Design and Analysis of Composite Mono Leaf Spring for Toyota LHD Hilux Double Cabin

Tajudin Nesri Feto

A Thesis Submitted to

The Department of Mechanical System and Vehicle Engineering

School of Mechanical, Chemical and Materials Engineering

Presented in Partial Fulfillment of the Requirements for the Award of degree of Master of Science in Automotive Engineering

Office of Graduate Studies

Adama Science and Technology University

August, 2021 GC

Adama, Ethiopia

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Declaration

I hereby declare that in this Master Thesis entitled “Design and Analysis of Composite Mono Leaf Spring for Toyota LHD Hilux Double Cabin” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis has been duly acknowledged through citation.

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Recommendation

We, the advisers of this thesis, herby certify that we have read the revised version of the thesis entitled "Design and Analysis of Composite Mono Leaf Spring for Toyota LHD Hilux Double Cabin" prepared under our guidance by Tajudin Nesri Feto, in Partial Fulfillment of the Requirements for the degree of Master of Science in Automotive Engineering

Therefore, we recommended the submission of revised version of the thesis to the Department following the application procedures.

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Major Advisor	Signature	date
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Co-Advisor	Signature	date

Approval Page.

We, the advisers of the thesis entitled "Design and Analysis of Composite Mono Leaf Spring for Toyota LHD Hilux Double Cabin" and developed by Tajudin Nesri Feto, herby certified that the recommendation and suggestions made by the Board of Examiners are appropriately incorporated in to the final version of the thesis.

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Co-advisor	Signature	date

We, the undersigned members of the Board of Examiners of the thesis by Tajudin Nesri Feto have read and evaluated the thesis entitled "Design and Analysis of Composite Mono Leaf Spring for Toyota LHD Hilux Double Cabin" and examined the candidate during open defense. Therefore, this is to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Automotive Engineering.

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Nomenclature

FRP	Carbon Fiber Reinforcement Plastics
CMCs	Ceramic Matrix Composite
CSM	Chopped Strand Mat
FEA	Finite Element Analysis
G-CFRP	Glass Carbon Fiber Reinforcement plastic
HCl	Hydro chloric Acid
GPa	Giga Pascal
MMC	Metal Matrix composite
OMC	Organic Matrix Composites
ROF	Rule of Mixture
UD	Unidirectional
WRM	Woving Reinforcement Mat

ABSTRACT

In this research project, design and analysis of leaf spring using epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials have been performed and compared with the conventional steel leaf spring which is used by light vehicle (Toyota pickup). The main objective of this research project analysis is to design, static and dynamic analysis of leaf spring using epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite material for light vehicle by using finite element analysis without changing of the dimension and load carrying capacity of the existing conventional steel leaf spring. The main investigation of this project was to reduce overall weight of the leaf spring with the same strength of the existing one. To solve this problem in this case composite materials have play an important role. The 3D modeling of both conventional and composite mono leaf spring was done on Solid work 2013 and analyzed using ANSYS 19.2 workbench software. Analysis results of stress, weight, natural and harmonic frequency of existing and mono composite leaf spring was compared. Through analysis it has been observed that Mono composite leaf spring has 35.29 % less stress, 2.96 % less deflection and 67.9 % weight reduction than conventional leaf spring. The ranges of Natural frequency of composite leaf were 8Hz-400Hz. This project has also been determined which material is best to design leaf spring for light vehicle (Toyota pickup). Finally in this research project researcher has designed and analysis the epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials leaf spring and conventional steel leaf spring and compared their performance. It has been observed that E-glass UD, epoxy S-glass UD composite material leaf spring has better performance than the epoxy carbon UD (395 Gpa) prepreg composite mono leaf spring and conventional steel leaf spring.

Keywords: ANSYS software, composite material, design analysis, epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg, leaf spring, solid work, and structural steel.

CHAPTER ONE
INTRODUCTION

1.1 Background

1.1.1 Suspension system

A suspension system is one having springs and other devices that protect the chassis of a vehicle from shocks transmitted through the wheels. The main components of the suspension system are: Struts, shock absorbers, springs, tires and the automobile chassis is mounted by the axles, not directly but through some form of springs, (D. Lydia Mahanthi1 and C. Venkata Siva Murali, 2017). This is needed to keep the vehicle body from road shocks like as bounce, pitch, roll, and sway. These tendencies lead in an uncomfortable ride and also some additional stress on the car's frame and body. A suspension system is made up of all of the components that work together to separate the vehicle from road shocks. The spring device and various mountings are also included. A spring and a damper create a suspension system. The spring oscillates due to the energy of the road shock. The damper, commonly known as a shock absorber, holds these oscillations to a controlled degree. A spring is an elastic body with the characteristic of distorting when loaded and restoring to its original shape when the load is removed. Helical springs, conical and volute springs, torsion and spiral springs, leaf springs, disk or Belleville springs, and special purpose springs are the different kinds of springs (Parkhe Ravindra, et.al, 2014).

The suspension system's key element is the leaf spring. It also has the ability to control the wheels during acceleration, braking, and turning, as well as general movement caused by road bumps. Leaf spring is originally called laminated or carriage spring. Leaf springs were very common on automobiles, right up to the 1970s in Europe and Japan and late 70's in America when the move to front wheel drive, and more sophisticated suspension designs saw automobile manufacturers use coil springs instead. Today leaf springs are still used in heavy commercial vehicles such as vans and trucks, SUVs, and railway carriages. For heavy vehicles, they have the advantage of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point. Unlike coil springs, leaf springs also locate the rear axle, eliminating the need for trailing arms and a Pan hard rod, thereby saving cost and weight in a simple live axle rear suspension. Leaf springs are designed in two methods: multi-leaf and mono leaf. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. The leaf spring bends and slide on each other allowing suspension movement. An example of a mono-leaf spring is the tapered leaf spring. The leaf is thick in the middle and tapers towards the two ends. Many of these leaf springs are made of composite material, while others are made of steel. In most cases leaf springs are used in pairs mounted longitudinally (front and back). However, there are an increasing number of vehicle manufacturers using single transverse (side to side) mounted leaf spring. Three types of leaf springs are: Laminated or Multi-leaf springs, single or mono-leaf springs, tapered leaf springs (Ganesh R. Chavhan, Pawan V. Chilbule, 2018).

The third type of leaf spring is the combination of the above two. The multi-leaf springs are commonly used in the automobile suspension system at the rear side and are still in use for commercial vehicles suspension system. It consists of a number of steel strips or leaves placed on the top of each other and then clamped together. The type of application and load carried determines the length and number of leaves. The top leaf is called as the main leaf and the ends of the leaf are rolled to form the eye of the spring. This is for attachment to the vehicle chassis or body (Kumar DA, Abdul Kalam SD 2016)

A leaf spring is a long, flat, thin, and flexible piece of spring steel or composite material that resists bending. The basic principles of leaf spring design and assembly are relatively simple, and leafs have been used in various capacities since medieval times. Most heavy duty vehicles today use two sets of leaf springs per solid axle, mounted perpendicularly to support the weight of the vehicle. This Hotchkiss system requires that each leaf set act as both a spring and a horizontally stable link. Because leaf sets lack rigidity, such a dual-role is only suited for applications where load-bearing capability is more important than precision in suspension response, (Priyanka Kothari, et al, 2014).

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. The main function of leaf spring assembly as suspension element is not only to support vertical load, but also to isolate road-induced vibrations. The behavior of leaf spring is complicated due to its clamping effects and inter-leaf contact etc. It carries lateral loads, brake torque, driving torque in addition to shock absorb. Springs are crucial suspension elements on cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight. The use of composites will aid in the design of a better suspension system with increased ride quality if it can be performed without a significant increase in cost and a decrease in quality, as well as a reduction in load carrying capacity and reliability. Strain energy becomes a major factor in the design of springs. (S. Arun Kumar, 2016).

1.2 Statement of the Problem

In order to safeguard natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present development. The introduction of better material, design optimization and better manufacturing processes can cause weight reduction in vehicle .The leaf spring is one of the potential components for weight reduction in automobile as it accounts for ten to twenty percent of the un-sprung weight.

To solve problem in this regard composite materials play an important role. The foremost component of the suspension system of vehicle is leaf spring, it has substantial amount of weight, and it is necessary it would have ample strength because it needs to resist vibrations and jolts during its working. The prominence of this project research work is to reduce the overall weight of suspension system and improve load carrying capacity of the leaf spring by using the composite material. To reduce the overall weight of suspension system, epoxy E-glass UD, epoxy S-glass UD and Epoxy carbon UD (395GPa) composite material has been used. This composite materials show better performance compared to conventional leaf spring when researcher did analysis by using ANSYSIS V19.2 software. So by using epoxy E-glass, epoxy S-glass epoxy and carbon UD (395 GPa) prepreg composite materials, weight can be reduce and economize the energy.

1.3 Objective

1.3.1 The general objective

The general objective of this project was to design and analysis of leaf spring made epoxy E-glass UD, epoxy S-glass UD epoxy and carbon UD (395 GPa) prepreg composite material for light vehicle (Toyota pickup).

1.3.2 Specific Objectives

The main objective of this research project is achieved through the following specific objectives:

- To gather the detail about the existing leaf spring of the selection vehicle.
- To design and model of conventional and composite leaf spring.
- To select appropriate composite material for leaf spring.
- To analysis and compare the characteristics of conventional leaf spring with selective composite materials leaf spring.

1.4 Significance of the study

The significance of this study would give input for individuals, researchers and leaf spring manufacturer. It would provide some guideline, how to design leaf spring from composite materials and its performance like static and dynamic analysis using ANSYS software. It also give better understand about the composite materials advancement over the conventional steel leaf spring and reduce the weights of the vehicle.

1.5 Scope of the project work

The goal of this work was to design and study static and dynamic analysis of epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395GPa) prepreg composite materials principles and processes. To lower the unsprung weight of the vehicle, a suspension system (like a mono leaf spring) is used. Automobile engineering is a field of study, Furthermore, the study used finite element analysis to evaluate the spring manner without risking the spring's natural state .The parameters investigated in this study, however, were the spring's criteria as a machine component are not exhaustive. Friction and temperature effects, fatigue behavior, and the service life of the spring were not taken into account.

1.6. Limitation

Experimental investigation has not been done due to unavailability of proper laboratory. The prototype of leaf spring is not manufactured due to lack of budget.

1.7 Organization of the research project

Chapter 1 is about introduction of leaf spring, the statement of the problem and thesis objectives, scope and limitations. The chapter 2 literature review consists of past works done by many researchers related to design and analysis of composite leaf spring compared with conventional leaf spring. Chapter 3 materials, the methodology followed during the research work and design. Chapter 4 result and recommendation, chapter 5 contains conclusions of the research work as well as directions of future works.

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CHAPTER TWO

LITERATURE REVIEW

The literature review consists of past works done by many researchers related to design and analysis of composite leaf spring compared with conventional leaf spring. Some of them which are considered to be essential and basic for this project are discussed below. The chapter is divided into two sections, the first section briefs composite leaf spring materials, the other section is concentrating on reviewing relevant other researcher works and show how this work is deferent from others.

2.1 Composite material

A composite material is classified as a material composed of two or more materials which have better properties than the individual components when it's used separately. Unlike metallic alloys, each material retains its own chemical, physical, and mechanical characteristics. The composites' reinforcing phase provides strength and stiffness, enabling them to be harder, thicker, and stiffer than the matrix. The reinforcement is usually in the form of a fiber or a particulate. The length-to-diameter ratio is known as the aspect ratio, and can vary greatly for fibers because the length of the fiber is much greater than its diameter. Continuous fiber composites have high aspect ratios, while discontinuous fiber composites have low aspect ratios, and continuous fiber composites' orientation is usually perfect, while discontinuous fiber composites have a random orientation, (Barbero, E. J. 2017).

Continuous fiber composites are often laminated by stacking single sheets of fibers in different orientations to obtain the right strength and stiffness properties, even while the fiber volume is as high as 60% to 70%. In general, the smaller the diameter of the fiber, the higher its strength; but, as the diameter starts to shrink, the cost increases. The matrix, which can be constructed of polymer, metal, or ceramic, is the living document. Polymers have low stiffness and strength, metals have medium stiffness and strength but high ductility, and ceramics have high stiffness and strength but are brittle. The random alignment of discontinuous fiber composites reduces their strength and modulus significantly. These composites, on the other hand, are usually less expensive than continuous fiber composites. Continuous fiber composites are used where higher strength and stiffness are required at a higher cost, while discontinuous fiber composites are used where cost is the main motivator and strength and stiffness are secondary (Kutz, M. Ed.,2015)

Historical development of composite materials

Composite materials have been in focus from a structure point of view recently applications and correspondingly the literature of composite materials are growing for quite some time. Adoption of composite materials has been started by aerospace industries; however they are used much more widely industries applications such as sporting well today, fact which is obvious from.

Classification of Composite materials

Composites materials are commonly classified at following two distinct levels

The first level of classification is usually made with respect to the matrix constituent. The main composite groups include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs) (CMCs). The term organic matrix composite is usually believed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon composites. Fiber reinforced composites, laminar composites, and particulate composites are the reinforcement types labeled at the second level. Fiber Reinforced Composites (FRP) is divided into two types: those with discontinuous fibers and those with continuous fibers. (Rupesh N. et.al. 2015).

The composite is termed fiber reinforced when the length of the fiber is such that any further increase in length does not result in an increase in the elastic modulus of the composite. Fibers have a small diameter and bend easily when moved axially, while having good tensile properties. Individual fibers must be supported to protect them from bending and buckling. Layers of materials are kept together by a matrix in laminar composites. This category includes sandwich structures. Particulate Composites are made up of particles that are spread or embedded in a matrix. The particles may be in the form of flakes or powder. This category contains concrete and wood.(J Jancirani and H Assarudeen 2014)

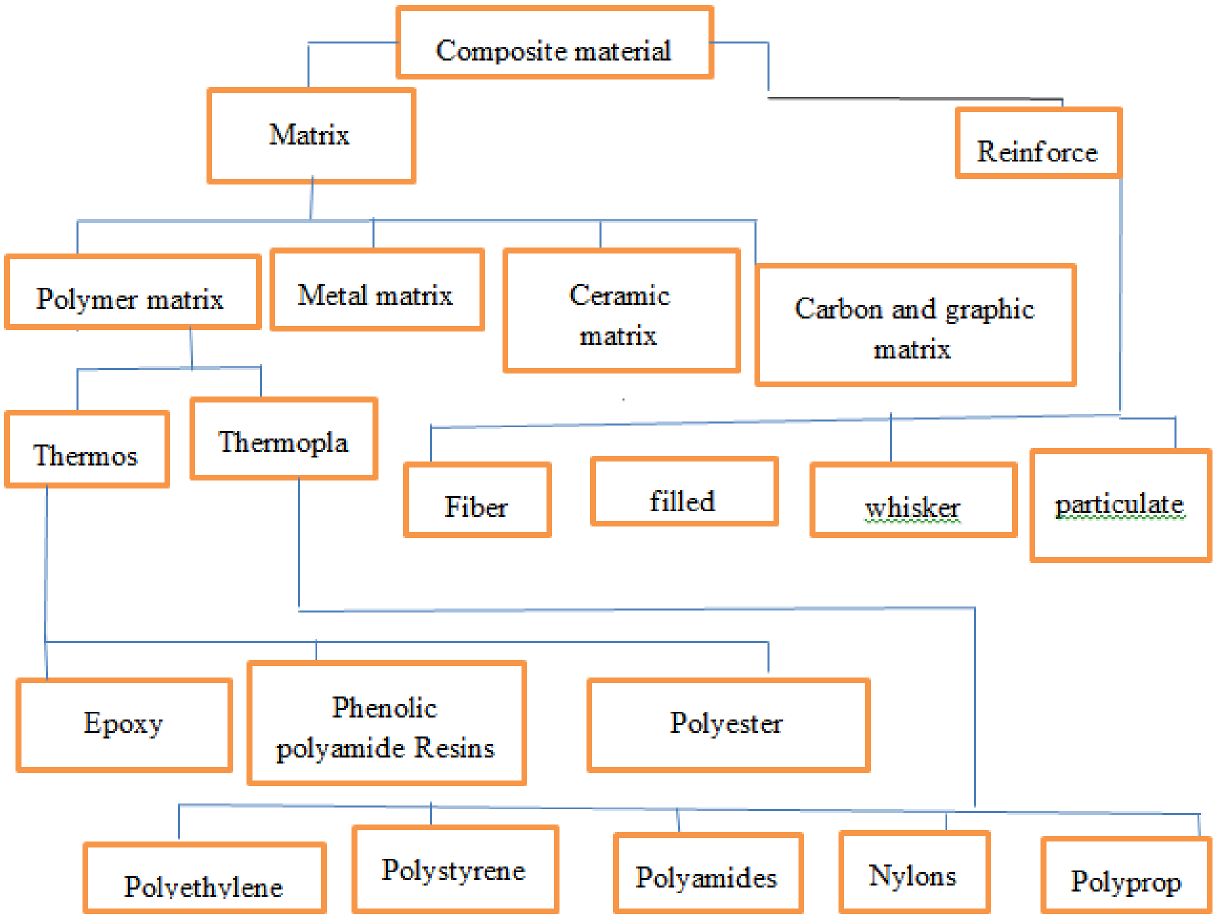

Figure 2. 1: Classification of composite material (Raut, H. A, 2017)

Matrix

Matrix is the percolating alloy/metal/polymer/plastic/resin/ceramic forming the constituent of a composite in which other constituents are embedded. If the matrix is a metal, then it is called as a metal matrix and consecutively polymer matrix, if the matrix is a polymer and so on. In composites, the matrix or matrices have two important functions. To start with, it holds the reinforcing process in place. It then deforms and distributes the tension to the reinforcement constituents under the influence of an applied force. The matrix may often act as a key bolstering factor. This can happen in certain metal matrix composites, (Dadasaheb Gaikwad, et.al. 2012).

Function of matrix

In composite material the matrix materials are the following function

- Hold the fiber together;
- Protect the fiber from environment;
- Distribute the load evenly between the fibers, so that all fibers are subjects to the same amount of strain;
- Enhance transverse property of a laminate;
- Improve impact and fracture resistance of a component;
- Help to avoid propagation of crack growth through the fibers by providing alternate failure path along the interface between the fiber and the matrix

A) Metal Matrix Composites (MMC)

Metal matrix composites are not as commonly used as their plastic counterparts, despite creating a lot of interest in the research community. Metal matrices have a higher level of strength, fracture resistance, and stiffness than their polymer counterparts. In corrosive environments, they can withstand higher temperatures than polymer composites. Most metals and alloys may be used as matrices, but they require reinforcing materials that are both stable and non-reactive across a wide temperature range. However, the matrix material serves as the primary guiding factor in the choice. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli. Most metals and alloys make very good matrices (Rupesh N. et.al. 2015).

However, there aren't many options for low-temperature applications in use. Only light metals are receptive, and their low density works in their favor. The popular matrix metals currently in vogue are titanium, aluminum, and magnesium, which are especially useful for aircraft applications. The strength-to weight ratios of resulting composites can be higher than most alloys. The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials, (Vaibhav chaudhari and Rahul b barjibhe, 2020).

B) Ceramic Matrix Materials (CMM)

Ceramics are rigid materials that have a lot of ionic bonding and a little bit of covalent bonding in general. Ceramic-based matrix materials are a favorite for applications requiring a structural material that doesn't give way at temperatures above 1500oC due to their high melting points, corrosion resistance, durability at elevated temperatures, and compressive strength. For high-temperature applications, ceramic matrices are, of course, the obvious alternative. The failure of attempts to add reinforcements to increase strength has been attributed to the high modulus of elasticity and low tensile strain that most ceramics have. This is because there is insufficient elongation of the matrix at the stress levels at which ceramics rupture, preventing the composite from transmitting an efficient quantum of load to the reinforcement, and the composite may fail unless the percentage of fiber volume is high enough, (Barbero, E. J, 2017). A material is reinforced to take advantage of the fiber's higher tensile strength and improve the matrix's load bearing capability. The addition of high-strength fiber to a softer ceramic has not always worked out, and the resulting composite has often proven to be weaker. The use of high-modulus-of-elasticity reinforcement may reduce the problem to some degree, and pre-stressing of the fiber in the ceramic matrix is becoming a more popular alternative. The resulting composite is unlikely to have a higher degree of strength when ceramics have a higher thermal expansion coefficient than reinforcement materials. As the composite cools, it develops strength within the ceramic, resulting in micro cracks spreading from fiber to fiber within the matrix. Micro cracking can cause a composite to have a lower tensile strength than the matrix, (Barbero, E. J, 2017).

C) Polymer Matrix Composites (PMC)

Fiber reinforced polymer or plastic is another name for it. A polymer-based resin serves as the matrix, with a variety of fibers such as glass, carbon, and aramid serving as reinforcement. Polymeric materials are the most popular. Polymers' mechanical properties are generally insufficient for many structural applications. In comparison to metals and ceramics, their strength and stiffness are particularly poor. These problems are solved by using polymers to reinforce other materials. Second, the manufacturing of polymers matrix composites does not necessitate the use of high pressure or high temperatures. In addition, the equipment needed to make polymer matrix composites is less complex. As a result of these factors, polymer matrix composites grew quickly in popularity for structural applications. There are two types of polymer composites.

a) Thermoset
b) Thermoplastic

Epoxy Resin

The name "resin" is a common term for the polymer. The resin, its chemical composition, and physical properties have a significant impact on the material's processing. Both man-made materials, thermosetting resins are the most diverse and commonly used. They can be poured or molded into any shape, are compatible with most other materials, and cure quickly into an insoluble solid (using heat or a catalyst). Thermos setting resins work well as adhesives and bonding agents as well. Epoxy resin is the most commonly used material. Because of the high cost of the precursor chemicals, especially epichlorohydrin (Dadasaheb Gaikwad, et.al. 2012). However, the increased complexity of the 'epoxy' polymer chain, as well as the potential for greater control over the cross linking mechanism, results in a much stronger and ductile matrix. The resin and hardener must be combined in equal proportions in most epoxies, and the curing process must be completed with heat for maximum strength. This has the advantage of allowing the resin to be applied directly to the fibers and requiring only one curing step during the manufacturing process. Pre-peg or pre-impregnated fiber is another term for it Epichlorohydrin and bisphenol-A are combined in an alkaline solution, which absorbs the HCl released during the condensation polymerization reaction. Each chain has a molecular weight ranging from 900 to 3000 and has an epoxide grouping at each end but none inside the polymer chain. The epoxy is cured by mixing in an equal amount of hardener and heating it to around 120°C. Short chain diamantes, such as ethylene diamante, are often used as hardeners. Since cross linking necessitates the condensation of water, which must be extracted in the vapor phase, heat is typically needed (Dadasaheb Gaikwad, et.al. 2012).

Fiber

Fibers are the principal constituents in a fiber reinforced composite material.

They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. Proper selection of the fiber type, fiber volume fraction, fiber length, and fiber orientation is very important.

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 (SushilB.Chopade,et al.,2015).

Glass fiber also called fiberglass. It is the material made from extremely fine fibers of glass. Fiberglass is a sturdy, lightweight, and durable material. Although the material has lower strength properties and is less stiff than carbon fiber, it is usually less brittle and the raw materials are less costly. As compared to metals, its bulk strength and weight properties are also very favorable, and it can be easily shaped using molding processes (D. Lydia Mahanthi, et al., 2017). Glass is the most well-known and oldest performance fabric. Since the 1930s, glass has been used to make fibers.

Types of glass fibers

A-type glass fiber: Alkali glass made with soda lime silicate is known as A-type glass fiber. When the electrical resistivity of E-glass isn't needed, this material is used. A-glass or soda lime glass is the predominate glass used for containers and windowpane.AR-type glass fiber is made of zirconium silicates and is alkali resistant. In Portland cement substrates, it's used. Glass fiber of type C is corrosive resistant and made of calcium borosilicate (Pankaj Saini,et al. 2013).

In acidic or corrosive conditions, this product is used. Glass fiber of type D has a low dielectric constant and is made of borosilicate. Used in the electrical industry. E-type glass fibers are made of alumina-calcium borosilicate and are alkali-free and extremely electrically resistive. E-glass is a term used in the industry. ECR-type glass fiber: A calcium alumina silicate-based E-glass with improved acid corrosion resistance. When power, electrical conductivity, and acid corrosion resistance are needed, this material is used. R – Type glass fiber: A reinforcement glass made of calcium alumina silicates that are used in applications requiring increased strength and acid corrosion resistance. S-type glass fibers are made of magnesium alumina silicates and have a high strength. When high strength, stiffness, extreme temperature resistance, and corrosive resistance are needed, this material is used (D. Lydia Mahanthi, et al., 2017).

2.2 Literature review related leaf spring

Gayatri J, et al. (2017) they studied on design analysis and experimental investigation of composite mono leaf spring by using the composite material E-glass/epoxy. They were used to FEA to compare the composite and conventional steel leaf spring which having higher strength to weight ratio and also they compare the deflection and bending stress of the E-glass/epoxy and steel materials of leaf spring. Finally they found that the deflection and maximum stress in composite mono leaf spring is less than conventional leaf spring.

Pankaj Saini,et al. (2013) studied on design and analysis of composite leaf spring for light vehicles. the material they selected was glass fiber reinforced polymer (e-glass/epoxy), carbon epoxy and graphite epoxy is used against conventional steel. The leaf spring was modeled in Auto-CAD 2012 and the analysis was done using ANSYS 9.0 software. Finally they were found that stress of the composite material was less than that of the conventional leaf spring; and also the weight of E-Glass/Epoxy composite of mono leaf spring was reduced by 81.22% and they found the deflection maximum stress of the composite material.

Syambabu Nutalapati, (2015) studied on design and analysis of leaf spring by using composite material for light vehicles the main objective of the research is to Compare the stresses, deformations and weight saving of composite leaf spring with that of steel leaf spring he describe in his study the composite materials has high strength to weight ratio, good corrosion resistance, the composite material he selected for leaf spring is E-glass/Epoxy. He done the model by pro/engineering and he used the analysis by ANSYS 12 software. Final he investigated that the weight of the composite leaf as compare with conventional steel leaf spring was reduced by 85%.

Prasad P.Kunzarkar, et al. (2018) studied review on automotive car composite leaf spring design and optimization they used composite materials which are good fatigue strength, high strength to weight ratio, high natural frequency and good corrosion resistance. They have taken dimensions of an existing conventional steel leaf spring of a light commercial vehicle and they verified by design calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results. They investigate that the fatigue life of steel leaf spring and composite leaf spring is found to have 67.35% lesser stress 64.95 % higher stiffness and 126.98% higher natural frequency than that of existing steel leaf spring. The weight reduction of 68.15% also achieved by using composite leaf spring.

Avinash Sharma1, et al. (2014) in their research they investigated that Design and Analysis of Composite Leaf Spring. For their work the model of leaf spring created in Pro/E with existing design data, and then analyzed on ANSYS and the finite element of leaf spring was created using solid tetrahedron elements. They analysis of both conventional and composite leaf spring (carbon/epoxy) and compared with each other. They were found that the stresses in the composite leaf spring were much lower than that of the steel spring. They also concluded that the composite spring can designed to strength and stiffness much closer to steel leaf spring by varying.

M. Raghavedra1, et al. (2012) Conducted studied on Design and Analysis of Composite Leaf Spring by Using FEA and ANSYS. They substituted a steel leaf spring by a composite leaf spring. Because for same load carrying capacity composite leaf spring possess high strength to weight proportion for same dimensions. A semi-elliptical composite multi leaf spring made of E-glass/epoxy is designed. Less stresses and deflection has been found for same load carrying capacity. Results compared well with the theoretical results. They had done a comparative study and found that composite leaf spring with E-Glass/Epoxy weighs 67.88% less compared to steel leaf spring. In their study they suggest to use E-glass/epoxy composite leaf spring from stiffness and stress perspective.

M. Raghavedra1, et al. (2014) has described a single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested.

Ajay B.K, et al. (2014) the aim of this study is to reduce the cost and weight of leaf spring, the Automobile sector is replacing steel leaf spring with fiber composite leaf spring, the objective of study was to replace steel material for leaf spring, the material selected was glass fiber reinforced plastic. A spring with constant width and thickness with different arrangements of composite leaves was used for analysis. And finally conclude that alternate placing of composite leaves provides similar strength as that of conventional steel leaves with additional advantages. According to the researcher works implementation of three steel leaves instead of four leaves, gives better results than alternate arrangement of steel and composite leaves. Fourth model arrangement shows better result than other two arrangements.

Stephan Krall, et al. (2017) studied on "Investigation of the Dynamic Behavior of CFRP Leaf Springs." The paper deals with the dynamic behavior of CFRP leaf springs. The experimental modal analysis is used for the investigation. The researcher done two different methods (impact test and shaker test) for the excitation of the parts have been applied. And take the standard steel leaf spring is used as reference, then three different composite springs are investigated and compared. The manufacturing was done by hand lay-up and autoclave, and the composite design was measured using classical lamination theory. The action of spring elements under various thermal conditions is a significant consideration. As a result, a low-temperature investigation was conducted on one of the test bodies. Finally, he decides to study and compare the suitability of the analytical calculation of the Euler – Bernoulli beam theory with experimental findings.

Jeevan Herekar (2017) studied on experimental Analysis of Epoxy Glass Fiber Composite Leaf Spring for Natural Frequency of Leaf Spring to Reduce the Vibration

Mohammed Asif Kattimani, et al. (2019) they were studied on design analysis and fabrication of composite leaf spring ;the composite leaf is designed, fabricated, tested experimentally and numerically using ANSYS workbench 17.0 for static and fatigue analysis and they conclude that polymer material shows higher strength and life when compared to conventional leaf spring.

Vaibhav chaudhari and Rahul b barjibhe (2020) studied on design and optimization of mono composite leaf spring As Design is designed in CATIA design software and CAD file has exported to the ANSYS 11.0 and they calculated Stress and Deflection. The analytical and FEA was compared the composite mono leaf spring with conventional finally they results show that the stress and deflection of composite material were less than that of steel leaf spring.

Mujawar Ajij and S.D.Katekar (2017) studied on Design and Analysis of S-Glass/Epoxy Composite Mono leaf Spring for Light Vehicle. The prominence of the paper is to reduce the overall weight of suspension system and improve load carrying capacity of the leaf spring by using the composite material. The design considerations for this study are stress and deflection. The work also gives focus on the application of FEA concept to compare two materials for leaf spring and propose the one having higher strength to weight ratio. Two materials used for comparison are; conventional steel and composite S-Glass/Epoxy. In their works deflection and natural frequency induced in the two leaf springs are compared. The solid modeling of leaf spring is done in CATIA V5 and analyses using ANSYS 14.5. Finally they observed that if steel is replaced by composite material in leaf spring there 63.41% reduction in displacement.

Mr. Rohit Vasant Rambade (2018) studied on Design, Analysis and Fabrication of Mono Leaf Spring using S-Glass Composite. The main Objective his project is to design a Mono Leaf spring Using Advance S-Glass Series composite Materials which will results into absorbing high Impact shocks. The study consider concept of Reverse engineering is used to measure all the design parameters of the mono leaf spring. Theoretical Designing is done using standard Mono Leaf Spring Design process and 3D modeling is done using Solid works2015 software. Finite Element Analysis software ANSYS Workbench 18.0 is used to study the static and dynamic Behavior of the spring under standard working conditions. ANSYS Composite Prep Post software Analysis was done for Composite leaf spring to find Load Carrying capacity. S-Glass Composite series was used to manufacture mono leaf spring and Tested experimentally for actual load Capacity using Experiment Setup. Finally he observed that, both the leaf springs perform better on actual loading conditions, the S-glass composite leaf sprig was less stress produced in the composite leaf spring and 46.29% weight saving.

SUREKHA S. et al, (2015) studied on "Design Analysis of Carbon/Epoxy Composite Leaf Spring." This work deals about the replacement of conventional steel leaf spring of a light commercial vehicle with composite leaf spring using Carbon/Epoxy. This project mainly focuses on design and analysis of laminated mono composite leaf spring with unidirectional fiber orientation angle 00 is considered. The implementation of Carbon/Epoxy composite materials for leaf springs of a suspension system can replace steel in conventional spring to reduce the weight, deflection, stresses, product development cost and increase the comfort. Finally the researcher concludes that: from the comparison that the deflection and bending stress induced in the Carbon/Epoxy composite leaf spring is less than the conventional steel leaf spring for the same load carrying capacity. The researcher done the study by considering laminated mono leaf spring with unidirectional fiber orientation angle of 00 and the researcher take the dimension of the conventional leaf spring for the new mono composite leaf spring.

Parkhe Ravindra A. et al, (2014) studied on Performance Analysis of Carbon Fiber with Epoxy Resin Based Composite Leaf Spring. This paper describes design and analysis of composite mono leaf spring. The researcher determines the suitable fiber and resin for his work. Validate performance of single leaf variable thickness carbon/epoxy composite material spring by analytical and FEA analysis, analytical procedure is followed by finite element analysis and he verified results experimentally. In addition he worked on the fabrication of the composite leaf spring by selecting the hand layup manufacturing technique. The design constraints were stresses and deflections. The researcher modeled composite mono leaf springs by considering varying cross-section, with unidirectional fiber orientation angle for each lamina of a laminate. And static analysis of a 3D model has been performed using ANSYS 12.0. Finally the researchers conclude that the stresses occurred in the carbon/epoxy composite leaf spring are 42% less than that of the steel leaf spring. The researcher achieved a weight reduction in mono composite leaf spring is about 22.15%

Literature review gaps

From the literature review it has been observed that many researchers have done researches on design and analysis of leaf spring using single composite material and compare with conventional leaf spring materials. There are no researches done by using more than one composite material and compare conventional steel leaf springs. This is the gap. So based on this research gap researcher has decided to do the design and analysis using, more than one composite materials like epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395GPa) and compare their static and dynamic analysis with conventional leaf spring.

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CHAPTER THREE

MATERIAL, METHODOLOGY AND DESIGN LEAF SPRING

This chapter contains materials, methodology and design of leaf spring. The material used for mono leaf spring is epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg. The material used design conventional leaf spring is usually plain steel having 0.9 to 1.0% carbon. The relevant data for this design is collected through literature review, the design calculation of both composite mono and conventional leaf spring. The 3D and 2D modeling was done by solid work and the analysis was done by ANSYSY 19.2

3.1 Leaf spring

Leaf springs (also known as flat springs) are made out of flat plates. The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks.

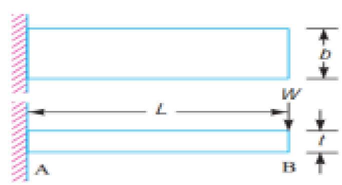


Figure 3. 1: Flat spring cantilever type

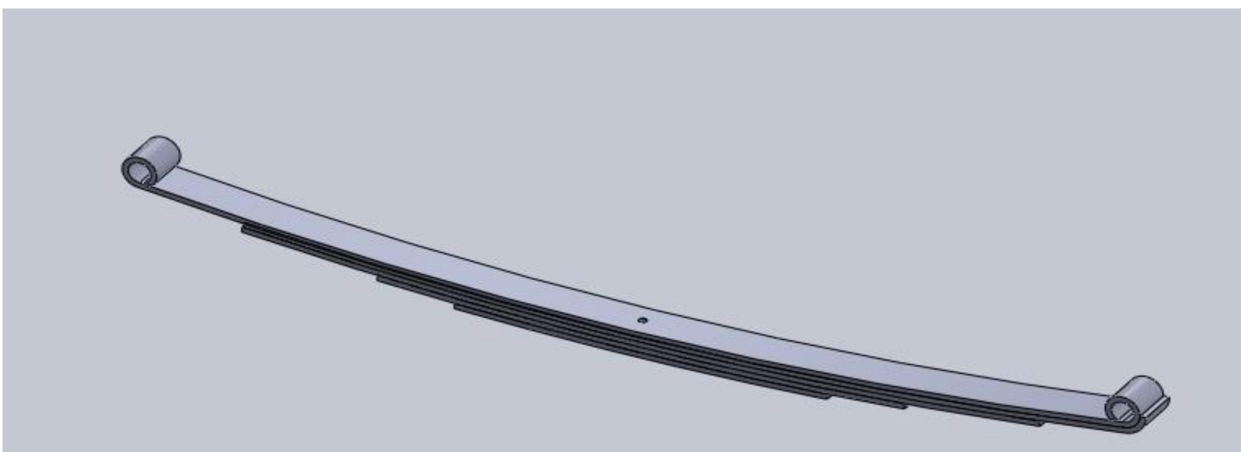


Figure 3. 2: Leaf spring

According to (jignesh, 2014) we know that the maximum bending moment at the cantilever A

$$M = WL \text{ – } 3.1$$

Where M=maximum bending momentum

W= load of the vehicle

L=length of the spring

$$Z = \mathbf{1/y} = \frac{\frac{\mathbf{b}t^3}{12}}{\frac{t}{z}} \text{ – } 3.2$$

Where y=the centroid of each leaf spring

Z= Section modulus

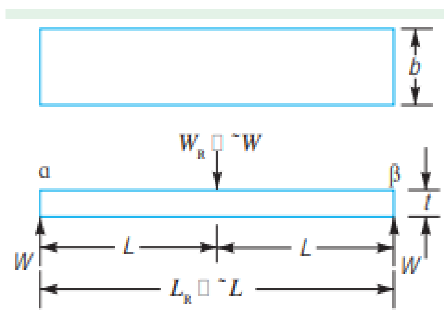


Figure 3. 3: Flat spring (simply supported beam type).

$Z = \frac{\mathbf{b}t^2}{6}$ Where b=width of leaf spring and t=thickness of leaf spring

Bending stress in such the spring is given as

$$\boldsymbol{\sigma} = \mathbf{M/Z} = \frac{WI}{\frac{bt^2}{6}} = \frac{6wl}{bt^2} \text{ – } 3.3$$

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

$$\delta max = \frac{wl^3}{3EI} = \frac{4wl^3}{Ebt^3} \text{ – } 3.4$$

$\delta max = \frac{2\sigma l^2}{3Et}, where: where\ \sigma = \frac{6wl}{bt^2}$

Where E=young modulus of material

I= moments of inertia

W= load of vehicle

b = width of leaf spring

t = thickness of leaf spring

L = distance of the load from the cant lever end

Length of Leaf Spring Leaves

The length of the leaf spring leaves may be obtained as discussed below:

Let 2L1 = Length of span or overall length of the spring,

l = Width of band or distance between centers of U-bolts.

It is the ineffective length of the spring, nF = Number of full length leaves,

nG = Number of graduated leaves, and

n = Total number of leaves = nF + nG.

We have already discussed that the effective length of the spring,

2L = 2L1 – l .(When band is used)

$$2L = 2L1 - \frac{2}{3} l \; when \; U - bolts \; are \; used - - - - - - - - - - - 3.5$$

Note : The maximum deflection (δ) of the spring is equal to camber (y) of the spring

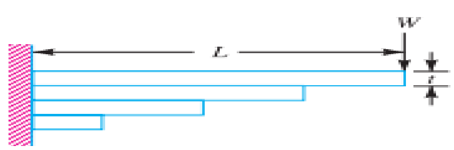


Figure 3. 4: Plate of cantilever

$$\text{Ix} = \sum_{k=0}^{n} \text{Ix}' + Ad^2 ---------------------- 3.6$$

Where Ix the total moments of inertia of the conventional multi steel leaf spring

Ix′ = Moments of inertia of each leaf spring

A = Area of each leaf spring

d = Distance from the centroid of each leaf spring to the neutral axis

$$\text{Ybar} = \frac{\sum_{k=}^{n} Ay}{\sum_{k=}^{n} A} -----------------------------3.7$$

Where Ybar = the centroid of the whole structure

A = the area of each leaf spring

y = the centroid of each leaf spring

$$\text{y1} = \sum_{t=2}^{5} \text{t} ----------------------------- 3.8$$

Where t= thickens of leaf springs

$$Ix = \frac{1}{12}(Ix + Ady)L1 - (Ix + Ad\,y^2)L2 - (Ix + Ady^2)l3 - (Ix + Ady^2)L4 - (Ix + Ay^2)L5 --------------------------- 3.9$$

$$I = \frac{1}{12}\text{bt}^3 ------------------------------ 3.10$$

When I=moment of inertia of rectangular cross-section

b=width of rectangle and t=thickness of rectangle

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

Density =mass/volume

$$\rho = \frac{m}{v} ------------------------------ \quad 3.11$$

$m = \rho \times v$

Where ρ is density of material

m=mass of material

Volume of material

w=mx g where m=ρxv

w=p x v

Now weight of master leaf

$$(wl) = \rho \times v \times g ---------------------- -3.12$$

$$V = L \times t \times w ------------------------- 3.13$$

V=volume of master leaf spring

L=length

t=thickness and

w=width

$$\omega n = \frac{n^2\pi}{nL^2}\left[\frac{\sqrt{EI}}{\rho A}\right] ------------------------ 3.14$$

Where,

n = Mode Shape

I = Moment of inertia of system

ρ = Density of material

A = Area of cross section

L = Length of spring

E = Modulus of Elasticity For simply supported beam

3.1.1 Construction of Leaf Spring

A leaf spring commonly used in automobiles is of semi-elliptical form as shown in Fig. 3.2 it is built up of a number of plates (known as leaves). The leaves are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaves are held together by means of a band shrunk around them at the center or by a bolt passing through the center. Since the band exerts stiffening and strengthening effect, therefore the effective length of the spring for bending will be overall length of the spring minus width of band. In case of a center bolt, two-third distance between centers of U-bolt should be subtracted from the overall length of the spring in order to find effective length. The spring is clamped to the axle housing by means of U-bolts.

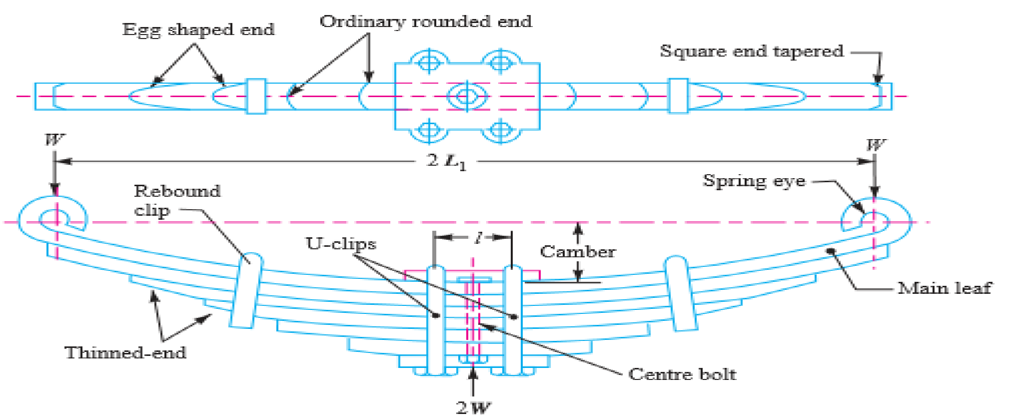


Figure 3. 5: Semi-elliptical leaf spring (Kurmi, R. S., & Gupta, J. K. 2005).

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

b 3.2, 4.5, 5, 6, 6.5, 7, 7.5, 8, 9, 10, 11, 12, 14, and 16 mm are the standard nominal thicknesses. The following bore diameters are recommended for the eye: 19, 20, 22, 23, 25, 27, 28, 30, 32, 35, 38, 50, and 55 mm are the dimensions.

3.2 Materials

The material used for conventional leaf spring is usually a plain carbon steel having 0.90 to 1.0% carbon. Parkhe Ravindra et al. (2014) EN47 is suitable for oil hardening and tempering. When EN47 is hardened it offers excellent toughness and shock resistance which make it a suitable alloy spring steel for parts exposed to stress, shock and vibrations SushilB.Chopade et, al.(2015)

Table 3. 1: Mechanical property of structural steel SushilB.Chopade et al. (2015)

It No	Mechanical property	Symbol	Value	Unit
1	Young modulus	E	200000	MPa
2	Shear modulus	V	76.9	Gpa
3	Poisson’s ratio	V	0.2	
4	Density	ρ	7700	kg/m^3
5	Tensile strength		650-880	MPa
6	Yield strength		350-550	MPa
7	Elongation		8-25	%

Selection of composite fiber

Suitable materials that satisfy the basic design requirements of leaf springs are glass and carbon fiber, which are among the list of composite materials covered in the literature review. And while the traditional material for leaf springs is normally plain carbon steel with 0.90 to 1.0 percent carbon, glass and carbon fiber were used for this composite material leaf spring design.

Selection of a matrix

Reinforcement materials are constantly counted on various types of matrix. As a result, the reinforcement and matrix are well suited to each other in order to provide improved fatigue resistance and lower stress distribution on the intended components. There are various types of matrix chemicals available commercially for structural design applications, as indicated in the literature session. Epoxy resin and polyester resin are appropriate for structural software, and epoxy resin is the most important matrix for leaf spring layout among these Design, Simulation, and. Fibers run in specific directions to center of attention the reinforcement where it is desired, and the epoxy holds the fibers where they are needed in fiber-reinforced constructions. Although the epoxy matrix's primary function is to adhere to and transfer masses to fibers, it is a strong substance in and of itself (Medhanye, B. 2018). It provides impact resistance while also helping to protect the fibers from damage. In comparison to other types of matrix, epoxy resin provides the following advantages (Ms. Surekha S. Sangale et al.2015). They have better adhesive properties, superior mechanical properties (strength and stiffness), better resistance to fatigue and micro cracking, increased resistance to osmosis (surface degradation due to water permeability), less resin required, faster curing at room temperature, and good chemical resistance properties

Table 3. 2: Properties of epoxy resin (David Richardson, (2016)

IT No	Property	Value	Unit
1	Elastic modulus	3.3	GPa
2	Tensile strength	0.13	GPa
3	Shear modulus	2.26	GPa
4	Density	1.2	g/cm^3
5	Poisson’s ratio	0.37	-
6	Flexural yield strength	0.125	GPa
7	Compressive strength	0.19	GPa
8	Elongation at break	0.8	-
9	Glass transition temperature (Tg)	120-130	^0C

Material properties of composite mono leaf spring

Along with steel, three different composite materials like E- glass/epoxy, S-glass/epoxy, carbon/epoxy, are taken in the present work. All the composite materials are assigned with the following material properties that are shown in below table.

Table 3. 3: property of epoxy E-glass, epoxy S-glass and epoxy carbon UD (395 Gpa) (M. Raghavedra et al 2012)

Material Property	Unit	E-glass/ Epoxy	S-glass/ Epoxy	Carbon/ Epoxy
Young modules along X direction	MPa	45000	50000	121000
Young modules along Y direction	MPa	10000	8000	8600
Young modules along Z direction	MPa	10000	8000	8600
Shear modules XY direction	MPa	5000	4700	657
Shear modules YZ direction	MPa	3846.2	3100	377
Shear modules XZ direction	MPa	5000	4700	377
Voice ratio XY		0.3	0.27	0.3
Voice ratio YZ		0.4	0.4	0.34
Voice ratio XZ		0.3	0.27	0.34
Density	g/cm^3	2	2	1.49

3.3 Methodology

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

- A relevant data was collected through literature review.
- Some crucial characteristics of S-glass/epoxy, E-glass/epoxy UD and carbon epoxy UD (395 GPa) prepreg composite and the analysis of leaf spring of these composites which was done by experimental investigation was collected.
- An actual data was collected by observing and measuring the specifically selected Toyota pickup four wheeled light vehicle leaf spring specification.
- Performed theoretical calculation of the steel and laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials leaf spring for light weight four wheeled vehicle.
- Make 3D model of E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials and steel leaf spring using Solid work 2013.
- Make analysis of laminated E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) composite materials and current steel material leaf spring using ANSYS 19.2 Workbench.
- Finally state the conclusion of ANSYS 19.2 workbench results.

3.4 Design guidelines of laminated composite

The following assumptions are made for this work:

(i) All Nonlinear effects are excluded

(ii) The stress strain relationship for composite material is linear and elastic; hence hook's law is applicable to composite material

(iii) The leaf spring has uniform cross section

3.4.1 Design consideration of conventional leaf spring

The following cross-sections of leaf spring for manufacturing easiness are considered:

(i) Constant thickness, constant width design;

(ii) Constant thickness, varying width design;

(iii) Varying thickness, varying width design;

Researcher has selected Toyota pickup car for conventional leaf spring and analysis

Specification of Toyota car is mentioned in table below:

Table 3. 4: Specification of Light vehicle Model Toyota Car

	General specification	
It No	Feature	Value
1	Brand	**LHD Hilux Double Cabin**
2	Model	LAN25L-PRMDENS
3	Transmission	5 speed and Manual.
4	Brake	Front: disc and Rear: drum
5	Tires	Radial Front: 205R16C 6J and Rear: 205R16C 6J. Steel
6	Suspensions	Front: coil and Rear: Leaf
7	Wheelbase	LWB 3085 mm, Ground Clearance: 212 mm
8	Weight Kerb Weight	1845 kg,
9	Gross Vehicle Weight	2790 kg,
10	Payload	945 kg
11	Seats	6 Seater
12	Front:	1+2 40/60bench, Rear: 3 forward facing Bench. Material: Vinyl

Body Dimensions		
13	Length	5255mm
14	Width:	1760mm
15	Height	1810mm
16	Volume	16.7m³ all excluding accessories
17	Colour	White
18	Country of Origin	South Africa
Engine		
19	Model	5L-E
20	Cylinder volume	2986cc
21	Diesel Tank capacity	80l
22	No of cylinder	4 cylinders
23	BHP	94 kw
24	No of doors	4
25	Cooling	Water cooled
26	Electrical	12 volt

Source: Technical Specification of Toyota

As described in the specification of the payload is the carrying capacity of the vehicle measured in terms of weight. The payload of vehicle include cargo, passenger, flight crew, munitions, scientific instrument or experiments extra fuel when optionally carried is also considered and other equipment.

Kerb weight of your car is the weight of the vehicle without any passengers or items in its except for the standard equipment that comes with it.

Therefore payload of vehicle =1845 Kg

Kerb weight of vehicle =945 kg

From the table the total mass of the vehicle is the sum of payload+kerb weight =2790kg

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

According to (Rupesh N. Kalwaghe and K. R. Sontakke 2015) the value of factor of safety ranges = (1.3-2.25), then take factor of safety 1.5

Therefore, Total Weight (w) = 2790×10×1.5

W=41850 N

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

$W = \frac{41850}{4}\ N$

W=1k0462.5 N

Load on each eye of spring is $w = \frac{10462.5}{2} = 5231.25$ N

The conventional steel leaf spring of Toyota car dimension (direct measuring) is as follow:

- Type of material = structural steel
- No. of leaves = 5
- Length of master leaf (eye to eye) = 130 cm
- Length of 2nd leaf = 118 cm
- Length of 3rd leaf = 107 cm
- Length of 4th leaf = 72 cm
- Length of 5th leaf =49 cm
- Width of leaves = 6 cm

- Thickness of leaf = 8mm
- Camber (no load condition) = 6 cm
- Eye bore diameter = 3 cm

3.4.2 Determination of weight

For conventional structural steel leaf sprig:

Calculate the weight of leaf spring by using the formula described on 3.12

$w = m \times g$ where $m = \rho \times v$

Where m= mass of leaf spring

ρ=density of leaf spring

g= acceleration due to gravity

V=volume of leaf spring and $v = l \times w \times t$ where l=length of leaf spring

W=width of leaf spring

$m = \rho \times v$

$w = m \times g$ where $m = \rho \times v$

$w = p \times v$

Density of steel=7.77 gm /cm^3 and take acceleration due to gravity

Now weight of master leaf (w1) = $\rho \times v \times g$

$V_1 = L_1 \times t \times w$

$1300mm x 8mm x 60mm\ \ where$ V=volume of master leaf spring

L=length

t=thickness and

w=width

$v_1 = 624\ cm^3$

$W1 = 7.77 gm/cm^3 x 624 cm^3 x 10 m/s^2 = 48.48\ N$

Weight of the 2nd leaf (w2) = 44.01 N

Weight of the 3rd leaf (w3) =39.9 N

Weight of the 4th leaf (w4) =26.854 N

Weight of the 5th leaf (w5) =18.27 N

Total weight = 177.513 N

Stress and Deflection Calculation of conventional leaf spring

Since the leaf springs are mounted on the axle of the vehicle firmly using U bolt, then the distance between the U bolt is 85 mm, this distance is unbent length of the leaf spring, then to calculate the deflection and stress of the leaf spring the effective length of the leaf spring must be calculated. According to the (Gubta 2005) text book of machine design, the effective length of leaf spring can be calculated as:

using the formula described on number 3.5

$2L = 2L1 - 2/3\ l$, take the width of the U-bolts = 85mm (direct measuring)

$2L = 1300mm - 2/3 \times 85\ mm$

$2L = 1243.33\ mm$

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

Now let us calculate stress of conventional leaf spring

By using th formula in equation numbe 3.3

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

$$\sigma = \frac{6x5231.25NX0.633m}{5x0.060mx(0.008m)^2} = \frac{198.78959x10^5 N/m}{1.92x10^{-5}m^3} = 103.53\ N/m^2$$

By using the equation (3.9) and (3.4) calculated the deflection of convention steel leaf spring

$$Ix = \frac{1}{12}(Ix + Ady)L1 - (Ix + Ad\ y^2)L2 - (Ix + Ady^2)l3 - (Ix + Ady^2)L4 - (Ix + Ay^2)L5$$

$$Ix = \frac{1}{12}(650mm)(24mm)^3 - (\frac{1}{12}(150mm)(6mm)^3 + 150mmx6mmx(3mm)^2]$$

$$- [\frac{1}{12}(350mm)(12mm)^3 + 350mmx12mmx(6mm)^2$$

$$- [\frac{1}{12}(44mm)(18mm)^3 + 44mmx18mmx(6mm)^2$$

$$Ix = \ 748800mm^2 - (10800 + 201600 + 4985960mm^3$$

Ix =37, 44000 mm^4

$$\delta = \frac{WL^3}{3EI} = 20925N(\frac{(633mm)^3}{3x200000\frac{N}{mm}x3744000mm^4} = \frac{5.307x10^{12}}{2.24x10^{12}}$$

=23.5 mm

Dimension of composite mono leaf spring

The Dimensions of Laminated composite leaf springs are taken as that of the conventional steel leaf spring (M. Raghavedra et al 2012).Based on this literature the dimension of the new mono leaf spring is done as follow:

The Toyota Hilux contains five life springs which have the same width and thickness and varies length of leaf springs as mentioned their dimension in the above. The length, and the width of the composite mono leaf spring is taken from the master leaf or leaf No 1 because of the width and the thickness of all conventional leaf springs are the same. The thickness of the composite mono leaf spring is by adding each leaf spring based on their length. Therefor e the new composite new mono leaf springs dimension is 40mm at the center and 16mm at the two end.

Weight of composite materials

By using the same formula the weight of epoxy E-glass, epoxy S-glass and epoxy carbon (395Gpa) prepreg is also calculated as follow

Weight epoxy E-glass

W=mg⇒ρ=m/v

ρ=2000Kg/m^3

$V=l\times t\times w \Rightarrow 1.3m\times 0.06m\times 0.04m=0.00312m^3$

$m=2000kg/m^3\times 0.00312m^3= 6.24$ kg

$w=mg\Rightarrow 6.24$ $Kg\times 10m/s^2 = 62.4$ N

Weight epoxy S-glass

$m=\rho V=2000kg/m3\times 0.00321=6.24$ kg

$w=mg\Rightarrow 6.24$ $Kg\times 10m/s^2 = 62.4$ N

Weight of carbon (395Gpa) prepreg

$W=mg\Rightarrow \rho=m/v$

$\rho=1490$ kg/m^3

$V=l\times t\times w\Rightarrow 1.3m\times 0.06m\times 0.04m=0.00312m^3$

$m=1490kg/m3\times 0.00312m^3=4.65kg$

$w=mg\Rightarrow 4.65kg\times 10m/s^2 = 46.5$ N

4.2.3 Design Concept

As previously stated, composite materials are strong, but they are not the sole alternative for optimizing the vehicle structural application.

It necessitates various design optimization principles in terms of reinforcement behavior and composite matrix. According on the unique requirements of the project, the following three design concepts are explored.

- Stacking sequence of composite layers
- Lamination types of the composites
- Composition of fiber and matrix (fiber matrix volume ratio)

i stacking sequence of composite layer

The strength, stiffness, rigidity, and fatigue resistance characteristics of a composite layer are determined, as well as the stacking sequence and angle of orientation of a composite layer. There are various forms of stacking patterns in composite design, as discussed in the literature. Because composite materials are stronger and stiffer in the direction of the fiber, the applied load of the intended components should be applied in the direction of the fiber to achieve the optimal material attributes (lower stress, better strength, etc.). As a result, the preferred stacking sequence is decided based on the requirements of the chosen design.

Strength of fatigue behavior of composite in different orientation

Tensile fatigue test was performed at 120^0c and room temperature for specimen having both {45^0/+45^0} and {0^0/90^0} fiber orientation .as observed from the Figure 3.6 of the S-N curve of both {-45^0/+45^0} and {0^0/90^0} orientation the fatigue strength of {00/90^0} is better than {-45^0/+45^0} orientation.(Kueh,J.T.J., & Fais,T.2012)

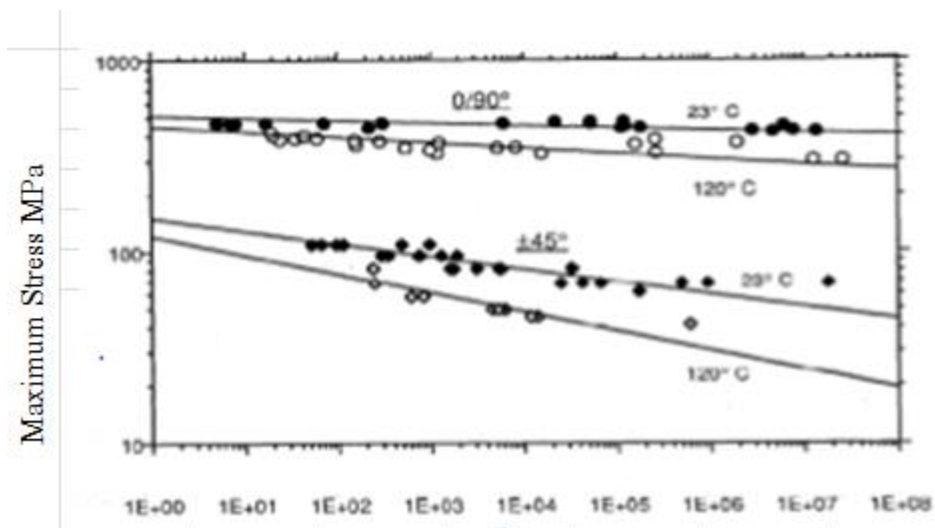


Figure 3. 6: Comparison of (- 45/+45) Fatigue Curve with (0/900) Curves (Huston, R. J.1994)

The strength, stiffness, rigidity, and fatigue resistance characteristics of a composite layer are determined, as well as the stacking sequence and angle of orientation of a composite layer. There are various forms of stacking patterns in composite design, as discussed in the literature. Because composite materials are stronger and stiffer in the direction of the fiber, the applied load of the intended components should be applied in the direction of the fiber to achieve the optimal material attributes (lower stress, better strength, etc.). As a result, the preferred

stacking sequence is decided based on the requirements of the chosen design regarding composite materials the preferred stacking sequence for this study is arranged as [45/0 / 90/90 / 0/90 /-45/ 90 /0 / 90/90 /0/45] T, T ⇒ Total [45/0 / 902 / 0/90 / -45¯] S, S ⇒ Symmetry

ii. Typs of composites that are laminated. The selection of ply angles relevant to a given application is the first step in laminate design. The permitted ply orientations have been restricted to a discrete range of angles due to manufacturing constraints.

As in 0^0,15^0,30^0, 45^0, 60^0, 75^0, and 90^0 the overall number of plies and fraction of each orientation in the laminate are set once the angles are specified, and a stacking sequence is determined. Thickness changes are also accomplished by dropping plies at precise spots when building constructions with multiple zones of various thicknesses. Several rules apply to both laminate stacking sequence design and ply-drop design, based on industry test and analysis experience (Irisarri et al. 2014). The design of the different layers of most composite laminate structures in the automotive and aerospace industries is based on six laminate design standards (Gaikwad, et al. 2012).

Symmetry is an important concept. Stacking sequences should be symmetric about the mid plane wherever possible. Maintaining equilibrium Stacking sequences should be balanced whenever possible, with the equal amount of + and - plies (0 and 90). Contiguity is the third factor to consider. There should be no more than a certain amount of plies of the same orientation piled together. The limit is two plies in this case. Disorientation is number four. The difference between two successive plies' orientations should not exceed 45^0 5.10% - regulation. In each of the 00, 45^0, and 90^0 directions, a minimum of 10% of plies must be present. Damtol is number six. On the lower and top sides of the laminate, no 0^0-ply should be used. Shear-extension and membrane bending linked phenomena are avoided using symmetry and balancing principles. The many guidelines are quite beneficial to the structure's energy. They seek to avoid matrix-dominated behaviors (10% rule) and possible energy problems caused by undesirable failure modes as free-edge delamination (disorientation) or transverse matrix cracking propagation (contiguity). The effect of exterior scratches or surface ply delamination on strength is decreased when the major load carrying plies are insulated from the exposed floor of the laminates (Irisarri, F. X et al 2014). Regarding the current specific design requirement, the above design guide line considers quasi isotropic composite property, and the lamination design type is symmetric laminate. The symmetric laminate composite structure is depicted in Figure 3.2. It has ten layers of composite, each with a distinct fiber angle symmetrically placed. It's commonly referred to as a quasi-isotropic symmetric laminate.

Figure 3. 7: Symmetric Laminate

The need of mid plain symmetry

When the stacking of the plies on each faces starting from the middle plane is same, a laminate is said to have midline symmetry or to be symmetric. The successive impregnated plies are layered at room temperature for the production of laminated components before being placed inside an autoclave for curing. With the exception of warping, the whole laminate extends at high temperatures. However, depending on their orientations, the plies tend to compress differentially during cooling. Thermal residual stresses result as a result of this. When midline symmetry is used, it imposes symmetry on these stresses and prevents the entire portion from deforming, such as warping, as seen in the diagram below. The advantages and disadvantages of symmetric lamination kinds of composite structures are depicted in Figure 3.8 The first figure lacks mid-plane symmetry, causing it to flex in its structure. The second figure, on the other hand, has mid-plane symmetry and does not deform or bend due to the symmetrical plane.

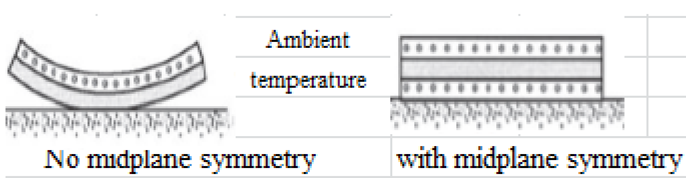


Figure 3. 8: Improve of mid plan Symmetry (Campbell and F. C. Ed. 2012)

Quasi isotropic laminates

A quasi isotropic laminate is one that meets the following criteria.

The laminate must include three or more district fiber angles. If m is the number of district fiber angles, then m 3 is the number of district fiber angles (Tuttle, M. E. 2012). The varieties of lamination are depicted in Figure 3.9. The first illustration has the same orientation angle as the second and shows unidirectional lamination kinds. The second picture is called as quasi isotropic laminate because it contains different orientation angles symmetrically sequenced.

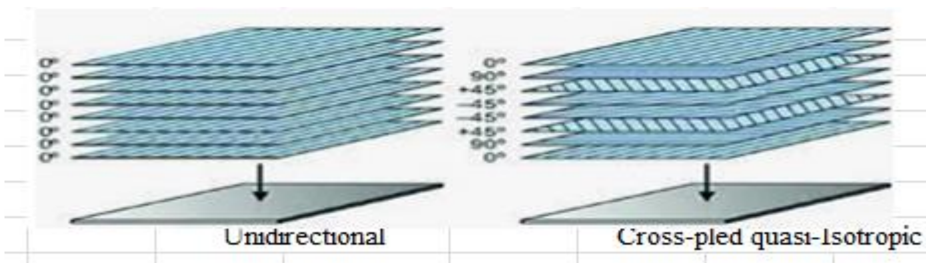


Figure 3. 9: Unidirectional (left) and quasi Isotropic (right) laminate type (Rana, S., et al. 2016)

iii. Fiber and matrix composition (fiber matrix volume ratio)

The determination of constituent percentages such as fiber and matrix fraction presence in laminate is the first and most important task in the design, production, and analysis of composite materials. These values govern and limit the strength and characteristics of composites (Malaga eth al. 2012). Experience can be used to establish the reinforcement to matrix ratio. It could be determined by the volume or weight ratio. Three molds are used to create experimental specimens in order to determine the required amounts of fiber reinforcement composition for composite structure construction. The three specimens are essentially made up of a volume percent of fiber and matrix. These percentages of reinforcement to matrices are 40/60, 50/50, and 60/40. This aids in the selection of the next points.

1. To create a strong bond between the fiber and the matrix.

2. To make the leaf spring's overall weight as little as possible.

3. To make the leaf spring less brittle. Then, in the design phase 3, all of the required parameters are determined using the rule of mixture.

Composite Leaf Spring Design and Methods

The following assumptions are examined when developing composite mono leaf spring technologies and designs.

- All layers are the same thickness,
- The angle of the laminate is varied.
- The size and strength of all the reinforcements are the same.
- Up until failure, both the fiber and the matrix act linearly.

Individually, the fiber and matrix must be isotropic.

Bending Stress and deflection of Composite materials

The bending stress of epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg were calculated using the same formula of the conventional leaf spring

The half effective length of epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg calculated by using equation number 3.4

$$2L = L1 - \frac{2}{3}l = 1300mm - \frac{2}{3}85\ mm$$

L=621.67 mm

The bending stress of epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg were calculated using the same formula of conventional steel leaf spring which described in formula 3.10

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

$$\sigma = \frac{6x5231.25x621.67}{60mm(32mm)^2} = \frac{19512667.125\text{Nmm}}{61440\text{m}m^3} = 317.58\ N/mm^2$$

The deflection of the epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg were also calculated using the equation of number 3.10

The deflection of the epoxy E-glass UD

Using equation number 3.10 calculate the moment of inertia

$$I = \frac{1}{12}bt^3 = \frac{1}{12}60mmx(40mm)^3 = 163840\ mm^4$$

$I=3.2X10^{-7}m^4$

$EI=3.2X10^{-7}*45X10^9=14400\ Nm^2*3=43200\ Nm^2$

$E=45X10^9 N/m^2$

$$\delta = \frac{WL^3}{3EI} = 5231.25N(\frac{0.622)^3}{43200} = 29.14\ mm$$

The deflection of the epoxy S-glass UD

$I=3.2X10^{-7}m^4$

$EI=3.2X10^{-7}*50X10^9=16000\ Nm^2X3=48000\ Nm^2$

$E=50X10^9 N/m^2$

$$\delta = \frac{WL^3}{3EI} = 5231.25N\frac{(0.622)^3}{48000} = 26.22\ mm$$

The deflection of the epoxy carbon UD (395 GPa)

$I=3.2X10^{-7}m^4$

$EI=3.2X10^{-7}*121X10^{12}=387.2*10^5\ Nm^2*3=1161*10^4 Nm^2$

$E=121x10^{12} N/m^2$

$$= \frac{WL^3}{3EI} = 5231.25N(\frac{0.622)^3}{116160000} = 0.01\ mm$$

3.5 Dynamic analysis of leaf springs

Modal analysis helps us to identify various modes of vibration as well as the frequency at which those modes are created. Modal analysis helps us to calculate natural frequency of system so we know which frequency can be destructive and dangerous for system that causes resonance. In modal analysis we need not to apply any external load but it is first step of dynamic analysis. A modal analysis is typically used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a harmonic response or full transient dynamic analysis.

A. Theoretical Euler Bernoulli Beam Theory Beam theory is a simplification of the linear theory of elasticity which provides a means of calculating the load carrying and deflection characteristics of beams. It covers the case for small deflections of a beam that are subjected to lateral loads only. The Euler's equation for natural frequency is given as

$$\omega n = \frac{n^2\pi^2}{L^2}\left[\frac{\sqrt{EI}}{\rho A}\right] ------------------- 3.14$$

Where,

n = Mode Shape

I = Moment of inertia of system

ρ = Density of material

A = Area of cross section

L = Length of spring

E = Modulus of Elasticity For structural steel

$E=200\times10^{9}$ N/m^2

$I=37, 44000 \times10^{-12}$ m^4

$\rho = 7700$ kg/m^3

L=1.3 m

W=0.06 m

A=0.078 m^2

a) 1st Mode Natural Frequency of conventional steel leaf spring

EXI =200x10^9N/m^2x374410^{-9}=748800 Nm^2

= ρxA=7700 kg/m^3×0.078m^2 =600.6

$$\omega n = \frac{n^2\pi^2}{L^2}\left[\frac{\sqrt{EI}}{\rho A}\right] = \frac{1^2 \times 3.14^2}{1.3^2}\left[\frac{\sqrt{748800\ Nm^2}}{600.6\,\frac{kg}{m}}\right] = 205.94\ rad/s$$

$f_1=\omega_1/2\pi$=205.94 rad/s /6.28=32.79Hz

ω_2=4×5.83×35.3=823.76 rad/s ⇒f_2=131.11 Hz

ω_3=9×5.83×35.3=1852.19 rad/s ⇒f_3=294.93 Hz

ω_4=16×5.83×35.3=3292.78 rad/s ⇒f_4=524.32 Hz

ω_5=5×5.83×35.3=5144.97 rad/s⇒$f_{5=}$819.26 Hz

Similarly, for composite materials theoretical calculations modal analysis

Were done using formula 3.14

The modal natural frequency of E-glass/epoxy

$\omega n = \frac{n^2\pi^2}{L^2}\ [\frac{\sqrt{EI}}{\rho A}]$

From equation 3.12 the moment of inertia is calculated as follow

I=bt^3/12=0.06× $(0.04)^3$/12

A=b×l=0.06×1.3=0.078 m^2

I=3.2X$10^{-7}$$m^4$

EI=3.2X10^{-7}×45X10^9=14400 Nm^2

E=45X10^9N/m^2

ρXA =2000Kg/m^3x0.78m^2=1560 kg/m

$\omega 1 = \frac{1^2\pi^2}{1.3^2}\left[\frac{\sqrt{14400}}{156}\right]$ =56.01 rad/s$\Rightarrow f_1$=8.9 Hz

ω_2 =224.04 rad/s = $\Rightarrow f_2$ =35.67 Hz

ω_3 =504.09 rad/s $\Rightarrow f_3$ =80.26 Hz

ω_4=896.15 rad/s$\Rightarrow f_4$=142.67

ω_5=1400.25 rad/s $\Rightarrow f_5$ =222.96 Hz

The modal natural frequency of S-glass/epoxy UD

$\omega n = \frac{n^2\pi^2}{L^2}\left[\frac{\sqrt{EI}}{\rho A}\right]$

From equation 3.12

I=b×t^3/12=0.06× $(0.04)^3$/12

A=b×l=0.06×1.3=0.078m^2

I=3.2X10^-7 m4

EI=3.2X10^{-7}×50X10^9=16000 Nm^2

E=50X10^9 N/m^2

ρXA =2000Kg/m^3x0.78m^2=1560 kg/m

$\omega 1 = \frac{1^2\pi^2}{1.3^2}\left[\frac{\sqrt{16000}}{156}\right] = 59.04 \Rightarrow f_2$ =9.4

ω_2 =236.16 rad/s = $\Rightarrow f_2$ =37.6Hz

ω_3 =531.36 rad/s $\Rightarrow f_3$ =84.61 Hz

ω_4=944.16 rad/s$\Rightarrow f_4$=150.353 Hz

ω_5=1475.25 rad/s $\Rightarrow f_5$ =234.91Hz

The modal natural frequency of epoxy carbon UD (395 GPa) prepreg

$\omega n = \frac{n^2\pi^2}{L^2}\left[\frac{\sqrt{EI}}{\rho A}\right]$

From equation 3.12 the moment of inertia is calculated as follow

$I=bt^3/12=0.06\times(0.04)^3/12$

$A=bl=0.06\times1.3=0.078\ m^2$

$I=3.2X10^{-7}m^4$

$EI=3.2\times10^{-7}\times121X10^{12}=387.2\times10^5\ Nm^2$

$E=121x10^{12}N/m^2$

$\rho\times A=1450kg/m^3x0.078m^2=113.1\ kg/m$

$\omega n=\frac{n^2\pi^2}{L^2}\ [\frac{\sqrt{EI}}{\rho A}]$

$\omega 1=\frac{1^2\pi^2}{1.3^2}\ \left[\frac{\sqrt{38720000}}{156}\right]=2904.5\Rightarrow f_1=462$

$\omega_2=11618$ rad/s = $\Rightarrow f_2=1850$ Hz

$\omega_3=26140.5$ rad/s $\Rightarrow f_3=4162.5$ Hz

$\omega_4=46472$ rad/s$\Rightarrow f_4=7400$ Hz

$\omega_5=72600$ rad/s $\Rightarrow f_5=11560.5$ Hz

Harmonic response

Frequency (harmonic response analysis calculates the response of an object when load is applied. It is steady-state response of a linear structure exited at a single frequency. In frequency response analysis each frequency is solved independently for applied force. It can be used for structure which operates continuously at a single speed or those which change speed slowly enough so that steady state is maintained.

3.6 Modeling of leaf spring

Modeling and numerical simulation are essential aspects of today’s automotive sector. They are necessary in order to reduce the time-to-market for new products and the costs associated with experimental testing. A good modeling and simulation in design and analysis give many benefits such as: minimizing product manufacturing time, material scrap and material cost. In vehicle structure design, the automotive sector has been undertaking structural analyses (static, dynamic, safety, noise and vibration, handling, etc.) for many years. Gradually, the precision and accuracy of models increase in its quality, but until now except metals and a few polymer components composite materials does not involved. The polymer components, in the majority of cases, have only been modeled as isotropic materials. However, as the use of structural composite materials in the automotive sector increased, it has now become necessary to model composites more rigorously. It is also desirable to integrate design and analysis processes to verify a product's performance in relation to its manufacturing and vice versa. Light weighting is one of the major drivers for the use of composites in the automotive industry. However, the benefits of light weighting are different for different categories of vehicle. Light weighting in trucks allows for payload increases whilst maintaining the same overall mass. In mass production vehicles, the most important driver for light weighting is the reduction of fuel consumption and the associated reduction of CO2 and other emissions in order to reduce environmental hazards. Overall, there is no doubt that the importance of modeling and simulation in the automotive sector will continue to increase time to time. In terms of composite materials, the focus for continued development will be the improvement of failure theories, damage modeling, and fatigue life prediction whilst achieving reasonable solution times.

3.6.1 2D sketching and 3D Modeling of Leaf Spring

The 3D Modeling is a geometrical representation of a real object without losing information which the real objects have. Various mechanical design and manufacturing operations modeled using Solid work. This software allows the user to make changes very easily without having to go to back at the beginning and update all the drawings and assemblies. Generally solid work is easy to use and feature based parametric solid modeling software with many extended design and manufacturing applications. In this specific research, based on the dimension obtained from theoretical calculation and direct measuring data 3D modeling and 2D sketching of the leaf spring was created with the help of solid work 2013 solid modeling software and analysis is done by using ANSYS19.2 workbench for stress and deflection. The light vehicle (Toyota pickup) model vehicle is selected for this study, because of the following reasons;

- Toyota pickup model vehicles are currently used laminated type of steel leaf spring
- To replace the steel leaf spring with epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) composite materials leaf spring material to make the leaf spring light weight.
- Easy to take the necessary data due to its availability

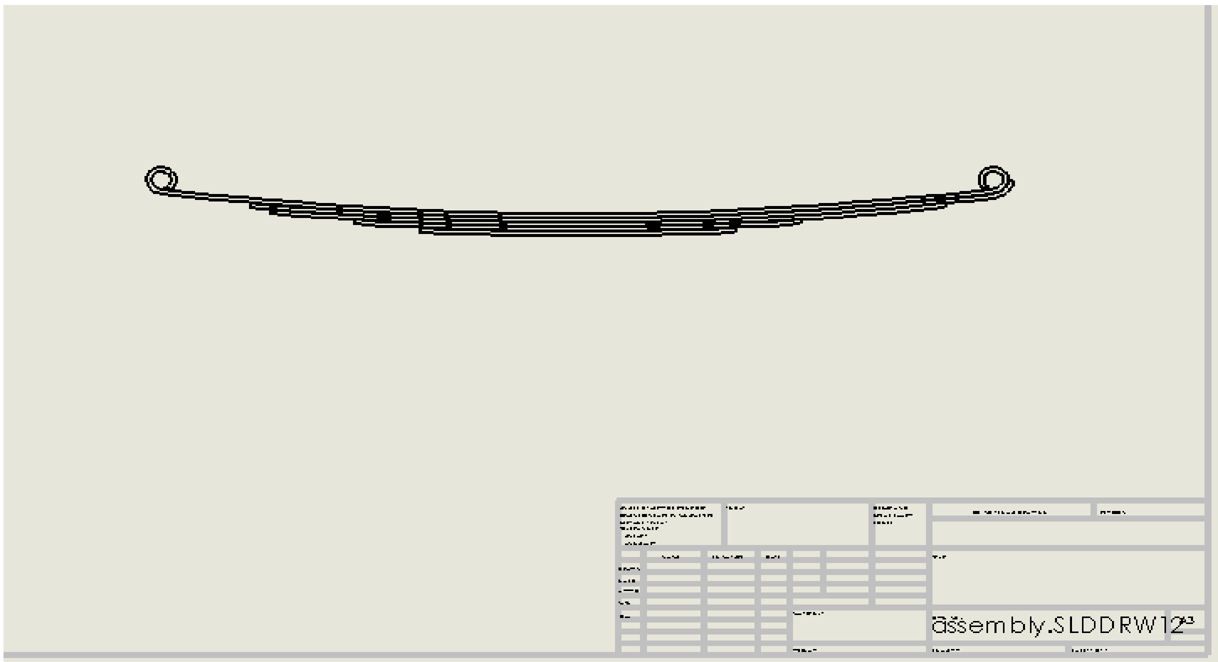


Figure 3. 10 : 2D Drawing of laminated steel leaf spring using Solid work 2013 Software.

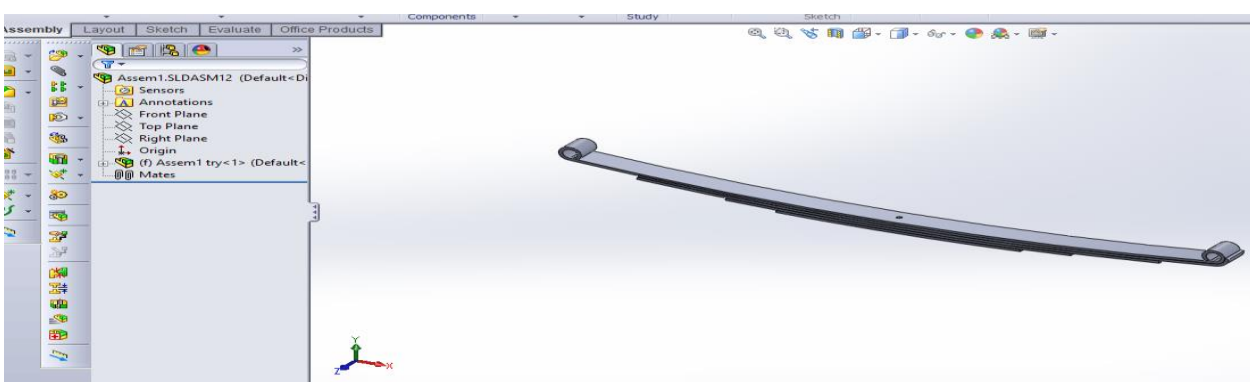


Figure 3. 11: 3D Modeling of steel leaf spring using solid work 2013

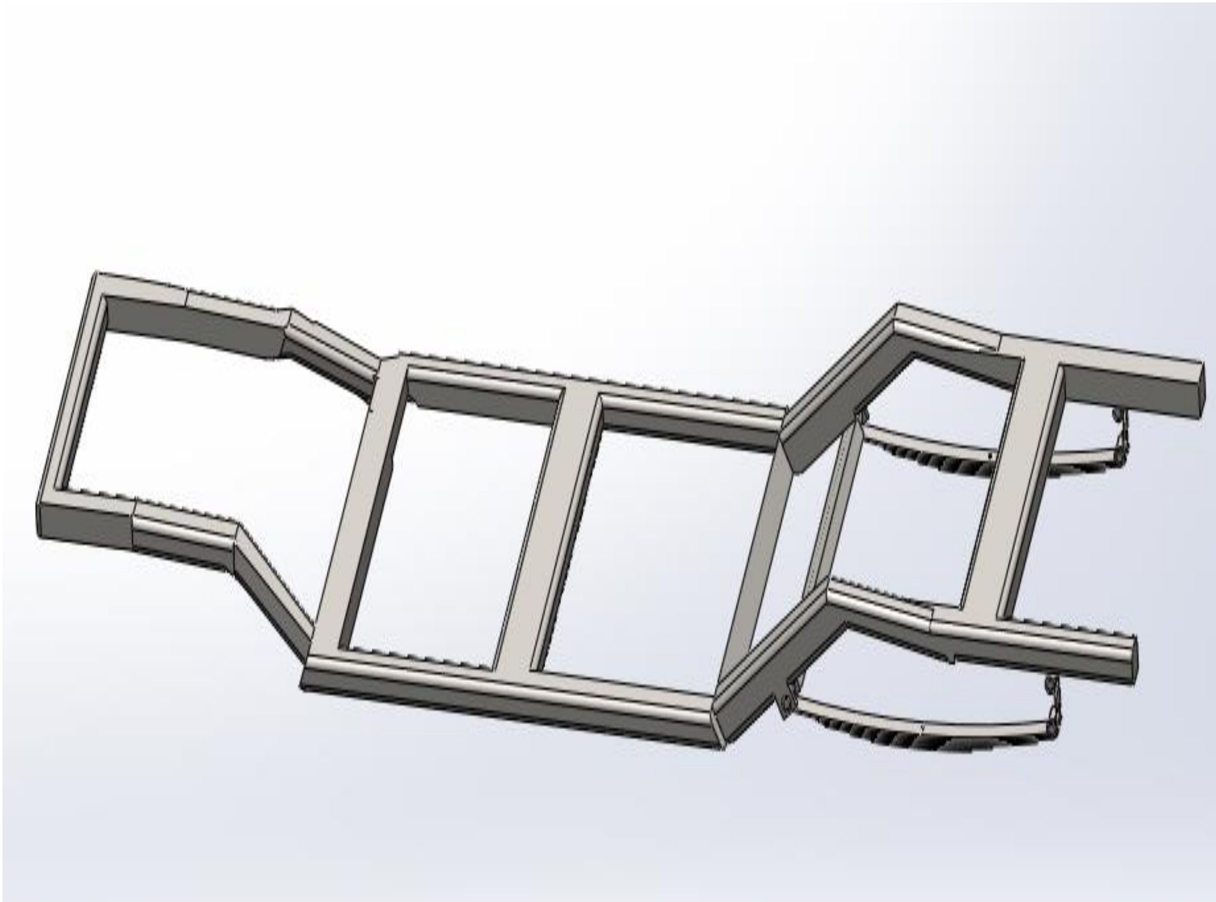


Figure 3. 12: Chassis assembly of conventional steel leaf spring using solid work 2013

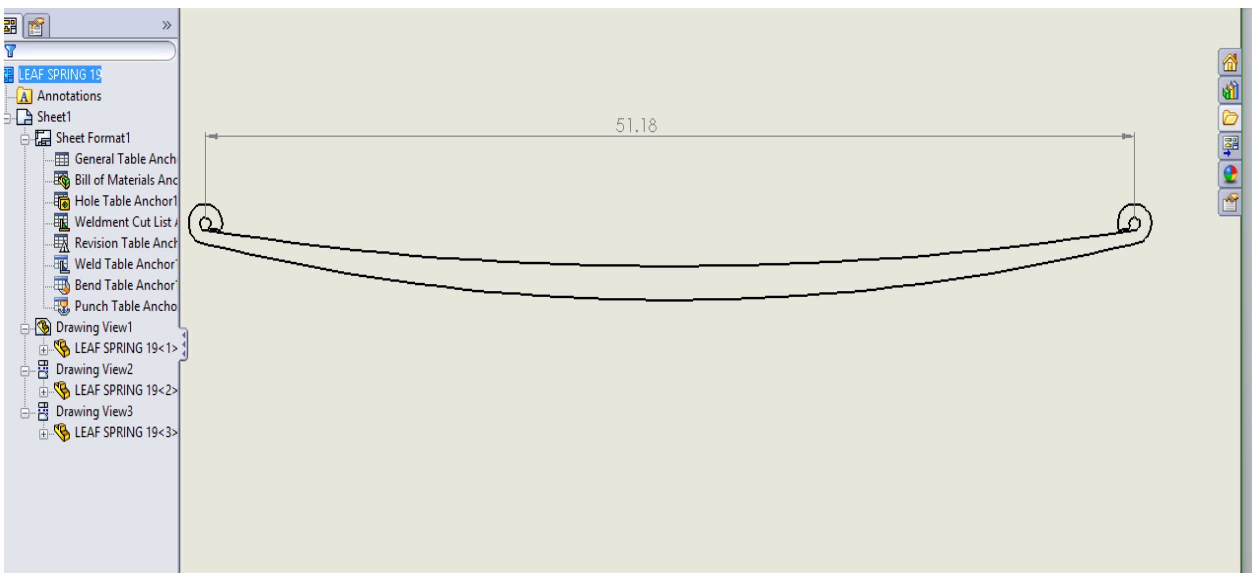


Figure 3. 13: 2D drawing of composite materials leaf spring using solid work

Figure 3. 14: Chassis assembly of composite materials leaf spring using solid work 2013

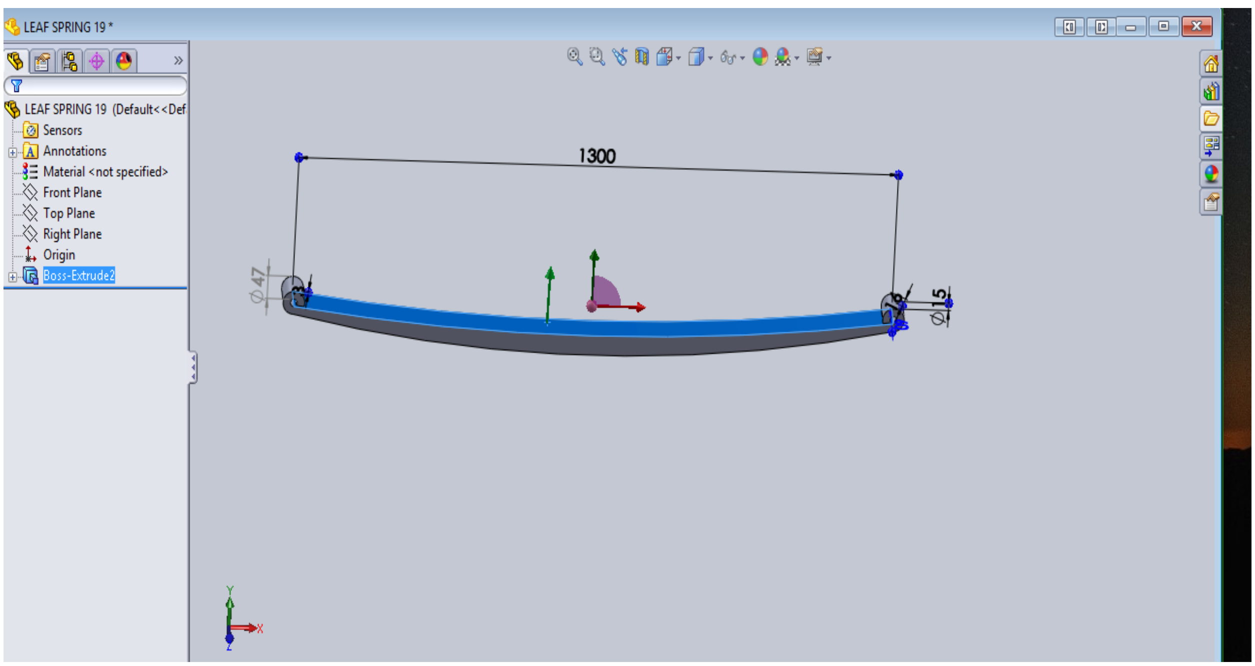


Figure 3. 15: 3D modeling of composite materials leaf spring using Solid work.

3.7 Analysis of leaf Spring Using Finite Element Method

The Finite element Method (FEM) is a numerical method of solving system of partial different equation (PDFs) arising in engineering and mathematical modeling. Traditional fields of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. Designers use ANSYS in a wide range of industries, including aerospace, automobile, construction, nuclear, communications, biomedical, and many others. Designers may use ANSYS simulation tools to monitor design performance on their desktop. As a consequence, it facilitates rapid, dependable, and cost-effective product development from concept to validation. The ANSYS kit aids designers in resolving issues such as structural deformation, heat transfer, fluid flow, electromagnetic effects, a mixture of these phenomena working together, and so on, which helps to speed up and streamline the product development process (Jagbhooshan Patel). ANSYS is a finite element analysis (FEA) software package that can be used for a variety of applications. Finite Element Analysis (FEA) is a computational tool for breaking down a complex structure into tiny parts known as components. The program creates a detailed description of how the system functions as a whole by implementing equations that control the action of these elements and solving them all. These findings can then be presented in tabular or graphical form. This form of analysis is usually used to design and optimize a system that is too complex to manually analyze. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations. (Sagar Manchanda, Beant Singh and Gurmeet Singh December 2015).

3.7.1 Static structure analysis

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

- Externally applied forces and pressures
- Steady-state inertial forces (such as gravity or rotational velocity)
- Imposed (nonzero) displacements
- Temperatures (for thermal strain) Assumptions were developed during analysis of both for mono composite E-glass/epoxy, S-glass/epoxy UD and epoxy carbon UD (395 GPa) and conventional leaf spring materials, to be compatible with the modeling of the leaf spring.

1. The eye of the leaf spring count as within the length of it. Therefore it doesn't consider for analysis separately.

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

3. However the physical model of the leaf spring is double cantilever beam, the analysis is done on the whole geometry of the leaf spring.

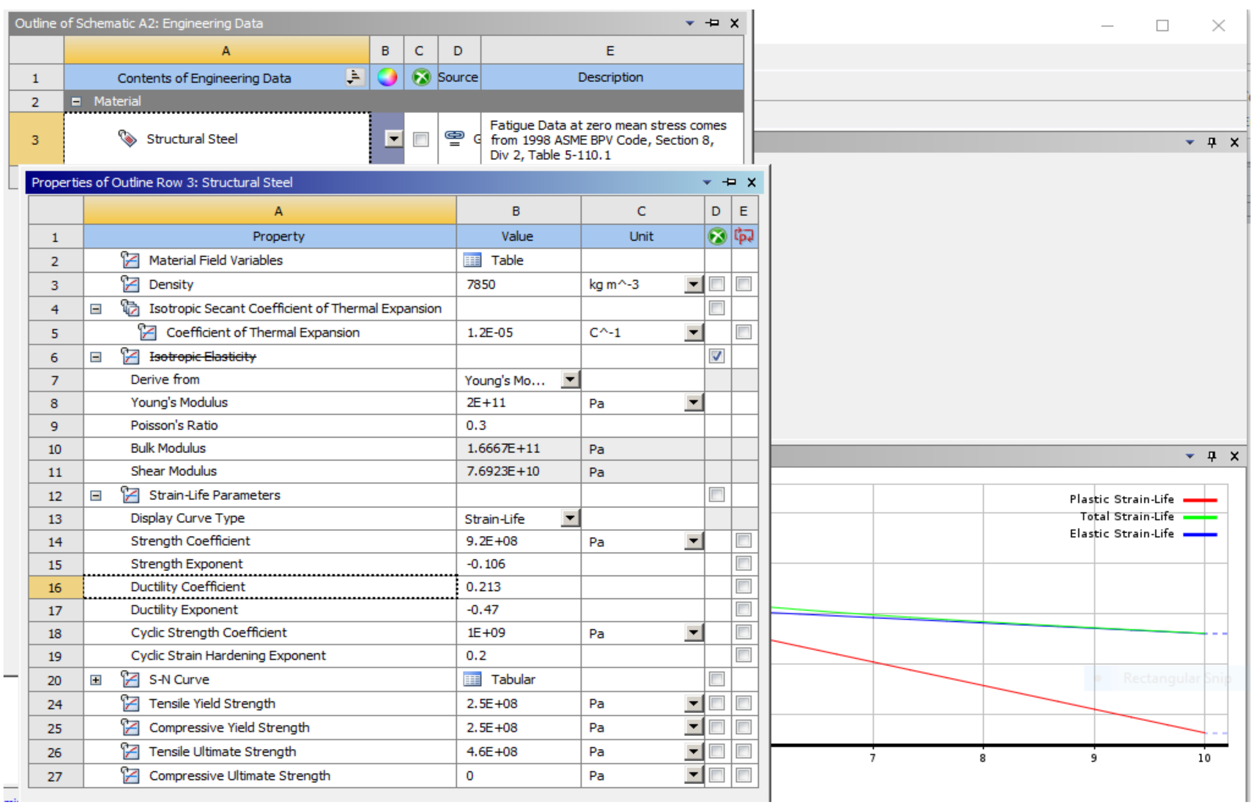
4. The quasi isotropic laminated epoxy E-glass UD, epoxy S-glass UD and epoxy E-glass UD (395GPa) composite material is strongly bonded and has homogenous nature.

4.5 Static analysis of conventional steel leaf spring

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

Define Engineering Data

The specific material property of the structural steel was stated in the figure below:



	Property	Value	Unit
2	Material Field Variables	Table	
3	Density	7850	kg m^-3
4	Isotropic Secant Coefficient of Thermal Expansion		
5	Coefficient of Thermal Expansion	1.2E-05	C^-1
6	~~Isotropic Elasticity~~		
7	Derive from	Young's Mo...	
8	Young's Modulus	2E+11	Pa
9	Poisson's Ratio	0.3	
10	Bulk Modulus	1.6667E+11	Pa
11	Shear Modulus	7.6923E+10	Pa
12	Strain-Life Parameters		
13	Display Curve Type	Strain-Life	
14	Strength Coefficient	9.2E+08	Pa
15	Strength Exponent	-0.106	
16	Ductility Coefficient	0.213	
17	Ductility Exponent	-0.47	
18	Cyclic Strength Coefficient	1E+09	Pa
19	Cyclic Strain Hardening Exponent	0.2	
20	S-N Curve	Tabular	
24	Tensile Yield Strength	2.5E+08	Pa
25	Compressive Yield Strength	2.5E+08	Pa
26	Tensile Ultimate Strength	4.6E+08	Pa
27	Compressive Ultimate Strength	0	Pa

Figure 3. 16: ANSYS Workbench engineering data material properties steel leaf spring

Attach Geometry

That is possible create the geometry of the leaf spring using Design Modeler in ANSYS workbench, beyond this From a CAD system supported by Workbench or one that can export a file that is supported by ANSYS Workbench. Before attaching geometry, specify several options that determine the characteristics of the geometry to import. These options are: solid bodies, surface bodies, line bodies, parameters, attributes, named selections, material properties; Analysis Type (2D or 3D), allowing CAD associativity, importing coordinate systems (Import Work Points are only available in the Design Modeler application), saving updated CAD file in reader mode, "smart" refreshing of models with unmodified components, and allowing parts of mixed dimension to be imported as assembly components that have parts of different dimensions. Then the browsed solid model of the steel leaf spring is done on Solid work 2013, saved as "igs" form looks like in the following figure.

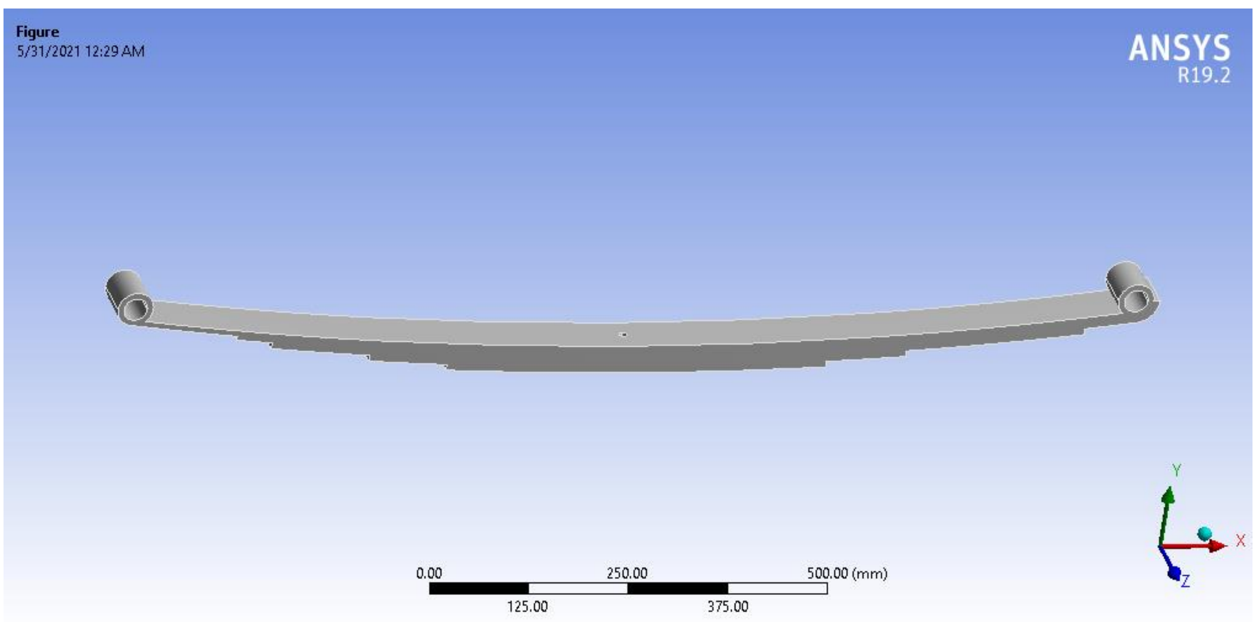


Figure 3. 17: The browsed 3D model of conventional steel leaf spring.

Apply Mesh Control/preview mesh

Applying mesh; provide an adequate mesh density on contact surfaces to allow contact stresses to be distributed in a smooth fashion. Likewise, provide a mesh density adequate for resolving stresses; areas where stresses or strains are of interest require a relatively fine mesh compared to that needed for displacement or nonlinearity resolution. Then the meshed model of the steel leaf spring looks like in the figure below with 246596 nodes and 166950 numbers of elements

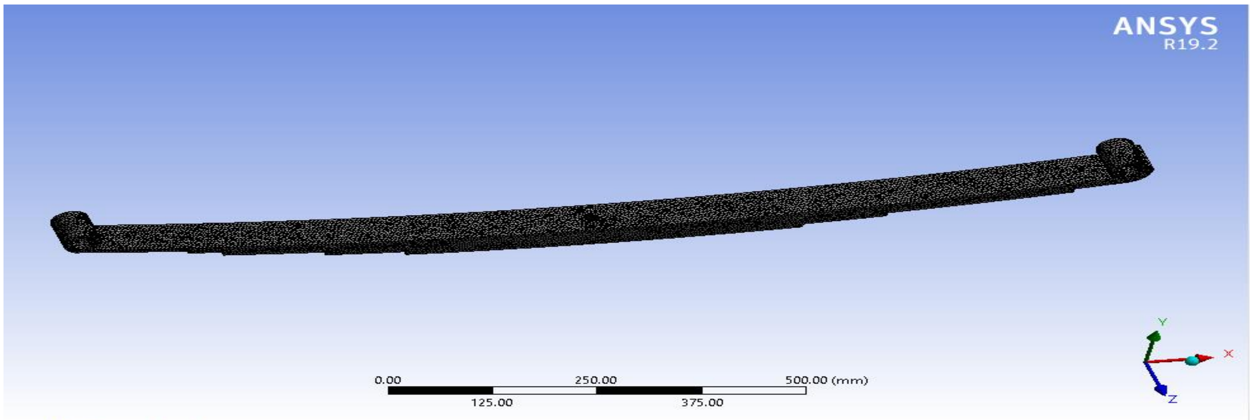


Figure 3. 18: Meshed model of steel leaf spring.

3.7.2 Applying Load and boundary condition

1. Displacement constraint: By considering the actual behavior of leaf spring in the vehicle, one end of leaf spring is rest on the shackle and the other end is on the chassis firm. So one end of leaf spring in X, Y, and Z components are fixed support and in rotation constraint X, Y and Z components are also fixed. The other ends of displacements of the X component are free; Y and Z components are fixed. Figure 3.19 shows how conventional steel leaf spring is mounted to the vehicles. One end is mounted to the shackle and the other end is to the chassis frame .the middle of the spring is mounted on the axel.

2. Force constraint:

Figure 3. 19: Mounting of steel leaf spring [Observation]

When observing the leaf spring mounting position concerning the exerting load of the vehicle. The right and left sides of the wheels are connected by the axel and the whole structure or body of the vehicle is rest or stand by the tire of the vehicle and leaf spring of Toyota pickup is mounted on its center to the axel using U- bolts finally loads of the vehicle is rest at the center of the leaf spring through the axel in left and right sides. Regarding to this characteristic the load is applied at the center of the leaf spring. The front and the rear links (specially the shackle one) are act as the flexibilities of the motion of the vehicle in pump and speed breaker road as a suspension. For this analysis the applied load is 10462.5 N at the center of the leaf spring

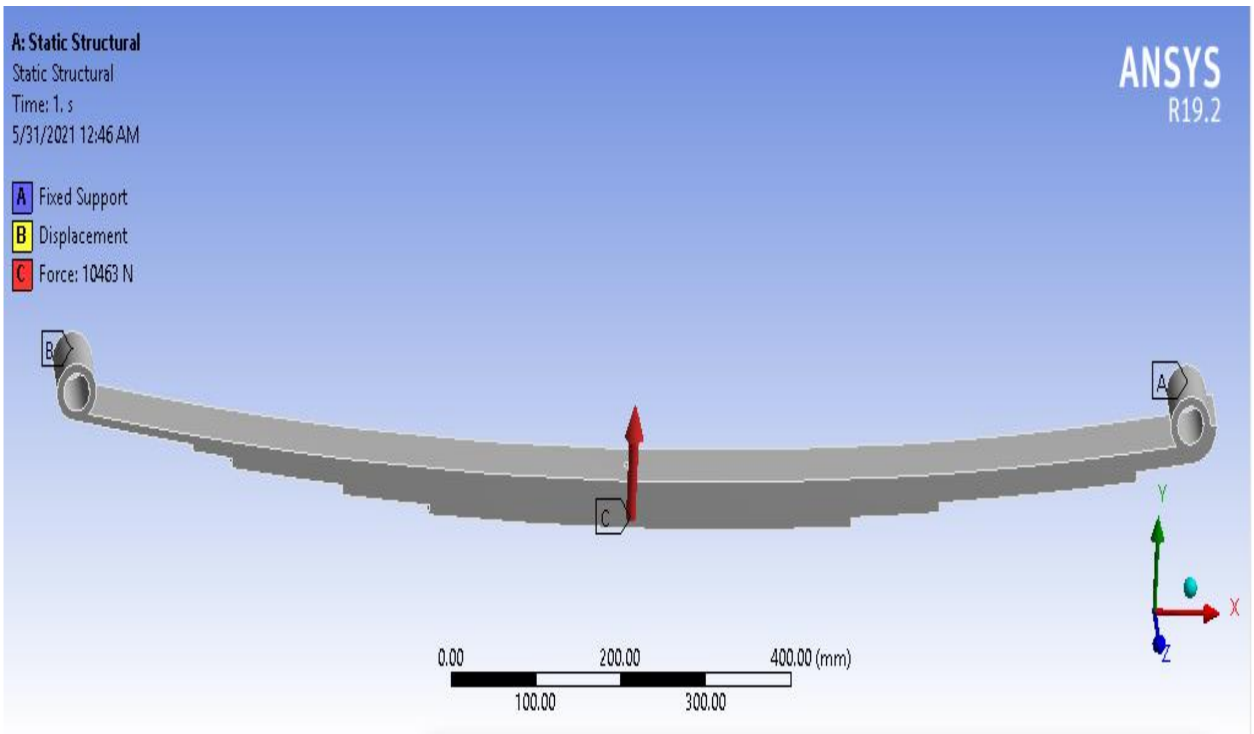


Figure 3. 20: Applied load and boundary conditions of conventional steel leaf spring

Generate solution

The solution is generated from the above input parameters of the project. The total deformation, normal stress, strain, shear force and equivalent (Von Misses) stress are the basic variables to be solved by this software analysis. Solution output continuously updates any listing output from the solver and provides valuable information on the behavior of the structure during the analysis.

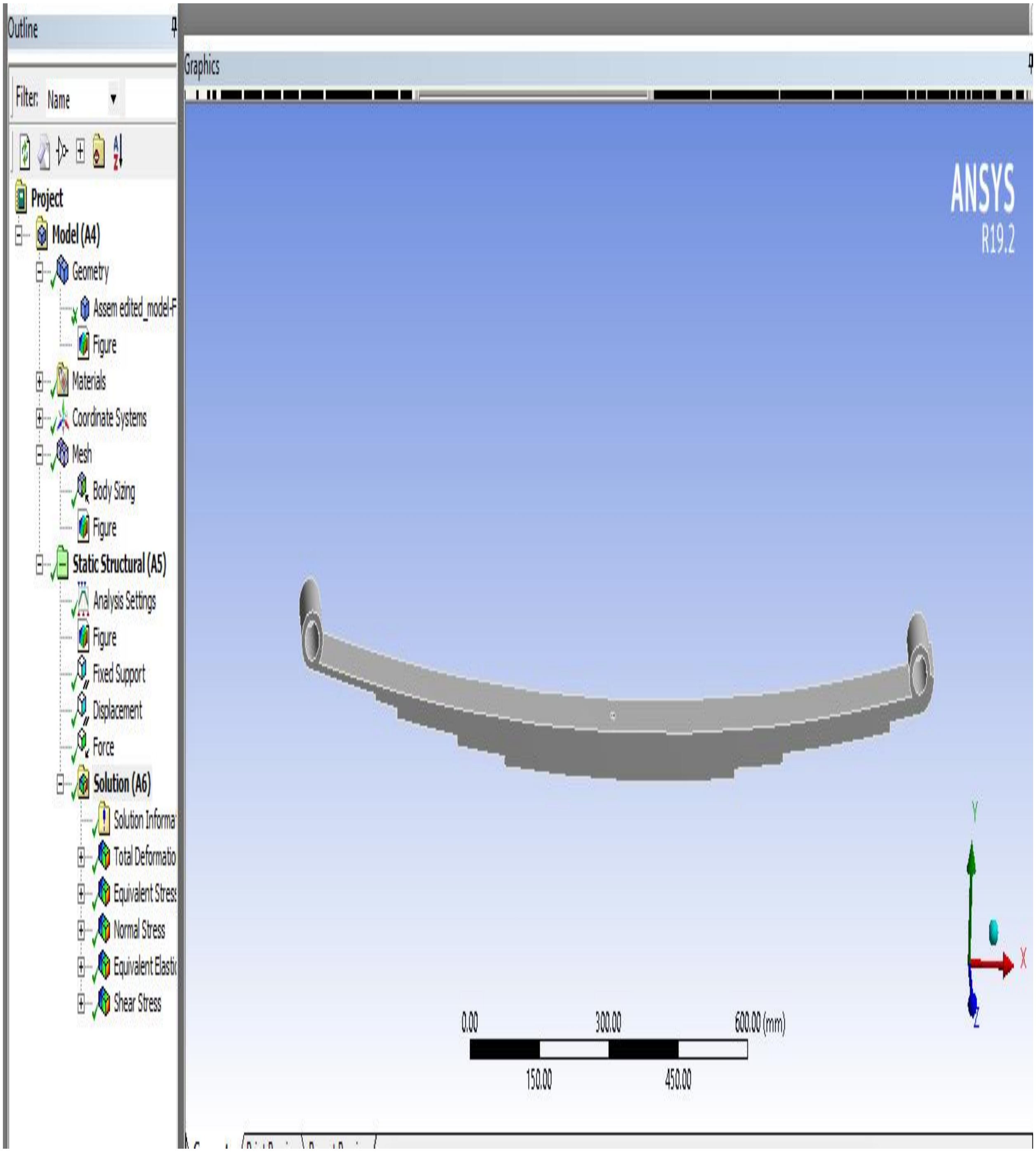
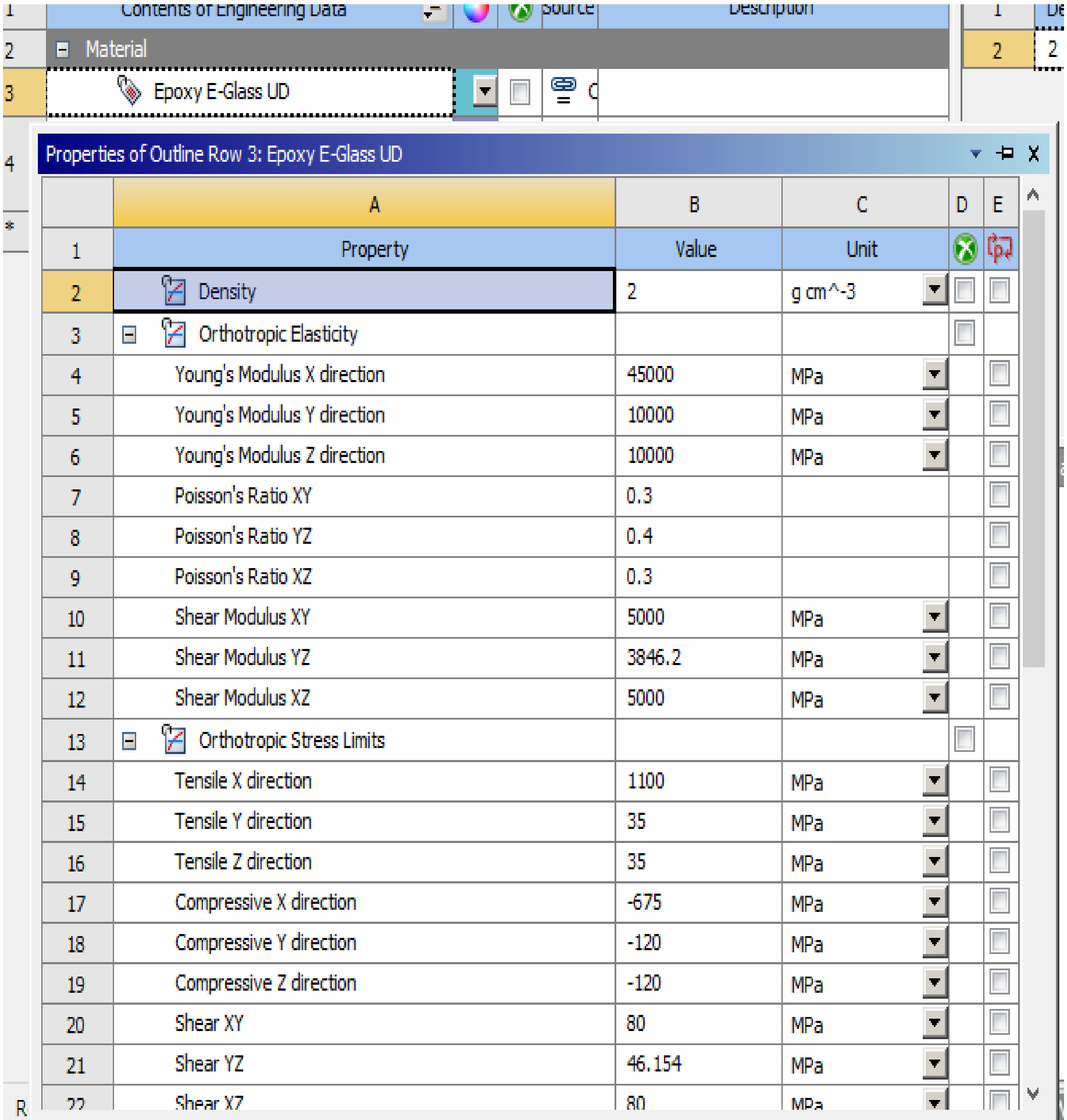


Figure 3. 21: Generating solution of steel leaf spring.

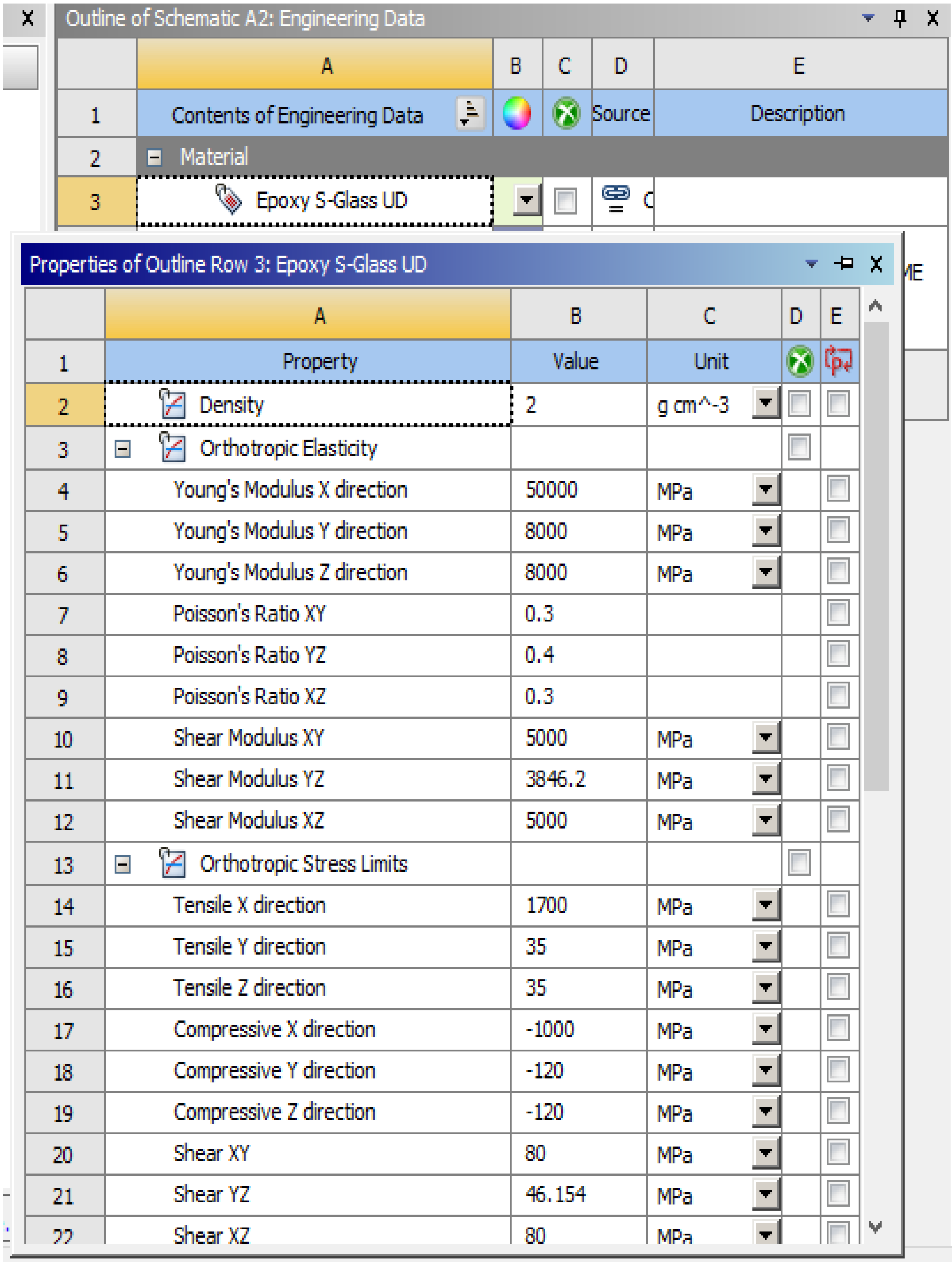
The details solution of each dependent parameter can be displayed one by one. Once the solution is generated, each dependent parameter is solved and ready to be seen and interpreted. Then this will be discussed in the result and discussion part of this paper, next chapter.



Properties of Outline Row 3: Epoxy E-Glass UD

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2	g cm^-3		
3	Orthotropic Elasticity				
4	Young's Modulus X direction	45000	MPa		
5	Young's Modulus Y direction	10000	MPa		
6	Young's Modulus Z direction	10000	MPa		
7	Poisson's Ratio XY	0.3			
8	Poisson's Ratio YZ	0.4			
9	Poisson's Ratio XZ	0.3			
10	Shear Modulus XY	5000	MPa		
11	Shear Modulus YZ	3846.2	MPa		
12	Shear Modulus XZ	5000	MPa		
13	Orthotropic Stress Limits				
14	Tensile X direction	1100	MPa		
15	Tensile Y direction	35	MPa		
16	Tensile Z direction	35	MPa		
17	Compressive X direction	-675	MPa		
18	Compressive Y direction	-120	MPa		
19	Compressive Z direction	-120	MPa		
20	Shear XY	80	MPa		
21	Shear YZ	46.154	MPa		
22	Shear XZ	80	MPa		

Figure 3. 22: Workbench engineering data material properties of quasi isotropic laminated of epoxy E-glass UD composite material



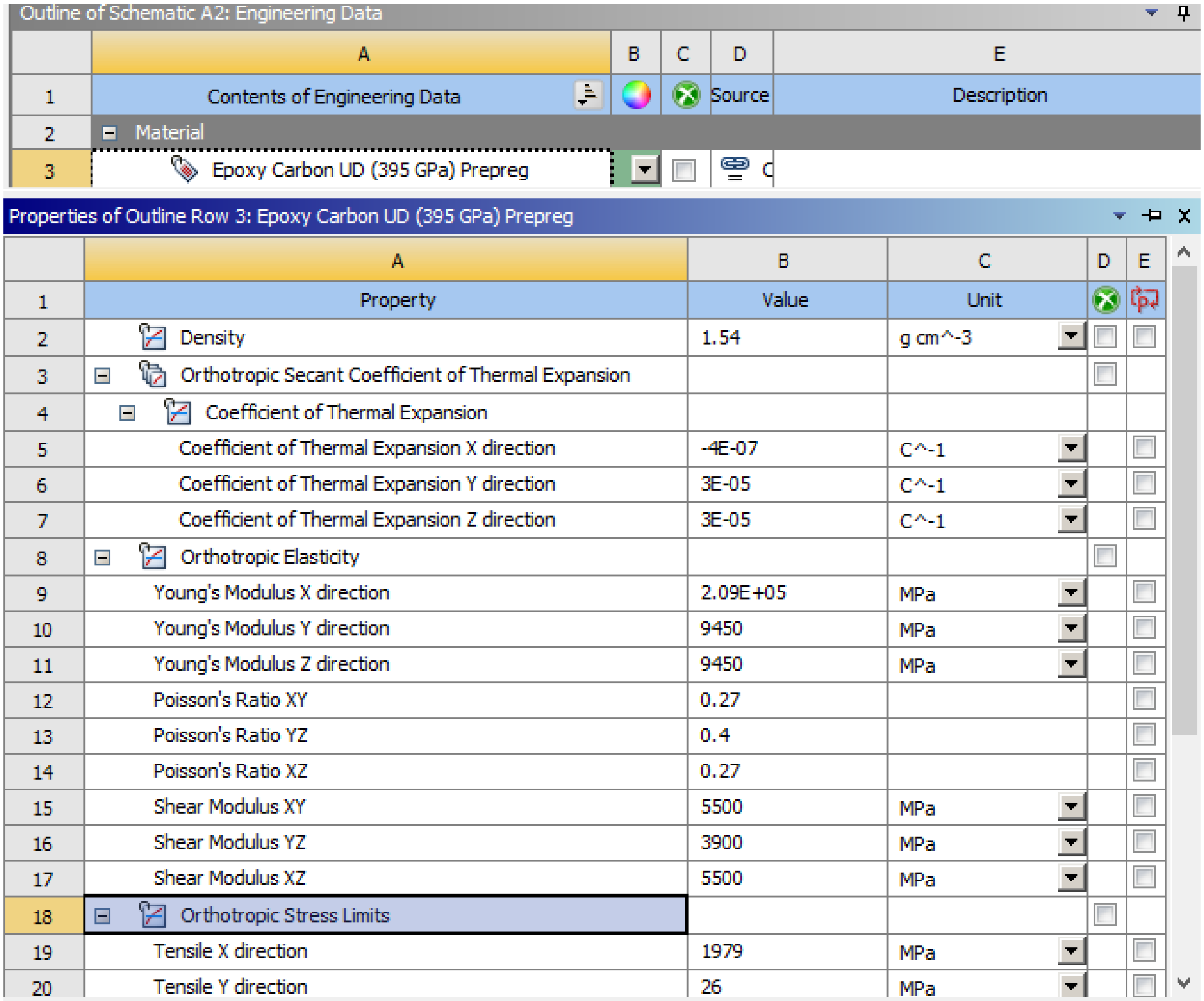
Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Epoxy S-Glass UD				

Properties of Outline Row 3: Epoxy S-Glass UD

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	2	g cm^-3		
3	Orthotropic Elasticity				
4	Young's Modulus X direction	50000	MPa		
5	Young's Modulus Y direction	8000	MPa		
6	Young's Modulus Z direction	8000	MPa		
7	Poisson's Ratio XY	0.3			
8	Poisson's Ratio YZ	0.4			
9	Poisson's Ratio XZ	0.3			
10	Shear Modulus XY	5000	MPa		
11	Shear Modulus YZ	3846.2	MPa		
12	Shear Modulus XZ	5000	MPa		
13	Orthotropic Stress Limits				
14	Tensile X direction	1700	MPa		
15	Tensile Y direction	35	MPa		
16	Tensile Z direction	35	MPa		
17	Compressive X direction	-1000	MPa		
18	Compressive Y direction	-120	MPa		
19	Compressive Z direction	-120	MPa		
20	Shear XY	80	MPa		
21	Shear YZ	46.154	MPa		
22	Shear XZ	80	MPa		

Figure 3. 23: Workbench engineering data material properties of quasi isotropic laminated of epoxy S-glass UD composite



Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Epoxy Carbon UD (395 GPa) Prepreg			C	

Properties of Outline Row 3: Epoxy Carbon UD (395 GPa) Prepreg

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1.54	g cm^-3		
3	Orthotropic Secant Coefficient of Thermal Expansion				
4	Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion X direction	-4E-07	C^-1		
6	Coefficient of Thermal Expansion Y direction	3E-05	C^-1		
7	Coefficient of Thermal Expansion Z direction	3E-05	C^-1		
8	Orthotropic Elasticity				
9	Young's Modulus X direction	2.09E+05	MPa		
10	Young's Modulus Y direction	9450	MPa		
11	Young's Modulus Z direction	9450	MPa		
12	Poisson's Ratio XY	0.27			
13	Poisson's Ratio YZ	0.4			
14	Poisson's Ratio XZ	0.27			
15	Shear Modulus XY	5500	MPa		
16	Shear Modulus YZ	3900	MPa		
17	Shear Modulus XZ	5500	MPa		
18	Orthotropic Stress Limits				
19	Tensile X direction	1979	MPa		
20	Tensile Y direction	26	MPa		

Figure 3. 24: Workbench engineering data material properties of quasi isotropic laminated of epoxy carbon (395 Gpa) prepreg composite.

Attach Geometry

That is possible to create the geometry of the leaf spring using Design Modeler in ANSYS workbench, beyond this From a CAD system supported by Workbench or one that can export a file that is supported by ANSYS Workbench. Before attaching the geometry, specifies several options to determine the characteristics of the geometry to import from solid work software. These options are; solid bodies, surface bodies, line bodies, parameters, attributes, named selections, material properties; analysis type 2D or 3D, allowing CAD associativity, importing coordinate systems import work points are only available in the design modeler application), saving updated CAD file in reader mode, “smart” refreshing of models with unmodified components, and allowing parts of mixed dimension to be imported as assembly components that have parts of different dimensions. Then the browsed solid model of the E-glass/epoxy leaf spring is done on solid work 2013 software, saved as “igs” and “STEP” form looks like in the following figure.

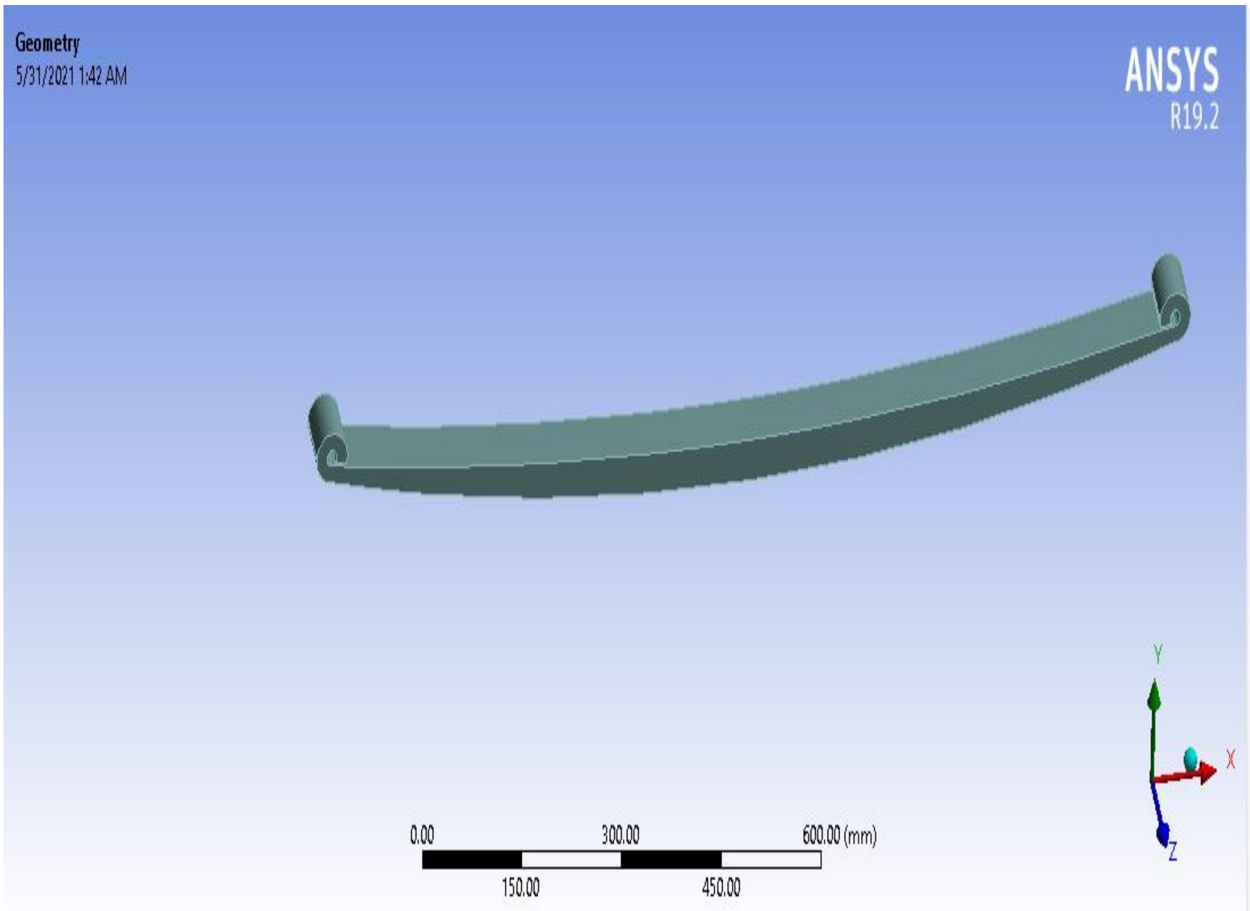


Figure 3. 25: The imported 3D model of epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring to ANSYS 19.2 work bench

Apply Mesh Controls/Preview Mesh

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

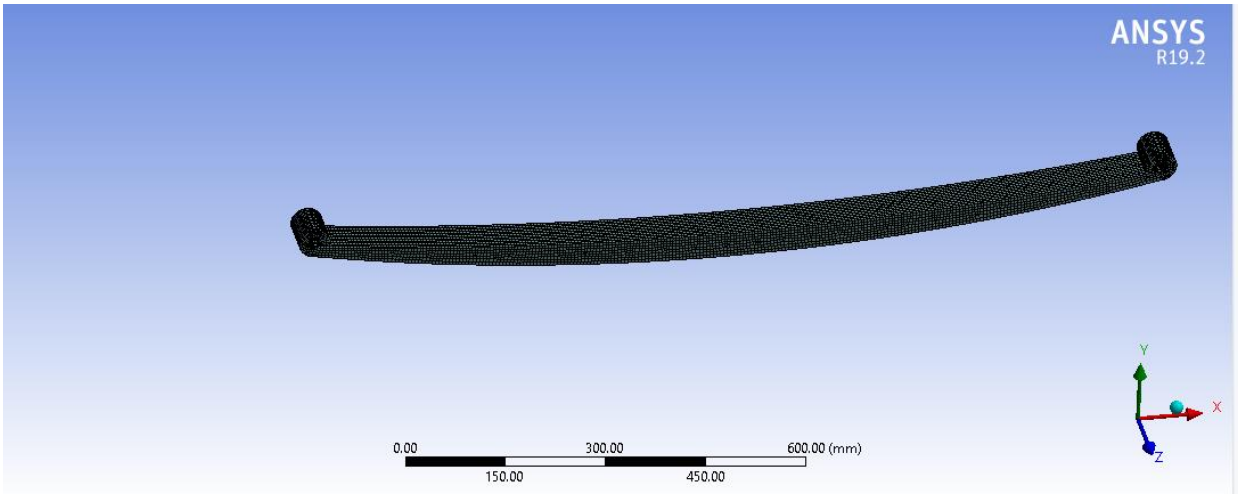


Figure 3. 26: Meshed model of epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring.

3.4.8. Applying Load and boundary condition

1. Displacement constraint: By considering the actual behavior of leaf spring in the vehicle, one end of leaf spring is rest on the shackle and the other end is on the chassis firm. So one end of leaf spring in X, Y, and Z components are fixed support and in rotation constraint X, Y and Z components are also fixed. The other ends of displacements of the X component are free, Y and Z components are fixed. .

2. Force constraint:

When observing the leaf spring mounting position concerning the exerting load of the vehicle. The right and left sides of the wheels are connected by the axel and the whole structure or body of the vehicle is rest or stand by the tier of the vehicle and leaf spring of Toyota pickup is mounted on its center to the axel using U- bolts finally loads of the vehicle is rest at the center of the leaf spring through the axel in left and right sides. Regarding to this characteristic the load is applied at the center of the leaf spring. The front and the rear links (specially the shackle one) are act as the flexibilities of the motion of the vehicle in vamp and speed breaker road as a suspension. For this analysis the applied load is 10462.5 N at the center of the leaf spring.

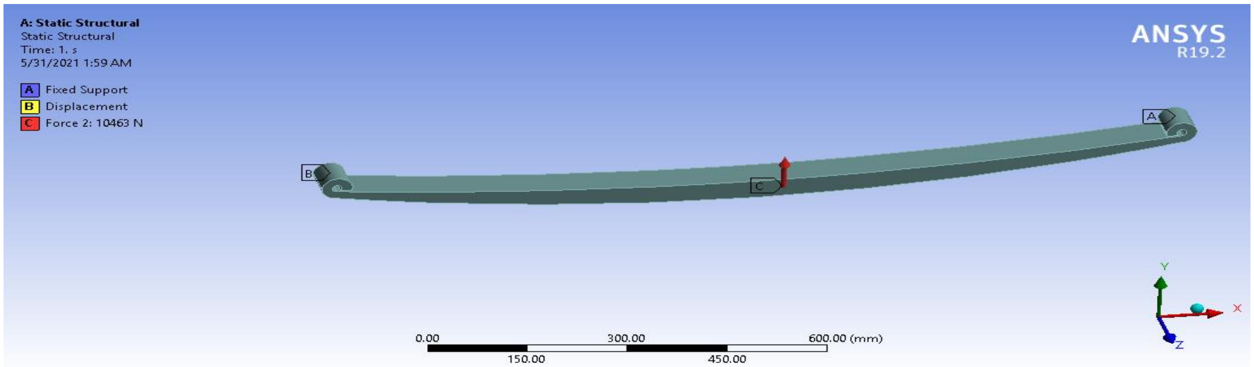


Figure 3. 27: Boundary condition and load applied epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring.

Generating solution

The solution is generated from the above input parameters of the project. The total deformation and equivalent (Von Misses) stress, normal stress, shear stress and equivalent strain are the basic variables to be solved by this software analysis. Beyond this, directional deformation and normal stress in X, Y, and Z directions are also solved and the results are displayed in the appendix part of this study. Solution Output continuously updates any listing output from the solver and provides valuable information on the behavior of the structure during the analysis.

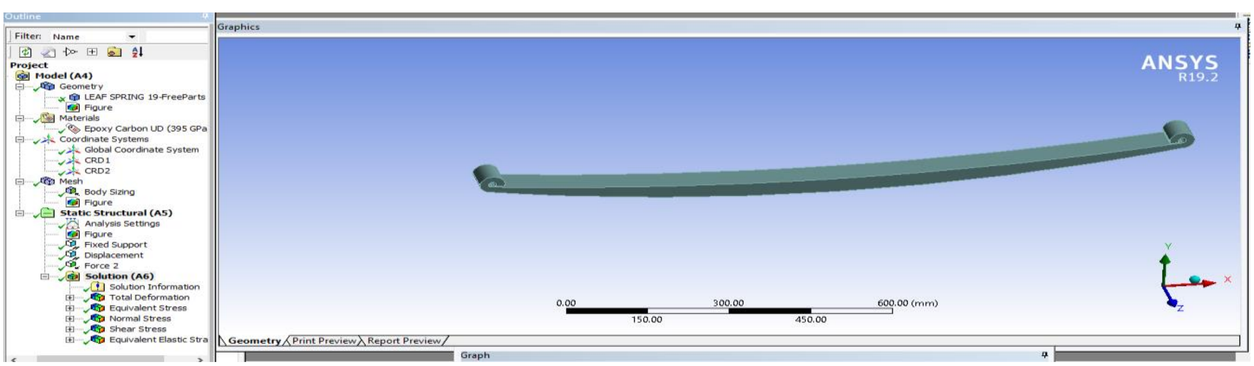


Figure 3. 28: Generating solution of laminated epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring.

Dynamic analysis of leaf spring

In dynamic analysis the process is similar to static analysis but the difference is instead of static structural we use the modal analysis, different types of modal shape of natural frequency and harmonic response

Modal Analysis

Modal analysis helps us to identify various modes of vibration as well as the frequency at which those modes are created. Modal analysis helps us to calculate natural frequency of system so we know which frequency can be destructive and dangerous for system that causes resonance. In modal analysis we need not to apply any external load but it is first step of dynamic analysis. A modal analysis is typically used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a harmonic response or full transient dynamic analysis. Modal analyses, while being one of the most basic dynamic analysis types available in ANSYS, can also be more computationally time consuming than a typical static analysis. A reduced solver, utilizing automatically or manually selected master degrees of freedom is used to drastically reduce the problem size and solution time.

Harmonic response

Frequency (harmonic response) analysis calculates the response of an object when load is applied. It is steady-state response of a linear structure exited at a single frequency. In frequency response analysis each frequency is solved independently for applied force. It can be used for structure which operates continuously at a single speed or those which change speed slowly enough so that steady state is maintained.

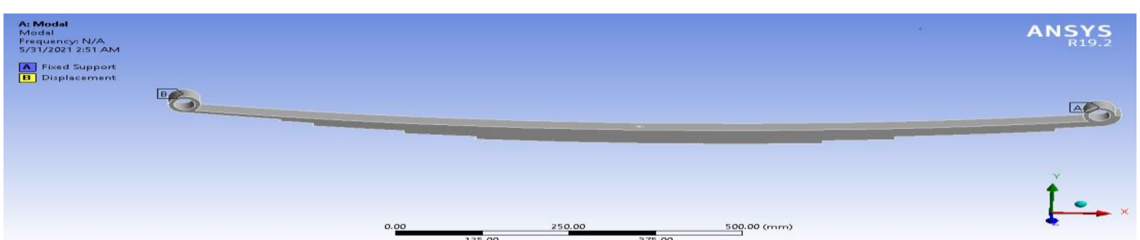


Figure 3. 29: Boundary condition of modal analysis of multi Steel leaf springs.

Generating solution

The solution is generated from the above input parameters of the project. In dynamic analysis there are two solutions the modal shape of natural frequency and the harmonic response in the first solution the total deformation at different modal of natural frequency was solved, at the second solution after load is applied the frequency response and the normal stress and the equivalent (Von Misses) stress was solved. Solution Output continuously updates any listing output from the solver and provides valuable information on the behavior of the structure during the analysis

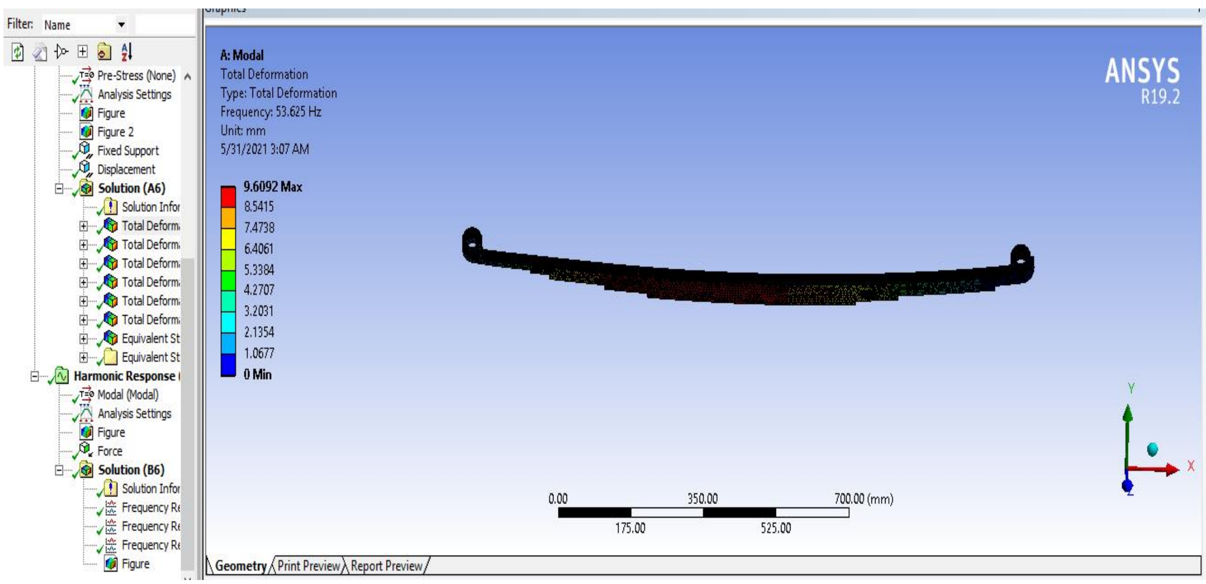


Figure 3. 30: Generating solution of conventional steel leaf spring.

The same procedure for composite materials the detail of the static and dynamic analysis explained in the next chapter

*****

CHAPTER FOUR

RESULT AND DISCUSSION

In this chapter the results for laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials and conventional steel leaf spring materials obtained from the static and dynamic structural analysis clearly defined. Then the results presented here were the four leaf spring's materials namely the epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) and steel materials of; total deformation, equivalent (Von Misses) stress, normal stress and equivalent elastic strains. However all results were presented, in this designed and analyzed; the basic solutions were the total deformation and equivalent (Von Misses) stress. In another word the conclusion of the study will be done based on the total deformation and equivalent (Von Misses) stress results. The remaining results of the analysis which are done on ANSYS 19.2 workbench have been displayed on the appendix. The most important step of finite element analysis procedure is the physically realistic interpretation of the results by the analysis. Since finite element analysis procedures are invariably accompanied by an extensive output of data, it is extremely important that we interpret the results correctly. For this design and analysis, the leaf spring static and dynamic structural analysis was performed using finite element method by using ANSYS 19.2 workbench. This is for the purpose of getting the maximum and minimum equivalent stress and displacement on the structural model. The static and dynamic structural analysis determines the characteristics of the stress and deformation of the structure caused by the applied static loading systems and boundary conditions. The following typical static structural analysis system of ANSYS 19.2 workbench could be performed one by one to complete the analysis and get an appropriate solution of the problem.

Figure 4. 1: Epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg and conventional steel leaf spring Engineering solution.

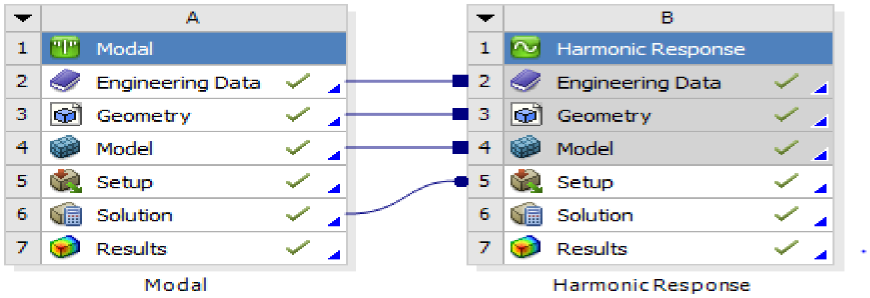
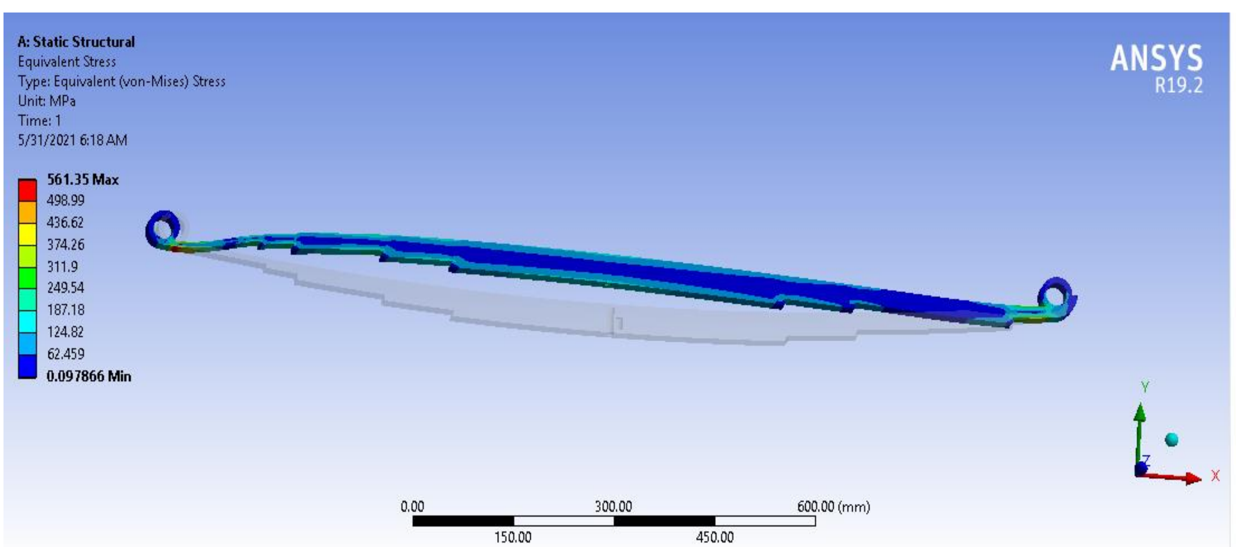


Figure 4. 2: Modal analysis E-glass/epoxy, S-glass/epoxy and epoxy carbon UD (395 GPa) and conventional steel leaf spring Engineering solution.

4.1. Results

4.1.1. Equivalent (von misses) stress

The equivalent (Von Misses) stress values of steel leaf spring the laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg and of FEA respectively looks like in the following figures.



.Figure 4. 3: Equivalent (Von Mises) stress of steel leaf spring

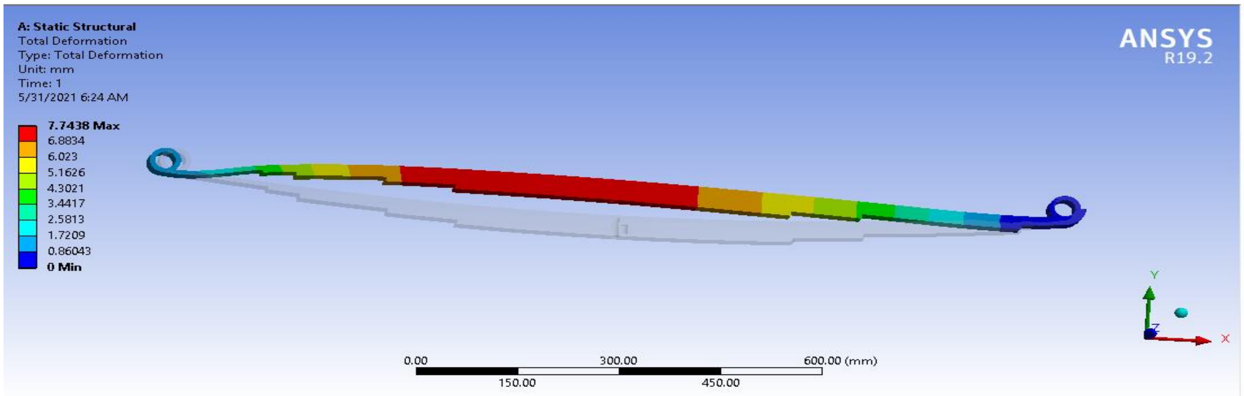


Figure 4. 4: Total deformation of conventional steel leaf spring

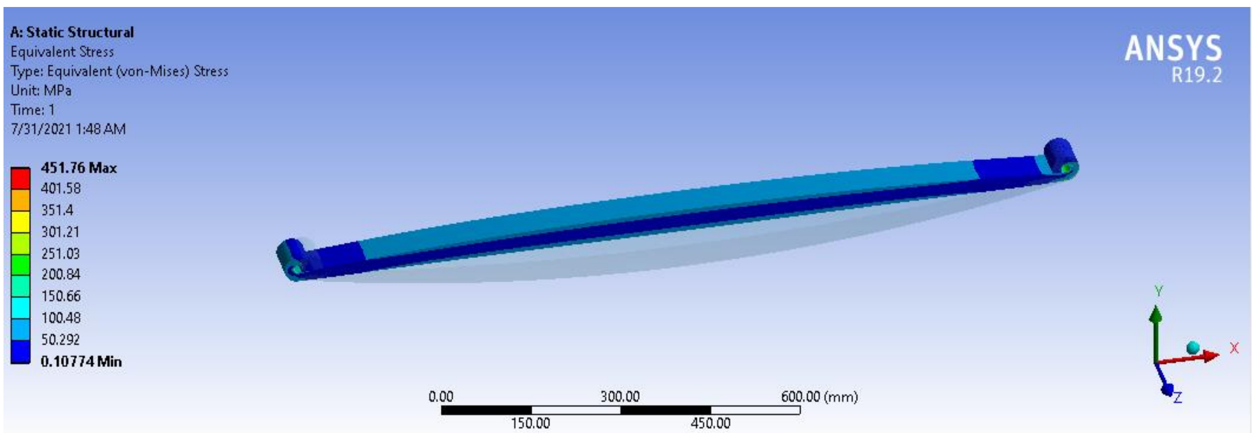


Figure 4. 5: Equivalent (Von Mises) stress epoxy E-glass UD leaf spring

Deformation

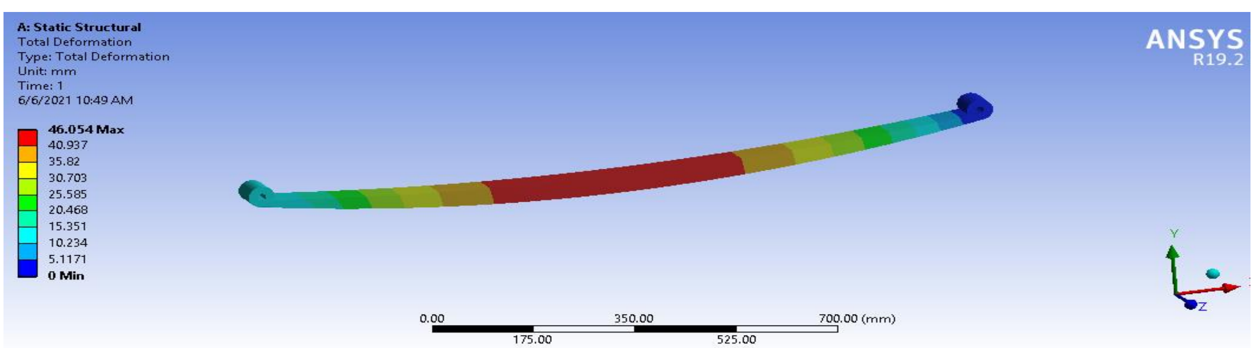


Figure 4. 6: Total deformation of epoxy E-glass UD leaf spring.

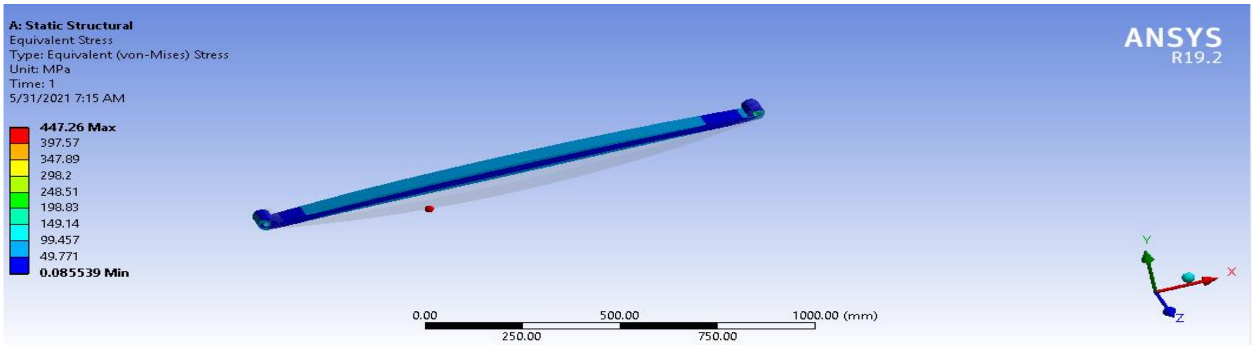


Figure 4. 7: Equivalent (Von Mises) stress of epoxy S-glass UD leaf spring

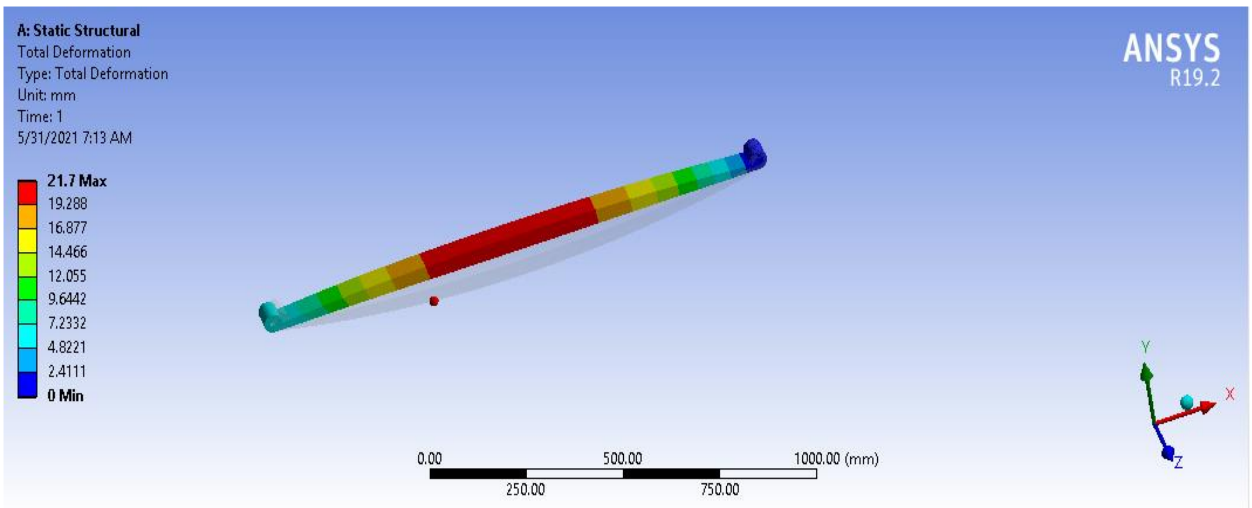


Figure 4. 8: Total deformation of epoxy S-glass UD leaf spring.

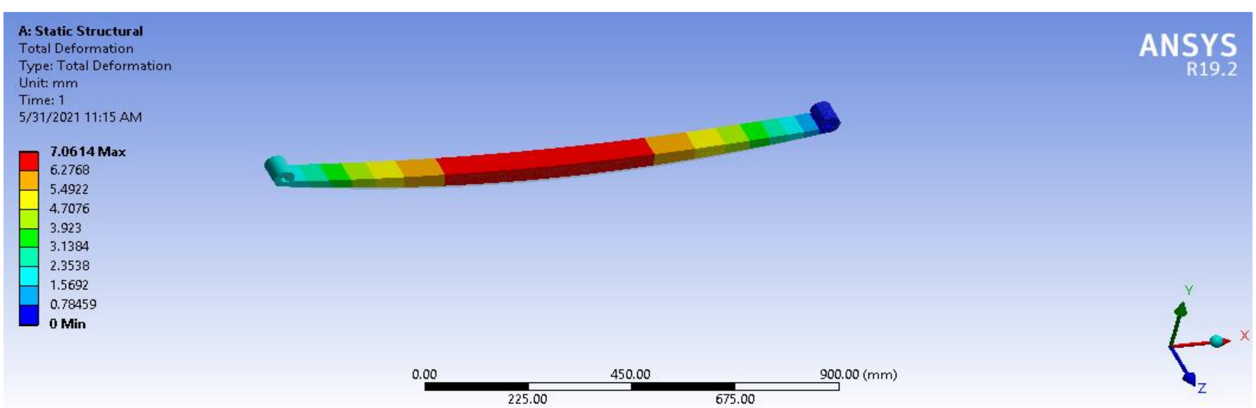


Figure 4. 9: Total deformation of epoxy Carbon UD (395 Gpa) prepreg leaf spring

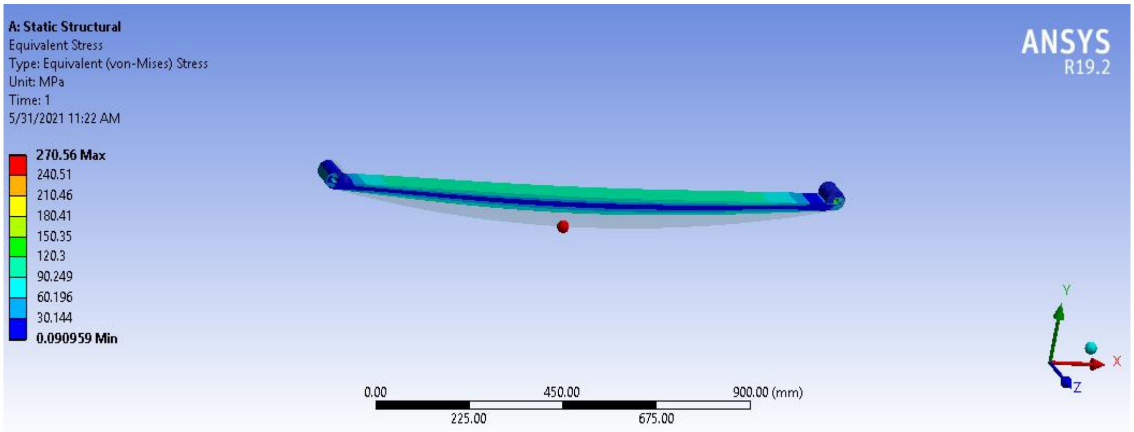


Figure 4. 10: Equivalent (Von Mises) stress of epoxy carbon UD (395Gpa) prepreg leaf spring

4.1.2. Dynamic analysis

Modal analysis

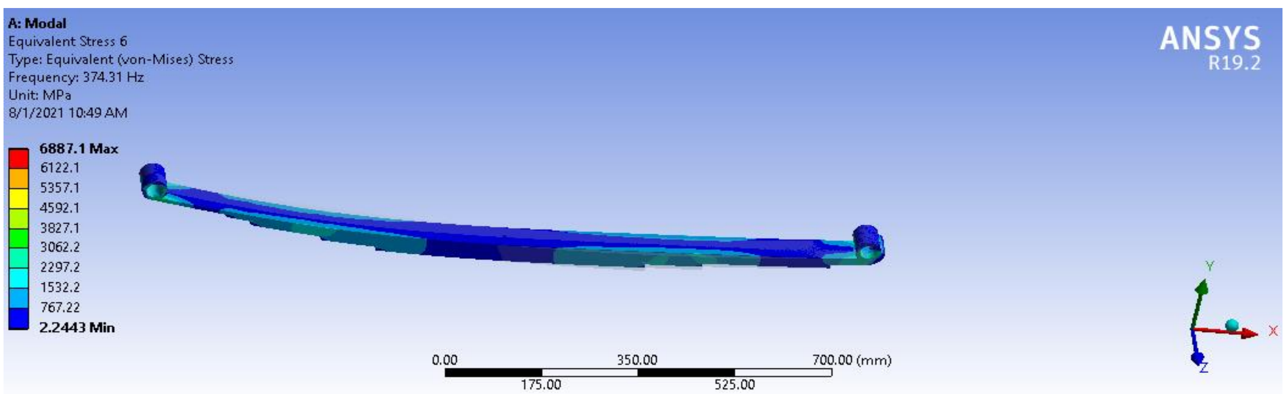


Figure 4. 11Max Equivalent stress of steel leaf spring

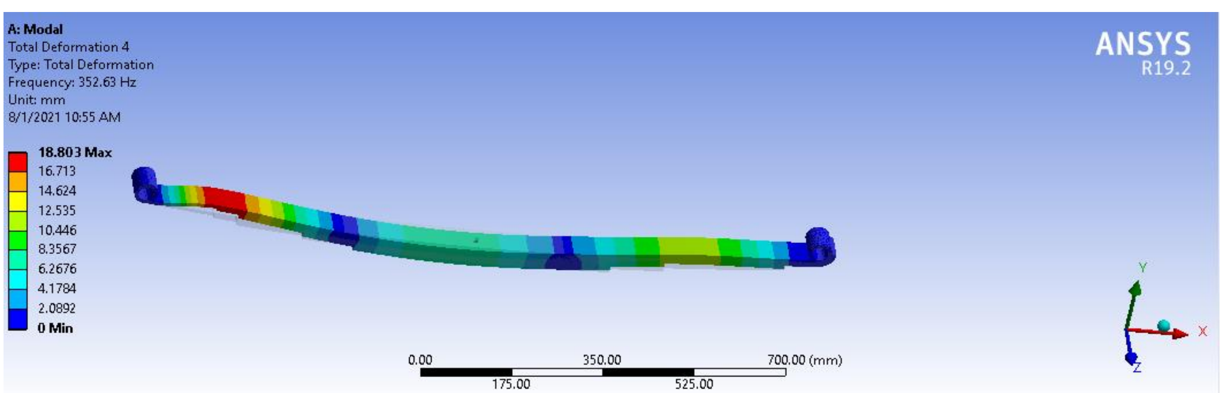


Figure 4. 12: Max Total deformation of steel leaf spring

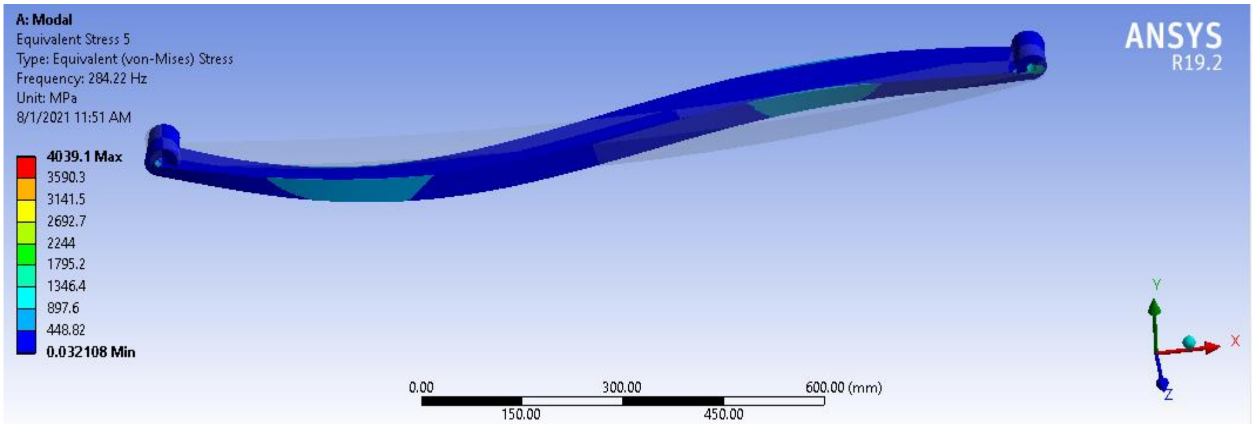


Figure 4. 13: Max Equivalent stress of epoxy E-glass UD leaf spring

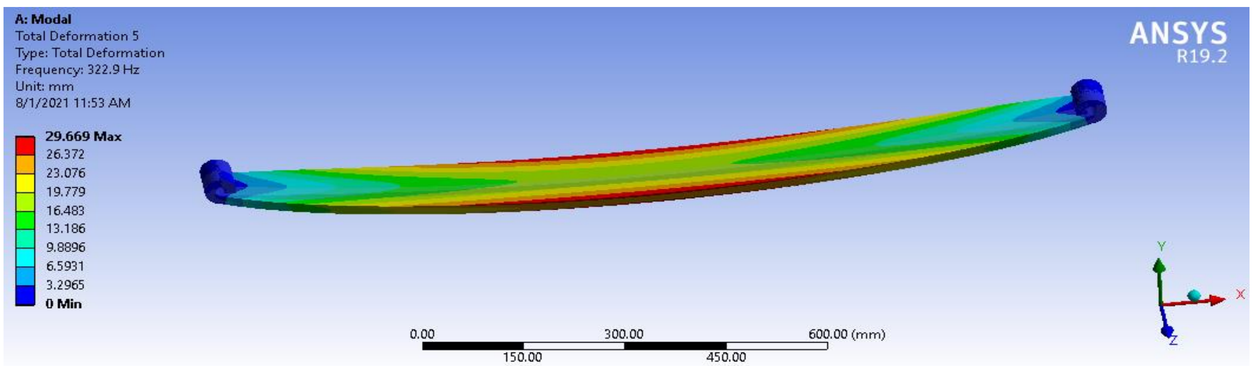


Figure 4. 14: Total deformation of E-glass/epoxy leaf spring

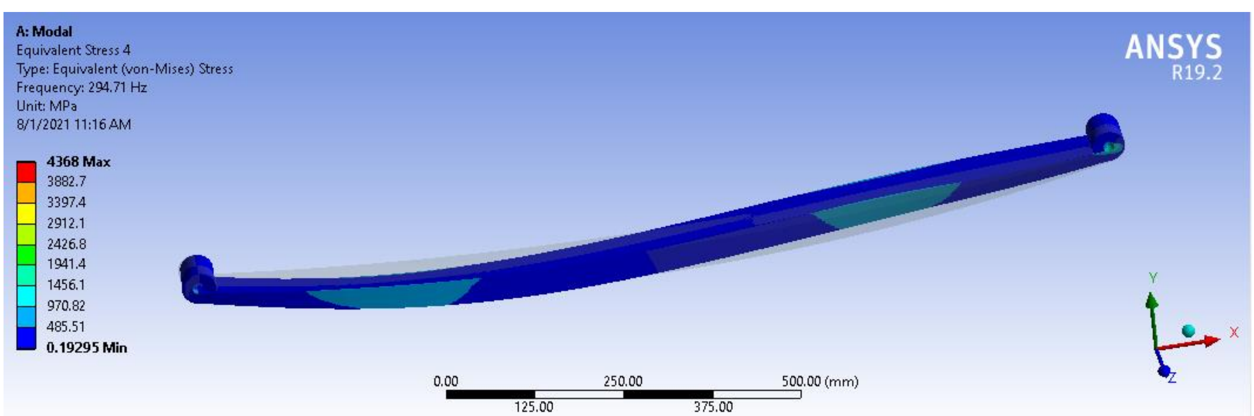


Figure 4. 15: Max Equivalent stress of S-glass/epoxy leaf spring

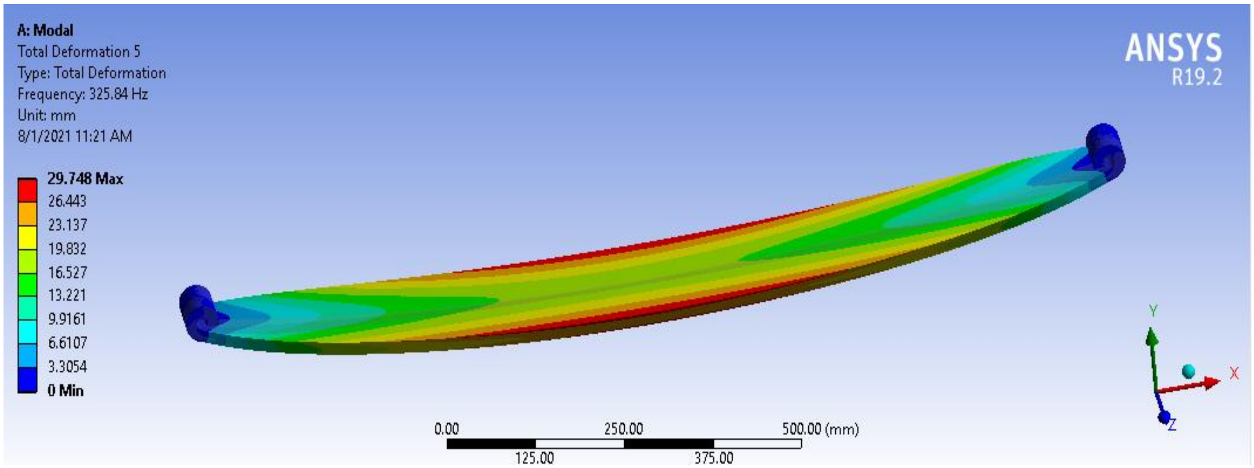


Figure 4. 16: Total deformation of S-glass/epoxy leaf spring

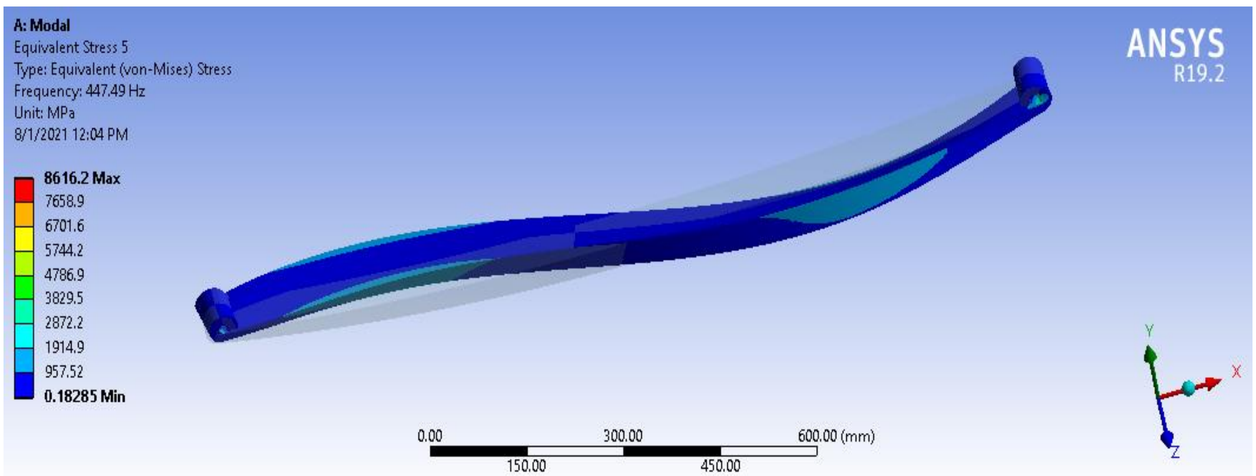


Figure 4. 17: Equivalent of epoxy carbon UD leaf spring

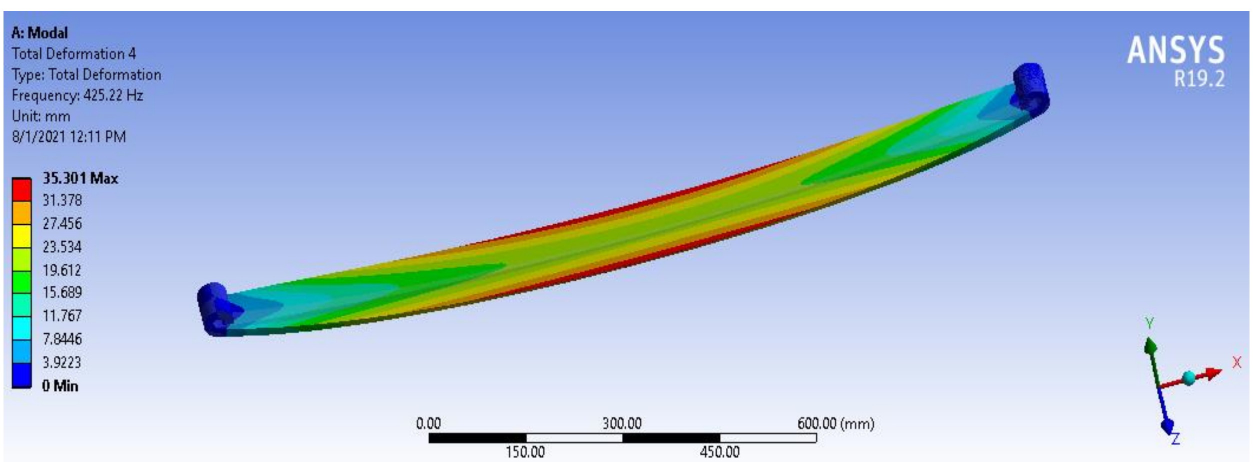


Figure 4. 18: Total deformation of epoxy carbon UD leaf spring

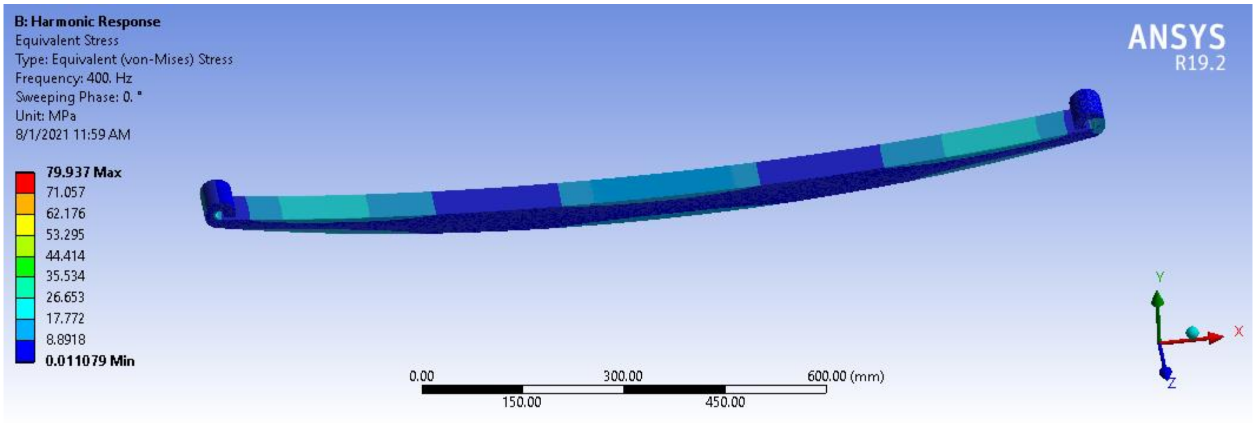


Figure 4. 19: Max Equivalent stress of E-glass/epoxy leaf spring

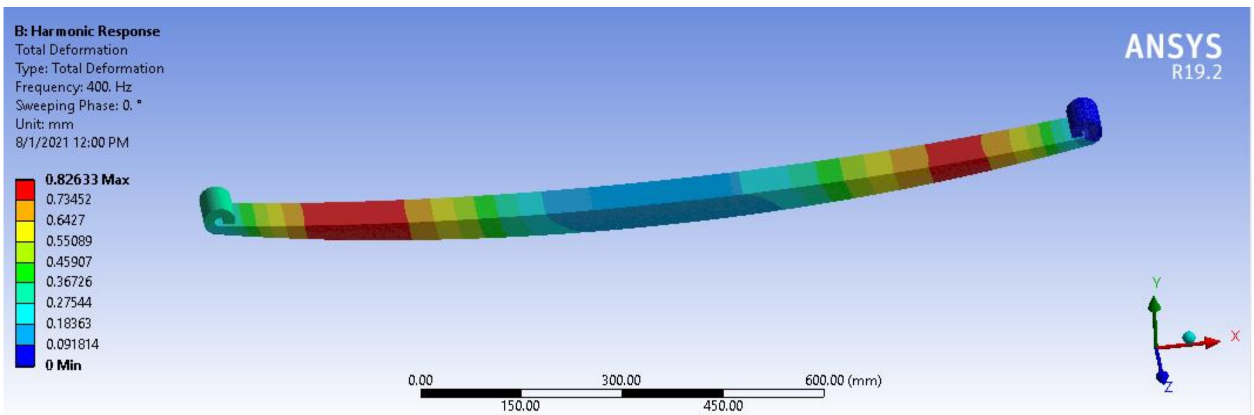


Figure 4. 20: Total deformation of E-glass/epoxy leaf spring

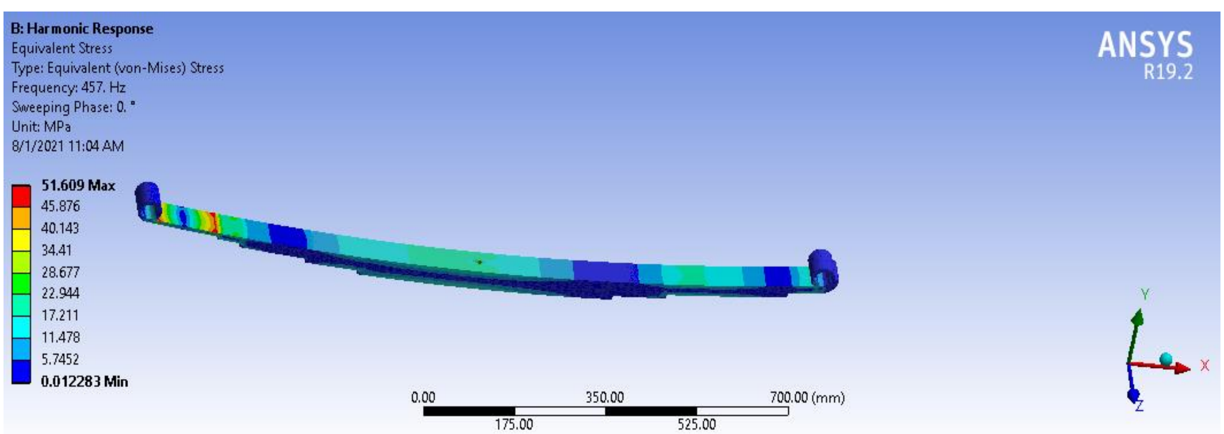


Figure 4. 21 Equivalent of epoxy carbon UD leaf spring

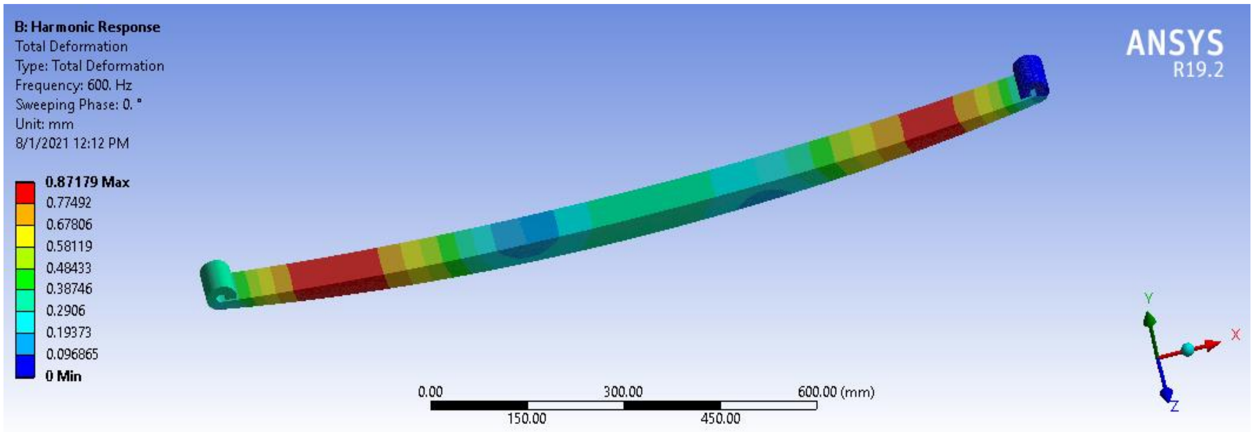


Figure 4. 22: Total deformation of epoxy carbon UD leaf spring

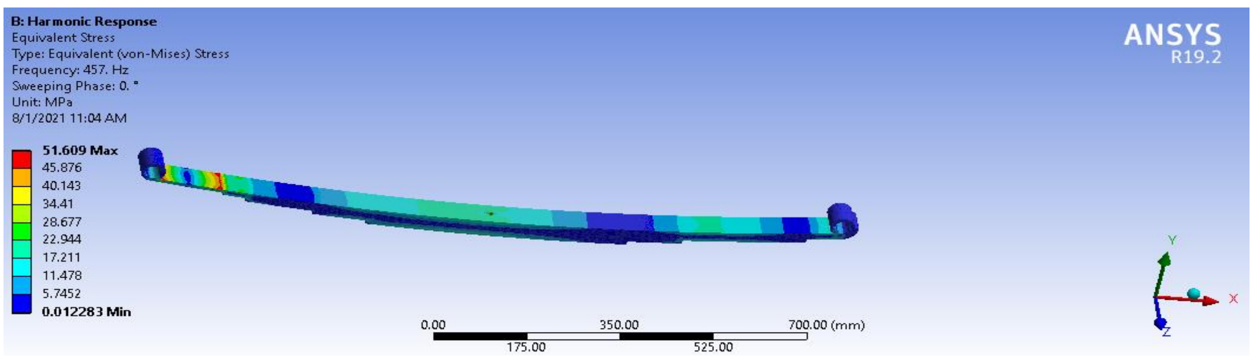


Figure 4. 23: Max Equivalent stress of steel leaf spring

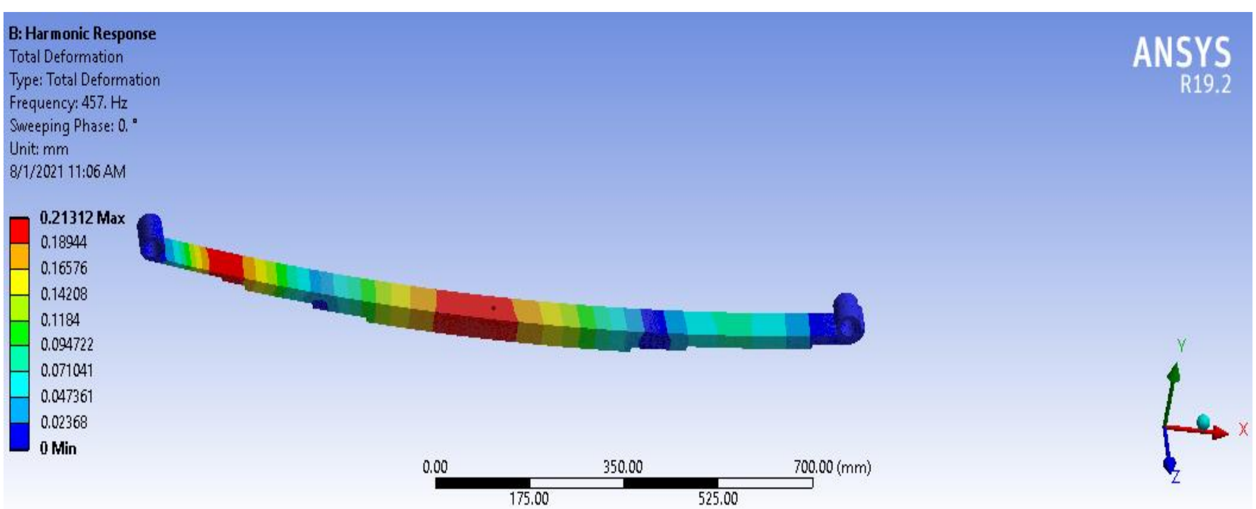


Figure 4. 24: Max Total deformation of steel leaf spring

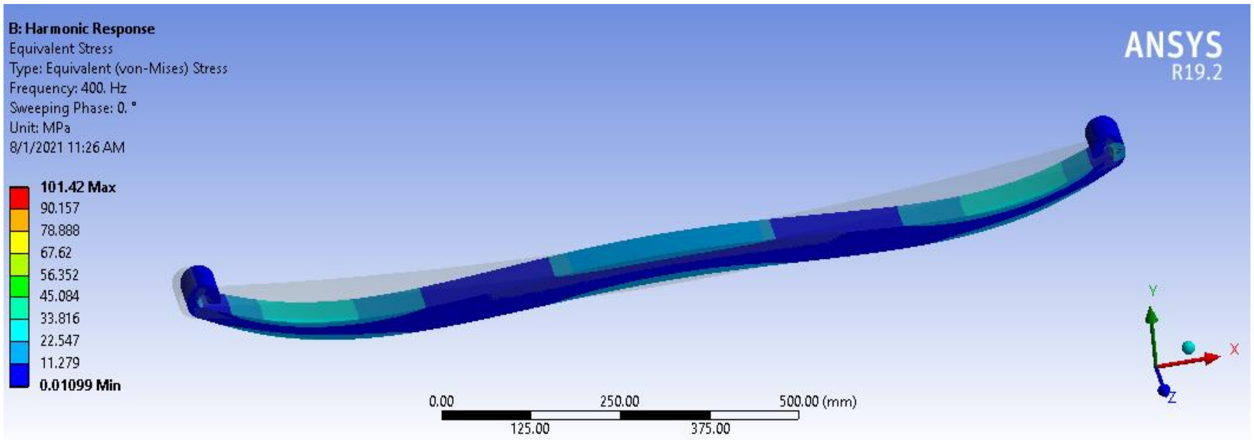


Figure 4. 25: Max Equivalent stress of S-glass/epoxy leaf spring

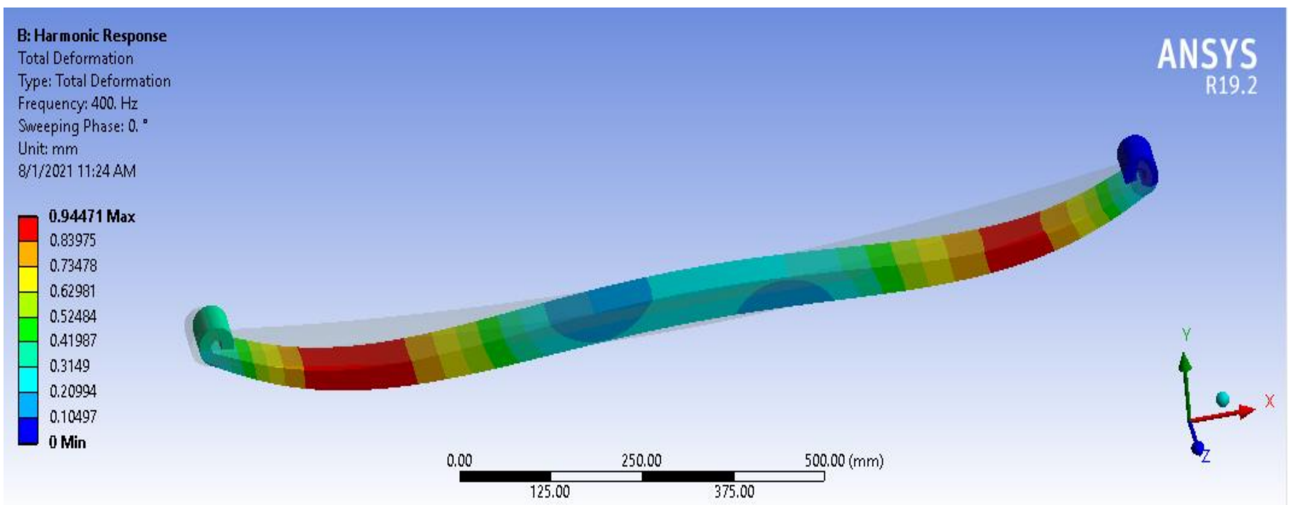


Figure 4. 26: Total deformation of S-glass/epoxy leaf spring

4.2. Discussion

This static and dynamic structural analysis of leaf spring of a light vehicle (Toyota pickup) using laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite and steel material was achieved for applying a static load of 1046.5 N and dynamic analysis on a leaf spring. In this specific design the comparison between the results of the FEA of these epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) and steel leaf spring is carried out by making everything the same, except material properties; i.e.

at the same loading type and magnitude, the same boundary condition and the same method of FEM analysis. Stress when external loads applied to an elastic body, the body may deform or elongate according to the nature frequency and harmonic frequency of the applied load. Then stress is defined as the average load per unit area that some particle of a body exerts on an adjacent particle, across an imaginary surface that separates them.

4.2.1. Equivalent (Von-Misses) stress

Equivalent (Von Misses) stress is a value used to determine if a given material will yield or fracture. It is mostly used for ductile materials, such as metals, composite materials. It computed from equation based on distortion energy failure theory, this criteria has been shown to be particularly effective in the prediction of failure for ductile materials and widely used by designers to check whether their design will withstand a given load condition. Using the ANSYS 19.2 Workbench software, the values of equivalent (Von-Misses) stress found along with the given boundary conditions and applied load of 10462.5 N. Then the maximum equivalent (Von-Misses) stress values and the stress reduction were presented in table 4.1 below. The results of this static structural analysis shows that the equivalent (Von-Misses) stress of the laminated E-glass/epoxy, S-glass/epoxy, epoxy carbon (395 GPa) prepreg composite materials leaf spring are when compared to that of the current conventional steel leaf spring under the same load and boundary conditions. This implies that laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials leaf spring is less stressed, light weight and has a better performance than that of conventional leaf spring.

Validation of the von mises stress

From the previous research done on Design, Simulation and Experimental Testing of E-Glass/Epoxy Composite Mono Leaf Spring for Land Cruiser Vehicle Application it is observed that for the leaf spring at 10080N load, the maximum von-Mises stress is 196.28 MPa, (Sisay Asmare 2020) in this research projects at 10462.5N load the maximum von-mises stress is 451.76 MPa.For the validation, the finite element analysis the von-mises stresses are compared to the analytical as shown in the figure below

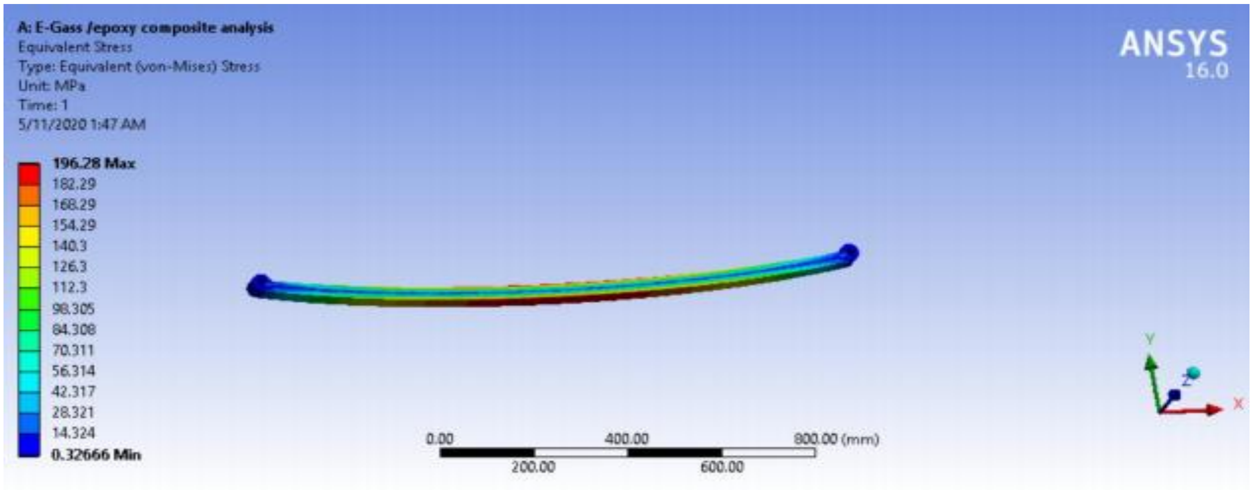


Figure 4. 3 Equivalent (von misses) stress of E - glass/Epoxy mono leaf spring

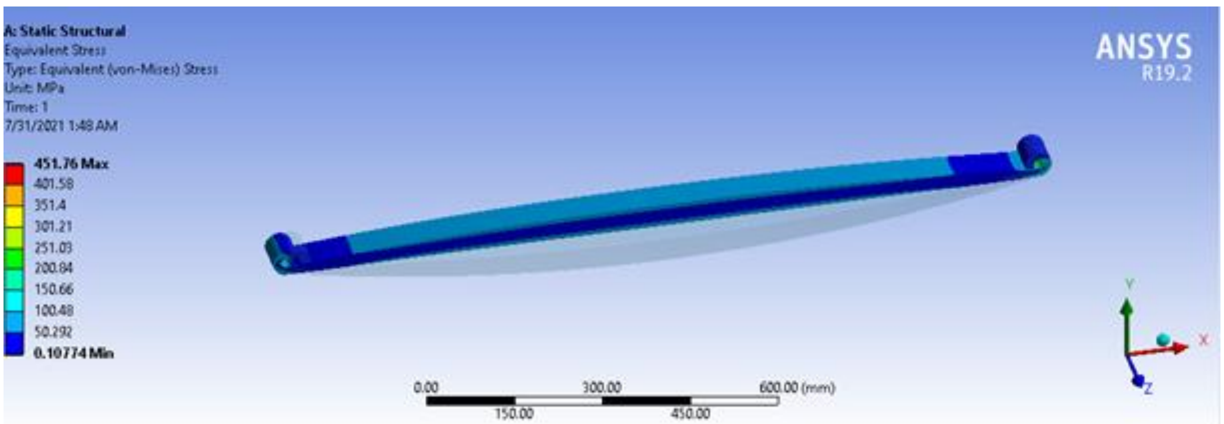


Figure 4.5: Equivalent (Von Mises) stress epoxy E-glass UD leaf spring

4.2.2. Deformation

As observed from the analytical and the simulation result of ASYSIS 19.2 software, the values of total deformation at the center of the composite materials mono leaf spring and conventional steel leaf spring were obtained in the table 5.3 below.

4.2.3 Weight reduction

Since the weight of laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials leaf spring are = 62.4N, 62.4 N and 46.5 N respectively and the weight of conventional steel leaf spring = 177.5 N by converting the weight of them into the mass =6.24 Kg, 6.2 kg, 4.65 Kg and 17.75 Kg respectively.

Then the ratio of epoxy E-glass UD mass becomes: $\frac{6.24}{17.75}\ Kg = 0.35$

Epoxy S-glass UD mass becomes: $\frac{6.24}{17.75}\ Kg = 0.35$

Epoxy carbon UD (395 GPa) prepreg mass becomes: $\frac{4.65}{17.75}\ Kg = 0.261$

Now the percentage reduction of mass of epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) becomes: (1 – 0.35) × 100 = 65%, (1 – 0.35) × 100 = 45% and (1 – 0.261)×100 =73.8% respectively. The weight of the leaf spring is reduced about 67.93 % by replacing conventional steel leaf spring with a laminated composite materials leaf spring. The smaller mass of the laminated composite materials leaf spring helps to make the vehicle lightweight, so that efficiency, running speed and fuel consumption of the Toyota pickup is improved.

5.2.3 Summary of the Results of static structure leaf spring

Table 4. 1: Summary of result of conventional multi steel and composite materials of mono leaf spring of static structure.

Leaf Spring	Max. Equivalent stress (MPa) at 10462.3N	Max Total deformation(mm) at 10462.3N	Weight in N
Conventional steel	670	7.7438	177.5
epoxy E-glass UD	510	23.027	62.4
Percent reduction	23.88 %		65%
epoxy S-glass UD	460	21.7	62.4
Percent reduction	31.34%		65%
Epoxy carbon UD (395 Gpa) prepreg	330.56	7.0614	46.5
Percent reduction	50.66%	8.8%	73.8%

The graph plotted below would show the comparisons of FEA values clearly for laminated epoxy E-glass, epoxy S-glass and epoxy carbon composite materials and conventional steel leaf spring. The results are the values obtained due to an applied load of 10462.5 N on a leaf spring

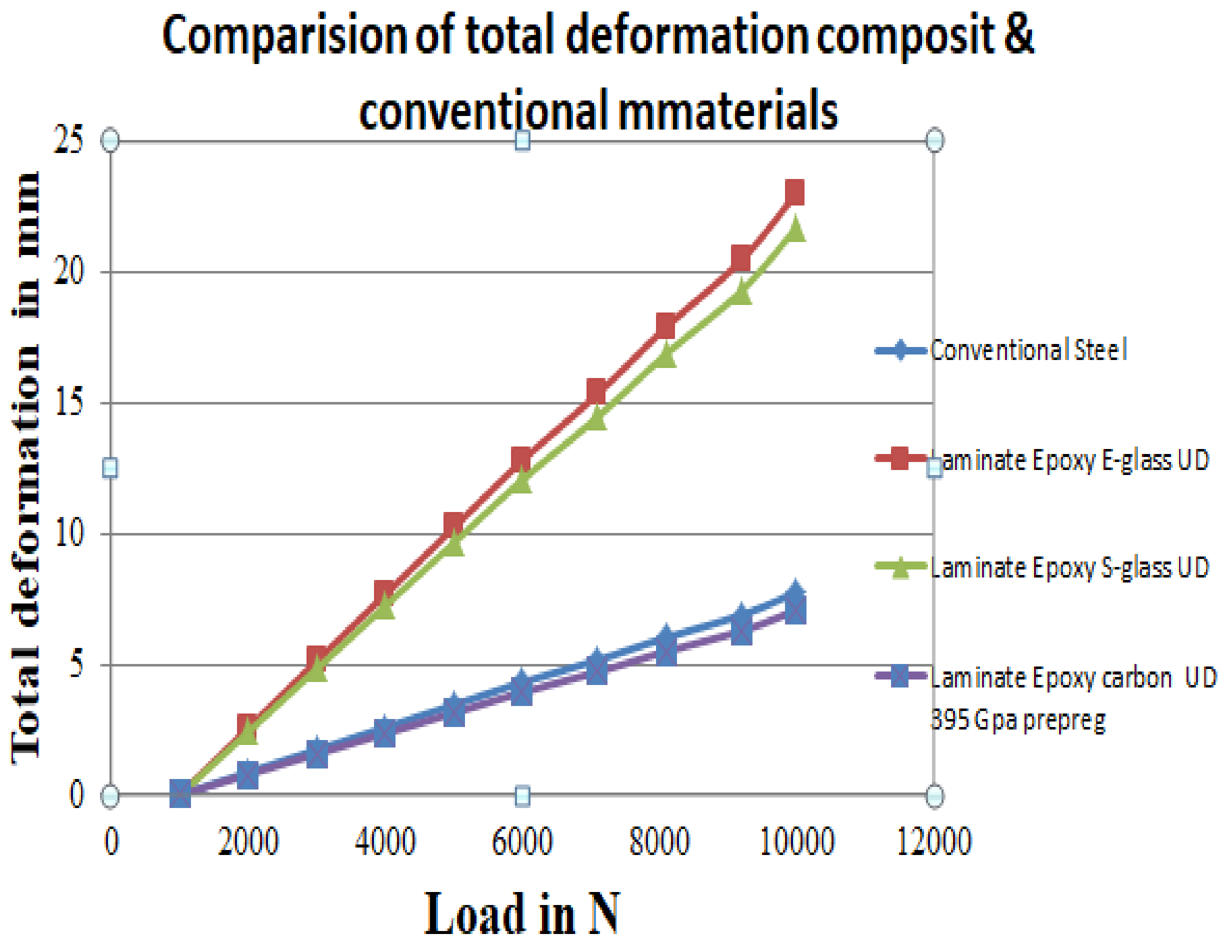


Figure 4. 27: Comparison graph of Deformation of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring.

As observed from the above graph (Figure 4.27) when static load applied on composite materials of mono leaf and conventional steel leaf spring. The two composite materials epoxy E-glass UD and epoxy S-glass UD was varied deformation occurs when compared with conventional leaf spring. The laminated epoxy carbon UD (395 Gpa) prepreg composite material leaf springs was the smallest deformed than that of the other two composite materials and the conventional steel leaf spring.

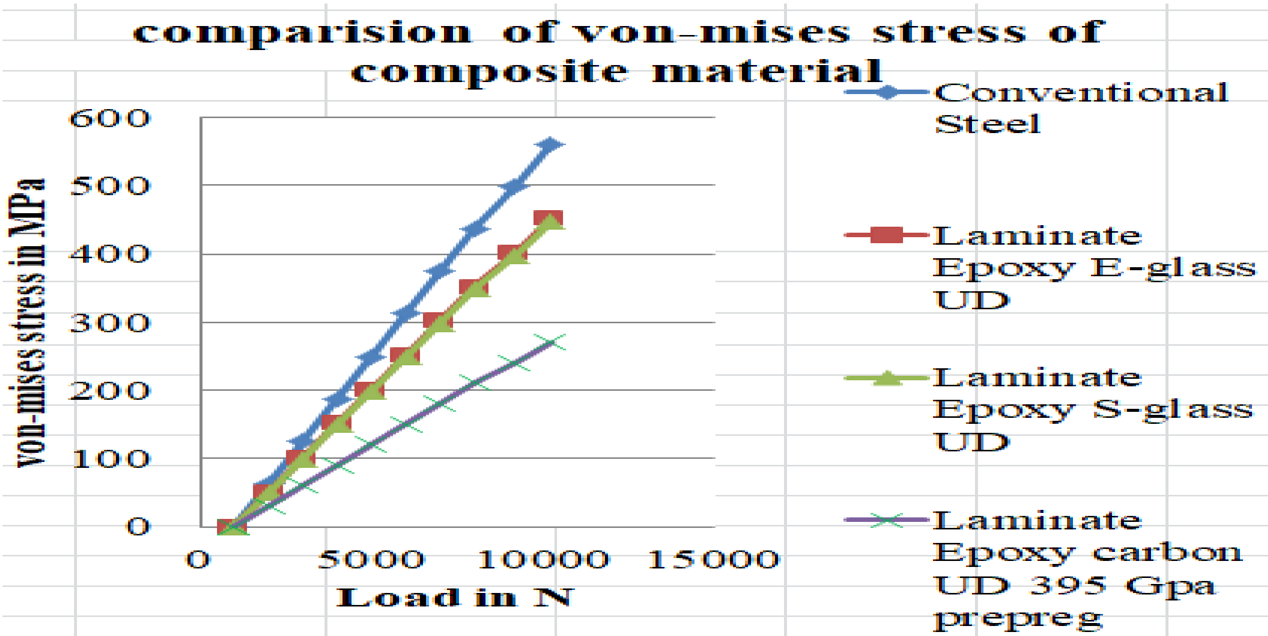


Figure 4. 28: Comparison graph of Equivalent (Von misses stress) of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring.

As observed from the above graph (Figure 4.28 Comparison of equivalent stress the conventional steel verses epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg mono leaf spring).The conventional steel leaf spring was more stressed than new design of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg composite material mono leaf spring.

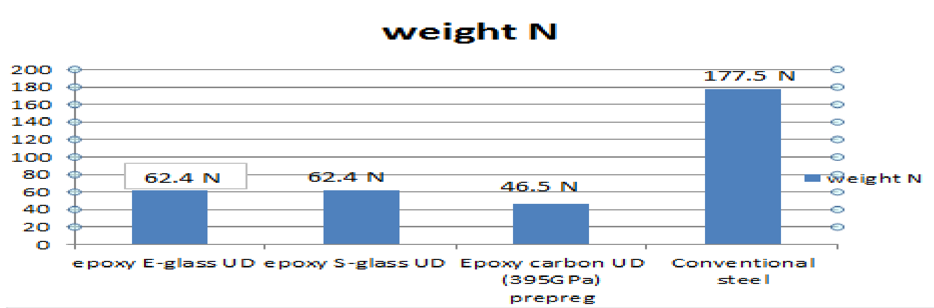


Figure 4. 29: Comparison of mass of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD(395 GPa) prepreg mono leaf spring) and conventional steel leaf spring

As we have seen from the above figure 4.29 the comparison of weight between the conventional steel leaf spring of Light vehicle (Toyota pickup) and the newly designed laminated epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) the composite leaf spring is light weight than that of the conventional steel leaf spring light vehicle (Toyota Pickup).

Modal analysis table

Table 4. 2: Natural frequencies (Hz) for each material property up to six modes

Materials	mod1	mod2	mod3	mod4	mod5	mod6
Conventional steel leaf spring	53.625	114.51	155.92	352.63	374.31	456.03
Epoxy E-glass UD	49.278	79.465	155.6	284.22	322.9	333.77
Epoxy S-glass UD	50.744	81.611	160.76	294.71	325.84	345.76
Epoxy carbon UD (395 Mpa) pregpreg	82.417	116.2	257.11	425.22	447.49	555.97

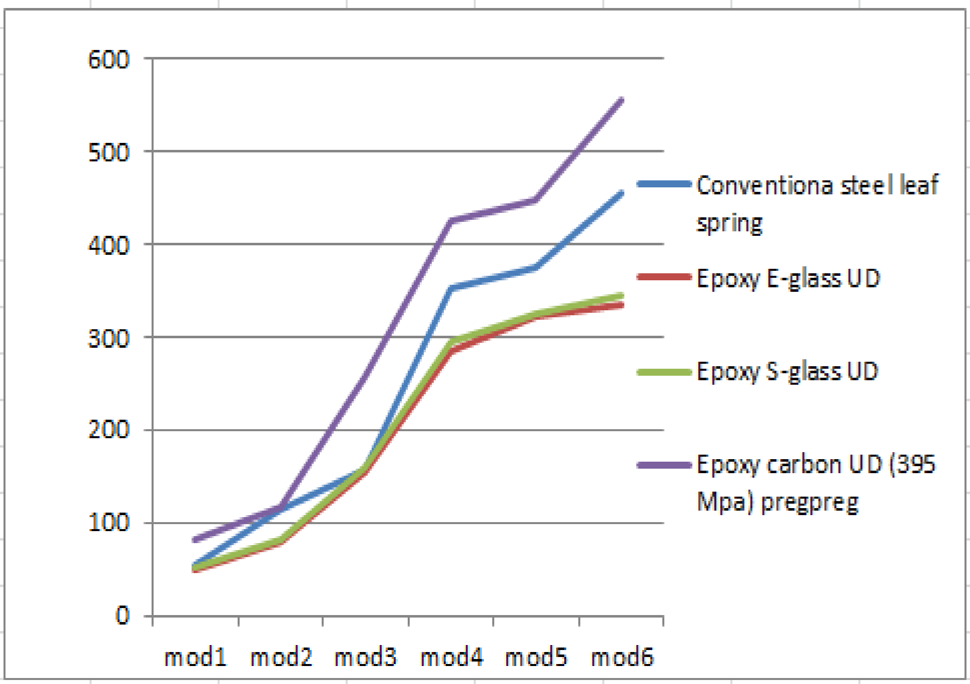


Figure 4. 30: Comparison graph of natural frequency of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring.

As observed from the above graph (Figure 4.30) the epoxy carbon UD (395 MPa) prepreg has high natural frequency than the conventional leaf spring. The epoxy E-glass UD and epoxy S-glass UD composite material mono leaf spring have less natural frequency than the conventional leaf spring.

Table 4. 3: Total deformation at the given natural frequency by modal

		Conventional Steel	Laminate Epoxy E-glass UD	Laminate Epoxy S-glass UD	Laminate Epoxy carbon UD 395 Gpa prepreg
Mode1	max total deformation(mm)	9.609	17.954	17.893	20.414
	frequency(Hz)	53.625	49.278	50.744	82.417
Mode2	max total deformation(mm)	10.785	20.242	20.373	25.123
	frequency(Hz)	114.51	79.465	81.611	116.2
Mode3	max total deformation(mm)	12.918	19.98	19.97	23.174
	frequency(Hz)	155.92	155.6	160.76	257.11
Mode4	max total deformation(mm)	18.803	20.948	21.183	35.301
	frequency(Hz)	352.63	284.22	294.71	425.22
Mode5	max total deformation(mm)	11.844	29.669	29.748	26.526
	frequency(Hz)	374.31	332.9	325.84	447.49
Mode6	max total deformation(mm)	15.743	22.193	22.175	25.665
	frequency(Hz)	456.03	333.77	345.76	555.97

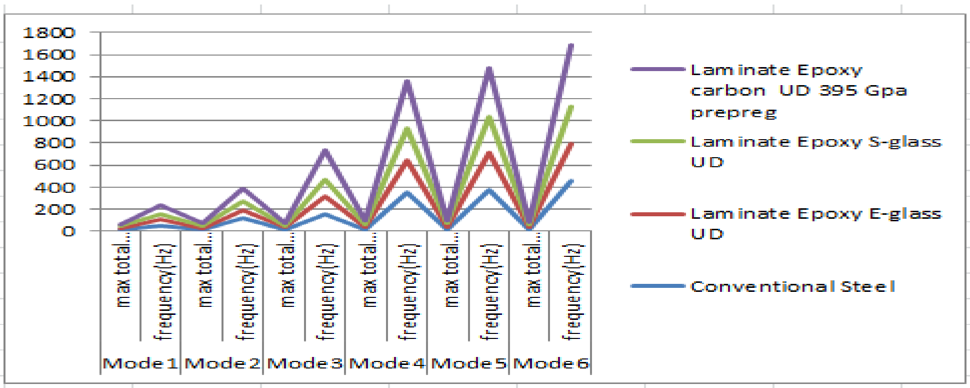


Figure 4. 31: Comparison graph of total deformation of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring.

In dynamic analysis as observed from the analytical and the simulation result of ASYSIS 19.2 version software, the values of total deformation at the center of each leaf springs; for epoxy E-glass UD 29.66mm, epoxy S-glass UD 29.748, epoxy carbon UD (395GPa) prepreg 35.301mm and conventional steel leaf spring 18.802mm. This is because steel leaf spring has different size graduated leaves and the structure is not uniform but the composite leaf spring is a single leaf spring and uniform size throughout its length.so small variation of deformation occurs.

Table 4. 4: Equivalent (von mises) stress at the given natural frequency by modal

		Conventional Steel	Laminate Epoxy E-glass UD	Laminate Epoxy S-glass UD	Laminate Epoxy carbon UD 395 Gpa prepreg
	max Equivalent (von-mises) stress MPa	786.34	349.97	362.78	591.18
Mode1	frequency (Hz)	53.625	49.278	50.744	82.417
	max Equivalent (von-mises) stress MPa	2621	1616.4	1763.4	3480
Mode2	frequency (Hz)	114.51	79.465	81.611	116.2
	max Equivalent (von-mises) stress MPa	2182.5	1082	1142.7	1959.3
Mode3	frequency (Hz)	155.92	155.6	160.76	257.11
Mode4	max Equivalent (von-mises) stress MPa	4419.9	4039.1	4368	1897.6
	frequency (Hz)	352.63	284.22	294.71	425.22
	max Equivalent (von-mises) stress MPa	6887.1	2547.2	2441.5	8616.2
Mode5	frequency (Hz)	374.31	332.9	325.84	447.49
	max Equivalent (von-mises) stress MPa	6442.7	2609.6	2823	5874.5
Mode6	frequency (Hz)	456.03	333.77	345.76	555.97

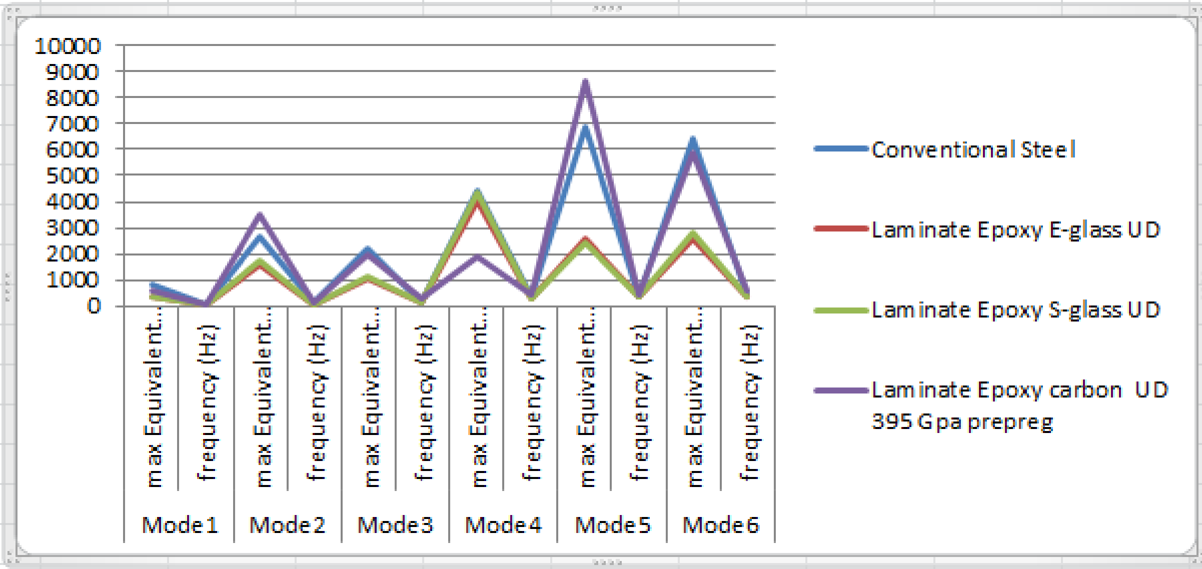


Figure 4. 32: Comparison graph of Equivalent (Von misses stress) of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 Gpa) prepreg vs. conventional steel leaf spring.

As observed from the above graph (Figure 4.32 Comparison of equivalent stress the epoxy carbon UD (395 GPa) prepreg mono leaf spring at the given natural frequency was more stressed than conventional steel leaf spring. However epoxy E-glass UD and epoxy S-glass UD composite materials mono leaf spring was less stressed than the conventional multi leaf spring at the given natural frequency.

4.3. Harmonic Analysis

4.3. Harmonic Analysis

Modal analyses is done for the epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 Gpa) prepreg and conventional steel leaf springs and its frequency responses is plotted as shown in Fig: 4.33 below; which describe epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 Gpa) prepreg and conventional steel leaf springs. The step of harmonic analysis created was first it has been solved for modal analysis of natural frequency .The harmonic response was dragged and put into modal solution setting, in harmonic response of analysis setting it has been seen what is the frequency spacing we are doing from the modal analysis. The range harmonic response from of the minimum and maximum natural frequency has been taken. After that 10462.6 N load has been applied to harmonic response which was done for a frequency range of 8Hz to 400Hz for epoxy E-glass UD, 8Hz to 400Hz epoxy S-glass UD, 12Hz to 600Hz epoxy carbon UD (395 Gpa) prepreg and for 61.01Hz to 457 Hz. The analysis consists of plot of amplitude of spring which is nothing but the deflection and equivalent stress of spring plotted against the defined frequency range. From the graphs below it can be realized that for certain frequency values that obtained in the table 4.5 and 4.6 we get maximum deflection and maximum equivalent stress. This frequency is not the natural frequency of that materials but the frequency near to the natural frequency for which we get maximum deflection.

Table 4. 5: Comparison of Frequency response of deformation at high amplitude

Leaf pring	Frequency response at high amplitude	high amplitude
epoxy E-glass UD	48	59.194
epoxy S-glass UD	48	27.585
Epoxy carbon UD	84	60.156
Conventional steel	61.01	2.1777

Table 4. 6: Comparison of Frequency response of Equivalent (Von mises stress at high amplitude

Leaf pring	Frequency response at high amplitude	high amplitude
epoxy E-glass UD	48	34.069
epoxy S-glass UD	48	22.644
Epoxy carbon UD	84	39.632
Conventional steel	61.01	8.354

Table 4. 7: Total deformation done at frequency response for each material property

materials	Total deformation (mm)	frequency response by (HZ)	percent reduction
Conventional steel leaf spring	0.21312	457	
Epoxy E-glass UD	0.82633	400	
Epoxy S-glass UD	0.94471	400	
Epoxy carbon UD (395 Mpa) pregpreg	0.87179	600	

Table 4. 8: Equivalent (von misses) stress done at frequency response

Materials	Equivalent stress (MPa)	at frequency response by (HZ)	percent reduction
Conventional steel leaf spring	51.609	457	
Epoxy E-glass UD	79.937	400	
Epoxy S-glass UD	10142	400	
Epoxy carbon UD (395 Mpa) prepreg	177.16	600	

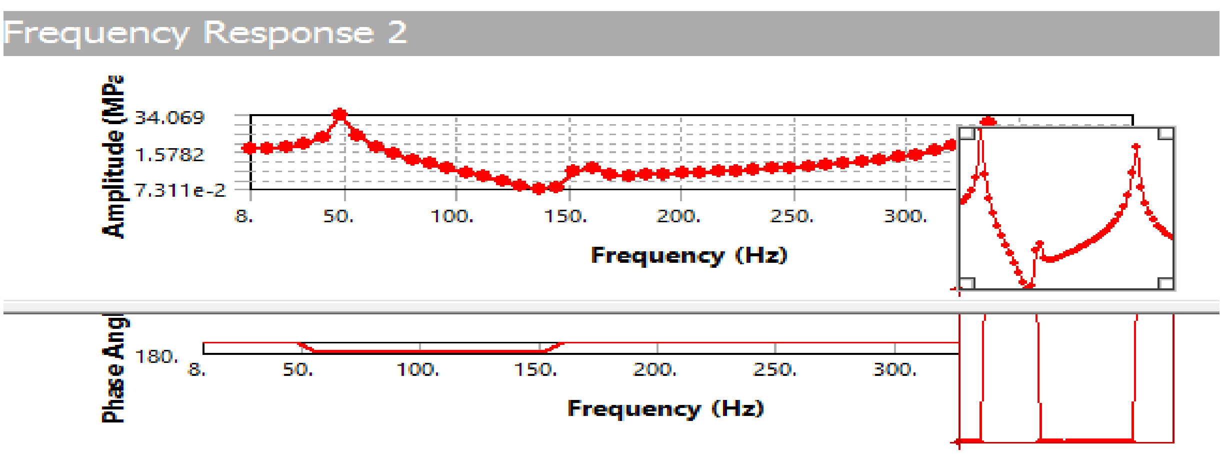


Figure 4. 33: The of deformation E-glass/epoxy leaf spring

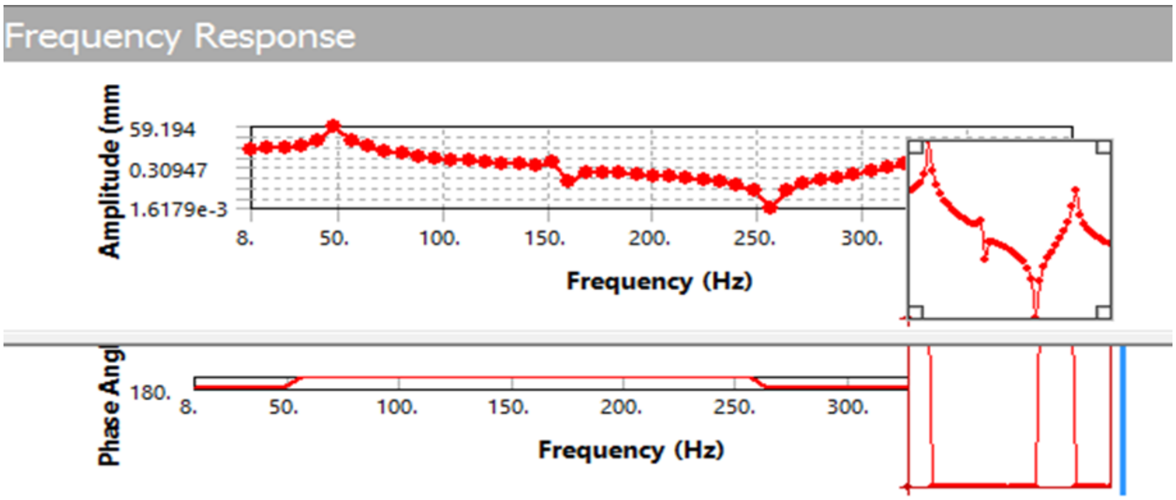


Figure 4. 34: Stress of E-glass/epoxy leaf spring

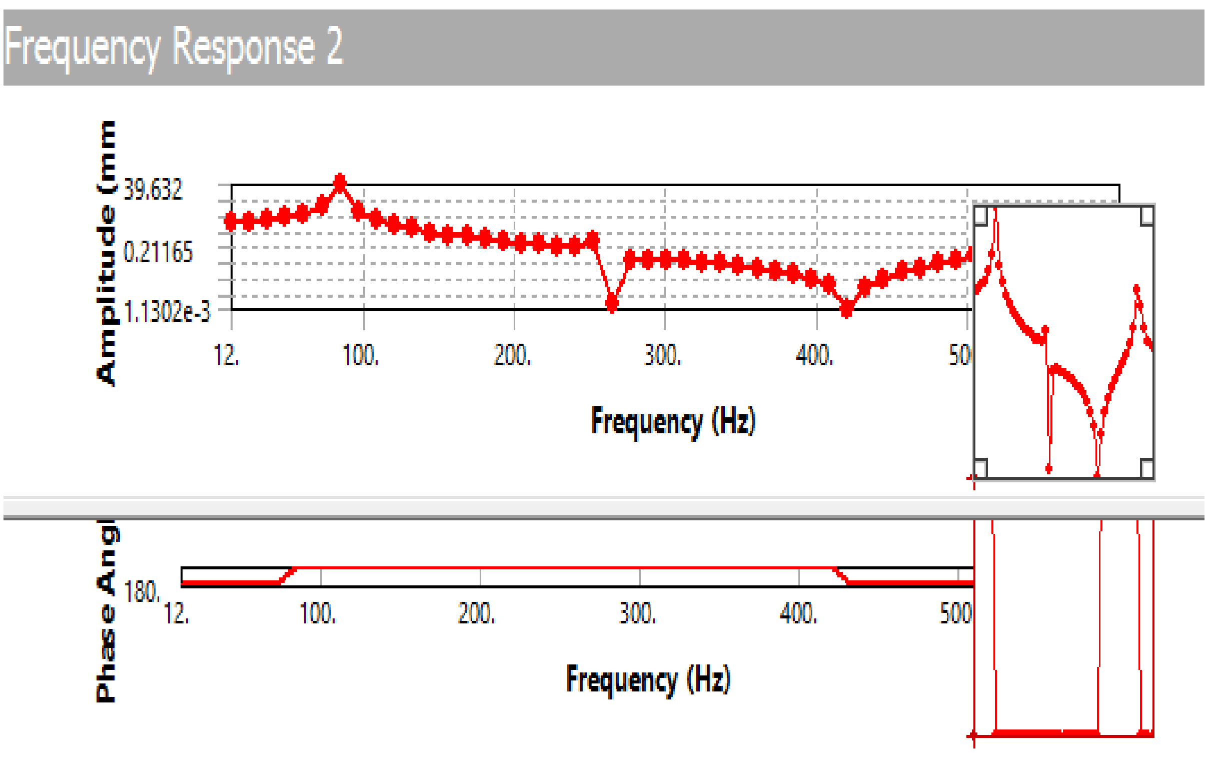


Figure 4. 35: Equivalent stress of epoxy carbon UD leaf spring

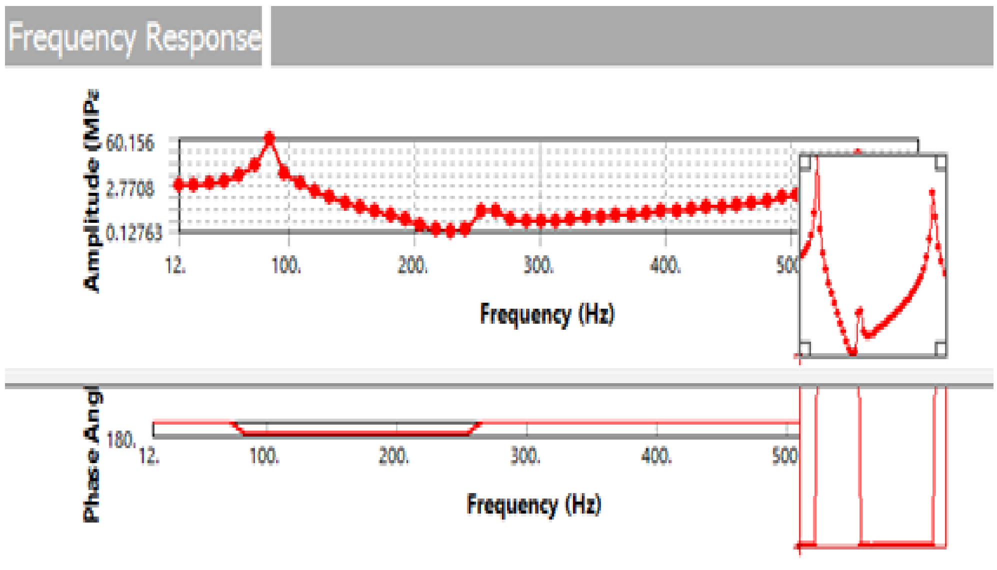


Figure 4. 36: Total deformation of epoxy carbon UD leaf spring

The harmonic analysis has been done for a frequency range of 8Hz to 400Hz for epoxy E-glass UD, 8Hz to 400Hz epoxy S-glass UD, 12Hz to 600Hz epoxy carbon UD (395 Gpa) prepreg and for 61.01Hz to 457 Hz. The analysis consists of plot of amplitude of spring which is nothing but the deflection of spring plotted against the defined frequency range. From the above graphs it can be realized that for certain frequency values we get maximum deflection. This frequency is not the natural frequency of that materials but the frequency near to the natural frequency for which we get maximum deflection.

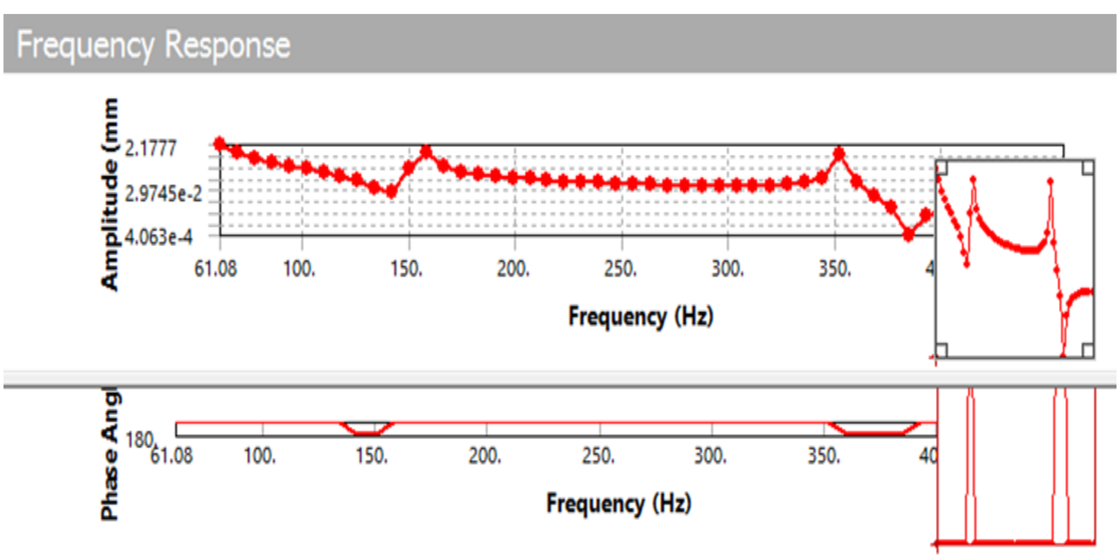


Figure 4. 37: The deformation of steel leaf spring

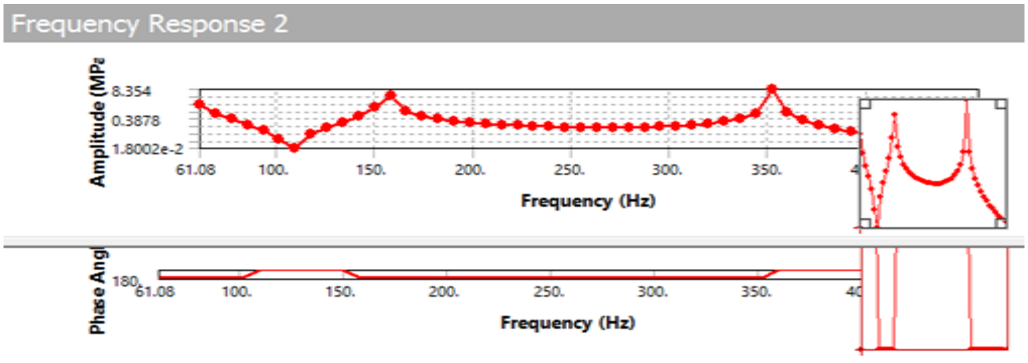


Figure 4. 38: Stress of conventional steel leaf spring

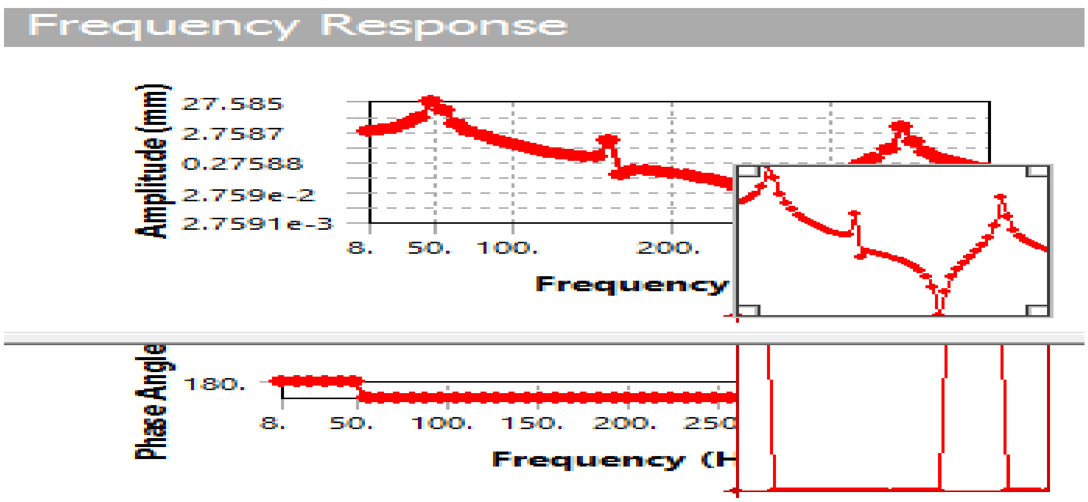


Figure 4. 39: The deformation of S-glass/epoxy leaf spring

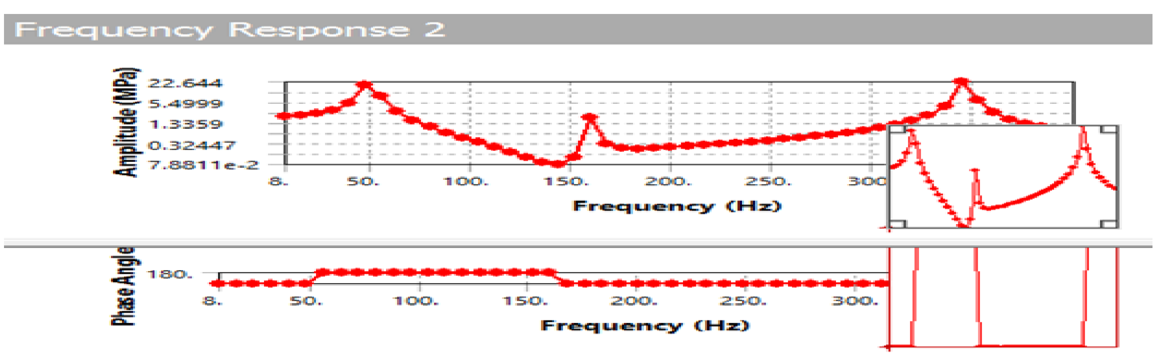


Figure 4. 40: Stress of S-glass/epoxy leaf spring

Cost comparison

The current price of epoxy resin is \$7.8 per kg (https://m.alibaba.com/showroom/epoxy-resin-price.html)

The current price of UD glass fiberreinforcement is \$1.62 per kg

(https://www.alibaba.com/showroom/glass-fiber.html)

The total mass calculation for this design is 6.24 kg

The percent of epoxy/E-glass=40/60 (Misganaw Abebaw, 2017)

$40\% \times 4.24 = 1696/100 = 1.696$ kg

$60 \times 4.24/100 = 2.544$ kg

Therefore the cost of epoxy resin =1.696kg ×\$7.8=13.22 \$

The cost of glass fiber =2.544 kg×\$1.62=4.12 \$

The cost of Epoxy/E-glass composite=13.22\$+4.12 \$=17.34 \$

The labor wage per hour in Ethiopia is 7.25\$/hour (https://www.minimum-wage.org/international/ethiopia) to complete this project it take 3hour it need 3 persons.

The total labor cost =3×12×3 =108 \$

Therefore the total cost to complete mono leaf spring is =17.34 \$+108=125.34 \$

The current total replacement cost of steel leaf spring is 706.91\$ (https://www.toyodiy.com/parts/p_G_200507_TOYOTA_HILUX_LAN25L-PRMDEN_4804.20.html)

% of save cost=89.34\$/706.91=0.12×100=0.126

% save cost =1-0.126=0.88×100=88%

Therefore total cost saved using e-glass/epoxy composite leaf spring =88%

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

In this research project design, static and dynamic analysis of epoxy E-glass UD, epoxy S-glass UD epoxy carbon UD (395 Gpa) prepreg composite materials and conventional steel leaf spring were conducted by considering the effects of variation of three composite material for light vehicle (Toyota pickup). First, analytical and finite element analysis was once performed between traditional steel leaf springs compared with epoxy E-glass UD, epoxy S-glass UD epoxy carbon UD (395 GPa) prepreg composite mono leaf spring with the same load and the same boundary condition by ANSYS workbench to evaluate the weight reduction, total deformation and equivalent (von mises) stress subjected to static and dynamic loading. In the static analysis, the stress-induced in conventional steel leaf spring were 670 MPa whereas in composite mono leaf springs were 510 MPa for epoxy E-glass UD, 460 MPa epoxy S-glass UD, 330.56 MPa. These values indicate composite mono leaf spring has correct strength and it is better for the utility of leaf spring. In dynamic analysis, the highest value of equivalent (von misses) stress occurred at natural frequency of epoxy E-glass UD 4039.1 MPa, epoxy S-glass UD 4368 MPa, epoxy carbon UD (395 Gpa) 8616.2 MPa and conventional steel leaf spring 6887.1 MPa and also from harmonic response, for frequency range of 8.08Hz to 600 Hz at highest frequency of the materials; the deflection of epoxy E-glass is 0.82633mm,for epoxy S-glass 0.994471mm,for epoxy carbon UD (395 Gpa) prepreg 0.8717mm and for conventional steel leaf spring 0.21312mm as observed from this value of total deformation at frequency response of the composite materials mono leaf springs there was small variation occurs when compared with conventional leaf springs. In the second case the analytical was done between the composite materials to select the best materials which were appropriate for design of leaf spring. As observed in the previous chapter which was explained by the table and the graph in static and dynamic analysis the deformation of epoxy E-glass UD 23.027mm, epoxy S-glass UD 21.7mm and epoxy carbon UD (395Gpa) prepreg 7.0614mm were deformed and the values of the equivalent stress value as explained on the above the less stressed materials was epoxy carbon U D(395 Gpa) prepreg. However in dynamic analysis at natural frequency of the deformation and equivalent stress of epoxy carbon UD (395 Gpa) prepreg was the highest when compared with the epoxy E-glass UD and epoxy S-glass. Hence the average Equivalent (von mises) stress of composite materials of mono leaf spring done at static load condition, at natural frequency and at frequency response of epoxy E-glass UD and epoxy S-glass UD were less equivalent (von misses) stress than the epoxy carbon UD (395 Gpa) prepreg. Therefore the epoxy E-glass UD and epoxy S-glass UD composite material mono leaf spring for Toyota pickup was more appropriate materials than the epoxy carbon UD (395 Gpa) prepreg mono leaf spring and conventional steel leaf spring.

5. 2. Recommendation

As discussed so far, the attention of a material with light weight and high performance is increasing in an unexpected way from time to time. Therefore the properties of composite materials, like high strength to weight ratio and high specific stiffness are attractive for the construction of lightweight, fuel efficient and environmentally friendly vehicle components. In general, the energy absorption capability of the composite materials offers a unique combination of reduced weight and improves the failure of the vehicle structures. The fuel efficiency of the vehicle directly depends on the total weight of the vehicle. So selecting a composite material is the best decision to get lightweight, fuel efficient and high speed vehicle since the dead weight of the vehicle reduced by composite materials. This implies the fuel economy of the vehicle become low and the running speeds becomes high and the reverse is true.

The finite element analysis result shows that laminated mono epoxy E-glass UD and epoxy S-glass UD composite leaf spring has much better performance than the current conventional steel multi leaf spring. Moreover, the weight of the laminated mono E-glass UD and epoxy S-glass UD composite leaf spring is reduced by about 65 %; this intern reduces the overall dead weight of the suspension system. Thus, applying the results of this research work will improve the efficiency and the fuel economy of the vehicle. Finally, it is recommended that laminated mono E-glass UD and epoxy S-glass UD leaf springs are appropriate for vehicle leaf spring applications.

5.2.1 Future works

Standing from different aspects, working on composite materials has several advantages. From this point of view, regarding laminated epoxy E-glass UD and epoxy S-glass composite leaf spring several things can be made and improved in the future in which this study didn't address. Therefore; the following research areas are recommended for future studies:

- Manufacturing of laminated epoxy E-glass UD and epoxy S-glass composite material leaf spring by studying.
- Designing the leaf spring by changing the orientation of the fiber and ply.
- Design of epoxy E-glass UD and epoxy S-glass for other components of the vehicle like propeller shaft and for body design.
- Study of effects of different resins on the performance of leaf spring:

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Appendix A

In this appendix the dynamic analysis of leaf spring

Directional deformation shear stress of epoxy S-glass composite leaf spring in X and Y direction is shown in figures below respectively

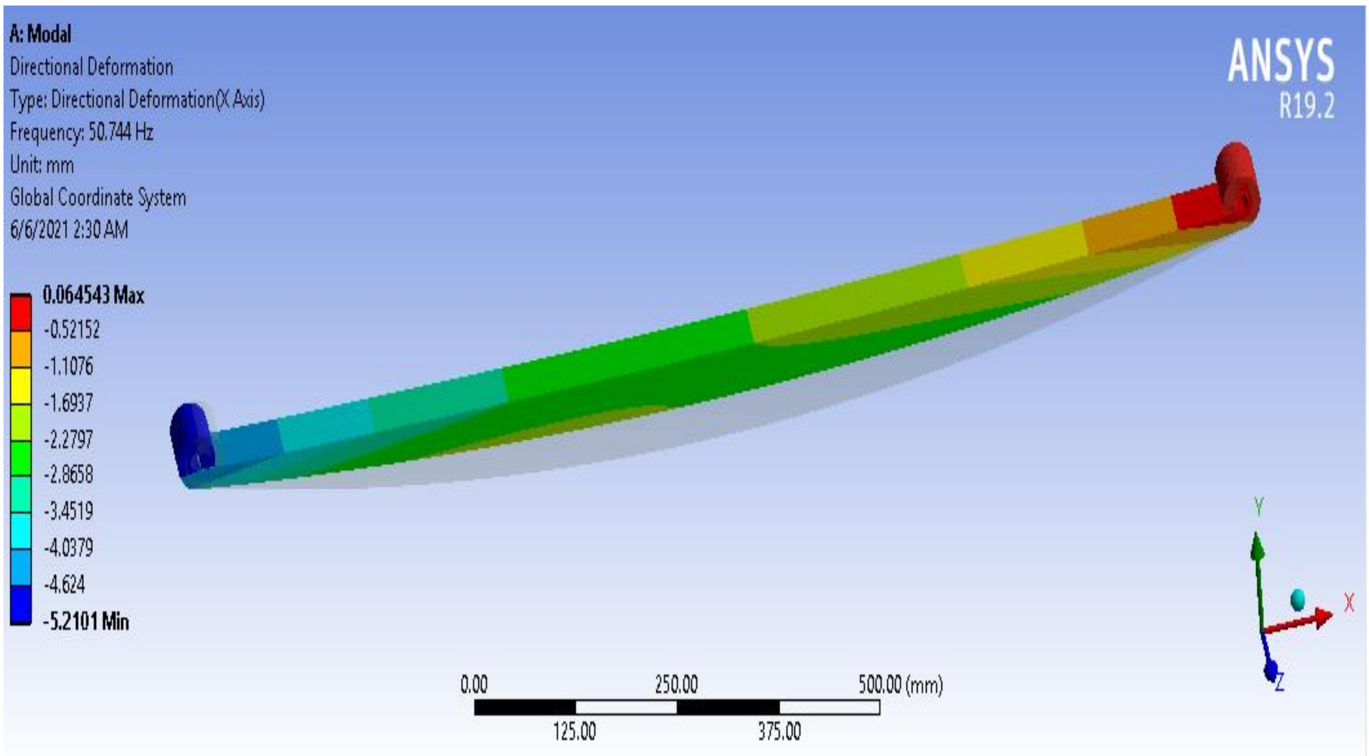

Fig. A 1: Directional deformation (X-Axis) of epoxy S-glass UD

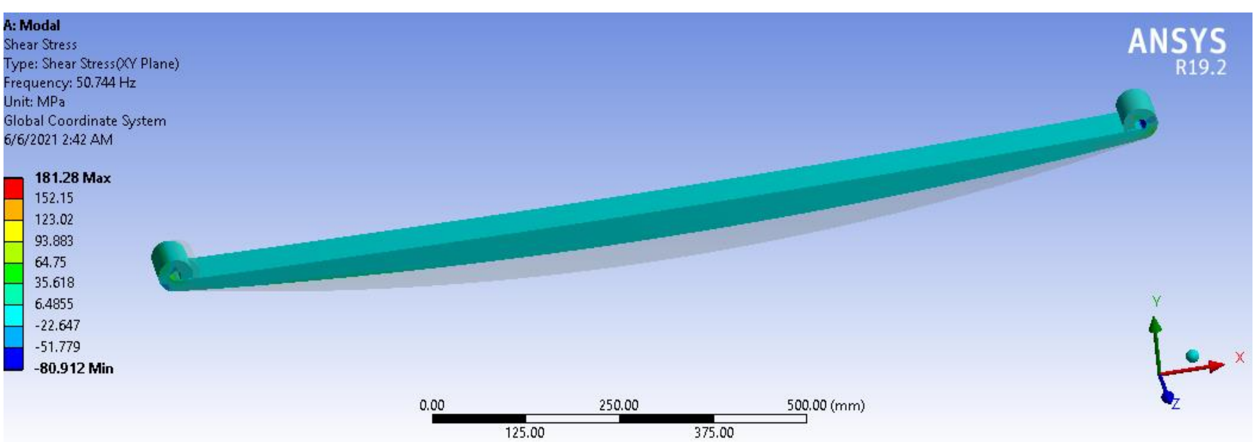

Fig. A 2: Shear stress (XY-plane) of epoxy S-glass UD

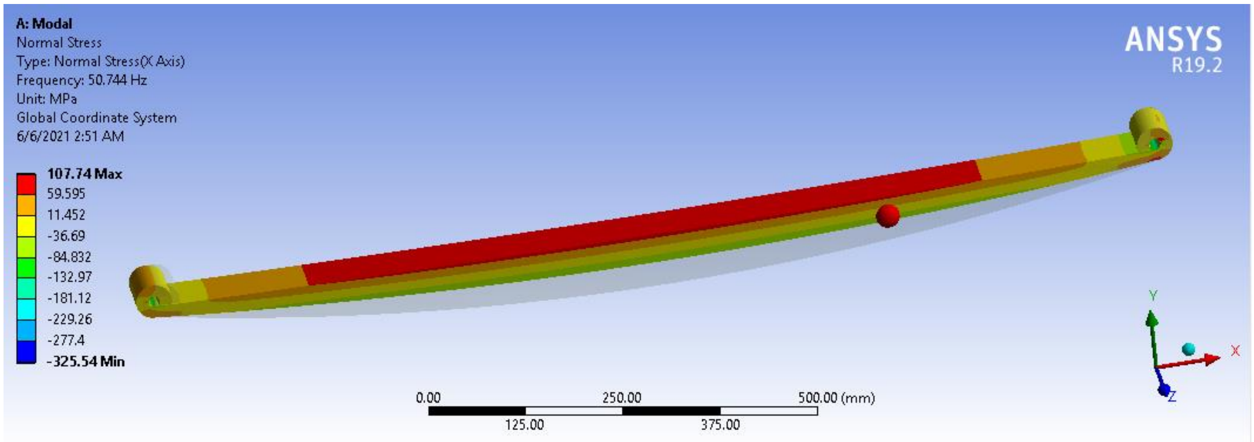

Fig. A3:Normal stress (X-axis) of epoxy S-glass UD

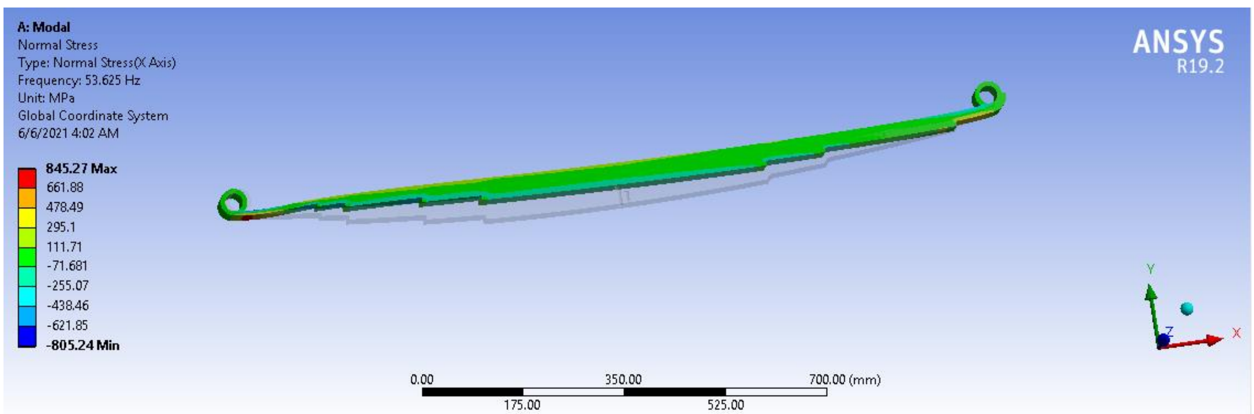

Fig A4 normal stress (X-axis) of steel leaf spring

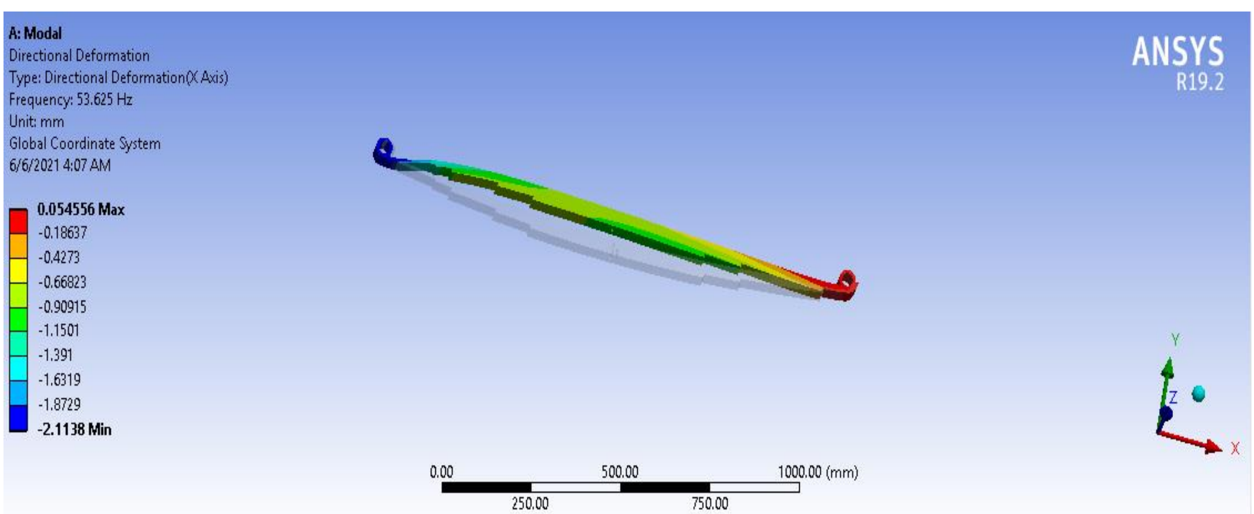

Fig A5 directional deformation (X-axis) of steel leaf spring

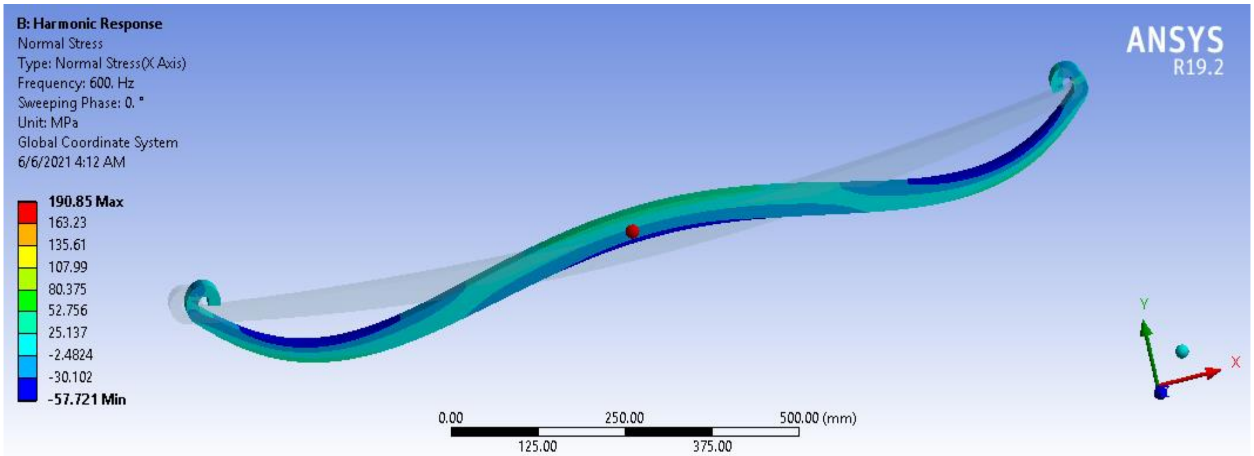

Fig A6:Normal stress (X-axis) of epoxy carbon UD composite mono leaf spring

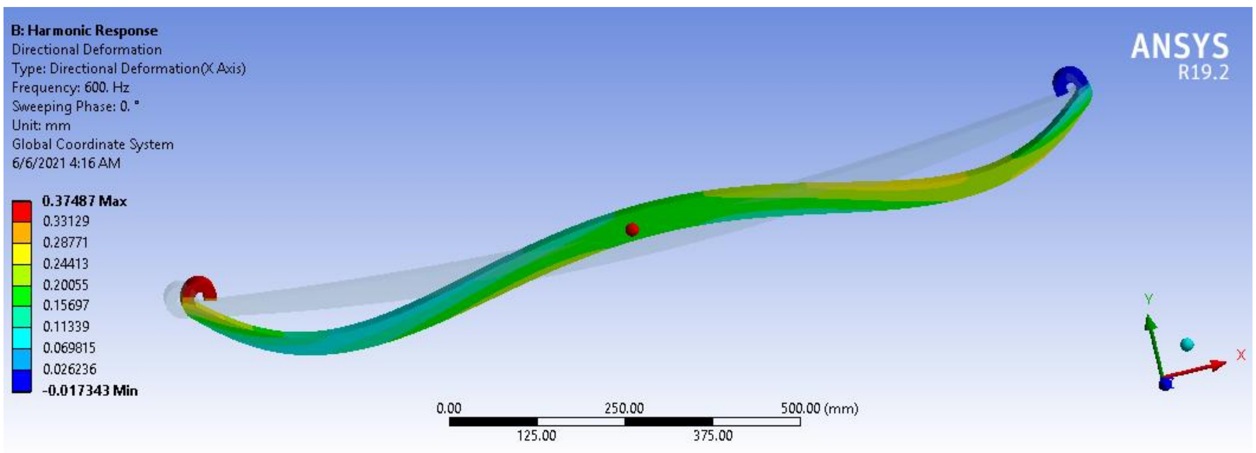

Fig A7 Directional deformation (X-axis) of epoxy carbon UD composite mono leaf spring

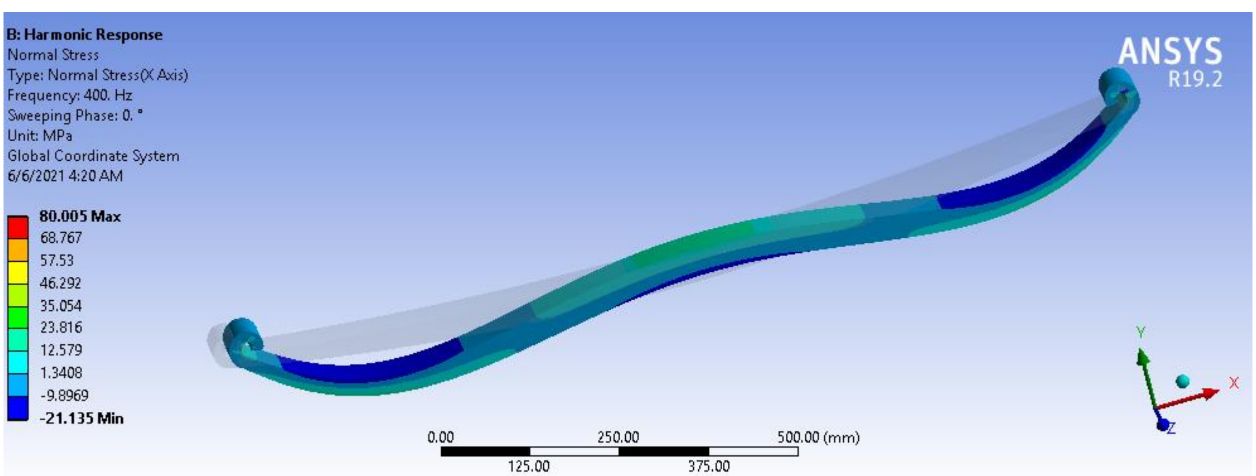

Fig A8: Normal stress (X-axis) of epoxy E-glass UD

Appendix B

In this appendix the static analysis of leaf spring

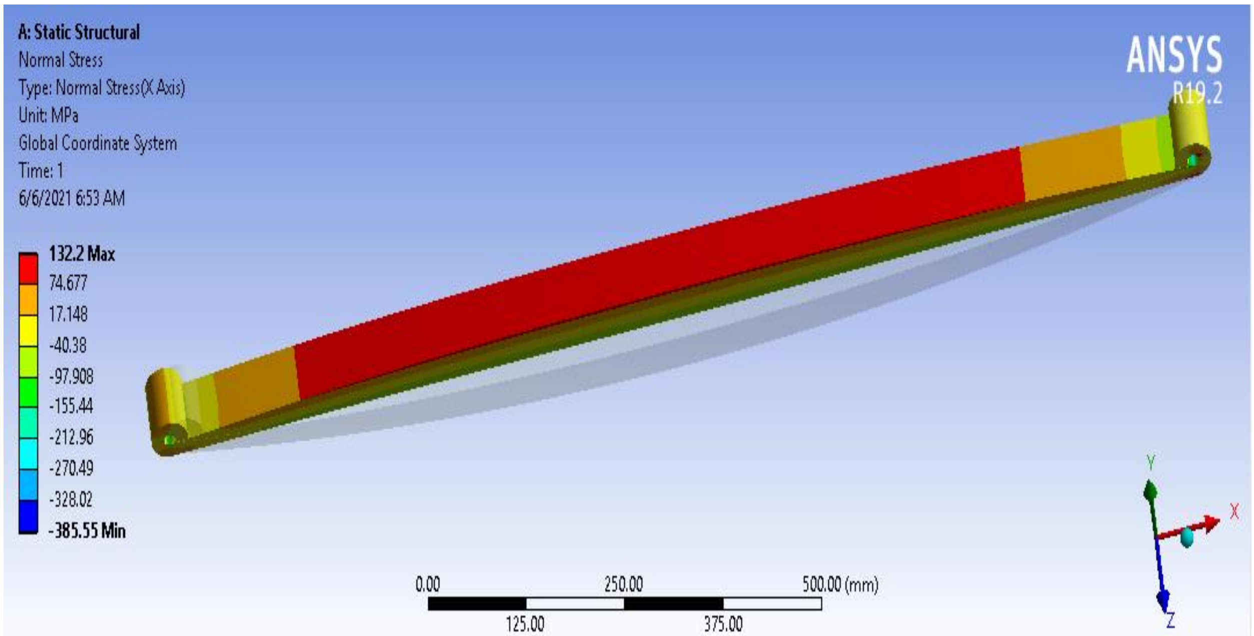

Fig B1 Normal stress (X-axis) of epoxy S-glass UD

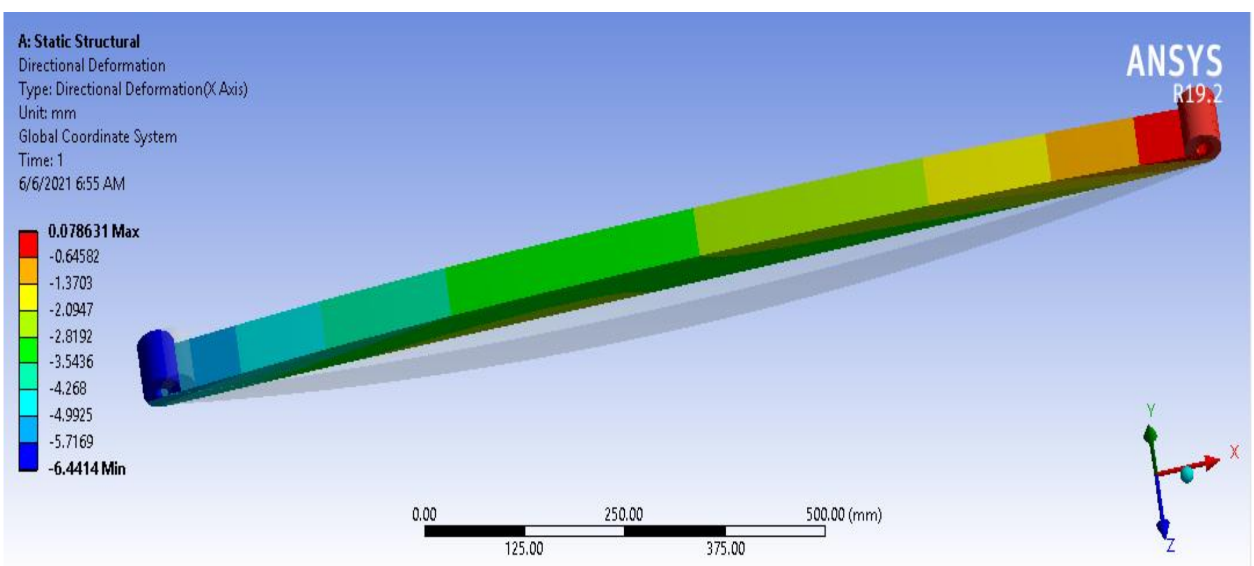

Fig B2 Directional deformation (X-axis) of epoxy S-glass UD

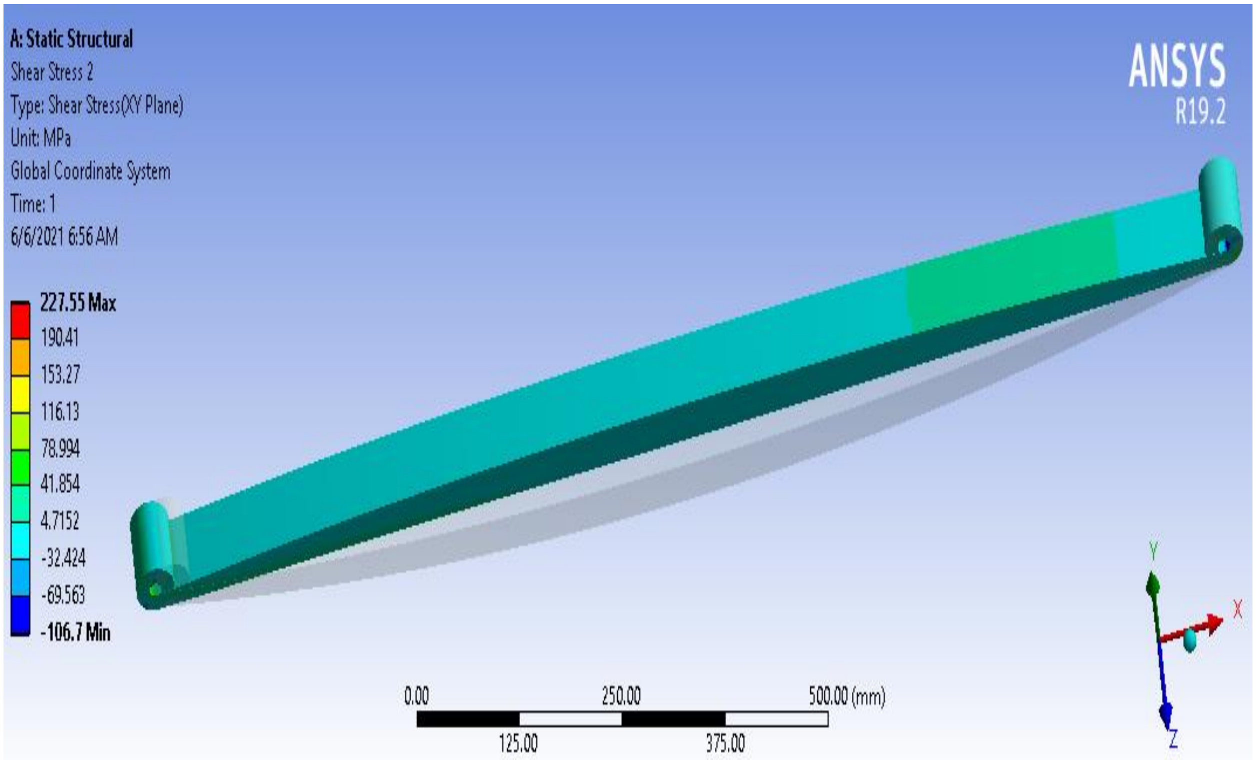

Fig B3 Shear stress (XY plane) (X-axis) of epoxy S-glass UD

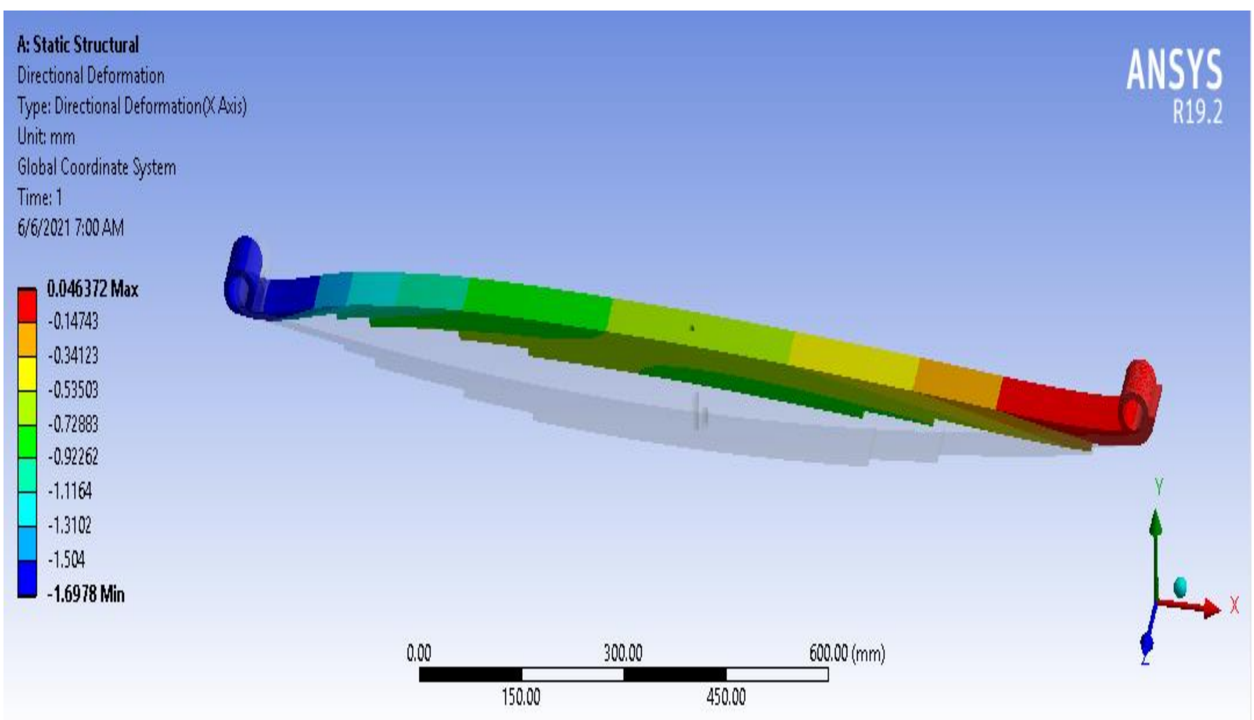

Fig B4 Directional deformation (X-axis) of conventional steel leaf spring

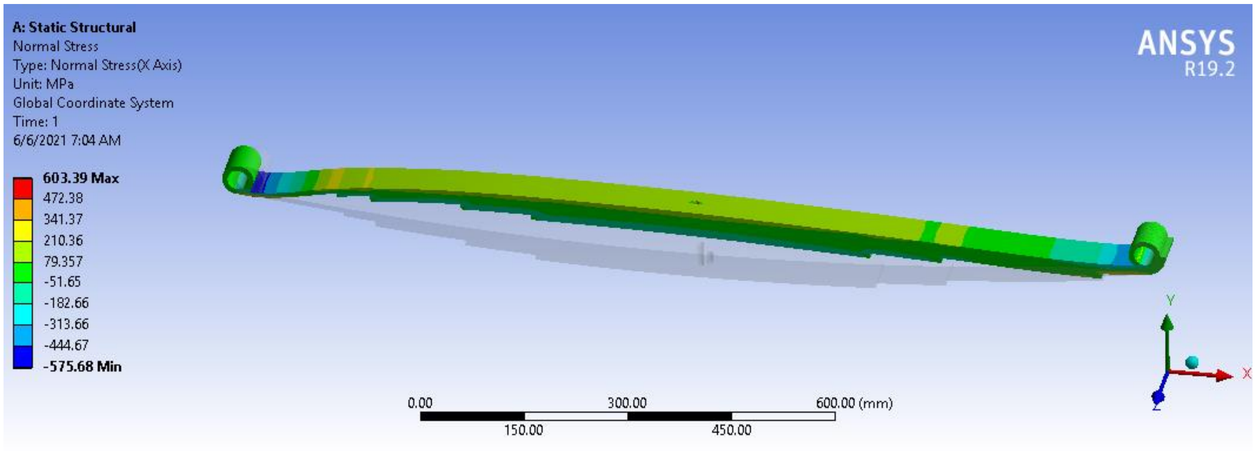

Fig B5 Normal stress (X-axis) of conventional steel leaf spring

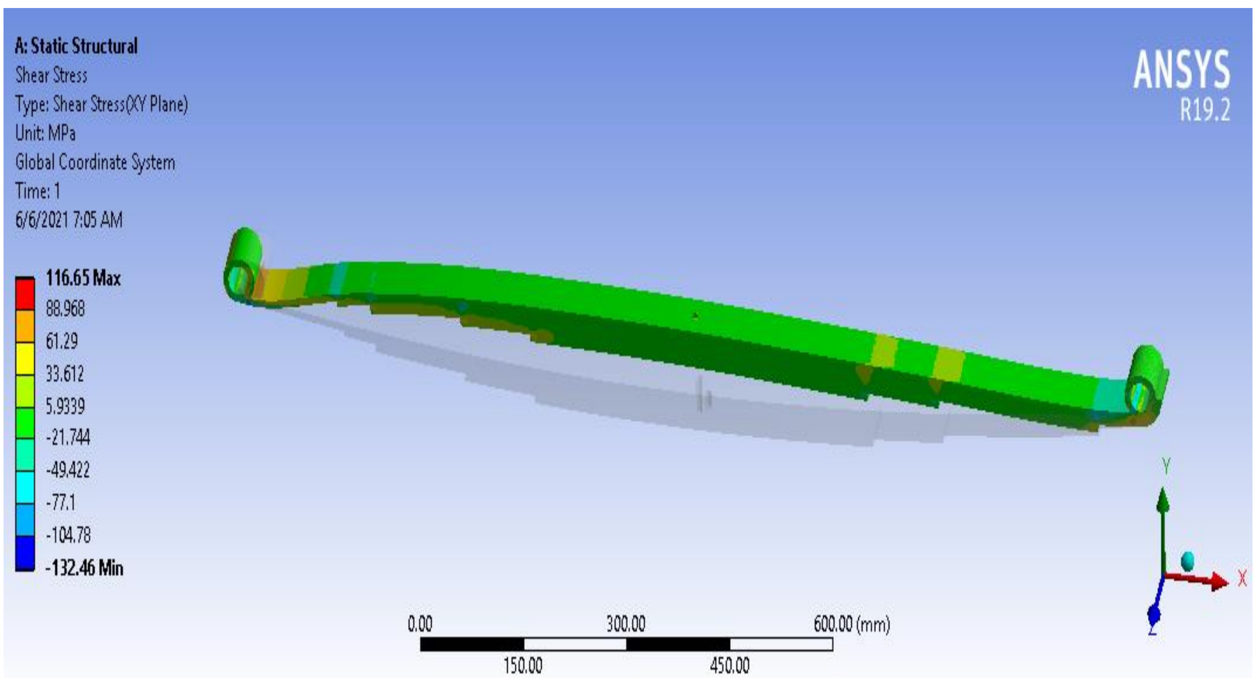

Fig B5 Shear stress (XY-plane) of conventional steel leaf spring

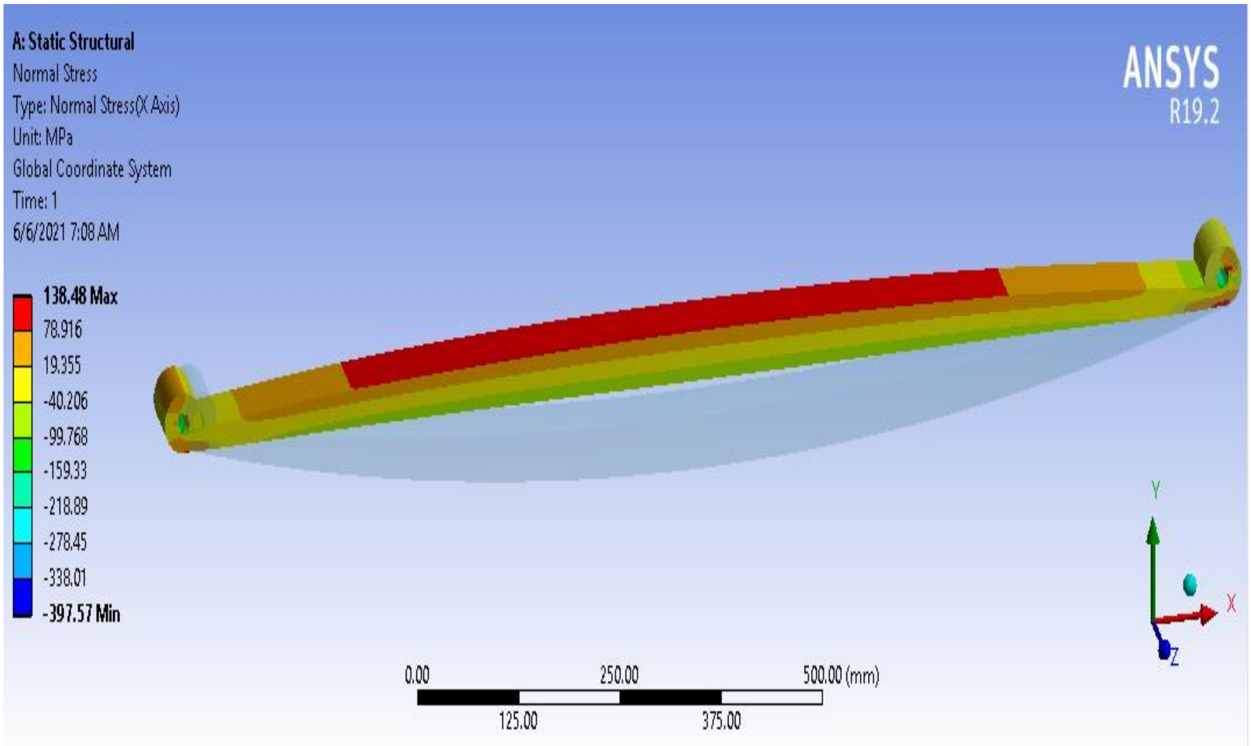

Fig B6 Normal stress (X-axis) of epoxy E-glass UD

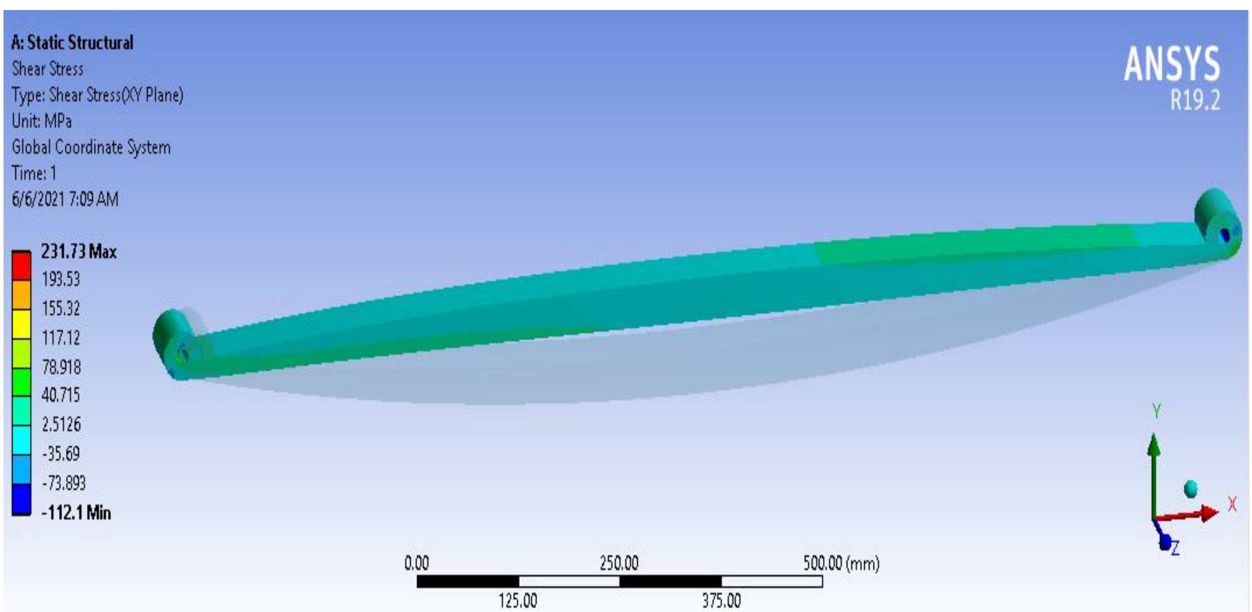

Fig B7 Shear stress (XY plane) (X-axis) of epoxy E-glass UD

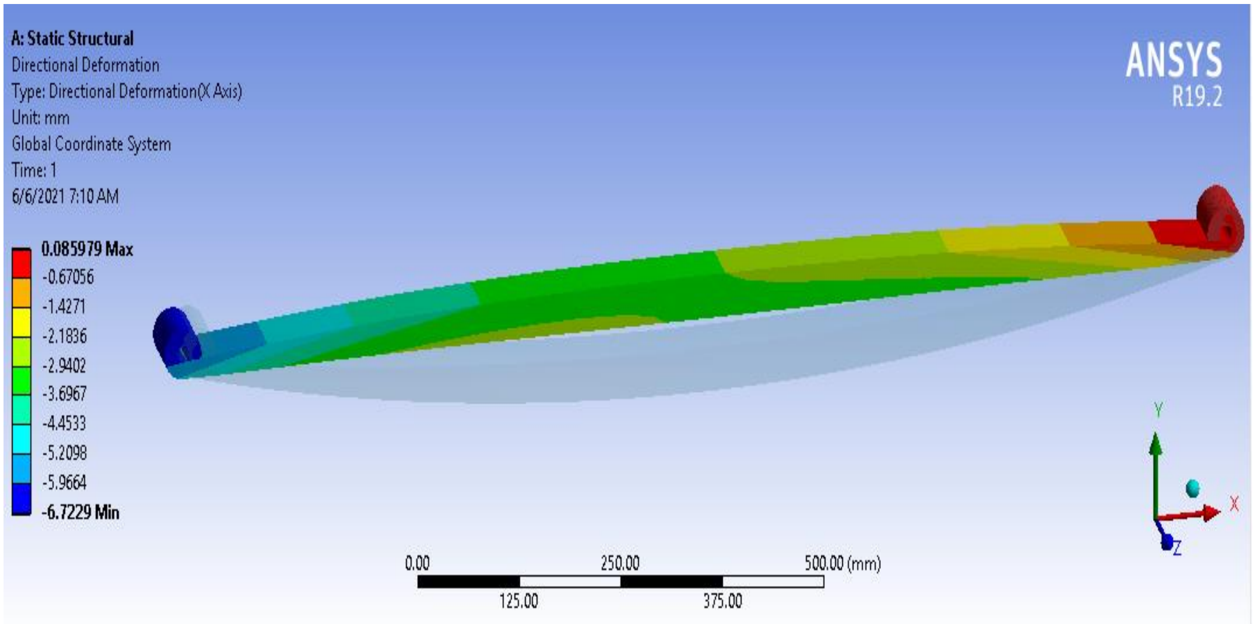

Fig B8 Directional deformation (X-axis) of epoxy S-glass UD

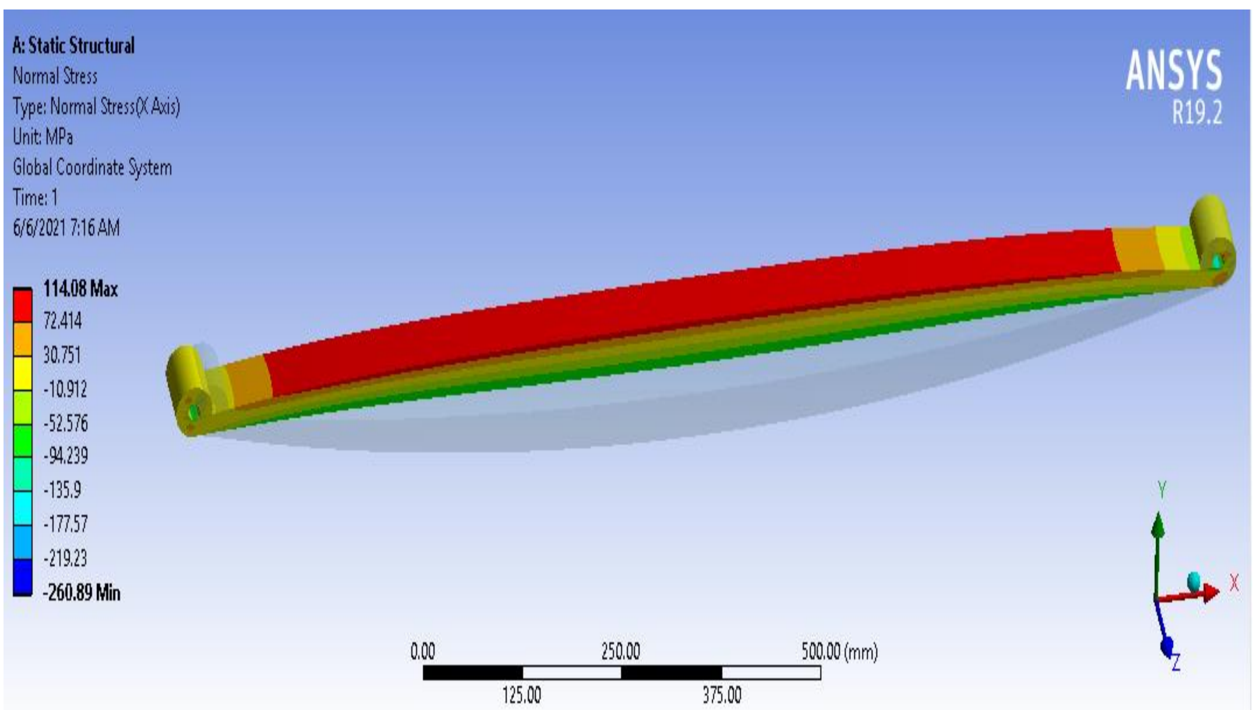

Fig B9 Normal stress (X-axis) of epoxy carbon UD (395 Gpa) prepreg

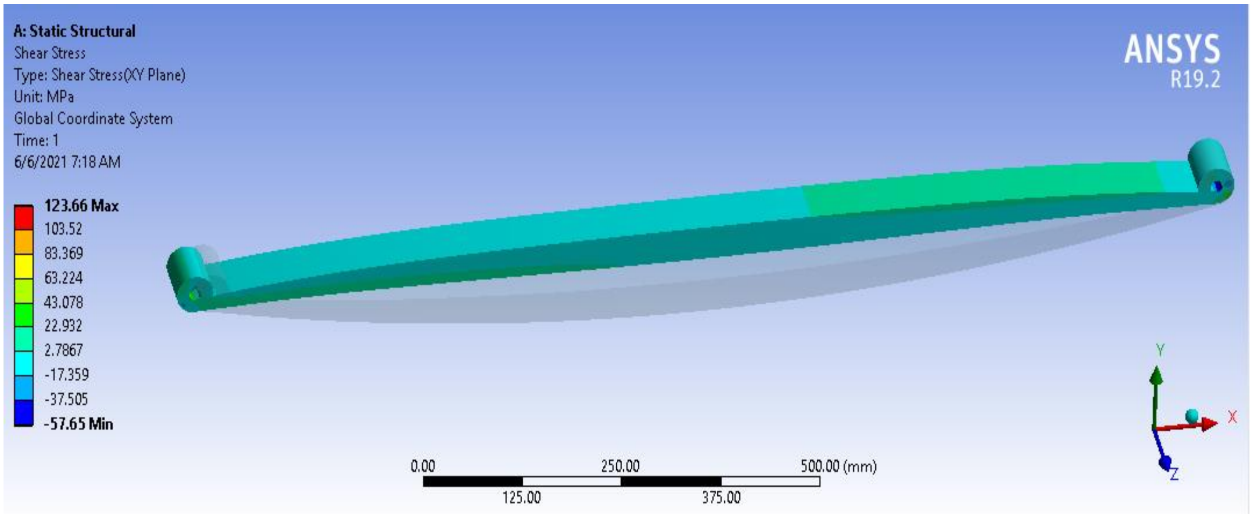

Fig B10 Shearl stress (X-axis) of epoxy carbon UD (395 Gpa) prepreg

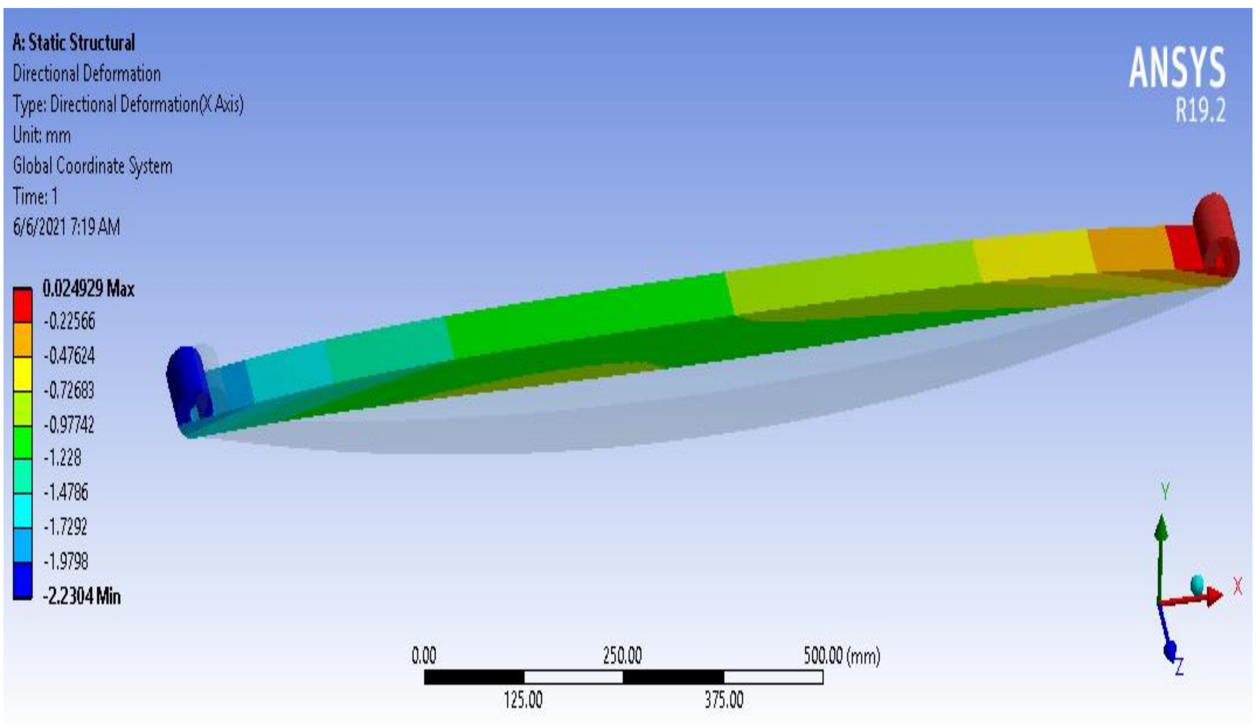

Fig B11 Directional deformation (X-axis) of epoxy carbon UD (395 Gpa) prepreg