



ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF GRADUATE STUDY  
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING  
(Mechanical Design)

**Design and Development of Hybrid Composite Mono Leaf spring for Lifan 1020 mini truck Application**

A thesis submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment of the requirement of the Degree of Master of Science in Mechanical Engineering (Mechanical Design)

By: Nebyat Yazachew

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November 10, 2018

Addis Ababa, Ethiopia

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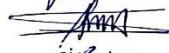
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This is to certify that the thesis prepared by Nebyat Yazachew, entitled: *Design and Development of hybrid composite mono leaf spring for light vehicle application*, do here by declare this thesis is my original work and that it has not been submitted in full for a degree in any university/institution, which compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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## Abstract

This thesis deals about the design and development of leaf spring for a Lifan 1020 mini truck car using hybrid composite materials. The aim of this work is to replace the existing steel leaf spring material with a mono laminated hybrid composite material. The dimensions (accept the thickness) and load bearing capacity of composite leaf spring is the same as steel leaf spring. Thus, the objective of this work is to reduce the weight of product while upholding its strength. Therefore, to solve this kind of problem, composite materials are the appropriate type of materials that can be customized according to the application types and load.

The thesis describes the development and characterization of Kevlar<sub>49</sub> and E- glass hybrid composite materials with general purpose epoxy. To characterize the material properties tests, such as flexural, compression and tensile strength was carried out. In the experimental test result material “B” has maximum tensile strength and material “A” has maximum compressive and flexural strength test. In addition, hyper work software was use to show the ply stacking (laminated) sequence of composite materials.

The total deflection and equivalent (Von- misses) stresses distribution applied both on steel leaf spring and composite leaf spring were done using ANSYS 18.2 workbench and were compared. The solid modelling of leaf spring was done on Solidwork 18 and was analyzed using ANSYS software. Finally, according to the static analysis results, the study revealed that hybrid mono composite leaf spring provides better performance than that of the current conventional steel leaf spring of Lifan 1020 mini truck car.

**Key words:** Mono leaf spring; hybrid composite; Finite element analysis. ANSYS 18.2 workbench.

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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 poisons ratio

$G_f$  = shear modulus of fiber

$G_m$  = shear modulus of matrix

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

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

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

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

$\delta$  = deflection of leaf spring

$\sigma_b$  = bending stress of the hybrid composite materials

$\sigma_c$  = compression stress of the hybrid composite materials

$\varepsilon$  = strain of the hybrid composite materials

$I$  = moment of Inertia for leaf spring

$b$  = width of leaf spring

$h$  = thickness of leaf spring

$l$  = length of leaf spring

$\bar{x}$  = mean

### List of abbreviations and acronyms

*CAD = Computer Aided Drawing*

*GFRP = Glass fiber reinforced plastic*

*FEM = Finite element method*

*FRP = Fiber reinforced plastic*

*GPa = Giga Pascal*

$\frac{g}{cm^3}$  = *Gram per centimeter cubed*

*Kg = Kilogram*

*g = gram*

*m = mass*

*MMC<sub>s</sub> = Metal Matrix Composites*

*mm = millimeter*

*Mpa = Mega Pascal*

*N = Newton*

*PMC<sub>s</sub> = Polymer Matrix Composites*

*ROM = Rule of Mixture*

*W = Weight*

*ASTM = American Society for Testing and Materials*

*UTM = Universal Testing Machine*

*SD = Standard Deviation*

*CV = Coefficient of Variance*

## Chapter One

### 1. Introduction

#### 1.1 Background of the study

Nowadays the fuel efficiency and gas emission regulation of automobiles are become hot issues. To fulfill this issue, the automobile industries are trying to make new vehicle that may provide high efficiency with low cost and weight.

To conserve natural resources and economize energy, weight reduction has been the focus of automobile manufacturers in the present scenario. Weight reduction achieved primarily by the introduction of better material, design optimization and better manufacturing processes [2].

Suspension is the term given to the system that is an integral part of different mechanical components, which are springs, shock absorbers and linkages, that connects a vehicle to its wheels. Suspension systems provides the following purposes.

- ✓ contributing to the car's road holding/handling and braking for good active safety
- ✓ driving pleasure and keeping vehicle occupants comfortable and reasonably well isolated from road noise, bumps, and vibrations.

These goals are generally at odds, so the tuning of suspensions involves finding the right compromise. It is important for the suspension to keep the wheel in contact with the surface as much as possible, because all the forces acting on the vehicle transmitted through the contact patches of the tires. The suspension protects body of the vehicle from damage and wear, and cargo or luggage may protect from damage. The primary function of the suspension system is to isolate the vehicle structure from shock and vibration that results from irregularities of the road surface [11].

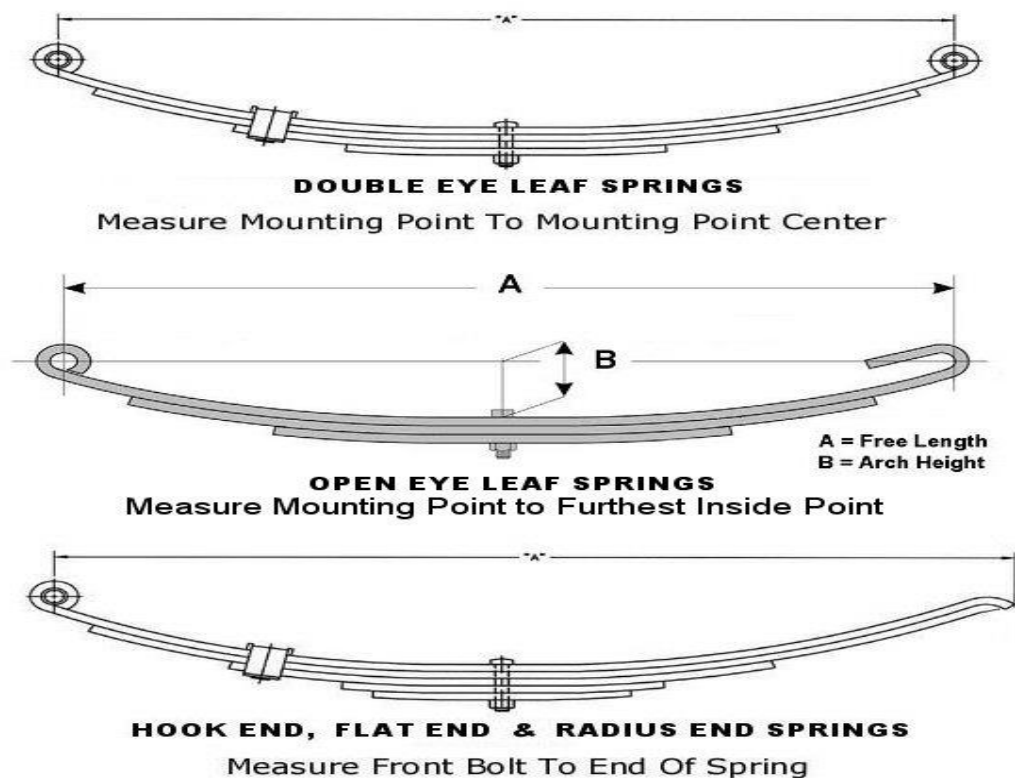
A spring, is characterized as an elastic body: its function is to distort during loading then recover to its original shape during unloading. In addition, it can be twisted, pulled, or stretched corresponding to loading directions. All these effects may be recovered to the original shape during unloading [3].

Types of spring

1. Laminated or leaf springs
2. Helical springs
3. Conical and volute springs
4. Torsion springs
5. Special purpose springs

A leaf (laminated) spring is a simple form of spring, commonly used for the suspension in the vehicles. It is also one of the oldest forms of spring dating back from medieval times [2].

Leaf spring (flat springs) is made up of flat plate. The advantage of leaf spring over other springs is that the two ends of the spring may be guided along a definite path as it deflects and it can act as a structural member. Therefore, the leaf springs may carry lateral loads, brake torque, and driving torque in addition to shock absorber. Based on the geometric characteristics of the two ends, leaf spring can be classified into different types; *Figure 1.1* presents basic types. “The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unsprung weight.” This achieves the vehicle with more fuel efficiency and improved riding qualities [4].



*Figure 1-1: Types of leaf spring [18]*

Replacing steel leaf spring with composite materials was made it possible to reduce the weight 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 than steel material, mono leaf composite springs are replacing conventional multi-leaf steel springs [1]. The laminated or leaf spring consists of several flat plates (known as leaves) of varying lengths held together by means of clamps and bolts. The arrangement of the leaf spring is shown using *figure 1.2*.



*Figure 1-2: Arrangement of leaf spring [19]*

A leaf spring can either be attached directly to the frame either at both ends or at one end; in the latter case the other end is attached through a shackle (a short swinging arm). The shackle provides the tendency of the leaf spring to elongate when compressed [1].

Considering several types of vehicles that have leaf springs and different loading on them, various kinds of composite leaf springs have been developed. In some designs the thickness and width of the spring are fixed along the longitudinal axis. Merits of composite leaf spring [10].

- Reduced weight.
- Due to laminate structure and reduced thickness of the mono composite leaf spring, the overall weight would be less.
- Due to weight reduction, fuel consumption would be reduced.
- They have high damping capacity; hence produce less vibration and noise.
- They have good corrosion resistance.

## **1.2 Statement of the problem**

The main problem in the automotive industry is weight of the car whereas increasing the strength and efficiency of automobile. Multi leaf spring creates problems such as producing squeaking sound, fretting corrosion there by decreasing the fatigue life. Composite materials are one of the material families which are attracting and being solutions of such issue. The Automobile industry has shown great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials have high strength to weight ratio and good corrosion resistance properties.

Due to strength and stiffness, high temperature resistance, fatigue strength and other properties, composite materials are superior to all other known structural materials. Because of these superior properties of composite materials, the weight problem of automobile will be reduced by the development of leaf spring using hybrid composite materials. The desired combination of properties can be tailored in advance and realized in the manufacture of a material.

## **1.3 Objective**

### **1.3.1 General objective**

The aim of this thesis is to design and develop leaf spring of Lifan 1020 mini truck automobile by using hybrid composite material

### **1.3.2 Specific objective**

1. To produce hybrid fiber reinforced composite materials
2. To characterize the tensile, compression and flexural properties of hybrid composite material
3. To design the leaf spring mathematically
4. Analyzing stress and deflection in leaf spring using finite element method
5. Comparing the weight of steel leaf spring with composite leaf spring
6. To develop the prototype of leaf spring

## 1.4 Methodology

The research is intended to go through two basic phases.

### 1. Data collection

The study started with literature review from previous papers on design and analysis of leaf spring using different materials.

- Data collection to design and analysis of leaf spring in Lifan 1020 mini truck car using hybrid composite material.
- Review of different journals, books, and articles

### 2. Method of Designing

- Prepare the specimens of hybrid composite materials
- Testing the tensile, bending and compression strength of the spacemen by using UTM (Universal Testing Machine).
- Determine the dimension of leaf spring by theoretical design.
- Modeling and analyzing the leaf spring by using Solidwork and ANSYS.
- Develop prototype of the leaf spring

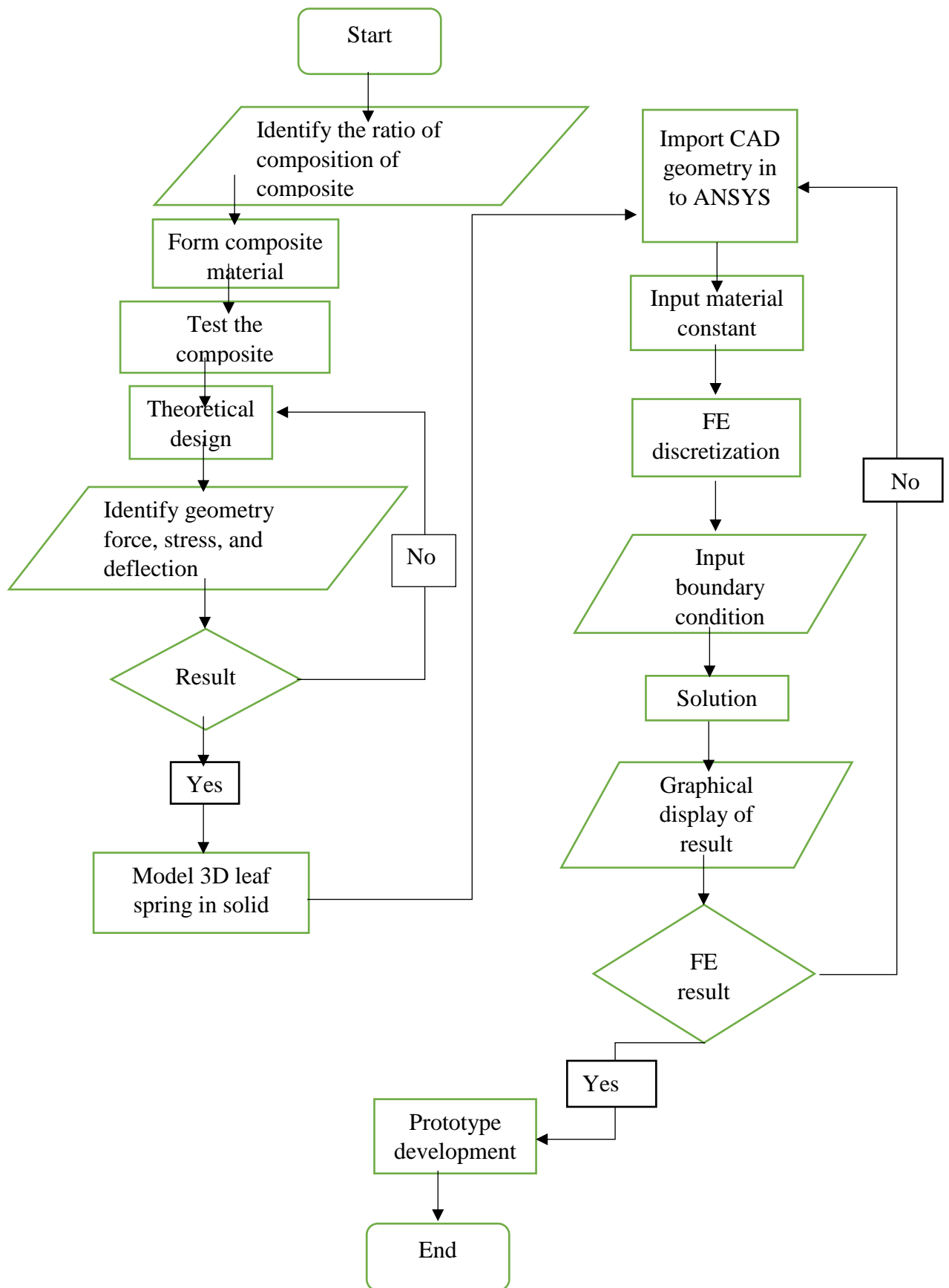


Figure 1-3: Methodology structure

## 1.5. Scope of the thesis

This thesis work on the development of leaf spring including characterization of hybrid composite materials that can be used for re-placing the conventional leaf spring and theoretical design. Modeling and static structural analysis of leaf spring will be done using solid work18 and ANSYS 18.2. Finally, prototype will be developed.

The thesis does not include the impact analysis and service life of hybrid composite leaf spring.

## 1.6 Thesis Organization

This work focuses on the fabrication of hybrid reinforced epoxy composite and characterizing mechanical property such as tensile, compression and flexural property, and modeling using finite element method. This work organized into six chapters.

**Chapter 1** is about introduction of leaf spring, the thesis objectives and statement of the problem, methodology, scope, and limitations.

**Chapter 2** reviewed all relevant research papers regarding steel and composite leaf spring, synthetic fiber composite materials, polymer types, fiber types, and composite's chemical, mechanical properties, manufacturing of composite leaf spring.

**Chapter 3** deals with material selection, specimen preparation, design the experimental procedure, and measurement of mechanical properties (such as tensile strength, compression strength and flexural strength).

**Chapter 4** describes about modeling of leaf spring using SOLIDWORK 2018, and stress analysis of leaf spring using ANSYS 18.2.

**Chapter 5** reports the result and discussion about deformation, equivalent stress, and weight of the leaf spring.

**Chapter 6** provides the conclusion, recommendations, and future work of the thesis.

## Chapter Two

### 2. Literature review

Composite materials are now extensively used in the automobile industry instead of metal parts. Several papers were published on this topic; some of these papers are reviewed here for the further study of composites materials leaf spring application for automobile.

Investigation of composite leaf spring in the early 60's failed to yield the production facility because of inconsistent fatigue performance and absence of strong need for mass reduction. Researches in automobile components have been receiving considerable attention now. Particularly the automobile manufacturers and parts makers have been attempting to reduce the weight of the vehicles in recent years. Emphasis of vehicles weight reduction in 1978 justified taking a new look at composite springs. [4]

Leaf springs were very common on automobiles, right up to the 1970s, when the move to front wheel drive, and more sophisticated suspension designs saw automobile manufacturers use coil springs instead. U.S. passenger cars used leaf springs until 1989 where the Chrysler M platform was the final production vehicle marketed. However, leaf springs are still used in heavy commercial vehicles such as vans and trucks, and railway carriages. [5]

#### 2.1. Composite materials

Composite material is defined as a material composed of two or more constituents combined on a macroscopic scale by mechanical and chemical bonds. Many composite materials offer a combination of strength and modulus that are better than any traditional metallic materials. The fatigue strength weight ratios as well as fatigue damage tolerances of many composite materials excellent. For these reasons, fiber composite has 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. The strength of the composite depends primarily on the amount, arrangement, and type of fiber (or particle) reinforcement in the resin. Typically, the higher the reinforcement content, the greater the strength. In some cases, glass fibers are combined with other fibers, such as carbon or aramid (Kevlar<sub>29</sub> and Kevlar<sub>49</sub>), to create a "hybrid" composite that combines the properties of more than one reinforcing material [12].

### 2.1.1 Types of fibers

The most common types of fibers being used in composite are classified in to two main categories [21]. These are:

- Artificial (synthetic) fiber composite materials
- Natural fiber composite materials

#### A. Artificial (synthetic) fiber Composite materials

Composite Material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical and mechanical properties.

The most common artificial (synthetic) fibers are:

##### 1. Glass fiber

Glass is the most common fiber used in polymer matrix composites. Its advantages include its strength, low cost, highly chemical resistant. The main types are E-Glass and S-Glass. The alphabet E-stands for electrical, as it was designed for electrical applications. However, it is being used for many other purposes now, such as decoration and structural applications. The alphabet S – stands for high content of silica, it retains its strength and elevated temperatures and has higher fatigue strength.

Glass fibers, also known commercially as 'fiberglass', are most extensively use reinforcements for polymer matrix composites due to their combination of low cost, high strength, and relatively low density. Unlike carbon or Kevlar fibers glass fibers are isotropic thus avoiding loss of properties when loaded in the transverse direction. Fiberglass is produced by pulling molten glass through orifices at a temperature where the glass has just the right amount of viscosity. Composition of various glass fiber grades [12].

##### 2. Carbon fiber

Carbon fibers are used in advanced structural composites for aerospace and sporting goods industries. They are characterized by very high stiffness and low density. Some carbon fibers have a stiffness that are ten times and densities that are one half that of glass fibers. Although many carbon fibers have high strength, they are generally not as strong as glass fibers or aramid (Kevlar) fibers. The thermal properties of carbon fibers are outstanding.

There are a few other drawbacks to carbon fibers especially in comparison to glass fibers. The primary drawback is their cost. The lowest cost carbon fibers are twice as expensive as S-glass but some grades can be 100 times more expensive than E-glass [12].

### 3. Aramid (Kevlar)

Aramid fibers such as DuPont Kevlar are very important reinforcement for advanced composites. These fibers are based on the amide linkage formed by the reaction between carboxylic acid and the amine group.

The superior toughness of aramid is an outcome of the energy consuming failure mechanism of its fibers. This energy absorbing failure mechanism makes it ideal for use in armor, military, and ballistic applications, like helmets and bullet-proof vests. Among many other very important uses, it is used for firefighting protection, on the underside of airplanes (protection against stone hits during takeoff and landing) and the underside of race cars.

Within the different types of Kevlar's, there is Kevlar<sub>29</sub> (with high toughness), Kevlar<sub>149</sub> (with ultra-high modulus) and Kevlar<sub>49</sub> (with high modulus). In structural composite production, Kevlar<sub>49</sub> is the most dominant form used today. Each of these Kevlar fibers are also available in a range of different short fiber forms and yarn counts [12].

#### B. Natural fiber composite materials

Natural fibers represent an environmentally friendly alternative by several attractive attributes include lower density, lower cost, non-toxicity, ease of processing, renewability, and recyclability [12].

#### 2.1.2 Hybrid composite material (HCM)

HCM represent the newest group of various composites where more than one type of fiber is used to increase cost-performance effectiveness. That is, in a composite system reinforced with carbon fiber, the cost can be minimized by reducing its content while maximizing the performance by optimal placement and orientation of the fiber [12].

Hybrid fabrics are a weaved mixture of two or more different types of fiber yarns. This mixing is generally utilized to take advantage of the good properties and characteristics of each reinforcement type, while at the same time mitigating the effects of their less preferable properties (synergy effect). A similar synergy result could be obtained by two or more layers of the different materials, however on the other hand, hybrid fabrics also prevent or reduce the possibility of delamination. This happens because on hybrid fabrics the different types of yarns are woven into each other, thus making the whole thickness of the laminate skin material more uniform, (avoiding layers of different materials, that have different mechanical properties, with higher concentration of stress and mechanical loads at the point of surface contact of different material layers) [4].

## **2.2 Matrix (resin) materials**

The resin system holds everything together and transfers mechanical loads through the fibers to the rest of the structure. In addition to binding the composite structure together, it protects from impact, abrasion, corrosion, other environmental factors, and rough handling. Resin systems come in a variety of chemical families, each designed and designated to serve industries providing certain advantages like economic, structural performance, resistance to various factors, legislation compliance.

### **Epoxy**

Epoxy resins are polymerizable thermosetting resins and are available in a variety of viscosities from liquid to solid.

There are many different types of epoxy, and the technician should use the maintenance manual to select the correct type for a specific repair. Epoxy resins are used widely in resins for prepreg materials and structural adhesives. The advantages of epoxy resins are high strength and modulus, low levels of volatiles, excellent adhesion, low shrinkage, good chemical resistance, and ease of processing. Their major disadvantages are brittleness and the reduction of properties in the presence of moisture. The processing or curing of epoxy resins is slower than polyester resins. Processing techniques include autoclave molding, filament winding, press molding, vacuum bag molding, resin transfer molding, and pultrusion. Curing temperatures vary from room temperature to approximately 350 °F (180 °C). The most common cure temperatures range between 250° and 350 °F (120–180 °C).

### **Hardener in composite**

Hardener is used mainly to cure the epoxy resin which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the unsaturated polyester and monomer ingredient from liquid to a solid state. When used as a curing agent, catalysts are referred to as catalytic hardeners. Hardeners are mainly used to increase the polymerization process. The curing time mainly depends on the hardener and epoxy mixing ratio. Here the mixing ratio is 100:10. This makes the fabrication process as per our requirements [30].

### 2.3. Previous work related to materials for leaf spring

Assarudeen *et.al* it provides comparative analysis between conventional steel (65Si7), E-Glass/Epoxy composite, E-Glass/Jute/Epoxy and E-Glass/Banana/Epoxy based hybrid composite leaf spring. At various loading conditions, hybrid composite leaf spring is found to have lesser stresses and negligible higher deflection as compared to conventional steel leaf spring. E-glass/Banana/Epoxy hybrid composite has higher elastic strain energy storage capacity than steel, E-glass/Epoxy and E-glass/Jute/Epoxy composite because it has lower young's modulus and lower density as compared to both. Hence hybrid composite leaf spring can absorb more energy which leads to good comfortable riding. Weight can be reduced by 81.5% if steel leaf spring is replaced by E-glass/Banana/Epoxy hybrid composite leaf spring [34].

Raghu *et al.* the work shows variety of composite material that used in the leaf spring such as Graphite/Epoxy, Boron/ Aluminum, Carbon fiber/Epoxy & Kevlar fiber/ Epoxy. But Kevlar fiber/ Epoxy is most efficient than the other composite materials [11].

*Shishay, et al.* as leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single E glass/ Epoxy leaf spring is designed and simulated following the design rules of the composite materials considering static loading only. shown that the resulting design and simulation stresses are much below the strength properties of the material, satisfying the maximum stress failure criterion. The designed composite leaf spring has also achieved its acceptable fatigue life [9].

Ghodake, *et al.*, the material selected was glass fiber reinforced plastic (GFRP) and the polyester resin (NETPOL 1011) is used against conventional steel. A spring with constant width and thickness was fabricated by hand lay-up technique which was very simple and economical. The numerical analysis is carried via finite element analysis using ANSYS software. Stresses, deflection, and strain energy results for both steel and composite leaf spring material were obtained and conclude that the composite spring has maximum strain energy than steel leaf spring and weight of composite spring was nearly reduced up to 85% compared with steel material [10].

J. Jayakanth, *et al.* have worked on the design and analysis of commercial vehicle leaf spring using aisi1008 carbon steel composite material the failure of leaf spring fatigue is to be determined the analysis of life prediction. By using NX Nastran materials various analysis were observed in the selected software with suitable material. In the system of vehicle suspensions Leaf springs are used most in common which are limited to varying cycles stress to millions

thus eventually leads to failure of fatigue. High definition value and high elastic limits are presented in spring material possess maximum strength with fatigue effects and shocks. Weight reduction is the focus in automobile manufactures in direct to preserve natural assets and power of economic in the current scenario [18].

Abdul, *et al.* have worked on developing a composite based elliptic spring for automotive applications. They consider light and heavy trucks with steel elliptic spring for analysis of fatigue behavior and weight reduction by using ANSYS software. The objective is to compare the load carrying capacity, fatigue behavior and weight savings of composite leaf spring with that of steel leaf spring. Also, they have compared the finite element result of fatigue life and weight reduction with existing analytical and experimental result. After that using this result they have replaced steel leaf spring by composite material and analyze it with same loading condition. They concluded that composite elliptical springs have better fatigue behavior than the conventional steel leaf spring and weight reduction ratio is achieved [20].

G. Gnana, *et al.* hybrid mono-composite leaf spring has-been designed using carbon fibers mixed with glass fiber in polymer matrix the current innovation to fulfill the need of enhancing the fatigue behavior along with weight reduction and it is analyzed using the ANSYS software. Thus, the use and advantage of steel over composite material has been proved with the design and it is clearly explained through the analysis report [25].

B. Arun, *et al.*, hybrid composite leaf spring with Jute/E-glass/ Epoxy composite materials is modeled and subjected to the same load as that of a steel spring. Deflection of hybrid composite leaf spring is less as compared to steel leaf spring with the same loading condition. The stress of steel and hybrid composite leaf spring is approximately same. From the results, it is observed that the hybrid composite leaf spring is lighter and more economical than steel leaf spring. The hybrid composite leaf spring has been modeled by their consideration. Static structural analysis of a leaf spring has been performed using ANSYS 14. Compared to steel leaf spring the laminated hybrid composite leaf spring weight reduction is achieved [26].

L. Muhammed, *et al.*, this study suggests various materials of hybrid fiber reinforced plastics (HFRP). Also, the effects of shear moduli of the fibers, matrices, and the composites on the composites performance and responses are discussed. The results and behaviors of each are compared with each other and verified by comparison with analytical solution; a good convergence is found between them. The elastic properties of the hybrid composites are calculated using rules of mixtures and Halpin-Tsi equation through the software of MATLAB v-7. The problem is also analyzed by the technique of finite element analysis (FEA) through

the software of ANSYS v-14. An element modeling was done for every leaf with eight-node 3D brick element (SOLID185 3D 8-Node Structural Solid) [28].

Monisha *et al.*, the process of fabrication was carried out by hand lay-up technique and the ratio of fiber is 5% and 10% by volume. Both the specimen was tested on UTM machine 10% wt glass fiber showed greater capability to carry the load with less weight compared 5% wt glass fiber. Hence, ultimate strength of 10% is 28% more than 5% wt glass fiber. From the results, it is observed that the 10% wt glass fiber composite is more suitable for a composite leaf spring design in making lighter and more economical than the conventional steel spring with similar design specifications and improves the fuel efficiency of the automobile. [33]

Dhiraj, *et al.*, the material for conventional steel leaf spring is 55Si2Mn90. Material selected for mono composite spring is E- glass/Epoxy thus the amount of E-glass-60%, Epoxy resin-40%. A mono leaf E-glass–epoxy has been used to replace a three-leaf steel spring with nearly an 80% weight savings. The experimental results were compared with FEA and the results show good agreement with test results. From the results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel leaf spring with similar design specifications. Composite mono-leaf spring reduces the weight by 85% for E-glass/Epoxy over steel (conventional) leaf spring [35].

R M Patil, *et al.*, a glass/epoxy composite multi-leaf spring is fabricated using hand lay-up vacuum bagging composite fabrication technology. The fabricated composite leaf spring has given 57.23 % weight reduction compared to the existing conventional metallic leaf spring. The stiffness of the composite leaf spring is found to be 18.78 % lower than the metallic leaf spring. However, the fabricated composite leaf spring has shown the potential to support the maximum static load of 150 kg with comparable deflection as that of metallic leaf spring. [36]

L.B. Raut, *et al.*, it works on experimental Analysis of Different Compositions of Carbon Fiber/Epoxy Composite and Its Application in Leaf Spring work the carbon fiber/epoxy composite is fabricated using simple hand layup technique and details of volume fraction of carbon fiber are 35%, 45% and 55% and epoxy volume fractions are 65%,55% and 45%. 45:55% by volume of Carbon fiber epoxy has higher tensile strength as compared to other two volume percentages. The volume percentage of 55:45% of Carbon fiber epoxy has the highest bending strength as compared to other two volume percentages. volume percentage of 55:45% of carbon fiber epoxy has the highest impact strength as compared to other two volume percentage. The weight of the composite leaf spring is reduced by 88.43% as compared to steel leaf spring with same stiffness. It is found that 55:45 volumetric fraction gives optimum results.

A comparative study has been made between composite leaf spring and steel spring with respect to weight, natural frequency, and deflection. A composite leaf spring can be used on smooth road condition as well as rough condition [37].

## 2.4. Conditions

E. Janarthan *et al.* the work done on design and Experimental Analysis of Leaf Spring Using Composite Materials, in this work Hand lay technique was used to manufacture the fiber glass reinforced specimen. For this an E – glass fiber material was used with the diameter of the fiber glass approximately epoxy (Diglyceryl Ether of Bisphenol A) and a hardener (Tri-ethylene Tetra-amine). Three samples of the fiber glass reinforced plastic were prepared that are 40%-60%: -40% epoxy and 60% E-fiber glass 60%-40%: -60% epoxy and 40% E-fiber glass 70%-30%: -70% epoxy and 30% E-fiber glass. E glass 60% and 40% epoxy is the best of tensile and bending stress, deformation, and natural frequency compare the other composition. The natural frequencies of various parametric combinations are compared with the excitation frequency for different road irregularities. The strength to weight ratio is higher for composite leaf spring than conventional steel spring with similar design. The emphasis in this project is on the experimental and computer aided analysis using finite element concept. The component chosen for analysis is a leaf spring which is an automotive component used to absorb vibrations induced during the motion of vehicle [38].

B. Vijaya *et al.* compare the load carrying capacity, stiffness, and weight savings of composite leaf spring with that of steel leaf spring. The design constraints are stresses and deflections. The dimensions of an existing conventional steel leaf spring of a Heavy commercial vehicle are taken Same dimensions of conventional leaf spring are used to fabricate composite multi leaf spring using E-glass/epoxy, C-glass/epoxy, S- glass/epoxy unidirectional laminates. Pro/Engineer software is used for modeling and COSMOS is used for analysis. Static & Dynamic analysis of Leaf spring is performed using COSMOS [17].

N.P. Dhoshi *et al.*, the leaf springs used in tractor trailer without much economical and technical consideration. In the present work improvement areas where one can improve the product quality while keeping the minimum cost. In the present work analytical and Finite element method has been implemented to modify the existing leaf spring with consider the dynamic load effect. One of the important areas where one can improve the product quality while keeping the cost low is the design aspect [15].

Sandip et al. Designing a vibration isolation solution is a dynamic process where concepts continuously evolve through vibration testing process and evaluation. No every vibration

problem can be approached in the same fashion. A single technology alone will solve this project's vibration problem perfectly. Vibration isolation can be passive or semi-active. Passive vibration isolation is implemented by proper structural design to make sure the optimal dynamic properties namely the mass, stiffness can be achieved. Active vibration isolation can be performed by measuring the sources of vibration and generating controllable forces to compensate for the vibration [16].

Mohammed *et al*, the aim of this paper is to design and analyze composite mono leaf spring of constant width and thickness having the same bending stiffness of semi-elliptical laminated leaf spring. Stress analysis was done by using analytical method and results obtained by analytical methods are compared with ANSYS. The results obtained by analytical methods showed good agreement with ANSYS results [17].

V. K. Aher, *et al.*, the purpose of this paper is to predict the fatigue life of semi-elliptical steel leaf spring along with analytical stress and deflection calculations. This present work describes static and fatigue analysis of a modified steel leaf spring of a light commercial vehicle (LCV). The dimensions of a modified leaf spring of an LCV are taken and are verified by design calculations. The non-linear static analysis of two dimensional model of the leaf spring is performed using NASTRAN solver and compared with analytical results. The preprocessing of the modified model is done by using HYPERMESH software. [19]

Naveen *et al* the work deals with finding a suitable composite material that can be a replacement for conventional steel leaf spring. The composites chosen are E-Glass/ Epoxy and Carbon/ Epoxy and are analyzed for minimizing weight of the composite leaf spring compared to that of conventional steel leaf spring. The leaf spring is modeled in NX CAE and analyzed using NX NASTRAN software [27].

P. JAGAN *et al* the work is on Ply Wise Failure Analysis of Mono Leaf Spring Using Hybrid C-GFRP Composites” And work characterized mechanical properties of the E-glass/epoxy material are evaluated by conducting tensile test and three-point bending test. Mono leaf spring like the dimensions of Maruthi 800 vehicle is made using hand layup method. Leaf spring of Maruthi 800 model was prepared for testing for Load vs deformation. The leaf spring was obtained and a mold is prepared for the layup of glass fibers. Here, Eye part of the leaf spring is neglected. Glass fiber weave are cut into the desired dimension prior to the start of the process. The load vs deformation results of leaf spring show a good agreement between the experimental and the simulation values. The failure theories which are considered in this study

is: Maximum stress failure theory, Maximum Strain failure theory, Tsai-Hill failure theory and Tsai-Wu failure theory. The reserve factor RF indicates margin to failure [39].

### 2.5. Stacking sequence of composite materials

According to [43] four laminate design guidelines are considered as a basis for the design of the stacking sequences of most composite structures in aerospace industry.

A laminate is an assemblage of individual lamina or plies bonded together normal to their principal plane (i.e., plies are stacked and bonded in their thickness direction).

- *Symmetric Laminate* – In a symmetric laminate all plies above the midplane have the same angle as the ply in the equivalent position below the midplane (i.e., the midplane of the laminate is a plane of symmetry).
- *Antisymmetric Laminate* - All plies above the midplane have the opposite (negative) angle as the ply in the equivalent position below the midplane. (The midplane is a plane of antisymmetric)
- *Asymmetric Laminate* - The midplane is not a plane of symmetry or antisymmetric.
- *Quasi-isotropic Laminate* - Three or more plies in which the orientation of constituent are increments of  $p/n$  where  $n$  is the total number of plies.

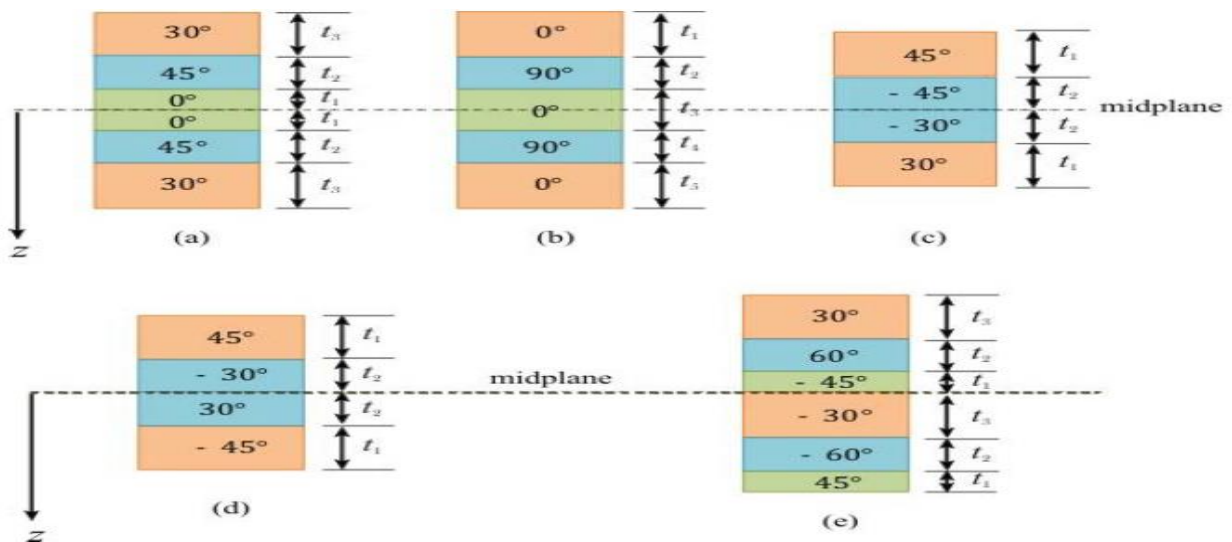


Figure 2-1:: Classification of laminates (a) Symmetric laminate (b) Cross ply laminate laminates (c) Angle-ply laminate (d) Anti-symmetric laminate and (e) Balanced laminate [41]

Mohammad *et al* the work is on Stacking Sequence Optimization of Composite Panels Subjected to Slamming Impact Loads using a Genetic Algorithm, in this study Optimization of stacking sequence for composite panels under slamming impact loads using a genetic algorithm method is studied. After validation, different cases of stacking sequence optimization are

investigated for a variety of composite panels. The investigations include symmetric as well as asymmetric conditions of stacking sequence.

In optimization of symmetric four-ply composite panels under slamming loads, stacking sequence is assumed in the form of  $[\alpha/\beta/\beta/\alpha]$ . Optimization subject is studied for three different dimensions of the panel;  $1 \times 0.5 \text{ m}$ ,  $1 \times 1 \text{ m}$  and  $1 \times 1.5 \text{ m}$ . Another remarkable matter is that for the composite panel of aspect ratio equal to 1, optimum stacking sequences are  $[45 / -45 / -45 / 45]$  and  $[-45 / 45 / 45 / -45]$ . In the other section, optimization process is performed on the same panels investigated in symmetric but having asymmetric stacking sequences where the angles of plies are  $[\alpha, \beta, \gamma, \lambda]$ . Out of the results obtained for various cases, it can be simply said that when the stacking sequence of the composite panel is asymmetric, then optimum lay-up follows the form of  $(\alpha/-\alpha, -\beta/\beta, \gamma/-\gamma)$  [41].

Adams *et al*, genetic Algorithm optimization and blending of composite laminates by locally reducing laminate thickness is studied and improves the ply continuity between adjacent panels with given local loading constraints. The guide-based approach defined a single laminate (called the guide laminate) used as a template for the stacking sequence of all the panels. Stacking sequences of all the laminates were obtained by taking a certain number of plies from the top or the bottom of this guide laminate to guarantee a fully blended solution at all stages of optimization. If the layers extracted from the top of the guide laminate were placed at the outmost stack of each panel, this was called outer blending. If the layers extracted from the bottom of the guide laminate were placed on the inside of the mid plane for each panel, this was called inner blending. In the optimization process, the design variables defined the stacking sequence of the guide laminate and the number of layers to be kept from the guide laminate to represent the configuration of layups [43].

Rahul Patwa, *et al* the work is work on analysis of cross-ply Laminate composite under UD load based on CLPT by Ansys APDL. The effect of variation of laminate layers is also studied along with the effect of variation of stacking patterns. The current study will also help to conclude which stacking pattern is best in 2 layered and 4 layered cross ply laminates. The sample is in form of square plate with  $1 \times 1$  sq meter area. The thickness of each lamina in the stacking is supposed to be 10 mm. In the current study the stacking arrangements for two layered, four layered and six layered cross ply laminates are given in stacking arrangement are  $0/90, 90/0, 90/0/0/90, 0/90/0/90, 0/90/90/0$ . From the above configuration the stacking pattern  $\{0/90\}$  is the best configuration as it can sustain maximum stress with minimum deflection and thus such stacking pattern can serve better than other for same loading conditions. [44]

## 2.6. Failure of composite materials

The failure of composites has been investigated extensively from the micromechanical and macro mechanical points of view. On the micromechanical scale, failure mechanisms and processes vary widely with type of loading and are intimately related to the properties of the constituent phases, i.e., matrix, reinforcement, and interface-interphase. Failure predictions based on micromechanics, even when they are accurate regarding failure initiation at critical points, are only approximate regarding global failure of a lamina and failure progression to ultimate failure of a multi-directional laminate. For these reasons a macro mechanical approach to failure analysis is preferred. Numerous failure theories have been proposed and are available to the composite structural designer. [45]

They are classified into three groups, limit or noninteractive theories (maximum stress, maximum strain); interactive theories (Tsai-Hill, Tsai-Wu); and *partially interactive or failure mode-based theories* (Hashin-Rotem, Puck). The validity and applicability of a given theory depend on the convenience of application and agreement with experimental results. The plethora of theories is accompanied by a dearth of suitable and reliable experimental data, which makes the selection of one theory over another rather difficult. Considerable effort has been devoted recently to alleviate this difficulty. The problem can be divided in two parts, one being the prediction of failure of a single lamina and the second dealing with prediction of first-ply-failure and damage progression leading to ultimate failure of a multi-directional laminate [46].

C. T. Sun is reviewed six failure theories and showed comparisons of theoretical predictions with experimental results. Existing lamina and laminate strength data are used to evaluate these failure criteria. For some laminates under certain loading conditions, all six criteria may predict similar results, and their performance cannot be ranked. Therefore, several laminates are identified for which the strength predictions according to these six criteria are substantially different. The validity and applicability of a given theory depend on the convenience of application and agreement with experimental results [47].

In an AIAA Failure Criteria Survey, 80% of the respondents said they utilized one of these four lamina failure criteria. Maximum Strain is most commonly used at 30% with Maximum Stress next at 22%. Hill-Tsai and Tsai-Wu usage came in at 17% and 12% respectively [48].

## 2.7 Composite leaf spring manufacturing

Fabrications of composites are carried out by certain methods, which are described in the following. All these methods are personalized for the definite materials that are being processed. For the selection of the appropriate resin, polymer chemistry plays an important role in it.

*R M Patil, et al* fabrication and Testing of Composite Leaf Spring for Light Passenger Vehicle is work using hand lay-up vacuum bagging method of composite fabrication, the fibers are laid on the mold by hand and matrix material is applied by brushing or spraying. Staking of the layers is done to get the required thickness. Simultaneously the deposited layers are densified with rollers. Then by vacuum bagging method the atmospheric pressure is used to hold the matrix or resin - coated components of a lamination in place until the adhesive cures [49].

*Vinay et al* “ in this work, the hand lay-up process was employed. The glass fibers and silk were cut to the desired lengths, so that they can be deposited on the template layer by layer during fabrication. In the conventional hand lay-up technique, a releasing agent (PVA) was applied uniformly to the mold which had good surface finish. This is followed by the uniform application of epoxy resin over glass fiber. Another layer is layered and epoxy resin is applied and a roller is using for removing all the trapped air. [50]

*M. K. Gupta et al* in this review work, method of composite fabrications are Hand lay-up, compression molding, injection molding and pultrusion [21].

**Hand lay-up:** this is the simplest method of processing the thermosets-based fibers (synthetic as well as natural) composite. In hand lay-up technique, first, a releasing agent is sprayed on the surface of mold to avoid the sticking of polymer to the surface. To get good surface finish of product, thin plastic sheets are used at top and bottom of mold. Fibers as a reinforcement either in form of woven mat or in chopped form are placed at the upper surface of mold. Then mixture of thermosetting resin and suitable hardener is poured on the surface of mat already placed in the mold. The polymer is uniformly spread with the help of brush. Second, layer of reinforcement is then placed on the polymer surface, and a roller is used to remove air as well as excess matrix present. The process is repeated for each layer of reinforcement and matrix till the required thickness is achieved. After placing the plastic sheet, release agent is sprayed on the inner surface of the top mold which is then kept on the achieved thickness and the pressure is applied.

**Compression molding:** this is a closed molding process with high pressure application. In this method, two matched metal molds are used to fabricate composite product. The base plate is

stationary while upper plate is movable in compression molder. Reinforcement and matrix are placed in the metallic mold and the whole assembly is kept in between the compression mold. The required amount of heat and pressure depends upon shape and size of composites. The reinforcement and matrix are placed between the molder plates, which flows due to application of pressure and heat. The curing of composites takes place at room temperature. After curing of composite, mold is opened and composite product is taken out for further processing. This method is suitable for thermosets as well as thermoplastics-based fibers (synthetic as well as natural) composites.

**Injection molding:** this process is used for the formation of plastic parts with excellent dimensional accuracy. The products such as house wares, toys, automotive parts, furniture, packaging items, appliances, and medical disposal syringes are produced by injection molding process. Injection molding is a process of forming product by forcing molten plastic material under pressure into a mold where it is cooled, solidify, and subsequently released by opening the two halves of mold. This process is suitable for thermosets as well as thermoplastics-based fibers (synthetic as well as natural) reinforced composite.

**Pultrusion:** this is a continuous process for the manufacture of products having a constant cross-section, for example, rod stock, structural shapes, beams, channels, pipe, tubing, fishing rods, and golf club shafts. In this process, continuous roving of reinforcement is impregnated with resin by passing through resin bath and then pulled through a steel die. The steel die strengthens the saturated reinforcement, put the shape of the stock, and controls the fiber/resin ratio.

T Gopalakrishnan, *et al* composite leaf spring is fabricated by vacuum bag molding. First the wooden mold is prepared and the E glass, carbon, Graphite fibers are placed on mold layer by layer in different sequence. The main advantage of vacuum bag molding is the void formation within the composite can be avoided [51].

## 2.8. Summary of literature review

According to the literatures, weight reduction and replacement of conventional leaf spring with composite are very common issues aiming to increase the fuel efficiency and reduce the air pollution. The composite materials also provide high riding quality. Also, the composite materials have much lower stresses and deflection and higher fatigue life. Therefore, the reduction of the weight, the reduction of stress, and the improvement of working life can be achieved using different composite materials in place of steel.

The fiber to resin volume ratio has its own effect on the material of leaf spring. Most literatures proposed that better material property can be found when the fiber volume ratio is from 50% up to 60%, and mostly used manufacturing technique of composite leaf spring is hand lay-up technique. The ply arrangement has its own factor in composite materials. Most ply arrangements are carried out by symmetric arrangement.

Among the different failure criterions, which were stated in the literature, mostly used failure criteria to determine the resistance of composite materials is the maximum strain failure criteria. The leaf spring is designed by considering as it is behaving like a cantilever beam. For the analysis purpose, many researchers were used different software, but ANSYS software is mostly used software.

## Chapter Three

### 3. Analytical, Experimental methods and conditions

Materials constitute nearly 60%-70% of the vehicle cost and contribute to the quality and performance of the vehicle and riding comfort of the passenger. Even a small amount in weight reduction of the vehicle, may have a wider economic impact in fuel consumptions.

Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. Hence, the composite material has been selected for leaf spring design.

#### 3.1 Leaf spring materials

The material of the spring should have high fatigue strength, high ductility, high resilience, and it should be creep resistant. It largely depends upon the service for which they are used i.e. severe service, average service, or light service. The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon and composite (fiber + matrix).

##### 3.1.1 Fiber selection for hybrid composite leaf spring

*Table 3:1: reports the property of the fibers, which are going to be used composite leaf spring synthesis [12]*

Types of fibers	Diameter $\mu\text{m}$	Density $(\text{g}/\text{cm}^3)$	Longitudinal Tensile modules E1 (Gpa)	Transverse Tensile modules (Gpa)	Poison ratio n12	Shear modules G12	Longitudinal Tensile Strengths (Mpa )
<b>E- Glass</b>	<b>10</b>	<b>2.45</b>	<b>81</b>	<b>81</b>	<b>0.22</b>	<b>30</b>	<b>3450</b>
<b>Kevlar 49</b>	<b>11.9</b>	<b>1.47</b>	<b>131</b>	<b>131</b>	<b>0.35</b>	<b>2.9</b>	<b>4100</b>

Thus, E-glass fiber and Kevlar 49 was found appropriate for this study application.

Hybrid composite materials reinforced with epoxy matrix are a new type of laminated composites, which are becoming increasingly popular for various structural applications in the automotive, aerospace, and other industrial sectors. In this research, the composite leaf spring has been carried out on two fibers materials that are E glass and Kevlar 49. The matrix material was medium viscosity epoxy resin, which is cost effective because they require minimal setup costs and the physical properties can be tailored to specific applications. The E glass and Kevlar 49 bi-directional fiber mesh were the reinforcements.

### 3.1.2. Resin (Matrix) selection

Table 3:2: Properties of Epoxy matrix [12]

No.	Property	Value	Unit
1	Density	1.2	g/cm <sup>3</sup>
2	Elastic modulus	3.3	Gpa
3	Tensile strength	0.06	Gpa
4	Shear modulus	1.25	Gpa
5	Poisson's ratio	0.33	-
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	°c

### 3.1.3. Hardener selection

Six hardeners are compared in this study and their properties are given in the table. For the hardeners trimethyl hexamethylene di amine, cyan ethylated mixture of isomers (trimethyl hexane -1,6-diamine) (CTMDA) and isophorone diamine (IPDA), the long pot-life times necessitated the use of benzyl alcohol (density 1.04 g/ml and viscosity @25<sup>0c</sup> 8 cp.) as an accelerator. The Properties of selected hardeners and stoichiometric quantities for 100 g is listed in *table 3.3.* [30]

Table 3:3: Properties of selected hardeners and stoichiometric quantities for 100 g of DGEBA. [30]

Hardener	Type	Viscosity (cp)	Density	Mole	Quantity (g)
Trimethyl hexamethylene diamine	Aliphatic	6	0.97	158.3	40

### 3.1.4 Rule of mixture for hybrid composite

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

When thermoset resins and hardeners are mixed up it is important that the correct amount of hardener is used for a certain weight of resin. Most thermoset systems have one fixed mixing

ratio that must not be varied if the optimum cured properties are to be obtained. For some special resin/hardener systems the weight ratio can be varied to produce cured material with differences in properties, usually in flexibility or hardness [31].

According to [31] in most fiber reinforced composite, the fiber is strong, stiff, and light weight. If the composite is to be used at elevated temperatures, the fiber should have high melting temperature. Thus, specific strength and specific modulus of the fibers are important characteristic.

To calculate properties by the rule-of-mixtures, the volume fraction or weight fraction of each constituent must first be determined.

$$V_f = \frac{v_f}{v_c} \dots\dots\dots 3.1$$

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

Where  $v_f$  is the volume of the fiber and  $v_c$  is the volume of the composite.

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

$$V_m = \frac{v_m}{v_c} \dots\dots\dots 3.2$$

The sum of the volume fractions of all constituents in a composite must be equal to 1. In a two-component system consisting of one fiber and one matrix, then, the total volume of the

Composite is  $v_c = v_f + v_m$

$W_f$  and  $W_m$  are the weight fractions of the fiber and matrix, respectively, can be defined as using eqn. 3.3 and eqn. 3.4

$$W_f = \frac{\rho_f \times V_f}{\rho_c} \dots\dots\dots 3.3$$

$$W_m = \frac{\rho_m \times V_m}{\rho_c} \dots\dots\dots 3.4$$

1. Composite Density

Applying the definitions of volume fraction of density of the composite ( $\rho_c$ ) can be expressed in terms of the fiber density,  $\rho_f$ , and the matrix density,  $\rho_m$ , given as using eqn. 3.5.

$$\rho_c = \rho_f \times V_f + \rho_m \times V_m \dots\dots\dots 3.5$$

Hence the density of the composite can be predicted using rule-of-mixtures based on volume fraction.

2. Longitudinal young's modulus of the composite ( $E_1$ ) defined as using *eqn. 3.6*.

$$E_c = E_f \times V_f + E_m \times V_m \dots\dots\dots 3.6$$

3. Transvers young's modules of the composite ( $E_2$ ) defined as using *eqn. 3.7*.

$$\frac{1}{E_{2c}} = \frac{V_f}{E_f} + \frac{V_m}{E_m} \dots\dots\dots 3.7$$

4. Major Poisson's ratio of composite ( $v_{12}$ ) defined as using *eqn. 3.8*.

$$v_{12} = v_f \times V_f + v_m \times V_m \dots\dots\dots 3.8$$

5. Minor Poisson's ratio of composite ( $v_{21}$ ) defined as using *eqn. 3.9*.

$$v_{21} = v_{12} \times \left( \frac{E_2}{E_1} \right) \dots\dots\dots 3.9$$

6. Longitudinal shear modulus of composite ( $G_{12}$ ) defined as using *eqn. 3.10*

$$G_{12} = G_f \times V_f + G_m \times V_m \dots\dots\dots 3.10$$

7. Transverse shear modulus of composite( $G_{21}$ ) defined as using *eqn. 3.11*.

$$\frac{1}{G_{21}} = \frac{V_f}{E_m} + \frac{V_m}{E_m} \dots\dots\dots 3.11$$

By using Hooks law of materials, the young's modulus of fibers ( $E_f$ ) and young's modulus of matrix ( $E_m$ ) can be expressed in terms of stress and strain using *eqn. 3.12*.

$$\sigma = E \times \varepsilon \dots\dots\dots 3.12$$

where:  $\sigma$  = stress

$\varepsilon$  = strain

By rearranging *eqn. 3.12*, strain can be calculated using *eqn. 3.13*.

$$\varepsilon_f = \frac{\sigma_f}{E_f} \dots\dots\dots 3.13$$

8. Strain of composite materials is defined as using *eqn. 3.6*.

$$\epsilon_c = \frac{\sigma_c}{E_c} \dots\dots\dots 6.14$$

where:  $\sigma_c$  = tensile strength of composite

$E_c$  = modulus of elasticity of composite

$\epsilon_c$  = strain of composite

$$\epsilon_c = \epsilon_f \times V_f + \epsilon_m \times V_m \dots\dots\dots 3.15$$

The load,  $P_c$ , applied parallel to the fibers they are strained the same amount as the matrix, hence the composite is also deformed the same amount. The load, however is partitioned between the fiber and the matrix and is given by using *eqn. 3.16*

$$P_c = P_f + P_m \dots\dots\dots 3.16$$

9. Tensile strength of composite in a longitudinal direction defined as using *eqn. 3.17*.

$$\sigma_{1L} = \sigma_f \times V_f + \sigma_m \times V_m \dots\dots\dots 3.17$$

10. Tensile strength of composite in transverse direction defined as using *eqn. 3.18*.

$$\frac{1}{\sigma_{2T}} = \frac{V_f}{\sigma_f} + \frac{V_m}{\sigma_m} \dots\dots\dots 3.18$$

11. Compressive strength of composite in longitudinal direction defined as using *eqn. 3.19*.

$$\sigma_{cL} = \sigma_{cf} \times V_f + \sigma_m \times V_m \dots\dots\dots 3.19$$

12. Compressive strength of composite in transverse direction defined as using *eqn. 3.20*.

$$\frac{1}{\sigma_{cT}} = \frac{V_f}{\sigma_f} + \frac{V_m}{\sigma_m} \dots\dots\dots 3.20$$

### 3.2 Sample Preparation Methods

The volume of the composite material was calculated by multiplying the length, width and thickness of the mold prepared for molding the composite material. The density of the composite was calculated by a method which enable the rule of law of mixture to be applied and was obtained first by adding the volume fraction of the epoxy resin and the hybrid E-glass and Kevlar 49 fiber for each fiber/matrix ratio. The mass of the fiber obtained after getting the density of the fiber multiplied by the volume of the fiber *eqn. 3.22*. Then the mass of the matrix

obtained from the density of the matrix multiplied by the volume of matrix ratio. Then in turn, the mass of each hybrid E-glass and Kevlar<sub>49</sub> fiber and epoxy resin obtained according to [31].

**3.2.1 Determination of fiber and resin mass fractions of the composite**

In the fiber reinforced material, the fibers are distributed throughout the matrix in a pattern we could describe as somewhat repeating or periodic.

The density of the E glass, Kevlar and epoxy resin were taken as 2.6 g/cm<sup>3</sup>, 1.45 g/cm<sup>3</sup> and 1.2g/cm<sup>3</sup> respectively with hardener density of 0.97g/cm<sup>3</sup>

Assumptions

- Fibers are uniformly distributed throughout the matrix.
- Perfect bonding between fibers and matrix.
- Matrix is free of voids.
- Applied loads are either parallel or normal to the fiber direction.
- Lamina is initially in a stress-free state (no residual stresses).
- Fiber and matrix behave as linearly elastic materials.

Table 3:4: Properties of selected materials [12,30]

No	Constituent	Density, g/cm <sup>3</sup>	Young’s modulus, GPa	Tensile Strength, GPa	Epoxy (%)	Fiber (%)
1	E-glass	2.45	89	4.59	45	55
2	Kevlar 49	1.47	131	4.1		
3	Epoxy	1.2	3.5	0.06		
4	Hardener	0.97				

According to [40] the weight fraction of the fiber and the matrix content of the composite were calculated as using eqn. 3.22.

Volume of the die =  $l \times w \times t$  .....3.21

- where =  $l$  = length of the the die
- $w$  = width of the die
- $t$  = thickness of the die

Mass= *Density* × *volume*

$M = \rho \times v$

Total mass = mass of fiber + mass of matrix

$$\begin{aligned} \text{Volume of die} &= l \times w \times t \\ &= 22.9 \times 22.9 \times 0.4 \\ &= 209.764 \text{cm}^3 \end{aligned}$$

Now calculate the mass of fiber and matrix in constitute in the composite

$$\frac{m_{\text{fiber}}}{m_{\text{matrix}}} = \frac{\rho_{\text{fiber}} \times V_{\text{fiber}}}{\rho_{\text{matrix}} \times V_{\text{matrix}}} \dots\dots\dots 3.22$$

$$\rho_{\text{fiber}} = \frac{\rho_{\text{E-glass}} + \rho_{\text{kevlar}}}{2} \dots\dots\dots 3.23$$

$$\rho_{\text{fiber}} = \frac{2.45 + 1.47}{2}$$

$$\rho_{\text{fiber}} = 1.96 \frac{\text{g}}{\text{cm}^3}$$

$$\Rightarrow \frac{55\%}{45\%} = \frac{1.96 \times v_{\text{fiber}}}{1.2 \times v_{\text{matrix}}}$$

$$1.22 = \frac{1.96 \times V_{\text{fiber}}}{1.2 \times V_{\text{matrix}}}$$

$$1.46 V_{\text{matrix}} = 1.96 V_{\text{fiber}}$$

$$V_m = 1.342 V_f$$

But, Volume of fiber + Volime of matrix = 209.764cm<sup>3</sup>

$$V_f + V_m = 209.764 \text{cm}^3$$

$$V_f + 1.342 V_f = 209.764 \text{cm}^3$$

$$V_f = 89.56 \text{cm}^3$$

Similarlly volume of matrix  $V_m = 1.342 V_f$   
 $V_m = 120.2 \text{cm}^3$

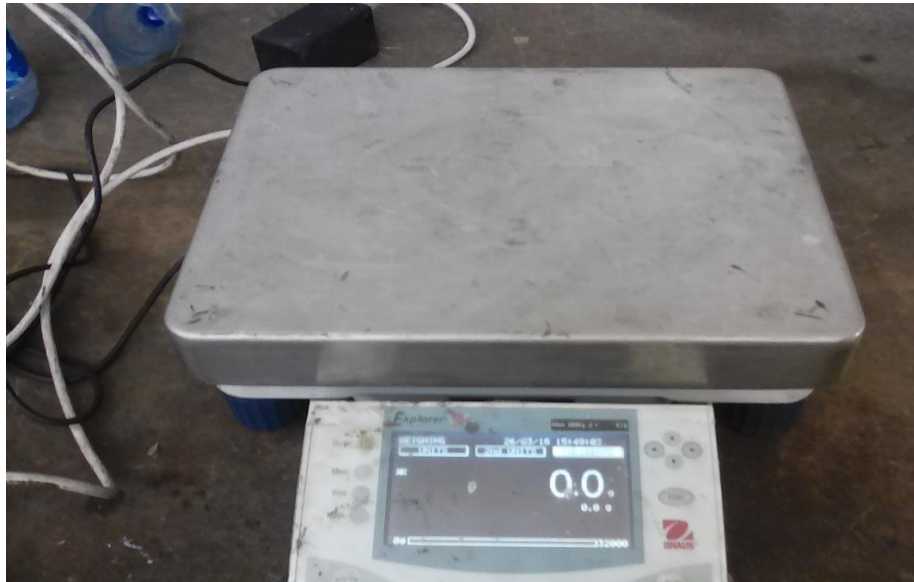
Now mass of fiber

$$\begin{aligned} &\rho_f \times V_f \\ &= 1.96 \frac{\text{g}}{\text{cm}^3} \times 89.56 \text{cm}^3 \\ &= 175.53 \text{g} \end{aligned}$$

Similarlly mass of matrix =  $\rho_m \times V_m$

$$1.2 \frac{g}{cm^3} \times 120.2 cm^3 = 144.24 g$$

- ✓ Digital weight measuring device are high precision instruments design to measure weight, force and mass when connected to a load cell.



*Figure 3-1: Digital weight measurement device*

### **3.2.2 Preparation of epoxy and hardener**

General purpose epoxy, mixed with hardener of Triethylene tetra amine is used to prepare the composite plate. The weight ratio for mixing epoxy and hardener is 100:4. Hardeners include anhydrides (acids), amines, polyamides, dicyandiamide etc. The mixer is strewed with stirrer for about 40 seconds continuously. The mixing is performed in the mixing containers (Bowl) the bowl is made up of transparent glass to prevent melting of the Bowl during the exothermic reaction with the tongue depressor the mix is done slowly to not entrain any excess air bubbles in the resin. Finally, after full mixing of the resin and hardener, it changes to green color.

### **3.2.3 Hand lay-up technique**

Hand lay-up technique is the simplest method of composite processing. The infrastructural requirement for this method is also minimal. The processing steps are quite simple. In hand lay-up technique, first, a releasing agent is sprayed on the surface of mold to avoid the sticking of polymer to the surface. To get good surface finish of product, thin plastic sheets are used at top and bottom of mold.

### 3.2.3.1 Materials Requirements of Hand-lay-up method

- Mold
- Brush (roller)
- Mold release(wax)

#### A. Mold

The pattern, as shown using *figure 3.3*, is made up of mild steel of 229 mm X 229 mm X 15 mm the pattern consists of three parts.

- Base Plate
- Frame
- Upper plate

The Base plate and upper plate are very thin and have smooth surface which is placed inside the frame. The upper and Base Plate surfaces of the mound and the walls are coated with wax and allowed to dry. The functions of upper plate and Base plates are to cover, compress the fiber after the epoxy is applied, and also to avoid the debris from entering into the composite parts during the curing time.



*Figure 3-2: Sample preparation mold*

#### B. Mold Release (Wax)

Mold release is essential for preventing the epoxy from sticking to the mold when the composites are apart. Even though, there are several types of mold release used depending on the mold material and desired characteristics of the finished part, the most common type and used for this work is paste wax, for better surface finish of the composite as shown *figure 3.4*.



*Figure 3-3: Mold release(wax)*

### **3.2.3.2 Hand lay-up procedure**

First, a release gel is sprayed on the mold surface to avoid the sticking of polymer to the surface. Thin plastic sheets are used at the top and bottom of the mold plate to get good surface finish of the product. Reinforcement in the form of woven mats are cut as per the mold size. Then thermosetting polymer (general purpose epoxy) in liquid form is mixed thoroughly in suitable proportion with a prescribed hardener (curing agent) and poured onto the surface of woven already placed in the mold. The polymer is uniformly spread with the help of brush. Second layer of woven is then placed on the polymer surface and a roller is moved with a mild pressure on the woven fiber -polymer layer to remove any air trapped as well as the excess polymer present. The fibers are sprayed into a flat mat preform and then a 50-ton press is used to stamp the shapes of the steel rule dies out of the mat.

The process is repeated for each layer of polymer and mat, until the required layers are formed. After placing the plastic sheet, release gel is sprayed on the inner surface of the top mold plate which is then kept on the stacked layers and the pressure is applied. After curing at room temperature, mold is opened and the developed composite part is taken out and further processed.

The KGRP hybrid bi-directional symmetric and quasi-isotropic hybrid composite laminates of 4 mm thickness have been prepared, specimen was fabricated at room temperature and under constant pressure in the shape of a square plate by hand lay-up technique. The KGRP hybrid system manufactured consisted of eight KGRP plies in the middle between KRP plies at top

and bottom symmetrically. The outer KRP plies are intended for a relatively high tensile strength and stiffness but low fracture strain while inner GRP plies are for a relatively low cost and thermal conductivity but for high impact strength.

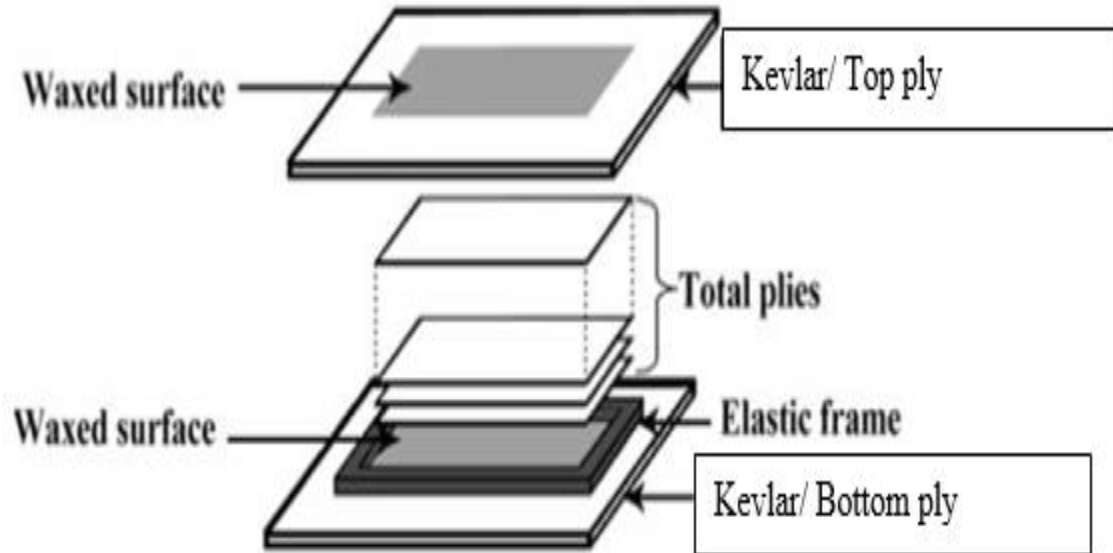


Figure 3-4: Composite preparation procedure arrangement



Figure 3-5: Hand layup manufacturing

The sample were prepared for varied volume fractions of the constituents; matrix material 45% was constant for all samples, the E glass fiber percentage and the corresponding volume of Kevlar 49 fiber was estimated. The different bi-directional fiber orientations of 0/90<sup>0</sup>, were considered for the preparation of specimen in this study.

Table 3:5: Composite laminate designation

Material	Arrangement of ply	Center ply	Thickness	% Kevlar
A	K: E-G: E-G: E-G: K: E-G: E-G: E-G: K	Kevlar	4mm	33.33
B	E-G: K: K: K: E-G: K: K: K: E-G	E-Glass	4mm	66.66
C	K: E-G: K: E-G: K: E-G: K: E-G: K	Kevlar	4mm	55.55
D	E-G: K: E-G: K: E-G: K: E-G: K: E-G	E-Glass	4mm	44.44

### 3.2.3.3 Compression and Curing

50 tone (5MPa) pressure press machine was maintained and it requires 7 hours for curing at room temperature. After curing period, the hybrid E-glass and Kevlar 49 fiber epoxy matrix were removed from the mold. A typical hydraulic press used for curing hybrid composite is shown in *figure 3.7*. The prepared composite boards were post cured at standard laboratory atmosphere prior to preparing specimens and performing mechanical tests.



*Figure 3-6: Fifty tone press machine*

#### **3.2.3.4 Fabricated Hybrid Composite Sample**

Typical hybrid E-glass and Kevlar hybrid reinforced epoxy composite sample is shown in *figure 3.8*. The sample is based on stacking sequence of composite manufacturing.



A



B



C



D

Figure 3-7: Stacking sequences of composite plate

### 3.3 Experimental Procedure and tests Setup

#### 3.3.1 Specimen sampling procedure

The test used in this research work required a total of about 60 specimens for both tensile, compression and bending test. Band saw blade as shown in *fig 3.9* was used to cut each laminate into smaller pieces for various experiments according to ASTM standards.



*Figure 3-8: Band saw cutting specimens*

### **3.3.2 Test setup**

After the hybrid E-glass and Kevlar fiber reinforced epoxy composite Specimen cut in to the desired dimension based on the respective ASTM standards for each stacking sequence were tested using the three different strength testing procedures: The flexural test, compression test and tensile test for each specimen.

#### **Universal Testing Machine (UTM) Testing System**

Microcomputer controlled universal testing machine testing Systems are highly integrated testing packages that can be configured to meet different testing needs. Each includes a load unit with integrally mounted actuator and servo valves, a hydraulic power unit, and the control system, as illustrated in *figure 3.10*. The control system has three major parts: the system software running on

a personal computer, the digital controller, and a remote station control panel. These functions work together to provide fully automated test control.

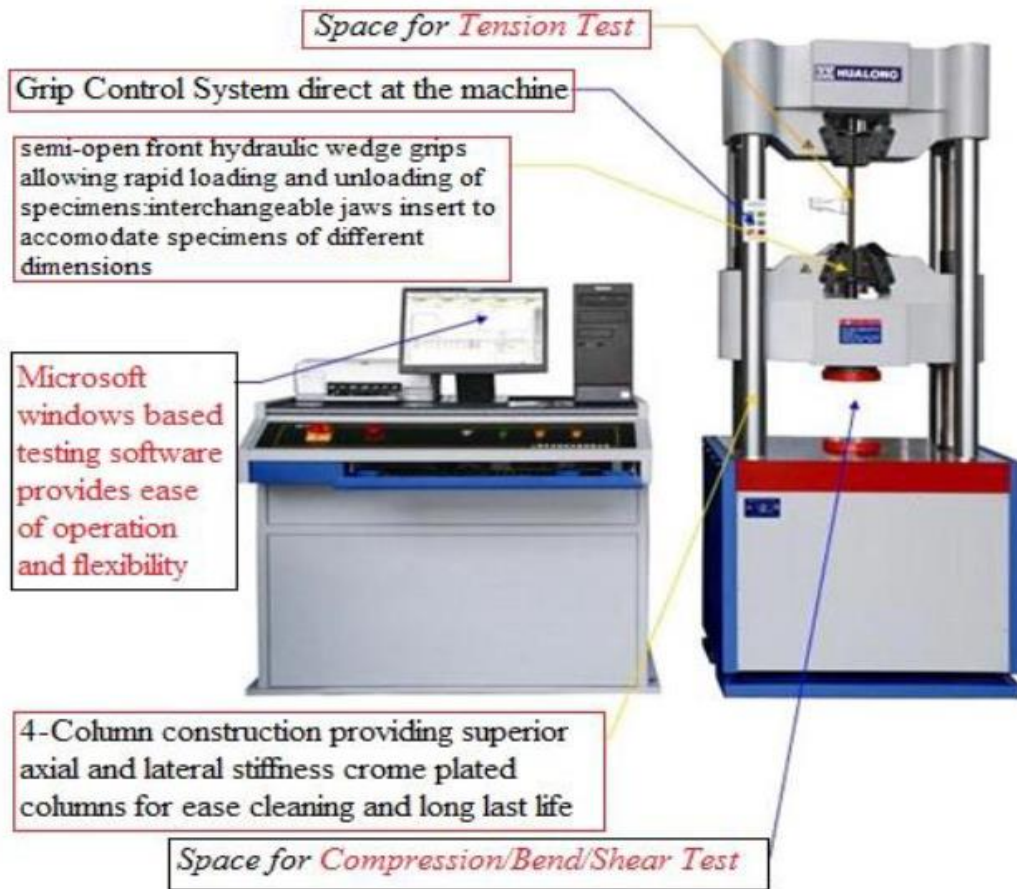


Figure 3-9: Description of Universal testing machine (UTM)

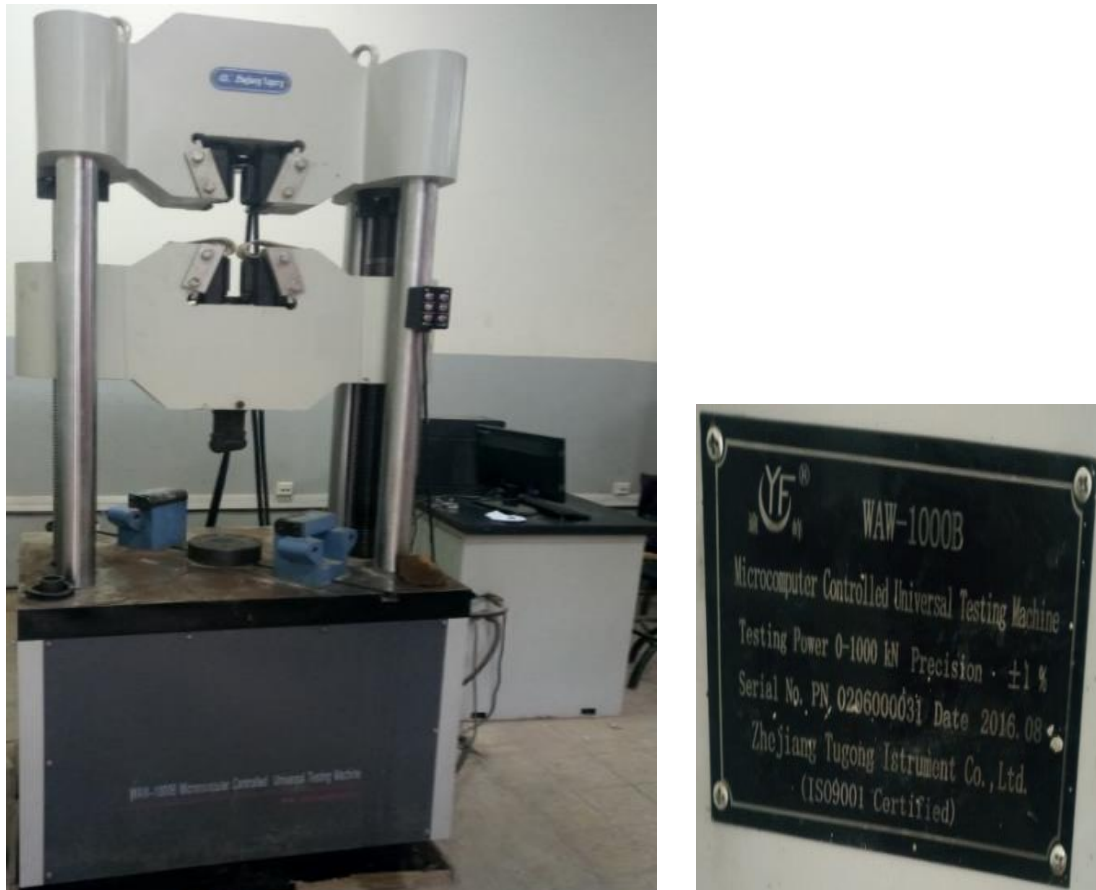
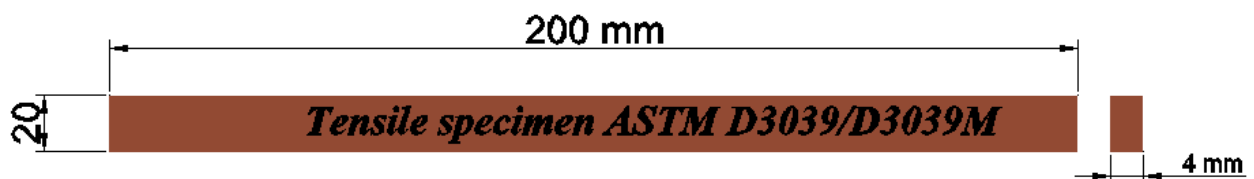


Figure 3-10: Universal testing machine (UTM)

### 3.3.2.1 Tensile Strength test

The tensile test is conducted on the prepared composite specimens to determine its elastic properties. Straight sided specimen is used specimen geometries. This test was conducted as per ASTM D3039/D3039M. Test standards were checked using computer controlled Universal Testing Machine (UTM). [51]

Five specimens from each composition of composite were tested in totally there were 20 specimens were tested. The dimensions of the test specimens were 200 mm in length, 20 mm in width, and, 4mm in thickness respectively. The five sample specimens were tested at a cross-head speed of 2mm / min. Tests are closely monitored and conducted at room temperature.



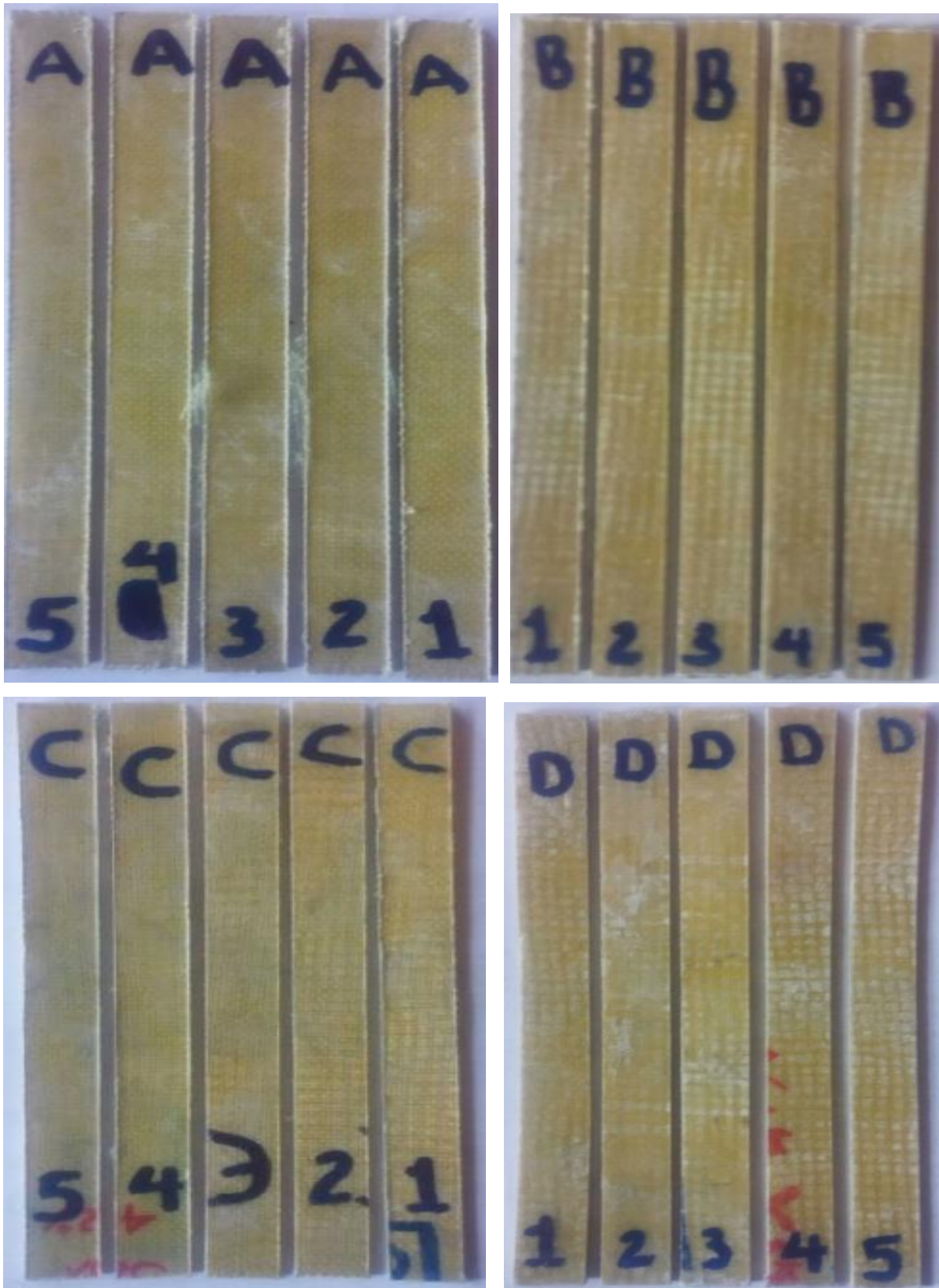
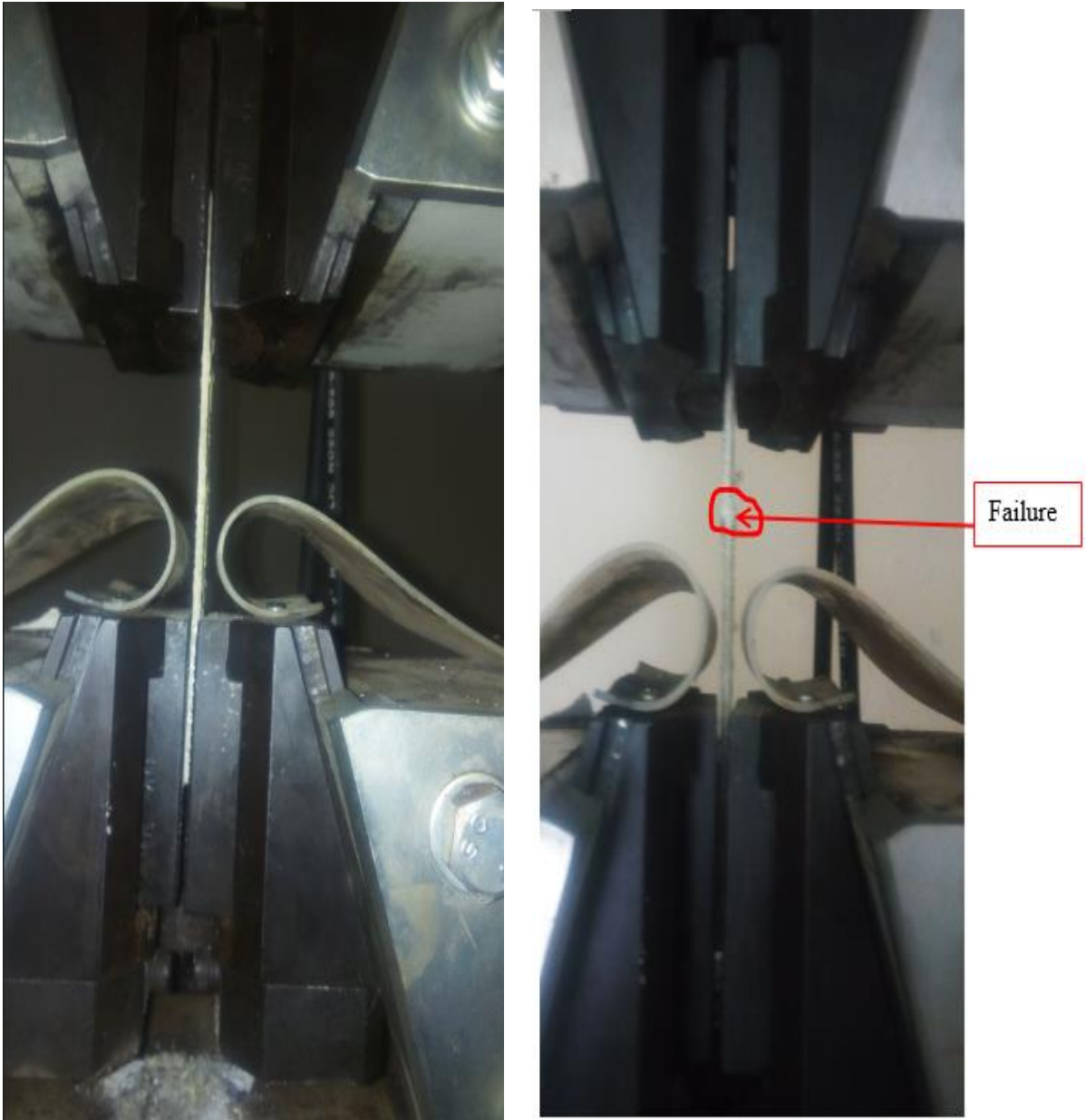


Figure 3-11: Tensile strength specimens' sample



*Figure 3-12: Tensile strength test*

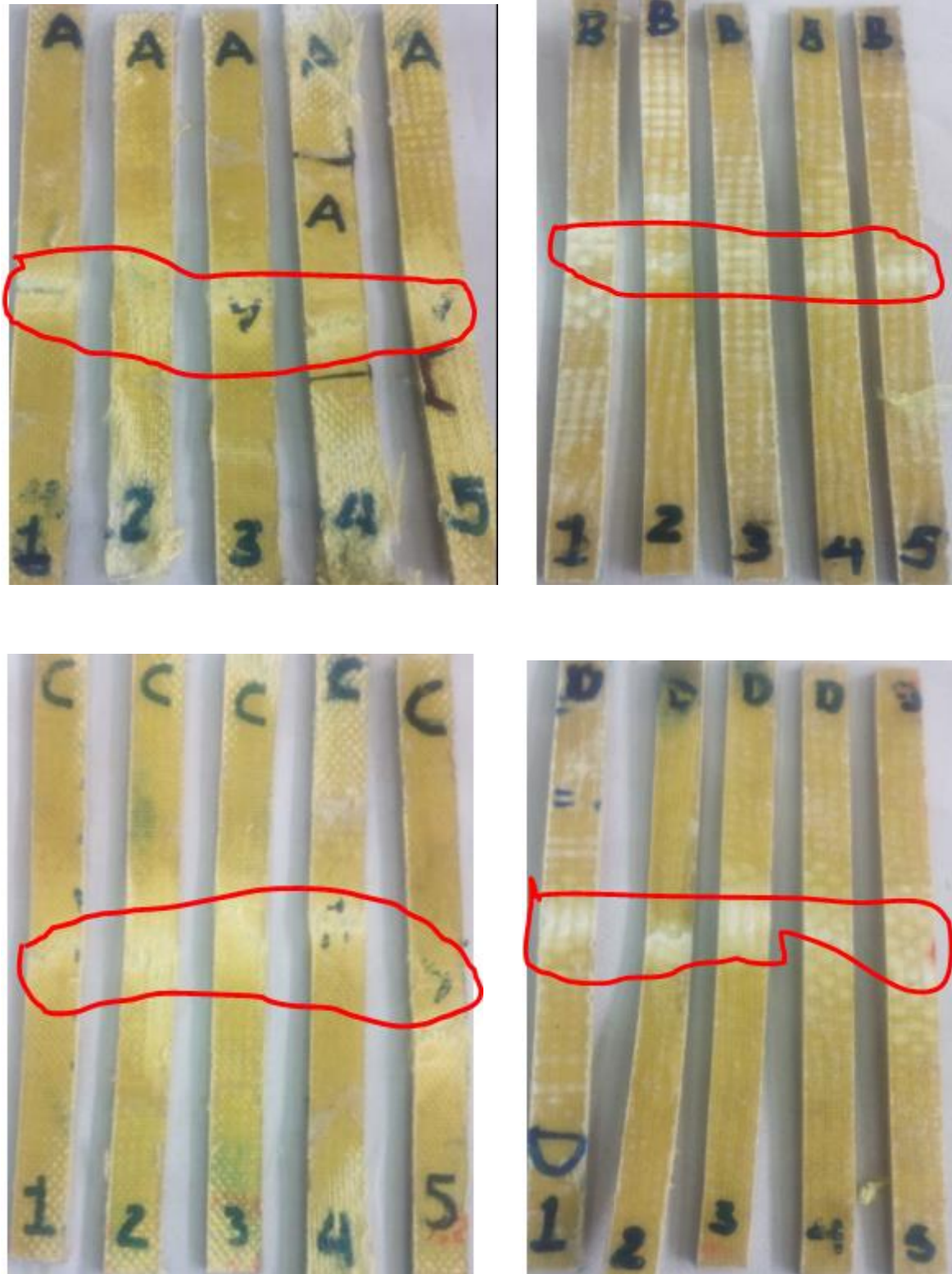
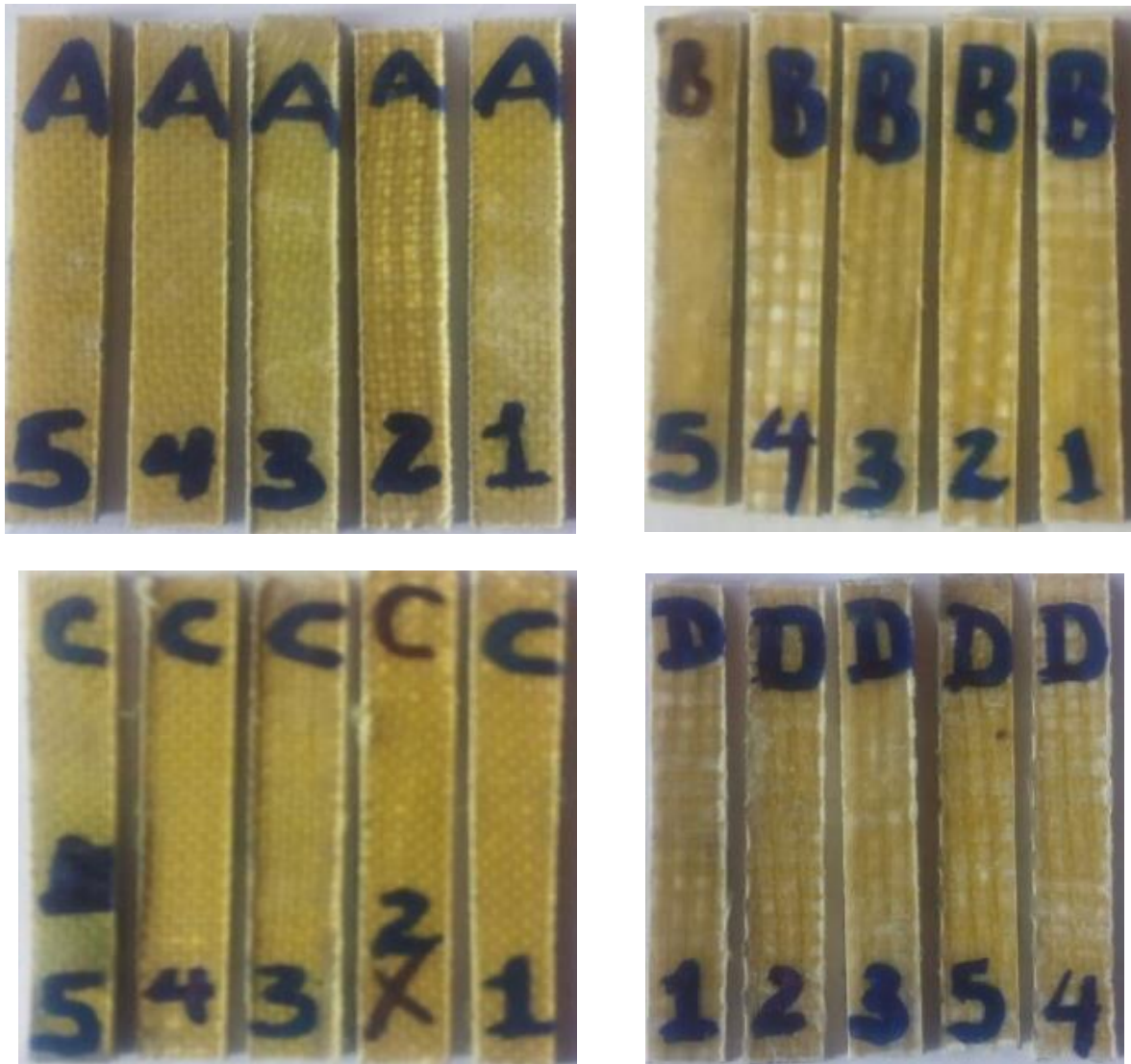
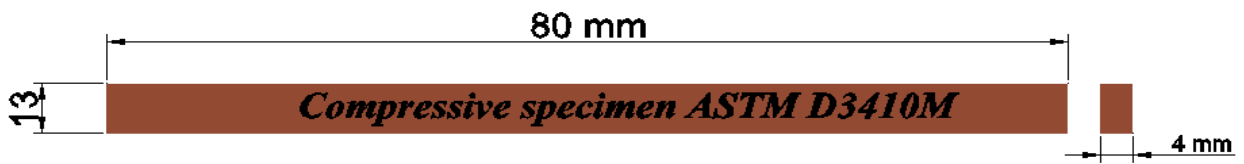


Figure 3-13: Tensile specimens after test

### 3.3.2.2 Compression Strength Test

Compression strength test experiment involved in subjecting specimen to axial compression loading using the UTM. The dimension of the specimen is (80x13x4) mm. The samples were then placed between the compression anvils to commence compression testing. During testing, the maximum load attained was recorded by the UTM testing system after the specimen failed. Each specimen was documented (by pictures) before and after failure. This test was conducted as per ASTM D 3410/D 3410M-3. A typical specimen failure is shown in *Figure 3 17* [55].



*Figure 3-14: Compressive strength specimens' sample*

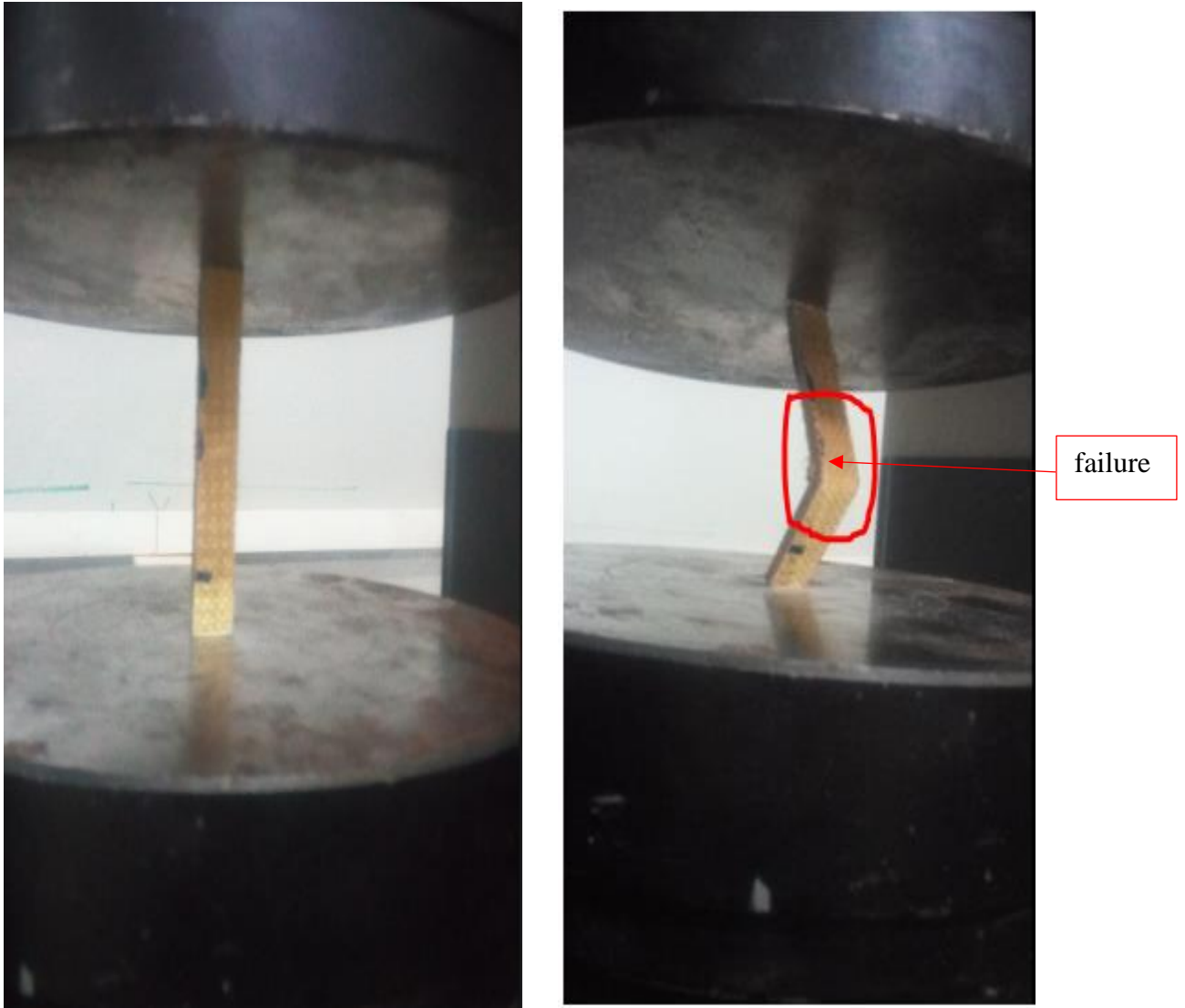


Figure 3-15: Compression strength test

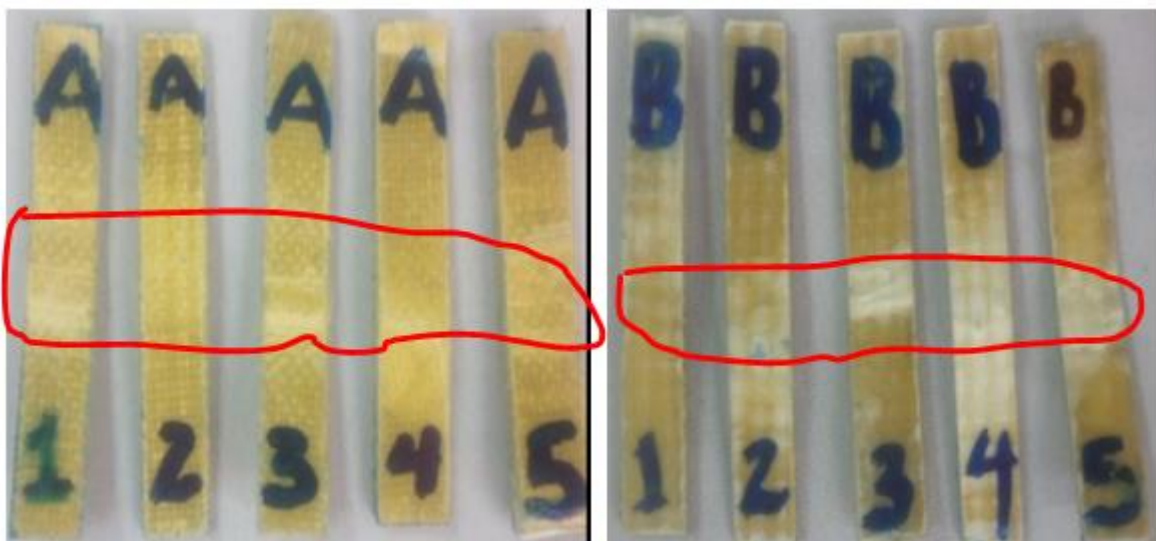
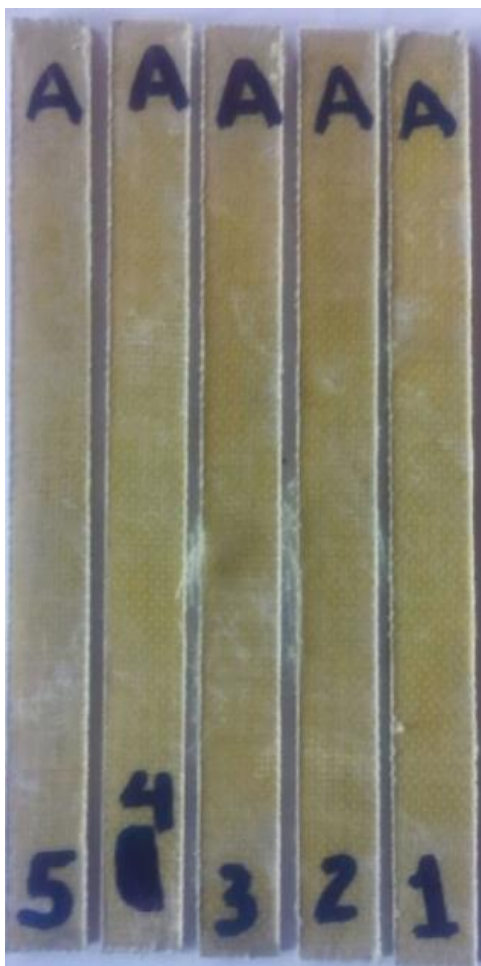
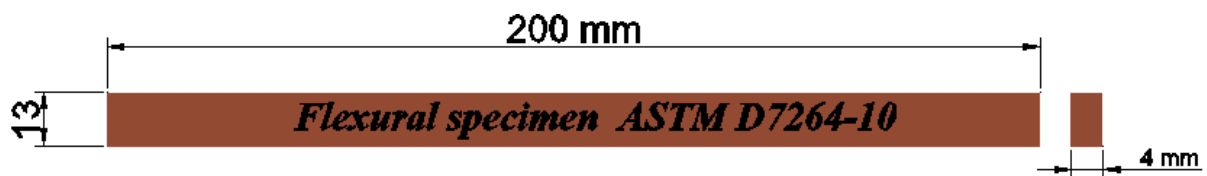
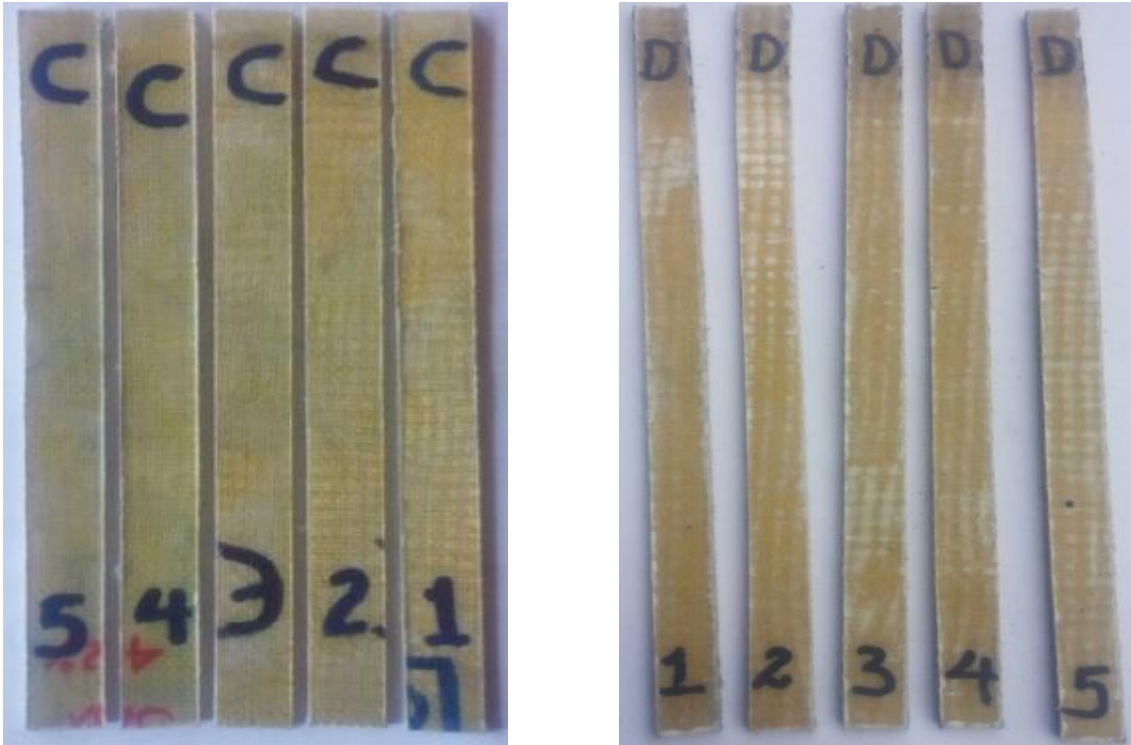


Figure 3-16: Compression specimens after test

### 3.3.2.3 Flexural Strength Test

Composite materials used in structures are prone to fail in bending and thus the testing of newly developed composite against flexural behavior is essential. In this research work, the variation of flexural strength of the hybrid epoxy composite has been tested. Five specimens from the various compositions of epoxy have been tested. The dimensions of the test coupons were computed and taken as per ASTM D7264-10 and are 200 mm in length, 13 mm in width, and 4 mm in thickness respectively. The loading arrangement and the UTM are shown in *figure 3.19* [56]





*Figure 3-17: Flexural strength specimen samples*



*Figure 3-18: Flexural Strength Test*

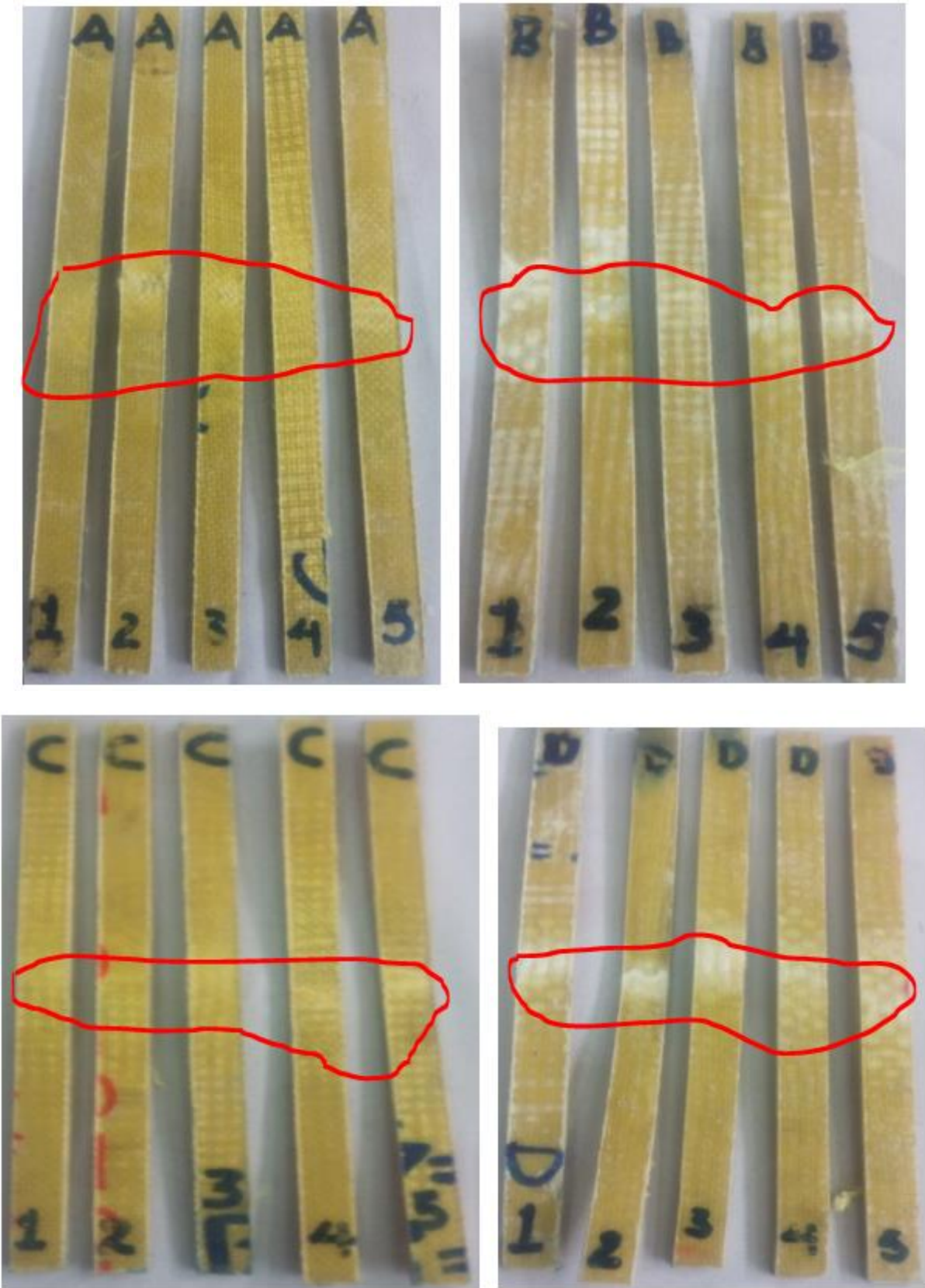


Figure 3-19: Bending specimens after test

### 3.4 Experimental Results

#### 3.4.1 Tensile Test Results

For tensile strength evaluation, there were five specimens for each group stacking sequence of hybrid laminated composite materials. The initial relatively steep part of the curve represents elastic behavior and the slope of the curve defines the elastic modulus. This straight line is referred to as the **Modulus Line**, from which the **Modulus of Elasticity** will be calculated for the material tested. According to [52] in the graph the straight line is referred to as the Modulus Line, from which the Modulus of Elasticity will be calculated for the material tested. The modulus of elasticity (Young’s Modulus) is the ratio of stress in Mpa to strain in millimeters per millimeter (mm./mm.) as computed from the modulus line (A-B).

$$\text{Modulus (Gpa)} = \frac{\Delta\text{Stress(Mpa)}}{\Delta\text{Strain}}$$

The stress is calculated for any point on the load-deflection curve by using eqn. 3.24.

$$\sigma_t = \frac{P}{A} \dots\dots\dots 3.24$$

where:  $\sigma$  = stress(MPa)  
 $p$  = Applied force(N)  
 $A$  = area (mm<sup>2</sup>)

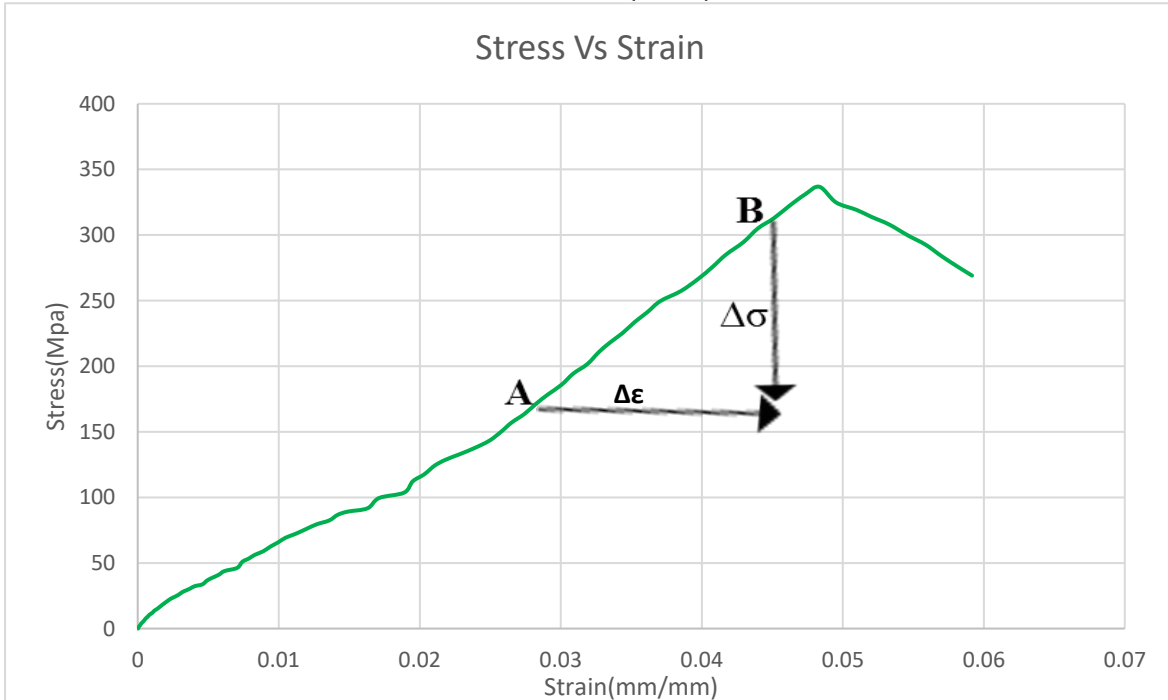


Figure 3-20: Modules of Elasticity graph

Table 3:6: Tensile strength test result

Material	Maximum Tensile Strength( $\sigma_t$ ) (MPa)	Standard Deviation	Maximum Tensile Modulus(E) (GPa)	Standard Deviation (MPa)
A	279.56	8.37	7.0523	0.83
B	389.57	6.83	9.23424	0.8
C	336.76	7.5	7.7751	0.82
D	299.36	8.4	7.1484	0.31

**Standard deviation of test specimens**

$$\bar{X} = \frac{\sum_{n=1}^n (x_1 + x_2 + x_3 + x_4 + x_5 \dots + x_n)}{n} \dots \dots \dots (3.25)$$

$$\bar{X} = \frac{\sum_1^5 (x_1 + x_2 + x_3 + x_4 + x_5)}{5} \dots \dots \dots (3.26)$$

$$\delta^2 = \frac{\sum_1^5 (x_1 - \bar{x})^2 + (x_2 - \bar{x})^2 + (x_3 - \bar{x})^2 + (x_4 - \bar{x}) + (x_5 - \bar{x})^2}{5} \dots \dots \dots (3.27)$$

$$\delta = \sqrt{\delta^2} \dots \dots \dots (3.28)$$

where  $\bar{x}$  = Mean

$\delta^2$  = Variance

$\delta$  = Standard deviation

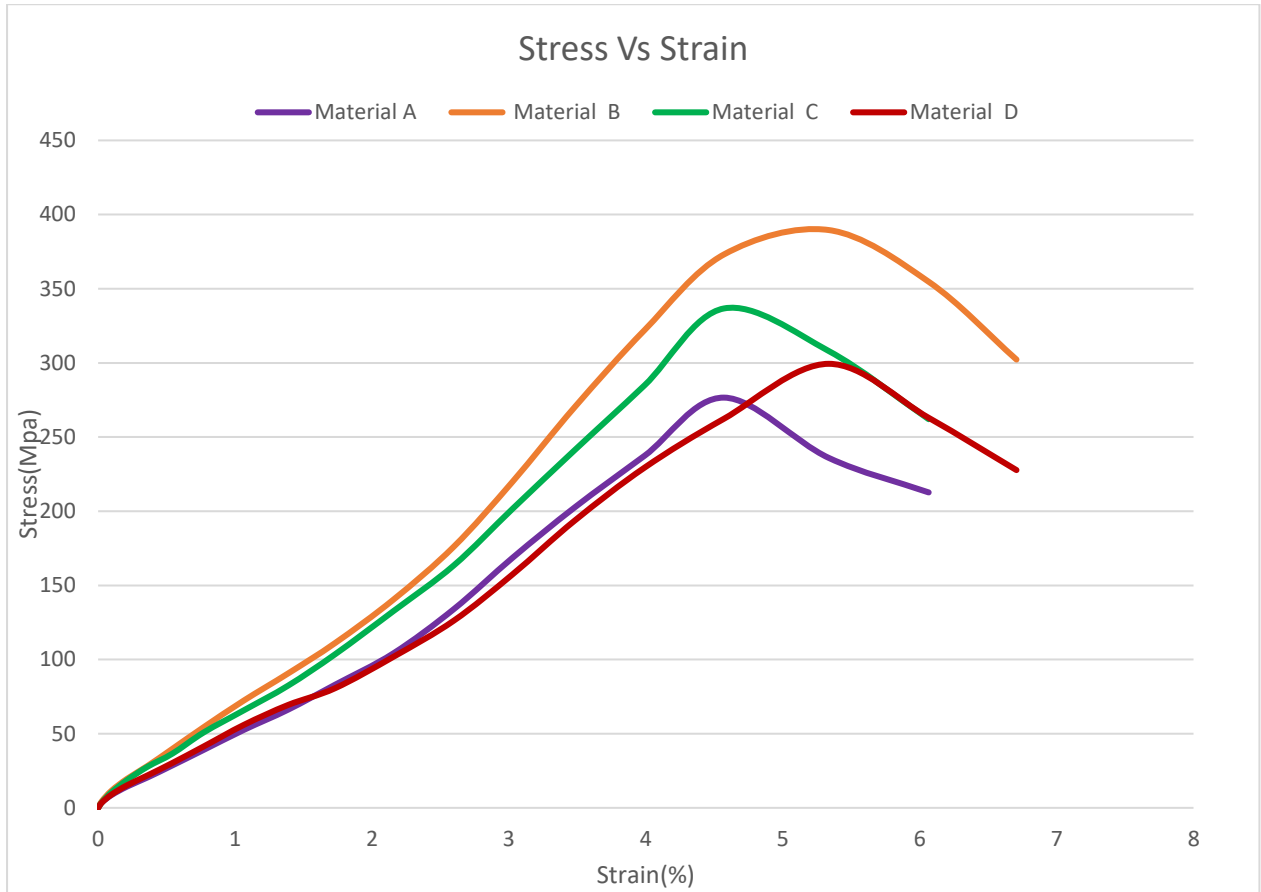


Figure 3-21: Engineering stress Vs Engineering strain for tensile test result

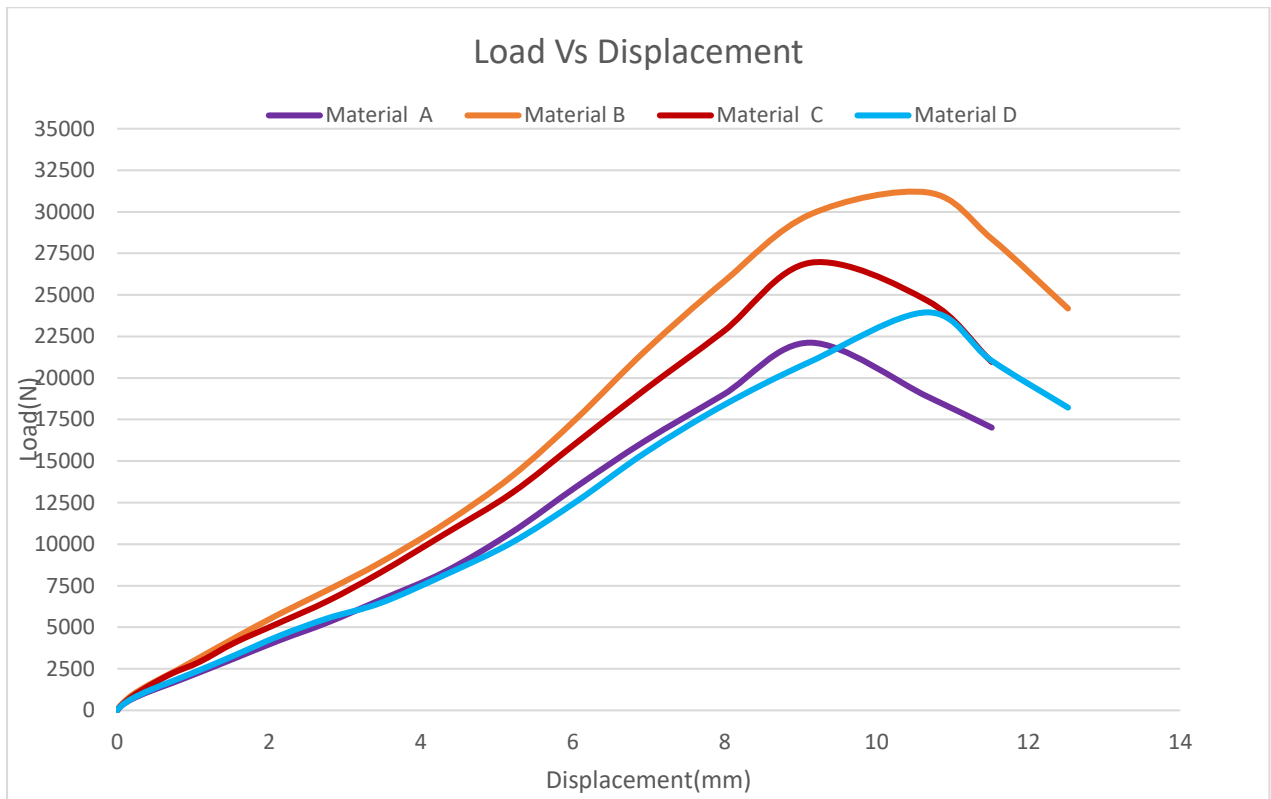


Figure 3-22: Load Vs Displacement for tensile test result

**Observation from tensile test results**

The ratio of Kevlar 49 and E-glass fiber did affect the tensile strength of the hybrid fiber reinforced epoxy composite. Comparing the maximum strength levels for the sample in the experimental test result the maximum tensile strength increase if the amount of Kevlar increases in the hybrid composite materials. For example, the tensile strength of composite shows an increase in sample ‘B’ where as in sample ‘A’ the tensile strength decreases. According to this property of fibers the fiber matrix ratio significantly affects tensile strength with increasing the Kevlar 49 fiber in the composite.

The effect of fiber content on tensile strength change was more pronounced in the Sample ‘A’ as shown in the figure 3.22. Based on the Kevlar 49 fiber ratio in composite the tensile strength for sample A, B, C and D are 276.58,389.56,336.76 and 299.36 respectively. Similarly, in the load displacement graph the displacement increase if the Kevlar 49 fiber increase in the hybrid composite materials.

**3.4.2 Compression Test results**

For compressive strength evaluation, there were five specimens for each group stacking sequence of hybrid laminated composite materials.

- Laminate Compressive Strength ( $F_{cu}$ ) Calculate the compressive strength of the laminate using eqn. 3.29.

$$F_{cu} = \frac{P_f}{wh} \dots\dots\dots 3.29$$

Where:  $P$  = final force  
 $w$  = width  
 $h$  = thickness

- Laminate Compressive Modulus: to calculate the compressive modulus eqn. 3.30 can be applied.

$$E_C = \frac{P_2 - P_1}{(\epsilon_{x2} - \epsilon_{x1})wh} \dots\dots\dots 3.30$$

Where:  $EC$ = compressive modulus, MPa  
 $P_2$ = load at ex1, N  
 $P_2$ = load at ex2.N

Table 3:7: Compressive strength test result

Material	Maximum compressive force (N)	Maximum compressive Strength( $\sigma_i$ ) (MPa)	Standard Deviation (MPa)
A	12241	239.6	4.48
B	10918	209.9	3.66
C	11722	225.4	4.9
D	11924	229.3	5.2

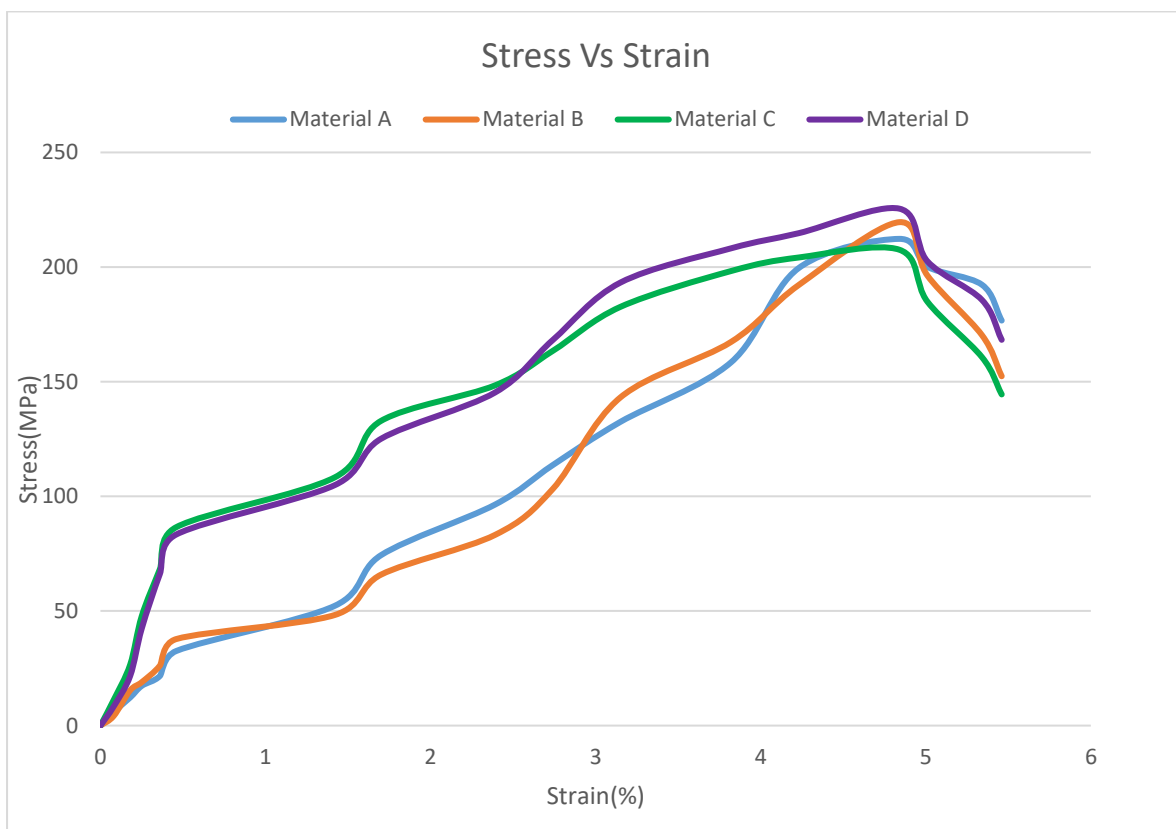


Figure 3-23: Engineering stress Vs Engineering strain for compressive test result

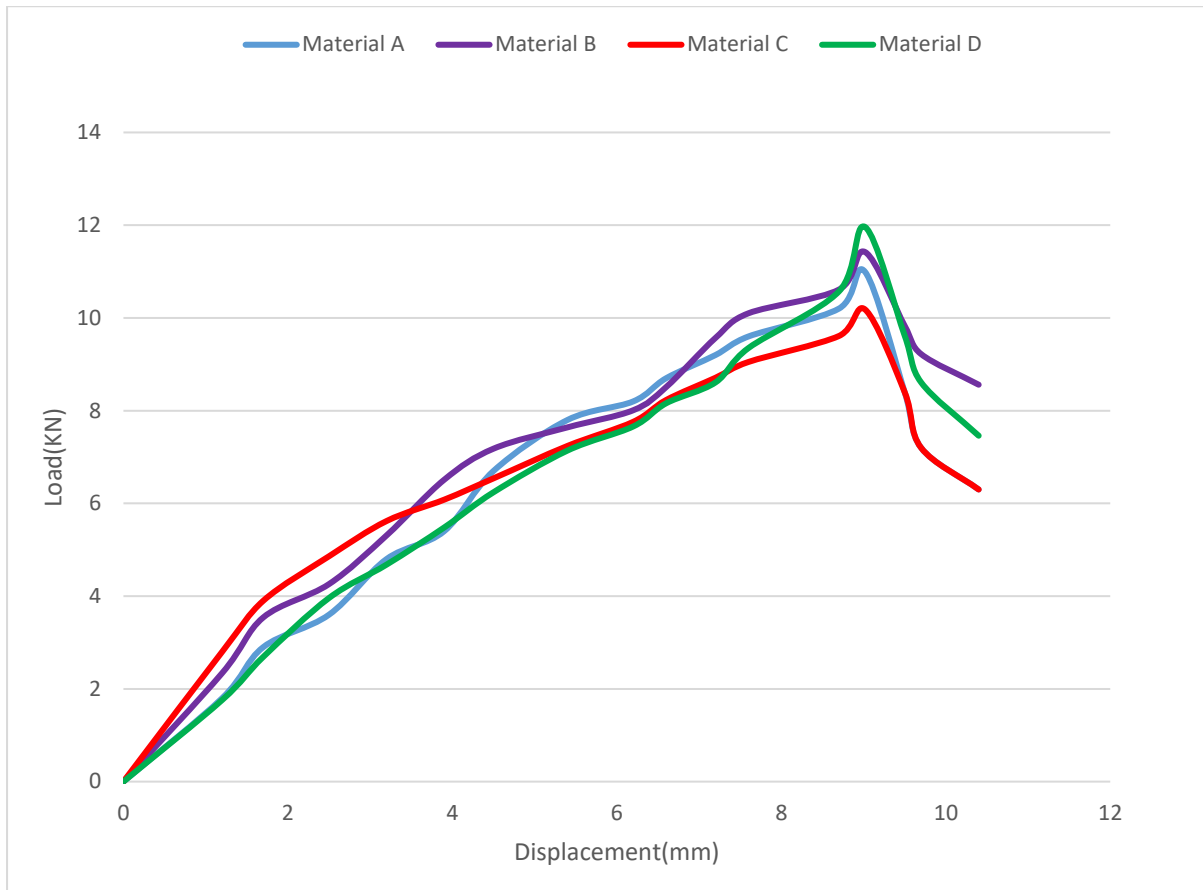


Figure 3-24: Load Vs Displacement for compressive test result

### Observation from compression test results

In this experimental result the ratio of Kevlar<sub>49</sub> and E-glass fiber affect the compressive strength of the hybrid fiber reinforced epoxy composite. Comparing the maximum strength levels for the sample in the experimental test result, the maximum compressive strength will be affected based on the fiber ratio. Comparing the maximum strength levels of the sample in the experimental test result, the maximum compressive strength increases if the amount of E-glass increases in the hybrid composite materials. For example, the compressive strength test of hybrid composite shows an increase in sample 'A' where as in sample 'B' the compressive strength decreases. According to this property of fibers, the fiber matrix ratio significantly affects compressive strength with increasing the E-glass fiber in the composite.

**3.4.3 Flexural Test results (Three-point bending test)**

The flexural test measures the force required to bend a beam under three-point loading situations. The data is often used to select elements for parts that will support loads without inflection. Flexural modulus is used as an indication of a material’s stiffness when inflection. Three-point bend test was carried out in an UTM machine in accordance with ASTM D790-10 standard to measure the flexural strength of the hybrid composites.

**Maximum Flexural Stress**

When a beam of homogenous, elastic material is tested in flexure as a beam simply supported at two points and loaded at the midpoint, the maximum stress at the outer surface occurs at mid-span. The stress is calculated for any point on the load-deflection curve by using eqn. 3.31.

$$\sigma_b = \frac{3PL}{2bh^2} \dots\dots\dots 3.31$$

where:  $\sigma$  = stress  
 $p$  = Applied force  
 $h$  = thickness

**Maximum Strain,**

The maximum flexural strain at the outer surface also occurs at mid-span, and it calculated using eqn. 3.32.

$$\varepsilon_{max} = \frac{6\delta h}{L^2} \dots\dots\dots 3.32$$

Where:  $\delta$  = mid span defelaction (mm)  
 $h$  = thickness of the beam (mm)  
 $L$  = Support span (mm)

**Flexural Chord Modulus of Elasticity**

The flexural chord modulus of elasticity is the ratio of stress range and corresponding strain range. To calculate the flexural chord modulus of elasticity from the stress-strain data using eqn. 3.33.

$$E_b = \frac{\Delta\sigma}{\Delta\varepsilon} \dots\dots\dots 3.33$$

where:  $E$  = flexural chord modulus of elasticity (MPa)  
 $\Delta\sigma$  = difference in flexural stress between the two selected strain points (MPa)  
 $\Delta\varepsilon$  = difference between the two selected strain points

Table 3:8 : Flexural test result

Material	Maximum Flexural Strength( $\sigma_t$ ) (MPa)	Standard Deviation	Maximum Flexural Modulus(E) (GPa)	Standard Deviation (GPa)
A	297.55	8.2	55.25	4.7
B	143.37	8.7	54.06	3.8
C	186.05	7.46	43.35	3.1
D	226.36	7.9	31.52	2

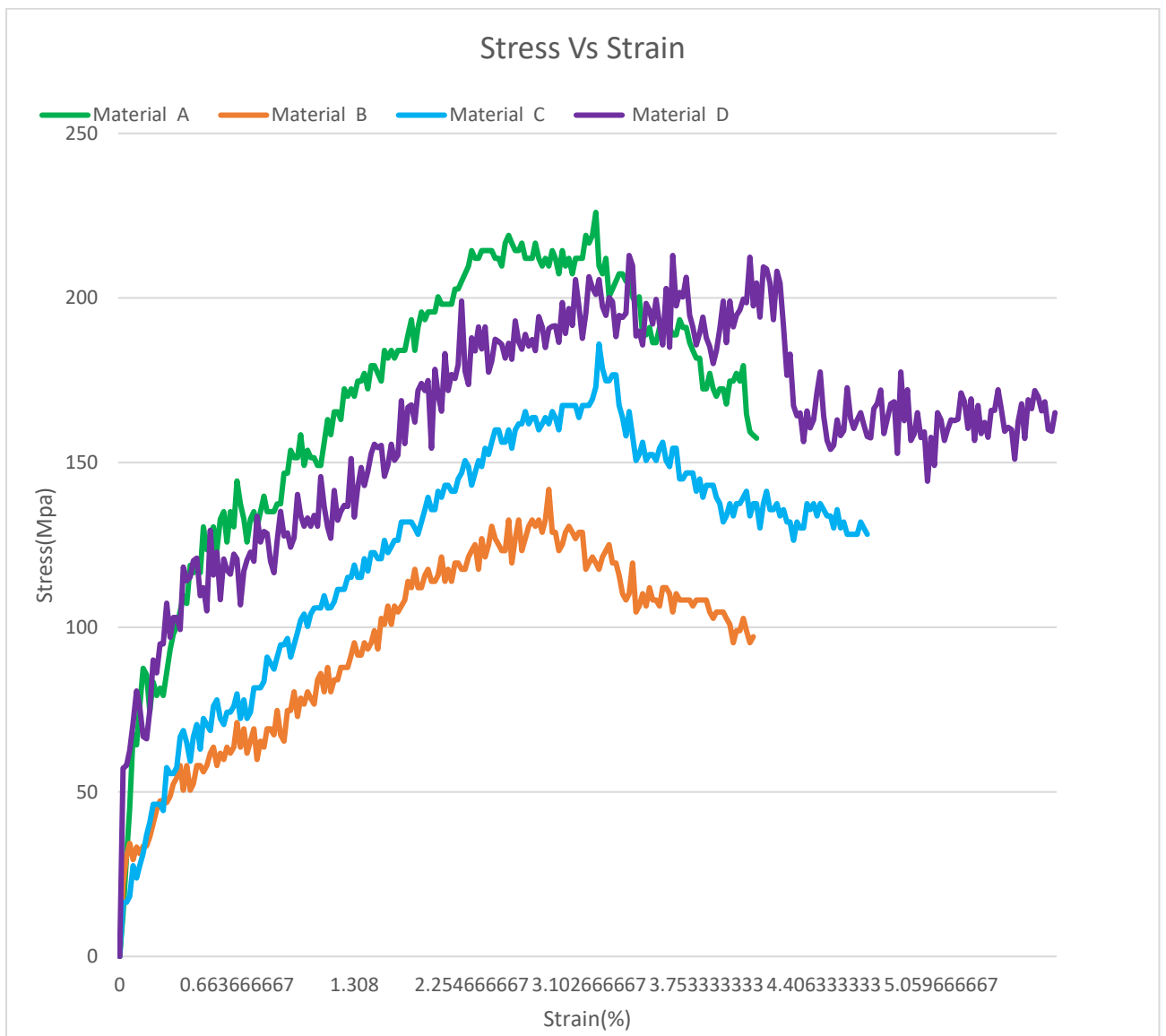


Figure 3-25: Engineering stress Vs Engineering strain for bending test result

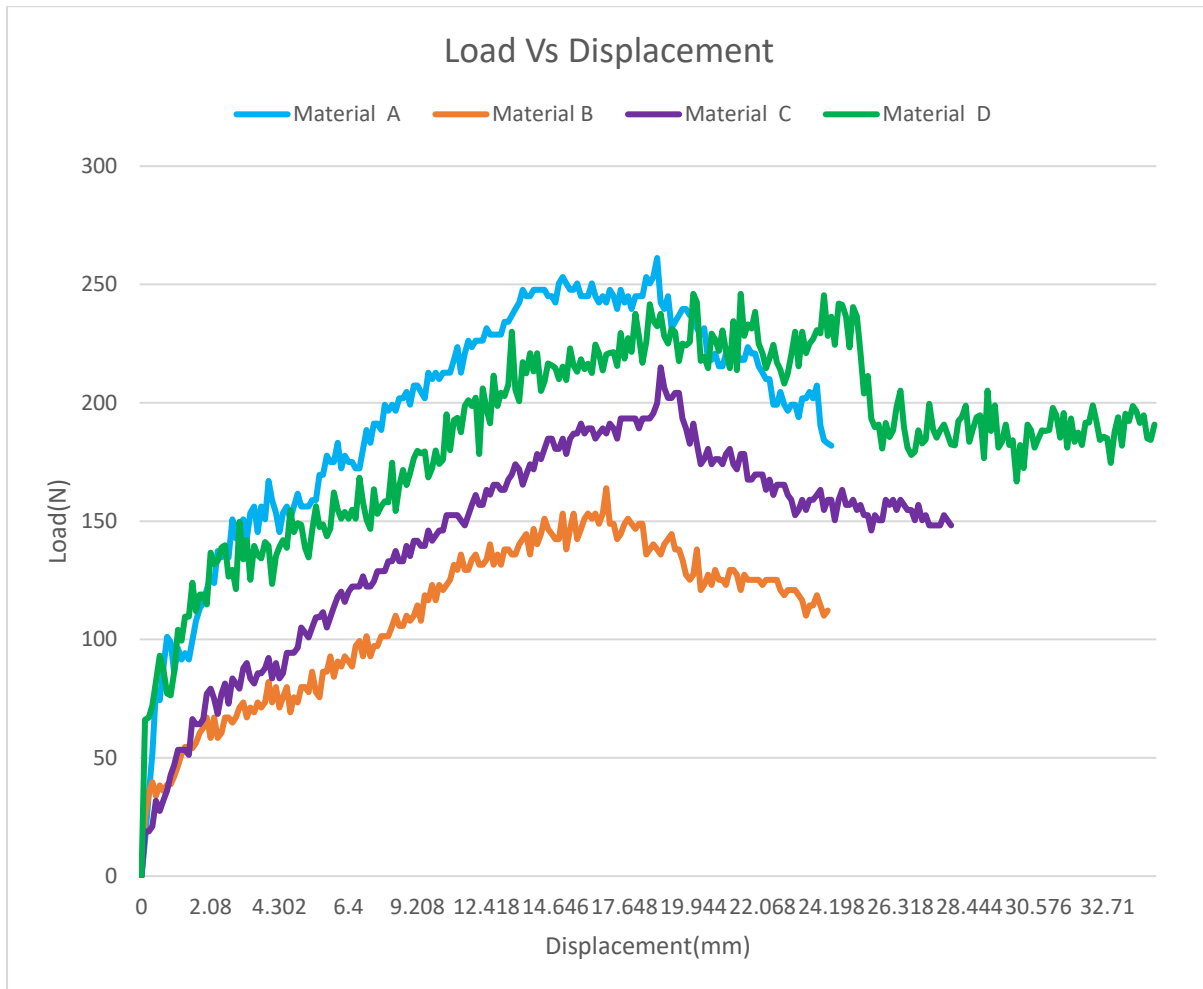


Figure 3-26: Load Vs Displacement for bending test result

### Observation from flexural test results

The ratio of Kevlar<sub>49</sub> and E-glass fiber did affect the three point-bending (flexural) strength of the hybrid fiber reinforced epoxy composite. Comparing the maximum strength levels for the sample in the experimental test result the maximum flexural strength increase if the amount of E-glass increases in the hybrid composite materials. For example, the three-point bending test strength of composite shows an increase in sample 'A' where as in sample 'B' the bending strength decreases. According to this property of fibers the fiber matrix ratio significantly affects flexural strength with increasing the E- glass fiber in the composite.

The effect of fiber content on flexural strength change was more pronounced in the Sample 'A' as shown in the figure. Based on the E-glass fiber ratio in composite the flexural strength for sample A, B, C and D are 244.81, 143.37, 186.05 and 226.36 respectively. Similarly, in the load displacement graph the displacement increase if E-glass fiber increase in the hybrid composite material.

### 3.5 Design of hybrid composite leaf spring

#### 3.5.1 Dimensions/ Specification

In this research work, the specification of Lifan 1022 mini truck was selected. *Table 3.8* reports detailed specifications of Lifan 1022 mini truck.

*Table 3:9: Lifan 1022 Mini truck Car specification [52]*

Lifan 1022 mini truck					
No			Units	Pick-up	
	Body Type				
	Grade				
	Engine			LF479Q5-1	LF465Q5A
	Transmission			5MT	
1	<b>Dimensions</b>				
1.1	Overall length		mm	4,580	
1.2	Overall width		mm	1,615	
1.3	Overall height		mm	1,892	
1.4	Wheelbase		mm	2,625	
1.5	Front overhang		mm	700	
1.6	Rear overhang		mm	830	
1.7	Tread	Front	mm	1,435	
		Rear	mm	1,435	
1.8	Minimum turning radius		m	10.5	
1.9	Minimum ground clearance		mm	155	
2	<b>Capacity</b>				
2.1	Seating capacity		persons	2	
3	<b>Engine</b>				
3.1	Type			LF479Q5-1	LF465Q5A
3.2	Number of cylinders			4	4
3.3	Number of valves			16	16
3.4	Piston displacement		Cm <sup>3</sup>	1,493	1,590
3.5	Bore x stroke		mm	75.0x84.5	75.0x90.0
3.6	Compression ratio			9.5	<b>9.5</b>
3.7	Maximum output		kW/rpm	67/6,000	68/6,000
3.8	Maximum torque		N.m/rpm	112/3,000	126/3,000
3.9	Fuel distribution			Multipoint electric Injection	
4	<b>Transmission</b>				
4.1	Type			5MT	
4.2		1 <sup>st</sup>		4.545	4.545
		2 <sup>nd</sup>		2.628	2.418
		3 <sup>rd</sup>		1.865	1.796

	Gear ratio	4 <sup>th</sup>		1.241	1.241
		5 <sup>th</sup>		1.000	1.000
		Reverse		4.431	4.431
4.3	Final gear ratio			4.300	4.300
5	<b>Chassis</b>				
5.1	Steering			Rack & Pinion	
5.2	Brakes	Front		Ventilated disc	
		Rear		Drum, leading & trailing	
5.3	Suspension	Front		Rigid axle with leaf spring	
		Rear		Rigid axle with leaf spring	
5.4	Tires			185R14C	
6	<b>Weights</b>				
6.1	Curb weight (min.) / (with full options)		Kg	1000	
6.2	Gross vehicle weight		Kg	1,930	
6.3	Loading mass		Kg	800	
7	<b>Fuel consumption</b>				
7.1	Fuel tank capacity		Liters	40	

Figure 3.32 and figure 3.33 represents the schematic representation of Lifan 1022 mini truck.

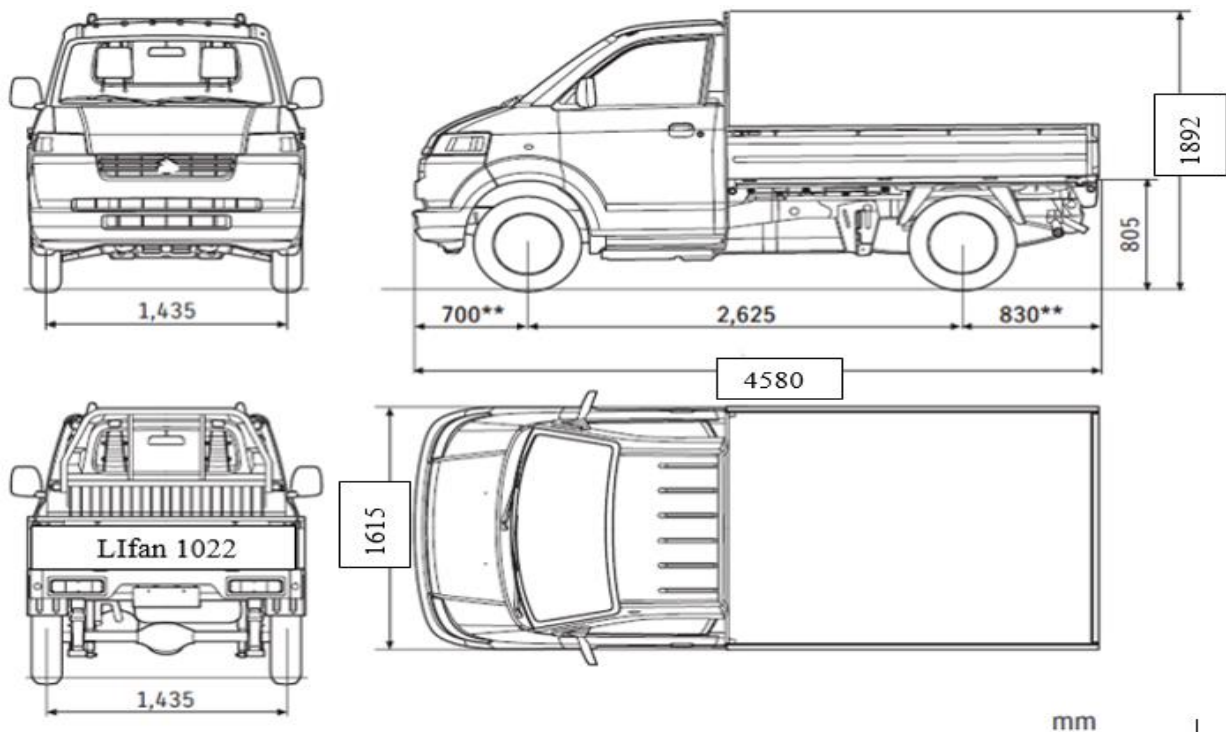


Figure 3-27: Lifan 1020 mini truck view

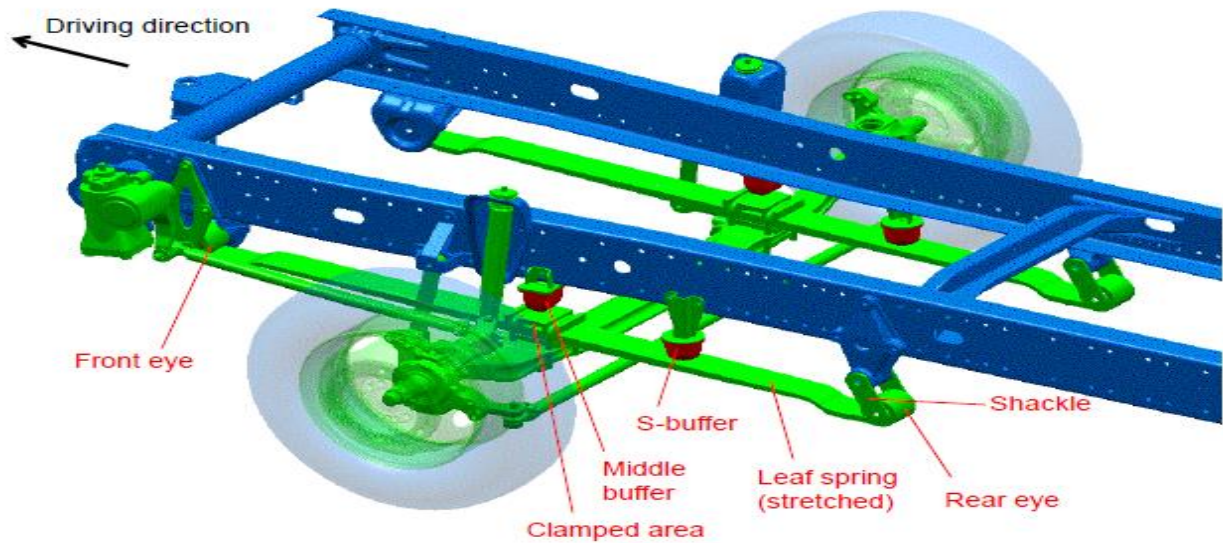


Figure 3-28: Assemble of leaf spring in frame using shackle

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 [52].

- ✓ 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 3.33, 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 [53] the cantilever beam is highly exposed to both bending stress and transverse shear stress [54]. 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 also, 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.

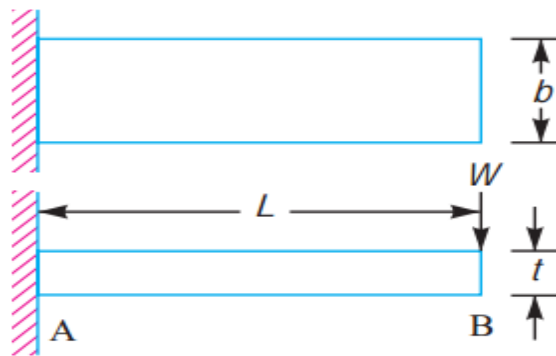


Figure 3-29: Leaf spring (cantilever type) [26]

In this study the weight and initial measurement of four-wheeler “Lifan 1022” light vehicle is taken.

Mass of Lifan 1022 vehicle = 1000Kg

Maximum load carrying capacity = 800Kg.

Total Mass = 1000 + 800

$M = 1800 \text{ Kg}$

Take Acceleration due to gravity ( $g$ ) =  $9.81 \text{ m/s}^2$

According to [51] the value of factor of safety ranges = (1.3 – 2.25), for this work take factor of safety = 1.6

Therefore, Total Weight ( $W$ ) =  $1800 \times 9.81 \times 1.6$

$W = 28253 \text{ N}$

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

Load on each wheel becomes,

$$W = \frac{28253 \text{ N}}{4}$$

$$W = 7063.25 \text{ N}$$

So again, load on each eye of spring is =3531.62 N, take = 3532 N

Design load = 7063.25 N

Straight length of the leaf spring (L) =108 cm

Design stress = 297.55 MPa, this stress is for material type A, because the property of leaf spring is subjected for bending stress rather than tensile stress. In material type A the bending stress is high compare to other materials.

According to [9] Strength of material concept

$$\sigma_{max} = \frac{6FL}{bh^2} \dots\dots\dots 3.34$$

$$\delta_{max} = \frac{4FL^2}{Ebh^2} \dots\dots\dots 3.35$$

Solving equation, the above for ‘h’ (thickness of the leaf spring)

$$h = \frac{\sigma_{max}}{E\delta_{max}} \dots\dots\dots 3.36$$

$$h = \frac{297.55 \text{ MPa}}{7\text{GPa} \times 27} = 34.5 \text{ mm say } 35 \text{ mm}$$

Rearranging the equation to get width ‘b’

$$b = \frac{6F \frac{L}{2}}{\sigma_{max} h^2} \dots\dots\dots 3.37$$

Therefore, width is taken as b = 40 mm

According to [55] the Camber Calculation is given by

$$\frac{c}{L} = 0.089 \dots\dots\dots 3.38$$

Camber = 97 mm

The present work concentrates only a constant cross section because the accommodation of reinforcement fibers must be continuous and uniform distribution of resin is essential for analysis.

**3.5.2 Stress and Deflection Calculation**

The current steel multi leaf spring of Lifan 1022 mini truck car specification (direct measuring):

- Type of material = structural mild steel
- No. of leaves = 4

- Length of master leaf (eye to eye) = 108 cm
- Length of 2nd leaf = 106 cm
- Length of 3rd leaf = 84 cm
- Length of 4th leaf = 69 cm
- Width of leaves = 4 cm
- Thickness of each leaf = 0.8 cm
- Camber (no load condition) = 17 cm
- Eye bore diameter = 1 cm
- Eye outer diameter 4 cm

Table 3:10: Mechanical properties of structural mild steel [54]

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>

The leaf spring is mounted on the axle of the vehicle firmly using U bolt or shackle, then the distance between the U bolt is 54 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 (R.S. Khurmi and J.K. Gupta), the effective length of leaf spring can be calculated as:

$$2L=2L1-l.....when\ band\ is\ used.\ and$$

$$2L=2L1-2.3l.....\ when\ U-bolts\ is\ used.$$

Where: 2L = effective length leaf spring

2L1 = 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:

$2L=2L1-2.3l$ , take the width of the U-bolts = 54 mm (direct measuring from lifan 1022 vehicle)

$$2L=1080mm - \frac{2}{3} \times 54mm$$

$$2L=1034mm$$

$$L=517\ mm\ (half\ effective\ length\ of\ current\ steel\ leaf\ spring)$$

Similarly, the hybrid composite leaf spring effective length calculated as:

$$2L = 1080 \text{ mm} - \frac{2}{3} \times 54 \text{ mm}$$

since length is like conventional leaf spring

$$2L = 1034 \text{ mm}$$

$$L = 517 \text{ mm}$$

(half effective length of the hybrid composite leaf spring)

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

$$\sigma = \frac{6WL}{nbt^2} \dots\dots\dots 3.38$$

Where: n = No. of leaves, in this case n = 4

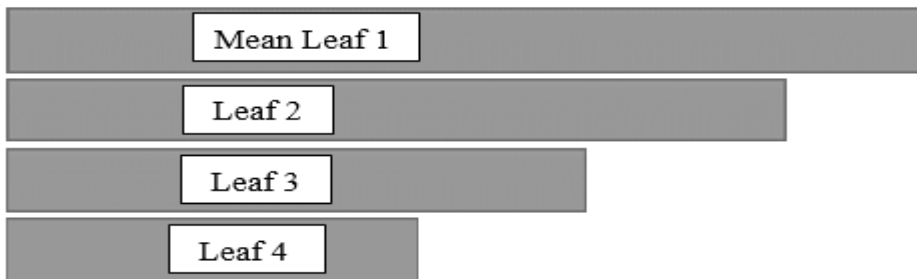
$$= \frac{6 \times 3532 \text{ N} \times 517 \text{ mm}}{4 \times 40 \text{ mm} \times (8 \text{ mm})^2}$$

$\sigma = 452.09 \text{ N/mm}^2$ , this much amount of stress is occurred around at the center of the steel leaf spring

**Deflection:**

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

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



We know that maximum deflection of the cantilever beam at the loaded end is given by this equation.

$$\delta = \frac{WL^3}{3EI} = \frac{WL^3}{3E \times b \times \frac{h^3}{12}} = \frac{4WL^3}{Ebt^3} \dots\dots\dots 3.39$$

$$\delta = \frac{4 \times 3532 \times 517^3}{207 \times 60 \times 10^3} = 18 \text{ mm}$$

**Bending stress of the hybrid mono composite leaf spring can be calculated as:**

The maximum bending stress at the free end of the hybrid composite leaf spring material with the above designed dimension is calculated as using equation:

$$\sigma = \frac{6WL}{bt^2} \text{-----3.40}$$

$$\sigma = \frac{6 \times 3532 \times 517}{40 \times 35^2}$$

$\sigma=292.16 \text{ N/mm}^2$ , Since, stress of steel leaf spring  $452.09 \text{ N/mm}^2$  is much greater than that of hybrid mono composite leaf spring  $292.16 \text{ N/mm}^2$ . Then the hybrid mono composite 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 hybrid mono composite leaf spring is exposed to about  $292.16 \text{ N/mm}^2$ . Then the hybrid mono composite leaf spring becomes 35.4 % less stressed than that of the steel leaf spring.

**Deflection**

Deflection of the hybrid mono composite leaf spring material is calculated as by using the following equation:

$$\delta = \frac{WL^3}{3EI} \text{ Where: } - \delta = \text{difelection}$$

$E = \text{modules of elasticity of the material}$

$$I = \text{moment of Inertia} = \frac{bh^3}{12}$$

$$I = \frac{60 \times 25^3}{12} = 78125 \text{ mm}^4$$

$$\delta = \frac{3532N \times (517mm)^3}{3 \times 7.05 \text{ Gpa} \times 78125mm^4}$$

$$\delta=12.75mm$$

Then the hybrid mono composite leaf spring material has a good ability to with stand 38.47% deformation than that of the current steel leaf spring when loaded the same amount of load.

**3.5.3 Weight calculation**

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

Density = mass/volume

$$\rho = M/ V \text{-----3.41}$$

$$M=\rho \times V \text{-----3.42}$$

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

$$\text{Therefore, } W=\rho \times V \times g \text{-----3.43}$$

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

Take acceleration due to gravity( $g$ ) = 9.81 m/s<sup>2</sup>

Now weight of the master leaf ( $W_1$ ) =  $\rho \times V_1 \times g$

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

Where:  $L$  = length

$t$  = thickness of the leaf spring and

$w$  = width of the leaf spring

$V_1$  = volume of master leaf spring

$$V_1 = 1080 \text{ mm} \times 8 \text{ mm} \times 40 \text{ mm}$$

$$V_1 = 345.6 \text{ cm}^3$$

$$W_1 = 7.85 \text{ gm/cm}^3 \times 345.6 \text{ cm}^3 \times 9.81 \text{ m/s}^2$$

$$W_1 = 26.61 \text{ N}$$

$$\text{Weight of the 2nd leaf } (W_2) = 26.12 \text{ N}$$

$$\text{Weight of 3rd leaf } (W_3) = 20.69 \text{ N}$$

$$\text{Weight of 4th leaf } (W_4) = 17.003 \text{ N}$$

Therefore, the total weight of the current existing steel leaf spring of the Lifan 1020 mini car becomes  $WT = W_1 + W_2 + W_3 + W_4$

$$\mathbf{WT = 90.62 \text{ N}}$$

Type of material = hybrid composite ( $V_f = 55\%$  and  $V_m = 45\%$ )

No. of leaves = 1

Length = 1080 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 = 35 mm,

Then according to the above specification, the weight of the hybrid composite leaf spring becomes:

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

$$= 1.58 \text{ g/cm}^3 \times 1512 \text{ cm}^3 \times 9.81 \text{ m/s}^2$$

$$\mathbf{W = 32.43 \text{ N}}$$

Now calculate the weight saved of the leaf spring:

$$\text{Weight saved} = 90.62 \text{ N} - 32.43 \text{ N} = 58.19 \text{ N}$$

$$\% \text{ weight saved} = (58.19 \div 90.62) \times 100$$

$\%$  weight saved = 64.21%, therefore the laminated mono hybrid composite leaf spring is very light weight material than that of the current conventional steel multi leaf spring.

## Chapter Four

### 4. Modeling and Finite Element Analysis of Steel and Composite Leaf Springs

#### 4.1 Modeling of Steel and Composite Leaf Springs

##### Conventional leaf spring

1. Create below the help of leaf spring length and camber. Divide leaf spring length and camber into equal division and draw a spline which passes through intersection of camber and length division.

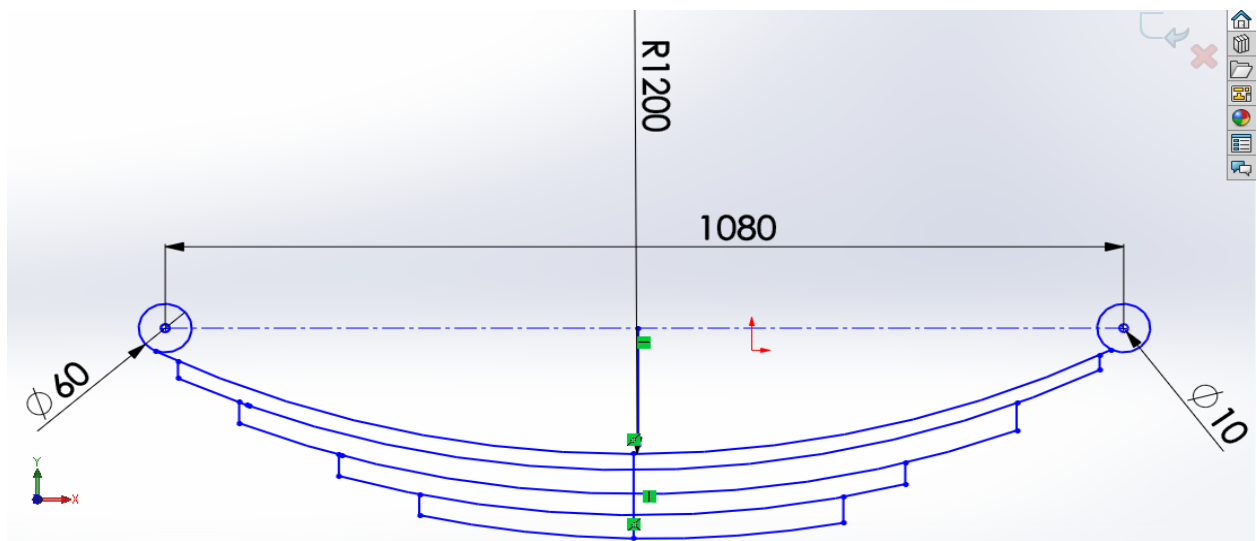


Figure 4-1: Two-dimensional Sketch of steel leaf

2. Extrude above sketch to leaf spring width to create steel leaf spring using extrude tool and assemble each leaf in the assemble window in solidwork 2018.

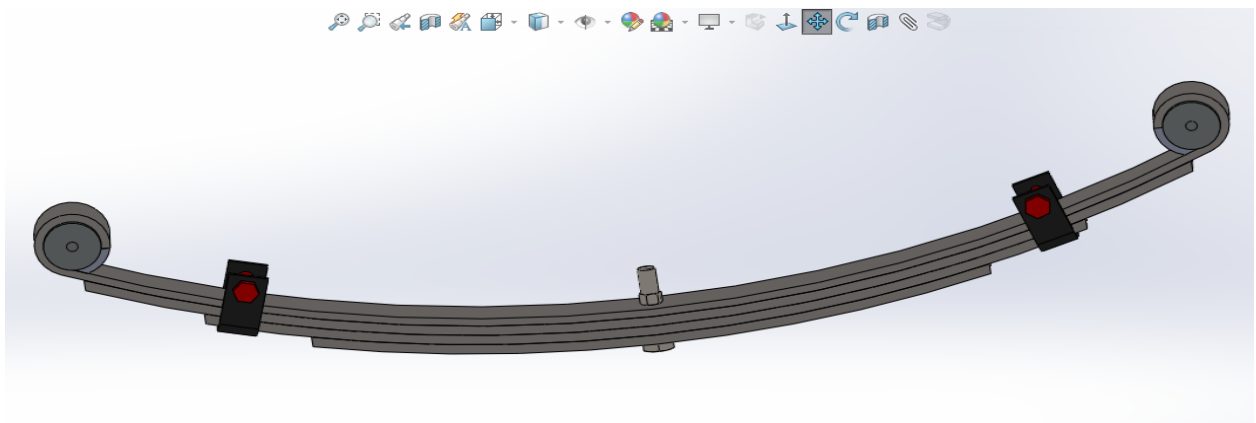


Figure 4-2: Three-Dimensional Sketch of steel leaf

## Composite leaf spring

### 1. Two-dimensional modeling

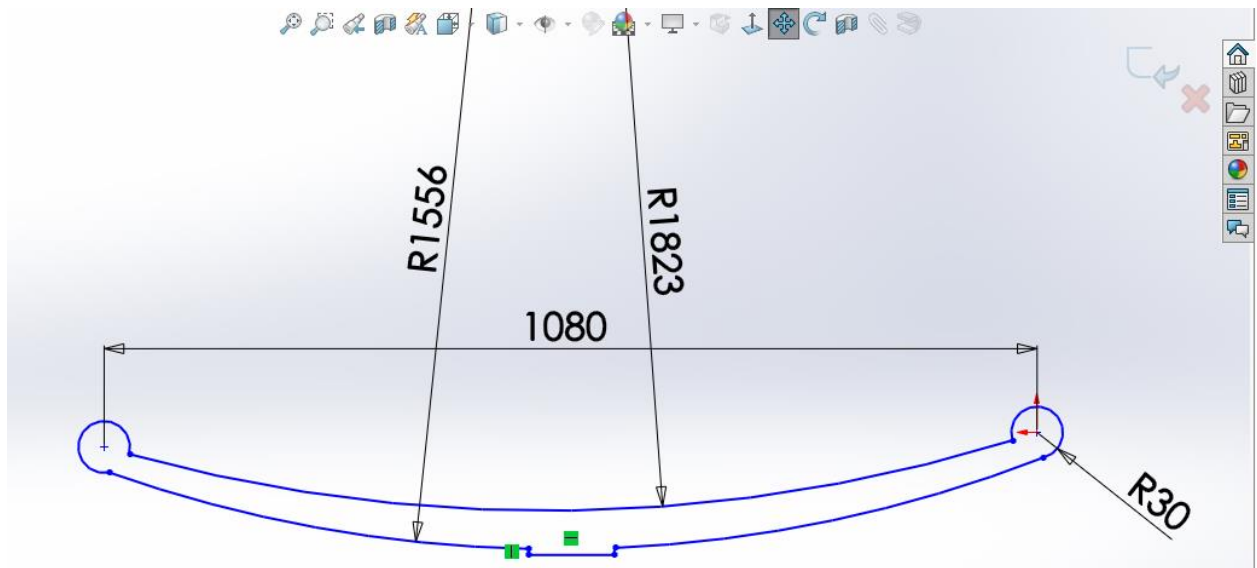


Figure 4-3: Two-Dimensional Sketch of Composite leaf

### 2. Three-dimensional modeling

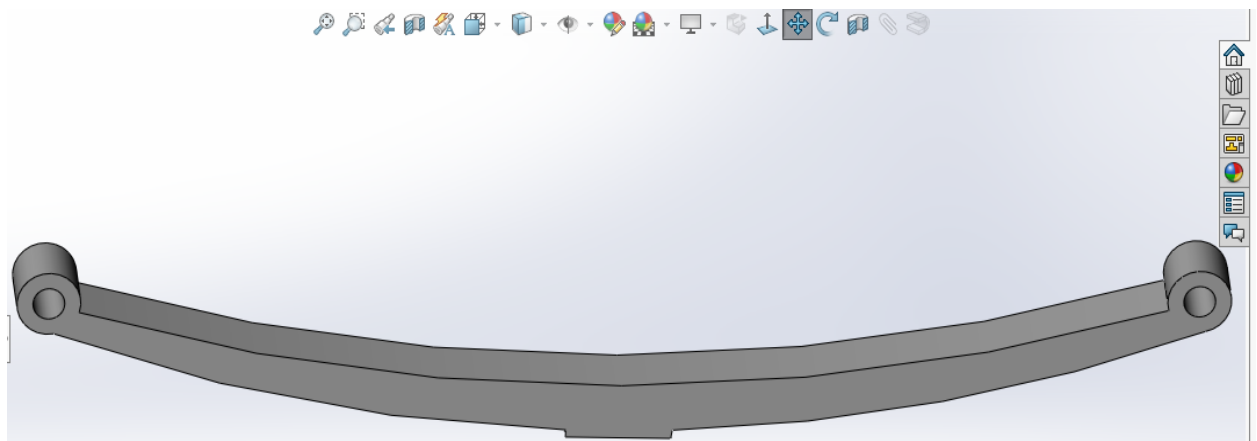


Figure 4-4: Three-Dimensional Sketch of Composite leaf spring

## 4.2 Analysis of Steel and Composite Leaf Springs

### 4.2.1 Static analysis of steel leaf spring

#### ➤ Assumptions:

- Software to be used for ANSYS 18.2
- Model simplification for FEA.
- Meshing size is limited to computer compatibilities.
- Static analysis is considered.
- Material used for steel leaf spring analysis is isotropic.

1. After solid model of steel leaf spring in Solidwork 2018. Save that model in STEP format.
2. Define Properties of structural steel material

The specific material properties of the selected material are listed using *figure 4.5*.

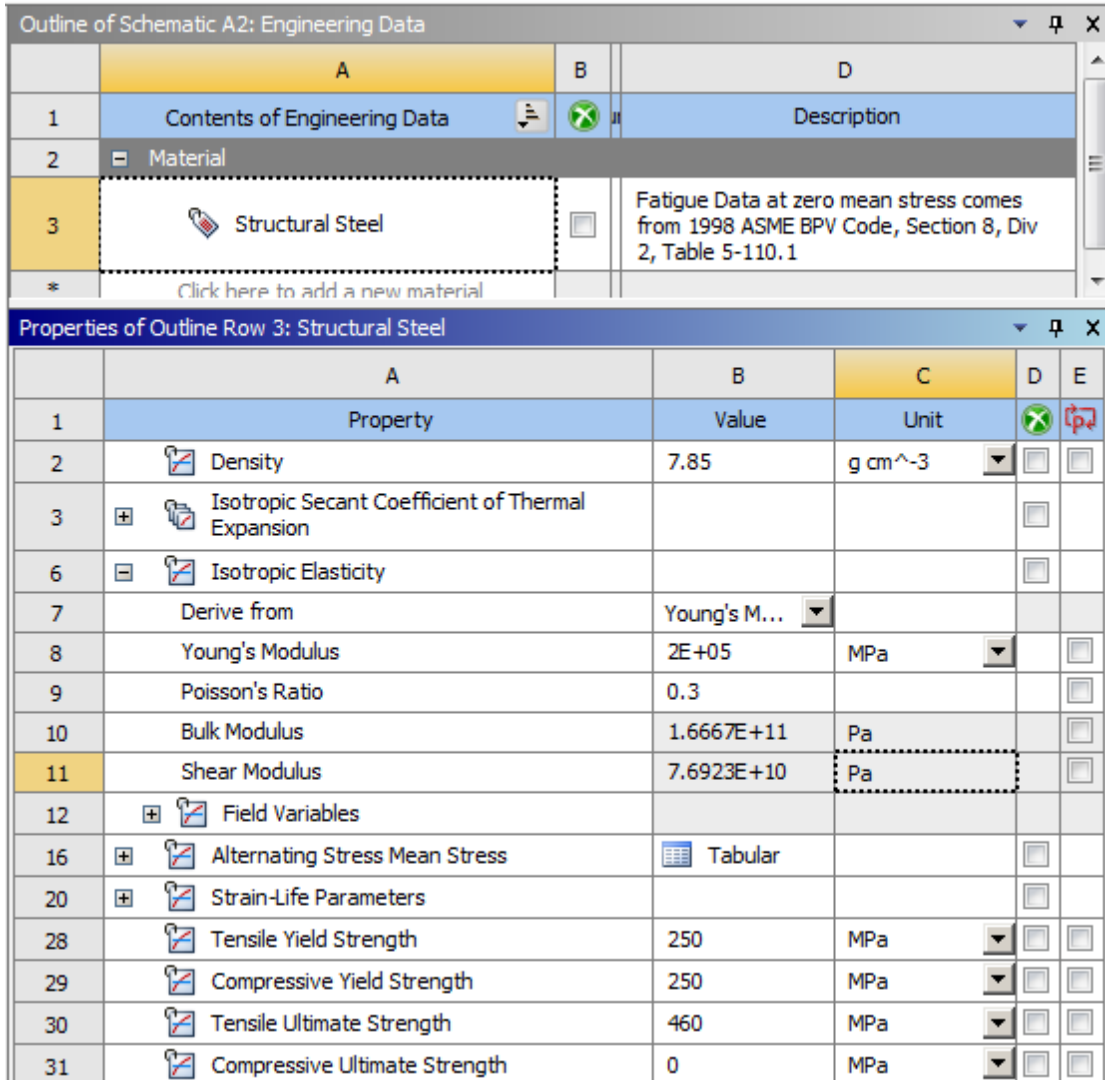


Figure 4-5: Workbench material properties of structural steel

3. Import above 3D model in ANSYS Workbench static structural module for static analysis. After model the conventional leaf spring in Solidwork then save the model CAD file in reader mode, "STEP format" 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 browsed solid model of the steel leaf spring is done on Solidwork saved as "STEP format" form looks like in the following figure.

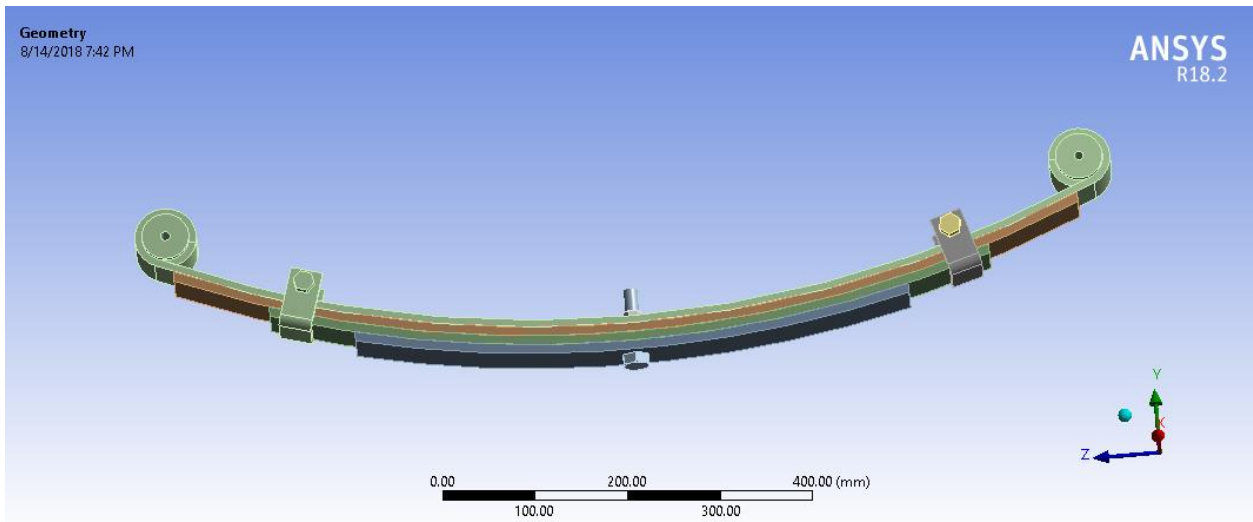


Figure 4-6: The browsed three-dimensional model of steel leaf spring

#### 4. Define contact between leaves of leaf spring

- Contact type: No separation

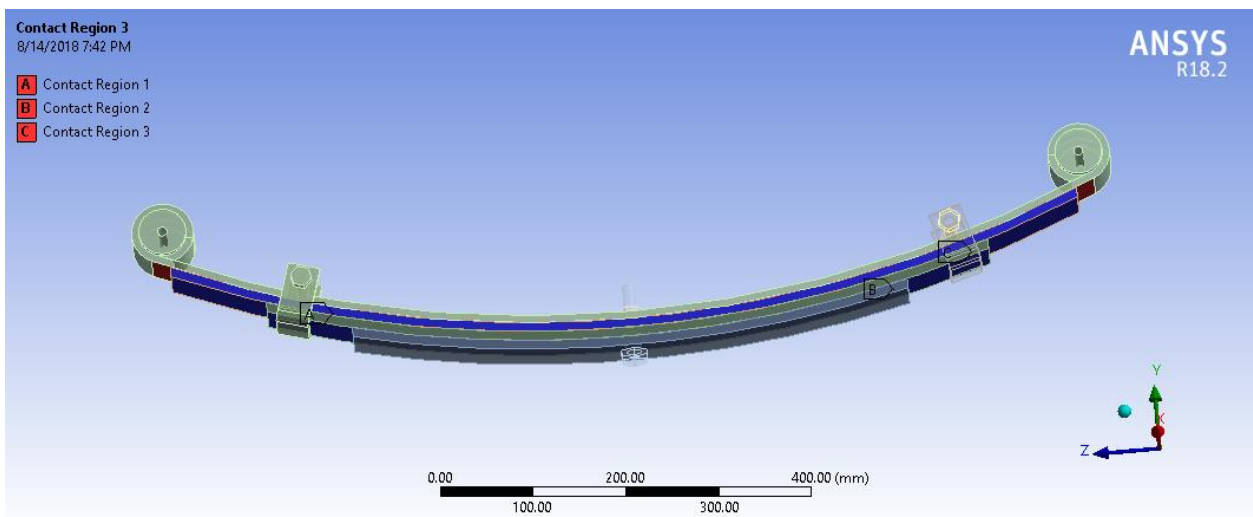


Figure 4-7: Define contact between leaves of steel leaf spring

#### 5. Apply Mesh Controls/Preview Mesh

Meshing is the process in which your geometry is spatially discretized into elements and nodes. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure. The mesh has been generated automatically. The default element size is determined based on a number of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. As shown in figure Number of elements used are 423582 and number of nodes used are 775864.

- Type of meshing: 3D
- Type of elements: Automatic

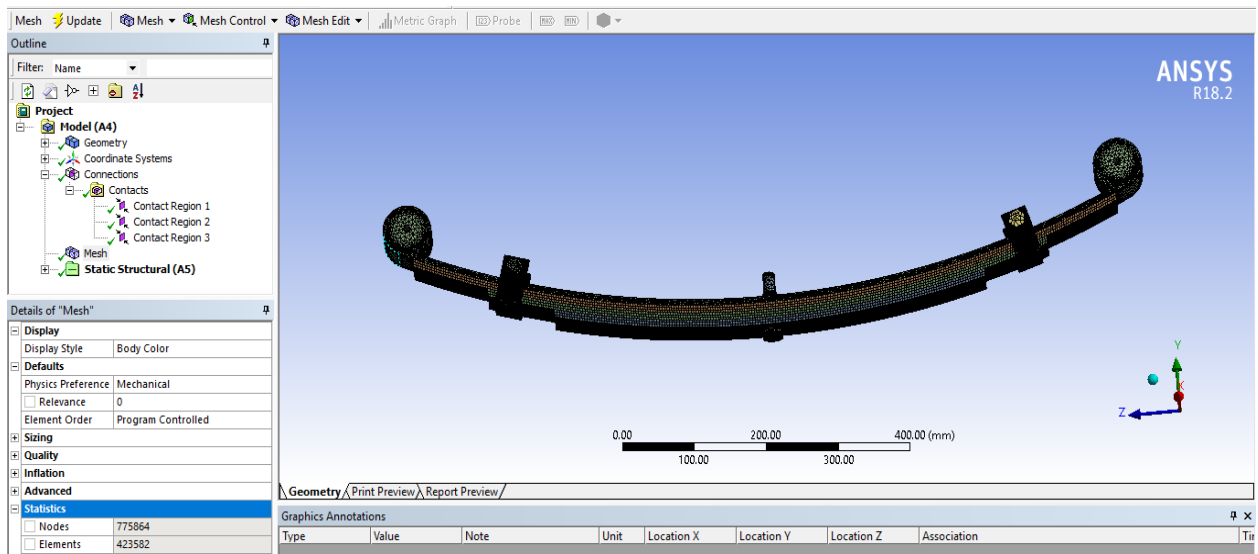


Figure 4-8: Meshed model of steel leaf spring

## 6. Apply boundary condition

- Define displacement constrain

Boundary condition one end remote displacement for component X free, Y and Z fixed and rotation Z free, X and Y fixed and other end remote displacement for component X, Y and Z fixed and rotation Z free, X and Y fixed. Loading conditions involves applying a load upper side at the center of the bottom leaf spring. One end of the leaf spring which rests on the shackle is fixed, while the other end is free. All the translational and rotational degrees of freedom on the fixed end are made to zero. As the front end of the leaf spring is considered, its length is 540 mm.

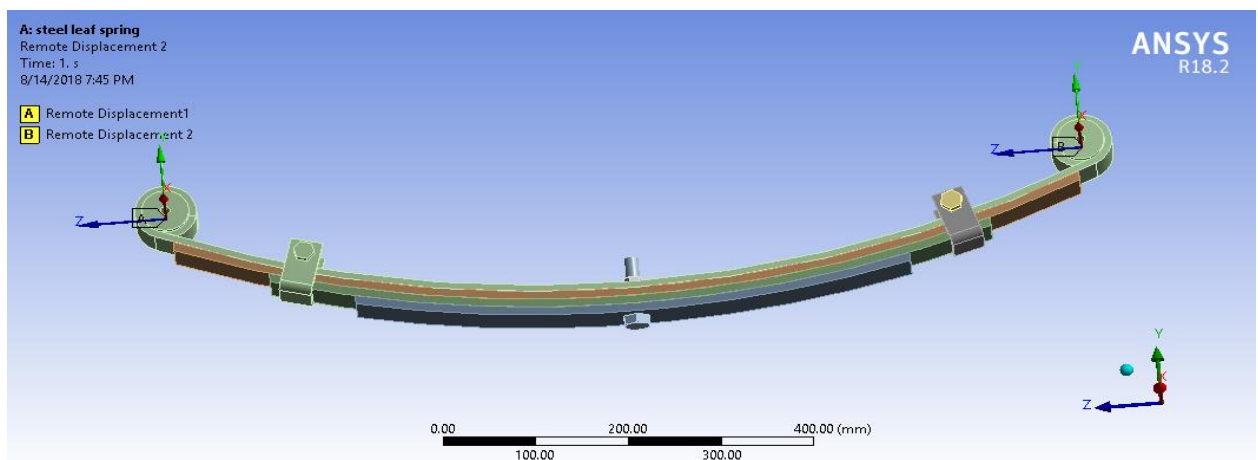


Figure 4-9: Boundary condition of the steel leaf spring

- **Define force constraint**

The FEA model is loaded with a force of 7063.25N at the free end of the leaf spring along the transverse direction as shown on *Figure 4.10*. Both end of the leaf spring which rests on the axle is fixed. All the translational and rotational degrees of freedom on the fixed end are made to zero. As the front end of the leaf spring is considered, its length is 540 mm.

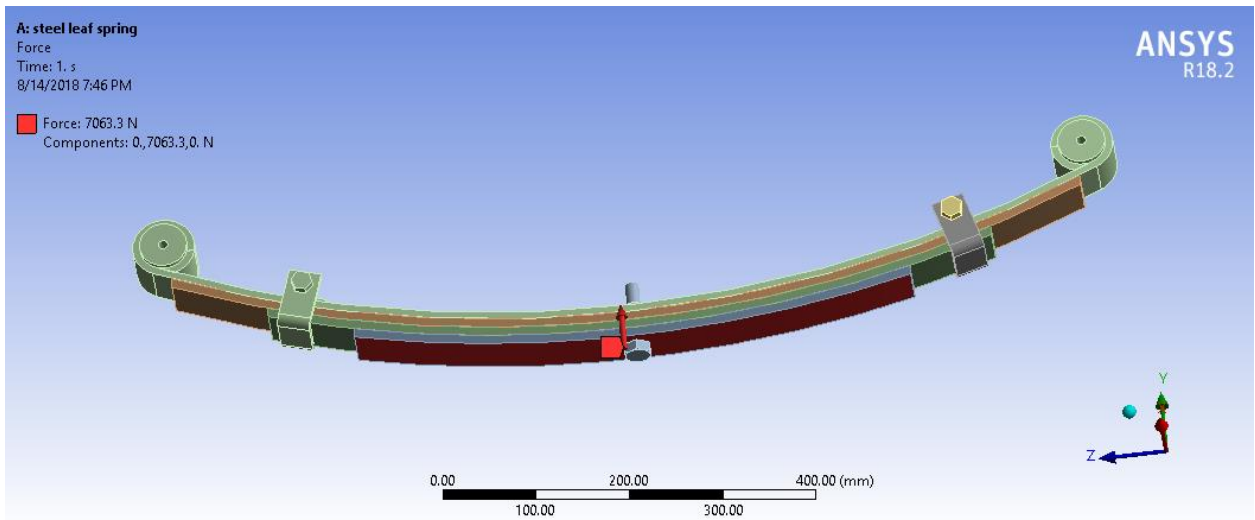


Figure 4-10: Applied load on the center of the steel leaf spring

## 7. 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 output solved by this software. The solution updates continuously and any listing output from the solver provides valuable information on the behavior of the structure during the analysis.

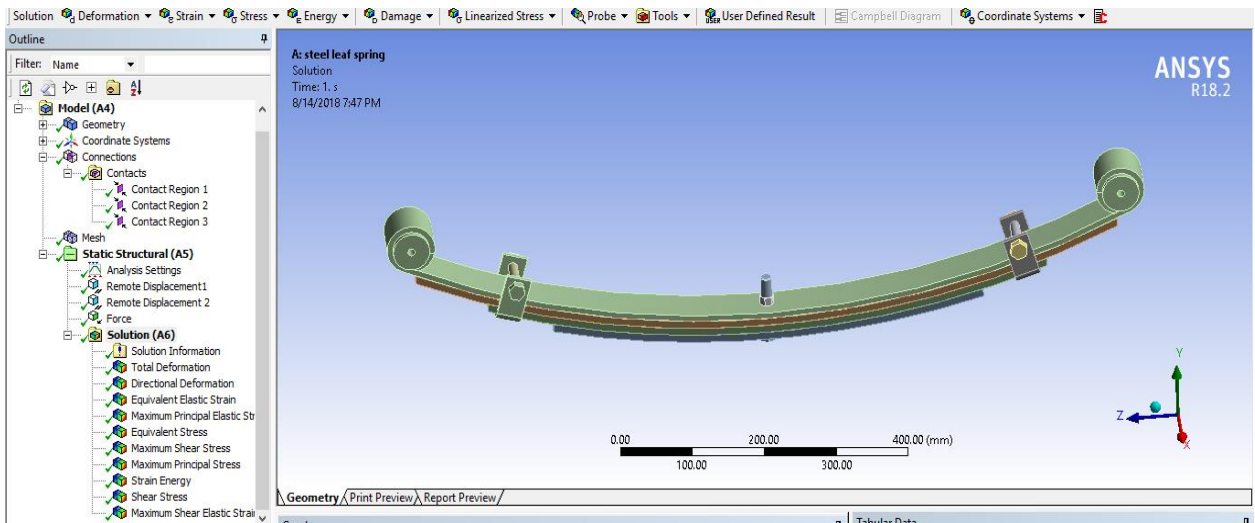


Figure 4-11: Generating solution of steel leaf spring

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 in chapter five.

### 4.2.2 Static analysis of composite leaf spring

➤ **Assumptions:**

- Software to be used for ANSYS 18.2
  - Meshing size is limited to computer compatibilities.
  - Static analysis is considered.
  - Material used for composite leaf spring analysis is woven hybrid composite materials.
1. After solid model of hybrid composite leaf spring in Solidwork 2018. Save that model in STEP format.
  2. Define Properties of hybrid composite material

The specific material properties of the hybrid composite material are stated in the *figure 4.12*.

The screenshot shows the 'Outline of Schematic A2: Engineering Data' and the 'Properties of Outline Row 3: Epoxy Kevlar49 and E- Glass hybrid woven composite' table. The table lists various material properties such as Density, Orthotropic Elasticity (Young's Modulus, Poisson's Ratio, Shear Modulus), and Orthotropic Stress Limits (Tensile and Compressive) with their respective values and units.

Outline of Schematic A2: Engineering Data				
	A	B	C	D
1	Contents of Engineering Data			Source
2	Material			Description
3	Epoxy Kevlar49 and E- Glass hybrid woven composite			C:\Users\Neba\Documen
*	Click here to add a new material			

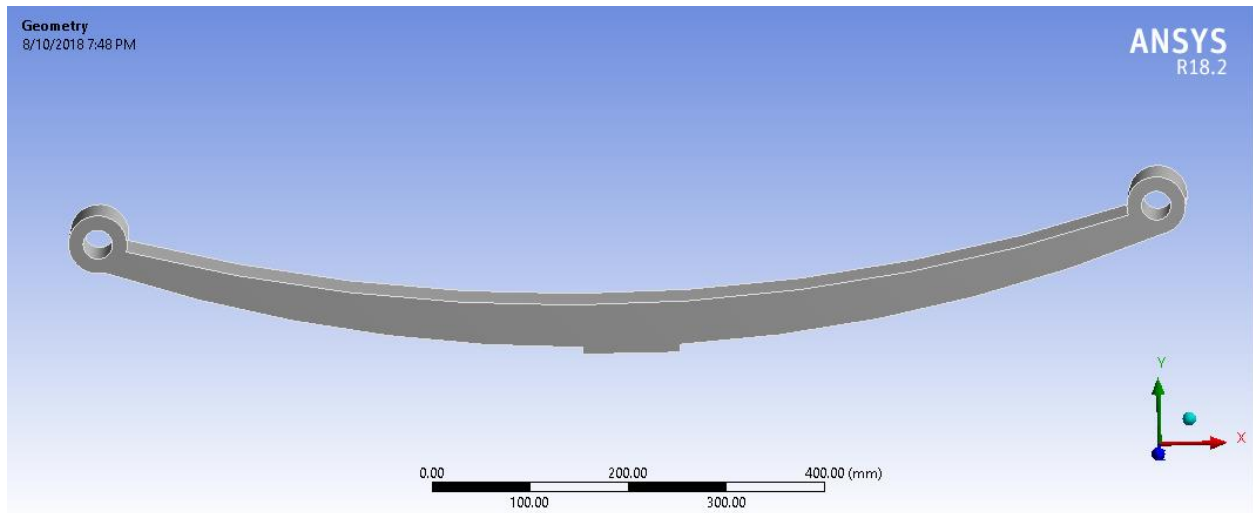
  

Properties of Outline Row 3: Epoxy Kevlar49 and E- Glass hybrid woven composite				
	A	B	C	D
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	1580	kg m <sup>-3</sup>	
4	Orthotropic Elasticity			
5	Young's Modulus X direction	7.058E+09	Pa	
6	Young's Modulus Y direction	7.058E+09	Pa	
7	Young's Modulus Z direction	1.3E+09	Pa	
8	Poisson's Ratio XY	0.3		
9	Poisson's Ratio YZ	0.3		
10	Poisson's Ratio XZ	0.06		
11	Shear Modulus XY	2.7115E+09	Pa	
12	Shear Modulus YZ	2.7115E+09	Pa	
13	Shear Modulus XZ	3.325E+09	Pa	
14	Orthotropic Stress Limits			
15	Tensile X direction	2.7658E+08	Pa	
16	Tensile Y direction	2.7658E+08	Pa	
17	Tensile Z direction	1.72E+07	Pa	
18	Compressive X direction	-2.123E+08	Pa	
19	Compressive Y direction	-2.123E+08	Pa	
20	Compressive Z direction	-7.09E+07	Pa	

Figure 4-12: Workbench material properties of hybrid Kevlar 49 and E- Glass woven composite Materials

3. Import above 3D model in ANSYS Workbench static structural module for static analysis.

After model the conventional leaf spring in Solidwork then save the model CAD file in reader mode, “STEP format” 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 browsed solid model of the steel leaf spring is done on Solidwork saved as “STEP format” form looks like in the following figure.



*Figure 4-13: The browsed 3D model of composite leaf spring*

#### **4. Apply Mesh Controls/Preview Mesh**

Meshing is the process in which the geometry is spatially discretized into elements and nodes. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure. The mesh has been generated automatically. The default element size is determined based on several factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. As shown in figure Number of elements used are 39752 & and number of nodes used are 61702.

- Type of meshing: 3D
- Type of elements: Automatic

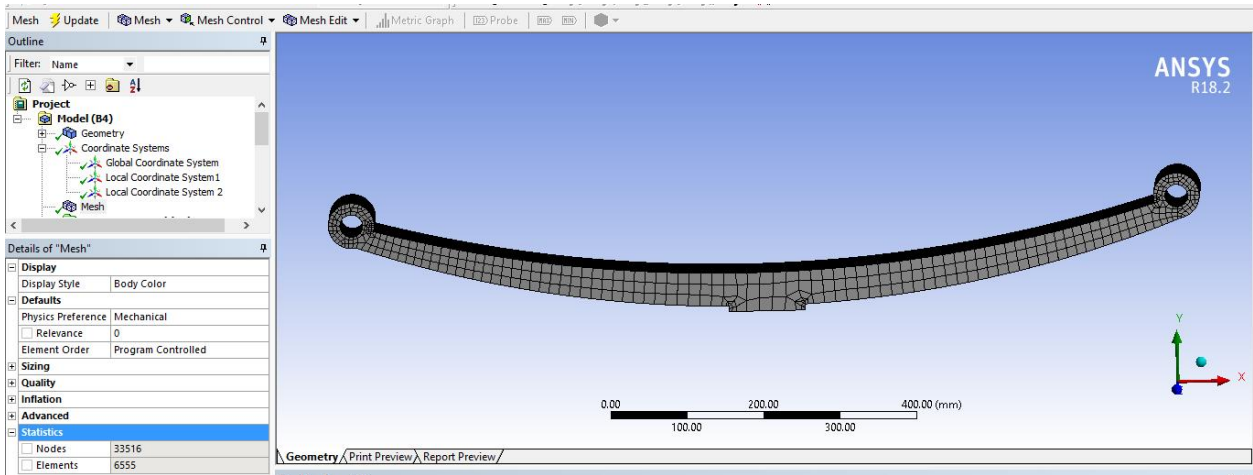


Figure 4-14: Meshed model of steel leaf spring

## 5. Apply boundary condition

- Define displacement constrain

Boundary condition one end remote displacement for component X free, Y and Z fixed and rotation Z free, X and Y fixed and other end remote displacement for component X, Y and Z fixed and rotation Z free, X and Y fixed. Loading conditions involves applying a load upper side at the center of the bottom leaf spring. One end of the leaf spring which rests on the shackle is fixed, while the other end is free. All the translational and rotational degrees of freedom on the fixed end are made to zero. As the front end of the leaf spring is considered, its length is 540 mm.

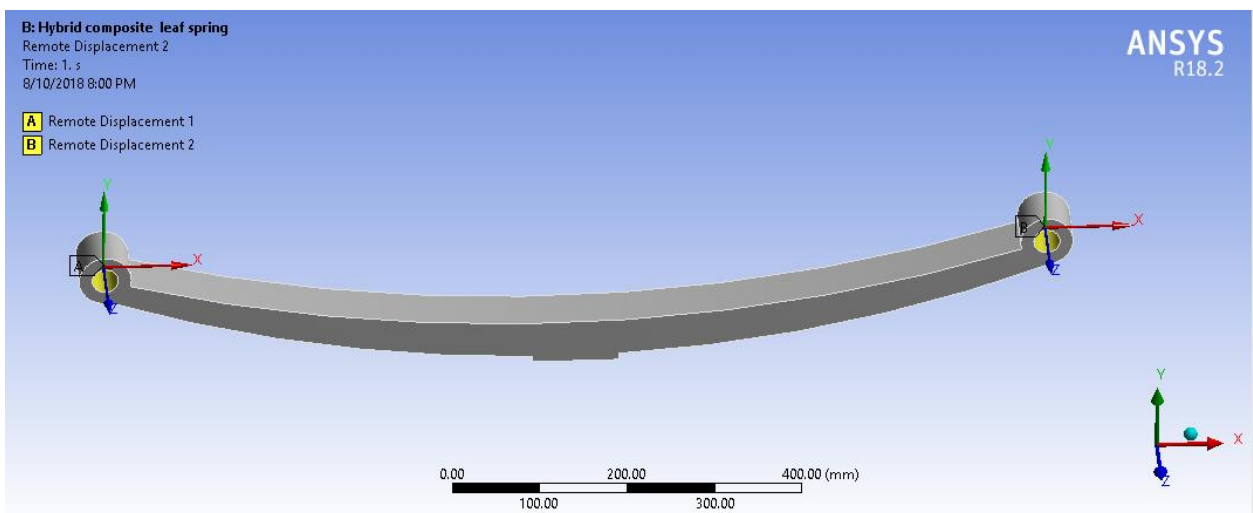


Figure 4-15: Boundary condition of the hybrid composite leaf spring

- Define force constraint

The FEA model is loaded with a force of 7063.3 N at the center of the leaf spring along the transverse direction as shown on figure 4.16. One end of the leaf spring which rests on the axle

is fixed, while the other end is free. All the translational and rotational degrees of freedom on the fixed end are made to zero. As the front end of the leaf spring is considered, its length is 540 mm. The FEA model is loaded with a force of 7063.3 N at the free end of the leaf spring along the transverse direction as shown on figure 4.16

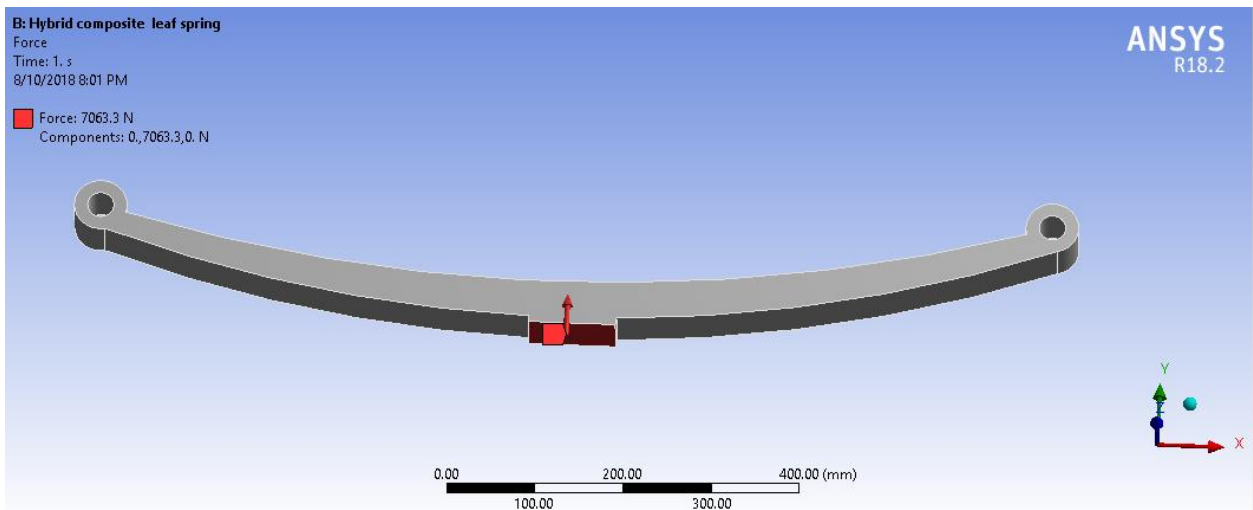


Figure 4-16: Applied load on the center of the hybrid composite leaf spring

## 6. 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 output solved by this software. The solution updates continuously and listing output from the solver provides valuable information on the behavior of the structure during the analysis.

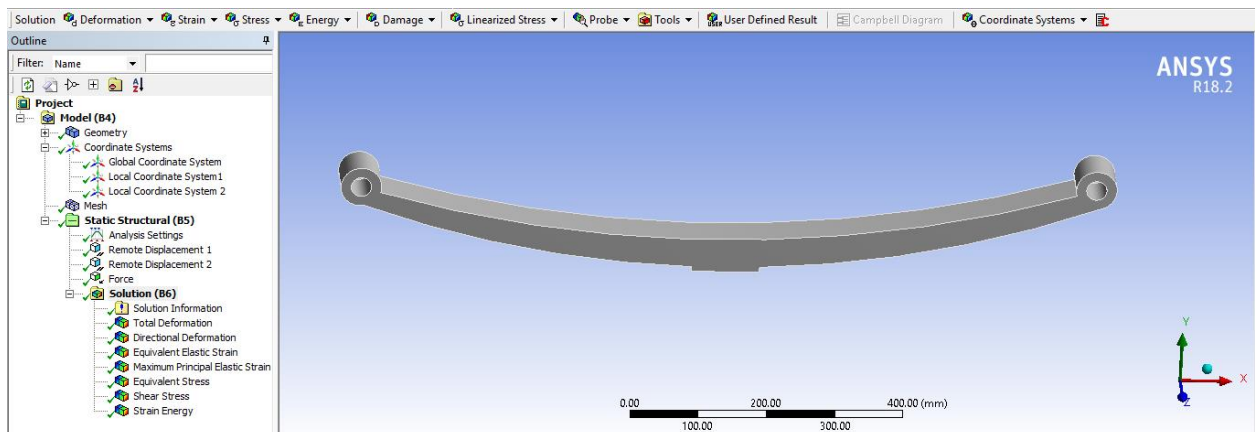


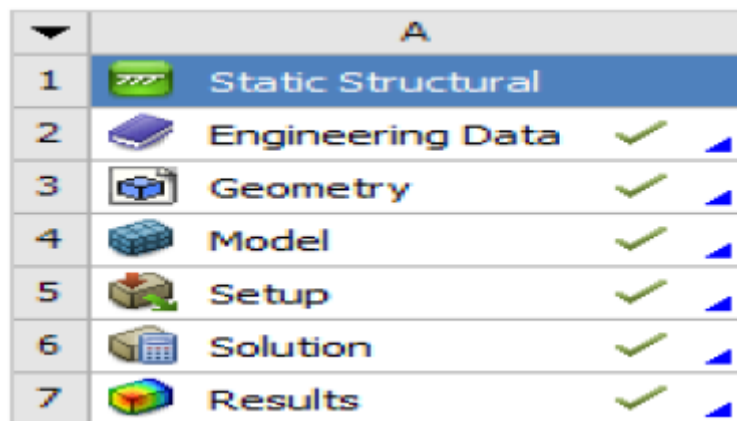
Figure 4-17: Generating solution of hybrid composite leaf spring

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 in chapter five.

## Chapter Five

### 5. Result and Discussion

In this chapter, the results of both laminated hybrid composite and conventional steel leaf spring materials obtained from the static structural analysis is clearly stated. For this study, the leaf spring static structural analysis was performed using finite element method by using ANSYS 18.2 workbench, that consist of a static structure. This is for 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 and boundary conditions. The following typical static structural analysis system of ANSYS 18.2 workbench could be performed one by one to complete the analysis and get an appropriate solution of the problem.



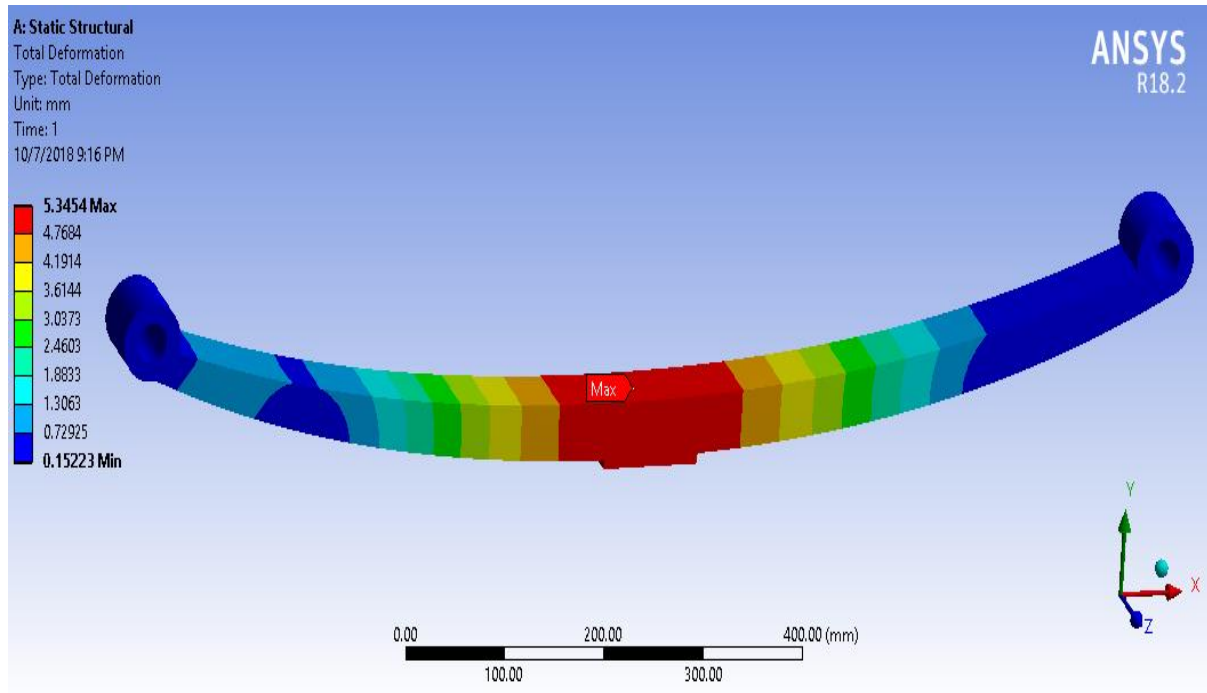
	A	
1	Static Structural	
2	Engineering Data	✓
3	Geometry	✓
4	Model	✓
5	Setup	✓
6	Solution	✓
7	Results	✓

Figure 5-1: ANSYS 18.2 Workbench static structural analysis system

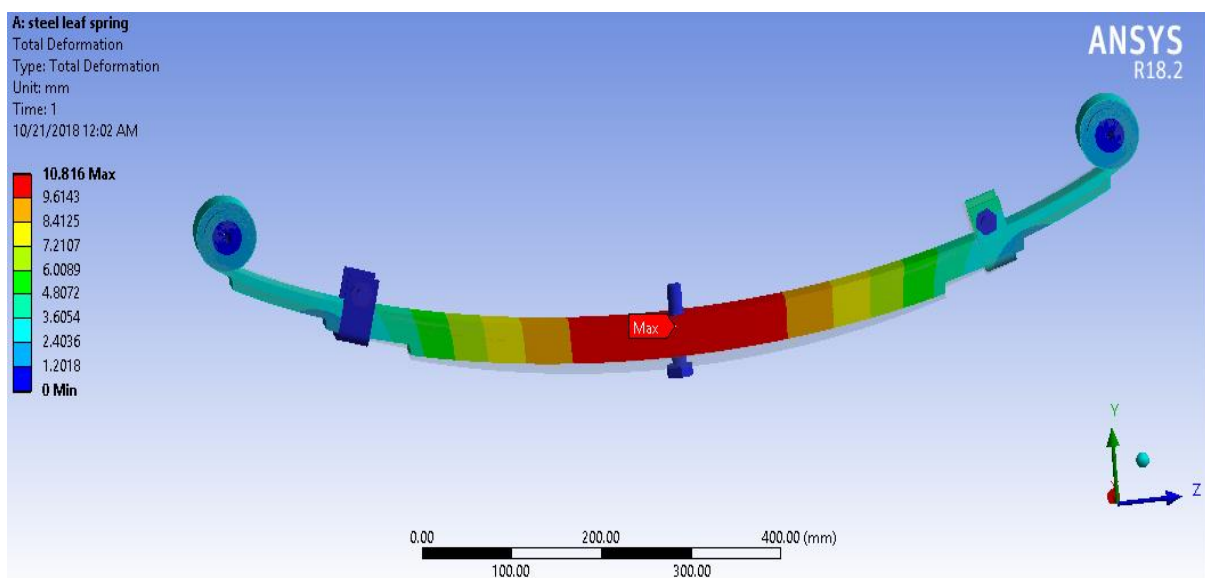
## 1.1 Results

### 5.1.1 Deformation

The total deformation result of both laminated hybrid composite and steel leaf spring of FEA are shown in *figures 5.2* and *figure 5.3* respectively.



*Figure 5-2: Total deformation of hybrid composite leaf spring*



*Figure 5-3: Total deformation of steel leaf spring*

### 5.1.2. Equivalent (von misses) stress

The equivalent (Von- Misses) stress result of both laminated hybrid composite and steel leaf spring of FEA is shown in *figure 5.4* and *figure 5.5* respectively.

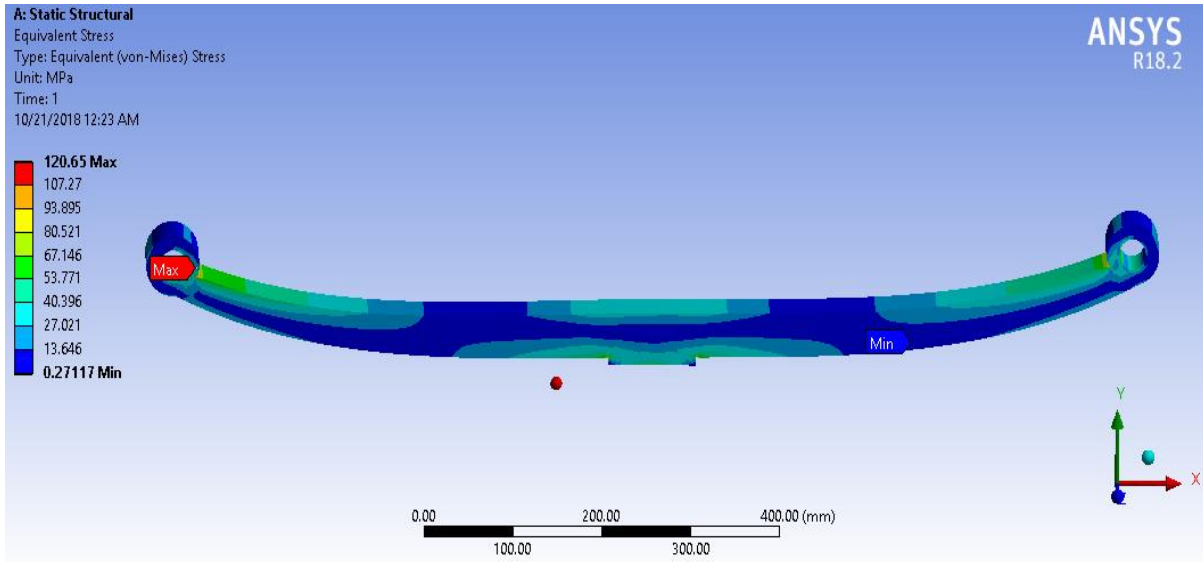


Figure 5-4: Equivalent (Von Mises) stress of hybrid composite leaf spring

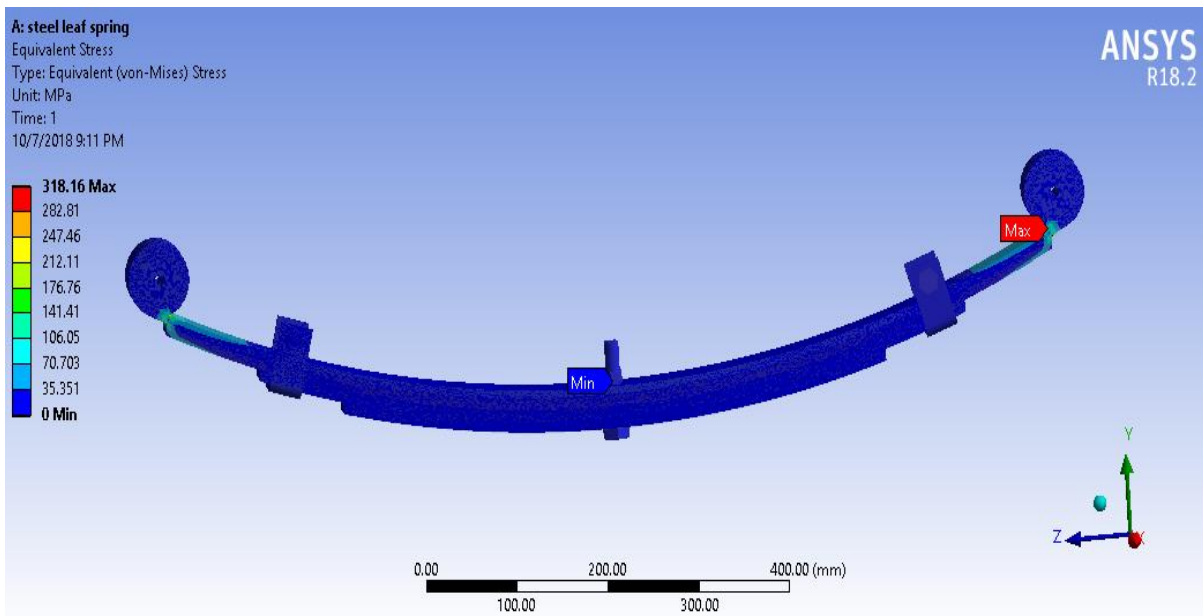


Figure 5-5: Equivalent (Von Mises) stress of steel leaf spring

## 1.2 Discussion

The static structural analysis of leaf spring of a vehicle using laminated hybrid composite and steel material was performed by applying a static load of 7063.3 N on a leaf spring.

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

In this specific research work the comparison between the results of the FEA of these hybrid composite leaf spring and steel leaf spring is carried out by making everything the same, except the thickness and material properties are different; i.e. at the same loading type and magnitude, the same boundary condition, and the same method of FEM analysis.

### 5.2.1. Deformation

From this static structural analysis of ANSYS 18.2 workbench software, it shows that, the maximum displacements of the laminated hybrid composite material leaf spring have the lowest deformation value compare with that of the current conventional steel leaf spring. It is about 50.62% lower than the current conventional steel leaf spring.

### 5.2.2. Equivalent (Von-Misses) stress

Equivalent (Von Misses) stress, computed from equation which is based on distortion energy failure theory. These criteria have effective in the prediction of failure for ductile materials and widely used for designers to check whether their design will withstand a given load condition. Using the ANSYS 18.2 Workbench software, the values of equivalent (Von-Misses) stress found along with the given boundary conditions and applied load of 7063.3N. Then the maximum equivalent (Von-Misses) stress values and the stress reduction are presented in *table 5.1*.

The results of this static structural analysis show that the equivalent (Von-Misses) stress of the laminated hybrid 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 hybrid composite material leaf spring is less stressed, light weight and has a better performance.

### 5.2.3. Weight reduction

The mass of laminated hybrid composite material leaf spring = 3.24 Kg

The mass of conventional steel leaf spring = 9.06 Kg,

Now the percentage reduction of mass becomes:  $(9.06-3.24) \div 9.06 \times 100 = 64.23\%$

The weight of the leaf spring is reduced about 64.23% by replacing conventional steel leaf spring with a laminated hybrid composite material leaf spring.

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

*Table 5:1: Comparison of the FEA results of the laminated hybrid mono composite leaf spring and conventional steel leaf spring.*

Leaf spring based on material	Max. Equivalent stress (Mpa) at 7063.3 N	Max. Total deformation (mm) at 7063.3 N	Mass (Kg)
Laminated hybrid composite leaf spring	120.65	5.34	3.24
Conventional(steel) leaf spring	311.15	10.816	9.06
By percent	61.22	50.62	64.23

The charts plotted in figure 5.6 and 5.7 will show the comparisons of FEA values clearly for both laminated hybrid composite and conventional steel leaf spring. The results are the values obtained from due to an applied load of 7063.3N on a leaf spring.

## Comparison of Deformation

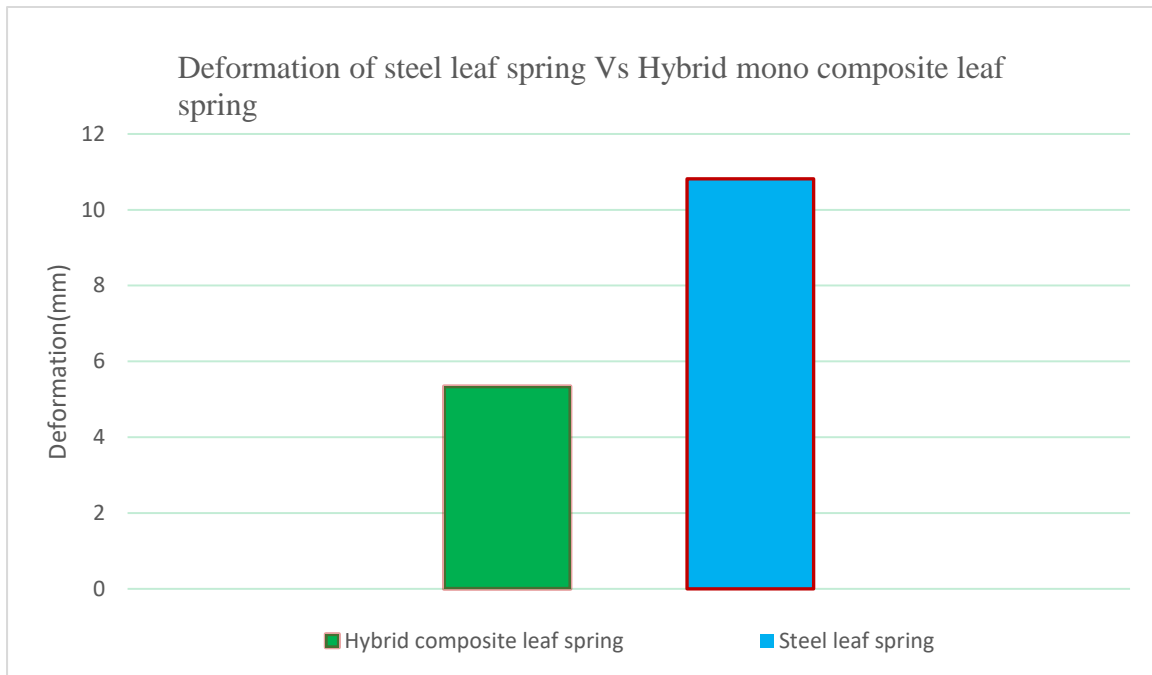


Figure 5-6: Comparison of total deformation of a laminated hybrid composite and steel leaf spring

## Comparison of equivalent stress

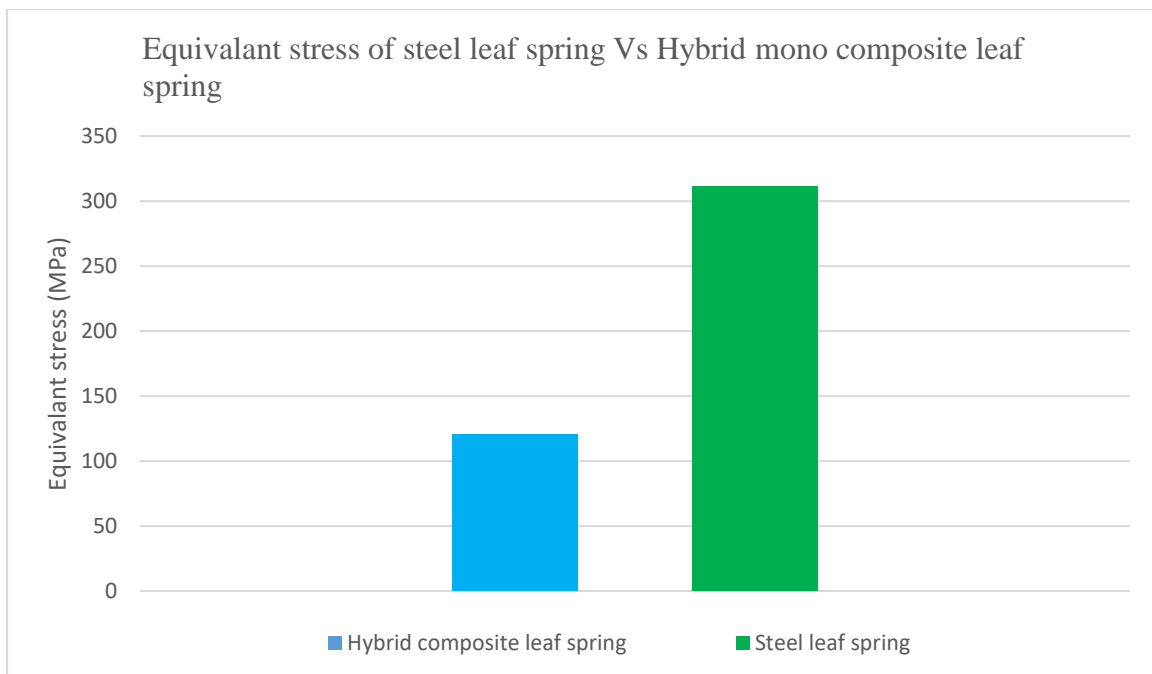
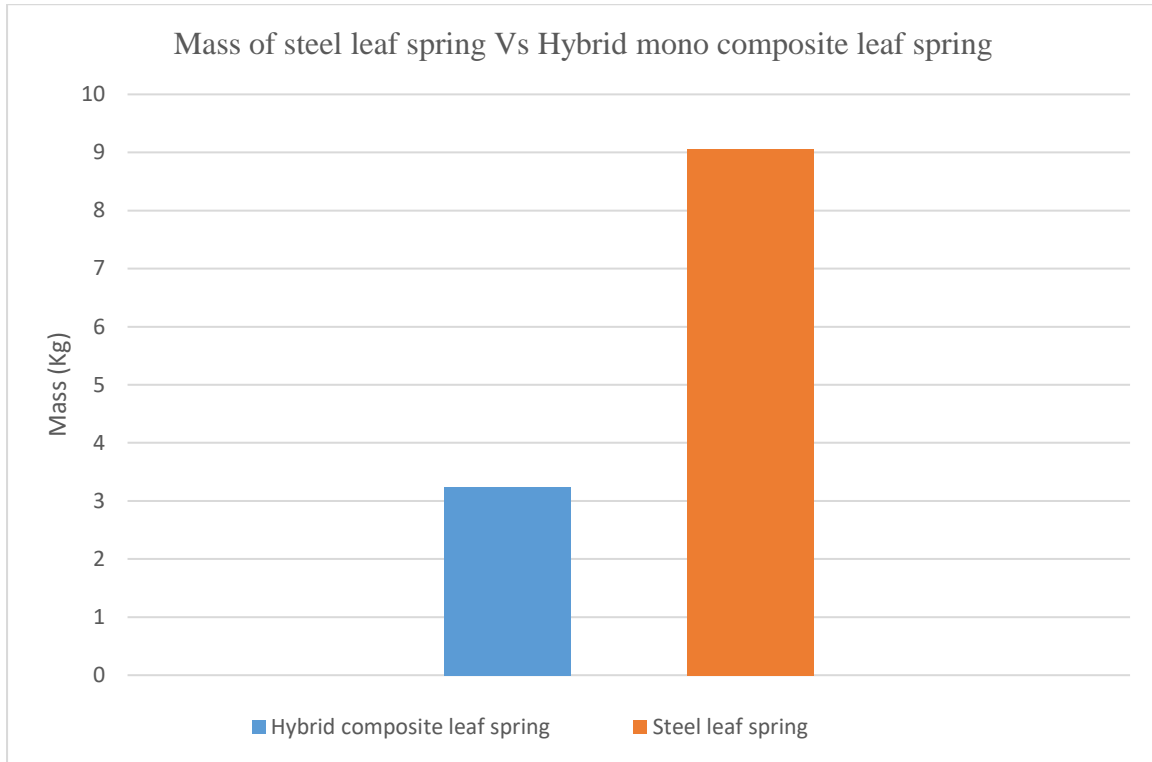


Figure 5-7: Comparison of equivalent stress of a laminated hybrid composite and steel leaf spring



*Figure 5-8: Comparison of weight of a laminated hybrid composite and steel leaf spring*

## 6. Conclusion and Recommendation

### Chapter Six

#### 6.1 Conclusion

The hybrid fiber reinforced epoxy composite was manufactured and its mechanical performance such as the tensile, compression and flexural properties are determined using experimentally. These fundamental properties are the confirmation of the reliability of the material and of its usage for leaf spring application. From experimental test result, material A has high flexural and compressive strength and material B has high tensile strength.

The design and static structural analysis of steel leaf spring and composite leaf spring has been carried out. Comparison has been made between hybrid composite leaf spring with steel leaf spring having same design and same load carrying capacity. The stress and displacements have been calculated analytically as well as using ANSYS 18.2 for steel leaf spring and hybrid composite leaf spring. From the static analysis results, it is found that there is a maximum deformation of 10.81 mm in the steel leaf spring and the corresponding displacements in hybrid composite leaf spring is 5.33 mm.

From the static analysis results, the von-mises stress in the steel leaf spring is 311.15 MPa and in hybrid composite leaf spring is 120.65 MPa. These indicates that composite material A has higher resistance to the applied load.

A comparative study has been made between steel and hybrid composite leaf spring with respect to strength and weight. Hybrid composite leaf spring reduces the weight by 64.23% over steel leaf spring. The size optimization has been carried out for further mass reduction of composite leaf spring. The stresses in the composite leaf spring are much lower than that of the steel. Of course, the reduction is attributed to lower elastic modulus and better geometric (free of notch) characteristics of the composite materials.

#### 6.2 Recommendation

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 speed becomes very slow. Then to maintain light weight, fuel efficient and high-speed vehicle design, selecting composite materials is the only best decision.

Finally, it is recommended that laminated hybrid composites mono leaf springs are suitable for vehicle leaf spring applications.

### **6.3 Future Scope**

Generally, working on composite materials have several advantages. From this point of view, regarding laminated hybrid composite leaf spring several things will improve in the future which didn't address in this research.

Therefore; the following research areas are recommended for future studies

#### **1. Study of effects of different resins on the performance of leaf spring:**

In this research work general purpose epoxy (GPE) is used for manufacturing the leaf spring instead of GPE, polyester, vinyl ester etc. can be used to study effects of different resin on the performance of composite leaf spring.

#### **2. Study of effects of temperature on the stress and strain of the leaf spring material:**

As environment temperature increases, the stresses of E-Glass and Kevlar<sup>49</sup> fiber get reduced hence the effect of temperature on the performance of the spring material is an important part of study.

#### **3. Designing the leaf spring by changing the orientation and types of the fiber and ply.**

#### **4. Dynamic analysis and design of laminated hybrid composite mono leaf spring.**

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## Appendix

### Appendix A

In this appendix the composite laminate staking sequence is shown clearly by using HyperWork software.

#### 1. Introduction to HyperWork

HyperWork is a complete package solution of CAE by ALTAIR Engineering. The package includes pre-processor, post-processor and solver. HyperWork package includes software's like

- Hypermesh
- HyperView
- Hypergraph
- Hypermath, etc.

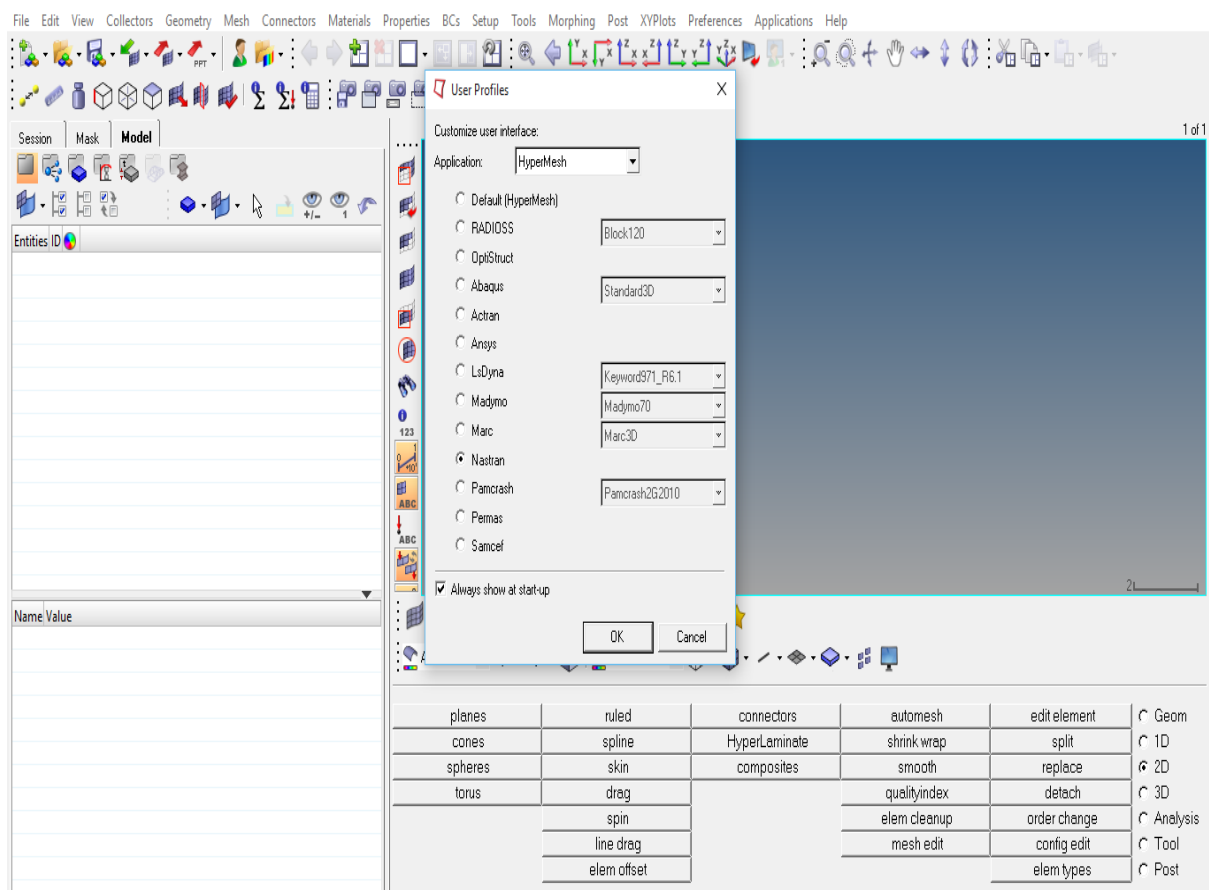


Figure A 1: General interface of HyperWork

### Input material

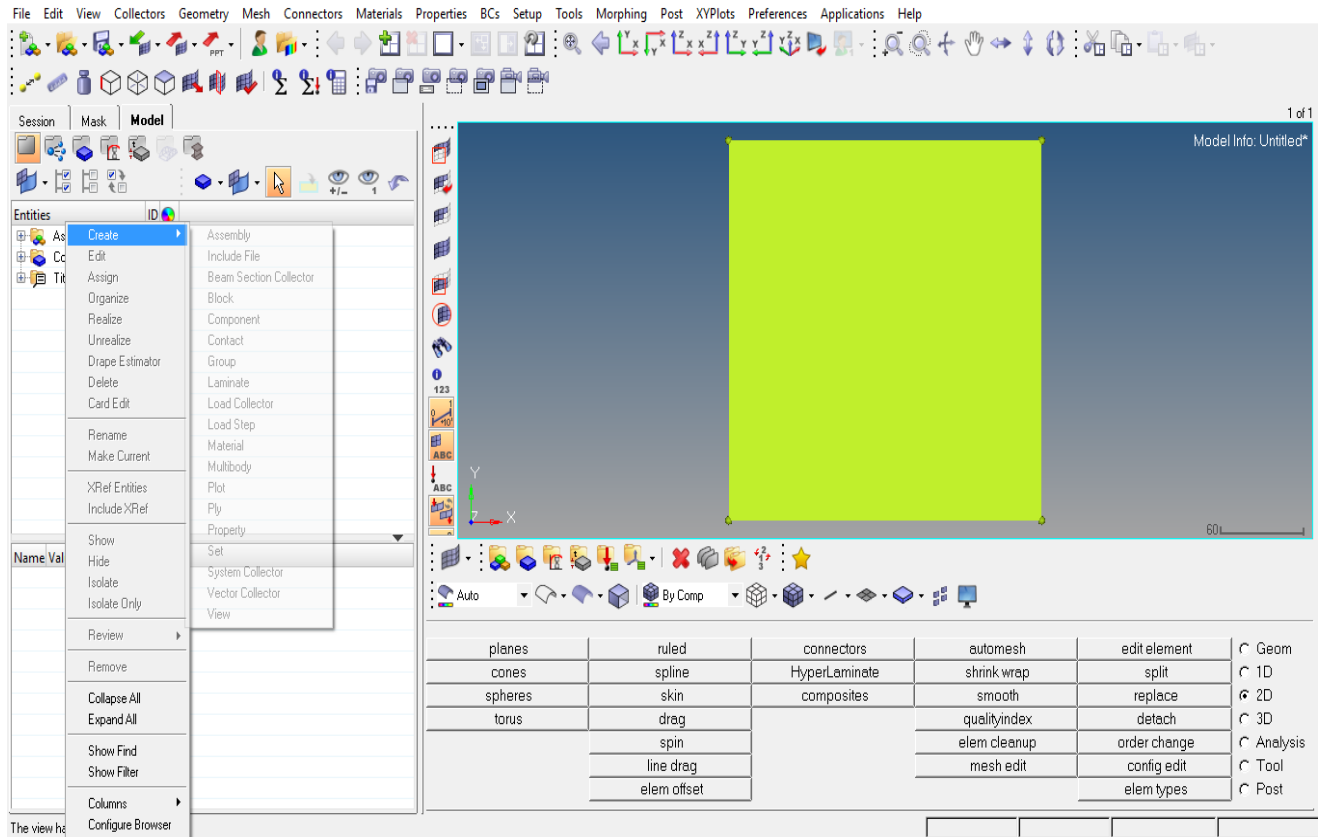


Figure A 2: Input materials in HyperWork

### Input ply in HyperWork

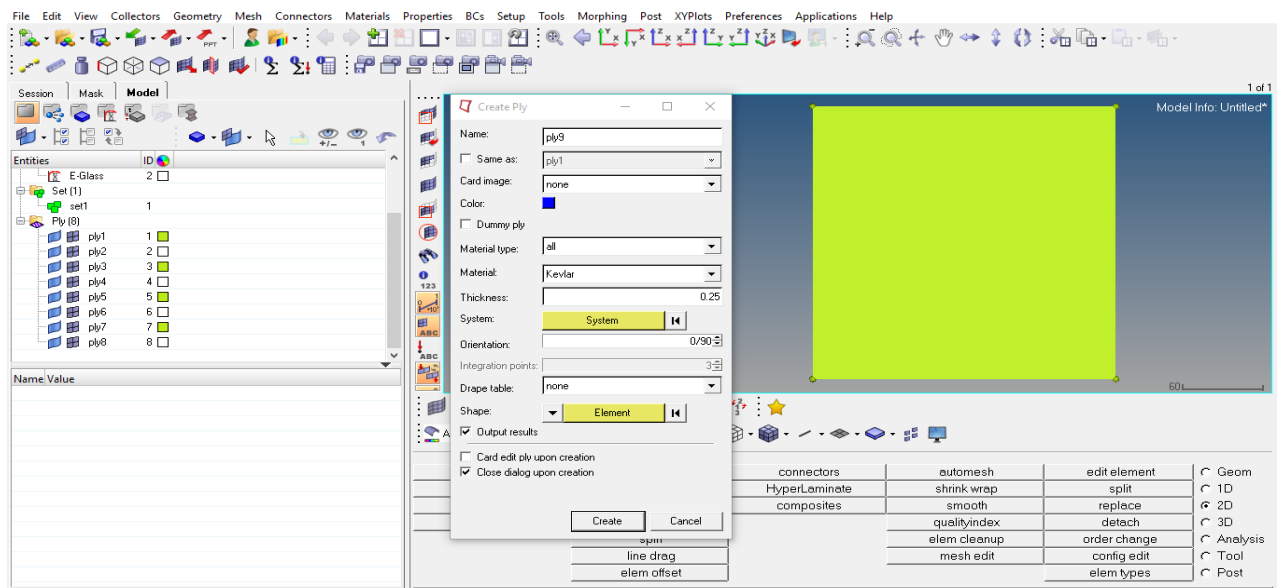


Figure A 3: Input ply in HyperWork

### Crate laminate in HyperWork

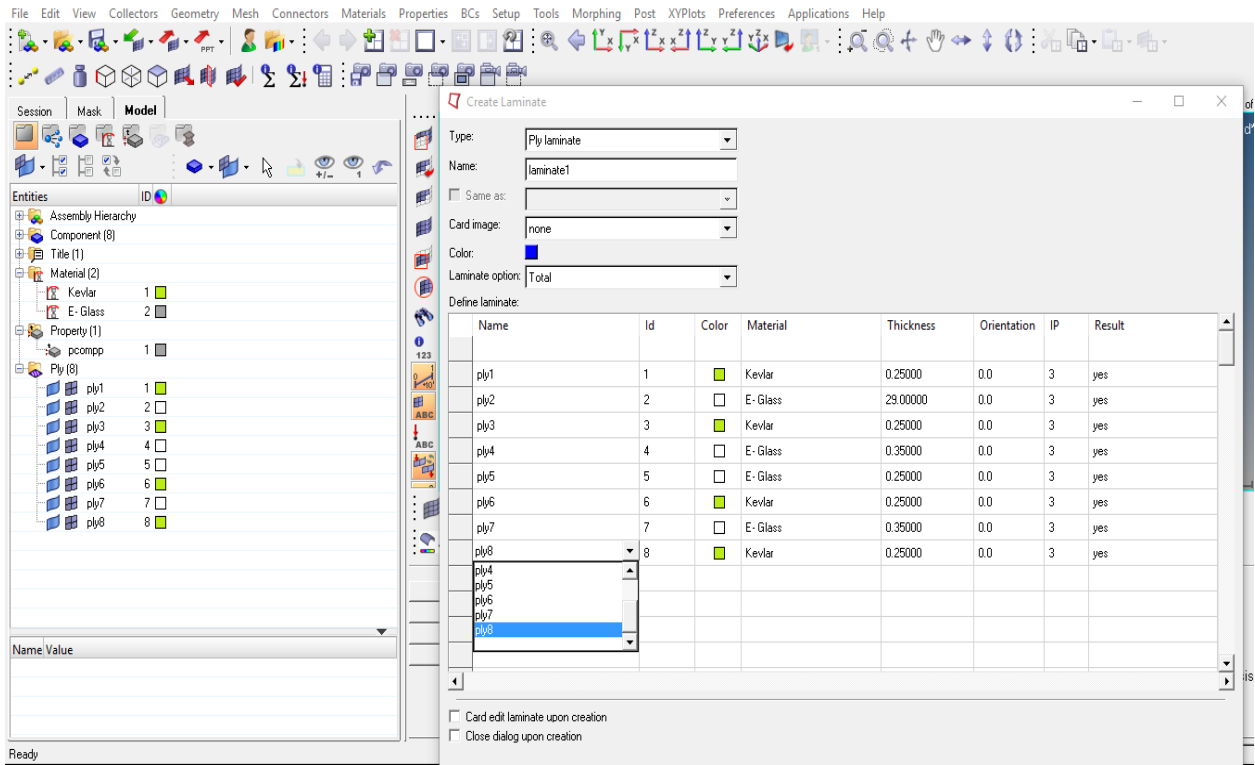


Figure A 4: Crate laminate in HyperWork

### Symmetric laminated composite plate

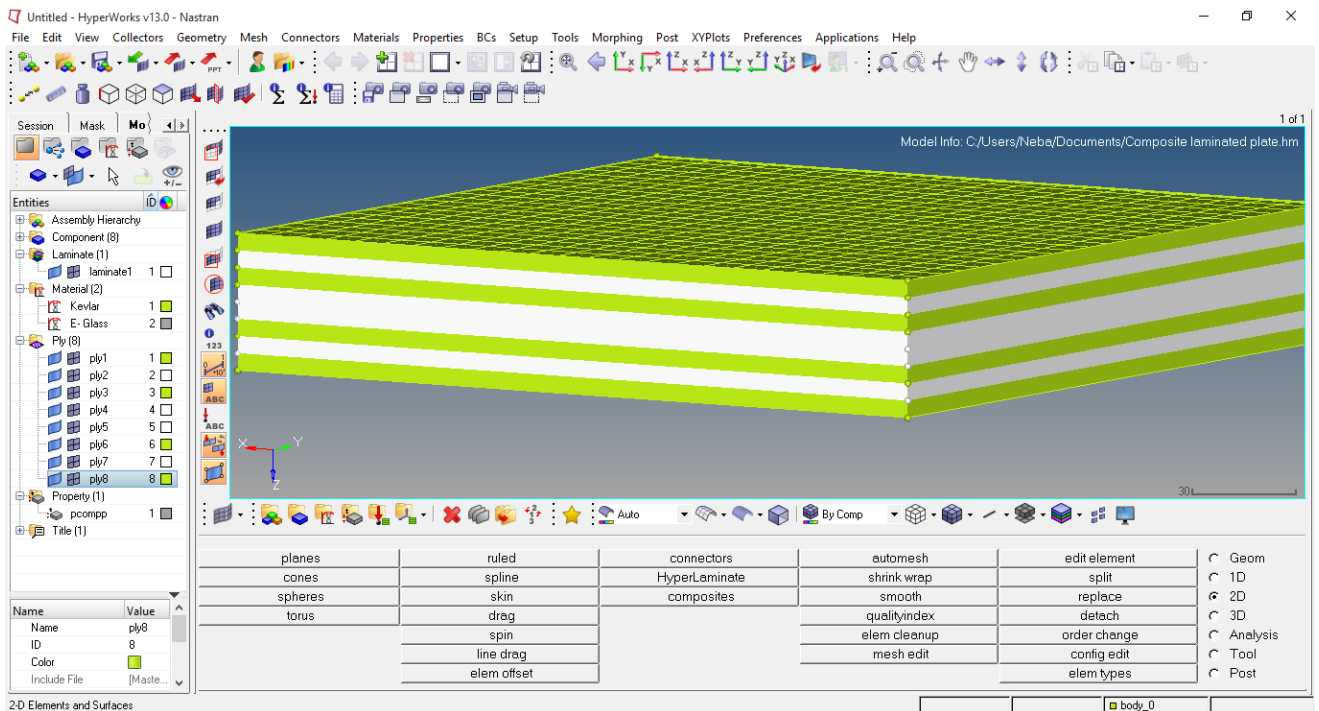


Figure A 5: Symmetric laminate composite

## Appendix B

### 1. Datasheets

In this appendix, all the data have been collected during the laboratory specimens' testing were provided.

*Table B 1: Tensile strength test result*

Material type A			
Area		Extensometer gage length	
80mm <sup>2</sup>		79mm	
Sample No.	F <sub>max</sub> (N)	σ <sub>max</sub> (MPa)	E (GPa)
1	22414.91	280.18	7.0053
2	21316.24	266.45	6.909
3	20486.86	256.08	6.3595
4	23158.13	289.47	6.3624
5	23253.47	290.66	8.6253
Mean	22125.92	276.58	7.0523
S.D		8.37	0.83
C.V		70.09	0.69

Material type B			
Area		Extensometer gage length (mm)	
80mm <sup>2</sup>		79	
Sample No.	F <sub>max</sub> (N)	σ <sub>max</sub> (MPa)	E (GPa)
1	31510.73	393.88	9.3413
2	31944.52	399.36	8.8165
3	30894.18	386.17	7.6358
4	31140.74	389.25	9.3146
5	30335.31	379.19	11.063
Mean	31165.1	389.56	9.23424
S.D		6.83	0.8
C.V		46.76	0.64

Material type C			
Area		Extensometer gage length (mm)	
80mm <sup>2</sup>		79	
Sample No.	F <sub>max</sub> (N)	σ <sub>max</sub> (MPa)	E (GPa)
1	27067.01	338.33	5.3655
2	26660.91	333.26	8.6708
3	27222.65	340.28	8.5627
4	28123.23	351.54	9.6618
5	25608.58	320.17	6.6147
Mean	26936.48	336.761	7.775
S.D		7.58	0.82
C.V		57.54	0.675

Material type D			
Area		Extensometer gage length (mm)	
80mm <sup>2</sup>		79	
Sample No.	F <sub>max</sub> (N)	σ <sub>max</sub> (MPa)	E (GPa)
1	24478.624	305.98	7.7459
2	23447.857	293.09	6.8498
3	22945.283	286.81	7.0319
4	24084.455	301.05	7.0217
5	24789.747	309.87	7.093
Mean	23949.19	299.36	7.1484
S.D		8.4	0.31
C.V		70.79	0.095

Table B 2: Compression strength test result

Material type A		
Area = 52mm <sup>2</sup>		
Sample No.	F <sub>max</sub> (N)	σ <sub>com. max</sub> (Mpa)
1	12155	227.5
2	12325	230.7
3	12725	238.4
4	11875	226.3
5	12125	226.9
Mean	12241	239.9
S.D		4.48
C.V		20.11

Material type B		
Area = 52mm <sup>2</sup>		
Sample No.	F <sub>max</sub> (N)	σ <sub>com. max</sub> (Mpa)
1	10900	209.6
2	11200	215.3
3	10700	205.7
4	11060	212.6
5	10730	206.3
Mean	10918	209.9
S.D		3.66
C.V		13.42

Material type C		
Area = 52mm <sup>2</sup>		
Sample No.	F <sub>max</sub> (N)	σ <sub>com. max</sub> (MPa)
1	11979	230.3
2	11550	222.1
3	11900	228.8
4	11300	217.3
5	11881	228.4
Mean	11722	225.4
S.D		4.9
C.V		24.21

Material type D		
Area =52mm <sup>2</sup>		
Sample No.	F <sub>max</sub> (N)	σ <sub>com. max</sub> (Mpa)
1	12300	236.5
2	11850	227.8
3	11920	229.2
4	12250	235.5
5	11300	217.3
Mean	11924	229.3
S.D		6.8
C.V		47.3

Table B 3: Flexural strength test result

Material type A			
Area =52mm <sup>2</sup>		Support span of specimen=120mm	
Sample No.	F <sub>max</sub>	σ <sub>b.max</sub> (MPa)	E <sub>b max</sub> (MPa)
1	302.84	285.16	52.42
2	355.45	307.6	55.78
3	314.42	296.07	57.4
4	320.06	301.38	48.34
5	244.84	211.88	62.32
Mean	307.52	280.41	55.25
S.D		8.2	4.7
C.V		67.84	22.13

Material type B			
Area=52mm <sup>2</sup>		Support span of specimen=120mm	
Sample No.	F <sub>max</sub>	σ <sub>b. max</sub> (GPa)	E <sub>b max</sub> (MPa)
1	161.12	139.82	50.06
2	140.03	121.17	57
3	148.11	128.53	59.15
4	124.22	143.15	54.709
5	233.38	201.96	49.43
Mean	161.37	146.92	54.06
S.D		8.7	3.8
C.V		77.33	14.48

Material type C			
Area=52mm <sup>2</sup>		Support span of specimen=120mm	
Sample No.	F <sub>max</sub>	σ <sub>b. max</sub> (GPa)	E <sub>b max</sub> (MPa)
1	212.68	184.12	42.23
2	215.42	186.42	46.74
3	269.79	233.47	40.56
4	194.6	168.46	37.41
5	193.88	167.78	39.83
Mean	217.27	188.05	41.35
S.D		7.46	3.1
C.V		55.72	9.65

Material type D			
Area =52mm <sup>2</sup>		support span of specimen=120mm	
Sample No.	F <sub>max</sub>	σ <sub>b. max</sub> (GPa)	E <sub>b max</sub> (MPa)
1	317.35	274.63	32.67
2	250.9	217.15	28.45
3	229.99	198.63	30.25
4	257.73	223.05	34.42
5	238.46	206.37	31.83
Mean	258.88	224	31.52
S.D		9.9	2
C.V		98.27	4.17

## Appendix C

### ANSYS results

#### 1. Directional deformation

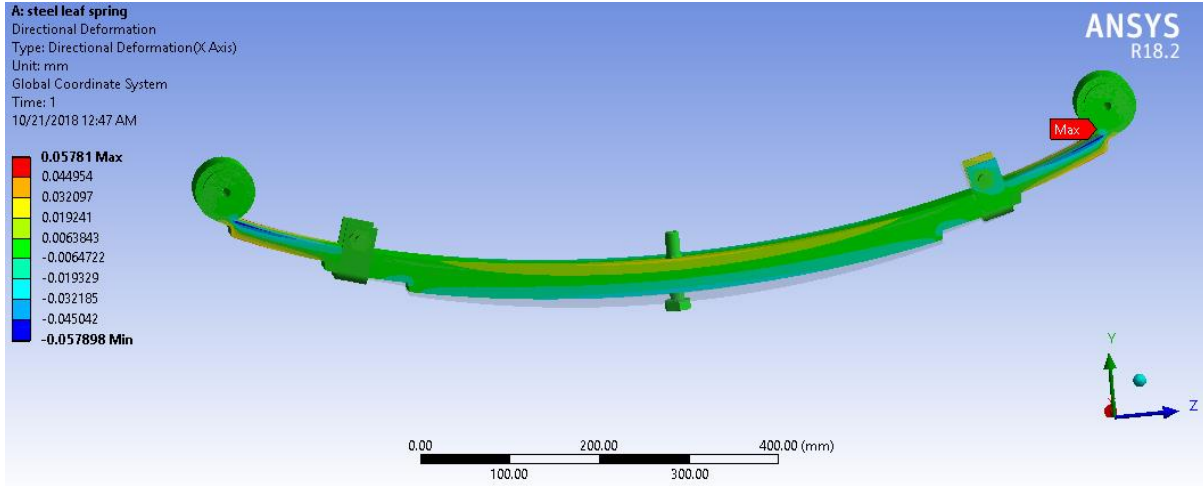


Figure C 1: Directional deformation of steel leaf spring

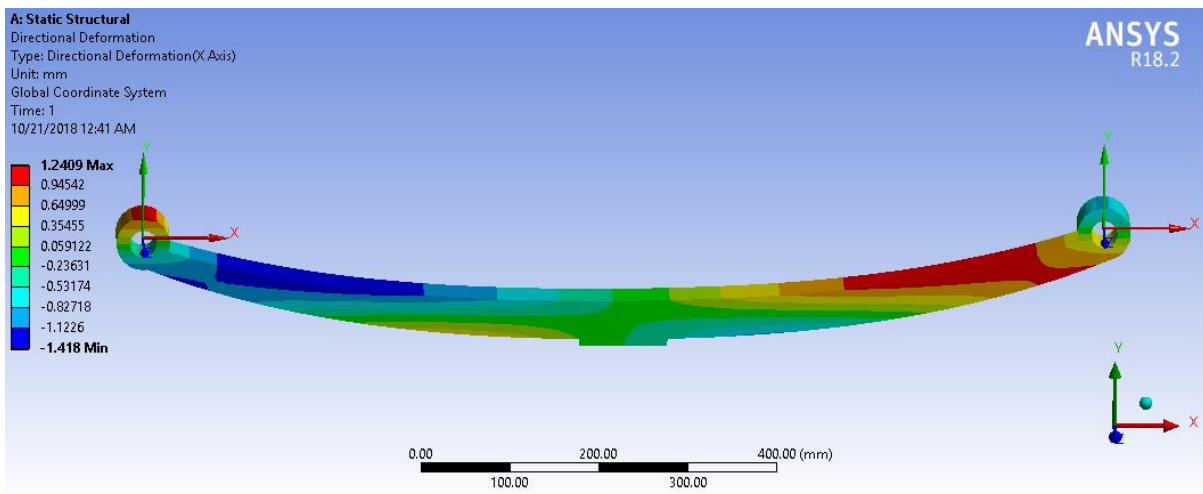


Figure C 2: Directional deformation of hybrid composite leaf spring

## 2. Equivalent elastic strain

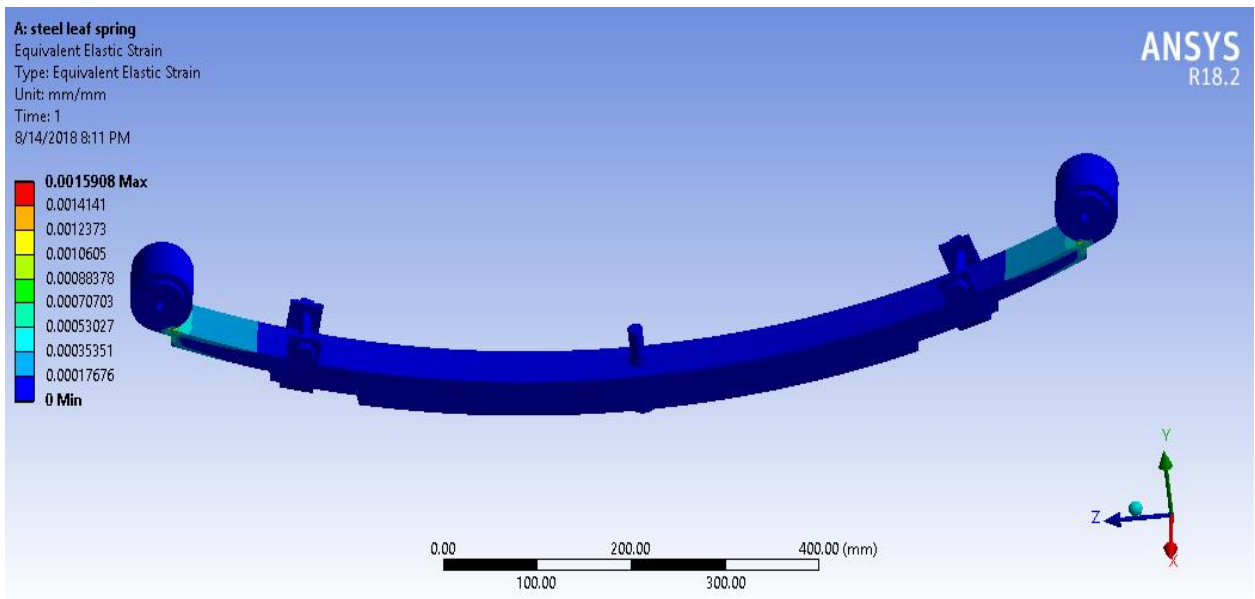


Figure C 3: Equivalent elastic strain of steel leaf spring

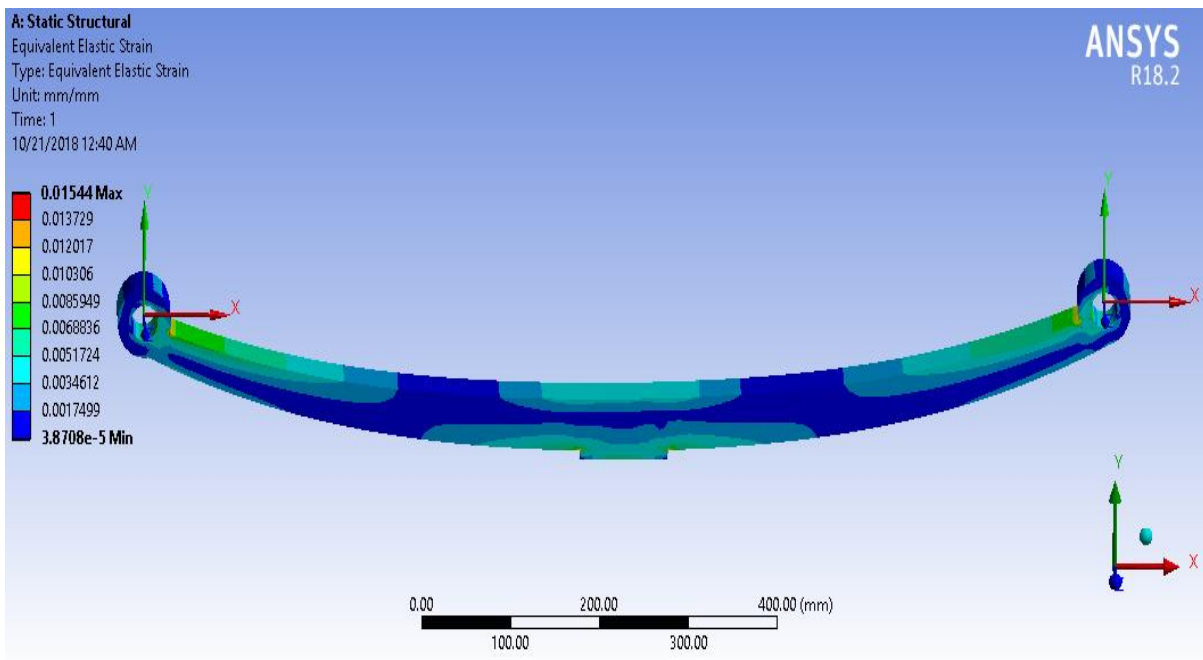


Figure C 4: Equivalent elastic strain of hybrid composite leaf spring

### 3. Maximum principal elastic strain

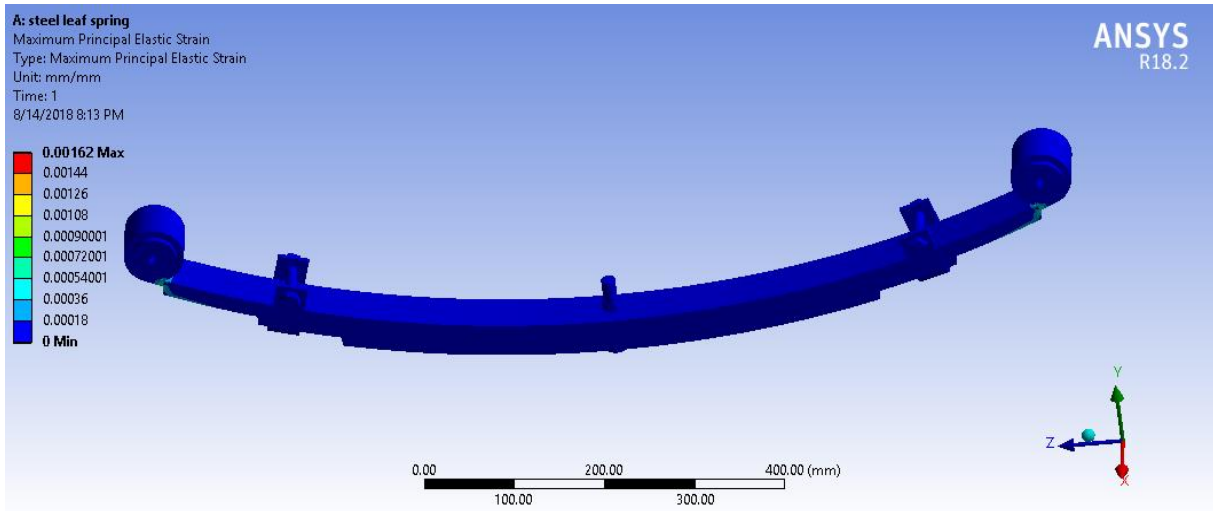


Figure C 5: Maximum principal elastic strain of steel leaf spring

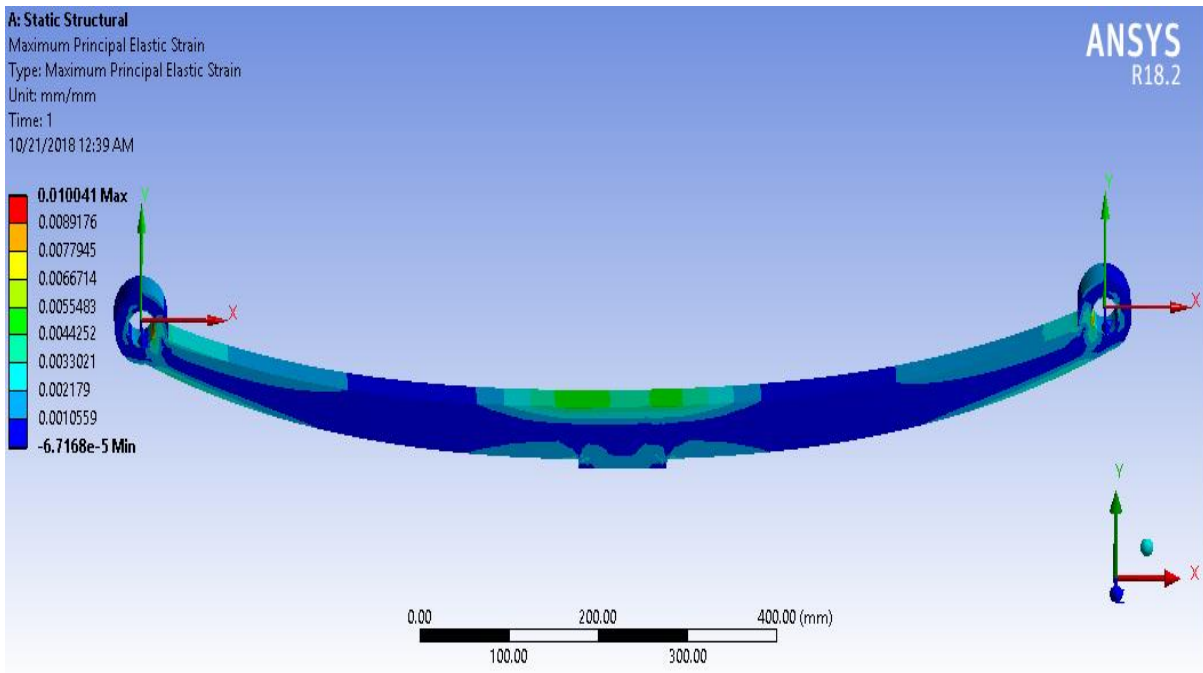


Figure C 6: Maximum principal elastic strain of hybrid composite leaf spring

#### 4. Strain energy

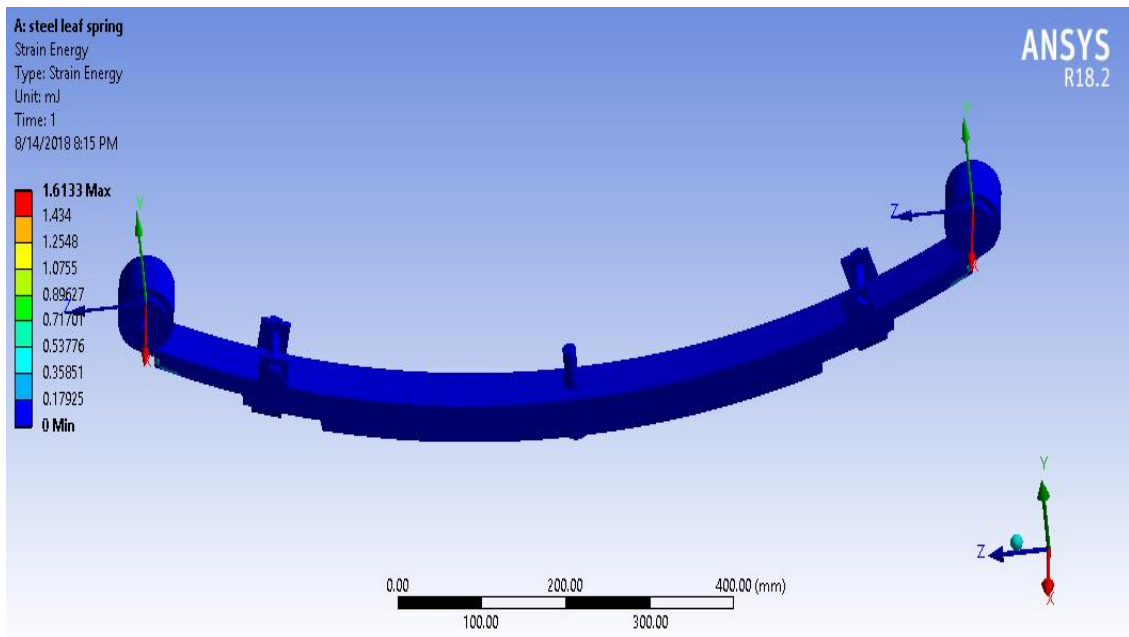


Figure C 7: Strain energy of steel leaf spring

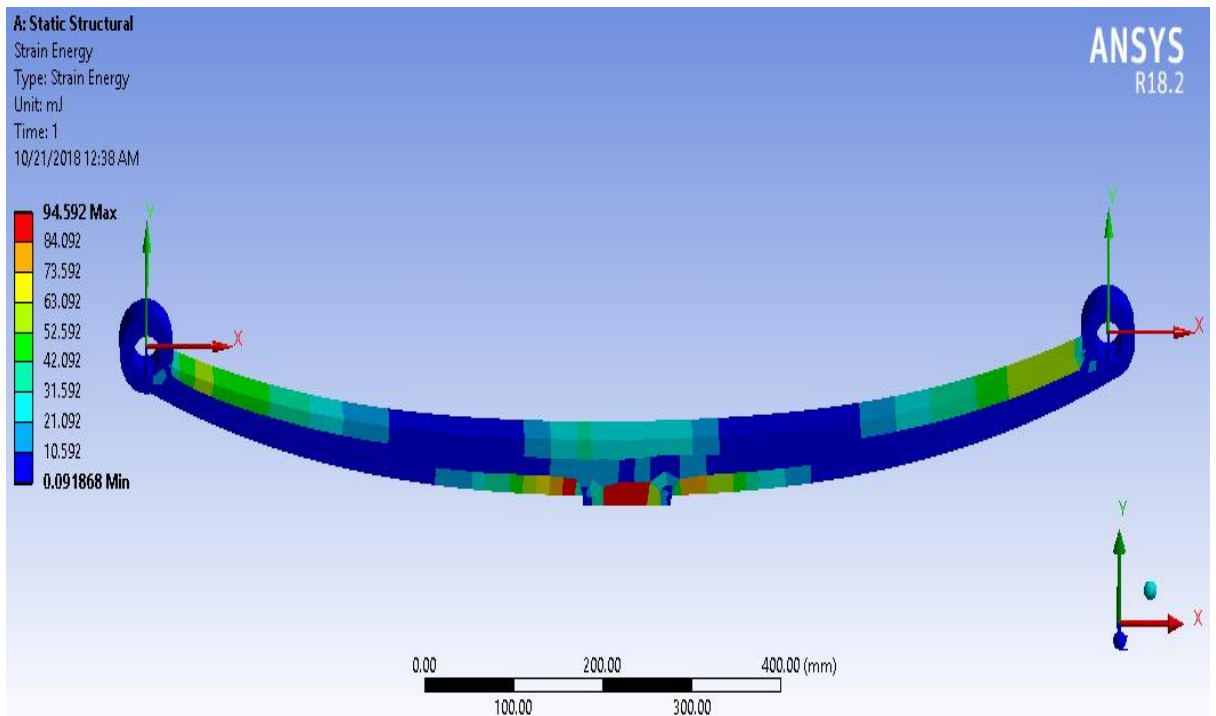


Figure C 8: Strain energy of hybrid composite leaf spring

### 5. Shear stress

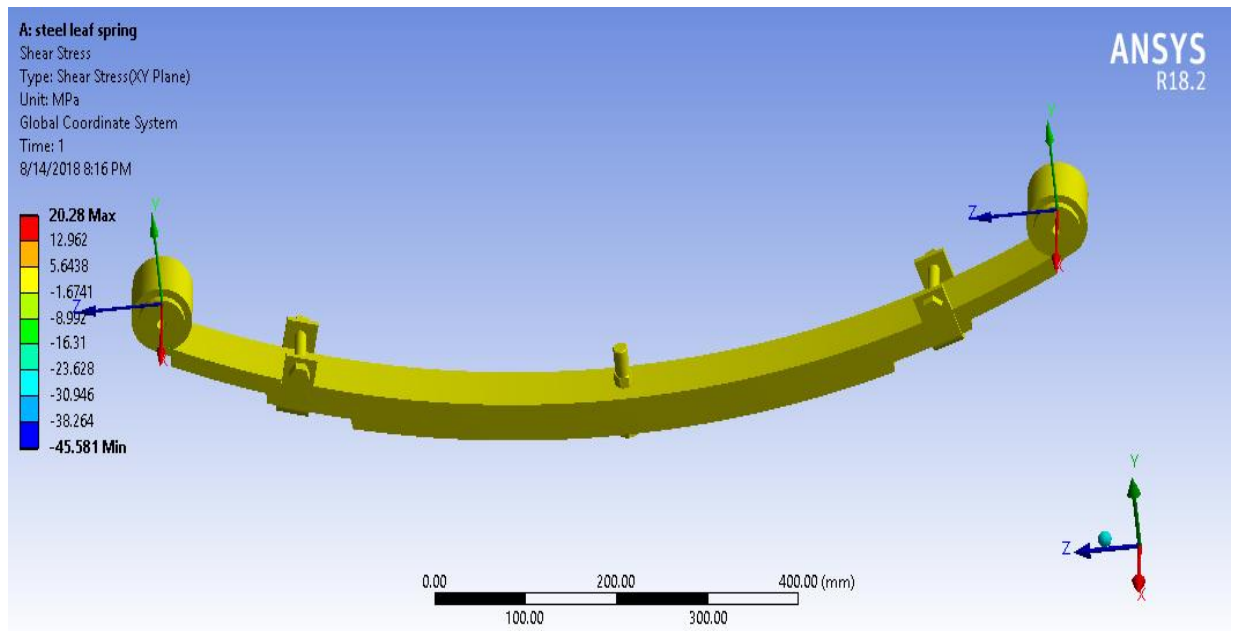


Figure C 9: Shear stress of steel leaf spring

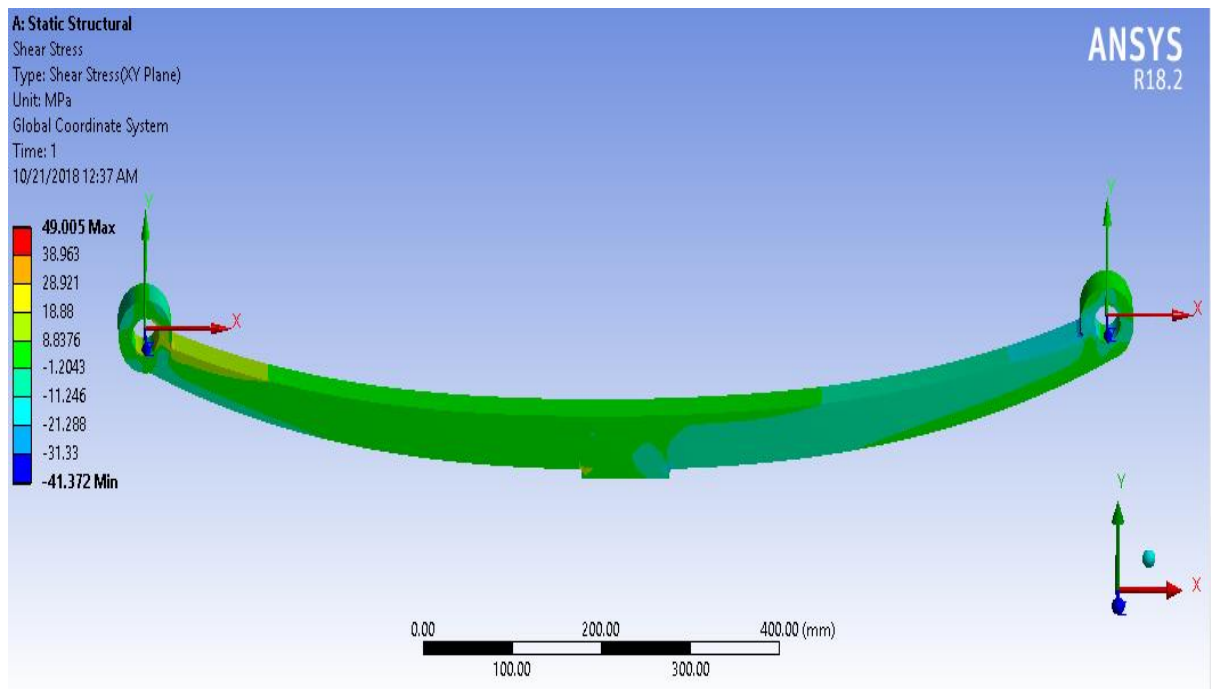


Figure C 10: Shear stress of hybrid composite leaf spring