M.Tech (Computational Design) VISHESH SINGH 2020

DESIGN AND STATIC ANALYSIS OF MONO COMPOSITE LEAF SPRING MADE OF VARIOUS TYPES OF COMPOSITE MATERIALS USING FINITE ELEMENT METHOD

A DISSERTATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

OF

MASTER OF TECHNOLOGY

IN

MECHANICAL ENGINEERING
(COMPUTATIONAL DESIGN)

Submitted by:

VISHESH SINGH

2K18/CDN/09

Under the supervision of

Dr. VIKAS RASTOGI

DEPARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

JULY 2020

DEPARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110020

CANDIDATE'S DECLARATION

I Vishesh Singh, Roll No. 2K18/CDN/09, student of M.Tech (Computational Design), hereby declare that the project Dissertation titled "Design and Static Analysis of Mono Composite Leaf Spring Made of Various Types of Composite Materials using Finite Element Method" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

Place: Delhi

Date: 30-06-2020

Vishesh Singh

VISHESH SINGH

DEPARTMENT OF MECHANICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110020

CERTIFICATE

I hereby certify that the Project Dissertation titled "Design and Static Analysis of Mono Composite Leaf Spring Made of Various Types of Composite Materials using Finite Element Method" which is submitted by Vishesh Singh, Roll No. 2K18/CDN/09, Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: 30-06-2020

Dr. VIKAS RASTOGI
SUPERVISOR
Professor
Department of Mechanical Engineering
Delhi Technological University
Bawana Road, Delhi-110042

ACKNOWLEDGEMENT

The success of a project requires help and contribution from numerous individuals and the organization. Writing the report of this project work gives me an opportunity to express my gratitude to everyone who has helped in shaping up the outcome of the project. I express my heartfelt gratitude to my project guide, Dr. Vikas Rastogi, for giving me an opportunity to do my project work under his guidance. His constant support and encouragement have made me realize that it is the process of learning which weighs more than the end result. I am highly indebted to the panel faculties during all the progress evaluations for their guidance, constant supervision, and for motivating me to complete my work. They helped me throughout by giving new ideas, providing necessary information, and pushing me forward to complete the work. I also reveal my thanks to all my classmates and my family for constant support.

ABSTRACT

In this study design and static analysis of mono composite leaf spring are performed in comparison to the existing structural steel leaf spring. The basic idea behind this work is to replace the existing structural steel leaf spring with composite materials. In this work, three different kinds of composite materials are taken such as laminated Carbon/Epoxy, Boron/Aluminum, and Carbon/Epoxy (Non-Laminated) with the same thickness, width, and load-carrying capacity. The main investigation of the study is to reduce the weight of existing structural steel leaf spring while upholding its strength. This study seeks to address, improving load-carrying capacity, and design less stressed and lightweight composite mono leaf spring. In this study, 60% fiber volume fraction and 40% matrix volume fraction is taken. In present work total deflection and equivalent von-misses stresses induced in the different kinds of composite leaf spring are compared with total deflection and equivalent von-misses stresses of structural steel leaf spring. For analysis purposes, ANSYS workbench 19.2 is used and for modeling of composite leaf spring, NX 10 (UNIGRAPHICS) is used. Finally, from the static analysis results, we can say that the newly designed composite spring made of Carbon/Epoxy (Non-Laminated) has better performance than the existing conventional structural steel leaf spring.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter-1

Introduction

CHAPTER 1

INTRODUCTION

1.1 Background

Leaf spring is also one of the oldest forms of spring, dating back to medieval times. Leaf springs can serve to locate and to some extent damping as well as spring functions. While the interleaf friction provides a damping action, it is not well controlled and results in satiation in the motion of the suspension [1]. 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 the location for 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 [2].

1.2 Suspension System

The vehicles must have a good suspension system that can deliver a good ride and good human comfort suspension system separate the axle from the vehicle chassis so that any road irregularities are not transmitted directly to the driver and the load on the vehicle. This is not only allowing a more comfortable ride, and protection of the load from possible damage, but it also helps to prevent distortion and damage to the chassis frame [15].

The automobile chassis is mounted on the axles, not direct but some form of springs is available. This is done to isolate the vehicle body from the road shocks, which may be in the form of bounce, pitch, roll, or sway. Then, the suspension system must consist of a spring and damper to isolate. During driving the energy of road shock causes the spring to oscillate, these oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber [16].

Generally, the suspension system of vehicles used to prevent the road shocks from being transmitted to a vehicle component, to safeguard the occupants from road shocks, and to preserve the stability of the vehicle in pitting or rolling, while in motion. Many types of springs are available in a vehicle suspension system such as helical spring, conical, and volute spring, laminated spring.

1.2.1 Leaf springs

Leaf springs (flat springs) made from flat plates which are called leaves. The leaves are usually given as initial curvature or cambered so that they will tend to straighten when the load is applied. And the leaves are held together by a means of a band shrunk around them at the center or by a means of bolt, passing through the center of it. Since the band exerts stiffening and strengthening effect, therefore the effective length of the spring for bending will be an overall length of spring minus width of the band. And again, in the case of a center bolt, two-third distance of U-bolt should be subtracted from the overall length of the spring in order to find effective length of the leaf spring [56]. Leaf springs are mounted on the axle of the vehicle by using a U-bolt. The leaf spring has two eyes which are front and rear eye, the front eye is found at the front end of the master leaf and the rear eye which is found at the rear end of the master leaf of 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 that connects between leaf spring rear eye and frame. When the vehicle comes across a projection on the road surface, the wheel moves up, this leads to deflecting the spring. This changes the length between the spring eyes [16] [17].

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 the energy absorbing device. Thus, leaf spring may carry lateral loads, brake torque, driving torque, in addition to the shocks. The ability to absorb and store more amount of energy ensures the comfortable operation of a suspension system. However, the problem of the heavyweight of spring is still persistent.

Now a day suspension system of any vehicles contains leaf spring to absorb jolts. But it is observed that the failure of steel leaf springs is usually catastrophic [18]. Then to reduce accidents, which comes through such failures conventional steel leaf spring can be replaced with gradually failing composite leaf springs. By doing this, the weight of the vehicle and fuel consumption may also be reduced while maintaining the strength of the leaf spring.

It is well known, the conventional steel leaf springs are all meet the basic requirement of strength and functionality, but the current Lightweight composite materials give several advantages over the current conventional steel leaf spring. This is because composite materials offer significant opportunities for enhancement of product performance in terms of strength, stiffness, life span, and energy absorption, combined with weight reduction and space-saving. Then now let's see in details about composite materials.

1.3 Composite Materials

Composites Materials are combinations of two materials in which one of the materials, called the reinforcing phase, which is in the form of fiber sheets or particles and are embedded in the other material called the matrix phase. The primary functions of this matrix are to transfer stresses between the reinforcing fibers or particles and to protect them from mechanical and environmental damage whereas the presence of fibers or particles in a composite improves its mechanical properties such as strength, stiffness, etc. A composite is therefore a synergistic combination of two or more micro-constituents that differ in physical form and chemical composition and which are insoluble in each other. Our objective is to take advantage of the superior properties of both materials without compromising on the weakness of either. Composite materials have successfully substituted the conventional materials in several applications like lightweight and high strength. The reasons why composites are selected for such applications are mainly due to their high strength-to-weight ratio, high tensile strength at elevated temperatures, high creep resistance, and high toughness. Typically, the reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. If the composite is designed and fabricated correctly it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single traditional material. The strength of the composites which are made depends primarily on the amount, arrangement, and type of fiber and /or particle reinforcement in the matrix.

1.3.1 Types of Composite Materials:

Basically, composites can be categorized into three groups based on matrix material. They are:

a) Metal Matrix Composites (MMC)

b) Ceramic Matrix Composites (CMC)

c) Polymer Matrix Composites (PMC)

a) Metal Matrix Composites:

These Composites have many advantages over monolithic metals like higher specific strength, higher specific modulus, better properties at elevated temperatures, and lower coefficient of thermal expansion. Due to these attributes metal matrix composites are under consideration for a wide range of applications viz. combustion chamber nozzle (in **a** rocket, space shuttle), housings, tubing, cables, heat exchangers, structural members, etc.

b) Ceramic matrix Composites:

The main objective in producing ceramic matrix composites is to increase the toughness. Naturally, it is hoped and indeed often found that there is a concomitant improvement in the strength and stiffness of ceramic matrix composites.

c) Polymer Matrix Composites:

These are the most commonly used matrix material. In general, the mechanical properties of polymers are inadequate for many structural purposes. In particular, their strength and stiffness are low compared to metals and ceramics. These difficulties are overcome by reinforcing other materials with polymers.

Secondly, the processing of this type of matrix composites do not require high pressure and high temperature. The equipment which is required for manufacturing polymer matrix composites is simpler. For this reason, polymer composites developed rapidly and soon became popular for structural applications. Polymer composites are used because the overall properties of these composites are superior to those of the individual polymers. The elastic modulus is greater than that of the neat polymer but is not as brittle as ceramics.

1.3.2 Classification of Composite Materials:

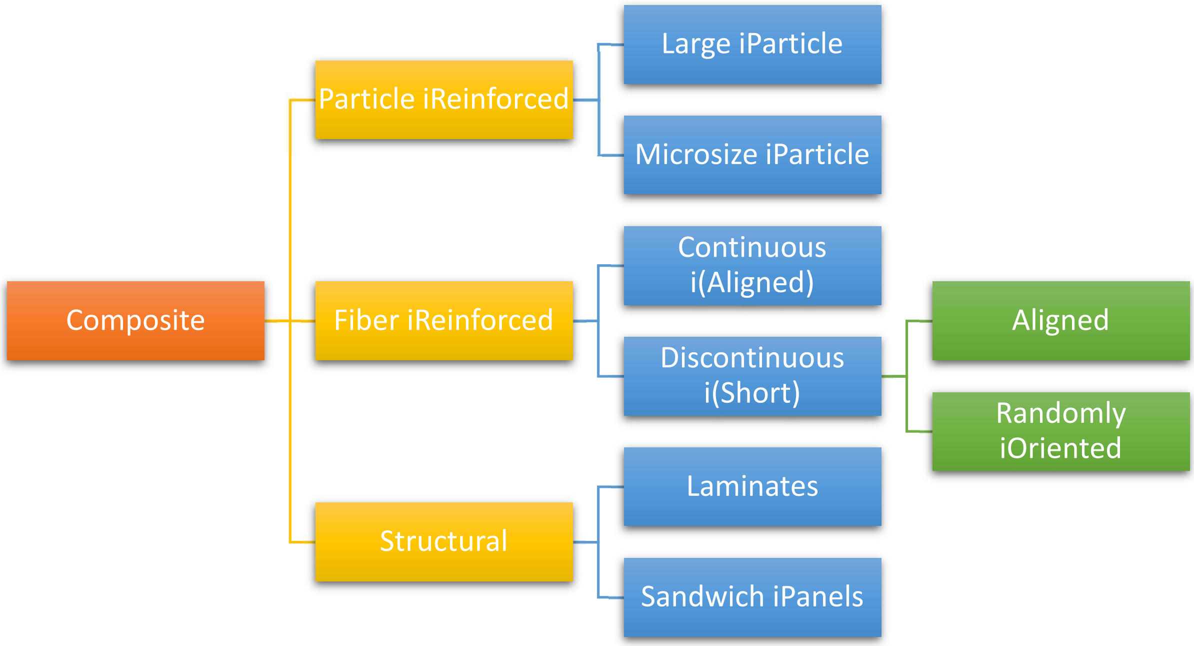


Fig 1.1 Classification of composites based on reinforcement type [24]

Polymer composites can be classified into the following three groups based on reinforcing material. They are:

(a) Fiber reinforced polymer (FRP)

(b) Particle reinforced polymer (PRP)

(c) Structural polymer composites (SPC)

(a) Fiber-reinforced polymer:

The fiber reinforced composites are composed of fibers and matrix. Fibers are the reinforcing elements and the main source of strength while matrix glues all the fibers together in shape and transfers stresses between the reinforcing fibers. The fibers carry the loads along their longitudinal directions. Sometimes, filler is added to smoothen the manufacturing process and to impart special properties to the composites. These also reduce the production cost. The most commonly used agents include asbestos, carbon/ graphite fibers, beryllium, beryllium carbide, beryllium oxide, molybdenum, aluminum oxide, glass fibers, polyamide, natural fibers, etc. Similarly, common matrix materials include epoxy, phenolic resin, polyester, polyurethane, vinyl ester, etc. Among these materials, resin and polyester are the most widely used. Epoxy, which has higher adhesion and less shrinkage than polyesters, comes in second for its high cost.

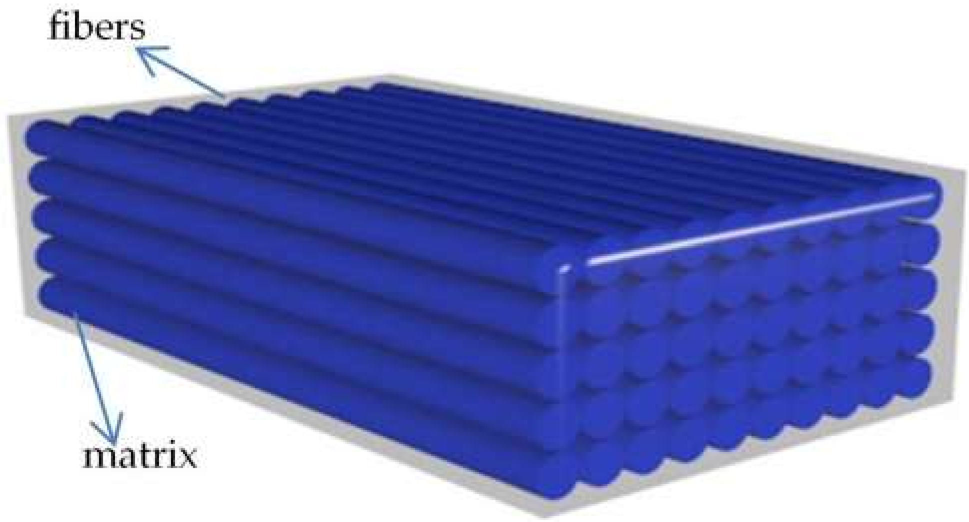


Fig.1.2 Unidirectional Reinforced Composite [23]

(b) Particle reinforced polymer:

Particles which are used for reinforcing include ceramics and glasses such as small mineral particles, metal particles such as aluminum and amorphous materials, including polymers and carbon black. Particles are used to enhance the modulus and to decrease the ductility of the matrix. Some of the useful properties of ceramics and glasses include high melting temp., low density, high strength, stiffness; wear resistance, and corrosion resistance, etc. Many ceramics are good electrical and thermal insulators. Some ceramics have special properties; some have magnetic properties; some are piezoelectric materials, and a few special ceramics are even superconductors at very low temperatures. one major drawback of ceramics and glass is their brittleness. An example of particle – reinforced composites is an automobile tyre, which has carbon black particles in a matrix of polyisobutylene elastomeric polymer.

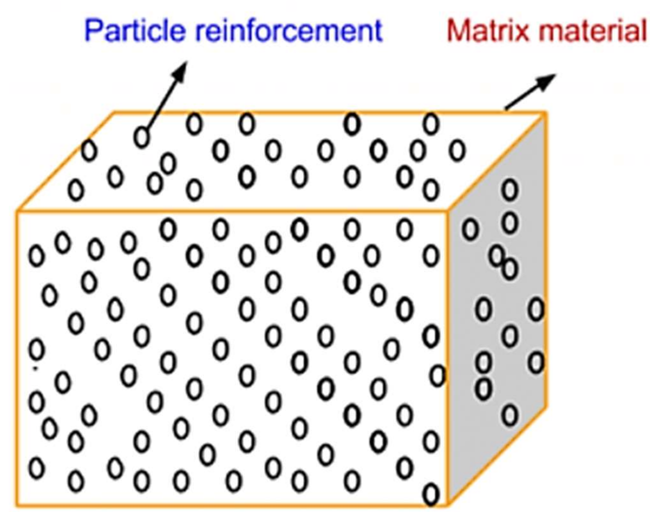


Fig 1.3. Particulate Composite [23]

(c) Structural Polymer Composites:

These are the laminar composites which are composed of layers of materials held together by matrix. This category also includes sandwich structures. Over the past few decades, we find that these polymers have replaced many of the conventional materials in various applications. The most

important advantages of using polymers are the ease of processing, productivity, and cost reduction. The properties of polymers are modified using fillers and fibers to fulfill the high strength and high modulus requirements. Fiber reinforced polymers offer advantages over other conventional materials when specific properties are compared. That's the reason for these composites finding applications in diverse fields from appliances to spacecraft. A lot of work has been carried out on various aspects of polymer composites, but a few researchers have reported on the thermal conductivity modification of particulate filled polymers. Because of this, the present work is undertaken to estimate and measure the effective thermal conductivity of epoxy filled with ceramic powder

Two classes of these composites widely used are:

- Laminar composites
- Sandwich structures.

Laminar composites:

- These are composed of two-dimensional sheets/layers that have a preferred strength direction.
- These layers are stacked and cemented together according to the requirement.
- General materials used in their fabrication are metal sheets, cotton, paper, woven glass fibers embedded in a plastic matrix, etc.
- Eg: thin coatings, thicker protective coatings, claddings, bimetallic, laminates.

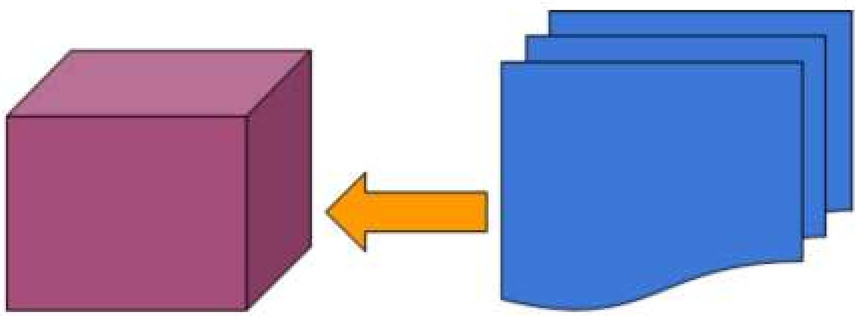


Fig 1.4 Laminar Composites [23]

Sandwich structures:

- As in the figure, these consist of thin layers of a facing material joined to a lightweight filler(core) material.
- Neither the filler material nor the facing material is strong or rigid, but the composite possesses both properties. Example: corrugated cardboard.
- **The faces**
  - Bear most of the in-plane loading and also any transverse bending stresses.
  - General face materials are Al-alloys, fiber-reinforced plastics, titanium, steel, and plywood.
- **The core** serves two functions –
  - Separates the faces and resists deformations perpendicular to the face plane
  - Provide shear rigidity along planes that are perpendicular to the faces.
  - General core materials are foamed polymers, synthetic rubbers, inorganic cements, balsa wood.

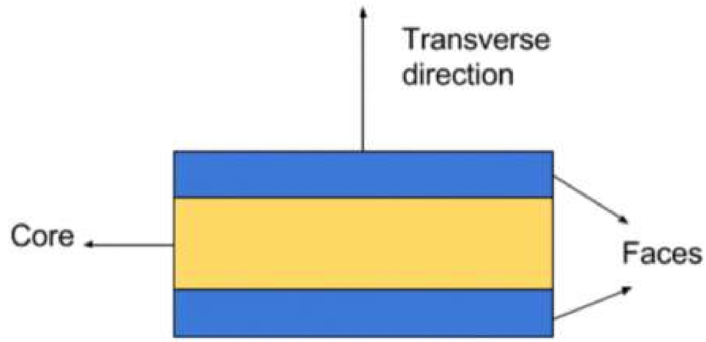


Fig 1.5 Sandwich Structures [23]

1.4 Objective of the study:

- Reduce the overall weight of the suspension system
- Develop a suitable model that has better load carrying capacity and high strength to weight ratio.
- Carry out the theoretical calculation on both the types of models i.e. structural steel model and newly developed composite material model.
- Carry out the static analysis of the newly developed model along with the existing model and finally compare the obtained results with analytical results.

Chapter-2

Literature Review

CHAPTER-2

LITERATURE REVIEW

There are many journals, articles, thesis papers, books, conferences and published a study on the world related to composite leaf spring materials which deals with it, manufacturing methods, type of materials, and analysis. Some of them which are considered to be essential and basic are discussed below here:

2.1. Previous Work-related to Composite Material Leaf Spring

SushilB. Chopade, et al, [1] this paper Study to reduce the weight of the product while upholding its strength. To solve the problem using E-glass/Epoxy composite materials. And finally concluded the study that shows the comparative weight reduction of E- glass/ Epoxy composite material between 30-40%. Also, the stresses produced in composite material are less as compare to conventional steel material.

Prakash E. J, et al, [2] in this paper the researcher study to suggest the best composite material for the design and fabrication of complete mono composite leaf spring. The researcher considers a single leaf with variable thickness and variable width for the constant cross-sectional area of different composite materials, with similar mechanical and geometrical properties to the multi-leaf spring. The design constraints were stresses and displacement. Compared to the steel spring, the composite spring has stresses and deflection that are much lower, and the spring weight nearly 78% lower. Finally, the researcher concludes his work that a comparative study has been made between different composite materials and with the steel in respect of weight, deflection, and stress. It can be observed that Boron Aluminum is the best suitable material for replacing the steel in the manufacturing of mono leaf spring. The saving in the weight is 90.3% [2].

V. K. Aher, et al, [3] in this study the researcher predicted the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations. In addition to this, the researcher described static and fatigue analysis of a modified steel leaf spring of a light commercial vehicle (LCV). The dimensions of a modified leaf spring of an LCV were taken and verified by design calculations. The non-linear static analysis of the 2D model of the leaf spring is performed using NASTRAN solver and compared with analytical results.

Preshit B, et al, [4] study on the "static and modal analysis of leaf spring using FEA" to estimate the deflection, stress, and mode frequency induced in the leaf spring of an army jeep design by the ordinance factory. The emphasis in this project was on the application of computer-aided analysis using the finite element concept. The study performing static analysis and concluded that the maximum safe load is 4000 N for the given specification of the leaf spring. The researcher making the analysis of the composite leaf spring by laminating the carbon fiber/epoxy with the orientation angle of [- 45, 45, 0, 90, 45, 45]. And static analysis results of mono composite Carbon Epoxy leaf springs are compared to steel leaf spring. And finally, the researcher concludes that:

1) The stresses induced in the composite leaf spring are much lower than that of the steel leaf spring.

2) The composite spring can be designed to strengthen and stiffness much closer to steel leaf spring by varying the layer configuration and fiber orientation angles.

3) The strength to weight ratio is higher for composite leaf spring than conventional steel spring with a similar design. And he recommended for future work "by varying the layer configuration higher strengths can be achieved" [4]. The researcher considers only the army jeep to estimate the deflection, stress, and mode frequency induced in the leaf spring of jeep design by the ordinance factory.

Putti Srinivasa R, et al, [5] the researcher study modal and harmonic analysis for a multi-leaf spring for different materials using ANSYS 12.1 and compared with theoretical values. The main idea behind this work is to replace the existing steel leaf spring material for the multi-leaf spring with a composite material with the same width, thickness, and load-carrying capacity. By using composite materials, the weight of the multi-leaf spring is reduced drastically. Finally, the researcher states a conclusion for his work as E-glass/epoxy and carbon/epoxy have a high amplitude of response than other materials and Kevlar/epoxy, graphite/epoxy and steel have low amplitude of response [5].

Ajay B.K, et al, [6] this study aims to reduce the cost and weight of leaf spring, the Automobile sector is replacing steel leaf spring with fiber composite leaf spring, the objective of the study was to replace steel material for leaf spring, the material selected was glass fiber reinforced plastic. A spring with constant width and thickness with different arrangements of composite leaves was used for analysis. And finally, conclude that alternate placing of composite leaves provides similar strength as that of conventional steel leaves with additional advantages. According to the researcher works implementation of three steel leaves instead of four leaves, gives better results than the alternate arrangement of steel and composite leaves. The fourth model arrangement shows a better result than the other two arrangements [6].

Sagar B, et al, [7] the researcher done the study on Design and Analysis of Mono Composite Leaf Spring by Varying Thickness using FEA. During this study, the researcher perform Static analysis in FEA based software Ansys14.5 with design constraints stress, deflection, and varying thickness.

Malaga A, et al, [8] the objective of this paper was to replace the multi-leaf steel spring by mono composite leaf spring for the same load-carrying capacity and stiffness. Since the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to those of steel. It was possible to reduce the weight of the leaf spring without any reduction in load carrying capacity and stiffness [8]. The design constraints were limiting stresses and displacement. Modeling and analysis of both the steel and composite leaf springs had been done using ANSYS software.

Ritesh M. [9] in this study the finite element results showing stresses and deflection verified the existing analytical. Dynamic load analysis of leaf spring using ANSYS 14 software. In this study, the researcher doesn't consider the weight reduction of the leaf spring in detail.

Bhaumik A, et al, [10] the objective of the study was to compare the load-carrying capacity, stiffness, and weight savings of composite leaf spring with that of steel leaf spring. The dimensions of an existing conventional steel leaf spring of a Light design calculations. A static analysis of a model of leaf spring was performed using ANSY S 11.0. The result of the FEA also experimentally verified. The stress-induced in the C-glass/Epoxy composite leaf spring 64% less than that of the steel spring nearly and the deformation induced in the C-glass/Epoxy composite leaf spring 57% less than that of the steel spring nearly [10]. And finally, the researcher concludes that the bending stress induced in the C-Glass/Epoxy composite leaf spring is 64% less than the conventional steel leaf spring for the same load-carrying capacity.

Akshay Kumar, et al, [11] Today's need for manufacturing industries is to make automobiles fuel-efficient. Considering this view the paper study on the manufacturing methods of glass epoxy mono composite leaf spring. Finally, conclude from the study mono composite leaf spring will reduce 77% weight as compared to steel leaf spring. Standing from the above literatures, this paper study changing the current steel leaf spring material by laminated mono carbon/epoxy composite material, because Carbon Fibers has a high strength-to-weight ratio in the direction of fibers, while glass fibers have a lower strength-to-weight ratio, In addition to this carbon Fiber is very stable and is not sensitive to chemical degradation.

M Rama Laxmi, et al, [12] the main objective of the study was to compare the load-carrying capacity, stiffness, and weight reduction of composite leaf spring with that of steel leaf spring, by considering design constraints like stresses and deflections [19]. The researcher on this paper designed a leaf spring by CATIA and analyzed for basic material steel through CATIA and ANSYS nearest values obtained for both soft wares in terms of von-messes stress, strain, and total deformation. Finally analyzed with S-glass, R-glass, and carbon epoxy composite properties through ANSYS. And conclude that S-glass epoxy is the best material to manufacture leaf spring because of good structural stability low production cost and good efficiency.

Parkhe Ravindra A. et al, [13] studied "Performance Analysis of Carbon Fiber with Epoxy Resin Based Composite Leaf Spring" This paper describes design and analysis of composite mono leaf spring. The researcher determines the suitable fiber and resin for his work. Validate performance of single leaf variable thickness carbon/epoxy composite material spring by analytical and FEA analysis, the analytical procedure is followed by finite element analysis and he verified results experimentally. Also, he worked on the fabrication of the composite leaf spring by selecting the hand layup manufacturing technique.

The design constraints were stresses and deflections. The researcher modeled composite mono leaf springs by considering varying cross-section, with unidirectional fiber orientation angle for each lamina of a laminate. And static analysis of a 3D model has been performed using ANSYS 12.0.

Finally, the researcher concludes that:

1. The stresses occurred in the carbon/epoxy composite leaf spring are 42% less than that of the steel leaf spring.

2. The researcher achieved a weight reduction in mono composite leaf spring is about 22.15%.

Chapter-3

Materials and Methods

CHAPTER-3

MATERIALS AND METHODS

3.1 Materials:

In this work three different types of fiber-reinforced composite materials are taken for the analysis of composite mono leaf spring i.e. **laminated Carbon/Epoxy**, non-laminated **Carbon/Epoxy** and **Boron/Aluminium**.

Some of the characteristics of these composites are as follows:

(i) Carbon fiber:

The advantages are high tensile strength to weight ratio as well as tensile modulus to weight ratio, very low coefficient of linear thermal expansion, high fatigue strength, and high thermal conductivity. The disadvantages are low strain to failure, low impact resistance, and high electrical conductivity. Their high cost has so far excluded them from widespread applications. They are mostly used in the aerospace industry, where weight saving is considered more critical than the cost.

S. No	Properties	Value	Unit
1	Elastic Modulus	230	GPa
2	Tensile Strength	3.53	GPa
3	Compressive Strength	1.2	GPa
4	Shear Modulus	52	GPa
5	Density	1.7	g/cm^3
6	Poisson's Ratio	0.15	-
7	Diameter of Fiber	1-10	μm

Table 3.1 Properties of Carbon Fiber Material [19] [20] [21]

(ii) Boron Fiber:

Boron fibers are characterized by their very high tensile modulus, the range of which is 379-414 GPa. Boron fibers have a relatively large diameter and due to which they are capable of withstanding large compressive stress and providing excellent resistance to buckling. Close to the outer surface of the boron a state of biaxial compression exists, which makes the fiber less sensitive to mechanical damage.

(iii) Epoxy Resin:

The chemistry of the epoxy resin component is such that it gives a better adhesion to reinforcing fiber than polyester resin.

The extensive use of epoxy resin in the industry is due to:

- The ease with which it can be processed
- Excellent mechanical properties in composite
- High hot and wet strength properties

Performance of epoxies superior to polyester resin due to their superior mechanical properties and better resistance to degradation by water and solvents.

S. No	Properties	Value	Unit
1	Elastic Modulus	3.3	GPa
2	Tensile Strength	0.13	GPa
3	Shear Modulus	2.26	GPa
4	Density	1.2	g/cm^3
5	Poisson's Ratio	0.37	-
6	Compressive Strength	0.19	GPa

Table 3.2 Properties of Epoxy Resin [19] [22]

(iv) Aluminium:

- It has better corrosion resistance and high damping capacity
- It is lightweight and has better strength
- It has good thermal and electrical properties and its cost-effective as well.

3.2 Terminologies of composite materials:

1. **Isotropic**: isotropic material has properties that are the same in all directions.
2. **Homogenous:** a homogeneous material has properties that are same at all points in the material.
3. **Anisotropic:** at a point in an anisotropic material, material properties are different in all directions.
4. **Nonhomogeneous**: a nonhomogeneous body has material properties which are a function of the position on the body.
5. **Lamina:** a lamina is a single flat layer of unidirectional fiber arranged in a matrix.
6. **Laminate**: a laminate is a stack of plies of composites. Each layer can be laid at various orientations and can be different material systems.
7. **Balanced laminate:** for each $+\theta$ ply in the laminate there an equally thick $-\theta$ ply in the laminate, but this does not apply to 0 degree and 90^0 plies.
8. **Symmetric laminate:** the plies of the laminate are a mirror image about the geometrical midplane.
9. **Angle ply laminate:** containing plies oriented at angles other than 0 degree and 90 degree.

3.3 Design Guidelines for laminated composite materials:

(i) The composite laminate thickness is very small compared to other dimensions of the composite materials.

(ii) The lamina (layers) of the composite laminate is homogenously bonded.

(iii) Lines perpendicular to the surface of the laminate remain straight and perpendicular to the surface after deformation.

(iv) The layers of the laminate are linear elastic.

(v) Since the layers of the laminate are linearly elastic, then through-the-thickness stresses and strains are negligible.

According to [25] Laminate design starts by selecting the set of ply angles relevant to a given application. Due to manufacturing constraints, the allowed ply orientations are reduced to a discrete set of angles such as $\{0°, \pm 15°, \pm 30°, \pm 45°, \pm 60°, \pm 75°, 90°\}$. Once the angles are selected, the total number of plies and the proportion of each orientation in the laminate are set and a stacking sequence is chosen. Additionally, when designing structures comprising several zones of different thicknesses, thickness variations are obtained by dropping plies at specific locations. For both laminate stacking sequence design and ply-drop design, numerous guidelines apply, based on industry experience from test and analysis.

According to [26, 27] about design guidelines and their justification is provided as below:

1. **Symmetry.** Whenever possible, stacking sequences should be symmetric about the mid-plane.

2. **Balance.** Whenever possible, stacking sequences should be balanced, with the same number of $+\theta°$and $-\theta°$ plies ($\theta \neq 0$ and $\theta \neq 90$).

3. **Contiguity.** No more than a given number of plies of the same orientation should be stacked together. The limit is set here to two plies.

4. **Disorientation.** The difference between the orientations of two consecutive plies should not exceed $45°$.

5. **10%-rule**. A minimum of 10% of plies in each of the 0o, ±45o, and 90o directions is required. Here, to allow for other ply orientations, this rule is transposed in terms of a minimal in-plane stiffness requirement in all directions.

6. **Damtol.** No 0^o -ply should be placed on the lower and upper surfaces of the laminate.

Symmetry and balance guidelines aim at avoiding respectively shear-extension and membrane-bending coupled behaviors. The other rules are beneficial to the strength of the structure. They aim at avoiding matrix dominated behaviors (10%-rule) and possible strength problems due to unwanted failure modes such as free-edge delamination (disorientation) or propagation of transverse matrix cracking (contiguity). With primary load-carrying plies shielded from the exposed surface of the laminates (damtol), the effect on strength of exterior scratches or surface ply delamination is reduced.

Based on the above design guideline of laminated composite material, the number of plies, stacking sequence of the plies and the remaining lamination parameters are discussed below:

Number of plies: no. of plies selected as = 10, which is easy to maintain the above-laminated material design guidelines with good laminated strength in both the longitudinal and transverse direction of the fibers of the laminated composite material. In addition to this, it is to good minimizing manufacturing time and material cost.

Stacking sequence: angle of orientation and the stacking sequence of a composite laminate play a great role in maintaining the required strength in all transverse and longitudinal direction of the composite laminate.

$[45°/0°/0°/-45°/90°/90°/-45°/0°/0°/45°]_T$

Or

$[45°/0°/0°/-45°/90°]_S$

Where,

T=Total number of plies angle sequence

S=Mid plane symmetry sequence

Ply thickness: Since the designed carbon/epoxy leaf spring has 24 mm thick, then the total thickness of the laminated material has also the same as to the leaf spring, therefore each ply has a thickness of 2.4 mm.

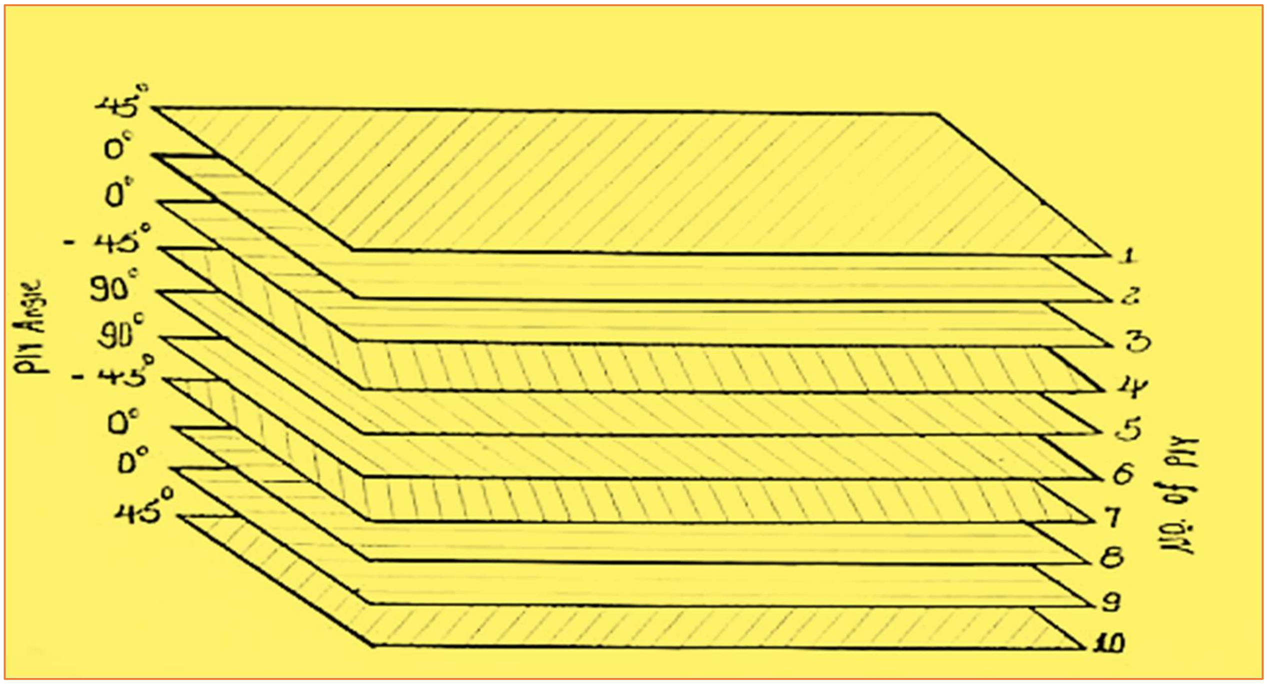


Fig. 3.1 *Stacking of plies in a composite laminate with* $45°, 0°, 0°, -45°, 90°, 90°, -45°, 0°, 0°, 45°$ *angle of the fiber reinforcement.*

In this study, we have chosen a 60% fiber volume fraction and a 40% matrix volume fraction. This selection is done by considering the following factors:

- To minimize the cost of the fiber.
- To make a strong bond between fiber and matrix.
- To minimize the overall weight of the leaf spring.
- To minimize the brittle of the leaf spring. Generally, the selected fiber and matrix volume fraction is a good selection for making the composite material for leaf spring.

3.4 Basic Lamina Properties:

The unidirectional lamina or ply is considered the basic building block of any laminate or composite structure. The basic material properties necessary for analysis and design are the average ply properties.

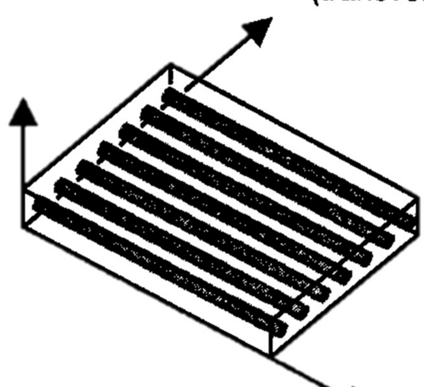


Fig. 3.2 Lamina and principle coordinate axes of unidirectional reinforcement [28]

Regarding fig 3.2 the unidirectional ply is characterized by the following properties:

E_1, E_2, E_3=Young's moduli along the principal ply direction

G_{12}, G_{23}, G_{13}=Shear moduli in 1-2, 2-3 and 1-3 planes, respectively
(These are equal to G_{21}, G_{32}, and G_{31}, respectively)

v_{12}, v_{23}, v_{13}=Poisson's ratios (the first subscript denotes the loading direction, and the second subscript denotes the strain direction: these poisons ratios are different from v_{21} v_{32}, v_{31}, that is, subscript are not interchangeable.)

in addition to the above, the composite lamina is characterized by the following properties: [28]

Fiber volume fraction: $V_f = \frac{volume\ of\ fiber}{volume\ of\ composite}$……………………………………………..(3.1)

Fiber weight fraction: $W_f = \frac{weigh\ \ of\ fiber}{weight\ of composite}$…………………………………………………(3.2)

Matrix weight fraction: $Vm = \frac{volume\ of\ matrix}{volume\ of\ composite}$………………………………………………(3.3)

Matrix weight fraction: $W_m = 1 - W_f = \frac{weight\ of matrix}{weight\ of\ composite}$…………………………………...(3.4)

The calculated properties of laminated Carbon/Epoxy for 60 % fiber volume fraction and 40 % matrix volume fraction are tabulated as follows:

S. No	Material Properties	Symbol	Value	Unit
1	Young's Modulus in X-Direction	E_x	60.7876	GPa
2	Young's Modulus in Y-Direction	E_y	60.7876	GPa
3	Young's Modulus in Z-Direction	E_z	6.675	GPa
4	Density	ρ	1.5	g/cm^3
5	Shear Modulus in X-Direction	G_{12}	32.1	GPa
6	Shear Modulus in Y-Direction	G_{12}	5.3	GPa
7	Major Poisson's Ratio	V_{12}	0.24	-

Table3.3: Calculated properties of laminated Carbon/Epoxy at 60% fiber volume fraction

3.5 Mechanical Properties of Boron/Aluminium and Carbon/Epoxy (Non-Laminated) Composite Material:

For fiber volume fraction of $V_f = 60\%$, Mechanical Properties is as follows:

(i) Boron/Aluminium:

S. No.	Properties	Values	Unit
1	Youngs Modulus X-Direction (EX)	215000	MPa
2	Youngs Modulus X-Direction (EY)	14400	MPa
3	Youngs Modulus X-Direction (EZ)	14400	MPa
4	Shear Modulus XY Direction (GXY)	5700	MPa
5	Shear Modulus YZ Direction (GYZ)	4590	MPa
6	Shear Modulus ZX Direction (GZX)	5700	MPa
7	Poisson's Ratio XY (v_{XY})	0.19	
8	Poisson's Ratio YZ (v_{YZ})	0.29	
9	Poisson's Ratio ZX (v_{ZX})	0.19	
10	Density (ρ)	2620	Kg/m^3

11	Longitudinal Tensile Strength	1300	MPa

Table 3.4 Mechanical Properties of Boron/Aluminium [14]

(ii) Carbon/Epoxy (Non-Laminated):

S. No.	**Properties**	**Values**	**Unit**
1	Youngs Modulus X-Direction (EX)	147000	MPa
2	Youngs Modulus X-Direction (EY)	10300	MPa
3	Youngs Modulus X-Direction (EZ)	10300	MPa
4	Shear Modulus XY Direction (GXY)	7000	MPa
5	Shear Modulus YZ Direction (GYZ)	3700	MPa
6	Shear Modulus ZX Direction (GZX)	7000	MPa
7	Poisson's Ratio XY (v_{XY})	0.27	
8	Poisson's Ratio YZ (v_{YZ})	0.54	
9	Poisson's Ratio ZX (v_{ZX})	0.27	
10	Density (ρ)	1520	Kg/m^3
11	Longitudinal Tensile Strength	1841	MPa

Table 3.5 Mechanical Properties of Carbon/Epoxy (Non-Laminated) [14]

3.6 Specifications of Daewoo Damas-II Car Leaf Spring

	1. General Information	
S No.	**Features**	**Value**
1.1	Brand	Daewoo
1.2	Modal	Damas
1.3	Generation	Damas II
1.4	Engine	0.8 (38HP)
1.5	Doors	5
1.6	Power	38 HP/5000 RPM

1.7	Acceleration	100 Km/hr.
1.8	Fuel Tank Volume	37 liters
1.9	Seats	7
1.10	Weight	885 kg
	2. Body Features	
2.1	Lengths	3230 mm
2.2	Width	1400 mm
2.3	Wheel Base	1920 mm
2.4	Front Track	1840 mm
2.5	Rear Track	1210 mm
	3. Chassis	
3.1	Front Brake	Disc
3.2	Rear Brake	Drum
3.3	Tyre Size	155 R12

Table 3.6 Specifications of Daewoo Damas II Car [30]

Here weight and initial measurement of four-wheeler Damas II light vehicle are taken [30]:

Mass of Damas II vehicle = 885Kg

Maximum load-carrying capacity = $7 \times 80 = 560$ Kg, by taking the average mass of human 80 kg.

Total Mass = 885 + 560

M = 1445 Kg

Take Acceleration due to gravity (g) =10 m/s^2

According to [33] the value of factor of safety ranges = (1.3 – 2.25), then take factor of safety =1.5

Therefore, Total Weight $(W) = 1445 \times 10 \times 1.5$

$W = 21675\ N$

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

Load on each wheel becomes,

W=21675 N

W = 5418.75 N

So again, load on each eye of spring is =2709.375 N, take = 2710 N

The current steel multi leaf spring of Damas II car specifications [30]

Type of material = structural steel

No. of leaves = 4

Length of master leaf (eye to eye) = 130 cm

Length of 2nd leaf = 100 cm

Length of 3rd leaf = 60 cm

Length of 4th leaf = 42 cm

Width of leaves = 4 cm

Thickness of leaf = 6 mm

Camber (no load condition) = 6 cm

Eye bore diameter = 2.8 cm

S. No.	Mechanical Property	Symbol	Value	Units
1	Youngs Modulus	E	207	GPa
2	Shear Modulus	G	76.9	GPa
3	Poisson's Ratio	v	0.3	
4	Density	ρ	7850	Kg/m^3
5	Compressive Yield Strength	σ_c	250	MPa
6	Ultimate Tensile Strength	σ_t	460	MPa
7	Tensile Yield Strength	σ_y	250	MPa
8	Behavior	Isotropic		

Table 3.7 Mechanical Properties of Structural Steel [29]

3.7 Modeling of Leaf Spring

In the current scenario modeling and numerical simulation is a very essential aspect of the automotive sector. Modeling and simulation is preferred because it reduces product manufacturing time, material, material scrap, and material cost. They are necessary to reduce the time to market for new products and the cost associated with experimental testing.

For many years in the majority of the cases, only isotropic materials are modeled but now more elements of an automotive product are replaced with the composite materials so, it has now become necessary to model composite more rigorously.

Overall, there is no doubt that the importance of modeling and simulation in the automotive sector will continue to increase from time to time. In terms of composite materials, the focus for continued development will be the improvement of failure theories, damage modelling, and fatigue life prediction whilst achieving reasonable solution times [34].

3.7.1 2D Sketching and 3D Modeling of Leaf Spring

For both Sketching and Modeling, NX 10 (Unigraphics) is used. various mechanical design and manufacturing operations are modeled using NX (Unigraphics). This software allows the user to make changes very easily without having to go back at the beginning and update all drawings and assemblies.

The Leaf spring is Sketched and modeled based on dimensions that are obtained through theoretical calculations.

(i) Sketching of Structural Steel Leaf Spring:

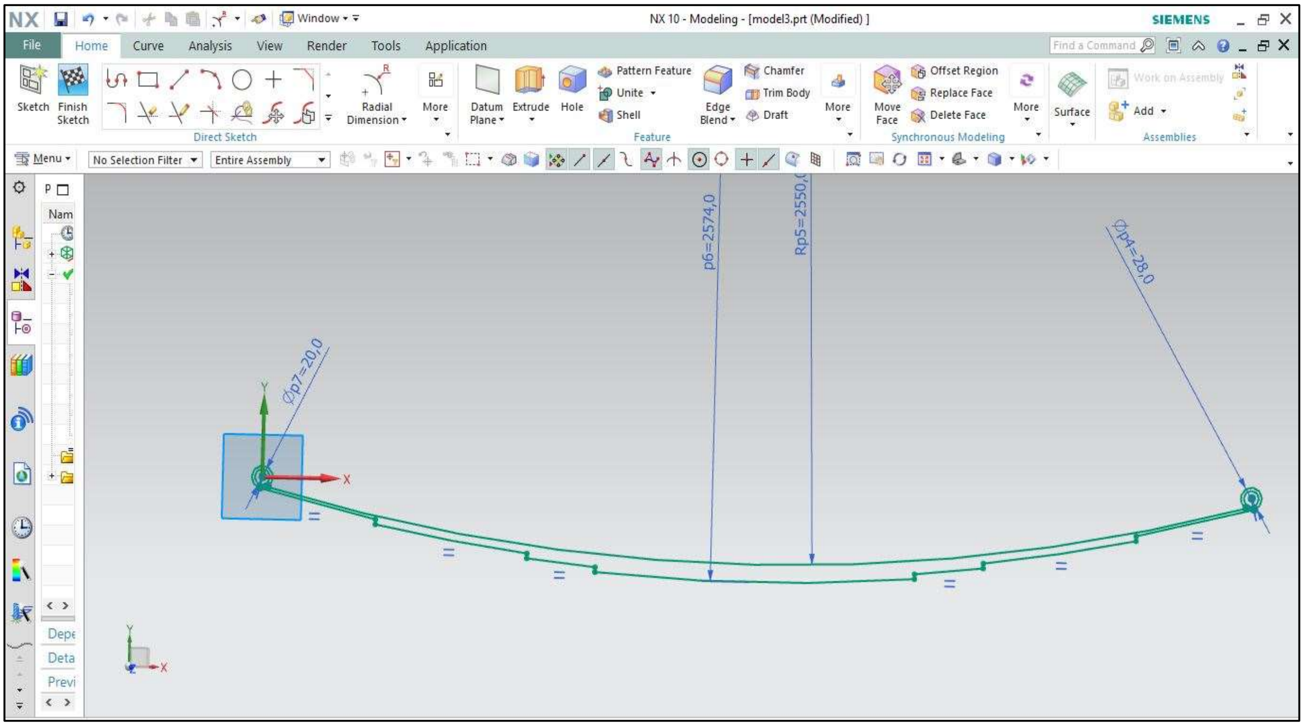


Fig. 3.3 2D Sketching of Structural Steel Leaf spring

(ii) Sketching of Laminated Carbon/epoxy leaf Spring:

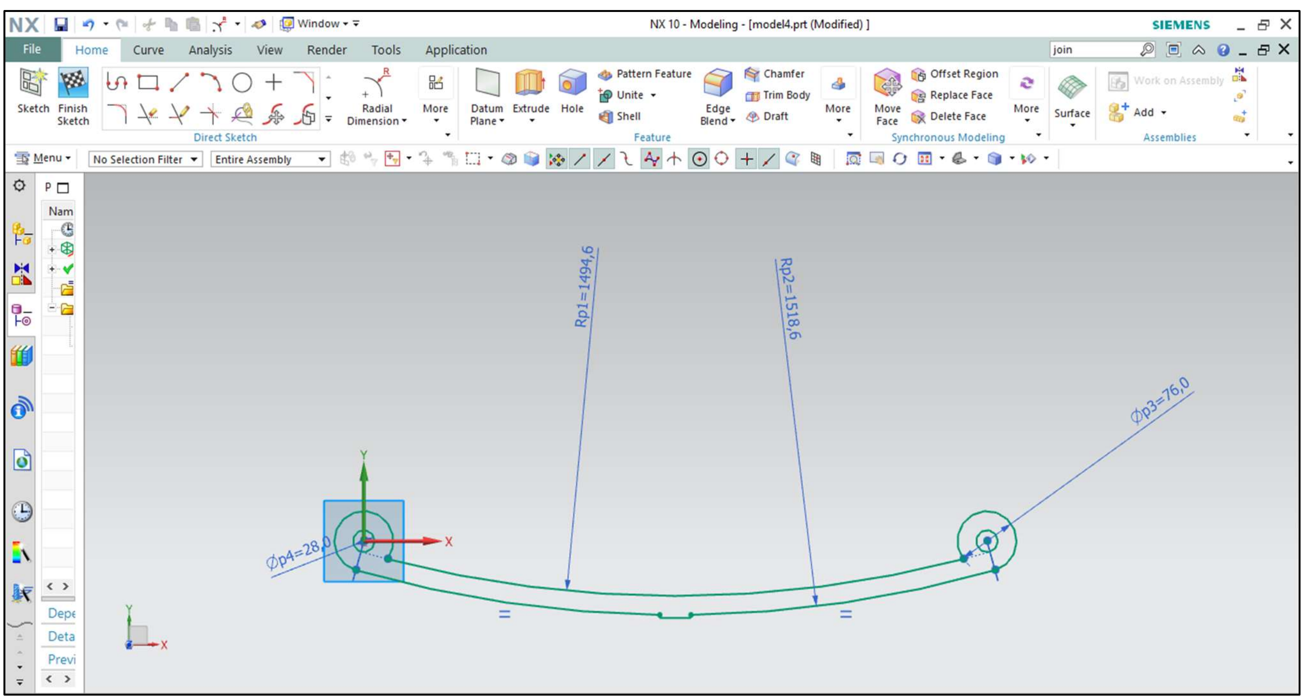


Fig. 3.4 Sketching of Newly Designed Leaf spring

(iii) Modeling of Structural Steel Leaf Spring:

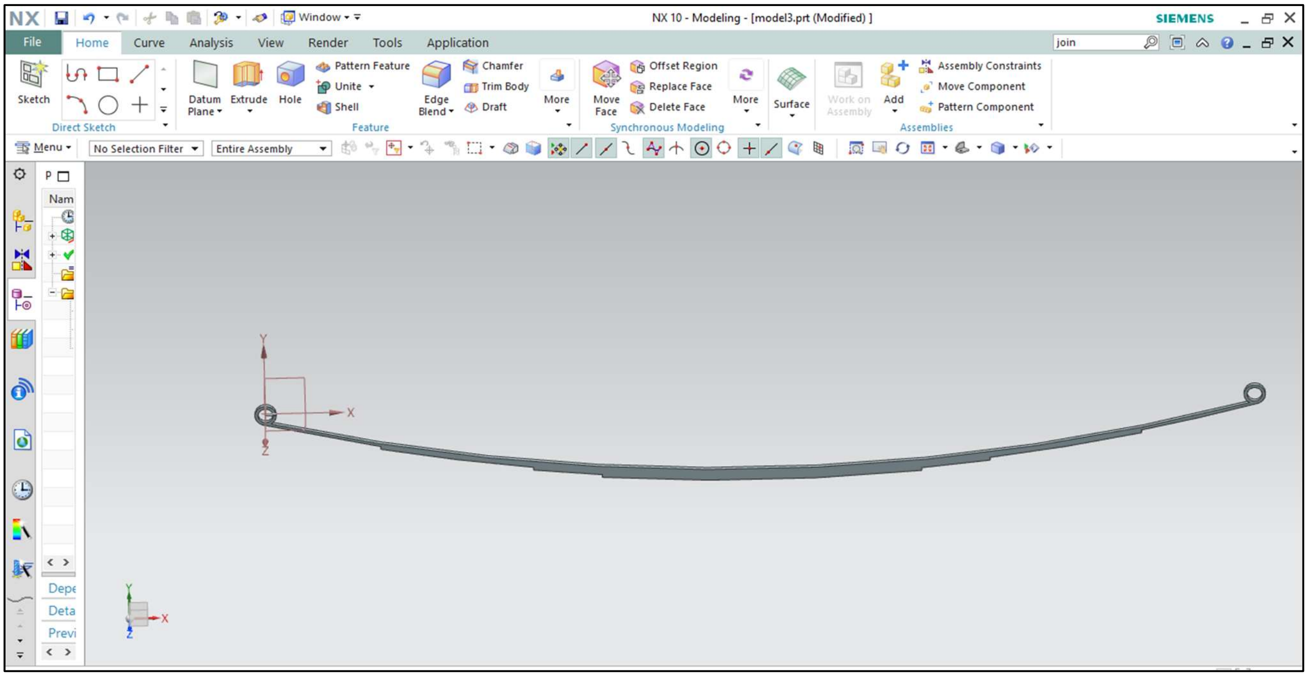


Fig. 3.5 3D Modeled Structural Steel Leaf Spring (Front View)

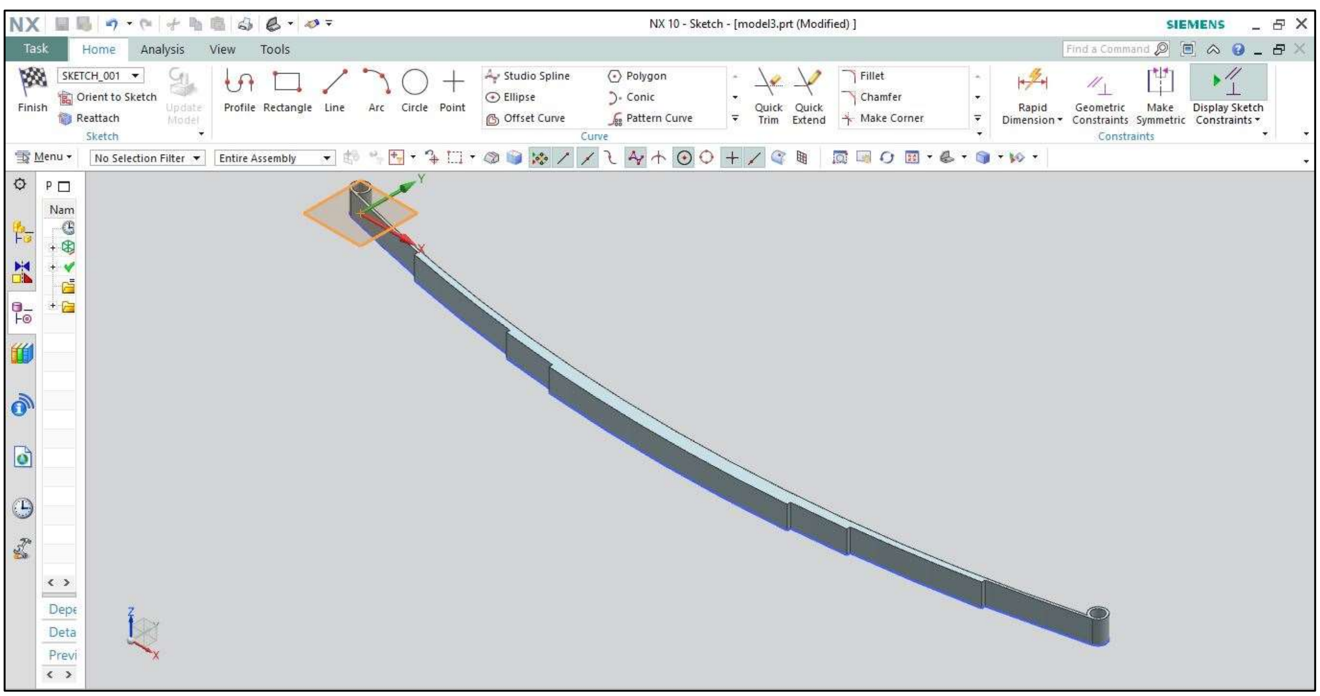


Fig. 3.6 3D Modeled Structural Steel Leaf Spring (Isometric View)

(iv) Modeling of Laminated Carbon/Epoxy Leaf Spring:

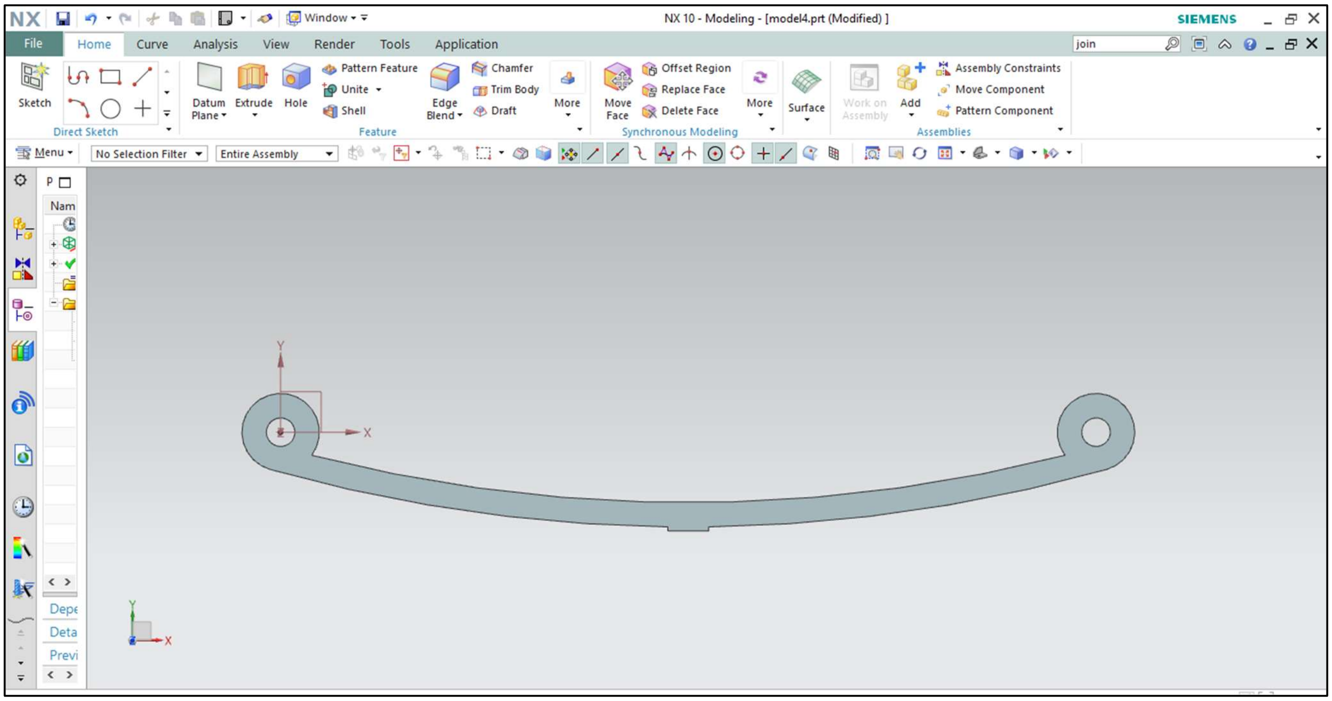


Fig. 3.7 3D Modeled Newly Designed Leaf Spring (Front View)

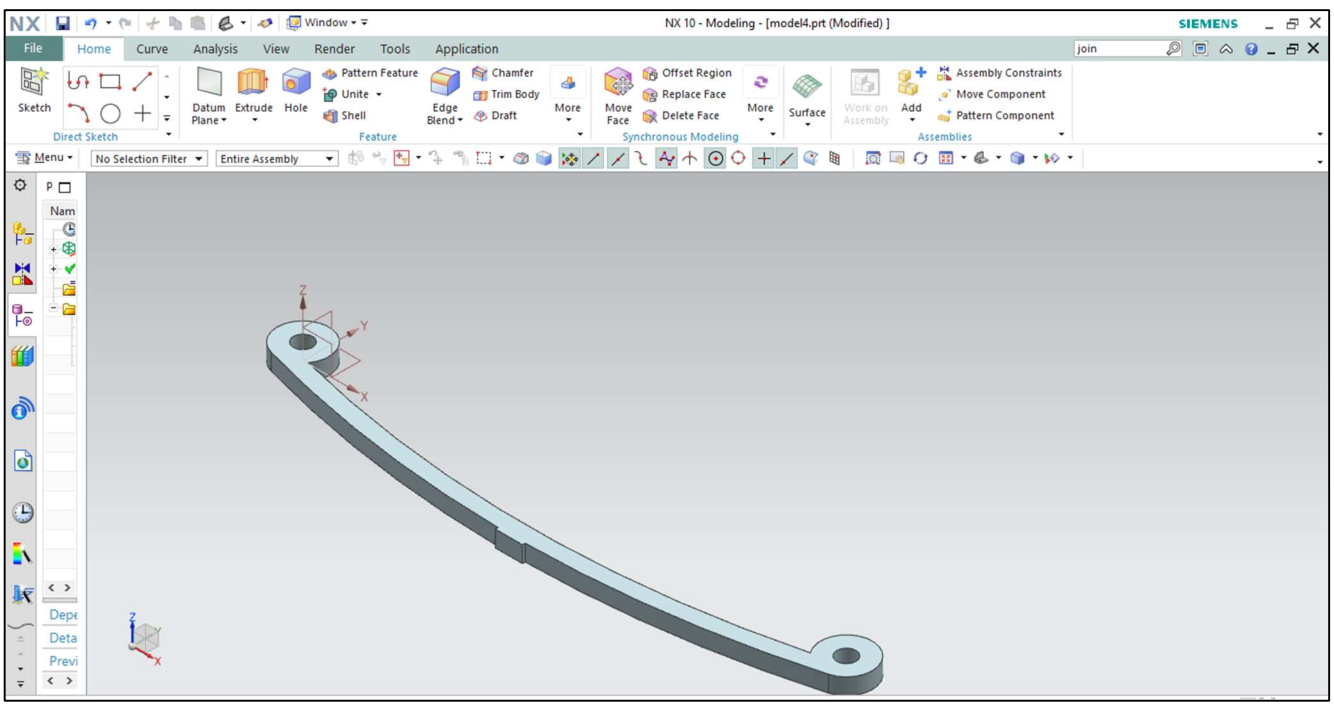


Fig. 3.8 3D Modeled Newly Desinged Leaf Spring (Isometric View)

3.7.2 Mathematical Modeling

Mathematical modeling is an important aspect to understand the actual behavior of any mechanical component when it subjected to loading. In this case, different types of loads are considered which can act in a real situation.

According to the literature, the main cause of failure of the leaf spring is shock produced by the static loading, road irregularities, braking during driving, etc. In this case, the spring is loaded with static loading.

Cross-section of the leaf spring:

(i) Constant Thickness, Varying Width Design:

In this design, the thickness is kept constant over the entire length of the leaf spring while the width varies from a minimum at the two ends to a maximum at the center.

(ii) Constant Width, Varying Thickness Design:

In this design the width is kept constant over the entire length of the leaf spring while the thickness varies from a minimum at the two ends to a maximum at the center.

(iii) Constant Cross-Selection Design:

Both thickness and width are varied throughout the leaf spring design, such that the cross-section area remains constant along the length of the leaf spring.

Out of the above-mentioned design concepts, the constant cross-section design method is selected for this thesis, due to the following reasons [13]:

- Due to its capability for mass production and accommodation of continuous reinforcement of fibers.
- Since the cross-section area is constant throughout the leaf spring, the same quantity of reinforcement fiber and resin can be fed continuously during manufacture.
- Also, this is quite suitable for the filament winding process.

Standing from the shape of the leaf spring nature and easy of analysis, as shown below in the figure, the leaf spring behaves like a cantilever beam, and the static analysis is done considering it as a cantilever beam. Since the leaf spring is mounted on the axle using U- bolts firmly, then the leaf spring counted as a double cantilever beam with a load W at the free end of the leaf spring and length L. According to [31] the cantilever beam is highly exposed to both bending stress and transverse shear stress. Now compute the bending stress and deflection of both the current steel leaf spring and newly designing laminated carbon/Epoxy composite material leaf spring. And the mathematical modeling can be derived standing from cantilever beam nature.

Consider a single plate fixed at one end and loaded at the other end as shown in Fig. below. 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.

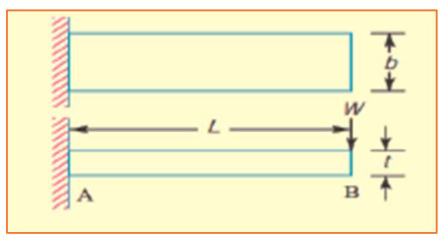


Fig. 3.9 Leaf spring (Cantilever Type)

According to [32], we know that the maximum bending moment at the cantilever end A is:

$M = W \times L$

Where,

W = Load

L = Length of the Spring

Section modulus, $Z = \frac{I}{Y} = \frac{\frac{bt^3}{12}}{\frac{t}{2}}$

$Z = \frac{bt^2}{6}$ Where, b = width

t = thickness

(i) Bending stress in the spring is given as:

$$\sigma = \frac{M}{Z} = \frac{W}{\frac{bt^2}{6}}$$

$$\sigma = \frac{6WL}{bt^2}$$

(ii) the maximum deflection for a cantilever with a concentrated load at the free end is given by:

$$\delta max = \frac{WL^3}{3EI}$$

$$\delta max = \frac{WL^3}{3E \times \frac{bt^3}{12}}$$

$$\delta max = \frac{4W\ ^3}{Ebt^3}$$

$$\delta max = \frac{2\sigma L^2}{3E}, \text{ Where } \sigma = \frac{6WL}{bt^2}$$

Where:

E = Youngs Modulus of Materials

I = Moment of Inertia

$I = \frac{bt^3}{12}$, For rectangular section

Chapter-4

Simulation & Analysis

CHAPTER– 4

SIMULATION & ANALYSIS

4.1 Introduction

Simulation is the process of creating and analyzing a digital prototype of a physical model to predict its performance in the real world. Simulation modeling is used to help designers and engineers understand whether, under what conditions, and in which ways a part could fail and what loads it can withstand.

4.2 Static Structural Analysis

Structural analysis is the determination of the effects of loads on physical structures and their components. Structures subject to this type of analysis include all that must withstand loads, such as buildings, bridges, aircraft, and ships. Structural analysis employs the fields of applied mechanics, materials science, and applied mathematics to compute a structure's deformations, internal forces, stresses, support reactions, accelerations, and stability. The results of the analysis are used to verify a structure's fitness for use, often precluding physical tests. Structural analysis is thus a key part of the engineering design of structures.

Assumption that are considered while carrying out analysis:

These are some of the assumptions that are considered while carrying out simulation and analysis of both conventional leaf spring and newly designed leaf spring.

(i) The eye of the leaf spring count as within the length of it. Therefore, it doesn’t consider for analysis separately.

(ii) The U-bolt clamp connects the leaf spring with the axle of the vehicle firmly, then the connection is counted as fixed and the support is fixed support of the leaf spring.

(iii) However, the physical model of the leaf spring is a double cantilever beam, the analysis is done on the whole geometry of the leaf spring.

4. The quasi-isotropic laminated carbon/epoxy, Boron/Aluminium, and Carbon/Epoxy (Non-Laminated) material is strongly bonded and has homogenous nature.

4.3 Static Structural Analysis of Structural Steel Leaf Spring

For carrying out simulation and analysis of steel leaf spring, we have to follow some steps which are as follows:

(i) Defining Engineering Data

This is the first step that we have to follow to carry out simulation and analysis. We have to feed engineering data in the Ansys workbench.

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	⊟ Material				
3	Structural Steel			G	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5 -110.1
*	Click here to add a new material				

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	7.85	g cm^-3		
4	⊞ Isotropic Secant Coefficient of Thermal Expansion				
6	⊟ Isotropic Elasticity				
7	Derive from	Young's Modu...			
8	Young's Modulus	2E+11	Pa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.6667E+11	Pa		
11	Shear Modulus	7.6923E+10	Pa		
12	⊞ Strain-Life Parameters				
20	⊞ S-N Curve	Tabular			
24	Tensile Yield Strength	250	MPa		
25	Compressive Yield Strength	250	MPa		
26	Tensile Ultimate Strength	460	MPa		
27	Compressive Ultimate Strength	0	MPa		

Fig. 4.1 Engineering Data of structural steel defined in Ansys workbench

(ii) Attach Geometry

After defining engineering data, we have to attach geometry. Either we can model geometry in Ansys design modeler or we can make a model on other designing software and then import geometry into the Ansys workbench. In this thesis modeling of geometry is performed on NX 10 (Unigraphics) and then after converting geometry format to .IGS it is imported into Ansys workbench for analysis purpose.

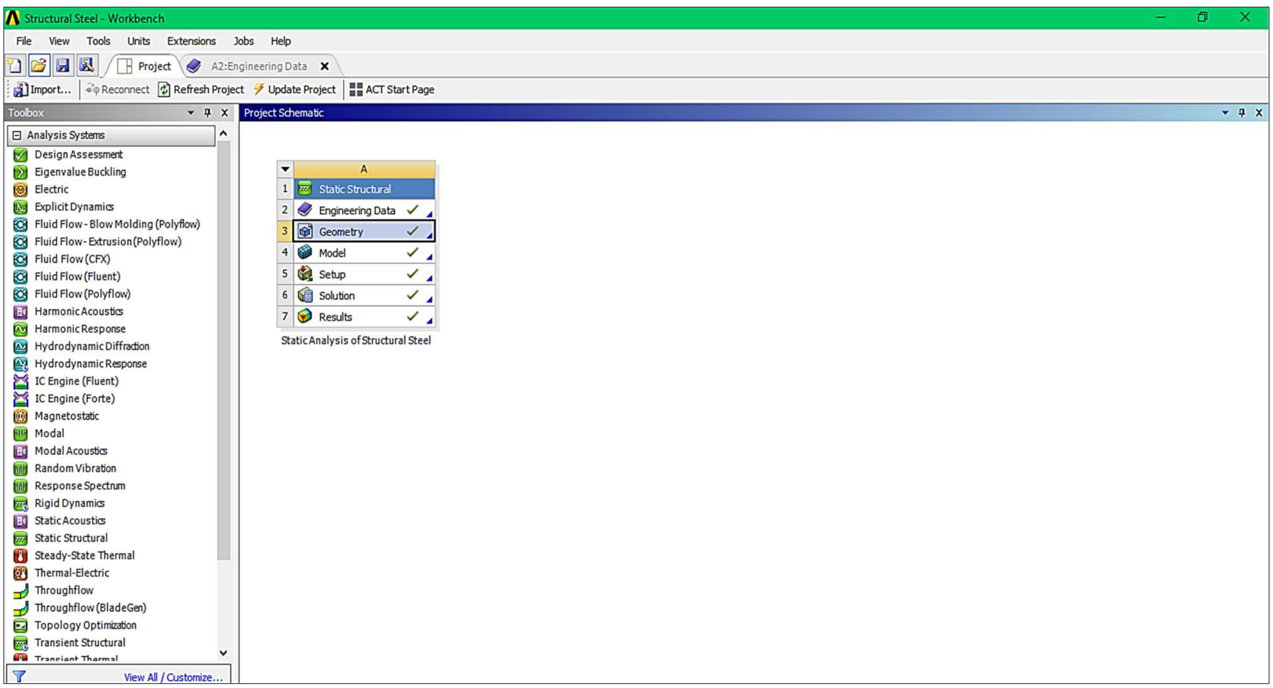


Fig 4.2 Geometry Selection in Ansys Workbench

One important point here is to be noted that the attached geometry should have file extension which is supported by Ansys workbench otherwise we will not be able to carry out simulation and analysis.

When we are done with attaching geometry to the Ansys workbench, then we can see our geometry in Ansys workbench mechanical module where we can apply meshing and boundary conditions to the geometry and obtain results.

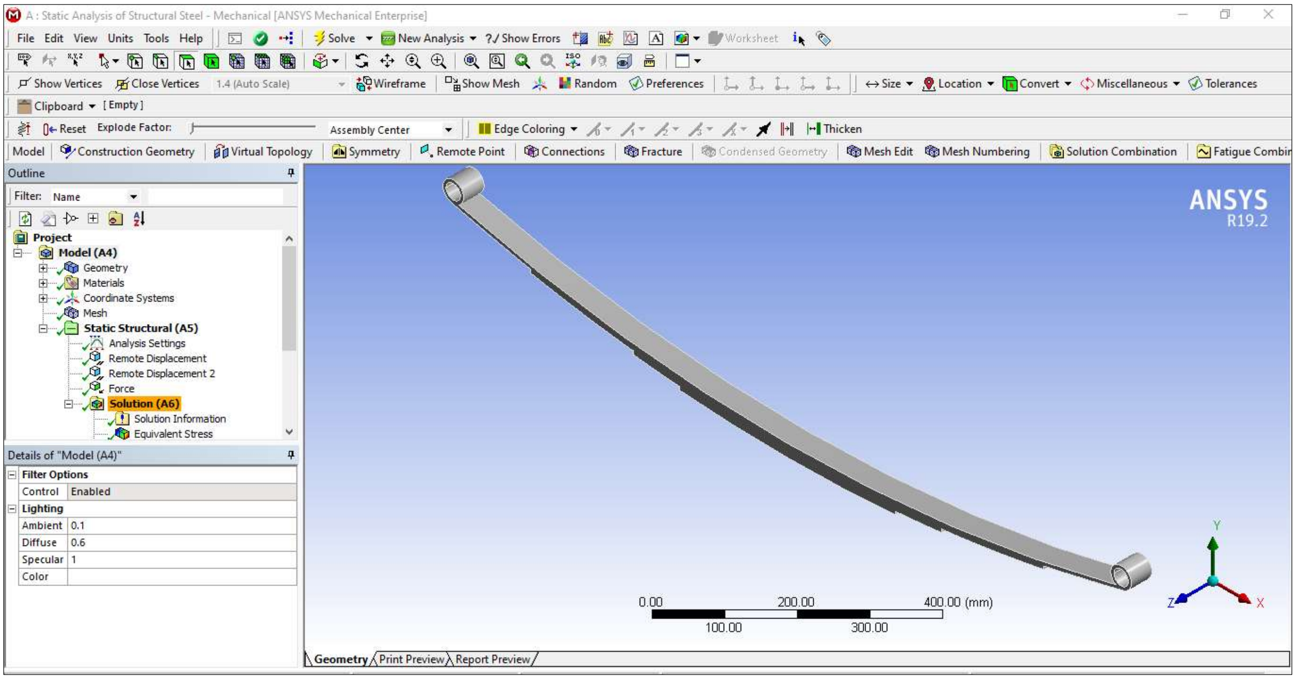


Fig 4.3 Attached Geometry in Ansys workbench

(iii) Mess Generation

This is the next step after the attachment of geometry. Meshing is a necessary operation to get the solutions. Meshed steel leaf spring is shown in below fig.

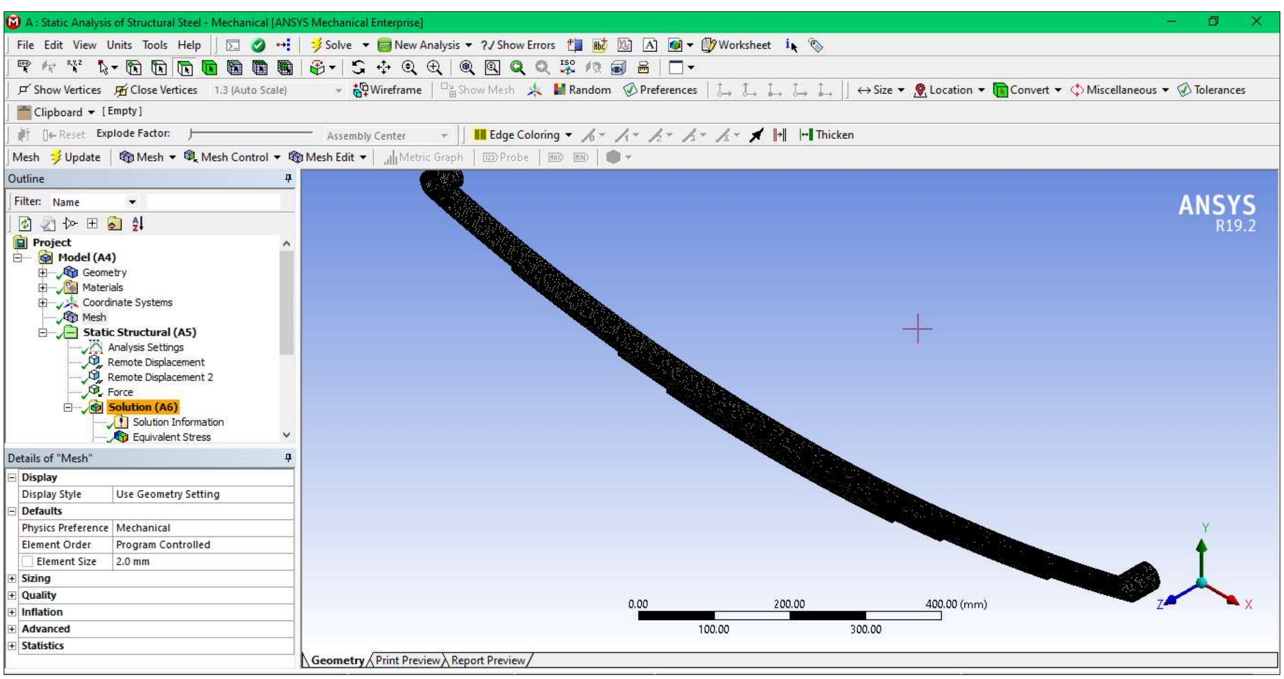


Fig. 4.4 Meshed Structural Steel Leaf spring

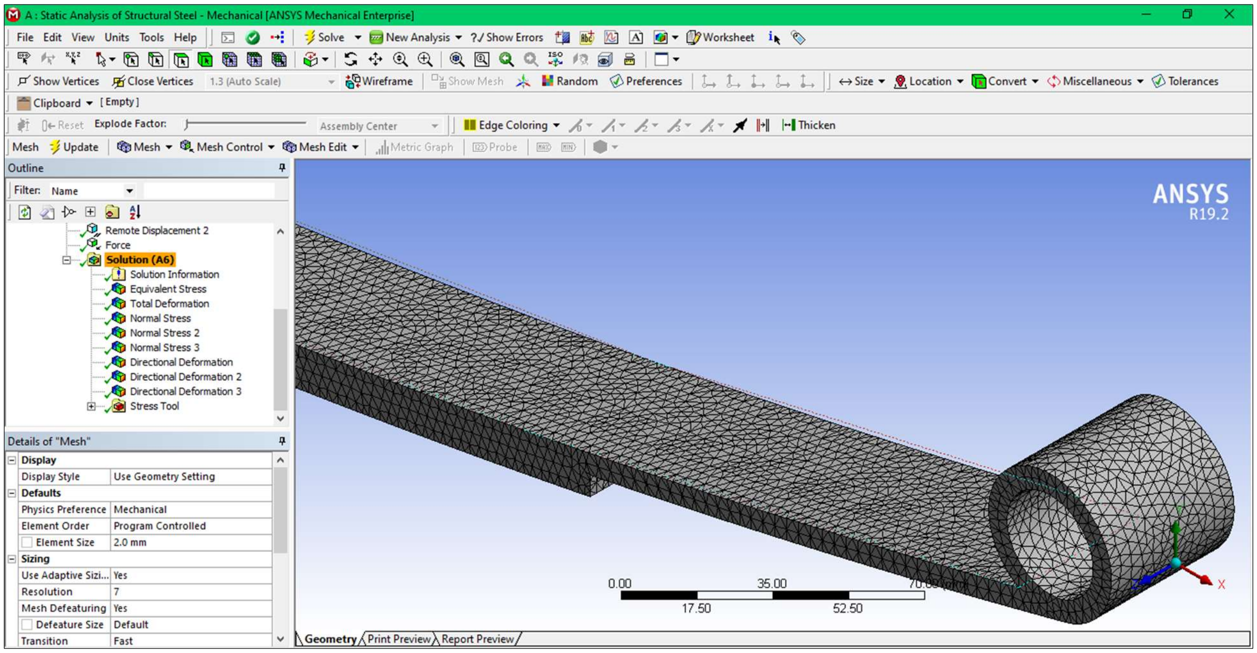


Fig. 4.5 Magnified view of meshed structural steel leaf spring

During meshing operation element size of 2 mm is taken along with program-controlled element order. The span angle center is chosen as fine. the total number of nodes generated is 195907 and the total number of elements generated is 116056.

Details of "Mesh"	
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	2.0 mm
Sizing	
Use Adaptive Sizi...	Yes
Resolution	7
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Fine
Initial Size Seed	Assembly
Bounding Box Di...	1373.8 mm
Average Surface ...	8276.0 mm^2
Minimum Edge L...	6.0201 mm
Quality	
Inflation	
Advanced	
Statistics	
Nodes	195907
Elements	116056

Fig 4.6 Details of Meshing of structural steel leaf spring

(iv) Boundary Conditions

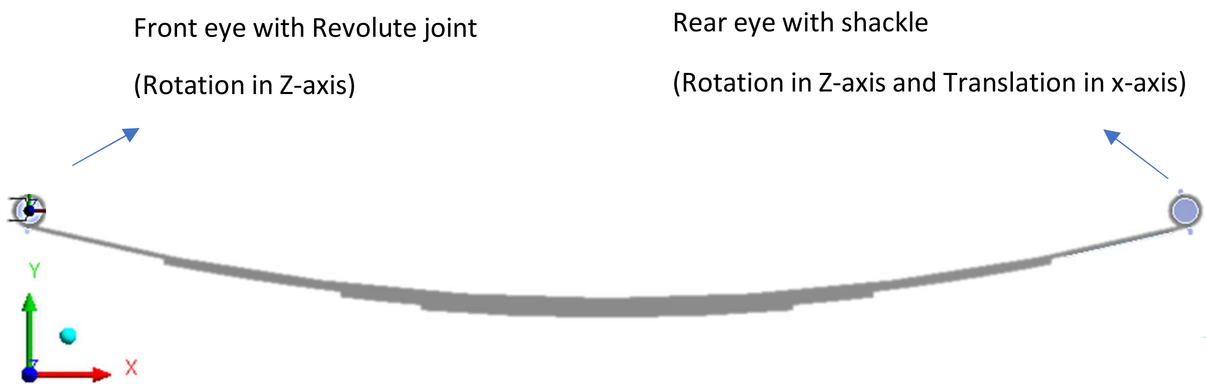


Fig 4.7 Boundary Conditions

One end is attached to the frame of the body while the other end is attached to the shackle (mostly the rear end). In this case, at the shackle end translation in X-axis and rotation moment in Z-axis are permitted while at the other end only rotation moment along Z-axis is permitted.

The advantage of attaching the leaf to the frame of the vehicle through shackle is that it provides additional motion i.e. translational motion along X-axis and the advantage is that it provides smooth springiness.

A load of 5420 N is applied in the Z-direction as shown in the below figure.

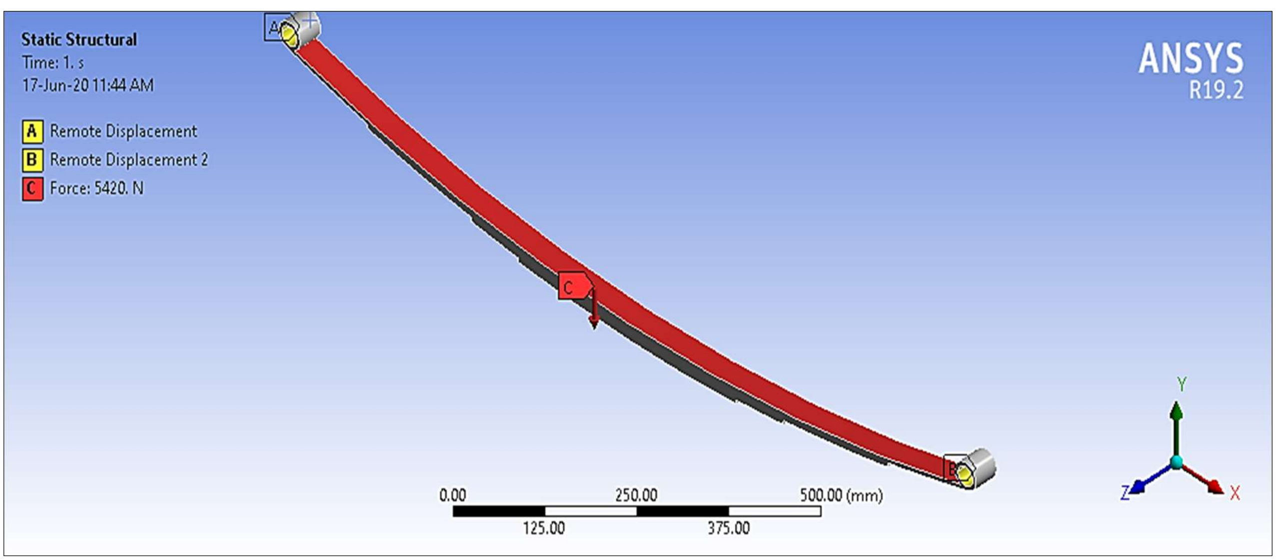


Fig. 4.8 Boundary Conditions and Loading

(v) Solution Generation

This is the last step of analysis on Ansys workbench. Solution are obtained according to the type of meshing chosen, boundary conditions, and loading. In this analysis, we have obtained solutions of equivalent von misses stresses and Deflection produced in the leaf spring.

(i) Equivalent von-misses stress in structural steel leaf spring:

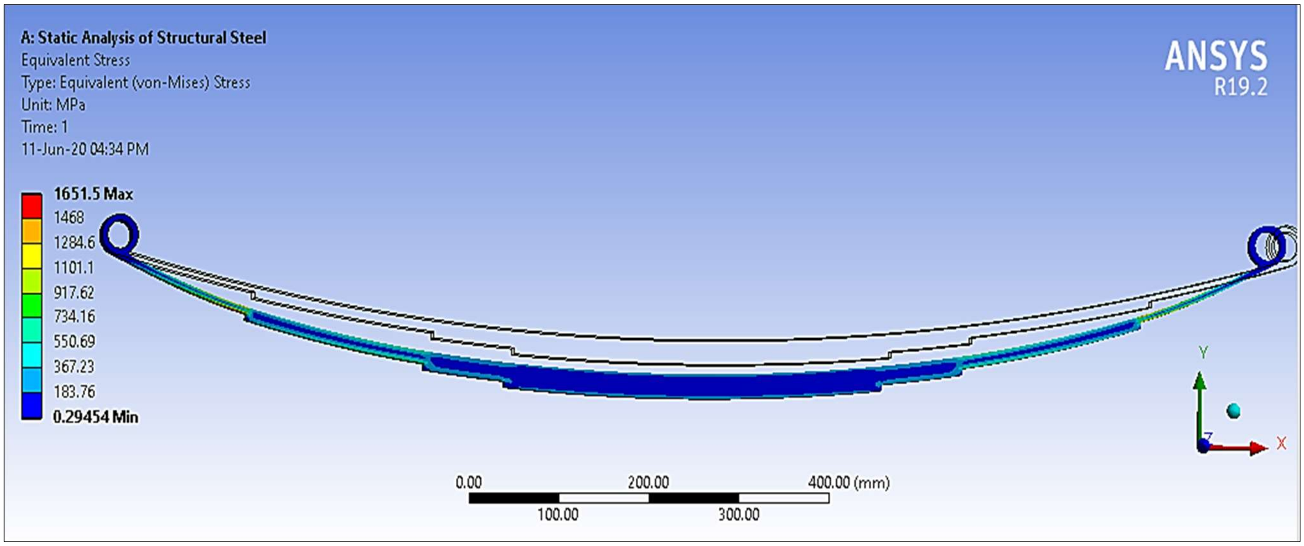


Fig.4.9 Equivalent Von-Misses Stress in Structural Steel leaf spring

(ii) Deflection produced in structural steel leaf spring:

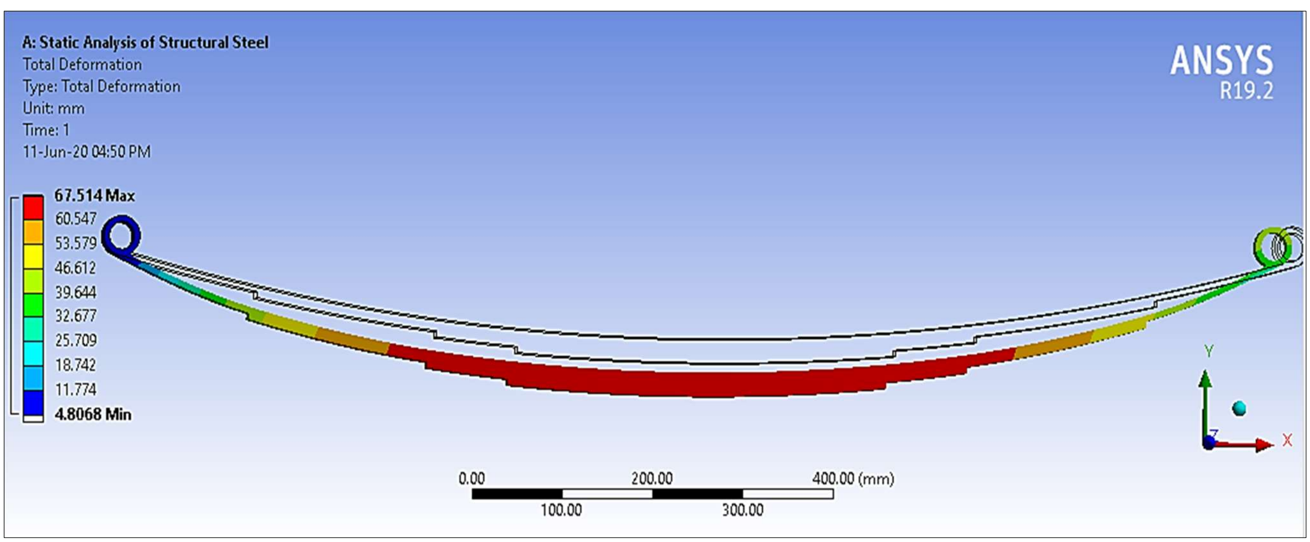


Fig 4.10 Deflection produced in the Structural Steel leaf spring

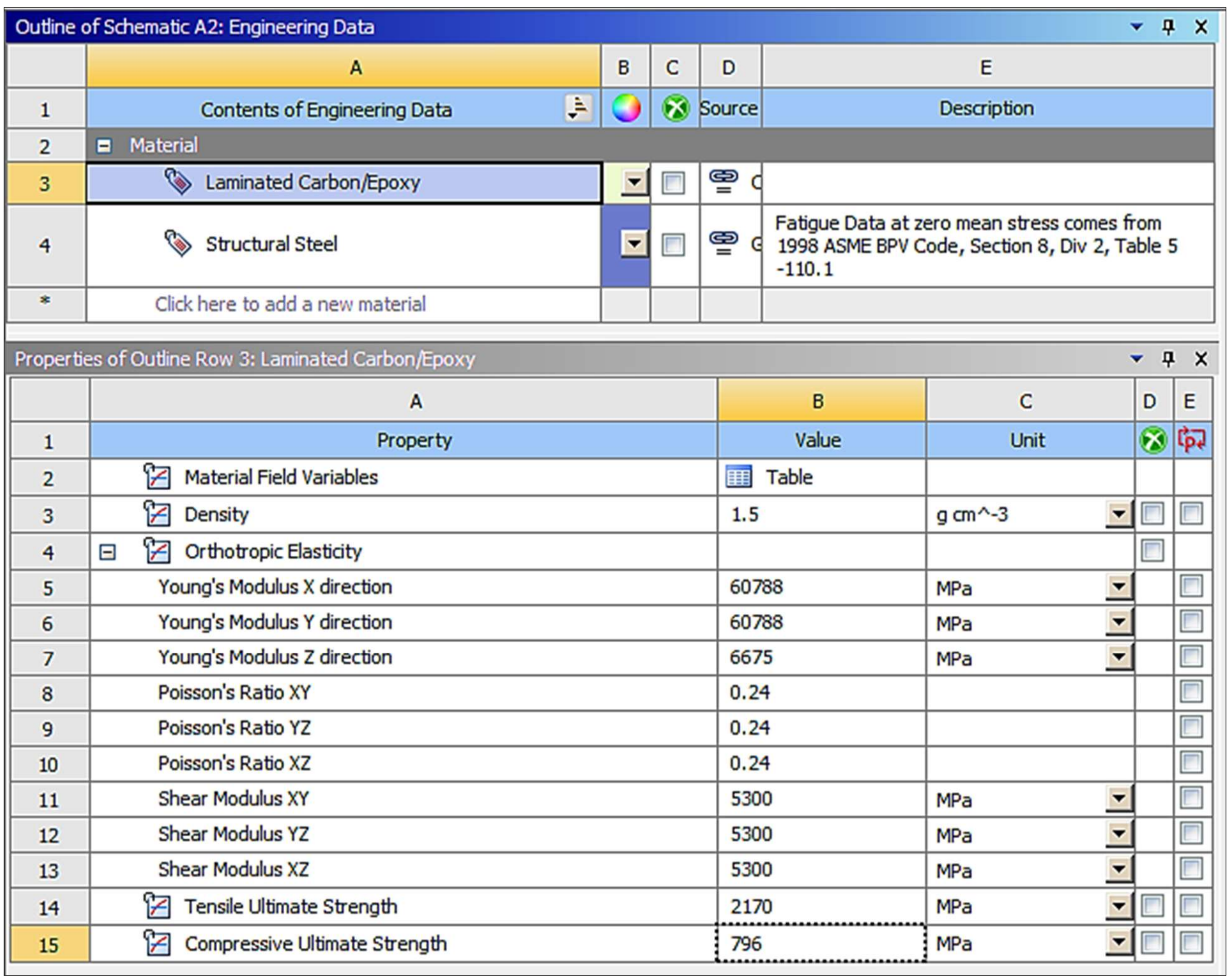
4.3 Static Structural Analysis of Newly Designed Leaf Spring

Similarly, we can carry out the analysis of newly designed leaf spring by following the same steps as described below:

(i) Defining Engineering Data

This is the first step to carry out analysis of newly designed leaf spring. I have considered three different types of composite materials such as Laminated Carbon/Epoxy, Boron/Aluminium, and Carbon/Epoxy (Non-Laminated). So, I have to define engineering data of all the materials separately in Ansys workbench.

Engineering Data of Laminated Carbon/Epoxy:



Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Laminated Carbon/Epoxy			C	
4	Structural Steel			G	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5 -110.1
*	Click here to add a new material				

Properties of Outline Row 3: Laminated Carbon/Epoxy

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	1.5	g cm^-3		
4	Orthotropic Elasticity				
5	Young's Modulus X direction	60788	MPa		
6	Young's Modulus Y direction	60788	MPa		
7	Young's Modulus Z direction	6675	MPa		
8	Poisson's Ratio XY	0.24			
9	Poisson's Ratio YZ	0.24			
10	Poisson's Ratio XZ	0.24			
11	Shear Modulus XY	5300	MPa		
12	Shear Modulus YZ	5300	MPa		
13	Shear Modulus XZ	5300	MPa		
14	Tensile Ultimate Strength	2170	MPa		
15	Compressive Ultimate Strength	796	MPa		

Fig. 4.11 Engineering Data of Laminated Carbon/Epoxy defined in Ansys Workbench

Engineering Data of Boron/Aluminium:

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	⊟ Material				
3	Boron Aluminum		☐	C	
4	~~Structural Steel~~		☑	G	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material				

Properties of Outline Row 3: Boron Aluminum

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	2620	kg m^-3	☐	☐
4	⊟ Orthotropic Elasticity			☐	
5	Young's Modulus X direction	2.15E+05	MPa		☐
6	Young's Modulus Y direction	14400	MPa		☐
7	Young's Modulus Z direction	14400	MPa		☐
8	Poisson's Ratio XY	0.19			☐
9	Poisson's Ratio YZ	0.29			☐
10	Poisson's Ratio XZ	0.19			☐
11	Shear Modulus XY	5700	MPa		☐
12	Shear Modulus YZ	4590	MPa		☐
13	Shear Modulus XZ	5700	MPa		☐
14	Tensile Yield Strength	1300	MPa	☐	☐
15	Compressive Yield Strength	1300	MPa	☐	☐

Fig 4.12 Engineering Data of Boron/Aluminium defined in Ansys Workbench

Engineering Data of Carbon/Epoxy (Non-Laminated):

Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Carbon/Epoxy		☐	C	
4	~~Structural Steel~~		☑	G	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1
*	Click here to add a new material				

Properties of Outline Row 3: Carbon/Epoxy

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	1520	kg m^-3	☐	☐
4	Orthotropic Elasticity			☐	
5	Young's Modulus X direction	1.47E+05	MPa		☐
6	Young's Modulus Y direction	10300	MPa		☐
7	Young's Modulus Z direction	10300	MPa		☐
8	Poisson's Ratio XY	0.27			☐
9	Poisson's Ratio YZ	0.54			☐
10	Poisson's Ratio XZ	0.27			☐
11	Shear Modulus XY	7000	MPa		☐
12	Shear Modulus YZ	3700	MPa		☐
13	Shear Modulus XZ	7000	MPa		☐
14	Tensile Yield Strength	1841	MPa	☐	☐
15	Compressive Yield Strength	1841	MPa	☐	☐

Fig. 4.13 Engineering Data of Carbon/Epoxy (Non-Laminated) defined in Ansys Workbench

(ii) Attach Geometry

After defining engineering data of all the composite materials, the next step is to attach geometry to the Ansys workbench, and here again, we have to firstly change the file format of the geometry to .IGS since we have used NX (Unigraphics) for modeling purposes.

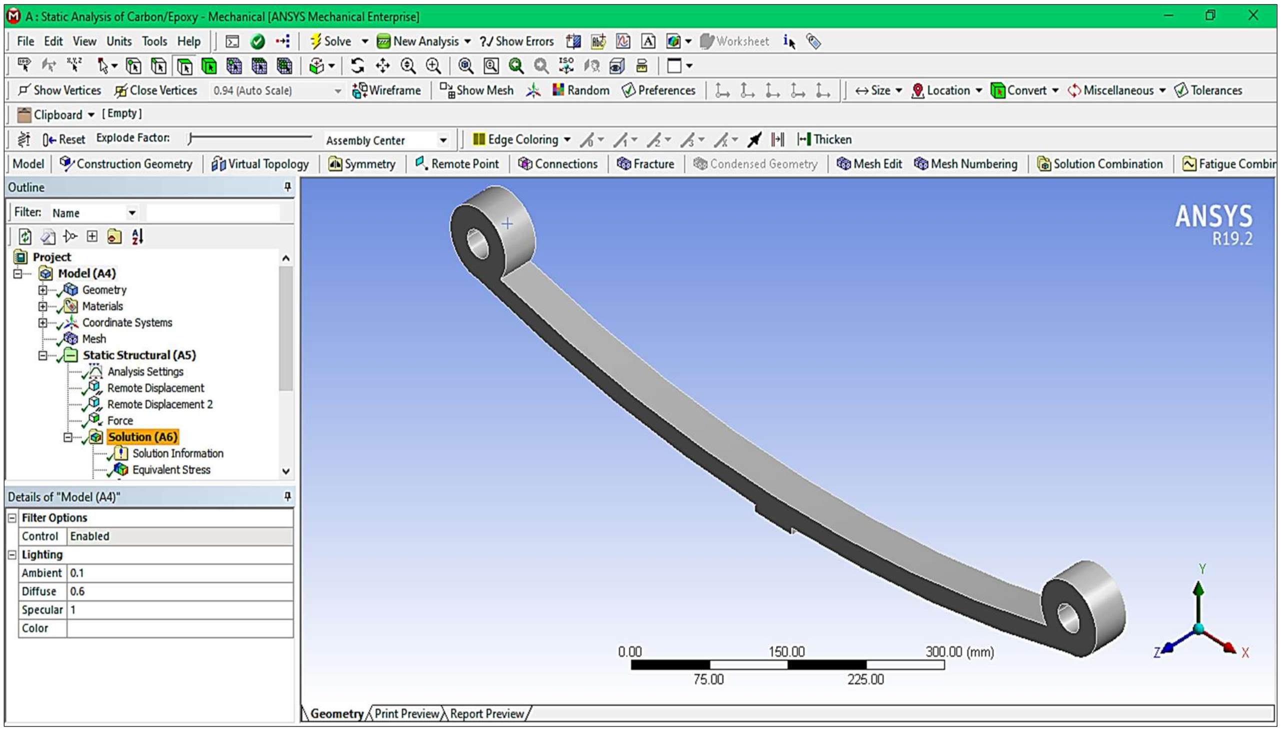


Fig. 4.14 Attached Geometry of Newly Designed leaf spring

(iii) Mesh Generation

For mesh generation, same meshing parameters are considered as that of conventional structural steel leaf spring. Like, element size, resolution and element order, etc.

During the meshing operation, the number of nodes that are produced is 655546 and the number of elements that are produced is 149980. The span angle center is taken as fine. Other meshing details can be found out in fig 4.14.

Details of "Mesh"

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	2.0 mm
Sizing	
Use Adaptive Sizing	Yes
Resolution	7
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Fast
Span Angle Center	Fine
Initial Size Seed	Assembly
Bounding Box Diagonal	938.59 mm
Average Surface Area	11432 mm²
Minimum Edge Length	7.453 mm
Quality	
Inflation	
Advanced	
Statistics	
Nodes	655546
Elements	149980

Fig 4.15 Details of Meshing of Newly Designed leaf sprig

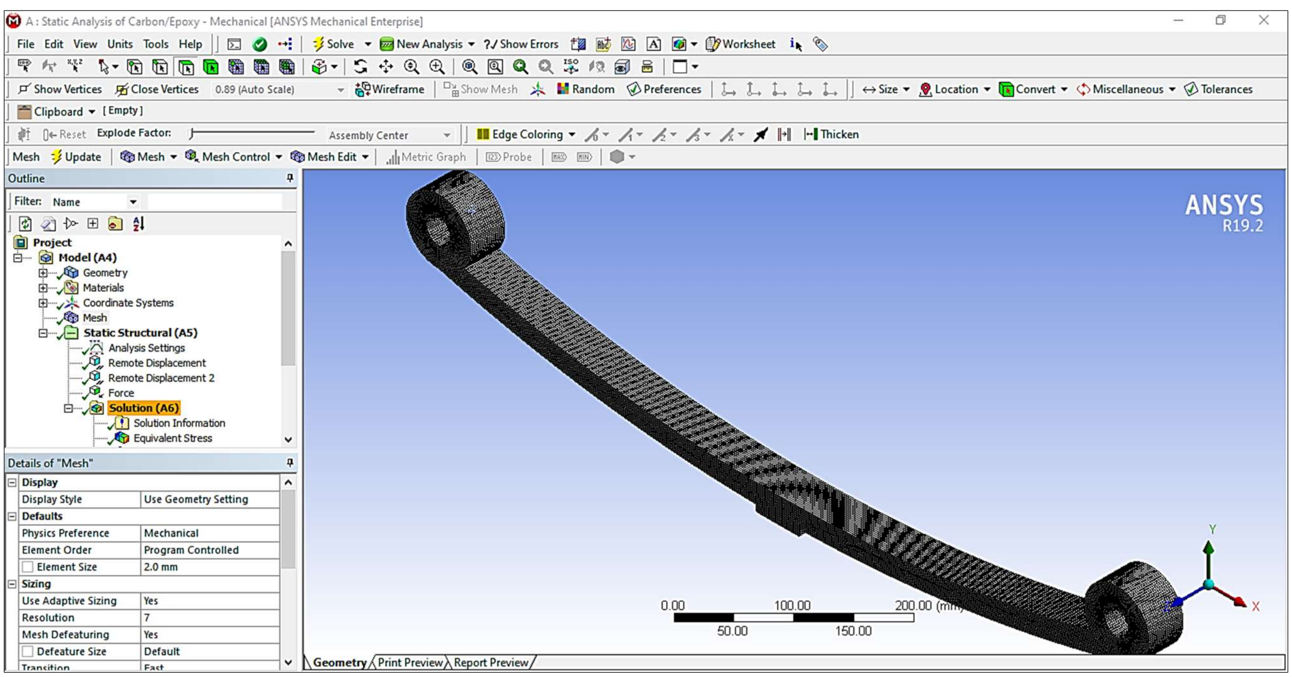


Fig 4.16 Meshing of Newly Designed Leaf Spring

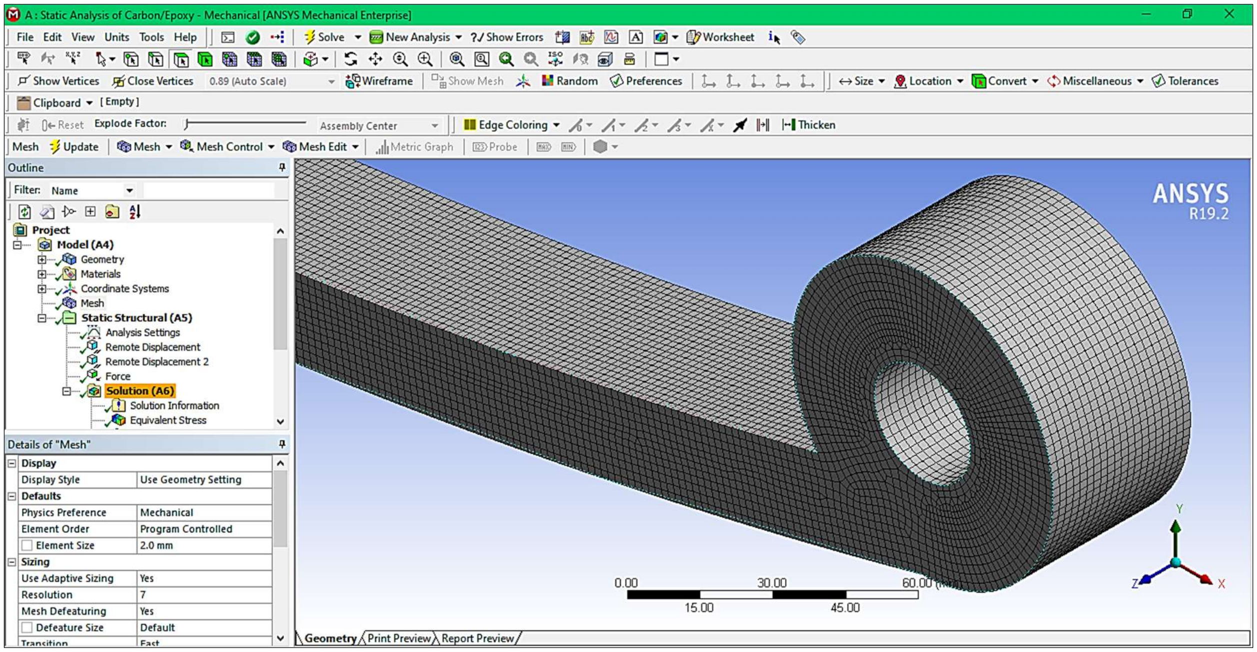


Fig. 4.17 Magnified view of Meshing of Newly Designed Leaf Spring

(iv) Boundary Conditions

The same boundary conditions and loading is applied as that of conventional structural steel leaf spring. (para 4.3 (iv))

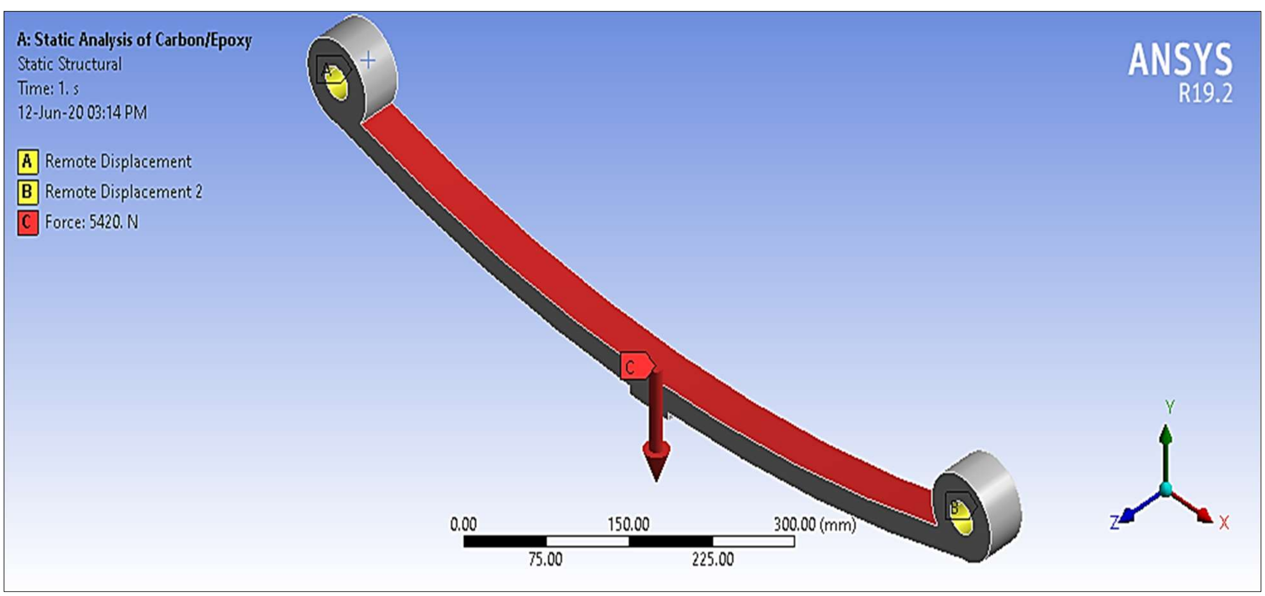


Fig 4.18 Boundary Conditions and loading of Newly Designed Leaf Spring

(v) Solution Generation

After defining engineering data, meshing, boundary conditions, and loading following results are obtained for different types of composite materials.

1. Solutions for Laminated Carbon/Epoxy Composite Leaf Spring:

(a) Equivalent Von-Mises Stress

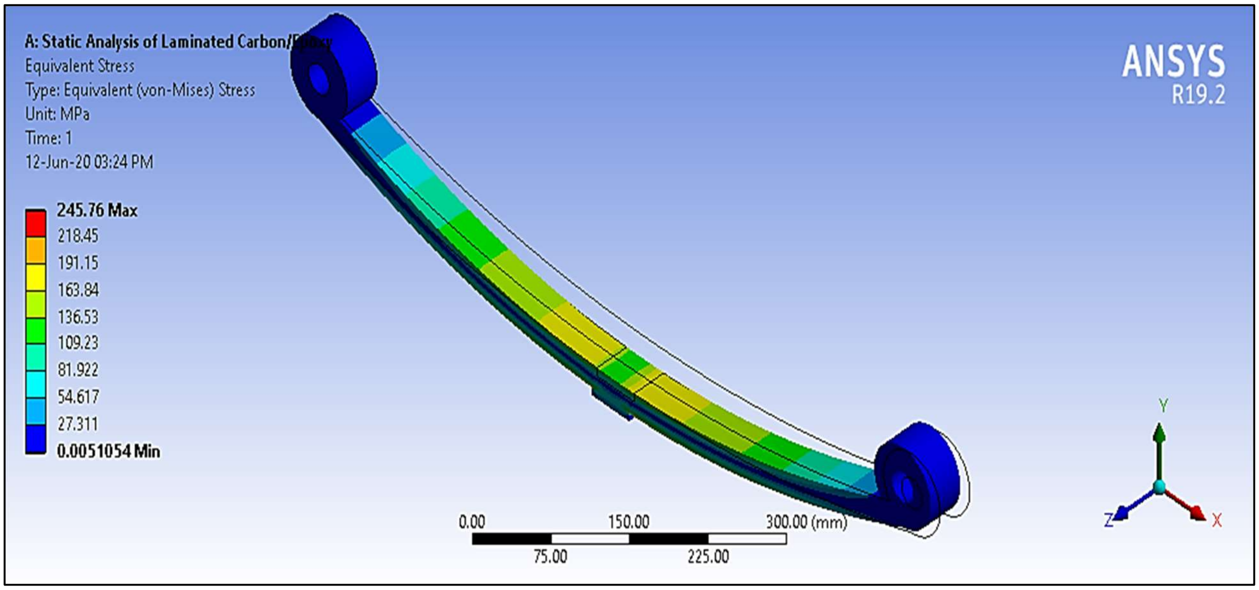


Fig 4.19 Equivalent Von-Mises Stress in Laminated Carbon/Epoxy composite Leaf spring

(b) Total Defection

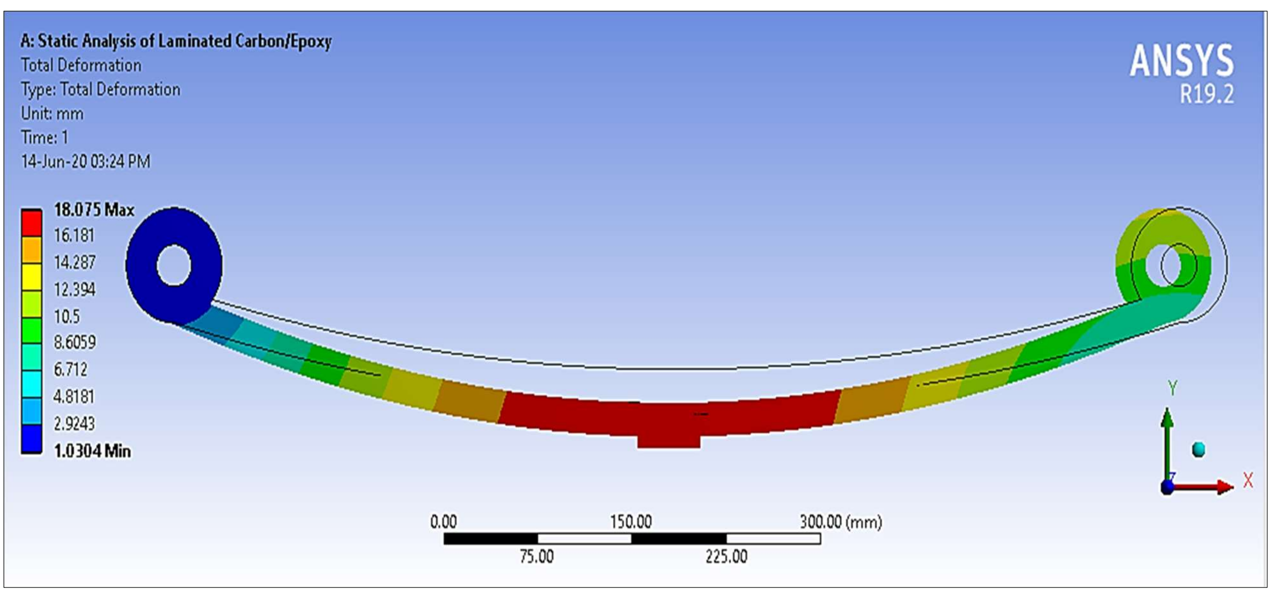


Fig 4.20 Total Deflection in Laminated Carbon/Epoxy composite Leaf spring

2. Solutions for Boron/Aluminium Composite Leaf Spring:

(a) Equivalent Von-Mises Stress

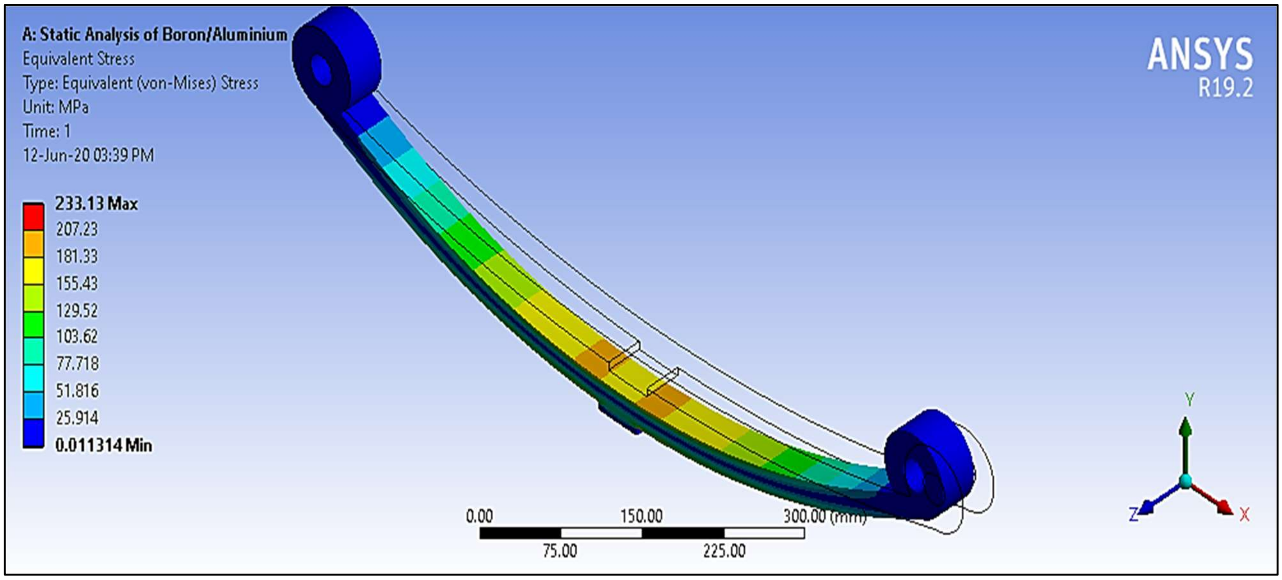


Fig 4.21 Equivalent Von-Mises Stress in Boron/Aluminium composite Leaf Spring

(b) Total Deflection

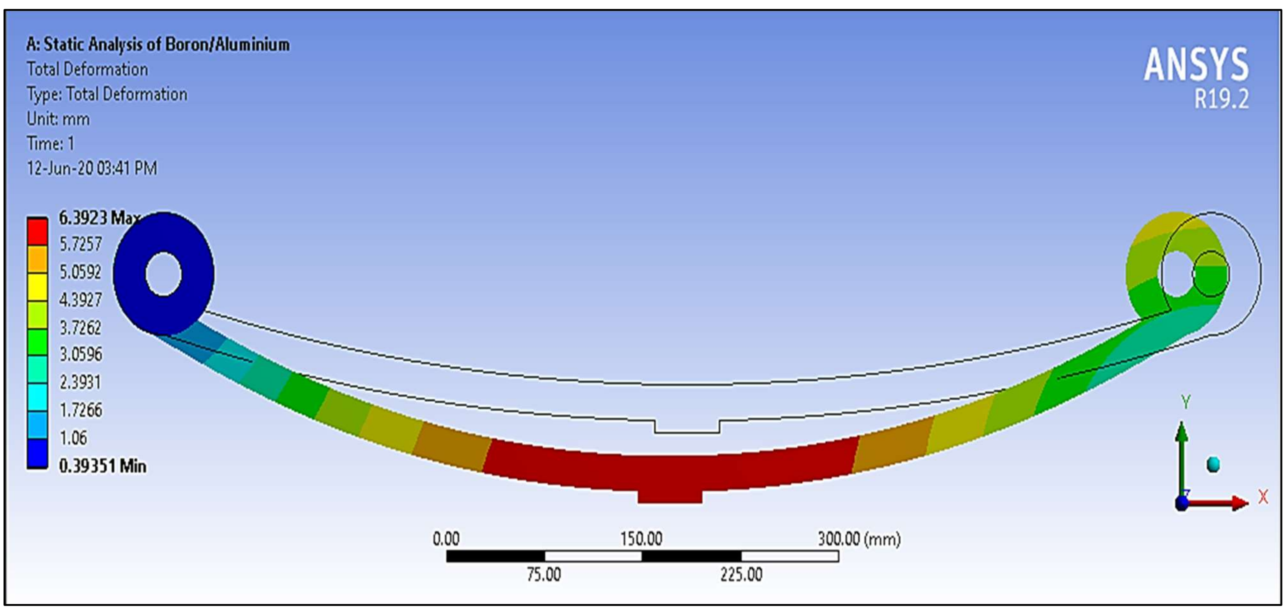


Fig 4.22 Total Deflection in Boron/Aluminium composite Leaf Spring

3. Solutions for Carbon/Epoxy (Non-Laminated) Composite Leaf Spring

(a) Equivalent Von-Mises Stress:

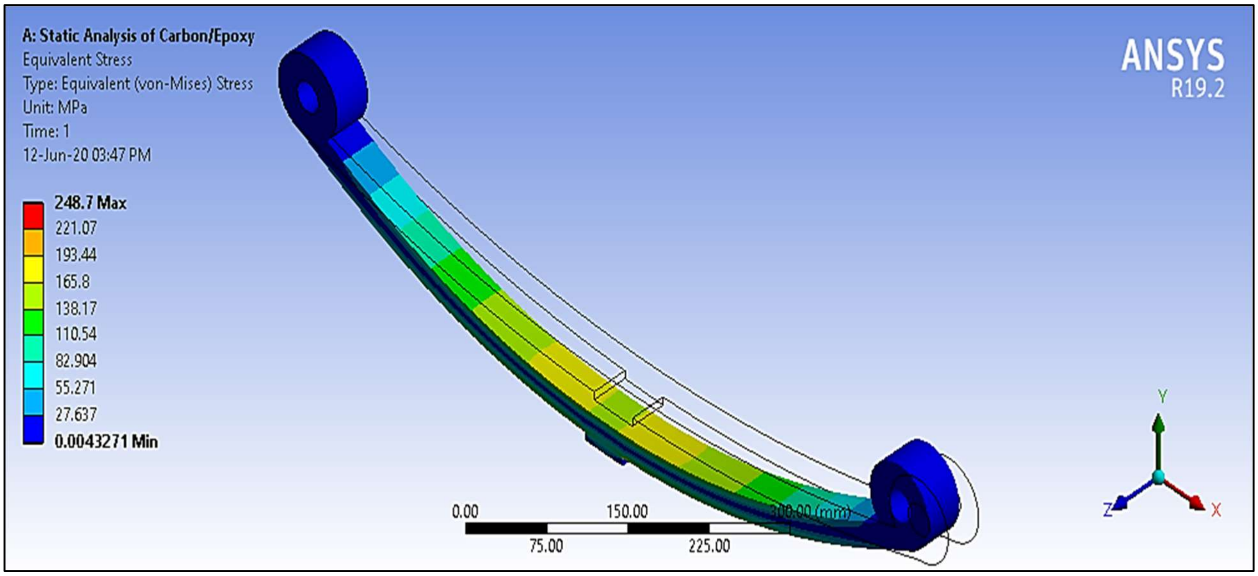


Fig 4.23 Equivalent Von-Mises Stress in Carbon/epoxy (Non-Laminated) composite Leaf Spring

(b) Total Deflection:

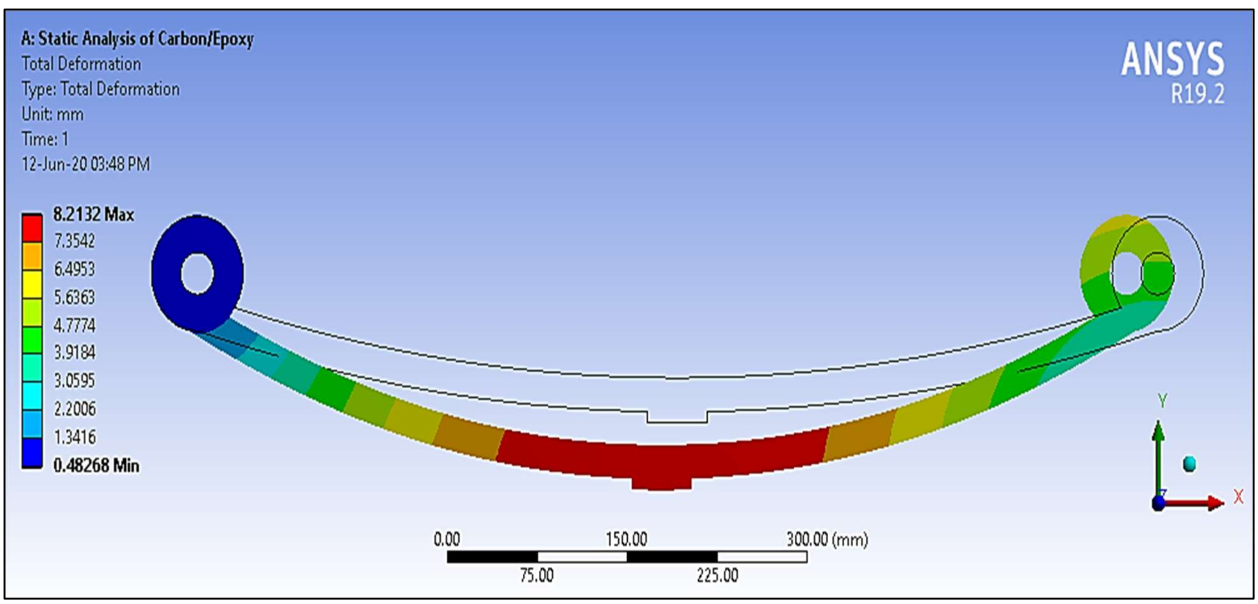


Fig 4.24 Total Deflection in Carbon/epoxy (Non-Laminated) composite Leaf Spring

Chapter-5

Results & Conclusion

CHAPTER- 5

RESULTS & CONCLUSION

In this chapter, all the obtained results from newly designed leaf spring are compared with the results of conventional structural steel leaf spring.

Here basically two parameters are discussed onto which we will decide which type of leaf spring is superior to the other i.e. Equivalent Von-Mises Stress and Deformation/Deflection.

5.1 Equivalent Von-Mises Stress

This criterion gives satisfactory results in the prediction of failure of a ductile material and it is widely used by the designers to check whether their design withstand a given load condition or not.

Maximum values of equivalent stresses that are seen in different types of leaf spring with respect to same boundary conditions and loading are tabulated as follows:

Sr. No.	Leaf Spring	Maximum value of Equivalent Von-Mises Stress (MPa) at 5420 N Load
1	Conventional Structural Steel	**1651.50**
2	Laminated Carbon/Epoxy	245.76
3	Carbon/Epoxy (Non-Laminated)	248.70
4	Boron/Aluminium	**233.13**

Table 5.1 Maximum values of Equivalent Von-Mises Stresses in different types of Leaf Spring

Values which are shown in table 5.1 are obtained through finite element analysis in Ansys Workbench. From the above table, we can conclude that equivalent von-mises stress developed in Boron/Aluminium leaf spring is least with respect to 5420 N load.

5.2 Deformation/Deflection

The maximum values of deflection obtained in different types of leaf spring is tabulated as follows:

Sr. No.	Leaf Spring	Deflection (mm) at 5420 N Load
1	Conventional Structural Steel	**67.51**
2	Laminated Carbon/Epoxy	18.07
3	Carbon/Epoxy (Non-Laminated)	8.21
4	Boron/Aluminium	**6.39**

Table 5.2 Maximum values of Deflection in different types of Leaf Spring

The values which are shown in table 5.2 are obtained through finite element analysis in Ansys Workbench. From the above table, we can conclude that the minimum deflection is produced in Boron/Aluminium leaf spring with respect to 5420 N load.

5.3 Weight of Leaf Spring

The mass values obtained in different types of leaf spring is tabulated as follows:

Sr. No.	Leaf Spring	Mass in Kg
1	Conventional Structural Steel	**6.83**
2	Laminated Carbon/Epoxy Carbon/Epoxy (Non-Laminated)	**1.53**
3	Boron/Aluminium	2.67

Table 5.3 Mass values of different types of leaf spring

The Mass values which are shown in table 5.3 are obtained from Ansys Workbench 19.2 during analysis. From table 5.3 we can conclude that the Laminated Carbon/Epoxy and Carbon/Epoxy (Non-Laminated) leaf spring is lightweight in nature.

5.4 Percentage Reduction

The percentage reduction in Equivalent Stresses and Deflection in various types of leaf spring with respect to Structural steel Leaf spring is tabulated as follows:

Sr. No	Leaf Spring	% Reduction with respect to Structural Steel Leaf Spring in		
		Equivalent Von-Mises Stress (MPa) at 5240 N	Maximum Deflection (mm) at 5240 N	Mass value in Kg
1	Laminated Carbon/Epoxy	85.08 %	73.23 %	**77.59 %**
2	Carbon/Epoxy (Non-Laminated)	84.94 %	87.83 %	**77.59 %**
3	Boron/Aluminium	**85.88 %**	**90.53 %**	60.90 %

Table 5.4 Percentage reduction in Equivalent Von-Mises Stress and Deflection in different types of leaf spring.

From table 5.4 we can conclude that there is a maximum percentage reduction of Equivalent Von-Mises Stress and Deflection in the case of Boron/Aluminium while there is a maximum percentage reduction of weight in the case of Laminated Carbon/Epoxy and Carbon/Epoxy (Non-Laminated) leaf spring.

5.5 Comparison of FEA Results

For a better understanding of results (Equivalent Von-Mises stress & Deflection) and its variation over a wide range of loads following graphs are generated based on the data which is obtained during simulation and analysis.

(i) Comparison of Equivalent Von-Mises Stress:

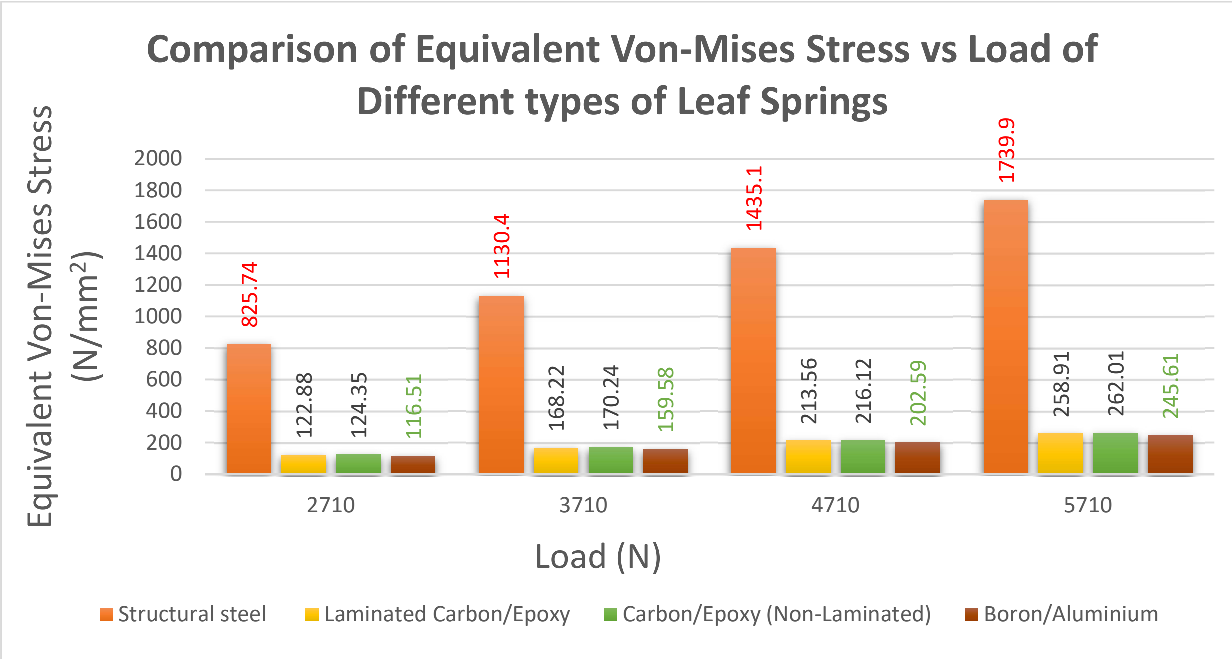


Fig 5.1 Comparison of Equivalent von mises stress vs Load of different types of Leaf Spring

From fig. 5.1 we can conclude that whatever be the load, maximum equivalent von-mises stress will be developed in Structural steel leaf spring and minimum in Boron/Aluminium leaf spring.

(ii) Comparison of Deflection:

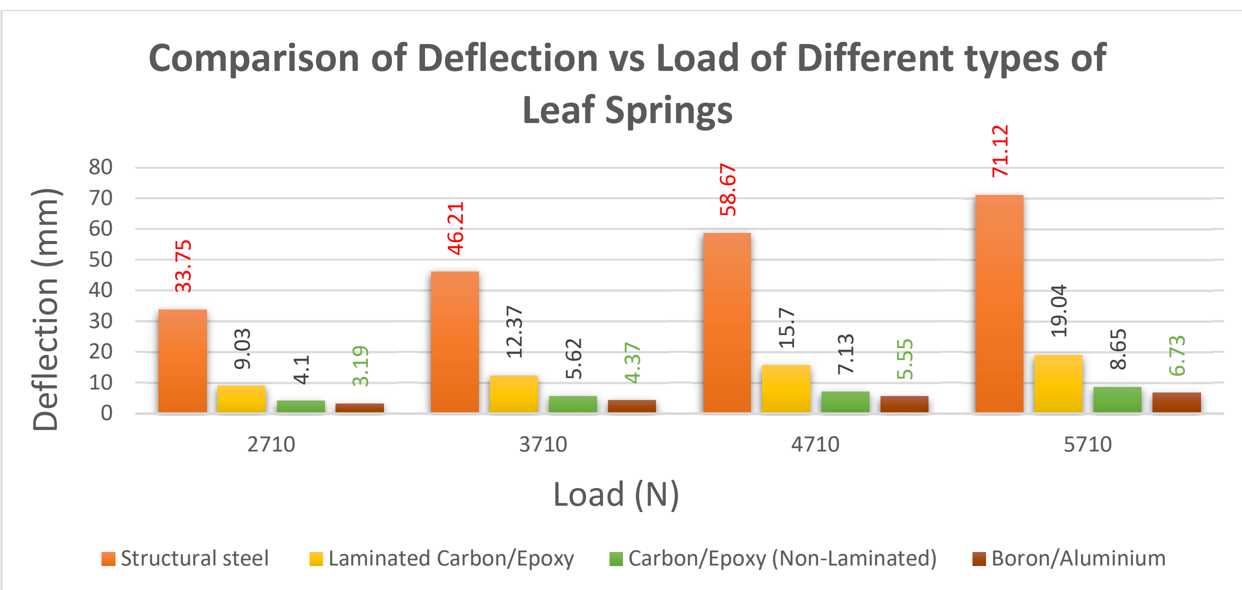


Fig 5.2 Comparison of Deflection vs Load of different types of Leaf Spring

From fig. 5.2 we can conclude that whatever be the load, the maximum deflection will be developed in Structural steel leaf spring and minimum in Boron/Aluminium leaf spring.

(iii) Comparison of Masses of different types of leaf spring:

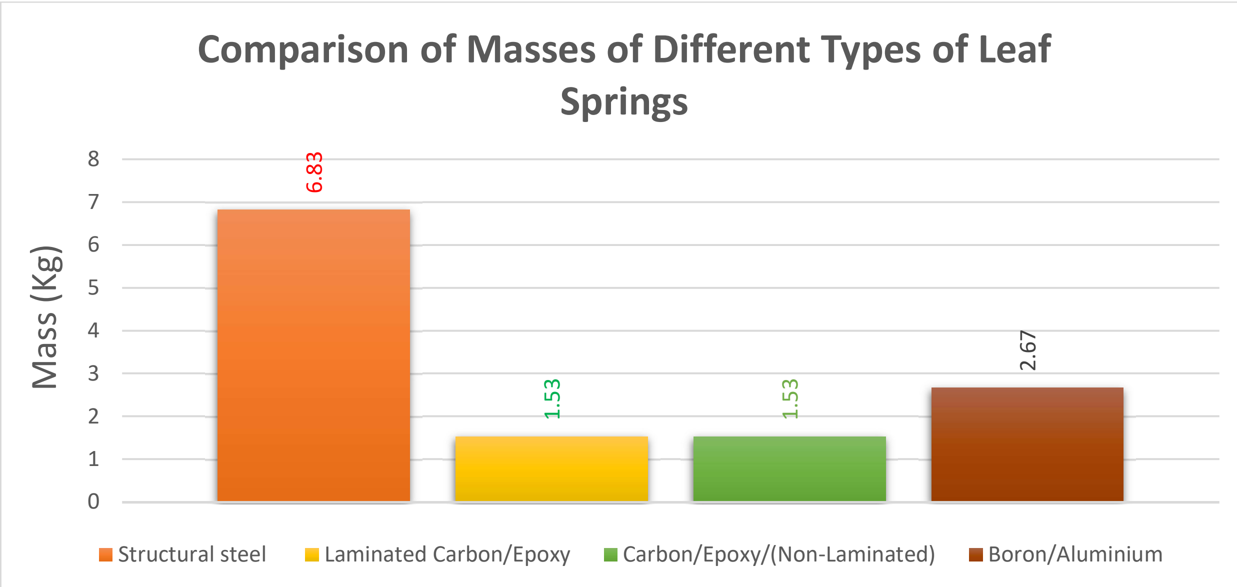


Fig 5.3 Comparison of Masses of different types of Leaf Spring

From fig. 5.3 we can say that leaf spring made of laminated Carbon/Epoxy and Carbon/Epoxy (Non-Laminated) is lighter in weight as compared to structural steel and Boron/Aluminium leaf spring.

5.6 Comparison of Analytical Results with FEA Results

Comparison of Analytical results with FEA results of Equivalent Von-Mises Stresses vs Load and Deflection vs Load of various types of leaf springs i.e. Structural Steel leaf spring, Carbon/Epoxy (Non-Laminated) leaf spring and Boron/Aluminium leaf spring are shown in figure 5.4 and 5.5 respectively. By observing the following graphs we can see the difference in the values of Equivalent Von-Mises Stresses and Deflection that we are getting in both the types of Results i.e. Analytical results and FEA results.

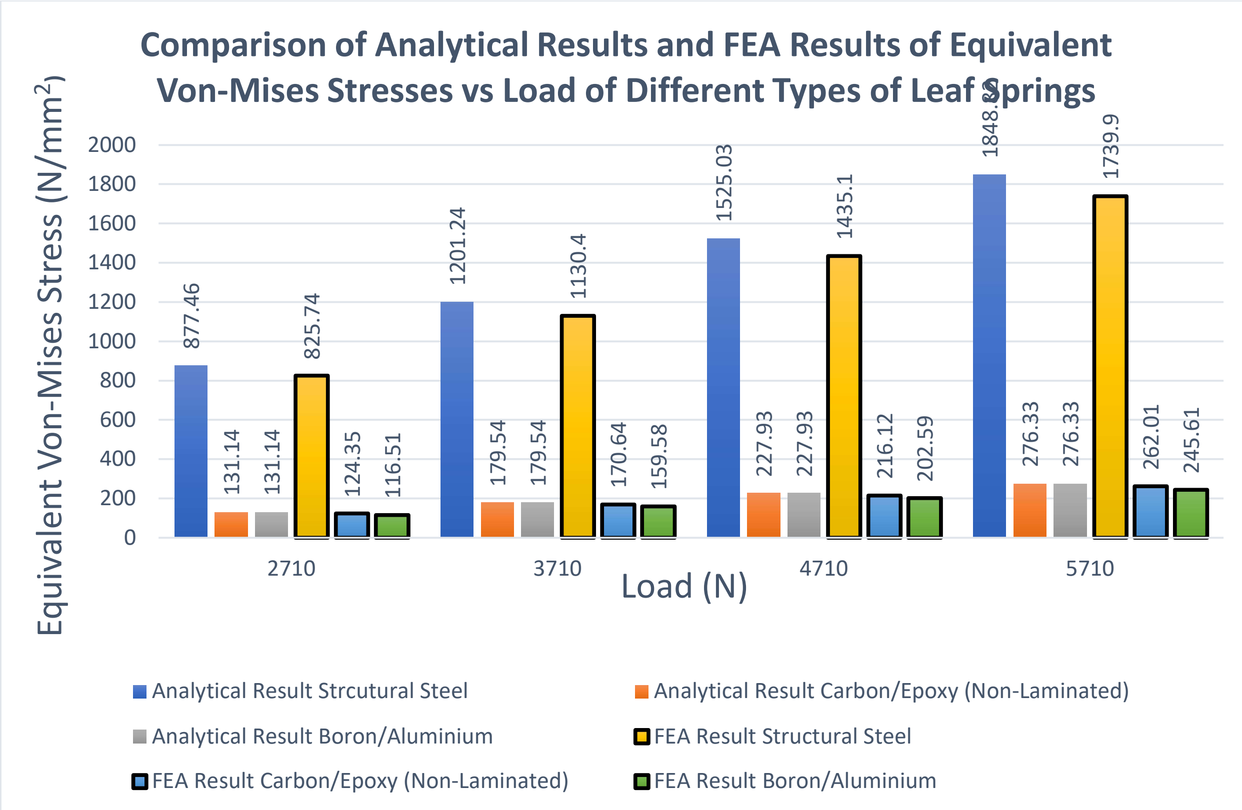


Fig. 5.4 Comparison of Analytical Results and FEA Results of Equivalent Von-Mises stresses vs Load of Different Types of Leaf Springs.

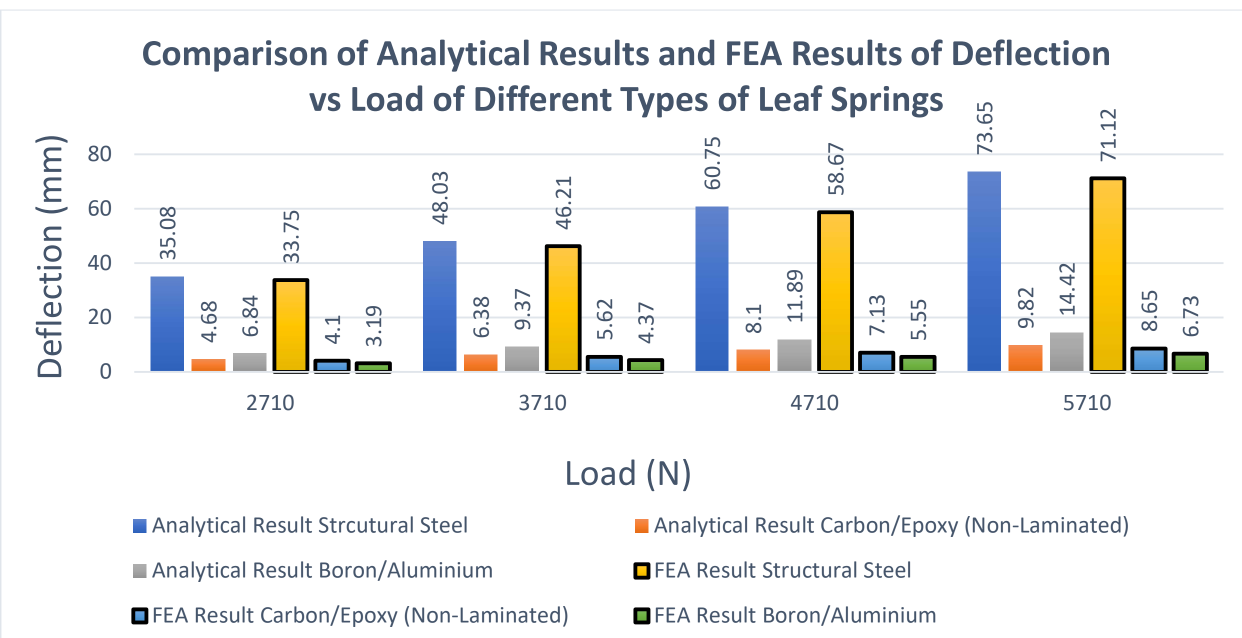


Fig 5.5 Comparison of Analytical Results and FEA Results of Deflection vs Load of Different Types of Leaf Springs.

From Fig. 5.4 and Fig. 5.5 we can conclude that both the results i.e. Analytical results and FEA results are lie in close proximity to each other.

5.7 Conclusion

From the obtained results we can say that composite materials are the best options to replace current structural steel leaf spring.

For a particular applied load, there are minimum equivalent von-mises stress & deflection in the case of Boron/Aluminium composite leaf spring as compare to the rest of the composite leaf springs which are designed in this thesis. To validate this point number of results is generated by varying the applied load.

The percentage reduction of equivalent von-mises stress in the case of Boron/Aluminium composite leaf spring with respect to structural steel leaf spring is 85.88 % and in the case of Carbon/Epoxy (Non-Laminated), it is 84.94 % which is a significant reduction.

And also, the percentage reduction of deflection in the case of Boron/Aluminium composite leaf spring with respect to structural steel leaf spring is 90.53 % and in the case of Carbon/Epoxy (Non-Laminated), it is 87.83 % which is a significant reduction.

Although percentage weight reduction in the case of Boron/Aluminium composite leaf spring is just 60.90 % whereas in the case of Laminated Carbon/Epoxy and Carbon/Epoxy (Non-Laminated) it is 77.59 % which is greater than the Boron/Aluminium Composite leaf spring.

So, in the end, we can say that although Boron/Aluminium composite leaf spring gives maximum percentage reduction in equivalent von-mises stress and deflection, it is not a good option to replace current structural steel leaf spring with this material because it has poor percentage weight reduction. Whereas Carbon/Epoxy (Non-Laminated) composite leaf spring gives a significant percentage reduction in weight as well as equivalent von mises stress and deflection.

Therefore, current structural steel leaf spring can be replaced with **Carbon/Epoxy (Non-Laminated)** composite material.

5.8 Future Work

Composite materials have several advantages and there is numerous research area in this field so following are some recommended studies:

- Dynamic analysis of composite leaf spring made of different types of composite materials
- Vibration analysis of composite leaf spring.
- Hybird composite materials can be considered.

APPENDICES

CHAPTER 3 MATERIALS & METHODS

3.8 Calculation of material properties for Laminated Carbon/Epoxy.

The density of the composite can be found out by considering the fiber volume fraction and matrix volume fraction, i.e.:

$\rho_c = \rho_f V_f + \rho_m V_m$…………………………………………………………………………… (3.5)

Where, ρ_f=Density of fiber

ρ_m =Density of matrix

For Fiber volume fraction of 60% and Matrix volume fraction of 40%

(i) Density of Laminated Carbon/Epoxy:

We know for laminated Carbon/Epoxy ρ_f=1.7 g/cm^3 and ρ_m = 1.2 gm/cm^3

$\rho_C = 1.7\times0.6 + 1.2\times0.4 = 1.50$ g/cm^3

(ii) Longitudinal Modulus:

$E_1 = E_f \times V_f + E_m \times V_m$

$E_1 = 230 \times 0.6 + 3.3 \times 0.4$

E_1 = 139.32 GPa

(iii) Transverse Modulus:

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{Em}$$

$$= \frac{0.6}{220} + \frac{0.4}{3{\cdot}3}$$

= 0.123 GPa

(iv) Major Poisson's Ratio:

$\nu_{12} = \nu_f \times V_f + \nu_m \times V_m$

= 0.15 × 0.6 + 0.37 × 0.4

= 0.24

(v) Transverse Shear Modulus:

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{Gm}$$

$$\frac{1}{G_{12}} = \frac{0.6}{52} + \frac{0.4}{2.26}$$

= 5.3 GPa

(vi) Longitudinal Shear Modulus:

$G_{12} = G_f \times V_f + G_m \times V_m$

= 52 × 0.6 + 2.26 × 0.4

= 31.104 GPa

(vii) Tensile strength of single ply in longitudinal direction:

$\sigma_{tl} = \sigma_{tf} \times V_f + \sigma_{tm} \times V_m$

= 3.53 × 0.6 + 0.13 × 0.4

= 2.17 GPa

(viii) Tensile strength of single ply in transverse direction:

$$\frac{1}{\sigma_{tt}} = \frac{V_f}{\sigma_{tf}} + \frac{V_m}{\sigma_{tm}}$$

$$= \frac{0.6}{3.53} + \frac{0.4}{0.13}$$

= 0.308 GPa

(ix) Compressive strength of single-ply in longitudinal direction:

$$\sigma cl = \sigma cf \times v_f + \sigma_{cm} \times v_m$$

=1.2 × 0.6 + 0.19 × 0.4

= 0.796 GPa

(x) Compressive Strength of single-ply in transverse direction:

$$\frac{1}{\sigma_{ct}} = \frac{V_f}{\sigma_{cf}} + \frac{V_m}{\sigma_{cm}}$$

$$= \frac{0.6}{1.2} + \frac{0.4}{0 \cdot 19} = 0.384 \text{ GPa}$$

Calculations of Effective Elastic constants:

According to [29], and engineering design with polymers and composites, J.C Gerdeonetal, suitable for calculating the young modulus of a unidirectional ply at different angles are formulated as:

$$\frac{1}{E_x} = \frac{cos^4\,\theta}{E_{11}} + \frac{sin^4\,\theta}{E_{22}} + (\frac{1}{G_{12}} - \frac{2v_{12}}{E_{11}})\, cos^2\,\theta\, sin^2\,\theta$$

For θ = 0º

$$\frac{1}{E_x} = \frac{1}{139.32} + 0 + 0$$

E_x = 139.32 GPa, for 0º ply laminate fibers

For θ = 45º

$$\frac{1}{E_x} = \frac{\cos^4\theta}{E_{11}} + \frac{\sin^4\theta}{E_{22}} + \left(\frac{1}{G_{12}} - \frac{2v_{12}}{E_{11}}\right)\cos^2\theta\sin^2\theta$$

$$\frac{1}{E_x} = \frac{0.25}{139 \cdot 32} + \frac{0.25}{8.077} + \left(\frac{1}{5 \cdot 3} - \frac{0 \cdot 48}{139.32}\right) 0.25$$

E_x = 12.649 GPa, for 45º ply laminate fibers

For θ = 90º

Similarly,

E_x = 8.077 GPa, for 90º ply laminate fibers

Now we can calculate the young's modulus properties of the explained laminated plies composite in X and Y-direction:

$[45^o/0^o/0^o/-45^o/90^o/90^o/-45^o/0^o/0^o/45^o]_T$

0º = 139.32 GPa

45º = 12.649 GPa

$90^o = 8.077$ GPa

Composite Young's Modulus in Longitudinal Direction:

$$\left(\frac{no.of\ 0^0\ plies}{total\ no.of\ plies} \times modulus\ of\ 0^0\ fiber\right) + \left(\frac{no.\ of\ 45^0\ plies}{total\ no.of\ plies} \times modulus\ of\ 45^0\ fiber\right)$$

$$= \frac{4}{10} \times 139.32 + \frac{4}{10} \times 12.649$$

$E_L = 60.7876$ GPa

Composite Young's Modulus in Transverse Direction:

$$\left(\frac{no.of\ 90^0\ plies}{total\ no.\ of\ plies} \times modulus\ of\ 90^0\ fiber\right) + \left(\frac{no.\ of\ 45^0\ plies}{total\ no.\ of\ plies} \times modulus\ of\ 45^0\ fiber\right)$$

$$= \frac{2}{10} \times 8.077 + \frac{4}{10} \times 12.649$$

$E_T = 6.675$ GPa

3.9 Weight Calculation of Leaf spring:

(i) Weight calculation of the current Steel Leaf Spring:

We can calculate the weight of Leaf Spring form the mass, volume, and Density Relationship,

$$\text{Density} = \frac{Mass}{Volume}$$

$M = \rho \times V$

$W = M \times g$

Therefore, $W = \rho \times V \times g$

Density of Structural Steel = 7.85 gm/cm^3

Taking Acceleration due to Gravity (g) as = 10 m/s^2

Now the weight of the master Leaf (W_1) can be calculated as:

$W_1 = \rho \times V_1 \times g$

$V_1 = L_1 \times t \times w$ Where V_1 = Volume of master leaf spring (cm^3)

$= 130 \times 6 \times 40$ L = Length of master leaf spring (mm)

$= 312$ cm^3 t = Thickness of master leaf spring (mm)

w = Width of master leaf spring (mm)

So, the weight of master leaf spring comes out to be:

$W_1 = 7.85 \times 312 \times 10$

$W_1 = 24.49$ N

Similarly,

Weight of the 2nd Leaf (W_2) = 18.84 N

Weight of the 3rd Leaf (W_3) = 11.304 N

Weight of the 4Th Leaf (W_4) = 7.912 N

Therefore, the total weight of the current existing steel leaf spring becomes:

$W_T = W_1 + W_2 + W_3 + W_4$

$W_T = 62.55$ N

(ii) Weight calculation of Laminated Carbon/Epoxy, Carbon/Epoxy (Non-Laminated), and Boron/Aluminium:

Dimension of the newly developed leaf spring is the same as that of the current leaf spring except the diameter of the eye. This is because to differentiate the advantage and disadvantages of the leaf spring materials and to know the best features of the materials. But some dimension is selected from the standard size of automobile suspension spring tables.

Following are the standard sizes for the automobile suspension springs [32]:

(a) Standard nominal widths are: 32, 40*, 45, 50*, 55, 60*, 65, 70*, 75, 80, 90, 100 and 125 mm. (Dimensions marked* are the preferred widths)

(b) Standard nominal thicknesses are: 3.2, 4.5, 5, 6, 6.5, 7, 7.5, 8, 9, 10, 11, 12, 14 and 16 mm.

(c) At the eye, the following bore diameters are recommended: 19, 20, 22, 23, 25, 27, 28, 30, 32, 35, 38, 50 and 55 mm.

(a) Weight calculation of Laminated Carbon/Epoxy and Carbon/Epoxy (Non-Laminated):

For fiber volume fraction of V_f= 60% and matrix volume fraction of V_m = 40%

Number of Leaf's = 1

Length = 800 (To reduce extra buckling and deformation and also for making Leaf spring to withstand heavy loading)

Width = 40 mm

Thickness = 24 mm

Then according to the above specification, the weight of the Laminated Carbon/Epoxy and Carbon/Epoxy leaf spring becomes:

$W_c = \rho_c \times V_c \times g$

$= 1.5 g/cm^3 \times 768\ cm^3 \times 10\ m/s^2$

$= 11.52$ N

Now calculating percentage weight Reduction:

Weight saved = 62.55 - 11.52 = 51.03 N

Hence, % weight reduction is $= \frac{51.03}{62.55} \times 100 = 81.58$ %

Therefore, Laminated Carbon/Epoxy and Carbon/Epoxy weights very less as compare to conventional leaf spring which is made up of Structural steel.

(b) Weight calculation of Boron/Aluminium:

For same fiber volume fraction, matrix fraction, and dimension as that of Laminated Carbon/Epoxy and Carbon Epoxy, weight of Boron/Aluminum Leaf spring can be calculated as:

$W_c = \rho_c \times V_c \times g$

$= 2.620\ g/cm^3 \times 768\ cm^3 \times 10\ m/s^2$

$= 20.12$ N

Now calculating percentage weight reduction:

Weight saved = 62.55 - 20.12 = 42.43

Hence, % weight reduction is = $\frac{42.43}{62.55} \times 100 = 67.83$ %

Therefore, Boron/Aluminium leaf spring is heavier than laminated Carbon/Epoxy and Carbon/Epoxy but it is lighter than conventional leaf spring made of structural steel.

3.10 Stress and Deflection calculations

Since the leaf springs are mounted on the axle of the vehicle firmly using U bolt, then the distance between the U bolt is 85 mm, this distance is unbent length of the leaf spring then to calculate the deflection and stress of the leaf spring the effective length of the leaf spring must be calculated. According to the textbook of machine design, the effective length of leaf spring can be calculated as:

$2L = 2L_1 - b \ldots\ldots\ldots\ldots\ldots\ldots \textit{when band is used, and}$

$2L = 2L_1 - \frac{2}{3} \times b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textit{when U-bolts is used.}$

Where: 2L = effective length leaf spring

$2L_1$ = total length of leaf spring

L = length of band or U – bolts

b = width of U- bolts

But in this work, we are considering a U-bolt clamping. So, the formula to calculate the effective length of leaf spring becomes:

$$2L = 2L_1 - \frac{2}{3} \times b$$

$2L = 130 \text{ mm} - \frac{2}{3} \times 85 \ mm$, (taking the width of U-bolt as 85 mm [30])

2L = 1243.33 mm

Hence, L = 621.67 mm (half effective length of current leaf spring)

Similarly, we can find effective length of Laminated Carbon/Epoxy, Boron/Aluminium, and Carbon/Epoxy:

$$2L = 800\ \text{mm} - \frac{2}{3} \times 85\ mm$$

2L = 743.33 mm

L = 371.67 mm (half effective length)

3.10.1 Bending stress and Deflection in current Steel Leaf Spring.

(i) Bending Stress in current Steel Leaf Spring:

$$\sigma = \frac{6Wl}{nbt^2}$$

where:

n = No. of leaves (n = 4)

t = thickness of leaf spring (t = 6 mm)

b = width of leaf spring (b= 40 mm)

W = weight on the leaf spring (W = 2710 N)

l = half effective length of leaf spring (621.67 mm)

$$\sigma = \frac{6 \times 2710 \times 621.67}{4 \times 40 \times 36} = 1754.90\ \text{N/mm}^2$$

(ii) Deflection in current steel leaf spring:

$$\delta = \frac{WL^3}{3E}$$

Before calculating deflection in steel leaf spring, it is important to first calculate the moment of inertia of leaf spring because each leaf has a different cross-section area as we can see in fig 3.10

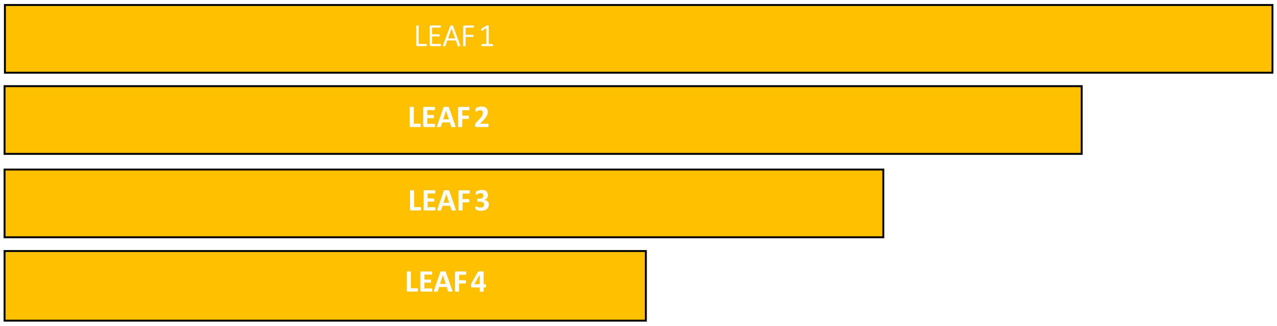


Fig. 3.10 Half cross-section of the current Structural Steel leaf spring

As we can see in above fig, Moment of inertia of current steel leaf spring can be calculated as:

$I = I_1 + I_2 + I_3 + I_4$

Where, I_1, I_2, I_3, and I_4 stands for leaf 1,2,3 and 4 respectively.

$$I_1 = \frac{650 \times 6^3}{12} = 11700 \text{ mm}^4$$

$$I_2 = \frac{500 \times 6^3}{12} = 9000 \text{ mm}^4$$

$$I_3 = \frac{300 \times 6^3}{12} = 5400 \text{ mm}^4$$

$$I_4 = \frac{210 \times 6^3}{12} = 3780 \text{ mm}^4$$

So total moment of inertia is come out to be:

$I = 11700 + 9000 + 5400 + 3780 = 9880 \text{ mm}^4$

Now, Deflection can be calculated as:

$$\delta = \frac{WL^3}{3EI} = \frac{2710 \times 621.67^3}{3 \times 207 \times 10^3 \times 29880} = 35.08 \text{ mm}$$

2. Bending Stress and Deflection in Laminated Carbon/Epoxy, Boron/Aluminium, and Carbon/Epoxy (Non-Laminated).

(i) Bending Stress in newly Designed leaf spring:

$$\sigma = \frac{6W}{bt^2} = \frac{6 \times 2710 \times 371.67}{40 \times 24^2} = 262.29\ \text{N/mm}^2$$

(ii) Deflection in newly Designed leaf spring:

$$\delta = \frac{WL^3}{3EI}$$

Where, I = Moment of Inertia can be calculated as:

$$I = \frac{b \times t^3}{12} = \frac{40 \times 24^3}{12} = 46080\ \text{mm}^4$$

(a) Deflection in Laminated Carbon/Epoxy:

$$\delta = \frac{WL^3}{3EI} = \frac{2710 \times 371.67^3}{3 \times 34000 \times 46080} = 29.60\ \text{mm}$$

(b) Deflection in Boron/Aluminium:

$$\delta = \frac{WL^3}{3EI} = \frac{2710 \times 371.67^3}{3 \times 215000 \times 46080} = 4.68\ \text{mm}$$

(c) Deflection in Carbon/Epoxy (Non-Laminated):

$$\delta = \frac{WL^3}{3EI} = \frac{2710 \times 371.67^3}{3 \times 147000 \times 46080} = 6.84\ \text{mm}$$

We can see that deflection is much less in the case of Boron/Aluminium (i.e.) 4.68 mm as compared to the other two cases.

REFERENCES

[1] SushilB.Chopade, Prof.K.M.Narkar, Pratik K Satav *"Design and Analysis of E-Glass/Epoxy Composite Mono leaf Spring for Light Vehicle."* International Journal of Innovative Research in Science, Engineering and Technology, Vol. 4, Issue 1, January 2015.

[2] Prakash E. J, Chittaranjan Gobind Singh and Akshay Mitra *"Fixed examination of mono leaf spring with special composite materials."* International Research Journal of Mechanical Engineering Vol. 2, January, 2014

[3] Mr. V. K. Aher, Mr. P. M. Sonawane, *"Static and Fatigue Analysis of Multi Leaf Spring Used in the Suspension System of LCV."* International Journal of Engineering Research and Applications. Vol. 2, Issue4, July-August 2012.

[4] Preshit B Waghmare, Raosaheb B Patil *"Static And Modal Analysis Of Leaf Spring Using FEA."* International Journal of Technical Research and Applications, Volume 3 Jan-Feb 2015.

[5] Putti Srinivasa Rao, Revu Venkatesh "Modal and Harmonic Analysis of Leaf Spring Using Composite Materials." International Journal of Novel Research in Electrical and Mechanical Engineering Vol. 2, Issue 3, Month: September-December 2015.

[6] Ajay B.K., Mandar Gophane, P Baskar *"Design and Analysis of Leaf Spring with Different Arrangements of Composite Leaves with Steel Leaves"*, International Journal of Engineering Trends and Technology (IJETT) – Volume 11 Number 2 - May 2014.

[7] Sagar B Mahajan, Prof.M.C.Swami, Permeshwar Patil *"Design and Analysis of Mono Composite Leaf Spring by Varying Thickness using FEA."* IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Volume 12, Issue 1 Ver. II (Jan- Feb. 2015).

[8] Malaga. Anil Kumar, T.N.Charyul, Ch.Ramesh *"Design Optimization of Leaf Spring."* International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue 6, November- December 2012.

[9] Ritesh Mistry *"Dynamic Analysis of A Leaf Spring"* IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 2, Issue 2, Apr-May, 2014.

[10] Bhaumik A. Bhandari & Bhavesh C. Patel *"Parametric Analysis of Composite Leaf Spring"* IJSTE–International Journal of Science Technology & Engineering Vol. 1, Issue 1, July 2014.

[11] Mr. Akshay Kumar, Mr. V. J. Shinde, Mr. S. S. Chavan *"Design, Analysis, Manufacturing and Testing of Mono Composite Leaf Spring Using UD E-Glass Fiber/Epoxy"* International Journal of Advanced Technology in Engineering and Science Volume No.02, Issue No. 12, December 2014.

[12] M Rama Laxmi, R.Rudrabi Ram "Design analysis of Leaf spring Through CATIA and ANSYS With different composites" International Journal of Engineering Technology, Management and Applied Sciences, Volume 3, Issue 10 October 2015.

[13] P. Ravindranatha Reddy, K. Suresh Kumar, "Mono Composite Leaf Spring – Design and Analysis by using FEA under Static Load Condition." IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 2 Issue 3, March 2015.

[14] Mohammed I. Hameed, Dhia A. Alazawi, Zaid S. Hammoudi "*Finite Element Analysis of Steel and Composite Leaf Springs Under Static Loading*" Scientific Conference of Engineering Science (ISCES) 2018.

[15] K. K. JADHAO Associate profe, *"Experimental Investigation & Numerical Analysis Of Composite Leaf Spring"* International Journal of Engineering Science and Technology (IJEST), Vol. 3 No. 6 June 2011.

[16] Sagar Manchanda, Beant Singh and Gurmeet Singh *"Design and Finite Element Analysis of Leaf Spring Using Different Material Properties."* Journal of Academia and Industrial Research (JAIR) Volume 4, Issue 7 December 2015.

[17] U. S. Ramakanth & K. Sowjanya *"Design and Analysis of Automotive multi-leaf Springs using Composite Materials"* International Journal of Mechanical Production Engineering Research and Development (IJMPERD) Vol. 3, Issue 1, Mar 2013.

[18] Jagbhooshan Patel Veerendra Kumar, *"Finite Element Analysis of Mono Composite Leaf Spring under the Static Load Condition",* International Journal of Emerging Trends in Engineering and Development Issue 4, Vol.4 (June-July 2014).

[19] M. Corum R., L. Battiste K., C. Liu, M. B. Ruggles, *"Basic Properties of Reference Cross-ply Carbon-Fiber Composite."* Oak Ridge National Laboratory Oak Ridge, Tennessee.

[20] Jing Zhang, *"Different surface treatments of carbon fibers and their influence on the interfacial properties of carbon fiber/epoxy composites."* Ecole Centrale Paris, 2012.

[21] Torayca, *"Technical Data Sheet"* Toray Carbon Fibers America, Inc.

[22] David Richardson, "*The Fundamental Principles of Composite Material Stiffness Predictions."* University of West of England.

[23] IES GS *"chapter-7 Composites'* June 29, 2017

[24] Sonam Agrawal *"Effective thermal conductivity of epoxy matrix composites filled with titania (tio2) powder,* NIT Rourkela, May 2011

[25] Ning Pan, *"Theoretical Determination of the Optimal Fiber Volume Fraction and Fiber-Matrix Property Compatibility of Short Fiber Composites."* Division of Textiles and Clothing University of California

[26] Katarinauusitalo, *"Designing In Carbon Fiber Composites."* Chalmers University of Technology Gothenburg, Sweden, 2013.

[27] F.-X. Irisarri, A. Lasseigne, F.-H. Leroy, R. Le Riche, *"Optimal design of laminated composite structures with ply drops using stacking sequence tables."* Onera, the French Aerospace Lab, F-92322 Châtillon, France, 4 September 2013.

[28] Isaac M.Daniel Ori Ishai "*Enginering Mechanics of Composite Materials",* Oxford university press page no. 26, 2011.

[29] David Richardson, *"The Fundamental Principles of Composite Material Stiffness Predictions."* University of West of England.

[30] Misganaw Abebaw "Design and Static Analysis of Carbon/Epoxy Composite Mono Leaf Spring for Light Vehicle Using FEM", Addis Ababa Institute of Technology, 2017.

[31] R.K Bansal *"Strength of materials"*, page no. 305, Laxmi publication ,2013.

[32] Jignesh R. Patel, *"Design and analysis of composite leaf spring."* Department of mechanical engineering, Ganpat University, 2014.

[33] Rupesh N. Kalwaghe Prof. K. R. Sontakke, *"Design and Analysis of Composite Leaf Spring by Using FEA and ANSYS",* International Journal of Scientific Engineering and Research (IJSER), Volume 3 Issue 5, May 2015.

[34] Dadasaheb Gaikwad; Rakhi Sonkusare; Sameer Wagh, *"Composite Leaf Spring for Light Weight Vehicle- Materials, Manufacturing Process, Advantages & Limitations."* Int J Engg Techsci Vol. 3(2) 2012.