



**ADDIS ABABA UNIVERSITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**SCHOOL OF GRADUATE STUDIES**

**Design and Static Analysis of Carbon/Epoxy Composite Mono Leaf Spring for  
Light Vehicle Using FEM**

**A Thesis Submitted to the Graduate School of Addis Ababa University in Partial  
Fulfillment of the Requirements for the Degree of Masters of Science in  
Mechanical Engineering (Mechanical Design)**

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**Addis Ababa Ethiopia**

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**Addis Ababa University**

**Addis Ababa University Institute of technology**

**School of Mechanical and Industrial Engineering**

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## ABSTRACT

*Design and Static Analysis of Carbon/Epoxy Composite Mono Leaf Spring for Light Vehicle Using FEM*

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*Addis Ababa University, Addis Ababa Institute of Technology, 2017*

In this study, design and static analysis of carbon/epoxy composite mono leaf spring was done by comparing the conventional steel leaf spring which is used by Damas II a four wheeled light vehicle. The main idea behind this work is to replace the existing steel leaf spring material with a mono laminated carbon/epoxy composite leaf spring with same width, thickness and load carrying capacity. In this study, the main investigation of the study is to reduce the weight of product while upholding its strength. Then to solve problem in this regard composite materials are play an important role. The prominence of the paper was to design and analysis of quasi isotropic laminated carbon/epoxy composite material leaf spring suspension system. Then this study seeks to address, improve load carrying capacity and designing less stressed, less deformed and light weight composite leaf spring, which have better performance than that of the existing Damas II car steel leaf spring. The composite material which is carbon fiber with a volume fraction of 60% and the matrix material is epoxy with a volume fraction of 40%, by using the two materials making a quasi-isotropic composite laminate with angle of orientation  $[45^{\circ}, 0^{\circ}, 0^{\circ}, -45^{\circ}, 90^{\circ}, 90^{\circ}, -45^{\circ}, 0^{\circ}, 0^{\circ}, 45^{\circ}]_T$ . The work also gives focus on the application of FEA concept to compare two materials of the leaf spring. The two materials used for comparisons are; the existing Damas II car conventional steel leaf spring and mono quasi isotropic laminated carbon/Epoxy composite leaf spring. In the present work total deflection and equivalent (Vone misses) stresses induced in the two leaf springs are done on ANSY 16 workbench were compared. The solid modelling of leaf spring was done on CATIA V5 R19 and analysis using ANSYS software. Finally, standing from the static analysis result the study conclude that the newly designed carbon/epoxy mono composite leaf spring has better performance than that of the current conventional steel leaf spring of Damas II car.

**Keywords:** *mono leaf spring, static load, carbon/epoxy, steel leaf, ANSYS 16 workbench, CATIA V5 R19.*

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## NOMENCLATURE

$W_c$  = weight of composite

$W_f$  = weight of fiber

$W_m$  = weight of matrix

$\rho_c$  = density of composite

$\rho_f$  = density of fiber

$\rho_m$  = density of matrix

$V_c$  = volume fraction of composite

$V_f$  = volume fraction of fiber

$V_m$  = volume fraction of matrix

$E_1$  = longitudinal modulus

$E_2$  = transverse modulus

$E_c$  = elastic modulus of composite

$E_f$  = elastic modulus of fiber

$E_m$  = elastic modulus of matrix

$G_{12}$  = in plane shear modulus

$\nu_{12}$  = major Poisson's ratio

$G_f$  = shear modulus of fiber

$G_m$  = shear modulus of matrix

$\sigma_{tl}$  = longitudinal tensile strength of a ply

$\sigma_{tt}$  = transverse tensile strength of a ply

$\sigma_{cl}$  = longitudinal compressive strength of a ply

$\sigma_{ct}$  = transverse compressive strength of a ply

$\eta$  = kernelfactor or efficiency factor of a laminated composite

## **LIST OF ABBREVIATIONS AND ACRONYMS**

ACF = Activated carbon fiber

CAD = computer aided drawing

CFRP = Carbon fiber reinforced plastic

CMCs = Ceramic matrix composite

CTE = Coefficient of thermal expansion

FEM = Finite element modeling

FRP = Fiber reinforced plastic

GPa = Giga Pascal

$\text{g/cm}^3$  = Gram per centimeter cubed

HS = high strength

Kg = kilo gram

M = Mass

MMCs = Metal matrix composite

mm = millimeter

MPa = Mega Pascal

N = Newton

PAN = poly acryl nitrile

PMCs = Polymer matrix composite

ROM = rule of mixture

UV = ultra violet

W = weight

$^{\circ}\text{c}$  = degree centigrade

$\mu\text{m}$  = micro meter

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1. Background of the study**

A leaf spring is a simple form of spring which is usually called ‘BALESTRA’, commonly used for the suspension in wheeled vehicles. It is also one of the oldest form of spring, dating back to medieval times. Leaf springs can serve locating 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 saturation in the motion of the suspension [5]. Sometimes referred to as a semi elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for 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 [11].

##### **1.1.1. 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 allows 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 [9].

The automobile chassis is mounted on the axles, not direct but some form of springs are 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, suspension system must consist 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 [12].

Generally suspension system of a vehicles used to prevent the road shocks from being transmitted to a vehicle components, to safeguard the occupants from road shocks, and to preserve the stability of the vehicle in pitting or rolling, while in motion. There are many types of springs which are

available in a vehicle suspension system such as: helical spring, conical and volute spring, torsion spring and laminated or leaf spring [12].

#### **1.1.1.1. 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 overall length of spring minus width of the band. And again in 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 which 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 [12, 15].

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 heavy weight 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 [13]. Then in order 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 meets the basic requirement of strength and functionality, but the current Lightweight composite materials gives several advantageous

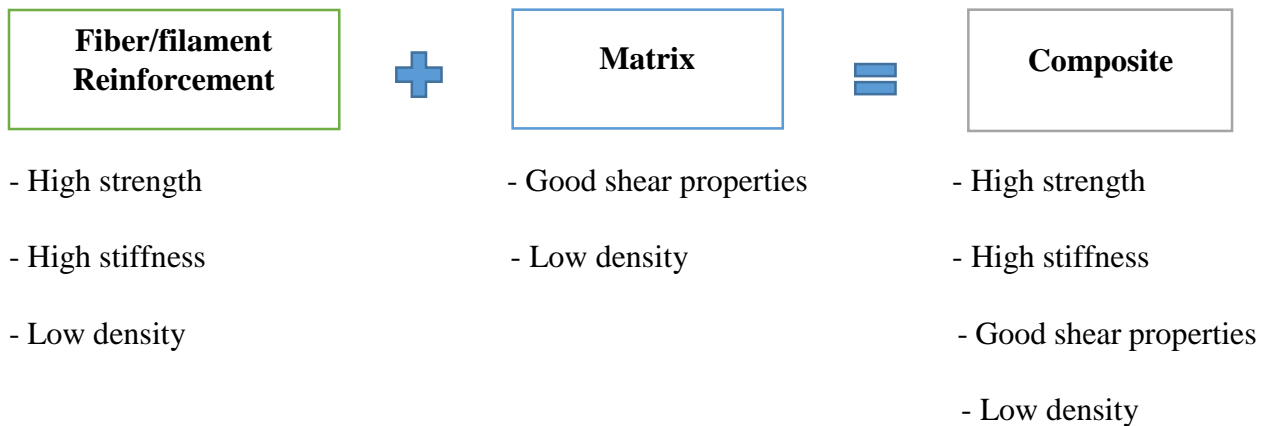
over the current conventional steel leaf spring. This is because composite materials offer significant opportunities for enhancement of product performance in terms of strength, stiffness, life span and energy absorption, combined with weight reduction and space saving. Then now let's see in details about composite materials:

### 1.1.2. Composite materials

Composite materials are engineering materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. There are two categories of constituent materials: matrix and reinforcement [5].

The primary functions of the matrix materials are to transfer stresses between the reinforcing material and to protect them from mechanical and/or environmental damage and whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness etc. [18]

The matrix material surrounds and supports the reinforcement or the fiber materials by maintaining their relative positions. The reinforcing material impart their special mechanical and physical properties to enhance the matrix properties [36]. In general terms composite are explained as the following:



*Figure 1.1: component of a composite.*

#### 1.1.2.1. Classification of composite materials

According to [20, 53] Composite materials are commonly classified as depicted in the following figure.

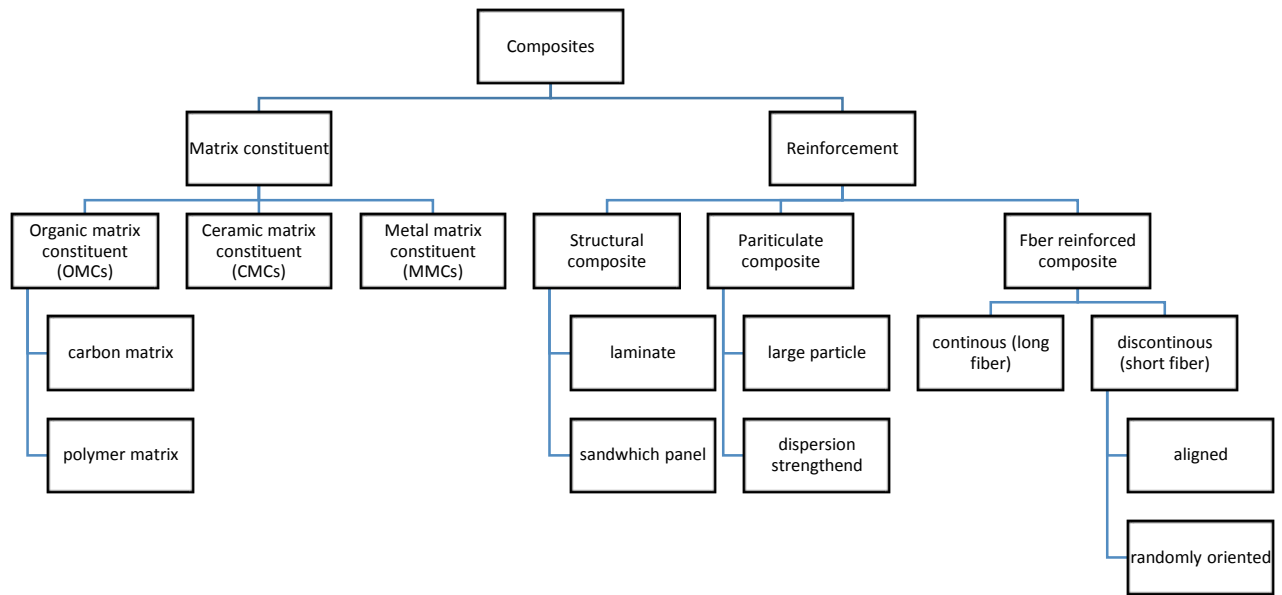


Figure 1.2: Classification of composite materials [20, 52, and 53].

### Laminar Composites

There are many types of laminate composites from these clad and sandwich laminates have many areas of application, although they are well known by following the rule of mixture from the modulus and strength point of view. Powder metallurgical processes such like; roll bonding, hot pressing, diffusion bonding, brazing and etc. can be employed for the fabrication of different alloys of sheet, foil, powder or sprayed materials. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. The main functional types of metal-metal laminates that do not possess high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost effective. They are usually made by pre-coating or cladding methods [52].

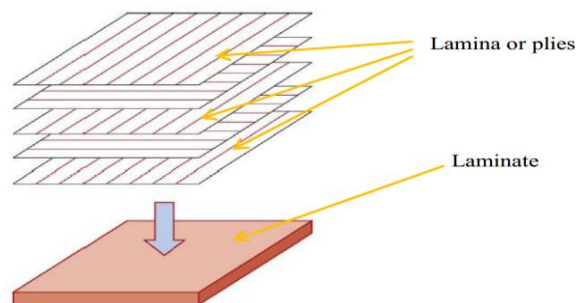


Figure 1.3: laminate composite [49].

### Particulate Composites

Particles usually reinforce a composite equally in all directions called isotropic composite. Plastics, cements and metals are examples of particles. Particles used to strengthen a matrix don't do so in the same way as fibers. For one thing, particles are not directional like fibers. Spread at random throughout a matrix, particles tend to reinforce in all directions equally. The difference between particulate composite and dispersion strengthened ones is, thus, obvious. The mechanism used to strengthen each of them is also different. The dispersed in the dispersion-strengthen materials reinforces the matrix alloy by arresting motion of dislocations and needs large forces to fracture the restriction created by dispersion. In particulate composites, the particles strengthen the system by the hydrostatic coercion of fillers in matrices and by their hardness relative to the matrix [49].

Microstructures of metal and ceramics composites, which show particles of one phase strewn in the other, are known as particle reinforced composites. Square, triangular and round shapes of reinforcement are known, but the dimensions of all their sides are observed to be more or less equal. Size and volume concentration of the dispersion distinguishes it from dispersion hardened materials [52].

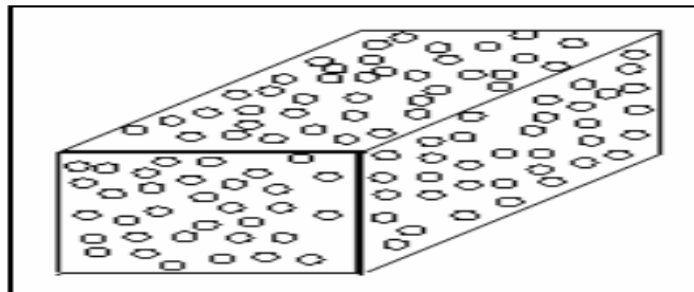


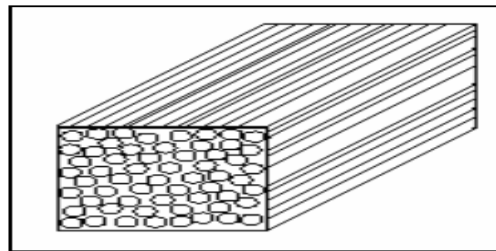
Figure 1.4: Particulate Composites [52].

### Fiber reinforced composites (FRP)

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired. Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat [33].

Optimum performance of longitudinal fibers can be obtained, when the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite. Unidirectional loading is found in few structures and hence it is prudent to give a mix of orientations for fibers in composites particularly where the load is expected to be the heaviest [49].

Fibers fall short of ideal performance due to several factors. The performance of a fiber composite is highly depend on by its length, shape, orientation, and composition of the fibers and the mechanical properties of the matrix material. Orientation of the fiber in the matrix is influence the strength of the composite and the strength is greatest along the longitudinal directional of fiber. This doesn't mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied [52].



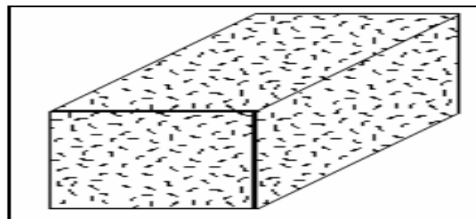
*Figure 1.5: Long-fiber reinforced composites [52].*

It goes without saying that fiber composites may be constructed with either continuous or short fibers. Experience has shown that continuous fibers (or filaments) exhibit better orientation, although it does not reflect in their performance. Fibers have a high aspect ratio, that their lengths being several times greater than their effective diameters. This is the reason why filaments are manufactured using continuous process [52].

There are several methods of random fiber orientations, in which a two-dimensional one, yield composites with one-third the strength of a unidirectional fiber-stressed composite, in the direction of fibers. In very strong matrices, moduli and strengths have not been observed. Application of the strength of the composites with such matrices and several orientations is also possible. The longitudinal strength can be calculated on the basis of the assumption that fibers have been reduced to their effective strength on approximation value in composites with strong matrices and non-longitudinally orientated fibers [53].

Mass production of filaments is well known and they match with several matrices in different ways like winding, twisting, weaving and knitting, which exhibit the characteristics of a fabric. Since they have low densities and high strengths, the fiber lengths in filaments or other fibers yield considerable influence on the mechanical properties as well as the response of composites to processing and procedures. Shorter fibers with proper orientation composites that use glass, ceramic or multi-purpose fibers can be endowed with considerably higher strength than those that use continuous fibers. Short fibers are also known to their theoretical strength. The continuous fiber constituent of a composite is often joined by the filament winding process in which the matrix impregnated fiber wrapped around a mandrel shaped like the part over which the composite is to be placed, and equitable load distribution and favorable orientation of the fiber is possible in the finished product. However, winding is mostly confined to fabrication of bodies of revolution and the occasional irregular, flat surface [52].

Short-length fibers incorporated by the open- or close-mold process are found to be less efficient, although the input costs are considerably lower than filament winding.



*Figure 1.6: Short-fiber reinforced composites [52].*

Most fibers currently in used are solids which are easy to produce and handle, having a circular cross-section, although a few non-conventional shaped and hollow fibers show signs of capabilities that can improve the mechanical qualities of the composites.

Given the fact that the vast difference in length and effective diameter of the fiber are assets to a fiber composite, it follows that greater strength in the fiber can be achieved by smaller diameters due to minimization or total elimination of surface defects.

On the other hand, when the length of the fiber is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fiber reinforced.

For these reasons, fiber composite have emerged as a major class of structural material and are considered as substitutions for metal in many weight-critical components in aerospace, automotive and other industries. High damping capacity, this leads to better vibration energy absorption within the material and results in reduced transmission of noise and vibration to neighboring structures.

Orientation of the fibers in the matrix is the factor that mainly influences the fibers' performance. The most optimal utilization is achieved when the fibers are placed in the direction of the load, small deviation can reduce the strength and stiffness of the composite [37]. Fibers orientation or placing the fibers in different directions, for example  $0^\circ$ ,  $+45^\circ$ ,  $-45^\circ$ ,  $90^\circ$ , play a great role to balance the load carrying capacity of the laminated composite material. When a laminate have an equal number of layers in the  $0^\circ$ ,  $90^\circ$ ,  $45^\circ$ ,  $-45^\circ$  directions it is called a quasi-isotropic laminate. It carries loads in all directions, therefore this is the preferred orientation of fibers. There are other factors that affect the performance of the composite, such as fiber volume fraction, the stiffness of matrix, damage tolerance, single ply thickness, voids, fiber matrix interface, moisture and media, temperature, holes and cut-outs.

### **Carbon fibers**

The properties of carbon fibers are equal to steel, but with lower density. As mentioned in Table 1 below, carbon fibers high stiffness and strength, and the fibers have also good thermal stability and when combined into a matrix is the fatigue resistance excellent [37, 38].

The chemical, corrosion resistance, as well as the dimensional stability, and vibration damping ability of CFRP compared to metals are excellent. The electrical resistivity is low, and the thermal conductivity is high. Composites based on carbon fibers have low energy-absorbing capacity, poor resistance to transverse impact loading and the plies have a tendency to separate from each other in the laminate [37].

Most of the time carbon fibers are combined with a polymer matrix, and which is called CFRP or carbon fiber reinforced plastics. It is possible to receive a high performance material with a weight reduction of more than 50 compared to high strength steel by using CFRP. The strength and stiffness of CFRP is as high as for high strength and stiffer steel and the density is 40 per cent lower than aluminum. The fatigue and creep resistance of CFRP are also good, and by

using laminate orientation the material can be designed to be tougher and more damage tolerant than metals [51].

Table below shows advantages and disadvantages of some common fibers.

*Table 1.1: Advantages and disadvantages of reinforced fibers [37].*

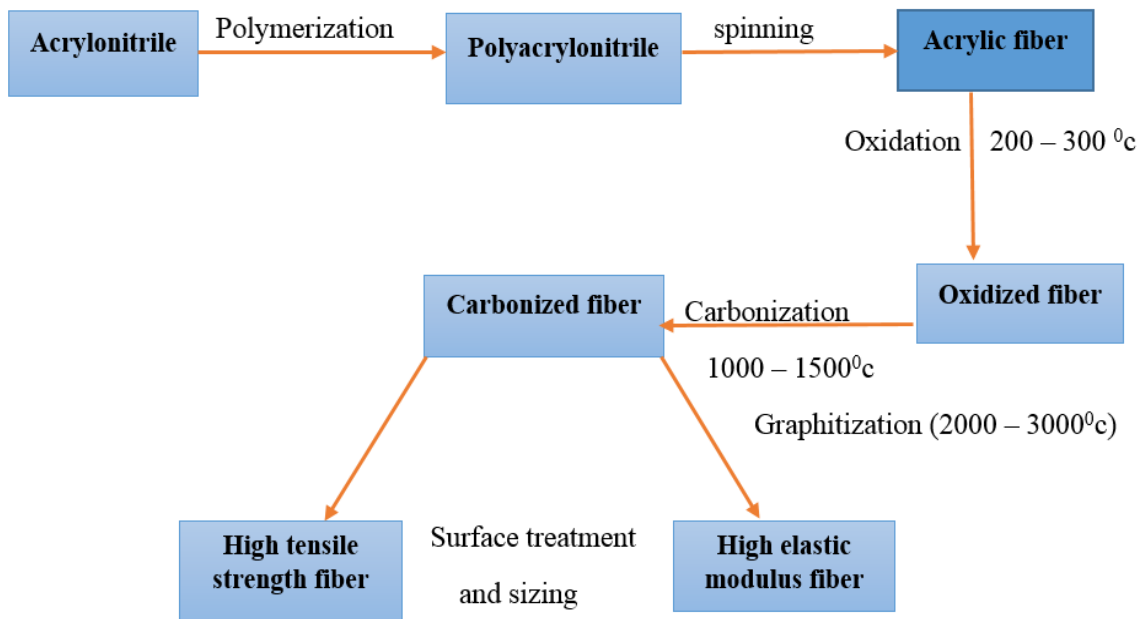
<b>Fiber</b>	<b>Advantageous</b>	<b>Disadvantageous</b>
E – glass	• High strength	• Low stiffness
	• Low cost	• Short fatigue life
		• High temperature sensitivity
Armide (Kevlar)	• High tensile strength	• Low compressive strength
	• Low density	• High moisture absorption
Boron	• High stiffness	• High cost
	• High compressive strength	
Carbon (AS4, T300, c6000)	• High strength	• Moderately high cost
	• High stiffness	
Graphite (GY – 70, pitch)	• Very high stiffness	• Low strength
		• High cost
Ceramic (silicon carbide, alumina)	• High stiffness	• Low strength
	• High use temperature	• High cost

It is possible to get carbon fibers with a wide range of different strength and stiffness. Carbon fibers classifies in three categories due to strength and stiffness; high strength, intermediate modulus or high modulus fibers [37]. Classifies carbon fibers a slightly different way, also in three categories; general-purpose (GP), high-performance (HP), activated carbon fibers (ACF). Activated carbon fibers have a large number of open micropores, which acts as adsorption sites,

the material has therefore a good adsorption capacity, comparable to activated carbon but the shape of the fibers allows the adsorbate to get to the adsorption site faster [37].

Carbon fibers and graphite are both names used to describe carbon fibers. The main difference between them is the content of carbon. Carbon fibers consists of typically 95 per cent carbon, and are carbonized at circa 1000 to 1500°C, while graphite fibers contain about 99 per cent carbon, and are first carbonized and then graphitized at temperatures between 2000°C and 3000°C. The graphitization process generally results in a fiber with higher modulus [47].

Carbon fibers can be made from rayon, polyacrylonitrile (PAN) or petroleum-based pitch. The best combination of properties is produced of PAN-based fibers, which is a form of acrylic fibers. Petroleum-based pitch fibers are mainly used to produce high and ultrahigh-modulus graphite fibers, but were developed as a lower cost alternative to PAN [51].



*Figure 1.7: PAN-based carbon fiber production process [42].*

Pitch is produced from destructive distillation of petroleum or coal tar which is made up of fused aromatic rings. Both isotropic and mesophase pitches are used to produce carbon fibers. Production of pitch-based carbon fibers involves melt spinning of pitch precursor fibers, oxidation, carbonization, and graphitization as shown below in fig. [42, 51]

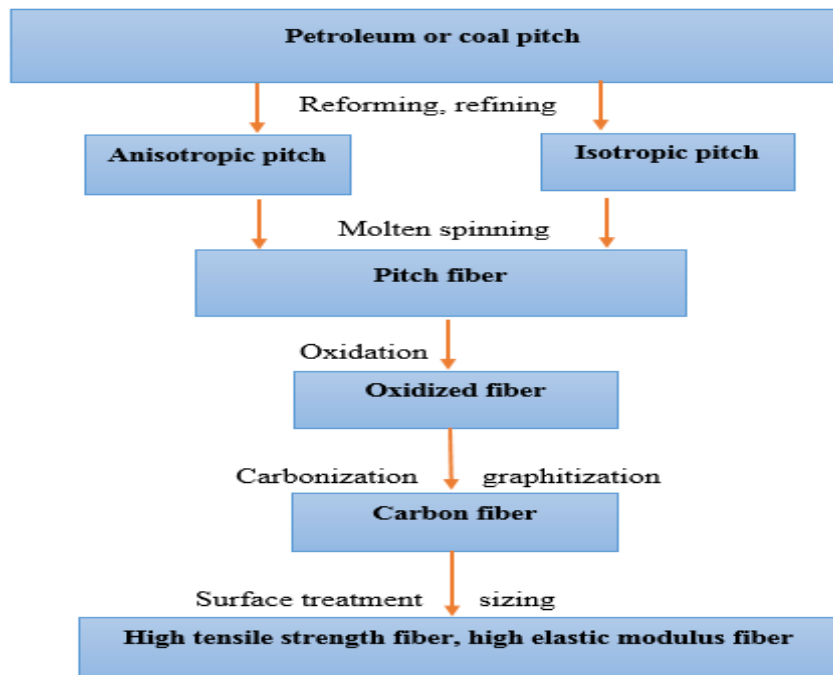


Figure 1.8: Pitch-based carbon fiber production process [42].

To get carbon fiber with high strength and high stiffness property the material must be processed with the temperature range of between 1200°C and 1500°C. Ultrahigh stiffness graphite fibers are processed at temperatures between 2000°C and 3000°C [51].

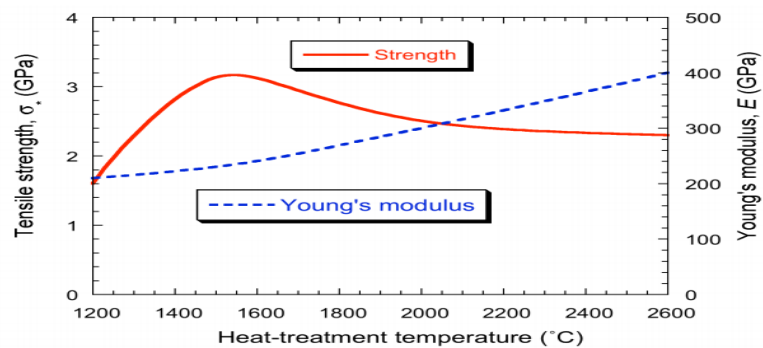


Figure 1.9: Effect of heat treatment temperature on the strength and Young's modulus of carbon fibers produced from a PAN precursor [36].

### 1.1.2.3. Matrix materials

The strength of composites is largely depend on the fiber reinforcement and the type of matrix material. Matrix material provides support for the fibers and assists the fibers in carrying the loads,

it also provides stability to the composite material. Resin matrix system acts as a binding agent in a structural component in which the fibers are embedded [17, 26]. During reinforcement when too much resin is used, the part is classified as resin rich, and on the other hand if there is too little resin, the part is called resin starved.

A resin rich part is more susceptible to cracking due to lack of fiber support, whereas a resin starved part is weaker because of void areas and the fact that fibers are not held together and they are not well supported [34].

The matrix material is used to maintain the position and orientation of the fibers as well as protects the fiber material from possible degrading environments [40].

The softening or melting temperature for the matrix limits the maximum temperature for metal composites. The matrix in ceramic matrix composites is ceramics as well as the fibers. This composite is well suited for very high temperature applications. The last one, carbon/carbon composites, is carbon or graphite matrix reinforced with graphite yarn or fabric. The properties are unique with relatively high strength at high temperatures in combination with low thermal expansion and density [46].

In polymer and metal composites the matrix materials transiting load from the matrix to the fibers through shear loading at the interface. The most commonly used matrices are polymer matrices, and they are reinforced with glass, carbon, aramid or boron fibers. These composites are used at relatively low temperature. Other matrices are metal and ceramic matrices and carbon/carbon composites. The metal matrices composites consist of metals or alloys and are reinforced with boron, carbon or ceramic fibers [52].

There are different types of thermosetting matrices; some of them are mentioned below:

- Polyester
- Epoxy
- Vinyl ester
- Polyimide
- Phenolic resins

## **Epoxy**

The most widely used polymer matrix for carbon fibers is epoxy. The material is common in high performance continuous fiber composites. According to their use in different environments depending on temperature and moisture variations epoxy has classify into two categories, which are used in. those that are cured at lower temperature (120°C) and used in components exposed to low or moderate temperature variations, e.g. sports equipment, and those that are cured at higher temperature (175°C). And the other are used in high performance components and are exposed to high temperature and moisture variations [37].

The curing process involves by addition of hardener and an accelerator, and the temperature ranges are between 60°C and 180°C. Epoxy has the combination of mechanical properties like, corrosion resistance, dimensionally stable, exhibits good adhesion and relatively inexpensive that gives the composite material good properties. When compared epoxy with polyester mechanical properties and water resistance of epoxy is superior, and the shrinkage property of polyester is minimum during curing.

There are several types of epoxy, and commonly epoxy for many commercial composite matrix systems are DGEBA (diglycidyl ether of Bisphenol A) and TGMDA (tetraglycidyl methylene dianiline) also known as TGGDM (tetraglycidyl-4,4''-diaminodiphenymethane). Their uses are common within aerospace applications. DGEBA is the most widely used epoxy type, which is often used for filament winding and pultrusion because it is found as a liquid at several viscosities, and can be either a solid or a liquid. TGMDA is the base resin used in a majority of the commercial epoxy matrix systems. It has high strength, high rigidity and elevated temperature resistance. It is also available in a variety of viscosity, and is sold commercially as MY-720 and MY-721. In adhesive systems, where toughness is an important factor, mix suppliers DBEBA and TGMDA to help provide more flexibility in the cured adhesive [37].

Basically epoxies are added to provide viscosity control, improve high-temperature properties, lower moisture absorption and improve toughness. Epon, Epi-rez, D.E.R., Epotuf and Araldite are all trade names of epoxy [48].

## **1.2. Statement of the problem**

The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to its high strength to weight ratio [14].

The objective of the paper is to reduce the overall weight of suspension system and improve load carrying capacity of the leaf spring by using the composite material.

The work also gives focus on the application of FEM concept to compare the current conventional steel leaf spring of Damas II light vehicle and the newly design carbon/epoxy composite mono leaf spring, finally propose the one having higher strength to weight ratio. Two materials used for comparison are; conventional steel and composite carbon/Epoxy material.

## **1.3. Objective of the study**

### **1.3.1. General objective:**

The general objective of this research paper is design and static analysis of laminated carbon/epoxy composite leaf spring using FEM.

### **1.3.2. Specific objective:**

This research paper has the following specific objective:

- 1) Selection of appropriate composite materials for leaf spring.
- 2) Develop a suitable model of steel and laminated carbon/ epoxy composite leaf spring.
- 3) Static analysis will be conducted on the current steel leaf spring of Damas II car and newly designing laminated carbon/epoxy composite leaf spring.
- 4) Theoretical calculations will be conducted on both leaf springs.
- 5) Finally comparison of result will be conducted between the current conventional steel leaf spring and composite carbon/epoxy leaf spring.

## **1.4. Limitation of the study**

The study has some limitations:

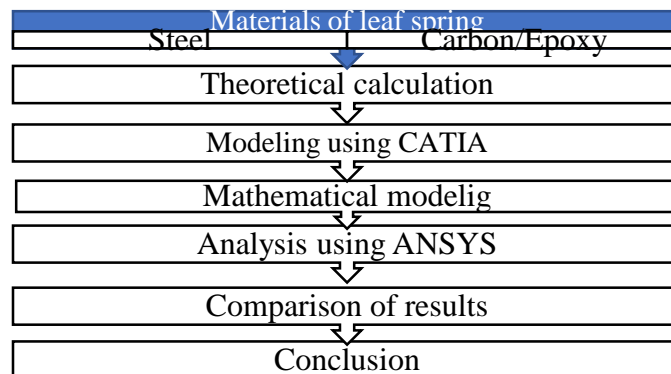
- 1) In this study experimental investigations will not be conducted; instead a reasonable data that was already done by appropriate experiments will be taken.
- 2) The prototype of the leaf spring does not manufacturing in this study.
- 3) The study work on for light four wheeled vehicles.

### 1.5. Methodology

The methods perform to achieve the objectives of the research are:

- A relevant data should be collected through literature review.
- Some crucial characteristics of Carbon/ epoxy composite and the analysis of leaf spring of these composites which was done by experimental investigation will be collected.
- An actual data will be collected by observing and measuring the specifically selected Damas II four wheeled light vehicle leaf spring specification.
- Perform theoretical calculation of the steel and laminated carbon/epoxy composite material leaf spring for light weight four wheeled vehicle.
- Perform mathematical modeling of the laminated carbon/epoxy composite and steel leaf spring for light four wheeled vehicle.
- Make 3D mode of composite carbon /epoxy and steel leaf spring using CATIA V5 R19.
- Make analysis of laminated carbon/epoxy composite material and current steel material leaf spring using ANSYS 16. Workbench.
- Finally state the conclusion of ANSYS 16 workbench results.

Generally the overall work flow of the study methodology looks like below:



*Figure 1.10: work flow of study methodology.*

### 1.6. Outline of the study

This work is organized in five chapters. The first chapter is devoted to brief description of leaf spring and composite material; the thesis background; problem of the statement; general and specific objectives, limitation and methodologies of the study.

The second chapter presents literature review on the past leaf spring materials and its analysis type. The third chapter deals with materials, design methods and conditions which focused on selection of materials, specifications/dimensions of leaf spring, modeling and analysis of steel and laminated carbon/epoxy composite leaf spring.

The fourth chapter addresses ANSYS 16 workbench software results and discussion. And the last chapter devoted to state the conclusions, recommendations and future works of the study.

## CHAPTER TWO

### LITERATURE REVIEW

There are many journals, articles, thesis papers, books, conference and published study on the world related to composite leaf spring materials which deals about 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 product while upholding its strength. To solve the problem using E-glass/Epoxy composite materials. And finally reached to the conclusion of 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 also 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 design and fabrication of complete mono composite leaf spring. The researcher consider a single leaf with variable thickness and variable width for 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 conclude 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 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 a LCV were taken and verified by design calculations. The non-linear static analysis of 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 were on the application of computer aided analysis using 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 conclude 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 strengths 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 similar design. And he recommended for future work “by varying the layer configuration higher strengths can be achieved” [4]. The researcher consider 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 composite material with same width, thickness and load carrying capacity. By using composite materials the weight of the multi leaf spring is reduced drastically. Finally the researcher state a conclusion for his work as: E-glass/epoxy and carbon/epoxy have 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]** the aim of this study is 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 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 alternate arrangement of steel and composite leaves. Fourth model arrangement shows better result than 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 on 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.

**Stephan Krall, et al, [10]** studied on “Investigation of the Dynamic Behavior of CFRP Leaf Springs.” The paper deals with the dynamic behavior of CFRP leaf springs. The experimental modal analysis is used for the investigation. The researcher done two different methods (impact test and shaker test) for the excitation of the parts have been applied. And take the standard steel leaf spring is used as reference, then three different composite springs are investigated and compared. The composite design is calculated via classical lamination theory and the manufacturing was done by hand lay-up and autoclave. An important aspect for spring elements is the behavior at different thermal conditions. Therefore one of the test bodies was investigated at low temperature. At last he decide that for the suitability of the analytical calculation of the Euler – Bernoulli beam theory was investigated and compared with the experimental results.

Finally the researcher conclude that:

1. Due to the fact that there is no physical connection between the excitation and the structure when performing the impact test. Thus, the impact test avoids the problem of interaction between the structure and the excitation unit. This determines the different results between

- the measurement methods. The point of coupling of the shaker excited leaf spring makes exactly the same movement as the shaker itself. Thus, the best solution to determine the material properties and the dynamic characteristics particularly for light weight structures like the leaf spring bodies is an excitement by an impulse [10].
2. Another result is the confirmation of the dependence between dynamic behavior and temperature. At lower temperatures the modal damping increases [10].
- On this research the researcher did experimental analysis of composite leaf spring by using two different methods impact test and shaker test for the excitation of the parts. And he took standard steel leaf spring used as reference, and compare three different composite leaf spring materials. The composite design calculated via classical lamination theory and the manufacturing was done by hand lay-up and autoclave.

**Ghodake A. et al, [14]** the researcher in this paper describes design and FEA analysis of composite leaf spring made of glass fiber reinforced polymer. The numerical analysis and finite element analysis done using ANSYS software. Stresses, deflection and strain energy results for both steel and composite leaf spring material were obtained during the design session. Result shows that, the composite spring has maximum strain energy than steel leaf spring and weight of glass fiber reinforced plastic composite spring was nearly reduced up to 84.94% compared with steel material. Finally the researcher conclude that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials was made it possible to reduce the weight of the leaf spring without any reduction on load carrying capacity and stiffness [14].

**U. S. RAMAKANTH, et al, [15]** the researcher study on ‘design and analysis of automotive multi-leaf springs using composite materials’. This work carried out on multi leaf springs having nine leaves used by a commercial vehicle. A Finite element approach for analysis of a multi leaf springs was performed using ANSYS software. The model is generated using solid works and imported in ANSYS. Finally the researcher conclude that, under the same static load conditions the stresses in leaf springs are found with great difference. Stresses in composite leaf spring is less as compared to the conventional steel leaf springs, also a new combination of steel and composite leaf springs (hybrid leaf springs) were given the same static loading and found to have values of stresses in between that of steel and composite leaf springs [15].

**Ritesh M. [16]** 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 details.

**Bhaumik A, et al, [17]** the objective of the study were 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. Static analysis of a model of leaf spring was performed using ANSYS 11.0. The result of 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 [17]. And finally the researcher conclude 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, [18]** Today's need of manufacturing industries is to make the 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 has 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, [19]** the main objective of the study were 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-mises 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.

**SUREKHA S. et al, [34]** studied on “Design Analysis of Carbon/Epoxy Composite Leaf Spring.” This work deals about the replacement of conventional steel leaf spring of a light commercial vehicle with composite leaf spring using Carbon/Epoxy. This project mainly focus on design and analysis of laminated mono composite leaf spring with unidirectional fiber orientation angle  $0^0$  is considered. The implementation of Carbon/Epoxy composite materials for leaf springs of a suspension system can replace steel in conventional spring to reduce the weight, deflection, stresses, product development cost and increase the comfort. Finally the researcher conclude that:

1. “From the comparison that the deflection and bending stress induced in the Carbon/Epoxy composite leaf spring is less than the conventional steel leaf spring for the same load carrying capacity.”
  - The researcher done the study by considering laminated mono leaf spring with unidirectional fiber orientation angle of  $0^0$  and the researcher take the dimension of the conventional leaf spring for the new mono composite leaf spring.

**Parkhe Ravindra A. et al, [36]** studied on “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 determine 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, analytical procedure is followed by finite element analysis and he verified results experimentally. In addition 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 a 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 conclude 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 THREE**

### **MATERIALS, METHODS AND CONDITIONS**

In design process the first and time consuming part is the selection of suitable material for the required designing component, which solves the problem of the existing design totally or partially. Then to meet the final goal and objective of the study, selection of material must be done within many consideration.

In this paper composite carbon/Epoxy mono leaf spring is designed and analyzed using ANSYS 16 Workbench Software to meet the final goal of the study that is; the stress in the composite material leaf spring are much lower than that of the current conventional leaf spring and the strength to weight ratio is higher for composite leaf spring than current steel leaf spring with the same design. Then to meet the objective of the study, the details of the materials discussed as the following.

#### **3.1. Materials**

The materials used for leaf spring are usually a plain carbon steel having 0.9% – 1% carbon. Materials constitute nearly 60% - 70% of the vehicle cost and contribute to the quality and performance of the vehicle [17, 12]. Even small amount in weight reduction of the vehicle may have a wider economic impact. Then Composite materials are best substitutes for the current steel leaf spring. Due to their high strength-to weight ratio, fatigue resistance and natural frequency, the composite materials have been selected for the study. Internal damping in the composite material leads to better vibration energy absorption within the material resulting in reduced transmission of vibration noise to neighboring structures [12].

Then composite materials were made possible to reduce the weight of the leaf spring without any reduction on 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 the current leaf spring material steel.

To select the best composite material for the leaf spring, first of all studying and knowing some properties of the materials such as; the tensile strength, density, strength to weight ratio, modulus

of elasticity, flammability and thermal degradation, UV degradation, fatigue resistance, abrasion resistance, chemical attack resistance, and Addison to matrix of the material should be done[5].

### **3.1.1. FIBERS SELECTION FOR COMPOSITE LEAF SPRING**

Commonly used fibers are carbon fibers, glass fibers, natural fibers etc. Among these fiber types, the carbon fiber has been selected as explained above on literature review; Carbon Fibers have a high strength-to-weight ratio when tested in the direction of the fibers while E-glass has a lower strength-to-weight ratio, in addition to this carbon fiber is corrosion resistant, chemically stable, high modulus of elasticity, good adhesion to polymer, and has good fatigue strength. [1]

In most cases, carbon fibers are combined with a polymer matrix, which are called carbon fiber reinforced plastics (CFRP). It is possible to receive a high performance material with a weight reduction of more than 50 per cent compared to high strength steel by using CFRP. The strength and stiffness of CFRP is higher than high strength steel and the density is 40 per cent lower than aluminum. The disadvantages of carbon fiber is the cost of the fiber [1, 33]. Then carbon fiber becomes appropriate for the suspension of DAMAS II vehicle leaf spring application. Hence from the above advantages and excellent light weight nature, carbon fiber material has been selected for the study.

*Table 3.1: properties of carbon fiber material [43, 42, and 38].*

<b>No.</b>	<b>Property</b>	<b>Value</b>	<b>Unite</b>
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 <sup>3</sup>
6	Poisson's ratio	0.15	-
7	Elongation at break (%)	1.5	-
8	Diameter of fiber	7-10	µm

### **3.1.2. Resins selection**

We can say that composite fibers are nothing without introducing epoxy. Although reinforcing fibers are used in many applications, epoxy is the substrate that will be dealing with. The substrate

materials are used to bind whatever strengthening fiber is being used and to lock them in position so they can stay in position to do their job. Then for this composite fibers epoxy is as a substrate material.

Fiber reinforced structures usually have the fibers, running in specific directions to focus the reinforcement where it is needed and the epoxy keeps the fibers where they are needed. Although the main purpose of the epoxy matrix is to adhere to and transfer the loads to the fibers it is a strong material in its own right [33]. It helps protect the fibers from damage and provides impact resistance.

Polyepoxide or better known Epoxy, is a thermosetting network polymer which forms when an epoxide resin react with a polyamine hardener. Then the resulting Epoxy polymer is heavily cross linked and thus strong, hard and rigid. Epoxy has found a wide range of applications, including fiber-reinforced plastic materials, general purpose adhesives and strong chemically resistant coatings and finishes [33].

In a FRP leaf spring, the inter-laminar shear strength is controlled by the matrix system used. Since these are reinforcement fibers in the thickness direction, fibers do not influence inter-laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermoset resins such as polyester, vinyl ester, epoxy resin are being used for fiber reinforcement plastics (FRP) fabrication. Among these resins epoxies show better inter laminar shear strength and good mechanical properties [34, 36]. Different grades of epoxy resins and hardener combinations are classified based on the mechanical properties. Epoxy resins are synthesized from a poly-condensation of epichlorohydrin with polyphenols. Generally Bisphenol-A is used as polyphenol in the production of epoxy resin [38].

In general, epoxy resins have the following advantage over the other resin types [34]:

- ✓ They have better adhesive properties.
- ✓ They have superior mechanical properties i.e. strength and stiffness.
- ✓ They have better resistance to fatigue and micro cracking.
- ✓ They have well resistant to water penetration.
- ✓ Increased resistance to osmosis (surface degradation due to water permeability) Quantity of resin required

- ✓ Faster curing at room temperature.
- ✓ Good chemical resistance properties.

Hence epoxy is found to be best resins that would suit this application. Therefore, epoxy is selected for this study to reinforce the carbon fiber.

*Table 3.2: properties of epoxy resin [38, 41].*

No.	Property	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 <sup>3</sup>
5	Poisson's ratio	0.37	-
6	Flexural yield strength	0.125	Gpa
7	Compressive strength	0.19	Gpa
8	Elongation at break	0.8	
9	Glass transition temperature (T <sub>g</sub> )	120 – 130	<sup>0</sup> c

As discussed in literature review the composite materials can be made from different fiber types, and forms, such as; fiber laminated, particle composite, randomly distributed short fiber composite and etc. For this study the composite type is quasi isotropic laminated composite material.

### **3.2. Fiber and matrix volume content of the composite**

The ratio of the resin to the laminate can be determined through experience. It may be based on the volume ratio or weight ratio.

The highest fibre volume fractions are obtained with unidirectional reinforcement. If we assume that all fibres have the same diameter, and can be arranged in a perfectly parallel fashion, then the theoretical maximum fibre volume fraction will be achieved with hexagonal close packing as shown below.

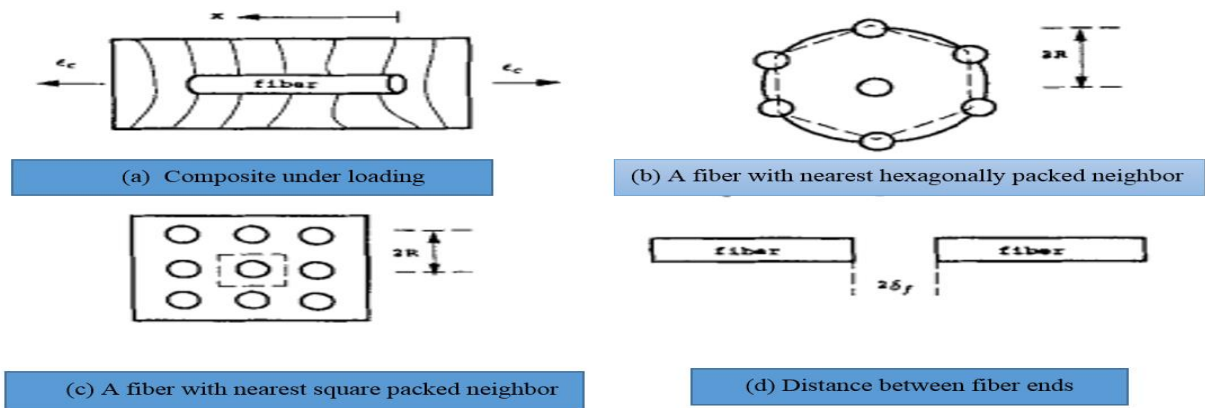


Figure 3.1: fibre embedded in a matrix and fibre packing forms [55].

Further, the composite will reach its highest strength at this maximum fibre volume fraction ‘ $V_{f_{max}}$ ’ as there is maximum amount of fibres in the composite and each is fully utilized. In other words, this maximum fibre volume fraction is also the optimal value in maximizing the composite tensile strength. Obviously the specific value of ‘ $V_{f_{max}}$ ’ depend on, besides the parameters included in the equation, the forms of fibre arrangement within a composite as well [55]. In addition, for the short fibre case where fibre ends don't meet, the maximum fibre volume fraction also varies with the distance between fibre ends. Let us assume this distance between the ends of two fibres in a composite to be ‘ $2\delta_f$ ’ as shown in Fig 3.1d.

The following are the two cases of fibre arrangement most often encountered in a composite.

### Hexagonally Packed Fibres

The fibre arrangement of this type is schematically shown in Fig. 3.1 b. suppose there are totally N fibres within the composite. Considering the hexagonal element with the area enclosed by the dotted line in Fig. 3.1b, and according to the definition of fibre volume fraction of a composite, we have the maximum fibre volume fraction in this case the maximum volume fraction of fibre will be:

$$V_{f_{max}} = \frac{V_{fiber}}{V_{total}} = \frac{3\pi r^2 l}{\frac{3\sqrt{3}}{2} (2R_{min})^2 (l+2\delta_f)} \dots\dots\dots (3.1)$$

Where: r = radius of a fibre,

l = length of fibre,

$2\delta_f$  = distance between the ends of two fibres in a composite, and

$2R$  = radius of hexagonal pack

$$= \frac{\pi}{2\sqrt{3}} \left(\frac{r}{R_{min}}\right)^2 \left(\frac{1}{1+2\delta f/l}\right)$$

For the case when the fibre length is as long as  $l \gg \delta f$  that the fiber end effect can be neglected, the expression becomes:

$$Vf_{max} = \frac{\pi}{2\sqrt{3}} \left(\frac{r}{R_{min}}\right)^2 \dots\dots\dots (3.2)$$

Because of this direct relationship between the maximum fibre volume fraction and the minimum fibre spacing ratio, it will be considered equivalent in the later analysis to refer to either of them.

If all fibres were packed so closely that then;  $R_{min} = r, \delta f = 0$

$$Vf_{max} = \frac{\pi}{2\sqrt{3}} = 0.907 = 91\%$$

### Square-Packed Fibres

The fibre arrangement in this case as shown in Fig 3.1c.

$$Vf_{max} = \frac{V_{fiber}}{V_{total}} = \frac{\pi r^2 l}{(2R_{min})^2 (l+2\delta f)} \dots\dots\dots (3.3)$$

$$Vf_{max} = \frac{\pi}{4} \left(\frac{r}{R_{min}}\right)^2 \left(\frac{1}{1+2\delta f/l}\right)$$

For long fibre case, it becomes;

$$Vf_{max} = \frac{\pi}{4} \left(\frac{r}{R_{min}}\right)^2 \dots\dots\dots (3.4)$$

In the closely packed case, there would be;

$$Vf_{max} = \frac{\pi}{4} \dots\dots\dots (3.5)$$

Of course, such a high volume fraction is not achievable in practice even if such a high degree of fibre collimation were available, the fact that fibres are touching would result in an ineffective composite. Filament winding is usually associated with the highest fibre volume fractions with careful control of fibre tension and resin content, values of around 70% are possible. But close packing is no longer possible, and the maximum fibre volume fraction is reduced [55]. When we see in multi direction design point of view, using maximum amount of fibre is not cost wise and it doesn't maintain a good design. Then to maintain a good final design out put the fibre and matrix material volume fraction is made standing from the cost of the fibre and matrix material, method of manufacturing, weight of the component and other factors.

### Terminologies of composite material

1. **Isotropic:** possessing the same mechanical properties in all directions. Composite laminate materials never been isotropic.

2. **Transversely isotropic:** possessing one plane that has the same mechanical properties at any direction in the plane of the materials (sometimes called quasi isotropic).
3. **Orthotropic:** a material that has different mechanical properties in the 3 mutually perpendicular planes. Note that the properties of the materials are direction specific in this case. All unidirectional laminates are individually orthotropic, most laminated composites are fall in to this category.
4. **Homogeneous:** material properties don't alter from point to point with in the material. Since filamentary composites consist of at least two distinct phases (matrix and fiber), laminated composites are never truly homogenous, although on macroscopic scale when discussing the linear elastic response (no damage) of laminated composite the material may be generalized as homogeneous, this assumption is termed as 'smearing' of fiber and matrix. In a real matter all composites are heterogeneous.
5. **Balanced laminate:** for each  $+\theta$  ply in the laminate there an equally thick  $-\theta$  ply in the laminate, but this is not apply to  $0^0$  and  $90^0$  plies.
6. **Symmetric laminate:** the plies of the laminate are a mirror image about the geometrical mid plane.
7. **Angle ply laminate:** containing plies oriented at angles other than  $0^0$  and  $90^0$

### Design guidelines of laminated composite

#### Assumptions

The following assumptions are considered for the study of the laminated composite carbon/epoxy material.

- (1) The composite laminate thickness is very small compared to other dimensions of the laminated composite.
- (2) The lamina (layers) of the composite laminate are homogenously bonded.
- (3) Lines perpendicular to the surface of the laminate remain straight and perpendicular to the surface after deformation.
- (4) The layers of the laminate are linear elastic.

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

According to [55] 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  $\{0^\circ, \pm 15^\circ, \pm 30^\circ, \pm 45^\circ, \pm 60^\circ, \pm 75^\circ, 90^\circ\}$ . Once the angles are selected, the total number of plies and 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 past experience from test and analysis.

According to [37, 47] 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  $+\theta^\circ$  and  $-\theta^\circ$  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  $45^\circ$ .
5. **10%-rule.** A minimum of 10% of plies in each of the  $0^\circ$ ,  $\pm 45^\circ$  and  $90^\circ$  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  $0^\circ$  -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 problem 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.

The ply-drop design guidelines aim on the one hand at avoiding delamination at ply-drop location and, on the other hand, at obtaining ply layouts that can actually be manufactured.

Then this paper selected quasi isotropic composite laminated material type, and 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 for 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.

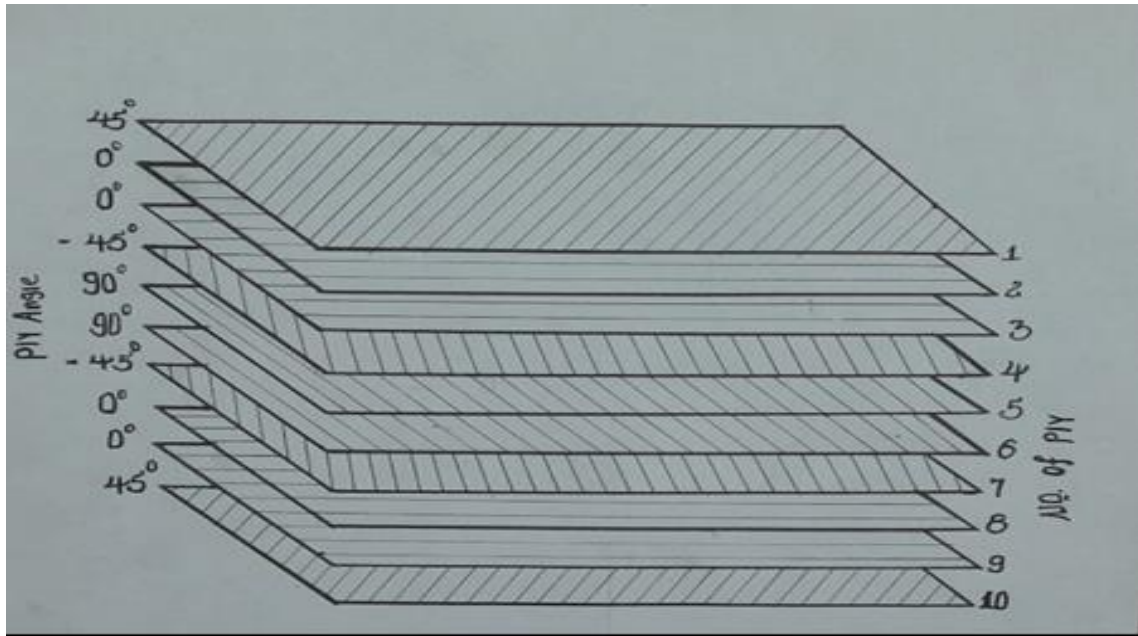


Figure 3.2: Stacking of plies in to a composite laminate with  $45^{\circ}$ ,  $0^{\circ}$ ,  $0^{\circ}$ ,  $-45^{\circ}$ ,  $90^{\circ}$ ,  $90^{\circ}$ ,  $-45^{\circ}$ ,  $0^{\circ}$ ,  $0^{\circ}$ ,  $45^{\circ}$  angles of the fiber reinforcement.

As discussed above the boundary of the laminated composite are  $\pm 45$  this is why? Because to minimize the splitting force, which are occurring by vertical loading and during drilling of the leaf spring. In addition to this the stacking sequence are symmetric about the mid plane and there is no grouping of  $90^{\circ}$ , separated by  $0^{\circ}$  or  $\pm 45^{\circ}$ , this is why? To minimize inter laminar shear and normal stress, multiple transverse fracture and grouping of critical plies. [37]

In design, fabrication and analysis of composite materials, the first and critical task is the determination of ingredient percentages such as fiber and matrix fraction presence in laminate. These components are microstructural elements of the composite laminate in which composites strength and properties are determined and limited by these values.

The ratio of the resin to the laminate can be determined through experience. It may be based on the volume ratio or weight ratio. Then for this study 60% volume fraction of fiber and 40% volume fraction of matrix is selected. The selection is done by considering the following factors:

- To minimize the cost of the fiber.
- To make 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 good selection to making the composite material for leaf spring.

The formula used to calculate the weight fraction and volume fraction of fibre and matrix was discussed below using rule of mixture.

### 3.2.1. Rule of mixtures

Certain properties in multi component material systems, including composites, obey the “Rule of Mixtures” (ROM). Properties that obey rule of mixture can be calculated as the sum of the value of the property of each composite constituents multiplied by its respective volume fraction or weight fraction in the composite mixture. In order to calculate composite properties using the rule of mixtures, the volume fraction or weight fraction of each constituent must first be determined.

According to [44], The Engineering constants of fiber reinforced composites can be determined using the following expressions.

**Weight fraction of the fiber is defined as ( $W_f$ ):**

$$W_f = \frac{\text{weight of fiber}}{\text{total weight}} = \frac{w_f}{w_t} = \frac{w_f}{w_f + w_m} \dots\dots\dots (3.6)$$

**Weight fraction of matrix is defined as ( $W_m$ ):**

$$W_m = \frac{\text{weight of matrix}}{\text{total weight}} = \frac{w_m}{w_t} = \frac{w_m}{w_f + w_m} \dots\dots\dots (3.7)$$

$$W_f + W_m = w_c = 1$$

**Volume fraction of the fiber component is defined as ( $V_f$ ):**

$$V_f = \frac{v_f}{v_c} = \frac{\text{volume of fiber}}{\text{volume of composite}} \dots\dots\dots (3.8)$$

**Volume fraction of the matrix component is defined as ( $V_m$ ):**

$$V_m = \frac{v_m}{v_c} = \frac{\text{volume of matrix component}}{\text{volume of composite}} \dots\dots\dots (3.9)$$

The sum of the volume fractions of all constituents in a composite must be equal to one. In the two components system consisting of one fiber and one matrix, then, the total volume of the composite is:

$$V_c = V_f + V_m, \text{ hence } V_m = 1 - V_f$$

Similarly the weight fractions  $W_f$  and  $W_m$  of the fiber and matrix respectively can be defined in terms of the fiber weight  $w_f$ , the matrix weight,  $w_m$  and the composite weight,  $w_c$ . Hence,

$$W_f = \frac{w_f}{w_m} \dots\dots\dots (3.10)$$

$$W_m = \frac{w_m}{w_c} \dots\dots\dots (3.11)$$

$$W_m = 1 - W_f \dots\dots\dots (3.12)$$

**Composite Density**

The density of the composite in terms of volume fraction can be found by considering the weight of the composite to be composed of the weights of their constituent,

$$W_c = W_f + W_m.$$

The weights can be expressed in terms of their respective densities and volumes,

$$\rho_c V_c = \rho_f V_f + \rho_m V_m$$

Applying the definitions of volume fraction the density of the composite,  $\rho_c$  can be expressed in terms of the fiber density,  $\rho_f$  and the matrix density  $\rho_m$  as:

$$\rho_c = \rho_f V_f + \rho_m V_m \dots\dots\dots (3.13)$$

We know that the result of volume fraction of fiber = 0.6, volume fraction of matrix material (epoxy) = 0.4, density of carbon fiber = 1.7 g/cm<sup>3</sup> and density of epoxy = 1.2 g/cm<sup>3</sup> from table.

Now calculate the density of composite carbon/epoxy material ( $\rho_c$ ):

$$\begin{aligned} \rho_c &= \rho_f V_f + \rho_m V_m = 1.7 \frac{g}{cm^3} \times 0.6 + 1.2 \frac{g}{cm^3} \times 0.4 \\ &= 1.02 \frac{g}{cm^3} + 0.48 \frac{g}{cm^3} \end{aligned}$$

$\rho_c = 1.50 \text{ g/cm}^3$
--------------------------------

Based on ROM longitudinal and transverse properties of the composite material ( $P_c$ ) can be estimated by:

$$P_c = P_f V_f + P_m V_m \dots\dots\dots (3.14)$$

Where:  $P_f$  &  $P_m$  = property of fiber and property of matrix material respectively.

This equation is easily understood by considering the analogy of calculating the stiffness of two springs connected in parallel.

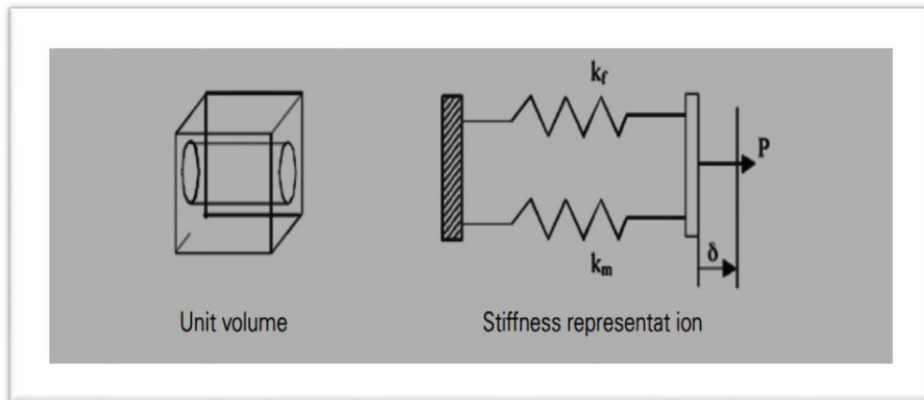


Figure 3.3: physical model for the longitudinal properties of a composite.

For properties perpendicular to fiber direction the calculation becomes a little more sophisticated, dependent on the fiber shape and fiber content, but a good estimate can be obtained using the model of two springs connected in series:

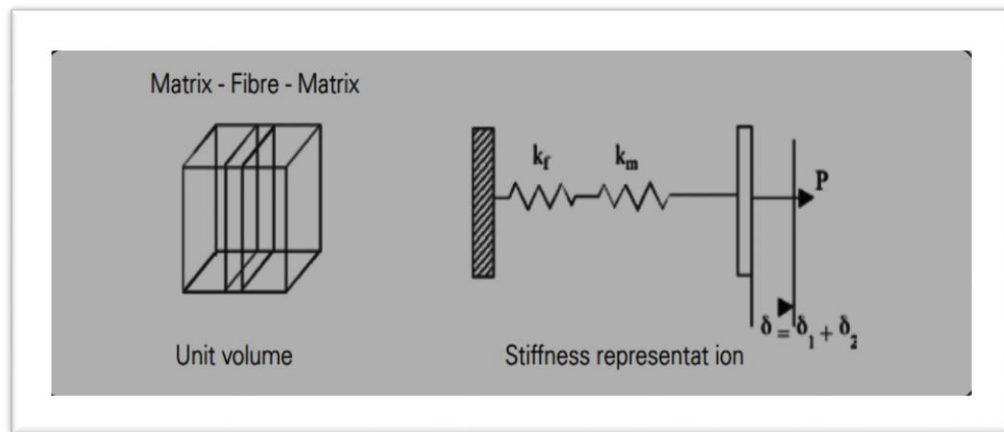


Figure 3.4: physical model for the transverse properties of a composite.

With this model, the total deformation at a point of load application in a direction perpendicular to fiber direction is the sum of the deflections in the fiber and the matrix. The resulting expression for transverse property of a composite is:

$$\frac{1}{p_c} = \frac{v_f}{p_f} + \frac{v_m}{p_m} \dots\dots\dots (3.15)$$

**a) Longitudinal modulus (E1):**

$$E_1 = E_f \times V_f + E_m \times V_m \dots\dots\dots (3.16)$$

$$= 230 \text{ GPa} \times 0.6 + 3.3 \text{ GPa} \times 0.4$$

$E_1 = 139.32 \text{ GPa}$
----------------------------

**b) Transverse modulus (E2):**

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \dots\dots\dots (3.17)$$

$$= \frac{0.6}{220 \text{ GPa}} + \frac{0.4}{3.3 \text{ GPa}}$$

$$\frac{1}{E_2} = 0.123808$$

$E_2 = 8.077 \text{ GPa}$
---------------------------

**c) Major Poisson's ration (v12):**

$$v_{12} = v_f \times V_f + v_m \times V_m \dots\dots\dots (3.18)$$

$$= 0.15 \times 0.6 + 0.37 \times 0.4$$

$v_{12} = 0.24$
-----------------

**d) Transverse shear modulus (G12):**

$$\frac{1}{G_{12}} = \frac{V_f}{G_f} + \frac{V_m}{G_m} \dots\dots\dots (3.19)$$

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

$$\frac{1}{G_{12}} = 0.1885 \text{ GPa}$$

$G_{12} = 5.3 \text{Gpa}$
---------------------------

**e) Longitudinal shear modulus**

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

$$= 52 \text{ GPa} \times 0.6 + 2.26 \text{ GPa} \times 0.4$$

$$G_{12} = 31.104 \text{ GPa}$$

The Young's moduli of fiber,  $E_f$ , the matrix,  $E_m$  and the composite,  $E_c$  can be expressed in terms of stress and strain:

$$E_f = \frac{\sigma_f}{\epsilon_f}$$

Using the above property of the fiber, the strain of the fiber calculated as:

$$\epsilon_f = \frac{\sigma_f}{E_f}$$

$$= \frac{3.53 \text{ GPa}}{230 \text{ GPa}}$$

$$\epsilon_f = 0.0153$$

$E_m = \frac{\sigma_m}{\epsilon_m}$  and , Also the strain of the matrix material given as:

$$\epsilon_m = \frac{\sigma_m}{E_m}$$

$$= \frac{0.13 \text{ GPa}}{3.3 \text{ GPa}}$$

$$\epsilon_m = 0.0394$$

$$E_c = \frac{\sigma_c}{\epsilon_c}$$

But  $\epsilon_c = \epsilon_f = \epsilon_m$  , Because of strain equivalency the ratio of the stresses in the constituents is the same as the ratio of their Young's moduli.

$$\frac{E_f}{E_m} = \frac{\sigma_f}{\sigma_m} \dots\dots\dots (a)$$

A continuous and angle oriented fiber composite may be loaded in the transverse direction; that is, the load is applied at a 90<sup>0</sup> angle to the direction of fiber alignment. For this situation the stress to which the composite as well as both phases are exposed is the same, or

$\sigma_c = \sigma_m = \sigma_f = \sigma$  This is termed an isostress state. Also, the strain or deformation of the entire composite is given by:

$$\begin{aligned} \epsilon_c &= \epsilon_m V_m + \epsilon_f V_f \\ &= 0.039 \times 0.6 + 0.0153 \times 0.6 \end{aligned}$$

$\epsilon_c = 0.02494$
------------------------

Expressing the above Equation (a) in terms of load as:

$$\frac{P_f}{P_m} = \frac{V_f E_f}{V_m E_m} \dots\dots\dots (3.20)$$

This result states that the stresses in a composite are proportioned by the stiffness of their constituents and independent of the amount or volume fraction of the constituent, i.e. the stiffer constituents take on more of the stress.

According to [44] ROM of the stress of the composite is given as:

**a) Tensile strength of a single ply in longitudinal direction**

$$\begin{aligned} \sigma_{tl} &= \sigma_f V_f + \sigma_m V_m \\ &= 3.53 \text{ Gpa} \times 0.6 + 0.13 \text{ GPa} \times 0.4 \\ \sigma_{tl} &= 2.17 \text{ GPa} \end{aligned}$$

**b) Tensile strength of a single ply in transverse direction**

$$\begin{aligned} \frac{1}{\sigma_{tt}} &= \frac{V_f}{\sigma_f} + \frac{V_m}{\sigma_m} \\ &= \frac{0.6}{3.53} + \frac{0.4}{0.13} \\ \sigma_{tt} &= 0.308 \text{ Gpa} \end{aligned}$$

**c) Compressive strength of a single ply in longitudinal direction**

$$\begin{aligned}\sigma_{cl} &= \sigma_{cf} V_f + \sigma_{cm} V_m \\ &= 1.2 \text{ Gpa} \times 0.6 + 0.19 \text{ GPa} \times 0.4 \\ \sigma_{cl} &= 0.796 \text{ GPa}\end{aligned}$$

**d) Compressive strength of a single ply in transverse direction**

$$\begin{aligned}\frac{1}{\sigma_{ct}} &= \frac{V_f}{\sigma_{cf}} + \frac{V_m}{\sigma_{cm}} \\ &= \frac{0.6}{1.2} + \frac{0.4}{0.19}\end{aligned}$$

$$\sigma_{ct} = 0.384 \text{ Gpa}$$

**3.2.1.1 Efficiency factor of the laminated composite (kernel factor)**

According to the classical laminate analysis each ply has different properties since the orientation angle of the fiber has different. Then the efficiency factor ( $\eta$ ) for the laminate is calculated as [41]:

$$\eta = \cos^4 \theta \dots\dots\dots (3.21)$$

The layup of the laminated composite orientation angle is as discussed above look like below:

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

Then the number of  $0^0$  laminates in the composite are = 4

Number of  $45^0$  laminates in the composite are = 4

Number of  $90^0$  laminates in the composite are = 2

**Efficiency factor for  $0^0$  plies are:**

$$\begin{aligned}\eta &= \cos^4 \theta \\ &= \cos^4(0) \\ &= 1\end{aligned}$$

**Efficiency factor for  $45^0$  plies are:**

$$\eta = \cos^4 \theta$$

$$= \cos^4(45)$$

$$= 0.25$$

**Efficiency factor for 90° plies are:**

$$\eta = \cos^4\theta$$

$$= \cos^4(90)$$

$$= 0$$

Therefore it can be estimated the efficiency factor of the laminate in the X-direction and Y-direction.

**Efficiency factor of the laminate in the X-direction:**

$$\left(\frac{\text{no. of } 0^\circ \text{ plies}}{\text{total no. of plies}} \times \eta. \text{ factor of } 0^\circ\right) + \left(\frac{\text{no. of } 45^\circ \text{ plies}}{\text{total no. of plies}} \times \eta. \text{ factor of } 45^\circ\right) \dots \dots \dots (3.22)$$

$$\left(\frac{4}{10} \times 1\right) + \left(\frac{4}{10} \times 0.25\right)$$

$$= 0.4 + 0.1$$

$$= \mathbf{0.5}$$

**Efficiency factor of the laminate in the Y-direction:**

$$\left(\frac{\text{no. of } 90^\circ \text{ plies}}{\text{total no. of plies}} \times \eta. \text{ factor of } 90^\circ\right) + \left(\frac{\text{no. of } 45^\circ \text{ plies}}{\text{total no. of plies}} \times \eta. \text{ factor of } 45^\circ\right) \dots \dots \dots (3.23)$$

$$\left(\frac{2}{10} \times 0\right) + \left(\frac{4}{10} \times 0.25\right)$$

$$= 0 + 0.1$$

$$= \mathbf{0.1}$$

### 3.2.2. Effective elastic constants

We assume that the effective material properties of each ply can be expressed in terms of a micromechanical model using rule of mixture:

According to [41], and engineering design with polymers and composites, J.c Gerdeonetal, suitable for calculating young modulus of a unidirectional ply at different angles are formulated as:

$$\frac{1}{E_x} = \frac{\cos^4\theta}{E_{11}} + \frac{\sin^4\theta}{E_{22}} + \left(\frac{1}{G_{12}} - \frac{2\nu_{12}}{E_{11}}\right) \cos^2\theta \sin^2\theta \dots\dots\dots (3.24)$$

- **For  $\theta = 0^0$**

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

$E_x = 139.32 \text{ GPa}$  , for  $0^0$  ply laminate fibers

- **For  $\theta = 45^0$**

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

$$\frac{1}{E_x} = \frac{0.25}{139.32} + \frac{0.25}{8.077} + \left(\frac{1}{5.3} - \frac{0.48}{139.32}\right) \times 0.25$$

$$\frac{1}{E_x} = \mathbf{0.07905}$$

$E_x = 12.649 \text{ GPa}$  for  $45^0$  ply laminate fibers

- **For  $\theta = 90^0$**

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

$$\frac{1}{E_x} = 0 + \frac{1}{8.077} + 0$$

$E_x = 8.077 \text{ GPa}$  for  $90^0$  ply lamiate fibers

Now we can estimate the young modulus properties of the explained laminated plies composite in X and Y direction:

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

$$0^0 = 139.32 \text{ GPa}$$

$$45^0 = 12.649 \text{ GPa}$$

$$90^0 = 8.077 \text{ GPa}$$

**Composite young modulus in longitudinal direction**

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

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

$$= 55.728 \text{ GPa} + 5.0596 \text{ GPa}$$

$E_L = 60.7876 \text{ GPa}$
-----------------------------

### Composite young modulus in transverse direction

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

$$= \frac{2}{10} \times 8.077 \text{ GPa} + \frac{4}{10} \times 12.63 \text{ GPa}$$

$$= 1.6154 \text{ GPa} + 5.0596 \text{ GPa}$$

$E_T = 6.675 \text{ GPa}$
---------------------------

### 3.2.3. Strength calculation of the composite

Using the same fashion like that of elastic modulus calculation in transvers and longitudinal direction of the composite laminate, now also calculate the tensile and compressive strength of the composite laminate in transverse and longitudinal direction by using equation (21) look like below:

#### Tensile strength

- **For  $\theta = 45^{\circ}$**

$$\frac{1}{\sigma_t} = \frac{\cos^4 \theta}{\sigma_{tl}} + \frac{\sin^4 \theta}{\sigma_{tt}} + \left( \frac{1}{G_{12}} - \frac{2\nu_{12}}{\sigma_{tl}} \right) \cos^2 \theta \sin^2 \theta$$

$$\frac{1}{\sigma_{tx}} = \frac{0.25}{2.17} + \frac{0.25}{0.308} + \left( \frac{1}{5.3} - \frac{0.48}{2.17} \right) \times 0.25$$

$$\frac{1}{\sigma_t} = 0.91876 =$$

$$\sigma_{tx} = 1.088 \text{ GPa}$$

- **For  $\theta = 0^{\circ}$**

$$\frac{1}{\sigma_t} = \frac{1}{2.17} + 0 + 0$$

$$\sigma_t = 2.17 \text{ Gpa}$$

- **For  $\theta = 90^\circ$**

$$\frac{1}{\sigma_t} = 0 + \frac{1}{0.308} + 0$$

$$\sigma_t = 0.308 \text{ Gpa}$$

Then the longitudinal and transverse tensile strength of a composite respectively becomes:

$$\sigma_{tl} = \frac{4}{10} \times 2.17 + \frac{4}{10} \times 1.088$$

$$\sigma_{tl} = 1.3032 \text{ Gpa} \quad \text{And}$$

$$\sigma_{tt} = \frac{2}{10} \times 0.308 + \frac{4}{10} \times 1.088$$

$$\sigma_{tt} = 0.4968 \text{ Gpa}$$

### **Compressive strength**

- **For  $\theta = 45^\circ$**

$$\frac{1}{\sigma_c} = \frac{\cos^4\theta}{\sigma_{cl}} + \frac{\sin^4\theta}{\sigma_{ct}} + \left(\frac{1}{G_{12}} - \frac{2\nu_{12}}{\sigma_{cl}}\right) \cos^2\theta \sin^2\theta$$

$$\frac{1}{\sigma_c} = \frac{0.25}{0.796} + \frac{0.25}{0.384} + \left(\frac{1}{5.3} - \frac{0.48}{2.17}\right) \times 0.25$$

$$\frac{1}{\sigma_c} = 0.862$$

$$\sigma_c = 1.161 \text{ Gpa}$$

- **For  $\theta = 0^\circ$**

$$\frac{1}{\sigma_c} = \frac{1}{0.796} + 0 + 0$$

$$\sigma_c = 0.796 \text{ Gpa}$$

- **For  $\theta = 90^\circ$**

$$\frac{1}{\sigma_c} = 0 + \frac{1}{0.384} + 0$$

$$\sigma_c = 0.384 \text{ Gpa}$$

Then the longitudinal and transverse compressive strength of a composite respectively becomes:

$$\sigma_{cl} = \frac{4}{10} \times 0.796 + \frac{4}{10} \times 1.161$$

$$\sigma_{cl} = 0.7828 \text{ Gpa} \text{ And}$$

$$\sigma_{ct} = \frac{2}{10} \times 0.384 + \frac{4}{10} \times 1.161$$

$$\sigma_{ct} = 0.5412 \text{ Gpa}$$

Now the calculated properties of the carbon/ epoxy (@  $V_F = 60\%$ ) laminated composite material properties are tabulated as:

*Table 3.3: calculated properties of carbon/epoxy laminated composite (@  $V_f = 60\%$ ).*

<b>No.</b>	<b>Material properties</b>	<b>Symbol</b>	<b>Value</b>	<b>Unit</b>
<b>1</b>	Young modulus x-direction	$E_x$	60.7876	Gpa
<b>2</b>	Young modulus y-direction	$E_y$	60.7876	Gpa
<b>3</b>	Young modulus z-direction	$E_z$	6.675	Gpa
<b>4</b>	Tensile Strength x-direction	$\sigma_{tx}$	2.17	Gpa
<b>5</b>	Tensile strength y- direction	$\sigma_{ty}$	2.17	Gpa
<b>6</b>	Tensile Strength z-direction	$\sigma_{tz}$	0.308	Gpa
<b>7</b>	Compressive Strength in x-direction	$\sigma_{cx}$	0.796	Gpa
<b>8</b>	Compressive Strength in y-direction	$\sigma_{cy}$	0.796	Gpa
<b>9</b>	Compressive Strength in z-direction	$\sigma_{cz}$	0.384	Gpa
<b>10</b>	Density	$\rho$	1.5	$\text{g/cm}^3$
<b>11</b>	Shear modulus in x-direction	$G_{12}$	32.1	GPa
<b>12</b>	Shear modulus in y-direction	$G_{12}$	5.3	Gpa
<b>13</b>	Major poisons ratio	$\nu_{12}$	0.24	-
<b>14</b>	Strain of a composite	$\epsilon_c$	0.02494	-

### 3.3. Specification/dimension of leaf spring

#### 3.3.1. Analytical data

Considering the multi leaf spring of Damas II car and standing from that, the aim of this research paper is design and analysis of a mono laminated carbon/epoxy composite leaf spring for this car, which will have a high strength to weight ratio and lower stress than that of the current steel leaf spring.

#### Model Damas II car specification

*Table 3.4: specification of model Damas II car.*

<b>1. General information</b>		
<b>No.</b>	<b>Features</b>	<b>Value</b>
1.1	Brand	Daewoo
1.2	Model	Damas
1.3	Generation	Damas II
1.4	Engine	0.8 (38 hp)
1.5	Doors	5
1.6	Power	38 hp/5000 rpm
1.7	Acceleration	100 Km/hr.
1.8	Fuel tank volume	37 liter
1.9	Seats	7
1.10	Weight	1,951.1 pounds (885 kg)
<b>2. Body features</b>		
2.1	Length	3230 mm
2.2	Width	1400 mm
2.3	Height	1920 mm
2.4	Wheel base	1840 mm
2.5	Front track	1210 mm
2.6	Rear track	1200 mm
<b>3. Engine transmission</b>		

3.1	Position of engine	Front transversely
3.2	Volume of engine	796 cm <sup>3</sup>
3.3	Fuel system	Carburetor
3.4	Valve train	OHC
3.5	Number of cylinder	3
3.6	Position of cylinder	Inline
3.7	Fuel type	Petrol /gasoline
3.8	Wheel drive	Rear wheel drive
<b>4. Chassis</b>		
4.1	Front brake	Disc
4.2	Rear brake	Drum
4.5	Tyre size	155 R12
<b>5. Running features</b>		
5.1	Torque	64 Nm/3000 rpm
5.2	Fuel consumption (urban)	7.5 L/100 km
5.3	Fuel consumption (extra urban)	6 L/100 km
5.4	Fuel consumption (combined)	6.5 L/100 km
5.5	CO <sub>2</sub> emission	224 gm/km

**Source: Technical specification of Daewoo – Damas II – 0.8 (38 HP)**

Here weight and initial measurement of four wheeler “Damas II” light vehicle are taken.

Mass of Damas II vehicle = 885Kg

Maximum load carrying capacity = 7 x 80 = 560Kg, 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<sup>2</sup>

According to [11] the value of factor of safety ranges = (1.3 – 2.25), then take factor of safety = 1.5

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

$$W = 21675 \text{ N}$$

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

Load on each wheel becomes,

$$W = \frac{21675 \text{ N}}{4}$$

$$W = 5418.75 \text{ N}$$

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 specification (direct measuring):**

- Type of material = structural steel
- No. of leaves = 4
- Length of master leaf (eye to eye) = 130 cm
- Length of 2<sup>nd</sup> leaf = 100 cm
- Length of 3<sup>rd</sup> leaf = 60 cm
- Length of 4<sup>th</sup> 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

*Table 3.5: Mechanical properties of structural steel [41].*

No.	Mechanical property	Symbol	Values	Units
1	Young modulus	E	207	GPa
2	Shear modulus	G	76.9	GPa
3	Poisson's ratio	$\nu$	0.3	-
4	Density	$\rho$	7850	Kg/m <sup>3</sup>

6	Compressive yield strength	$\sigma_c$	250	Mpa
7	Ultimate tensile strength	$\sigma_t$	460	Mpa
8	Tensile yield strength	$\sigma_y$	250	Mpa
9	Behavior	Isotropic		

### 3.4. Modeling of leaf spring

Modelling and numerical simulation are essential aspects of today's automotive sector. They are necessary in order to reduce the time-to-market for new products and the costs associated with experimental testing. A good modeling and simulation in design and analysis give many benefits such as: minimizing product manufacturing time, material scrap and material cost. In vehicle structure design, the automotive sector has been undertaking structural analyses (static, dynamic, safety, noise and vibration, handling, etc.) for many years. Gradually, the precision and accuracy of models increase in its quality, but until now except metals and a few polymer components composite materials does not involved. The polymer components, in the majority of cases, have only been modelled as isotropic materials. However, as the use of structural composite materials in the automotive sector increased, it has now become necessary to model composites more rigorously.

It is also desirable to integrate design and analysis processes to verify a product's performance in relation to its manufacturing and vice versa. Light weighting is one of the major drivers for the use of composites in the automotive industry. However, the benefits of light weighting are different for different categories of vehicle. Light weighting in trucks allows for payload increases whilst maintaining the same overall mass. In mass production vehicles, the most important driver for light weighting is the reduction of fuel consumption and the associated reduction of CO<sub>2</sub> and other emissions in order to reduce environmental hazards [9].

Overall, there is no doubt that the importance of modelling and simulation in the automotive sector will continue to increase 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 [33].

### 3.4.1. 2D sketching and 3D Modeling of Leaf Spring

The 3D Modeling is a geometrical representation of a real object without losing information which the real object have. Various mechanical design and manufacturing operations modeled using CATIA. This software allows the user to make changes very easily without having to go to back at the beginning and update all the drawings and assemblies. Generally CATIA is easy to use and feature based parametric solid modeling software with many extended design and manufacturing applications.

In this specific research, based on the dimension obtained from theoretical calculation and direct measuring data 3D modeling and 2D sketching of the leaf spring was created with the help of CATIAV5 R19 solid modeling software and analysis is done by using ANSYS 16 workbench for stress and deflection.

The DAMAS II model vehicle is selected for this study, because of the following reasons;

- DAMAS II model vehicles are currently used laminated type of steel leaf spring, then to minimize extra component of the leaf such as center bolt, U- clamp of the leaf.
- To replace the steel leaf spring with carbon/epoxy composite leaf spring material to make the leaf spring light weight.
- Easy to take the necessary data due to its availability.

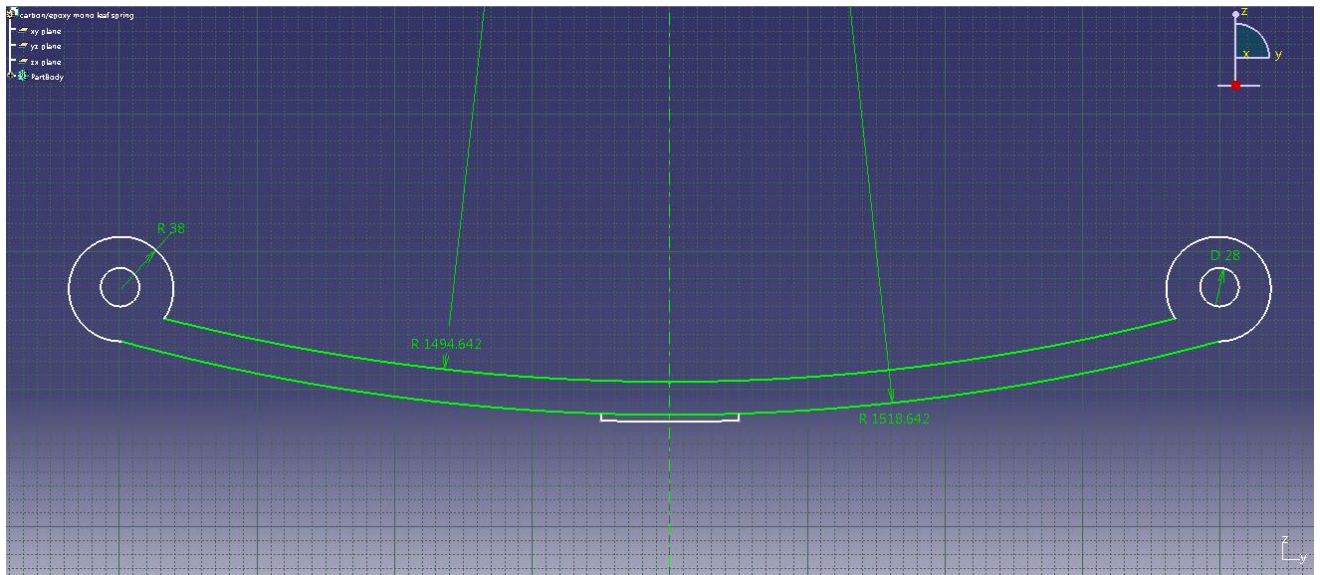


Figure 3.5: 2D drawing of mono carbon/epoxy leaf spring using CATIA V5 R19.

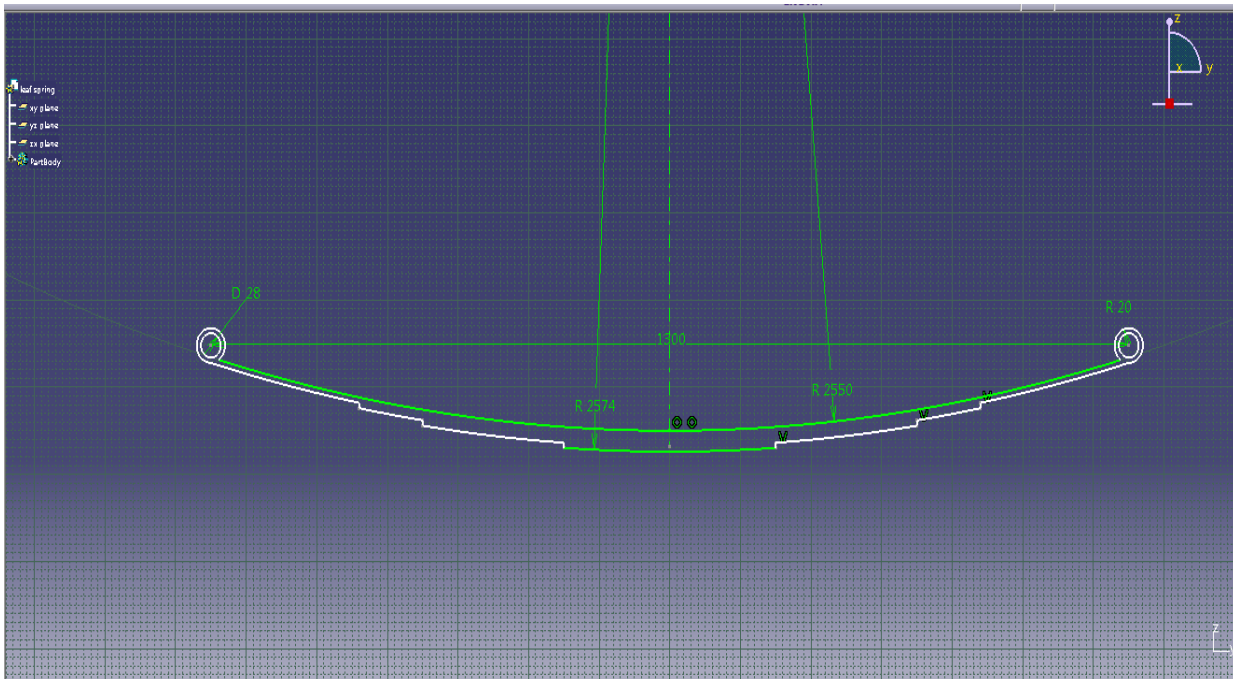


Figure 3.6: 2D drawing of laminated steel leaf spring using CATIA V5 R19.

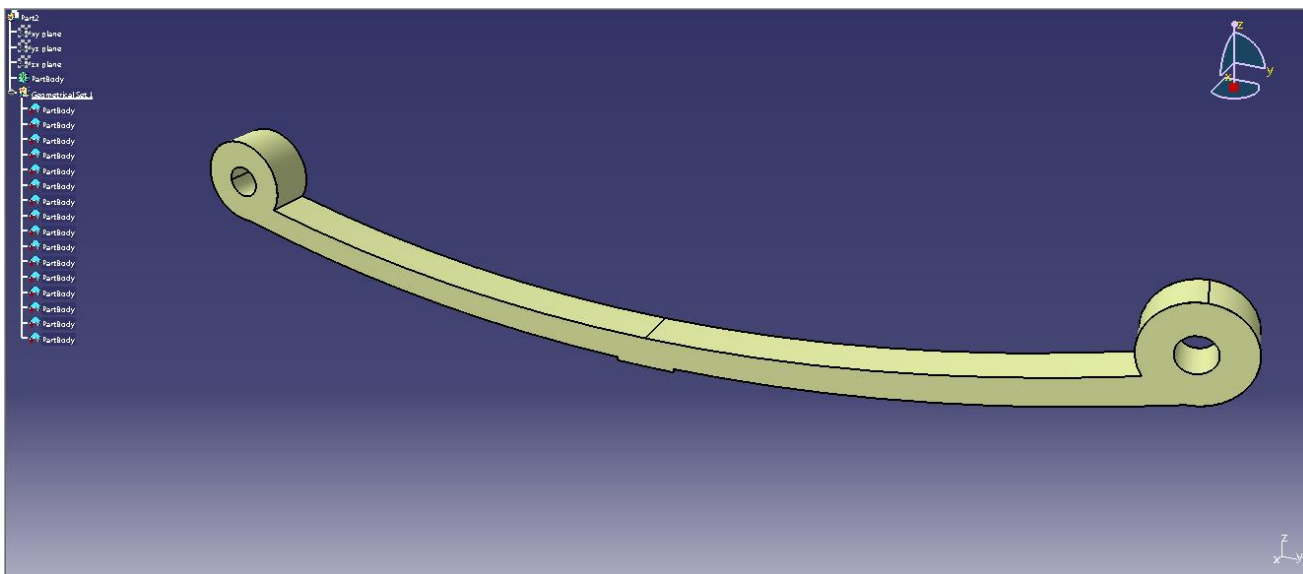


Fig 3.7: 3D modeling of mono carbon/epoxy leaf spring using CATIA V5 R19.

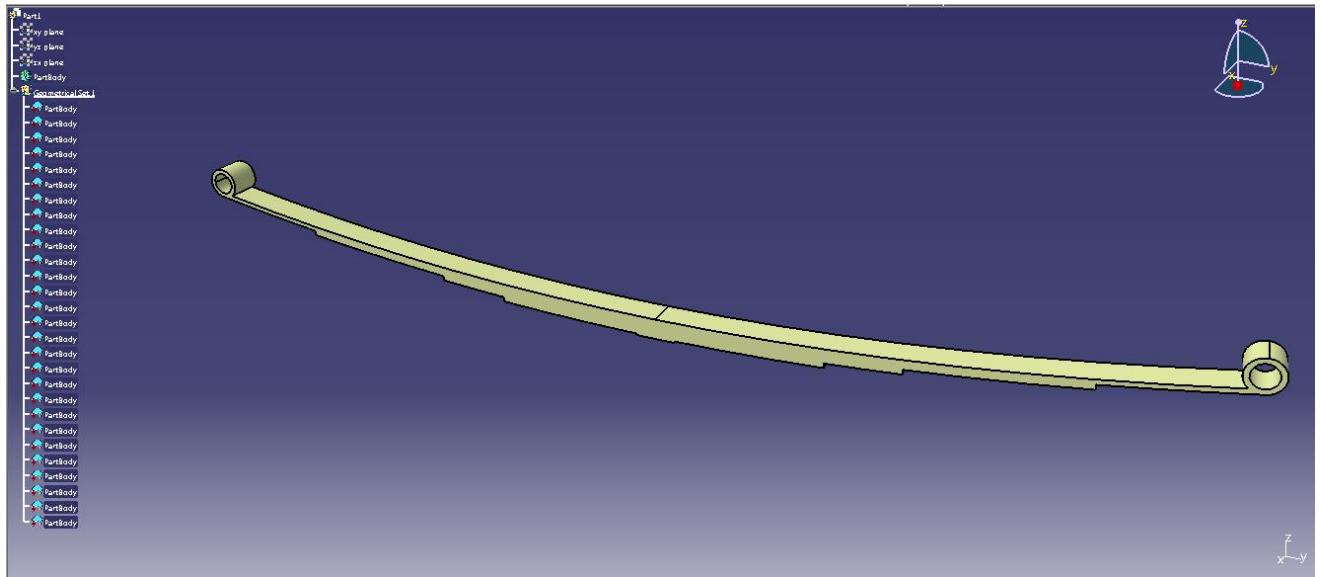


Figure 3.8: 3D modeling of laminated steel leaf spring using CATIA V5 R19.

### 3.4.2. Mathematical Modeling

The mathematical modeling is a crucial task to understand or predict the real situation of the designed components. In this case different loads or stresses which would be applied on the leaf spring could be considered.

According to the literature the main common mechanical stress, which affects the life of the leaf spring, is the shock produced by static loading, road irregularities, braking and cornering during driving. In this case the leaf spring is loaded a static load and during analysis also consider this type of loading.

- **Cross section of the leaf spring:**

- 1) **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.

- 2) **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.

- 3) **Constant Cross-Section 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 study paper, due to the following reasons [21]:

- ✓ 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, same quantity of reinforcement fiber and resin can be fed continuously during manufacture.
- ✓ Also this is quite suitable for filament winding process.

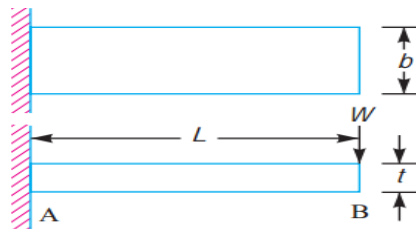
Standing from the shape of the leaf spring nature and easy of analysis, as shown below in the figure, the leaf spring behaves like a cantilever beam and the static analysis is done considering it as a cantilever beam. Since the leaf spring is mounted on the axle using U- bolts firmly, then the leaf spring counted as a double cantilever beam with a load  $W$  at the free end of the leaf spring and length  $L$ . According to [60] the cantilever beam is highly exposed to both bending stress and transverse shear stress [17]. 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 [56] we know that the maximum bending moment at the cantilever end A;

$$M = WL \dots\dots\dots (3.26)$$

Where: w = load and

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 and

t= thickness

1) Bending stress in such the spring is given as:

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

$$\sigma = \frac{6WL}{bt^2} \dots\dots\dots (3.27)$$

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

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

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

$$\delta_{max} = \frac{4WL^3}{Ebt^3} \dots\dots\dots (3.28)$$

$$\delta_{max} = \frac{2\sigma L^2}{3Et}, \text{ where: } \sigma = \frac{6WL}{bt^2}$$

Where: E = young modulus of materials and

I = moment of inertia

$I = \frac{bt^3}{12}$ , for rectangular cross section.

### 3.4.2.1. Weight calculation

#### I. For the current steel leaf spring:

From the mass, density and volume relation the weight of the leaf spring can be calculated as:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\rho = \frac{M}{V} \dots\dots\dots (3.29)$$

$$M = \rho \times V \dots\dots\dots (3.30)$$

$$W = M \times g, \quad \text{where: } M = \rho \times V$$

$$\text{Therefore, } W = \rho \times V \times g \dots\dots\dots (3.31)$$

Density of structural steel = 7.85 gm/cm<sup>3</sup> and

Take acceleration due to gravity(g) = 10 m/s<sup>2</sup>

Now weight of the master leaf (W<sub>1</sub>) = ρ × V<sub>1</sub> × g

$$V_1 = L_1 \times t \times w$$

$$= 1300\text{mm} \times 6\text{mm} \times 40\text{mm}, \text{ where: } V_1 = \text{volume of master leaf spring}$$

L= length

t= thickness and

w= width

$$V_1 = 312 \text{ cm}^3$$

$$W_1 = 7.85 \text{ gm/cm}^3 \times 312 \text{ cm}^3 \times 10 \text{ m/s}^2$$

$$W_1 = 24.49 \text{ N}$$

$$\text{Weight of the 2}^{\text{nd}} \text{ leaf } (W_2) = 18.84 \text{ N}$$

$$\text{Weight of 3}^{\text{rd}} \text{ leaf } (W_3) = 11.304 \text{ N}$$

$$\text{Weight of 4}^{\text{th}} \text{ leaf } (W_4) = 7.912 \text{ N}$$

Therefore the total weight of the current existing steel leaf spring of the Damas II car becomes

$$W_T = W_1 + W_2 + W_3 + W_4$$

$$W_T = 62.55 \text{ N}$$

## II. For carbon/epoxy composite material:

For the carbon/epoxy composite leaf spring design, dimension of carbon/epoxy leaf spring is the same to that of the current steel leaf spring except the diameter of the eye. This is because, to differentiate the advantages and disadvantages of the two leaf spring materials and to know the best features of the materials. But some dimensions are selected from the standard size of automobile suspension springs tables.

Following are the standard sizes for the automobile suspension springs [56]:

- 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.

The carbon/epoxy leaf spring is a mono leaf spring which have a uniform cross section. And the specification of the carbon/epoxy leaf spring becomes looks as below:

Type of material = carbon/epoxy ( $V_f = 60\%$  and  $V_m = 40\%$ )

No. of leaves = 1

Length = 800 mm, this is because to minimize the extra buckling and deformation of the leaf spring, to with stand a heavy load without deformation and break during loading session.

Width = 40 mm

Thickness = 24 mm,

Then according to the above specification the weight of the carbon/epoxy leaf spring becomes:

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

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

$$W = 11.52 \text{ N}$$

Now calculate the weight saved of the leaf spring:

$$\text{Weight saved} = 62.546 \text{ N} - 11.52 \text{ N} = 51.03 \text{ N}$$

$$\% \text{ weight saved} = (51.03 \div 62.546) \times 100$$

% weight saved = 81.58 %, therefore the laminated mono carbon/epoxy composite leaf spring is very light weight material than that of the current conventional steel multi leaf spring.

### 3.4.2.2. Stress and Deflection Calculation

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 text book of machine design, the effective length of leaf spring can be calculated as:

$$2L = 2L_1 - l \dots \dots \dots \text{when band is used. and}$$

$$2L = 2L_1 - \frac{2}{3}l \dots \dots \dots \text{when U - bolts is used.}$$

Where:  $2L$  = effective length leaf spring

$2L_1$  = total length of leaf spring

$L$  = length of band or U - bolts

But for this design U-bolts become the clamping/mounting unit of the leaf spring on the axle of the vehicle. Therefore the formula to calculate the effective length of the leaf becomes:

$$2L = 2L_1 - \frac{2}{3}l \text{ , take the width of the U-bolts} = 85\text{mm (direct measuring)}$$

$$2L = 1300\text{mm} - \frac{2}{3} \times 85\text{mm}$$

$$2L = 1243.33\text{mm}$$

$L = 621.67\text{mm}$  (half effective length of current steel leaf spring)

With the same fashion the carbon/epoxy material leaf spring effective length calculated as:

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

$$2L = 743.33\text{ mm}$$

$L = 371.67\text{ mm}$  (half effective length of the carbon/epoxy leaf spring)

**Bending stress of the steel leaf spring can be calculated as:**

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

where: n = no.of leaves, in this case n = 4

$$= \frac{6 \times 2710\text{ N} \times 633.34\text{mm}}{4 \times 40\text{mm} \times (6\text{mm})^2}$$

$$= \frac{10,298,1084\text{N}}{5760\text{mm}^2}$$

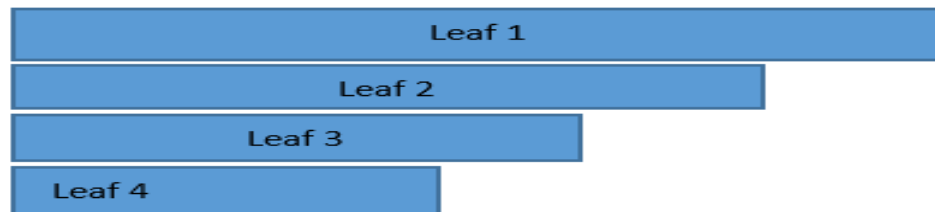
$\sigma = 1787.86\text{ N/mm}^2$ , this much amount of stress is occurred around eye of the steel leaf spring

**Deflection:**

We know that maximum deflection of the cantilever beam at the loaded end is given by equation (24):

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

But the laminated steel leaf spring hasn't the same cross section of each leaf as look like below in fig 3.8. Then the moment of inertia can be calculated as:



*Figure 3.10: half crosssection of the current steel leaf spring.*

Standing from the above figure, moment of inertia of the laminated steel leaf spring calculated as:

$$I_x = (I_x + Ady^2)L1 - (I_x + Ady^2)L2 - (I_x + Ady^2)L3 - (I_x + Ady^2)L4 \dots\dots\dots(3.32)$$

Where: A = area, L1, L2, L3, L4 = leaf 1, 2, 3, 4 respectvily.

$$I_x = \frac{1}{12}(650mm)(24mm)^3 - [\frac{1}{12}(150mm)(6mm)^3 + 150mm \times 6mm \times (3mm)^2]$$

$$- [\frac{1}{12}(350mm)(12mm)^3 + 350mm \times 12mm \times (6mm)^2]$$

$$- [\frac{1}{12}(440mm)(18mm)^3 + 440mm \times 18mm \times (6mm)^2]$$

$$I_x = 748,800mm^4 - (10,800 + 201,600 + 4985,960)(mm^4)$$

$$I_x = 37,440mm^4$$

Now the defelection of the steel leaf spring becoms:

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

$$= \frac{2710 N \times (633.34 mm)^3}{207 \times 10^9 \frac{N}{m} \times 3 \times 37440 mm^4}$$

$$= \frac{6.885 \times 10^{11}}{2.2862 \times 10^{10}}$$

$\delta = 29.61 mm$  at the loaded end of the spring.

**Bending stress of the carbon/epoxy mono leaf spring can be calculated as:**

The maximum bending stress at the free end of the carbon/ epoxy composite leaf spring material with the above designed dimension is calculated as using equation (23):

$$\sigma = \frac{6WL}{b(t)^2} = \frac{6 \times 2710 N \times 383.34 mm}{40 mm \times (24 mm)^2} = \frac{6.5 \times 10^6}{2.304 \times 10^4}$$

$\sigma = 270.53 N/mm^2$ , Since, stress of steel leaf spring  $1787.86 N/mm^2$  is much greater than that of carbon/epoxy leaf spring  $270.53 N/mm^2$ . Then the carbon/epoxy leaf spring material is exposed to minimum stress than that of the current steel leaf spring material, since the stress at the

free end of the carbon/epoxy leaf spring is exposed to about 270.53 N/mm<sup>2</sup>. Then the carbon/epoxy leaf spring becomes 84.8 % less stressed than that of the steel leaf spring.

### **Deflection**

Deflection of the carbon/epoxy leaf spring material is calculated as by using equation (26):

$$\delta = \frac{WL^3}{3EI} = \frac{2710 \text{ N} \times (383.34 \text{ mm})^3}{3 \times 60.79 \times \frac{10^3 \text{ N}}{\text{mm}^2} \times 46080 \text{ mm}^4}$$

$$\delta = \frac{1.734 \times 10^{11} \text{ mm}^5}{8.4 \times 10^9 \text{ mm}^4}$$

$$\delta = 18.17 \text{ mm}$$

Then the carbon/epoxy composite leaf spring material has a good ability to with stand 41.93% deformation than that of the current steel leaf spring when loaded the same amount of load.

### **3.5. Analysis of Leaf Spring Using ANSYS 16 Workbench**

ANSYS is being used by designers across a broad spectrum of industries such as aerospace, automotive, manufacturing, nuclear, electronics, biomedical, and many more. ANSYS provides simulation solutions that enable designers to simulate design performance directly on desktop. In this way, it provides fast, efficient and cost-effective product development from design concept stage to performance validation stage of the product development cycle. ANSYS package help to accelerate and streamline the product development process by helping designers to resolve issues related to structural deformation, heat transfer, fluid flow, electromagnetic effects, a combination of these phenomena acting together, and so on. [13]

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces called elements. The software implements equations that govern the behavior of these elements and solves them all creating a comprehensive explanation of how the system acts as a whole. These results then can be displayed in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system that is too complex to Analyze manually. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. [12]

### 3.5.1. Static structure analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain)

#### Assumption for analysis

Assumptions were developed during analysis of both for mono composite carbon/epoxy and conventional leaf spring materials, to be compatible with the modeling of the leaf spring.

1. The eye of the leaf spring count as within the length of it. Therefore it doesn't consider for analysis separately.
2. The U-bolt clamp connect 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.
3. However the physical model of the leaf spring is double cantilever beam, the analysis is done on the whole geometry of the leaf spring.
4. The quasi isotropic laminated carbon/epoxy composite material is strongly bonded and has homogenous nature.

#### 3.5.1.1. Static analysis of carbon/epoxy leaf spring

There are some steps to do static structure analysis of a structure or a component:

##### Define Engineering Data

The specific material property of the selected carbon/epoxy quasi isotropic laminated composite material are stated in the table below:

Outline of Schematic A2: Engineering Data				
	A	B	D	
1	Contents of Engineering Data	<input checked="" type="checkbox"/>	Description	
2	Material			
3	<input checked="" type="checkbox"/> laminated carbon/epoxy	<input type="checkbox"/>		
4	<input checked="" type="checkbox"/> Structural Steel	<input checked="" type="checkbox"/>	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2 Table 5.110.1	

Properties of Outline Row 3: laminated carbon/epoxy					
	A	B	C	D	E
1	Property	Value	Unit	<input checked="" type="checkbox"/>	<input type="checkbox"/>
2	<input checked="" type="checkbox"/> Density	1.5	g cm <sup>-3</sup>	<input type="checkbox"/>	<input type="checkbox"/>
3	<input checked="" type="checkbox"/> Orthotropic Elasticity			<input type="checkbox"/>	<input type="checkbox"/>
4	Young's Modulus X direction	60788	MPa	<input type="checkbox"/>	<input type="checkbox"/>
5	Young's Modulus Y direction	60788	MPa	<input type="checkbox"/>	<input type="checkbox"/>
6	Young's Modulus Z direction	6675	MPa	<input type="checkbox"/>	<input type="checkbox"/>
7	Poisson's Ratio XY	0.24		<input type="checkbox"/>	<input type="checkbox"/>
8	Poisson's Ratio YZ	0.24		<input type="checkbox"/>	<input type="checkbox"/>
9	Poisson's Ratio XZ	0.24		<input type="checkbox"/>	<input type="checkbox"/>
10	Shear Modulus XY	5300	MPa	<input type="checkbox"/>	<input type="checkbox"/>
11	Shear Modulus YZ	5300	MPa	<input type="checkbox"/>	<input type="checkbox"/>
12	Shear Modulus XZ	5300	MPa	<input type="checkbox"/>	<input type="checkbox"/>
13	<input checked="" type="checkbox"/> Field Variables			<input type="checkbox"/>	<input type="checkbox"/>
14	Temperature	Yes		<input type="checkbox"/>	<input type="checkbox"/>
15	Shear Angle	No		<input type="checkbox"/>	<input type="checkbox"/>
16	Degradation Factor	No		<input type="checkbox"/>	<input type="checkbox"/>
17	<input checked="" type="checkbox"/> Tensile Ultimate Strength	2170	MPa	<input type="checkbox"/>	<input type="checkbox"/>
18	<input checked="" type="checkbox"/> Compressive Ultimate Strength	796	MPa	<input type="checkbox"/>	<input type="checkbox"/>

*Figure 3.11: workbench material properties of quasi isotropic laminated of carbon/epoxy composite.*

### Attach Geometry

That is possible to create the geometry of the leaf spring using Design Modeler in ANSYS workbench, beyond this From a CAD system supported by Workbench or one that can export a file that is supported by ANSYS Workbench.

Before attaching the geometry, specifies several options to determine the characteristics of the geometry to import. These options are; solid bodies, surface bodies, line bodies, parameters,

attributes, named selections, material properties; analysis type 2D or 3D, allowing CAD associativity, importing coordinate systems import work points are only available in the design modeler application), saving updated CAD file in reader mode, “smart” refreshing of models with unmodified components, and allowing parts of mixed dimension to be imported as assembly components that have parts of different dimensions. Then the browsed solid model of the carbon/epoxy leaf spring is done on CATIA V5, saved as “igs” form looks like in the following figure.

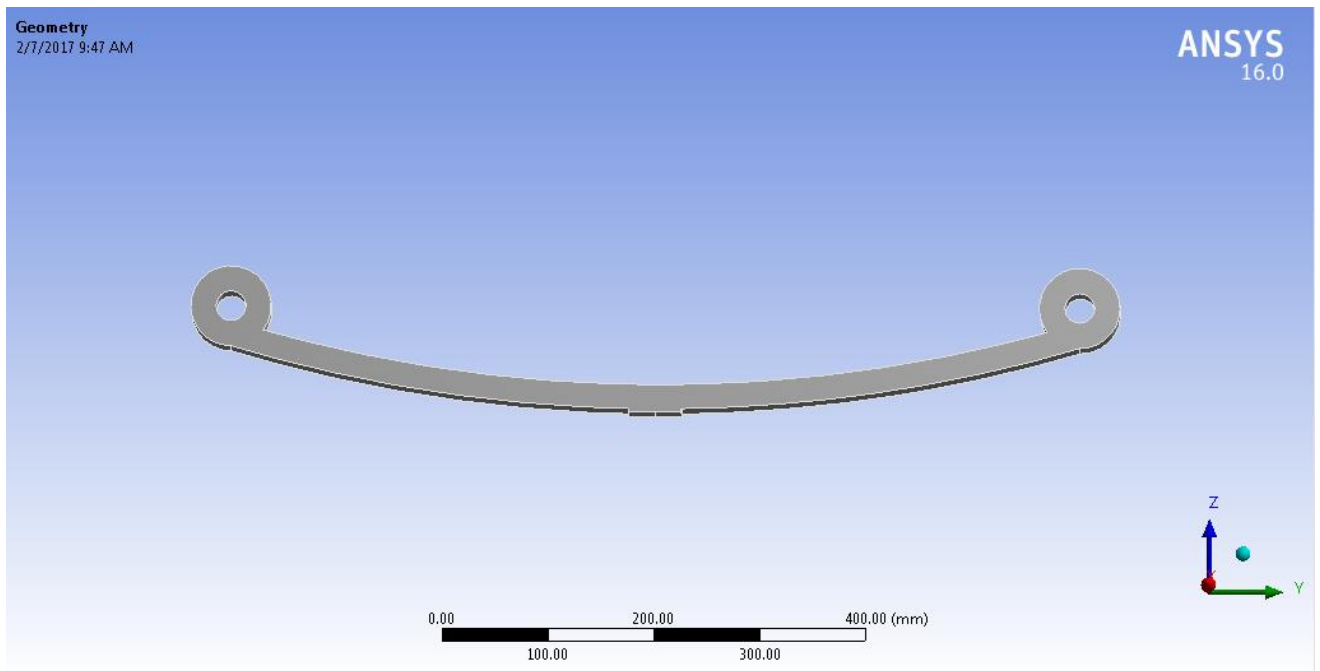


Figure 3.12: The browsed 3D model of carbon/epoxy leaf spring.

### Apply Mesh Controls/Preview Mesh

Applying mesh, Provide an adequate mesh density on contact surfaces to allow contact stresses to be distributed in a smooth fashion. Likewise, provide a mesh density adequate for resolving stresses; areas where stresses or strains are of interest require a relatively fine mesh compared to that needed for displacement or nonlinearity resolution. Then the meshed model of the carbon /epoxy leaf spring looks like in the figure below with 33315 node and 6440 number of elements.

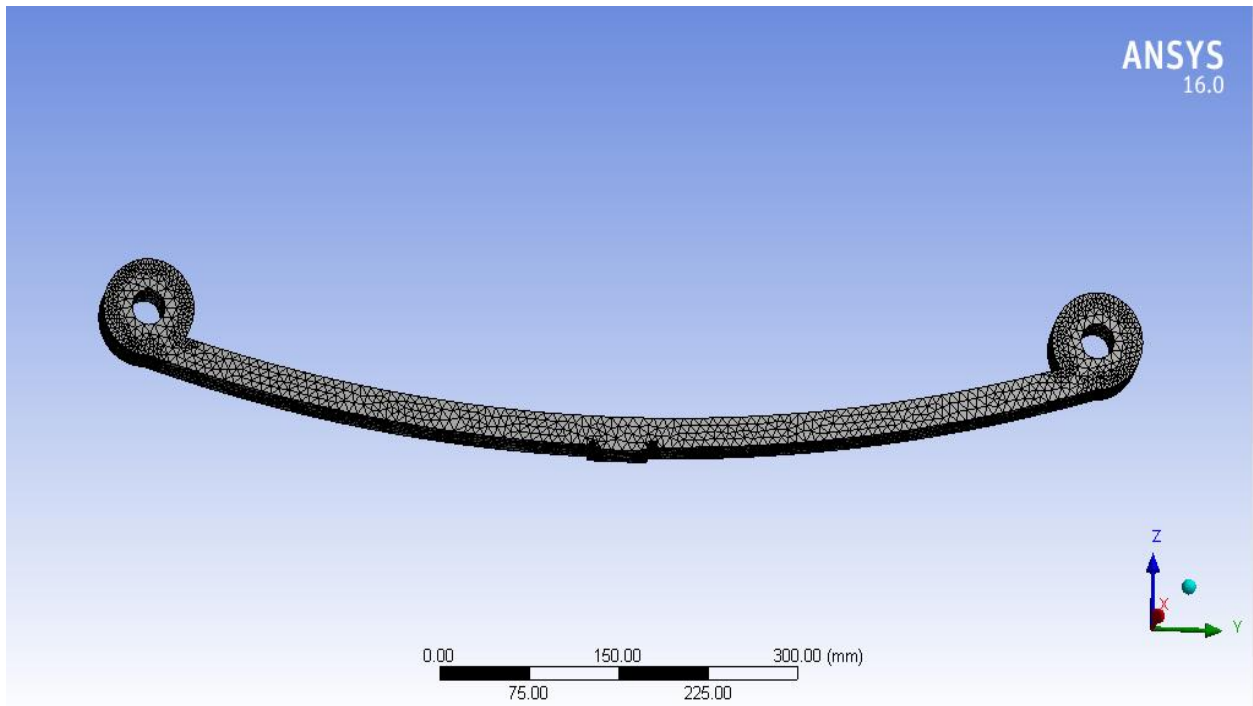


Figure 3.13: meshed model of carbon/epoxy leaf spring.

### Apply Loads and Supports

For a static structural analysis applicable loads are all inertial, structural, imported, and interaction loads, and applicable supports are all structural supports.

Loads and supports vary as a function of time even in a static analysis as explained in the role of time in tracking. In a static analysis, the load's magnitude could be a constant value or could vary with time as defined in a table or via a function. The boundary and loading condition of the leaf spring is mounted firmly on the axle of the vehicle, and the ends of the leaf spring attached with the frame of the vehicle. The ends of the leaf springs as shown before in their models are produced in the form of an eye. Both the front and rear eye of the leaf spring connected to the shackle, which is a flexible link, the other end of the shackle is connected to the frame of the vehicle, given certain degree of rotation to allow the leaf spring to deflect by some amount along its length to meet the actual conditions. Therefore both the rear and the front eye of the leaf spring has the flexibility to slide along the Y- direction when load applied on the leaf spring and also it can rotate about the shackle pin. And the link oscillates during load applied and removed.

Therefore the node of both eye of the leaf spring is constrained in the two translational degree of freedom, and constrained the two rotational degrees of freedom (UX, UZ, ROTX, and ROTZ). The models is constrained in all six degrees of freedom UX, UY, UZ, ROTX, ROTY ROTZ at the ends they are considered to be adhesively bonded end joints to enhance performance of composite leaf spring for delamination and stress concentration.

The static load is applied along Fz direction as shown in fig 3.13 below to apply load. For this analysis the applied load is 2710 N, and the numbers of associated nodes are bottom surface of bottom plate.

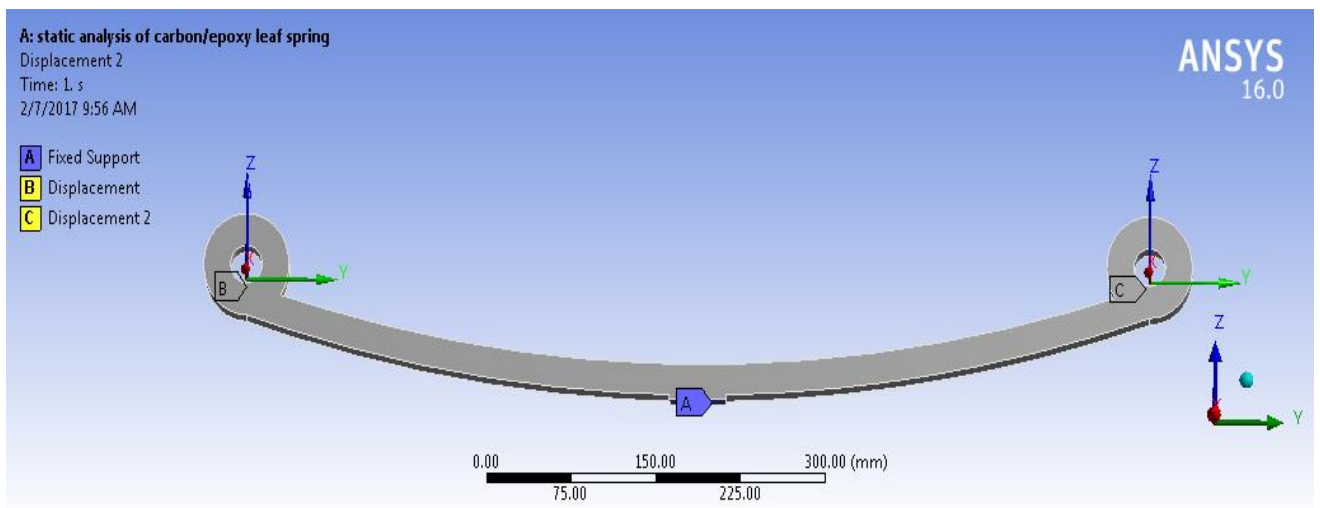


Figure 3.14: boundary condition of carbon/epoxy leaf spring.

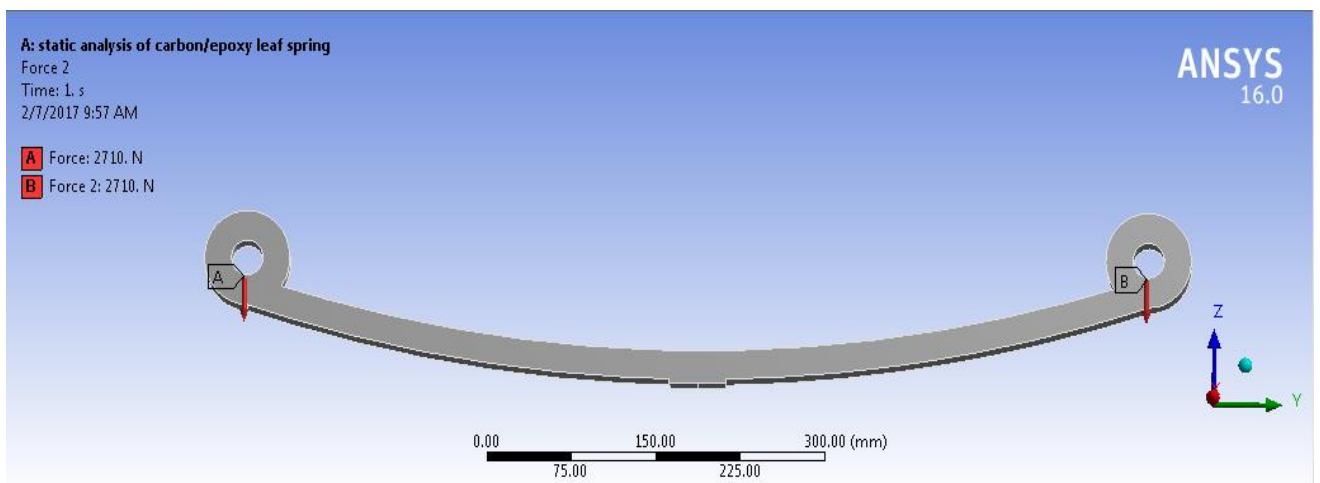


Figure 3.15: applied load on the rear and front eye of carbon/epoxy leaf spring.

### Generating solution

The solution is generated from the above input parameters of the project. The total deformation and equivalent (Von Misses) stress are the basic variables to be solved by this software analysis. Beyond this, directional deformation and normal stress in X, Y, and Z directions are also solved and the results are displayed in the appendix part of this study.

Solution Output continuously updates any listing output from the solver and provides valuable information on the behavior of the structure during the analysis.

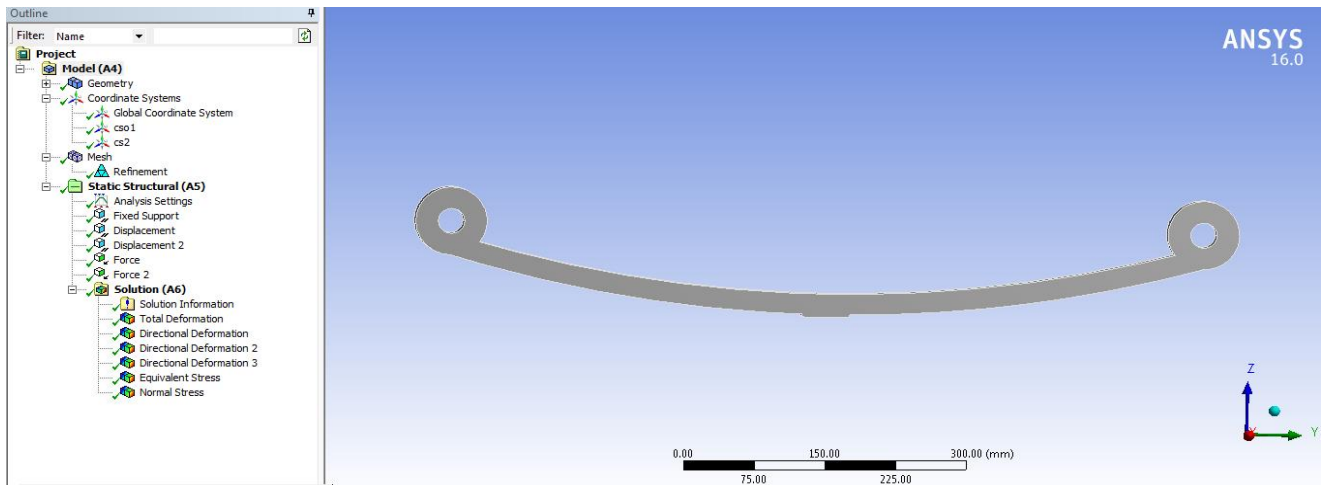


Figure 3.16: Generating solution of laminated carbon/epoxy leaf spring.

### 3.5.1.2. Static analysis of steel leaf spring

#### Define Engineering Data

The specific material property of the selected material are stated in the following table below:

Outline of Schematic A2: Engineering Data				
	A	B	D	
1	Contents of Engineering Data		Description	
2	Material			
3	Structural Steel		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	Density	7.85	g cm <sup>-3</sup>		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
7	Derive from	Young's M...			
8	Young's Modulus	2E+05	MPa		
9	Poisson's Ratio	0.3			
10	Bulk Modulus	1.6667E+11	Pa		
11	Shear Modulus	7.6923E+10	Pa		
12	Field Variables				
16	Alternating Stress Mean Stress	Tabular			
20	Strain-Life Parameters				
28	Tensile Yield Strength	250	MPa		
29	Compressive Yield Strength	250	MPa		
30	Tensile Ultimate Strength	460	MPa		
31	Compressive Ultimate Strength	0	MPa		

*Figure 3.17: workbench material properties of steel.*

### Attach Geometry

That is possible create the geometry of the leaf spring using Design Modeler in ANSYS workbench, beyond this From a CAD system supported by Workbench or one that can export a file that is supported by ANSYS Workbench.

Before attaching geometry, specify several options that determine the characteristics of the geometry to import. These options are: solid bodies, surface bodies, line bodies, parameters, attributes, named selections, material properties; Analysis Type (2D or 3D), allowing CAD associativity, importing coordinate systems (Import Work Points are only available in the Design Modeler application), saving updated CAD file in reader mode, “smart” refreshing of models with unmodified components, and allowing parts of mixed dimension to be imported as assembly

components that have parts of different dimensions. Then the browsed solid model of the steel leaf spring is done on CATIA V5, saved as “igs” form looks like in the following figure.

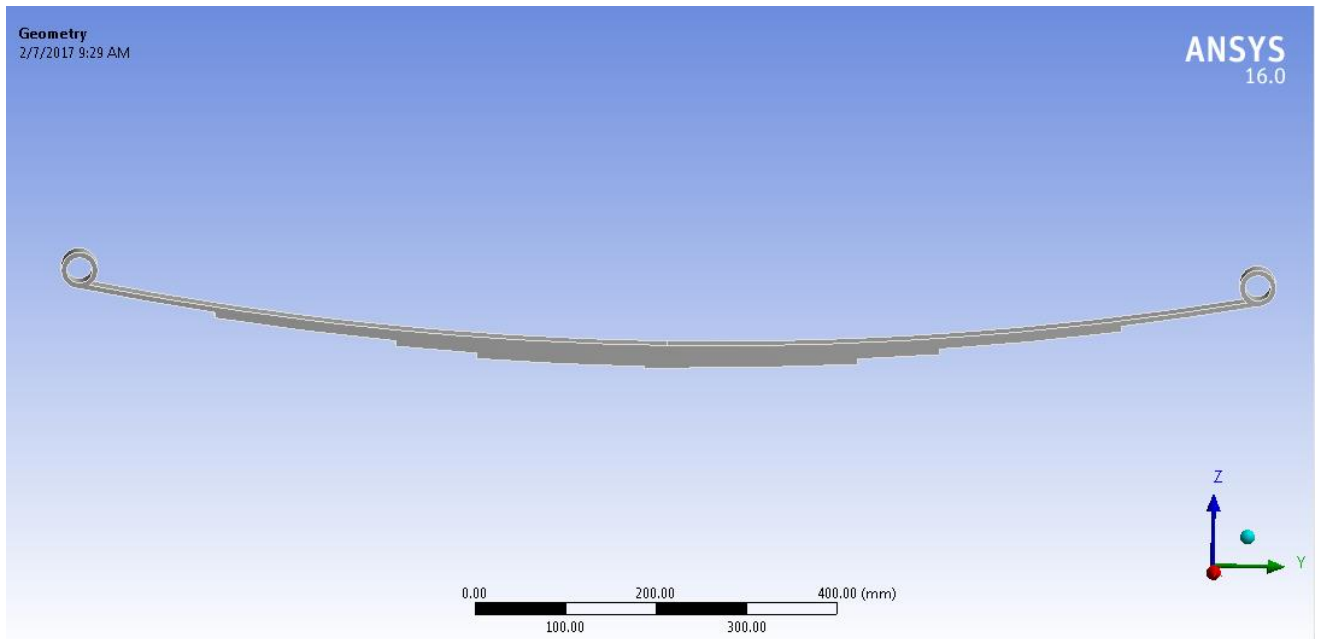


Figure 3.18: The browsed 3D model of steel leaf spring.

### Apply Mesh Controls/Preview Mesh

Applying mesh, Provide an adequate mesh density on contact surfaces to allow contact stresses to be distributed in a smooth fashion. Likewise, provide a mesh density adequate for resolving stresses; areas where stresses or strains are of interest require a relatively fine mesh compared to that needed for displacement or nonlinearity resolution. Then the meshed model of the steel leaf spring looks like in the figure below with 151850 node and 29693 number of elements.

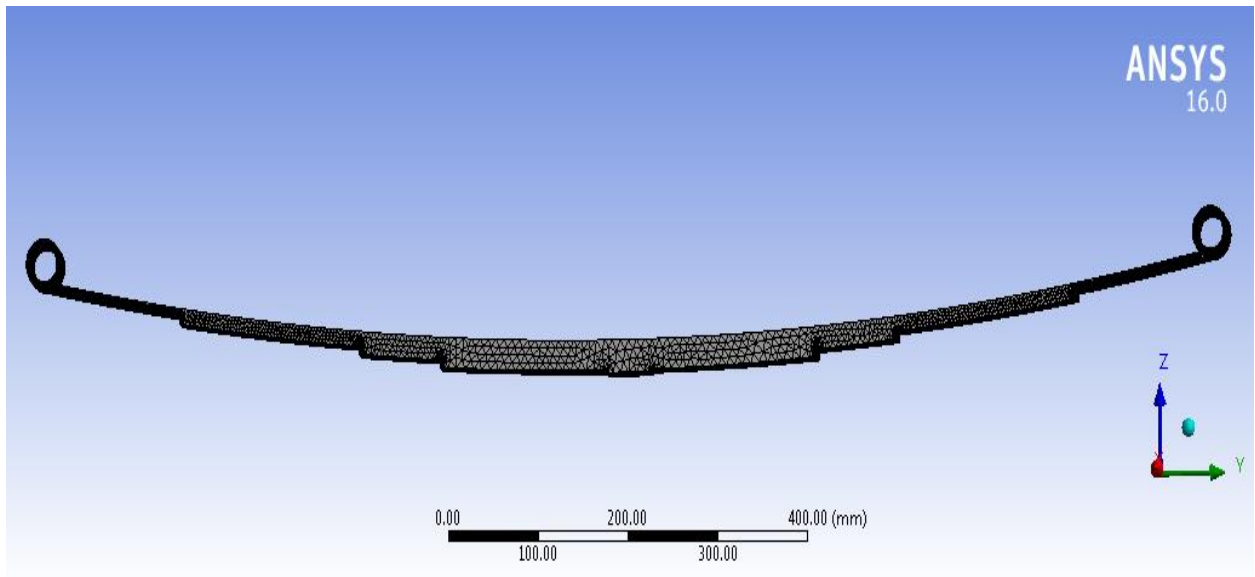


Figure 3.19: Meshed model of steel leaf spring.

### Apply Loads and Supports

For a static structural analysis applicable loads are all inertial, structural, imported, and interaction loads, and applicable supports are all structural supports.

Loads and supports vary as a function of time even in a static analysis. In a static analysis, the load's magnitude could be a constant value or could vary with time as defined in a table or via a function. The boundary and loading condition of the leaf spring is mounted firmly on the axle of the vehicle, and the ends of the leaf spring attached with the frame of the vehicle. The ends of the leaf springs as shown before in their models are produced in the form of an eye. Both the front and rear eye of the leaf spring connected to the shackle, which is a flexible link, the other end of the shackle is connected to the frame of the vehicle, given certain degree of rotation to allow the leaf spring to deflect by some amount along its length to meet the actual conditions. Therefore both the rear and the front eye of the leaf spring has the flexibility to slide along the X – direction when load applied on the leaf spring and also it can rotate about the shackle pin. And the link oscillates during load applied and removed.

Therefore the node of both eye of the leaf spring is constrained in the two translational degree of freedom, and constrained the two rotational degrees of freedom (UX, UZ, ROTX, and ROTZ). The models is constrained in all six degrees of freedom UX, UY, UZ, ROTX, ROTY ROTZ at the

ends they are considered to be adhesively bonded end joints to enhance performance of composite leaf spring for delamination and stress concentration.

The static load is applied along Fz direction as shown in the figure below. For this analysis the applied load is 2710 N, and the numbers of associated nodes are bottom surface of bottom plate. Looks like below in the figure below.

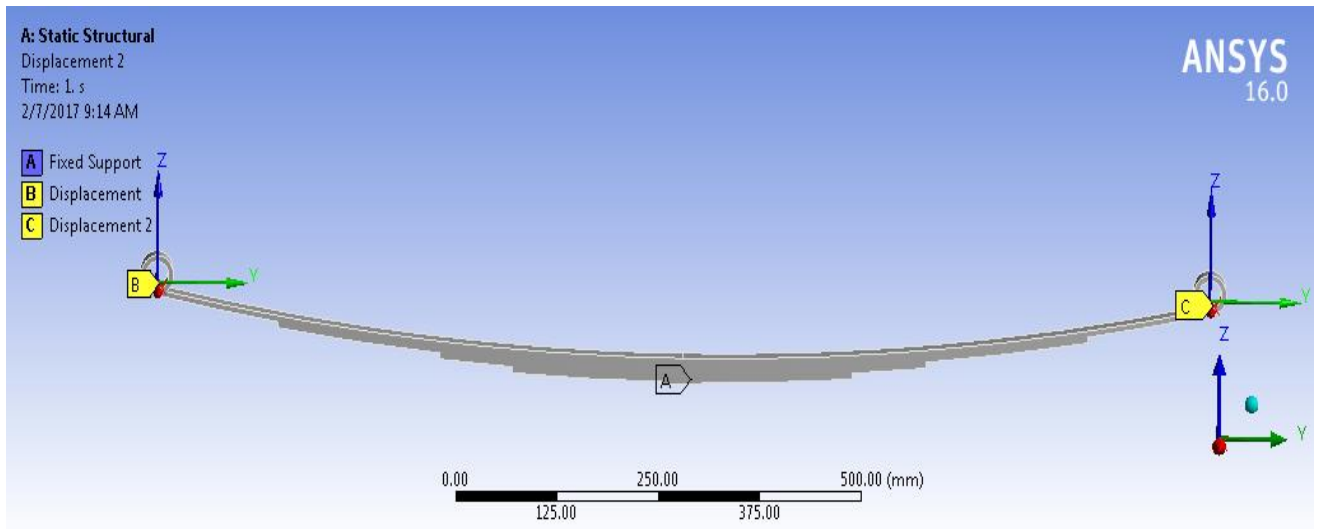


Figure 1Figure 3.20: boundary condition of the steel leaf spring.

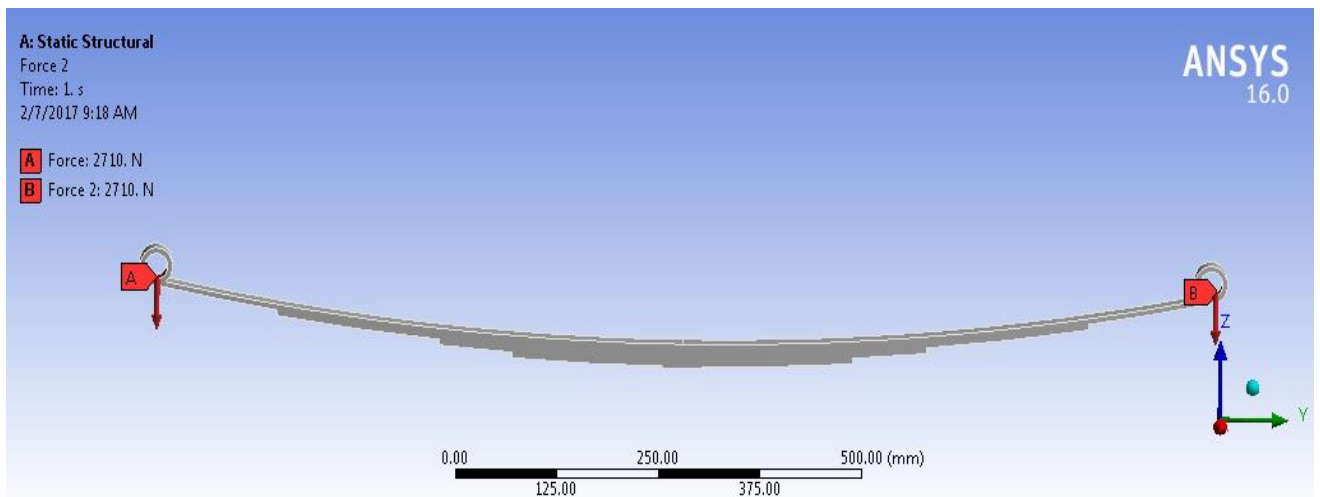


Figure 3.21: applied load on the rear and front eye of the steel leaf spring.

## Generate solution

The solution is generated from the above input parameters of the project. The total deformation, and equivalent (Von Misses) stress are the basic variables to be solved by this software analysis.

Solution output continuously updates any listing output from the solver and provides valuable information on the behavior of the structure during the analysis.

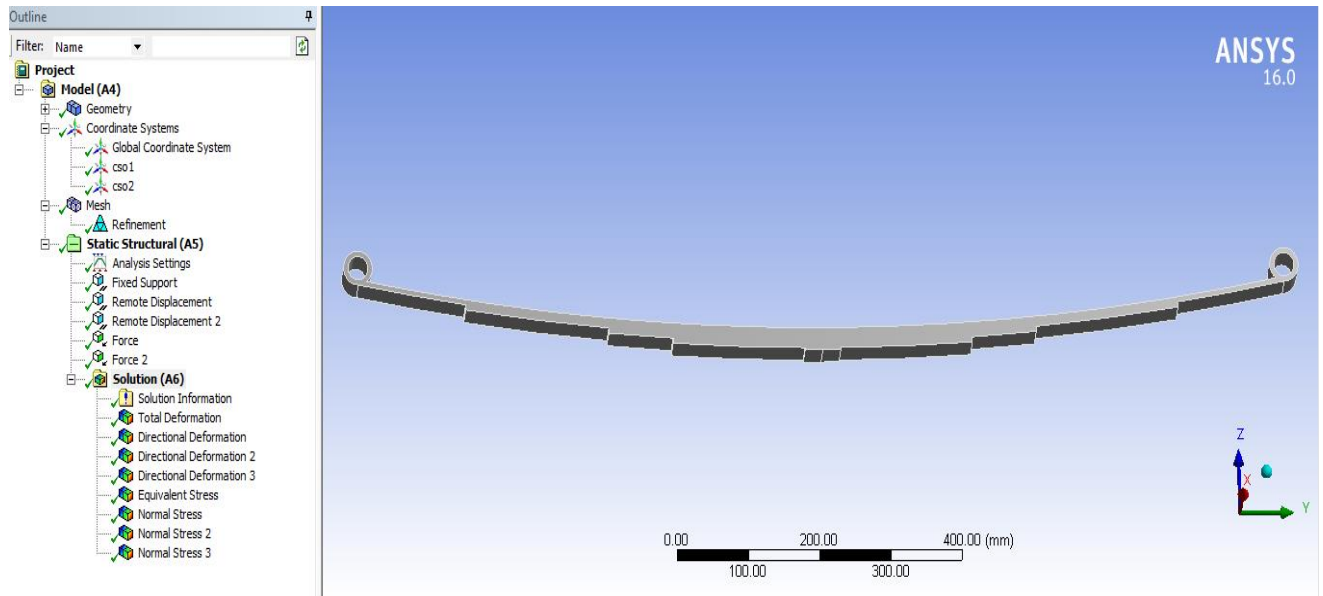


Figure 3.22: generating solution of steel leaf spring.

The details solution of each dependent parameter can be displayed one by one. Once the solution is generated, each dependent parameter is solved and ready to be seen and interpreted. Then this will be discussed in the result and discussion part of this paper, next chapter.

## CHAPTER FOUR

### RESULT AND DISCUSSION

In this chapter the results of both laminated carbon/epoxy composite and steel leaf spring materials obtained from the static structural analysis clearly stated.

Then the results presented here are the two leaf spring materials namely laminated carbon/epoxy composite and steel materials of; total deformation, directional deformation in X, Y, and Z directions, equivalent (Von Misses) stress, normal stress and equivalent elastic strains. However all results were presented, in this study the basic solutions are the total deformation and equivalent (Von Misses) stress. In a simple word the conclusion of the study will be done based on the total deformation and equivalent (Von Misses) stress results. The remaining results of the analysis which are done on ANSYS 16 workbench have been displayed on the appendix of this study.

The most important step of finite element analysis procedure is the physically realistic interpretation of the results by the analysis. Since finite element analysis procedures are invariably accompanied by an extensive output of data, it is extremely important that we interpret the results correctly.

For this study, the leaf spring static structural analysis is performed using finite element method by using ANSYS 16 workbench, that consist of a static structural. This is for the purpose of getting the maximum and minimum equivalent stress and displacement on the structural model. The static structural analysis determines the characteristics of the stress and deformation of the structure caused by the applied static loading systems and boundary conditions. The following typical static structural analysis system of ANSYS 16 workbench could be performed one by one to complete the analysis and get an appropriate solutions of the problem.

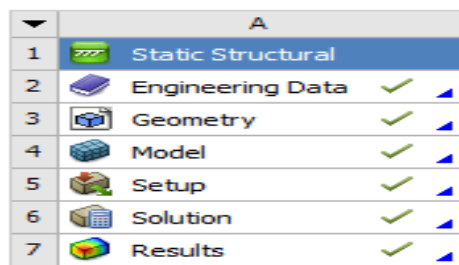


Figure 4.1: ANSYS 16 Workbench static structural analysis system.

## 4.1. Results

### 4.1.1. Equivalent (von misses) stress

The equivalent (Von Misses) stress values of both the laminated carbon/epoxy and steel leaf spring of FEA respectively looks like in the following figures.

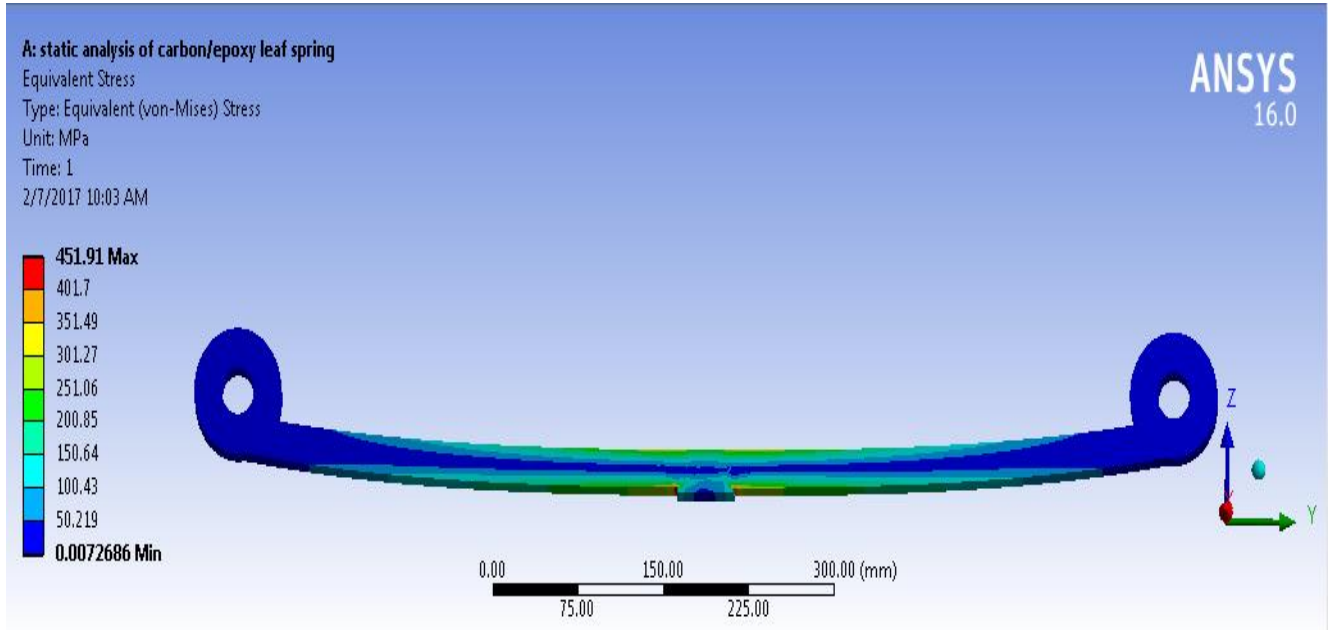


Figure 4.2: Equivalent (Von Mises) stress of carbon/epoxy leaf spring.

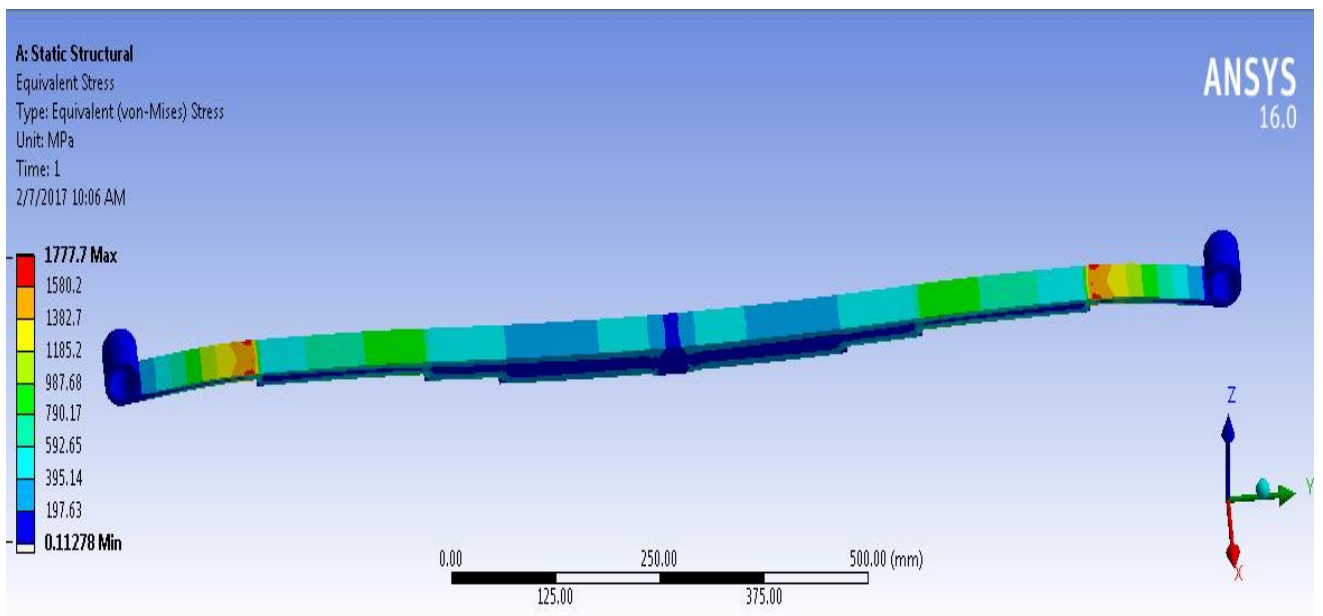


Figure 4.3: Equivalent (Von Mises) stress of steel leaf spring.

### 4.1.2. Deformation

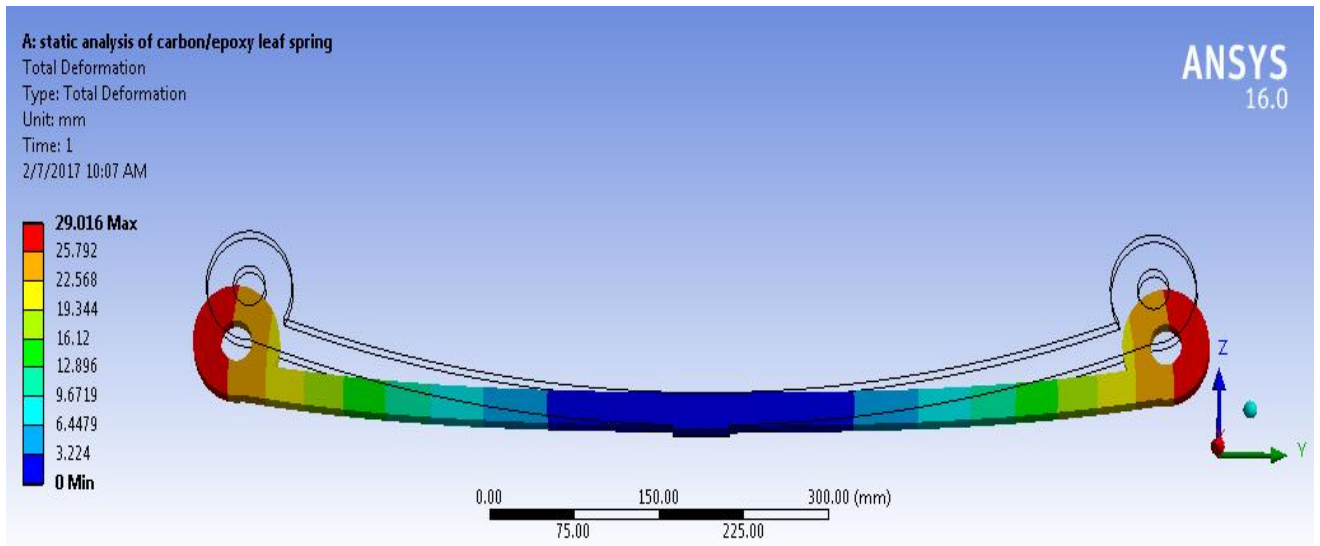


Figure 4.4: Total deformation of carbon/epoxy leaf spring.

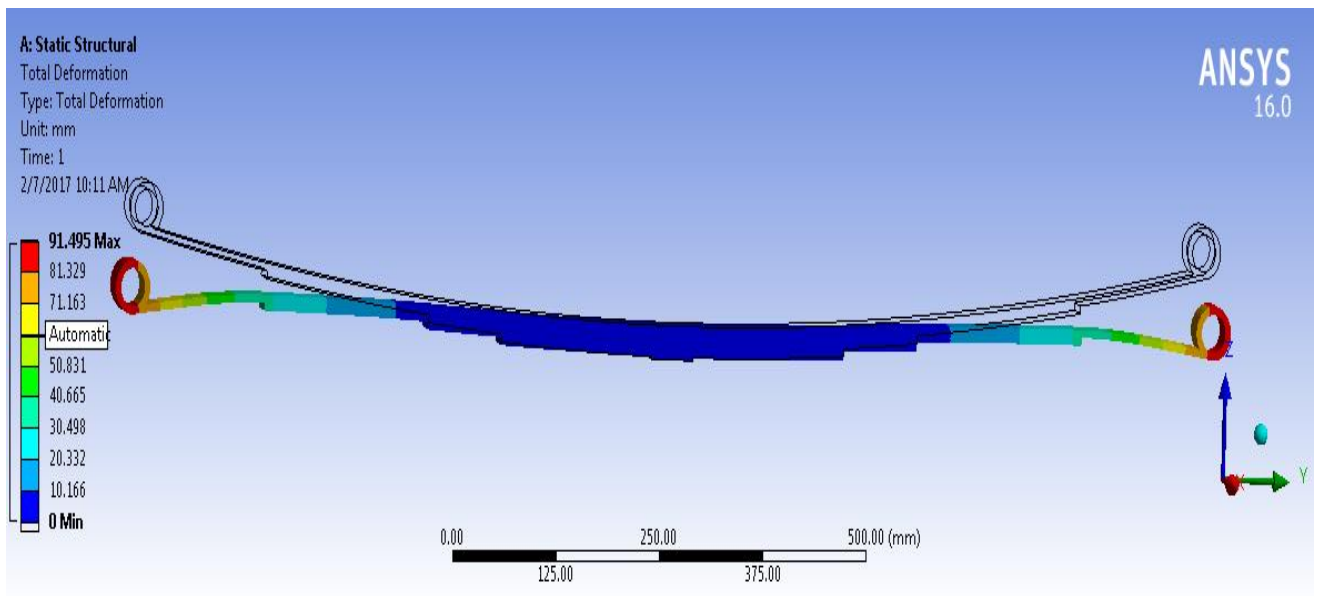


Figure 4.5: Total deformation of steel leaf spring.

### 4.2. Discussion

This static structural analysis of leaf spring of a vehicle using laminated carbon/epoxy composite and steel material was performed for applying a static load of 5420 N on a leaf spring.

When comparing the results obtained from FEA of the designed laminated mono carbon/epoxy composite leaf spring and existing steel leaf spring, the newly designed laminated mono carbon/epoxy composite material leaf spring has good performance than that of the current steel leaf spring.

In this specific research the comparison between the results of the FEA of these carbon/epoxy and steel leaf spring is carried out by making everything the same, except the length and material properties; i.e. at the same loading type and magnitude, the same boundary condition and the same method of FEM analysis.

## **Stress**

When external loads applied to an elastic body, the body may deform or elongate according to the nature of the applied load. Then stress is defined as the average load per unit area that some particle of a body exerts on an adjacent particle, across an imaginary surface that separates them.

### **4.2.1. Equivalent (Von-Misses) stress**

Equivalent (Von Misses) stress, computed from equation based on distortion energy failure theory, this criteria has been shown to be particularly effective in the prediction of failure for ductile materials and widely used by designers to check whether their design will withstand a given load condition.

Using the ANSYS 16 Workbench software, the values of equivalent (Von-Misses) stress found along with the given boundary conditions and applied load of 5420 N. Then the maximum equivalent (Von-Misses) stress values and the stress reduction are presented in table 4.1 below.

The results of this static structural analysis shows that the equivalent (Von-Misses) stress of the laminated carbon/epoxy composite material leaf spring is the smallest one as compared to that of the current conventional steel leaf spring under the same load and boundary conditions. This implies that laminated carbon/epoxy composite material leaf spring is less stressed, light weight and has a better performance.

### **4.2.2. Deformation**

From this static structural analysis ANSYS 16 workbench software, we show that, the maximum displacements of the laminated carbon/epoxy composite material leaf spring has the lowest

deformation value compare with that of the current conventional steel leaf spring. It is about 68.287% lower than the current conventional steel leaf spring.

#### **4.2.3. Weight reduction**

The mass of laminated carbon/epoxy composite material leaf spring = 1.544 Kg

The mass of conventional steel leaf spring = 6.67 Kg,

Then the ratio of mass becomes: 0.2315

Now the percentage reduction of mass becomes:  $(1 - 0.2315) * 100 = 76.85\%$

The weight of the leaf spring is reduced about 76.85% by replacing conventional steel leaf spring with a laminated carbon/epoxy composite material leaf spring.

The smaller mass of the laminated carbon/epoxy composite material leaf spring helps to make the vehicle lightweight, so that efficiency, running speed and fuel consumption of the vehicle is improved.

*Table 4.1: Comparison of the FEA results of the laminated carbon/epoxy leaf spring and conventional steel leaf spring.*

Leaf spring	Max. Equivalent stress (Mpa) at 5420 N	Max. Total deformation (mm) at 5420 N	Mass (Kg)
1. Laminated carbon/epoxy composite	451.91	29.016	1.544
2. Conventional steel	1777.7	91.496	6.67
<b>Percentage reduction</b>	<b>74.58%</b>	<b>68.287%</b>	<b>76.85%</b>

The charts plotted below will show the comparisons of FEA values clearly for both laminated carbon/epoxy composite and conventional steel leaf spring. The results are the values obtained from due to an applied load of 5420 N on a leaf spring.

### Comparison of equivalent stress

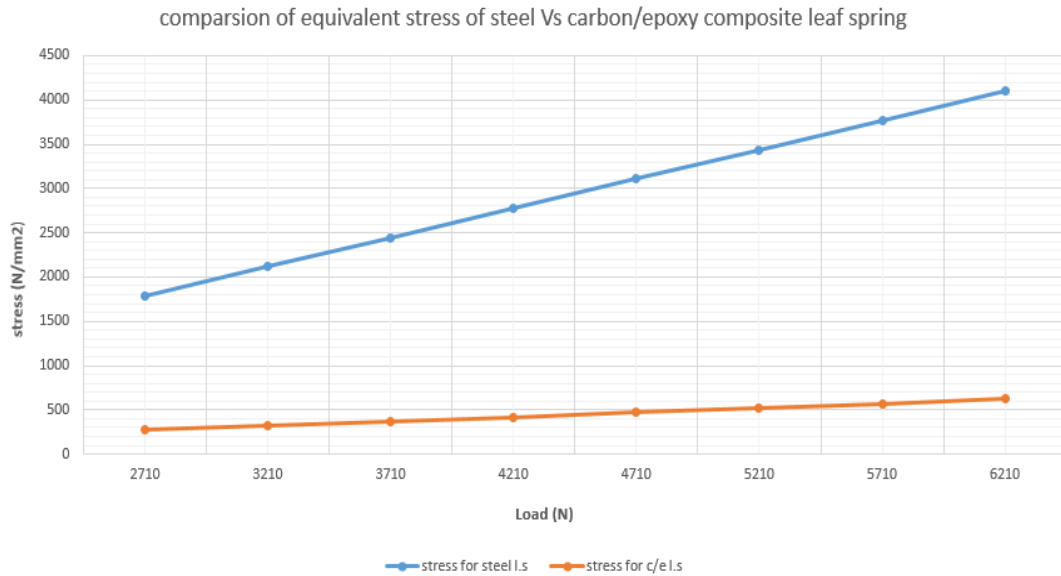


Figure 4.6: Comparison of equivalent stress of a laminated carbon/epoxy and steel leaf spring.

As we have seen from the above figure the comparison of stress between the current conventional steel leaf spring of Damass II car and the newly designed laminated carbon/epoxy mono leaf spring, the steel leaf spring is highly stressed than that of the carbon/epoxy mono leaf spring at the applied load of 5420 N.

### Comparison of total deformation

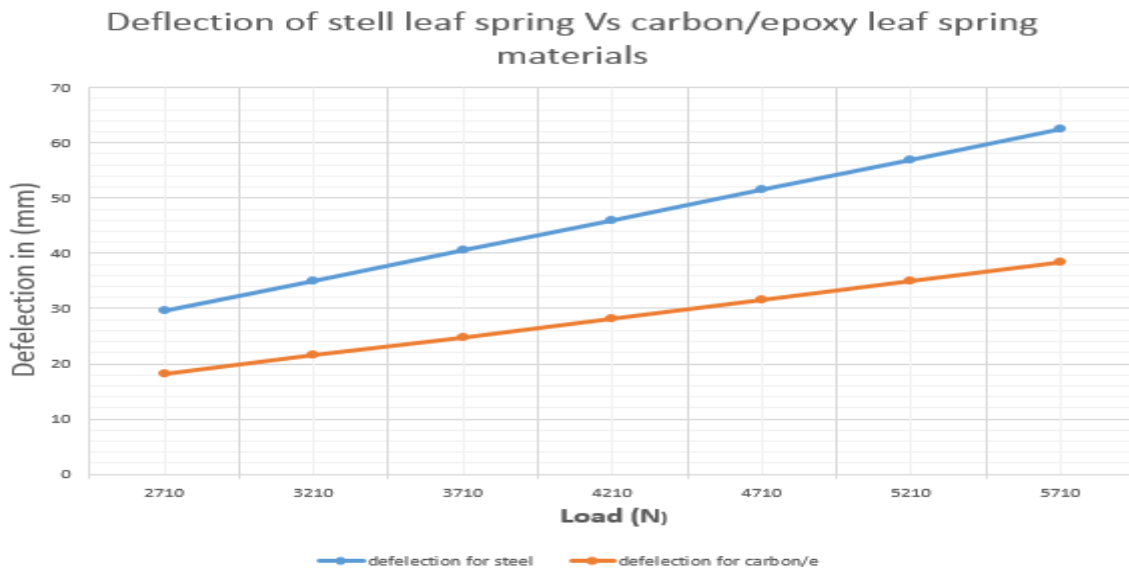


Figure 4.7: Comparison of total deformation of a laminated carbon/epoxy and steel leaf spring.

Figure 4.7 shows that the comparison of deformation between the current conventional steel leaf spring of Damass II car and the newly designed laminated carbon/epoxy mono leaf spring, the steel leaf spring highly deformed than that of the newly designed carbon/epoxy mono leaf spring at the applied load of 5420 N.

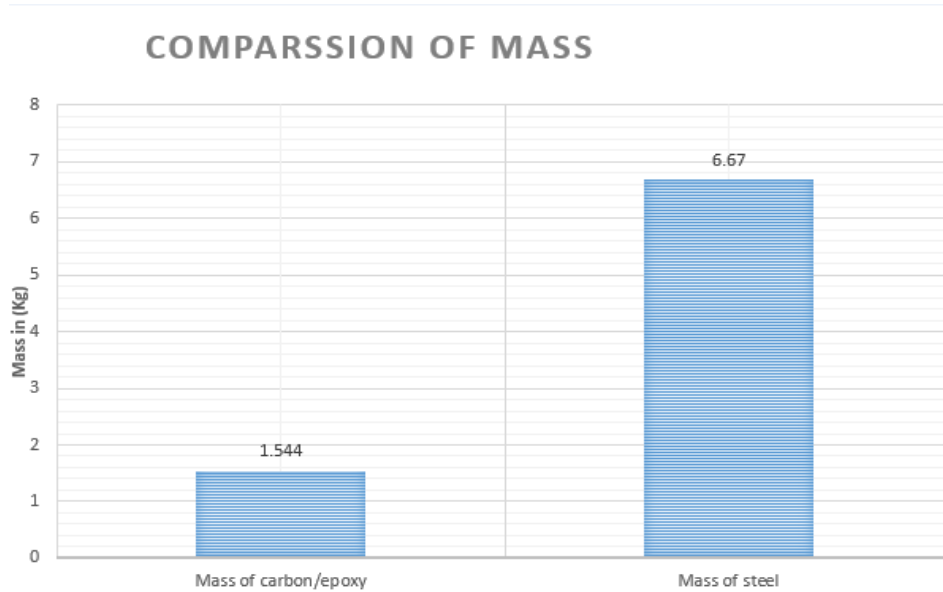


Figure 4.8: Comparison of weight of a laminated carbon/epoxy and steel leaf spring.

As we have seen from the above figure 4.8 the comparison of weight between the current conventional steel leaf spring of Damass II car and the newly designed laminated carbon/epoxy mono leaf spring, the composite carbon/epoxy leaf spring is light weight than that of the current conventional steel leaf spring of Damas II car.

## **CHAPTER FIVE**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1. Conclusion**

This thesis work involves, the comparison of Damas II multi steel leaf spring with laminated carbon/epoxy mono composite leaf spring under a static loading condition. Then to make the comparison using theoretical calculation and ANSYS software results.

The finite element analysis (FEA) is a powerful computational tool for analyzing complicated structural bodies. It can reduce prototype parts' producing and the number of physical tests to shorten the development cycle and reduce the development investment; i.e., it saves much time, effort and costs.

To conclude, this work as explained above, stress, weight and deformation in carbon/Epoxy composite leaf spring compared with conventional steel leaf spring for Damas II automobile suspension system. This is done to achieve the following.

As it was seen from the comparisons of the two leaf spring ANSYS results, the equivalent stress induced and deformation in the Carbon/Epoxy composite leaf spring is 74.58 % and 68.287% less than the conventional steel leaf spring for the same load carrying capacity respectively and achieve about 76.85% weight reduction in the suspension system. Then standing from design and static analysis of the study, steel leaf spring replaced with a laminated carbon/epoxy composite mono leaf spring is best one. The aim of replacing leaf spring with carbon/epoxy composite is to obtain a leaf spring which is light weight and capable of carrying given static load by constraints limiting stresses and displacements.

#### **5.2. Recommendations**

The properties of composite materials, like high strength to weight ratio and high specific stiffness are attractive for the construction of lightweight, fuel efficient and environmental friendly vehicle components. The energy absorption capability of the composite materials in general offers a unique combination of reduced weight and improves failure of the vehicle components. The fuel efficiency of the vehicle directly depends on the total dead weight of the vehicle. When the dead weight of the vehicle become large the fuel economy of the vehicle become high and the running

speeds become very slow, and the reverse is true. Then in order to maintain light weight, fuel efficient and high speed vehicle design, selecting composite materials is the only best decision.

The FEA result obtained from ANSYS 16 Workbench of this study shows that laminated carbon/epoxy composite mono leaf spring has much better performance than the current conventional steel multi leaf spring. Moreover, the weight of the laminated carbon/epoxy composite mono leaf spring is reduced about 76.85%; this intern reduces the overall dead weight of the vehicle. Thus, applying the results of this research work will improve the efficiency and the fuel economy of the vehicle.

For the last talk, it is recommended that laminated carbon/epoxy composite mono leaf springs are suitable for vehicle leaf spring applications.

### **5.3. Future work**

Standing from different aspects, working on composite materials have several advantages. From this point of view, regarding laminated carbon/epoxy composite leaf spring several things can be made and improved in the future in which this study didn't address.

Therefore; the following research areas are recommended for future studies:

- Dynamic analysis and design of laminated carbon/epoxy composite mono leaf spring.
- Designing the leaf spring by changing the orientation of the fiber and ply.
- Manufacturing of laminated carbon/epoxy composite leaf spring by studying the dynamic analysis and designing using dynamic loadings.

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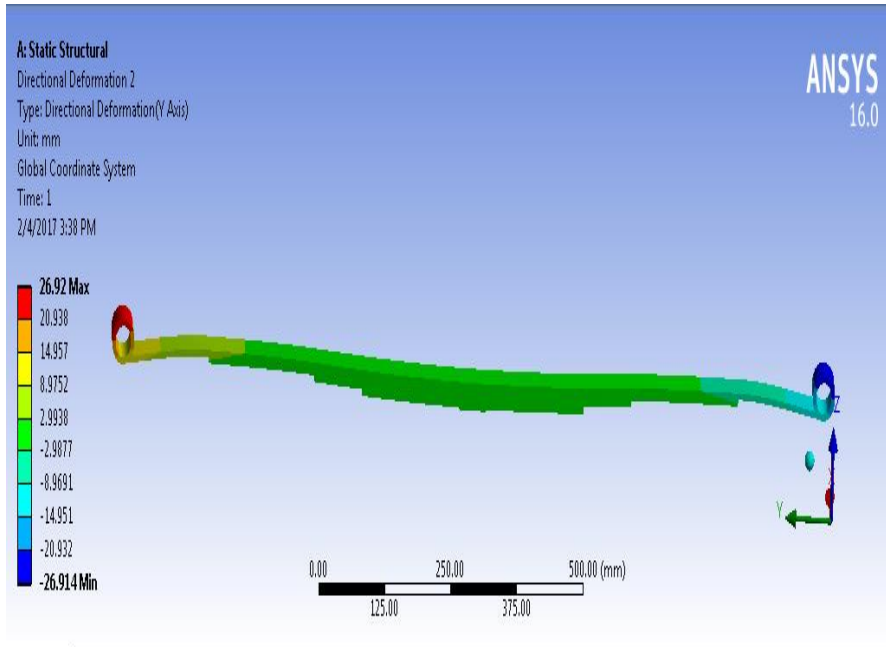
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## APPENDIX

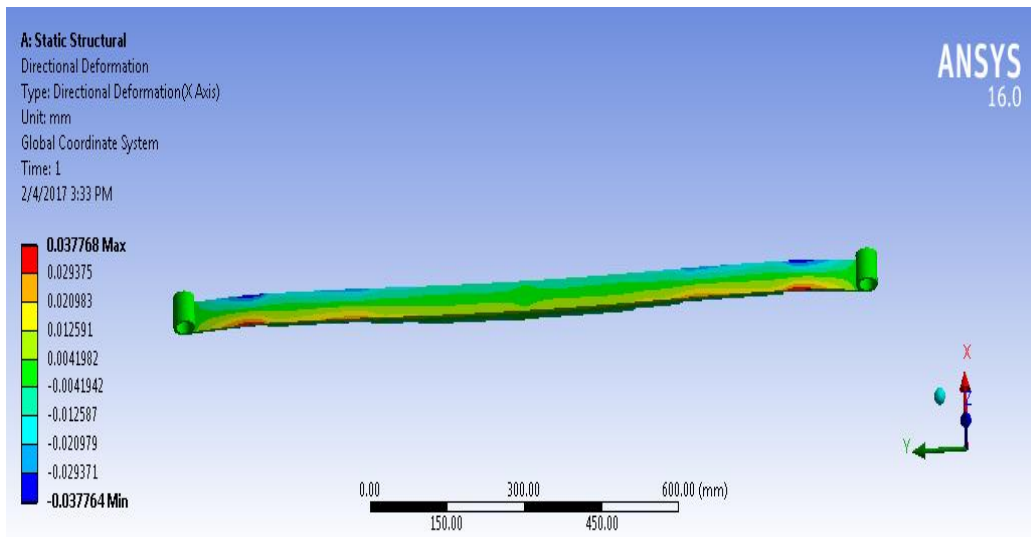
Directional deformation and normal stress results of current steel leaf spring and laminated carbon/epoxy composite mono leaf spring.

### Directional deformation of steel leaf spring

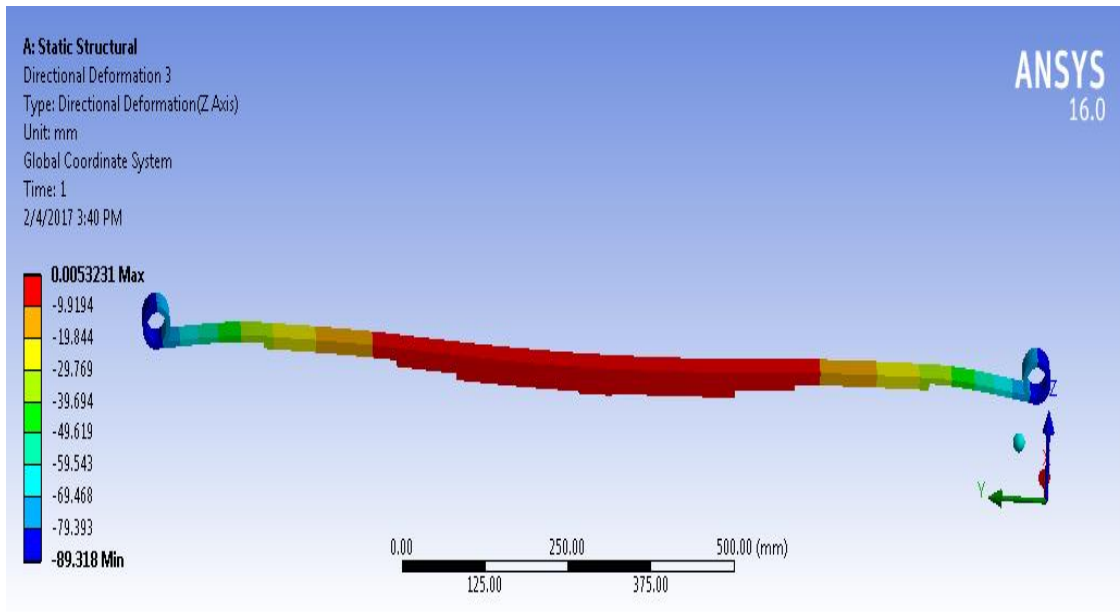
Directional deformation at y-direction:



Directional deformation at x-direction:

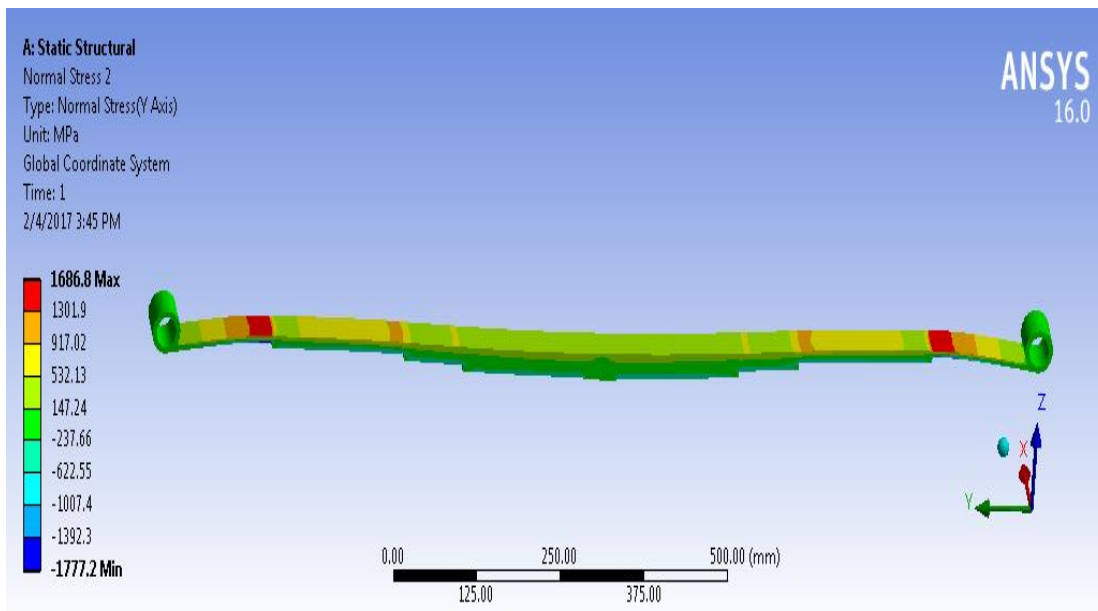


Directional deformation at z-direction:

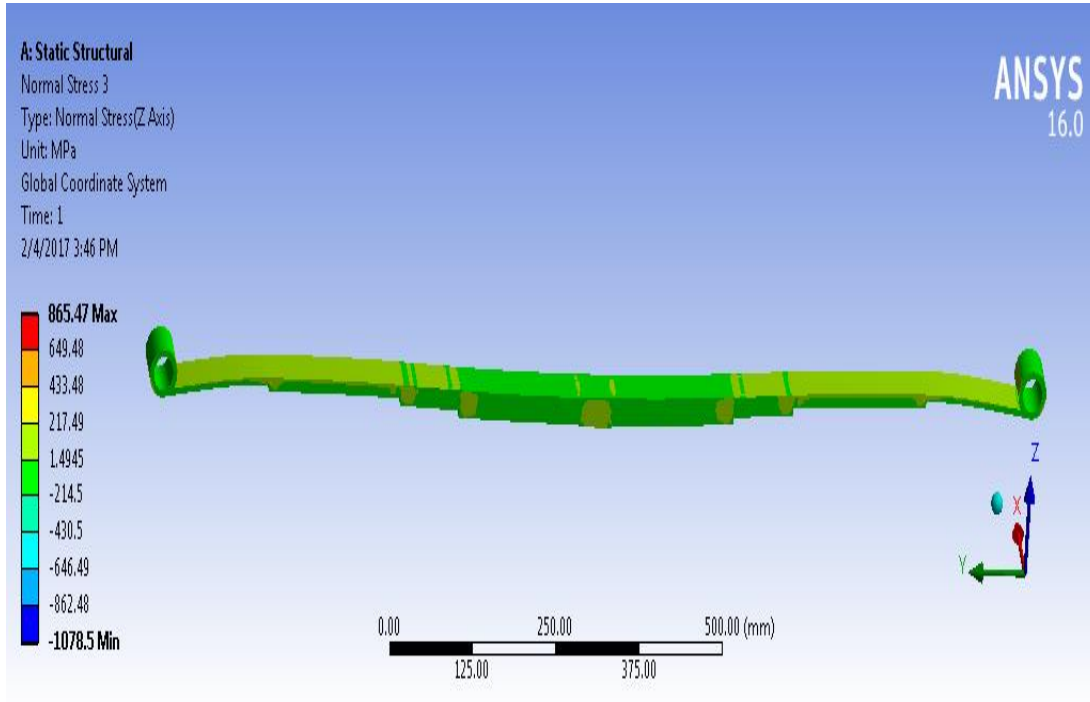


**Normal stress of steel leaf spring in y, z and x direction respectively**

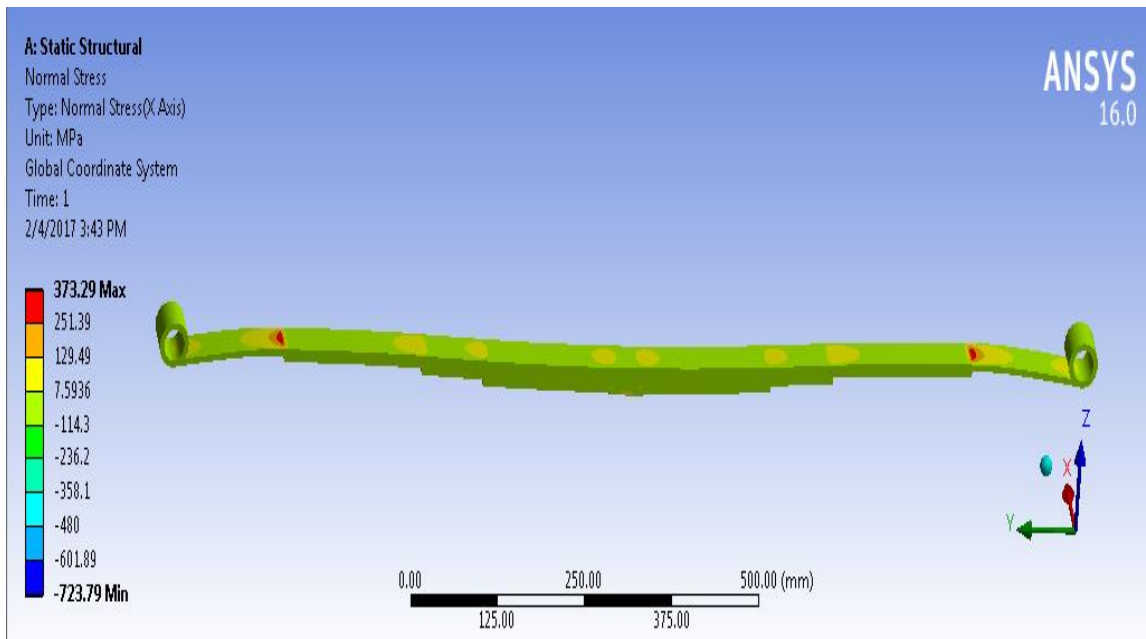
Normal stress at y-direction:



Normal stress at z direction:

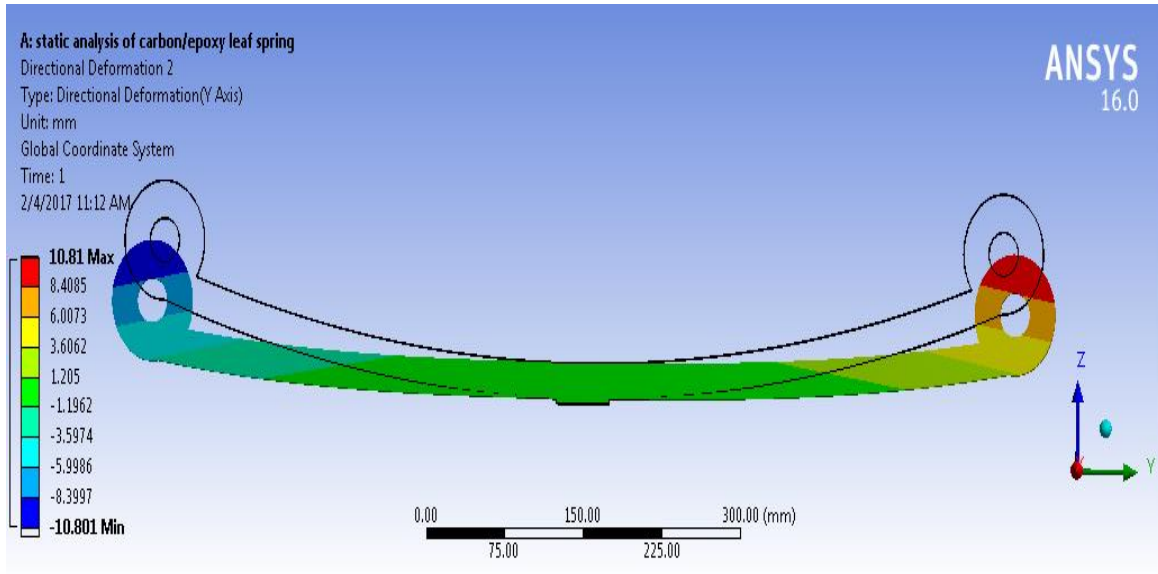


Normal stress at x-direction:

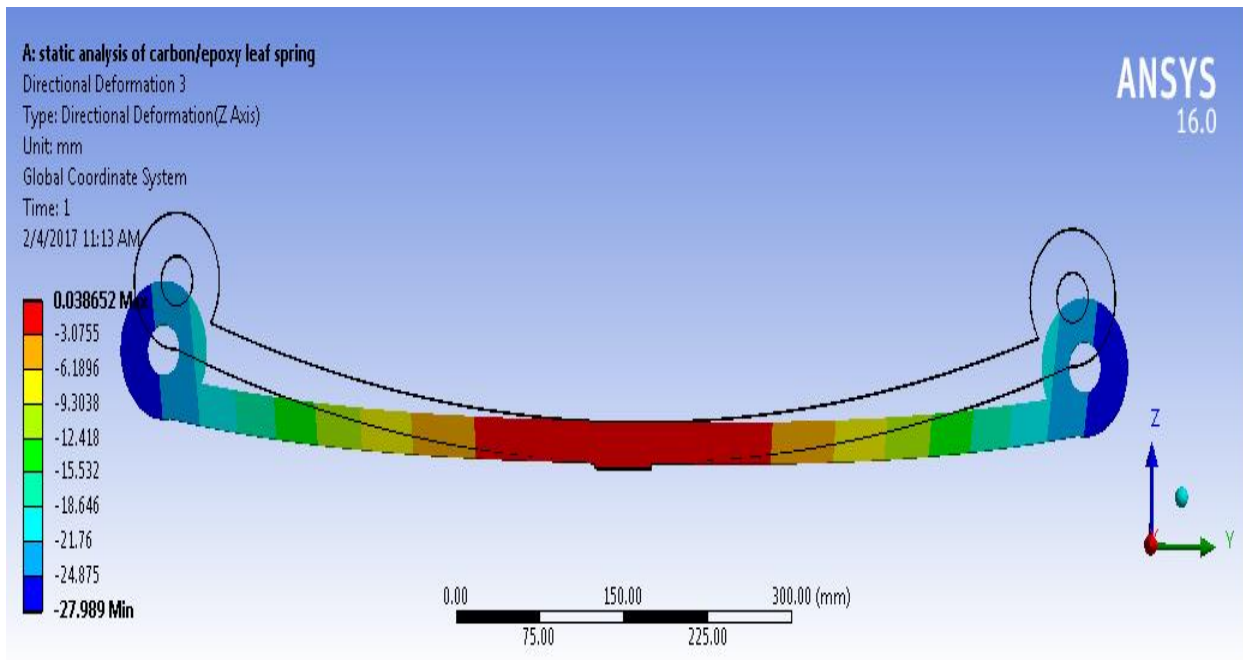


**Directional deformation of laminated carbon/epoxy composite leaf spring.**

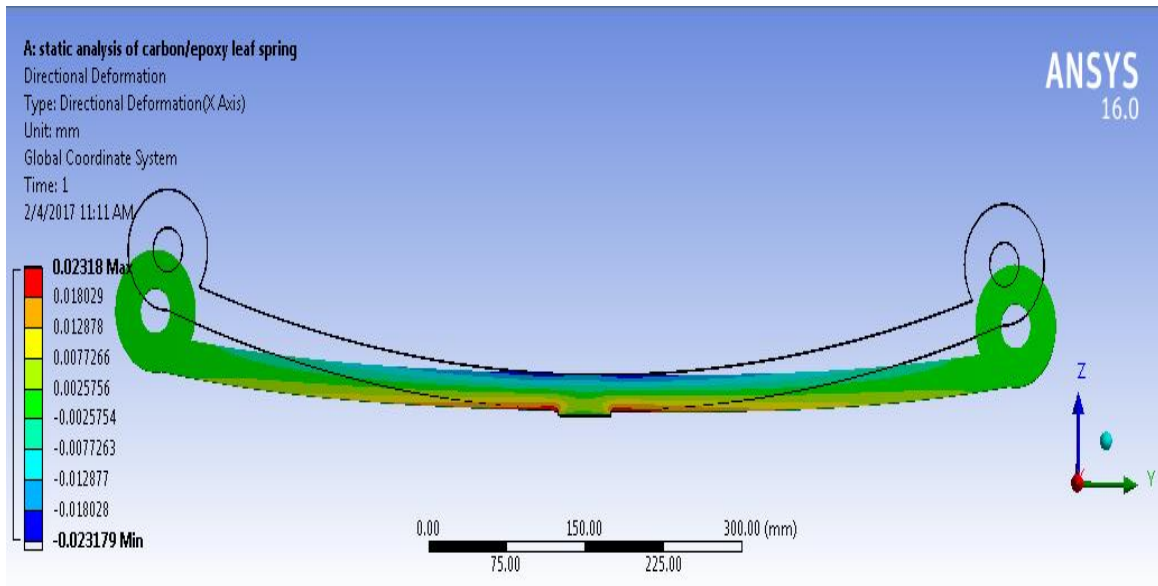
Directional deformation at y-direction:



Directional deformation at z-direction:

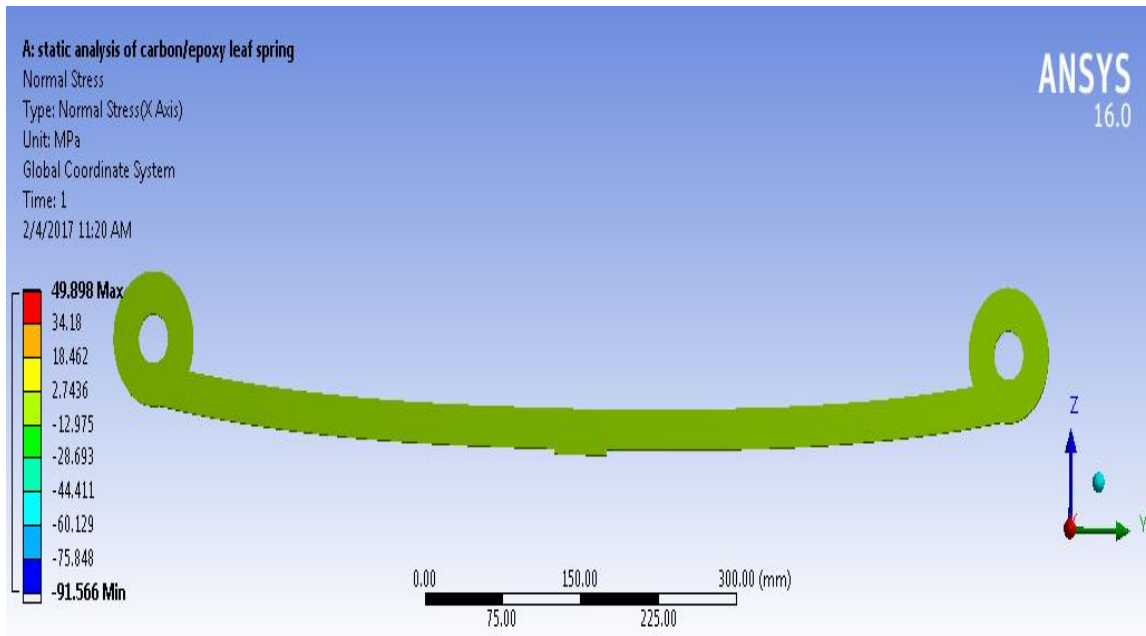


Directional deformation at x-direction:



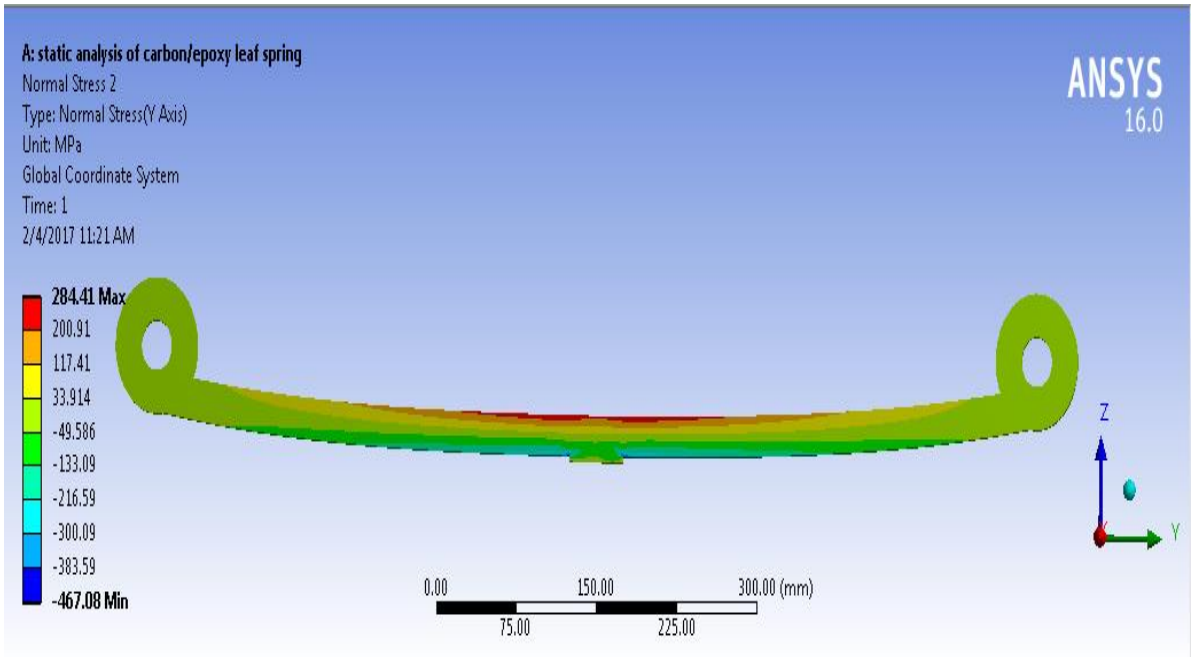
**Normal stress of laminated carbon/epoxy composite leaf spring in x, y, and z direction.**

Normal stress at x-direction:



Normal stress at y-direction:

DESIGN AND STATIC ANALYSIS OF CARBON/EPOXY COMPOSITE MONO LEAF SPRING FOR LIGHT VEHICLE USING FEM



Normal stress at z-direction:

