex structures such as plates and shells
- The classical methods can only be used for structural problems with relatively simple geometry, loading, and boundary conditions.

**4.1.2 Numerical methods:** Numerical methods address a broad range of problems.

**Boundary Element Method:** Solves the governing differential equation for the problem with integral equations over the boundary of the domain. Only the boundary surface is meshed with elements.

**Finite Difference Method:** Replaces governing differential equations and boundary conditions with corresponding algebraic finite difference equations.

#### Finite Element Method (FEM)

- Capable of solving large, complex problems with general geometry, loading, and boundary conditions
- Increasingly becoming the primary analysis tool for designers and analysts
- The Finite Element Method is also known as the Matrix Method of Structural Analysis in the literature because it uses matrix algebra to solve the system of simultaneous equations.

**4.2 Meshing:** Leaf spring is meshed using solid 186 element type and has the shapes of tetrahedral & hexa elements as shown in fig.3. Based on geometry flexibility ANSYS directly creates mesh as either hexa/tet or mixed mesh.

By default ANSYS use higher order element i.e., polynomial formulation. SOLID186 - 3D 20-Node homogeneous Structural Solid Mesh is used for leaf spring. The meshed model of the leaf spring is shown in fig-4.

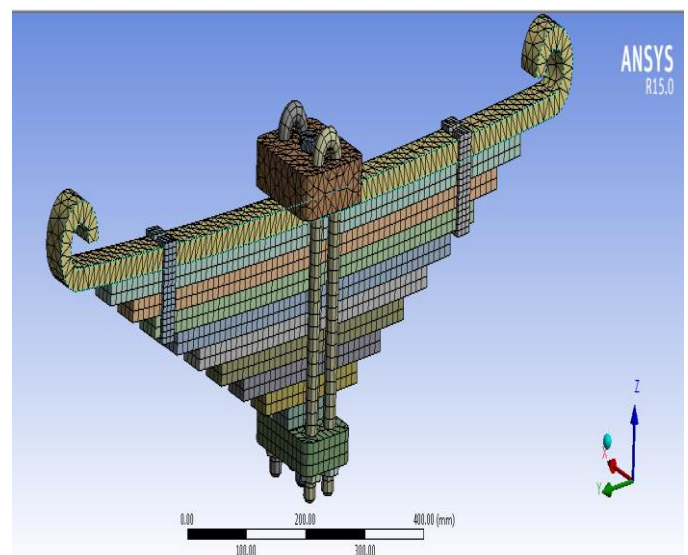


Fig4: Meshed model

#### 4.3 Loads and boundary conditions

For this static structural analysis the following boundary conditions are applied. Fixed remote displacements at two



sides of eye locations and remote force on the center of span. Figure 5. Shows the positions shown for remote displacements at points B & C.

The location of remote force value of 50000 N applied at center in downward direction is shown in fig.5.

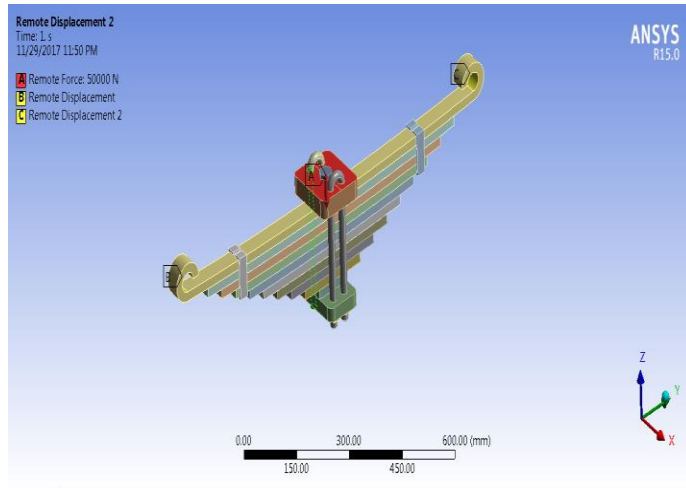


Fig5: Loads & Boundary conditions

#### 4.4 Analysis

This is the last step under pre-processing. This creates the guidance to the solver what parameters to take into consideration, type of analysis like linear, nonlinear, dynamics etc. And type of solver like direct and iterative type.

Solution of linear systems is an important and time-consuming component of Ansys runs. Mathematically, the solution process represents direct solutions.

A right-handed  $[A][X] = [B]$

The direct solution method contains two distinct parts: a forward and a backward substitution, hence its name forward-backward substitution. The forward-backward substitution is a follow-up operation to the decomposition process.

### 5. RESULTS & DISCUSSIONS

Within this thesis, it has been created a virtual design space to investigate the Strength of leaf springs implantation using the finite element method in ANSYS. This design tool is applicable to in a variety of leaf spring design locations, materials (low carbon steel, high carbon steel, Inconel etc.) and designs. Displacements and vonmises's stress plots considered for each analysis configuration.

#### 5.1 Results for Low carbon steel material

Displacement and stress plots are shown in Fig: 6

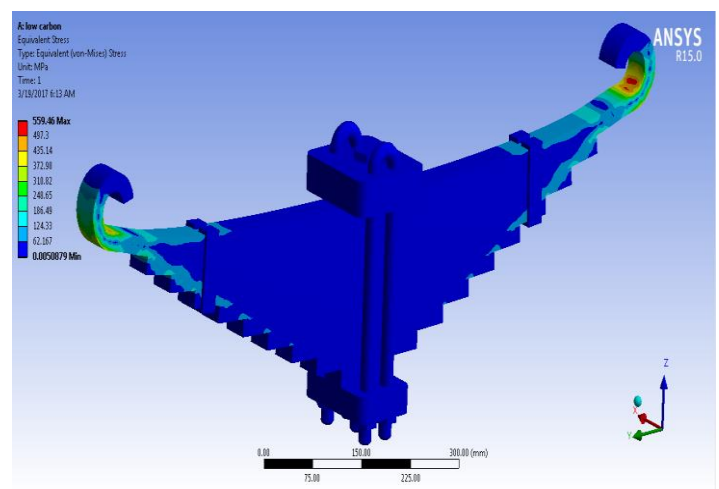
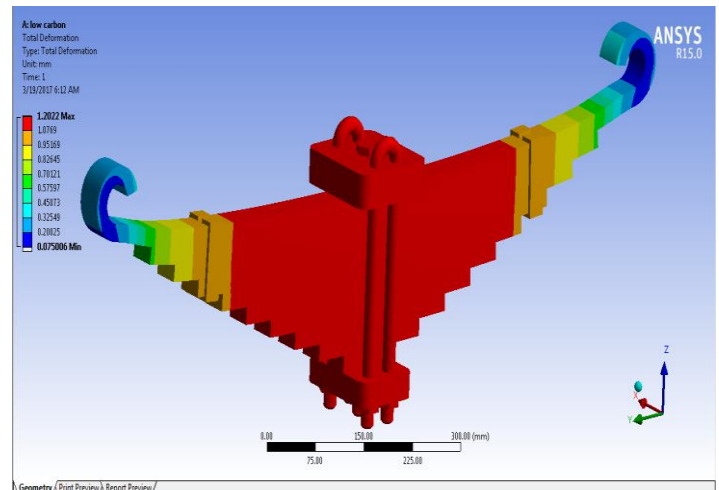
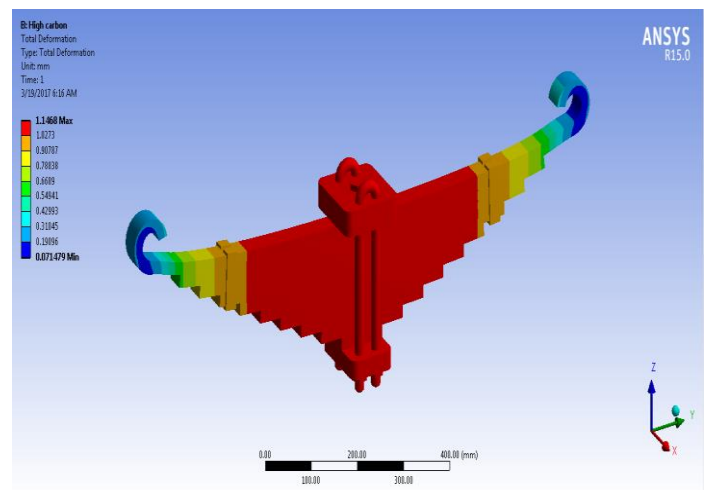


Fig 6: Displacement & stress plots for low carbon steel

Maximum displacement observed as 1.2022mm, Maximum stress observed as 559.46Mpa.

#### 5.2 Results for High carbon steel material

Displacement and stress plots are shown in Fig: 7



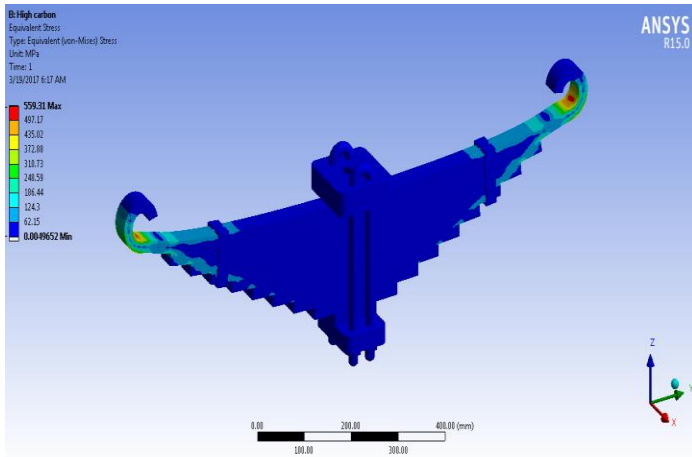


Fig -7: Displacement & stress plots for High carbon steel

Maximum displacement observed as 1.1468mm, Maximum stress observed as 559.31Mpa

### 5.3 Results for Inconel 600 material

Displacement and stress plots are shown in Fig: 8

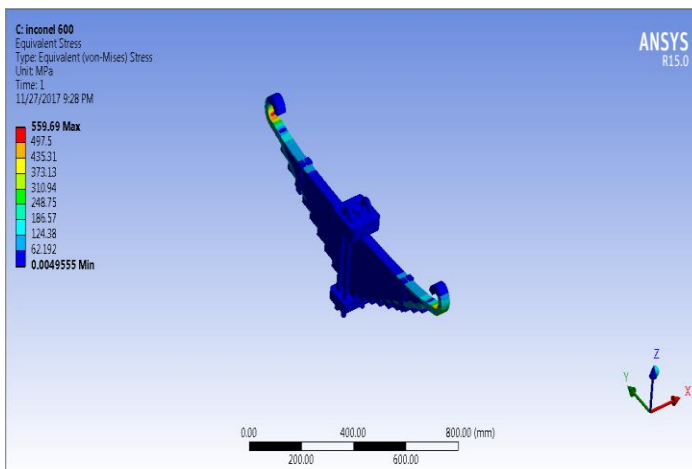
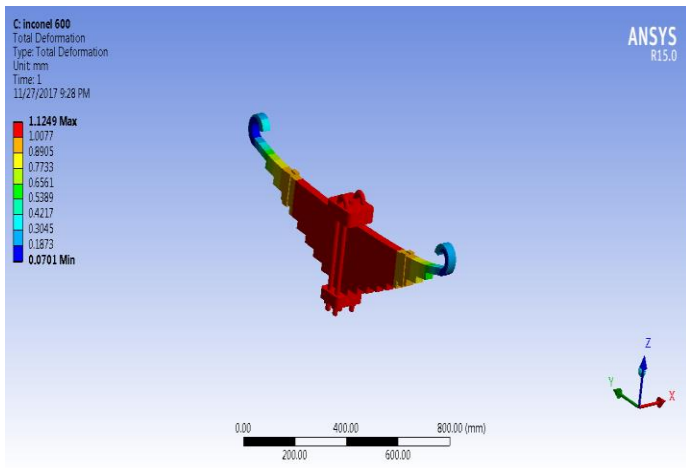


Fig 8: Displacement & stress plots for Inconel 600

Maximum displacement absorbed as 1.124mm Maximum stress observed as 559.68Mpa

### 5.4 Results for multi-material layers

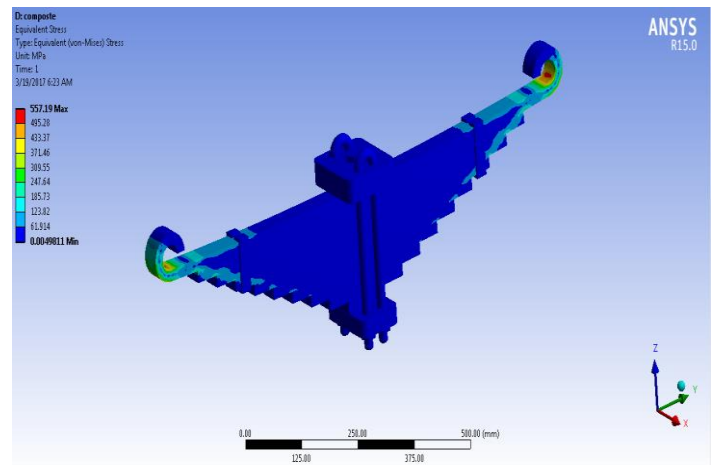
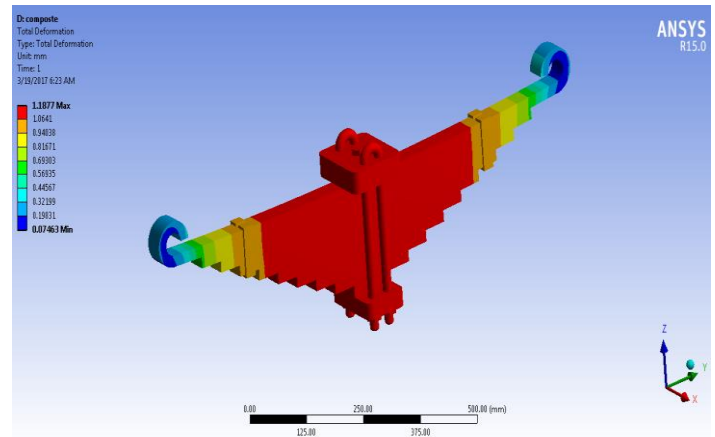


Fig 9: Displacement & stress plots for Multi-material layers

Maximum displacement absorbed as 1.187mm, Maximum stress observed as 557.19Mpa.

### 5.5. Results comparisons with mathematical calculation

The Stress results comparison is given in table 2 and displacement comparison in table 3

Material	Stress values(MPa)		% change	Allowable stress (MPa)	RF
	Theoretical stress	Fem results			
low carbon	546.875	559.77	2.30	400	0.715
high carbon	546.875	554.93	1.45	635	1.144
Inconal 600	546.875	559.69	2.29	690	1.233
multi metals	546.875	557.19	1.85	800	1.436

Table 2.Stress results comparison

Material	Deflection		% change
	Theoretical	Fem results	
low carbon	1.2854	1.2064	6.55
high carbon	1.2242	1.119	9.40
Inconal 600	1.2013	1.1249	6.79
multi metals	1.1177	1.1877	5.89

- [7] G. Harinath Gowd & E Venugopal Goud "Static Analysis Of Leaf Spring" International Journal of Engineering Science and Technology (IJEST), ISSN: 0975-5462 Vol. 4 No.08 August 2012.

Table 3.Displacement results comparison

## 6. CONCLUSION

The leaf spring has been modelled and analysed using ANSYS FEA Software. By performing static analysis it is concluded that the maximum safe load is 50000 N for the given specification of the leaf spring and it is concluded that for the given specifications of the leaf spring FEM gives quite accurate prediction of critical area stresses from the viewpoint of static loading. These static analysis results of 10 layered laminated leaf springs are compared to high and low carbon steel, Nickel based alloy (Inconel 600) to multi material leaf spring. By analysing the design, it is found that all the stresses in the leaf spring are well within the allowable limits and with good factor of safety for the materials high carbon, Inconel and multi-layer metals. This study will help to understand more the behaviour of the spring and give information for the manufacturer to improve the strength of the spring using CAE tools. It can help to reduce cost and time required for research and development of new products.

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