Debre Birhan University College of Engineering

Department of Mechanical Engineering

Design, Simulation and Experimental Testing of E-Glass/Epoxy Composite Mono Leaf Spring for Land Cruiser Vehicle Application

A Thesis Submitted to the Department of Mechanical Engineering Debre Birhan University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering (Motor Vehicle)

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Declaration

I hereby declare that the thesis prepared by Sisay Asmare Marye entitled **“Design, Simulation and experimental testing of E-Glass/Epoxy composite mono leaf spring for land cruiser vehicle application”** is an original work of my own, has not been submitted in full or partially for a degree in any university/institution. It also complies with the regulations of the university and meets the accepted standards. All sources of materials used for the thesis have been duly acknowledged.

Sisay Asmare Marye

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Date____________________

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ABSTRACT

This thesis deals with the design, simulation and experimental testing of the properties of E-Glass/epoxy composite materials for leaf spring of a Toyota land cruiser vehicle. The main aim being to replace the conventional steel multi leaf to a single leaf composite spring so as to achieve a reduction in vehicle weight, environmentally friendly, ergonomic design and to achieve a better fuel efficient vehicle.

The conventional multi leaf steel spring specifications and dimensions of the Toyota land cruiser vehicle has been investigated and consequently the leaf spring were designed for single leaf composite as well as the multi leaf conventional steel springs. The designs were simulated using ANSYS computational simulation package and the results were compared for different strength and material properties. The static structural analysis predicts a 22% in stress reduction and the analysis results of fatigue loading shows an increase in the fatigue life by 59% of the composite spring over the conventional steel spring. An overall significant weight reduction of 61.35% over the conventional steel has been achieved by replacing with a composite leaf spring. The experimental set up has been performed for the impact and creep properties of E-Glass/epoxy composite materials by considering the composite materials in three fiber volume ratio parameters; such as 60%/40%, 50%/50%, and 40%/60% respectively. It has been concluded from the experimental analysis that the composition parameters with fiber volume ratio of 60%/ 40% shows a much higher impact energy absorption capability and a much longer creep life. The detail results has been instigated and presented, however more in-depth results can be ascertain by incorporating temperature gradient in the analysis, which was beyond the scope of the thesis.

Key Words: E-Glass/Epoxy, Mono leaf spring, Multi steel leaf spring, Creep, Fatigue, ANSYS work bench, FEA

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NOMENCLATURE

V_F	Volume fraction of fiber
V_f	Volume of fiber
V_c	Volume of composite
V_M	Volume fraction of matrix
Vm	Volume of matrix
P_f	Density of fiber (*g/cm*^{3})
ρ_m	Density of matrices(*g/cm*^{3})
P_c	Properties of composite
P_c	Properties of composite
P_f	Properties of fibers
P_m	Properties of matrix
E_f	Modulus of elasticity of fibers (*N/mm*^{2})
σ_f	Stress of fibers(*N/mm*^{2})
ε_f	Strain of fibers
W_{tota}	Total load capacity of the vehicle (*N*)
M_{total}	The total mass induced in the vehicle (*Kg*)
m_v	Single mass of the vehicle(*Kg*)
m_p	Mass of passengers(*Kg*)
n	Number of passengers
g	Acceleration due to gravity (*m/s*^{2})
I	Moment of inertia (*mm*^{4})
E	Young's modulus of the materials (*N/mm*^{2})
W	Load of the vehicle (*N*)
L	Distance of the load from the cant leaver end (*cm*)
b	Width of leaf springs (*cm*)
t	Thickness of leaf spring (*mm*)
$I_{x'}$	Moments of inertia of each leaf spring (*mm*^{4})
A	Area of each leaf spring (*cm*^{2})
d	Distance from the centroid of each leaf spring to the neutral axis (*mm*)
Y_{bar}	Centroid of the whole structure (*mm*)

y	Centroid of each leaf spring (*mm*)
σ_m	Mean stress (*N/mm²*)
σ_v	Reversed stress components *(N/mm²*)
σ_a	Stress amplitude(*N/mm²*)
$\sigma_{f'}$	Fatigue strength coefficient
b	Fatigue strength exponents (basuins exponents)
E_1	Longitudinal modulus (*N/mm²*)
E_2	Transvers modulus (*N/mm²*)
V_{12}	Major poisons ratio
G_{12}	In plane shear modulus (*N/mm²)*
σ_{tt}	Transverse strength of single layer(*N/mm²*)
σ_{cL}	Compressive strength of single layer in longitudinal direction(*N/mm²*)
σ_{ct}	Compressive strength of single layer in transverse direction (*N/mm²*)
a_b	Bending stress (*N/mm²*)
δ	Deflection of leaf spring (*mm*)
$S_{e'}$	Eendurance strength (*N/mm²*)
$\dot{\varepsilon}$	Strain rate
t_0	Initial time(*s*)
t_f	Final time(*s*)
▲t	Change of time(*s*)
ε_0	Initial strain
ε_f	Final strain
GPa	Giga Pascal
Kg	Kilogram
g	Gram
m	Mass
mm	Millimeter
N	Newton
KPa	Kilopascal
µm	Micrometer

LIST OF ABBREVIATIONS

PAN	Polyacrylonitrile
SiO_2	Silica oxide
PEEK	Polyether ether ketone
MMCS	Key metallic matrix materials
CMC	Key ceramic metrics
RTM	Resin transfer molding
VARTM	Vacuum-assisted resin transfer molding
CTMDA	Isomers (trimethyl hexane -1, 6- diamine)
IPDA	Isophorone diamine
ROM	Rule of- Mixture
CAD	Computer aided drawing
GFRP	Glass fiber reinforcement plastic
FEM	Finite element methods
FRP	Fiber reinforcement plastic
MMCS	Metal matrices composite
Mpa	Mega Pascal
PMCS	Polymer matrices composite
ASTM	American society for testing and materials
ANSYS	Analysis system
3D	Three dimension
igs	Initial graphics specification
f	Fiber
m	Matrix
c	Composite

Chapter 1: Background

1.1. Introduction

A well developed and less risky transport system is a critical factor to achieve sustainable development. In Ethiopia, road transport system is the largest and the most common mode of transportation, which accounts over 95% both in freight and passenger movement [1]. An improved road transportation system has many benefits for countries like Ethiopia where more than 85% of the population is living in the rural part of the country. It allows to get a better market access for agricultural products and also facilitate the provision of public and private services like health facilities, education access, banks and insurances.

However, the transport system (i.e, road transport) is highly challenged by many factors of which an increase in the number of poor-quality cars and associated accidents on human as well as on materials and animals are the main ones. In 2015, the vehicle population in Ethiopia was 587,400 with an annual growth rate of 6% of which 85 % were second hand imported cars [2]. Toyota car types account 90 % of all the imported second hand cars.

A higher car population and an increase in the concentration of poor quality second hand cars have many negative consequences. First, as these old cars are made up of heavy materials, they consume a huge amount of fuel that increases fuel cost and air pollution. Second, they will increase the occurrence of unexpected and damaging car accidents. According to world health organization, in 2014, road traffic accidents were 15,015 or 2.5% of total deaths in Ethiopia. This is one of the highest accidents in the world which leads the country to be 68th in road traffic accident in the world [3].

All these indicates that, improving the transportation system and reducing car related accidents and unexpected risks is mandatory. Many approaches are suggested as a solution for this. For example, road improvement, changing transport modalities, use of new vehicle technology, and use of less weight vehicles that can consume minimum fuel are the main ones [4].

Suspension device is one of the most important components of a vehicle. The suspension device separates the axle from the vehicle chassis so that any road irregularities are not transmitted directly to the driver and the load on the vehicle. This is not solely allowing an extra relaxed ride, and protection of the load from feasible damage, but it additionally helps to stop distortion and harm to the chassis frame [5].

Depending on the size and cars type there are different type suspension systems. Leaf spring suspension system is the common suspension system for medium and large cars. A leaf spring normally used in automobiles is of semi-elliptical form. It is built up of a different size of leaves. The leaves are typically given preliminary curvature or cambered so that they will have a tendency to straighten under the load. The leaves are held collectively making use of a center bolt passing by the center. The spring is clamped to the axle housing the use of U-bolts. The longest leaf recognized as main leaf or master leaf has its ends formed in the structure of an eye through which the bolts are exceeded to tightly close the spring to its supports.

Usually, the eyes, through which the spring is attached to the hanger or shackle, are provided with bushings of some anti-friction materials such as bronze or rubber. The other leaves of the spring are known as graduated leaves. In order to prevent digging in the adjoining leaves, the ends of the graduated leaves are trimmed in various forms. Rebound clips are positioned at intermediate positions in the length of the spring so that the graduated leaves also share the stresses triggered in the full-length leaves when the spring rebounds. [6].

The advantage of leaf spring over helical spring is that the ends of the spring might also in addition be guided alongside a particular route as it deflects to act as a structural member in addition to the energy absorbing device. Thus, leaf spring can additionally carry lateral loads, brake torque, driving torque, in addition to shocks. The functionality to take in and store more extent of energy ensures the comfortable operation of a suspension system.

A notable variety of spring materials are available to the designer, inclusive of simple carbon steels, alloy steels, and corrosion-resisting steels, as nicely as nonferrous substances such as phosphor bronze, spring brass, beryllium copper, and a number nickel alloys [5].

The material used for leaf springs is commonly carbon steel having 0.90 to 1.0% carbon. However, to gain larger strength, greater load-carrying capacity, an increased vary of deflection, and higher fatigue resistance using carbon steel the leaves need to be warmth dealt with after the forming process [3]. But this requires a large amount of human, material, and financial resource which is not easily affordable and accessible.

1.2. Statement of the Problem

Now a days, the type of leaf spring used by automobiles to soak up jolts is a traditional steel. This type of leaf spring is not only heavy in terms of weight but also, the failure of metal leaf spring is catastrophic and leads to an unexpected accident on the vehicles.

The suspension leaf spring is one of the potential elements for the increase of weight and greater utilization of space on the vehicle. Because the spring is a traditional steel material and it accounts for 10-20% of the un-sprung weight, it leads to greater consumption of energy. At current trend, vehicle producers are extra involved in design and manufactured an electric and hybrid vehicle for racing and transport purposes. But there is a big challenge for the mass production of these new-generation vehicles, because of the weight of the component materials which is conventional steel and aluminum. Besides this, as observed from the literature review the failure of steel leaf spring is catastrophic and leads to an unexpected accident on the vehicles. Any catastrophic failure of the leaf spring would eventually arise into secondary failures of the other supporting parts and would be particularly dangerous while the vehicle is in motion. The key reason for the mode of this failure is fatigue loading induced due to a higher shock in the irregularity of road and sudden (Impact) load on a bumpy surface. This precipitate physical, mental, and economic crises on the individual and the society as a whole at national level.

So, in order to limit and avoid this ruinous trouble which comes through such failure, traditional steel leaf spring is better to be replaced by a materials having, lightweight, excessive fatigue resistance, stiff, strong, tough, and step by step failing composite leaf springs.

By doing this it is possible to save the weight of the vehicle, consumption of fuel, and even life of a passenger. Even the conventional steel leaf springs are all meet the simple requirement of energy and functionality, but the modern-day, Light weight composite materials, gives several advantageous over the present-day traditional steel leaf spring. This is due to the fact that composite materials provide extensive opportunities for enhancement of product overall performance in terms of strength, stiffness, existence span, and energy absorption, mixed with weight discount and space-saving [7].

A composite material is made by combining two or more materials. Each component has very different properties. When these two materials hybrids together to give the composite unique properties, it is analogous with, why do horse breeders cross a horse with a donkey? To delivering a mule. The horse and donkey are as the constituent which have different property and appearance.

Mule is as composite and it also completely differ from the two. The result of Composite materials also like the above analogy. The property of the constitute material and the composite material is different. The composite material provides higher strength and higher fatigue resistance than the strength of each constitute material. Why Aircraft engineers, automobile makers, and designers of sports equipment all have one thing in common? Because they all want materials that are stiff, strong, tough, and light. So, the only materials which best achieve these characteristics is a fiber reinforced composite materials [8]. However, there is no enough study that tried to design, simulate and experimentally test composite material leaf spring for land cruiser vehicle application in Ethiopia.

Hence, this study explores the design, simulation and experimental teste of leaf spring for the land cruiser vehicles by performing static, fatigue analysis, and experimental testing of material property using creep and impact loading.

1.3. Objective of the Study

General objective

The general objective of this study is to design, simulate and experimentally test the E-Glass/epoxy composite mono leaf spring for land cruiser vehicle application.

Specific objectives

The specific objectives of the study are:

- **i.** Selecting the Suitable Materials for Composite Leaf Spring and conduct analytical design of Conventional Steel and Composite Material Leaf Springs
- **ii.** Develop Suitable 3-D Model Using Appropriate Modeling Software and experimental testing of materials using impact and creep loading
- **iii.** Conducting static and fatigue analysis of existing steel leaf spring and composite mono leaf spring

1.4. Methodology

In order to achieve the stated objectives, the study employed the following methods. The employed methods are summarized in two phases: data collection phase and Methodology design phase.

Phase I: Data Collection

To design a composite leaf spring the required and compatible information are necessary. So, in this phase different types of data such as primary and secondary data are collected. This is started by reviewing different kinds of literature that are done in past studies related to leaf spring. The literature review and data collection were mainly about design and analysis of conventional steel and composite leaf spring, determination of the optimal fiber volume fraction, layup, orientation and stacking sequence of laminae, Compatibilities of fiber, hardening, and matrix, taking the required design information of conventional steel leaf spring from the specification of Toyota land cruiser vehicle, taking the dimension of existing leaf spring by direct measurement from the specified vehicle.

Phase II: Methodology Design

In this phase, by using the collected information necessary in the first phase as the initial input, then selection of suitable composite materials for leaf sprig design, fiber volume ration of the current design of composite leaf spring, stacking sequences, orientation angle, and number of layers of composite leaf spring, techniques of laminate lay up for the composite leaf springs are conducted. This is followed by Mathematical modeling of the composite and steel leaf spring for the selected vehicle, analytical calculation of steel and composite material leaf spring, 3-D model of composite E-Glass /epoxy and steel leaf spring using solid work 2017, analysis of composite material and current steel material leaf spring using ANSYS Software Package, experimentally testing of E-Glass/epoxy composite materials using izod impact and creep test machine, finally the conclusions of the results are made.

To sum up, the following figure presents a general overview of the methodology design.

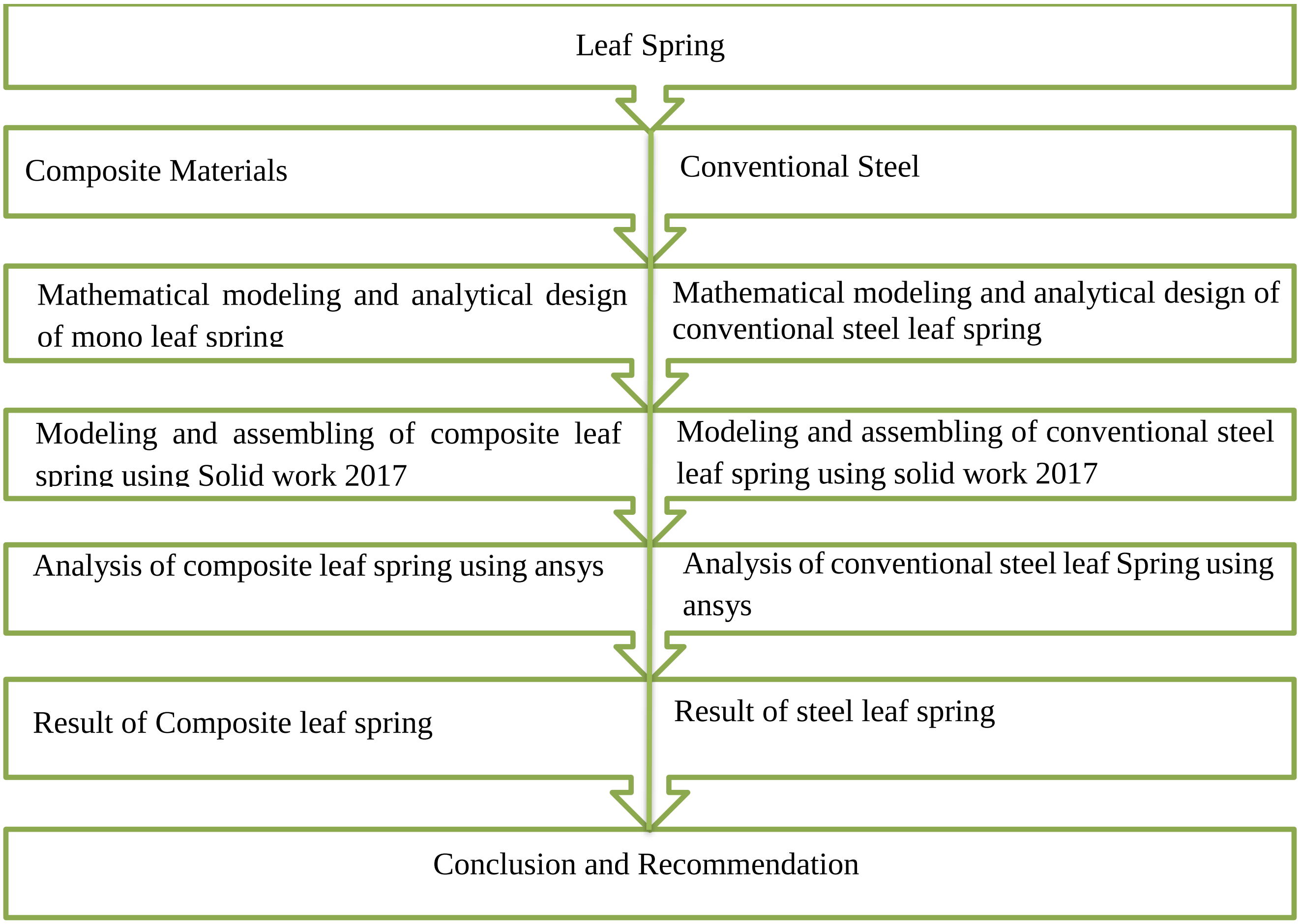


Figure 1. 1 Methodological Procedure

1.5. Significant of the Study

To meet the need for natural property conservation, auto manufacturers are attempting to minimize the weight of vehicles in present day. The hobby in reducing the weight of automobile components has necessitated the use of greater material, design, and manufacturing processes. The suspension leaf spring is one of the possible factors for weight discount in motor vehicles as it leads to the bargain of the un-sprung weight of automobiles. As referred to earlier, leaf spring includes 10-20% of the un-sprung mass [9]. So, minimizing this weight helps to achieve improved ride characteristics of the vehicles, load carrying capacity, increasing fuel efficiency and FRP springs also have excellent fatigue resistance and durability.

Hence, by designing, simulating and experimentally testing a composite material leaf spring, this study will provide the following benefits.

- As mentioned above, the weight reduction, fuel consumption, failure of components, are the principal trouble that wishes to give unique attention through automobile manufacturer, the current study will direct the automobile producer how to improve their vehicle elements weight and space utilization and it will give direction on how to reduce the consumption of energy.

- It will also be served as a basement on how to reduce the fatigue failure of the leaf spring and provides a complete solution for the electric and hybrid vehicles related to their weight.
- It will provide ways to strengthen the due attention to be given to the automotive industries focus on new generation materials rather than conventional materials.
- Finally, this study will serve the vehicle industry as an initial reference to immerse and produce new-generation products of the vehicles incorporating more efficient composite materials.

1.6. Scope and Limitation of the Study

The scope of this thesis is limited to design, simulate and experimentally (Creep and Impact) test the E-Glass/epoxy composite mono leaf spring for land cruiser vehicle application. Following the experimental investigation, conclusions are drawn based on the results. In the whole process of the thesis work the following assumptions are taken. The layers of the composite laminate are linear elastic, since the layers of the laminate are linearly elastic, then through-the-thickness stresses and strains are negligible. In addition, the composite laminate thickness is very small compared to other dimensions of the laminated composite and the lamina (layers) of the composite laminate is homogenously bonded.

Different hindrances were a challenge for this study. First, the price of composite materials and other materials are difficult to access for individuals because they are sold in large volumes or in dozens for the industrial companies or laboratory institute. In addition, the cost of buying these materials was also very difficult to afford. Second, due to the outbreak of coronavirus pandemic, the movements of people are restricted by the government and also academic institutes are closed for unknown period. So, all the research activities are done at home and it faces lack of internet accesses, lack of FEA laboratory, lack of experimental testing machine and laboratory equipment. However, maximum care, effort and time was given to keep the quality of the study and overcome the aforementioned challenges.

Chapter 2: Literature Review

The composite materials are widely used in today's aerospace and the automotive industry as a structural part. Some of the studies performed at various times for the parts of vehicles and application of leaf spring using composite materials are reviewed and discussed below.

2.1. Composite Materials

Composite materials are fashioned through the mixture of two or extra substances to attain properties (physical, chemical, etc.) that are most reliable to these of its constituents. The most important factors of composite materials, or composites, are fibers and matrix. The fibers provide most of the stiffness and strength. The matrix binds the fibers collectively thus offering load transfer between fibers and between the composite and the external masses and supports. Also, it protects the fibers from environmental attack. Other materials are used to improve particular properties [10]. The improvement of composite materials as properly as the associated format and manufacturing applied sciences is one of the most essential advances in the records of materials. Composites are multifunctional supplies having wonderful mechanical and bodily residences that can be tailor-made to meet the requirements of a unique application. Many composites additionally showcase top notch resistance to wear, corrosion, and high-temperature exposure. These unique behavior provide the mechanical engineer with design possibilities no longer viable with ordinary monolithic (unreinforced) materials. Composites technological know-how additionally makes possible the use of an entire class of solid materials, ceramics, in functions for which monolithic variations are unsuited because of their remarkable strength scatter and terrible resistance to mechanical and thermal shock. Further, many manufacturing approaches for composites are properly adapted to the fabrication of large, complicated structures, which allows consolidation of parts, decreasing manufacturing costs[11].Composites are important materials which are now used widely, no longer solely in the aerospace industry, however also in a large and increasing wide variety of industrial mechanical engineering applications, such as internal combustion engines; structural components; thermal insulation and electronic packaging; automobile, train, and plane structures and mechanical components, such as brakes, drive shafts, suspension, flywheels, tanks, and stress vessels; dimensionally steady components; process industries tools requiring resistance to high-temperature corrosion, oxidation, and wear; offshore and onshore oil exploration and production; marine structures; sports activities and entertainment equipment; ships and boats; and biomedical devices. It ought to be referred to that organic structural substances taking place in nature are commonly some type of composite. Common examples are wood, bamboo, bone, teeth, and shell [11].

2.1.1. Basic constituents of composite materials

Composite materials have two basic components in their structures. These are reinforcement and matrix.

2.1.2. Reinforcement

It is used to provide strength and stiffness to the matrix. And it can be a fiber and particles such as glass, carbon, aramid, natural ceramic. The reinforcing material imparts their special mechanical and physical properties to enhance the matrix properties [12].

Based on reinforcement type composite are classified as

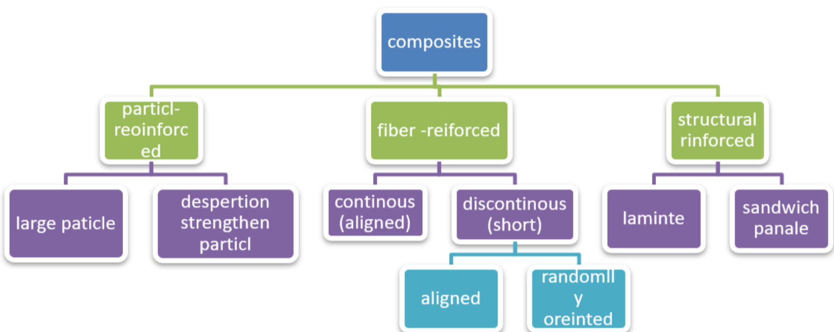


Figure 2.1 Classification of reinforcement. [16]

2.1.3. Types of reinforcement

Most of the time the reinforcement materials are different types of fibers. Some of these are:

1. Glass Fibers.

Glass fibers are used essentially to enhance polymers. The primary kinds of glass fibers for mechanical engineering features are E-glass and HS glass. E-glass fibers, the first indispensable structural composite reinforcements, firstly had been developed for electrical insulation features [13]. Its advantages consist of its strength, low cost, fantastically chemical resistant. The primary kinds are E-Glass and S-Glass. The alphabet E-stands for electrical, as it used to be designed for electrical applications. However, it is being used for many different features now, such as decoration and structural applications. The alphabet S – stands for high content material of silica, it retains its energy and prolonged temperatures and has greater fatigue strength. Glass fibers, additionally recognized commercially as 'fiberglass', are most considerably use reinforcements for polymer matrix composites due to their mixture of low cost, excessive strength, and distinctly low density. Unlike carbon or Kevlar fibers glass fibers are isotropic as a result retaining off loss of properties when loaded in the transverse direction. Fiberglass is produced with the aid of using pulling molten glass through orifices at a temperature where the glass has virtually the proper quantity of viscosity Composition of pretty a quantity glass fiber grades [14].

2. Carbon (Graphite) Fibers.

Carbon fibers regularly called graphite fibers in the United States, are used as reinforcements for polymers, metals, ceramics, and carbon. There are dozens of carbon fibers, with an extensive vary of strengths and moduli. As a category of reinforcements, carbon fibers are characterized via excessive stiffness and strength and low-density .Fibers with tensile moduli as excessive as 895GPa (130Msi) and with tensile strengths of 7000MPa (1000ksi) are commercially available. Carbon fibers have amazing resistance to creep, stress rupture, fatigue, and corrosive environments, though they oxidize at excessive temperatures [11].

The properties of carbon fibers rely on the raw material, the system used for its manufacture, and the unique manufacturing procedure used. Two important raw materials, or precursors, are used: polyacrylonitrile (PAN) and pitch. Pitch fibers are much less costly but have decrease electricity than PAN fibers. The tensile energy of pitch fibers is about one-half and their compressive power is about one-third of that of PAN fibers, due to intrinsic structure that makes them extra touchy to floor defects. PAN fibers dominate the high-performance market for aerospace purposes due to the fact they can be made with a variety of stiffness and electricity values [10].

3. Kevlar (Aramid) Fibers.

Aramid, or fragrant polyamide fiber, is a high-modulus organic reinforcement chiefly used to beef up polymers and cement and for ballistic protection. There are a number of commercial aramid fibers produced by countless manufacturers. “Kevlar” 49 and “Twaron” are examples. As for different reinforcements, they are proprietary materials [12]. The best toughness of aramid is result of the power ingesting failure mechanism of its fibers. This strength absorbing failure mechanism makes it perfect for use in armor, military, and ballistic applications, like helmets and bullet-proof vests. Among many other very important uses, it is used for firefighting protection, on the underside of airplanes (protection in opposition to stone hits in the course of takeoff and landing) and the underside of race cars. Within the special sorts of Kevlar’s, there is Kevlar 29 (with excessive toughness), Kevlar 149 (with ultra-high modulus) and Kevlar 49 (with excessive modulus). In structural composite production, Kevlar 49 is the most dominant structure used today. Each of these Kevlar fibers are additionally handy in a vary of extraordinary brief fiber forms and yarn counts [14].

4. Boron Fibers.

Boron fibers are specially used to give a boost to polymers and metals. Boron fibers are produced as monofilaments (single filaments) boron on a tungsten wire. They have incredibly massive diameters, 100–140 μm (4000–5600 μin.)[7]

High stiffness, excessive strength, and low density are common to boron fibers. They are most notably used as reinforcement in aerospace and wearing goods. The power values are managed with the aid of the statistical distribution of flaws all through the manufacturing process. The mechanical properties are preserved at excessive temperatures (typically, the tensile power at $500c^0$ is about 60% from the initial power fee at room temperature). They additionally feature excessive toughness, high fatigue strength, and a very correct compressive behavior. They are fragile, with low impact tenacity. Boron fibers are produced by chemical vapor deposition on a tungsten wire. Because of sluggish production rate, boron fibers are amongst the luxurious of all the fibers in modern times made, consequently motivating substitution of boron with carbon fibers each time possible [9].

5. Silica and Quartz Fibers.

Silica fibers and quartz fibers are extraordinary from classical glass fibers by means of their high concentration of silica (SiO_2) {98% for silica fibers and {99.97% for quartz fibers (Silica and quartz fibers costs up to {50% more than glass fibers, with a corresponding reap in bodily and mechanical properties. They characteristic related or higher stiffness, strength, and thermal steadiness than glass fibers, with long-term working temperatures up to 900-degree cent grad for silica fibers and up to 1050^0C for quartz fibers. They additionally show good thermal and electrical insulation properties, and very desirable steadiness beneath special chemicals, being without a doubt insensitive to humidity. Their properties make them pleasing for high-temperature, excessive chemical corrosion applications. Also, quartz fibers have higher radio-frequency transparency, which is wanted for antenna applications. The typical diameter of Astroquartztm , fibers is 9 microns. In addition processing and diameter reduction, very high energy values can be achieved. An application of this type of reinforcement blended with polymer matrices is in ablative buildings supplying thermal protection for atmospheric reentry and rocket engine nozzles.

Ablative insulation includes warmth dissipation through vaporizing a skinny sacrificial layer of polymer strengthened with quartz fibers. Use of these fibers requires high-priced tooling due to their high toughness [10].

6. Ceramic fiber.

Ceramic fibers are used for high temperature applications. Silicon Carbide (Sic) fibers are produced like boron fibers however on a carbon substrate. They have their greatest hardness as reinforcement for metal matrix, principally titanium, however they have also been used in combination with temperature-resistant polymeric matrix. Like boron fibers, Sic fibers are characterized by means of high stiffness and high strength. And most surprisingly they exhibit greater temperature capability as they preserve their preliminary tensile strength up to about $13000C^0$. Because of restrained use and low manufacturing volumes, the fee of these fibers is high [10].

7. Basalt Fibers.

Basalt fibers can be categorized as mineral fibers. This new product makes use of volcanic basalt rock, melted and extruded into fibers. Basalt fibers function higher mechanical properties than glass fibers, and are much less costly than the carbon fibers. They display awesome thermal stability, high energy and stiffness, exact chemical stability, accurate corrosion resistance, and suitable matrix adherence, now not being affected by way of any variety of radiation. They are doubtlessly applicable for thermal safety and structural applications [10].

8. Metallic Fibers.

Metallic fiber includes fibers made from a variety of base metals and alloys. By processing the raw fabric into fibers of small dimensions of the order of a µm, flaws inherent in the bulk materials are actually eliminated and more desirable homes are achieved. The fiber energy is directly associated to the fiber diameter that is in turn related to the fiber manufacturing cost. The fiber material can be selected for the required application, such as lightweight aluminum fibers, sturdy steel fibers, or stiff tungsten fibers. Other blessings of these fibers are their notable electrical and thermal conductivity. Metallic fibers are typically used as filler nets for polymer matrix, conferring electrical conductivity, electromagnetic interference protection, or lighting strike protection to the ultimate structural composite material. Two examples of metallic fibers, high carbon steel fibers and tungsten fibers. Characteristics of the composites that can be produced with these fibers are possibly to be the limiting factors in their application. Environmental degradation, most working temperature, transverse, and shear power are some of the limiting elements that need to be investigated for any new material [10].

2.1.4. Matrix of composite materials

The primary functions of the matrix materials are to transfer stresses between the reinforcing material and to protect them from mechanical and/or environmental damage and whereas the presence of fibers/particles in a composite improves its mechanical properties such as strength, stiffness, etc. These matrix materials can be, polymer, ceramic, and metal. The strength of composites is largely depending on the fiber reinforcement and the type of matrix material. Matrix material provides support for the fibers and assists the fibers in carrying the loads, it also provides stability to the composite material. The resin matrix gadget acts as a binding agent in a structural component in which the fibers are embedded [8]. During reinforcement when too plenty resin is used, the section is labeled as resin-rich, and on the different hand, if there is too little resin, the phase is known as resin starved. A resin rich phase is more inclined to cracking due to lack of fiber support, whereas a resin starved section is weaker due to the fact of void areas and the truth that fibers are not held together and they are not nicely supported [15]. In polymer and steel composites the matrix materials transiting load from the matrix to the fibers via shear loading at the interface. The most often used matrix are polymer matrices, and they are strengthened with glass, carbon, aramid, or boron fibers. These composites are used at rather low temperatures. Other matrixes are steel and ceramic matrixes and carbon/carbon composites. The metallic matrix composites consist of metals or alloys and are bolstered with boron, carbon, or ceramic fibers [16].

2.1.5 .Types of matrix

There are four basic class of matrix materials in a composite structural application. These are polymers, metals, ceramics, and carbon matrix [11].

Polymer Matrix Materials:

There are two major classes of polymers used as matrix materials,

a) Thermosets and
b) Thermoplastics.

a) Thermosets:

At this time, thermosets are by far the most extensively used matrix resins for structural applications, although thermosets are making constant gains. It tend to be extra resistant to solvents and corrosive environments than thermoplastics.

Thermosets are materials which endure a curing system all through part fabrication, after which they are inflexible and cannot be reformed. There are numerous types of polymers in each classes [11].The key kinds of thermosetting resins used in composites are

1) Epoxies resins
2) Polyesters resins
3) Polyimides resins
4) Phenolic resins
5) Cyanate esters resins
6) Vinyl esters resins and
7) Bismaleimides resins

1. **Epoxies resins:** Epoxies are the workhorse substances for airframe structures and different aerospace applications, with a long time of successful flight trip to their credit. They produce composites with wonderful structural properties. Epoxies have a tendency to be instead brittle materials, but toughened formulations with considerably improved impact resistance are available. The maximum service temperature is affected by way of reduced elevated-temperature structural properties resulting from water absorption. A normal airframe restrict is about 120^0C (25^0C) [7]. The material is frequent in high overall performance non-stop fiber composites. According to their use in one-of-a-kind environments relying on temperature and moisture versions epoxy has classify into two categories, which are used in. those that are cured at decrease temperature (120°C) and used in elements exposed to low or average temperature variations, e.g. sports activities equipment, and those that are cured at greater temperature (175°C). And the other are used in excessive overall performance factors and are exposed to high temperature and moisture variants [4]. The curing manner entails by addition of hardener and an accelerator, and the temperature levels are between 60^0C and 180°C. Epoxy has the combination of mechanical properties like, corrosion resistance, dimensionally stable, reveals desirable adhesion and fantastically less expensive that offers the composite materials suitable properties. When compared epoxy with polyester mechanical properties and water resistance

of epoxy is superior, and the shrinkage property of polyester is minimal at some stage in curing [9].

2. **Polyesters resins:** Thermosetting polyesters are the workhorse resins in industrial applications. They are surprisingly inexpensive, handy to process, and corrosion resistant.
3. **Polyimides resins:** Thermosetting polyimides are being used in applications at temperatures as high as 250– 290^{0}C (500–550^{0}F). However, new resins have been developed with even higher temperature limits.
4. **Phenolic resins**: Have good high-temperature resistance and produce less smoke and toxic Products than most resins when burned. They are used in applications such as aircraft interiors and offshore oil platform structures, for which fire resistance is a key design requirement.
5. **Cyanate esters resins:** Cyanate ester resins are not as moisture sensitive as epoxies and tend to outgas much less. Formulations with operating temperatures as high as 205^{0}C (400^{0}F) are available.
6. **Vinyl esters resins:** Vinyl esters are also widely used in commercial applications. They have better corrosion resistance than polyesters but are somewhat more expensive.
7. **Bismaleimides resins:** Bismaleimide resins are used for aerospace applications requiring higher temperature capabilities than can be achieved by epoxies. They are employed for temperatures of up to about 200^{0}C (390^{0}F).

b) Thermoplastics.

Thermoplastics, on the different hand, can be repeatedly softened and re-formed with the aid of the softness of warmth (think of wax). Thermoplastics are divided into three main classes, amorphous, crystalline, and liquid crystal. Polycarbonate, acrylonitrile–butadiene–styrene (ABS), polystyrene, polysulfide, and polyetherimide are amorphous materials. Crystalline thermoplastics include nylon, polyethylene, polyphenylene sulfide, polypropylene, acetal, polyethersulfone, and polyetheretherketone (PEEK). Amorphous thermoplastics have a tendency to have poor solvent resistance. Crystalline substances tend to be higher in this respect. Relatively inexpensive thermoplastics like nylon are substantially used with chopped E-glass fiber reinforcements in infinite injection-molded parts [7].Thermoplastics are includes the following types

1. Metals: the metals at first used for MMC matrix materials generally had been normal alloys. As time has progressed, however, unique matrix materials, tailor-made for use in composites, have been developed. The key steel matrix substances used for structural MMCs are alloys of aluminum, titanium, and iron. There was a widespread amount of lookup on composites the use of intermetallic compound matrix materials, such as titanium aluminides, however these were largely unsuccessful.

2. Ceramic Matrix: The key ceramics used as CMC matrices are silicon carbide, alumina, silicon nitride, mullite, and a number of sorts of cement. The residences of ceramics, specifically strength, are even extra manner touchy than these of metals. In practice, it is very difficult to determine the in-situ properties of ceramic matrix substances in a composite.

3. Carbon Matrix: Carbon is a notable material. It consists of materials ranging from lubricants to diamonds to structural fibers. The varieties of carbon matrices ensuing from the number of carbon-carbon manufacturing techniques have a tendency to be as an alternative weak, brittle materials. Thermal conductivities range from very low to high, depending on precursor materials and processes. As for ceramics, in situ matrix properties are difficult to measure.

2.2. Types of Composite Materials

1. Laminated Composite: Composites are labeled as laminated composites are the most frequently used composite materials in one of a kind industrial applications. This type of composite is fabricated via assembling numerous fibrous layers and mix them with the matrix materials [13].

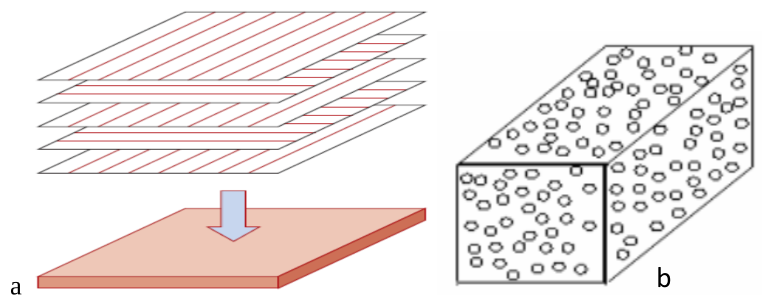


Figure 2.2. (a) Laminate and (b) Particulate Composite [12-8]

2. Particulate Composites: Particles generally strengthen a composite equally in all instructions called isotropic composite. Plastics, cement, and metals are examples of particles. Particles used to improve a matrix don't do so in the same way as fibers. For one thing, particles are no longer directional like fibers. Spread at random in the course of a matrix, particles have a tendency to improve in all instructions equally. The distinction between particulate composite and dispersion bolstered ones is, thus, oblivious. The mechanism used to fortify each of them is also different. The dispersed in the dispersion-strengthen substances reinforces the matrix alloy by arresting the motion of dislocations and desires massive forces to fracture the limit created via dispersion. In particulate composites, the particles reinforce the machine by using the hydrostatic coercion of fillers in matrix and through their hardness relative to the matrix. Microstructures of steel and ceramics composites, which exhibit particles of one phase strewn in the other, are acknowledged as particle bolstered composites. Square, triangular, and spherical shapes of reinforcement are known, but the dimensions of all their aspects are discovered to be extra or much less equal. Size and volume attention of the dispersion distinguishes it from dispersion hardened materials [8].

3. Sandwich Composites: Sandwich composites are fabricated by way of combining two skinny and robust skins with thick and lightweight core materials. Typically, the faces are high-strength composites, which are bonded to exceptional sorts of core materials (honeycombs, balsa wood, foam etc.) the usage of adhesives. Sandwich Composites existing countless advantages as in contrast to the composite laminates, such as Light weight, High bending stiffness, Cost-effectiveness, Thermal insulation, Noise insulation, and Vibration damping. Similar to laminated composites, one main problem with the sandwich composites is the deboning between the core and face materials [17].

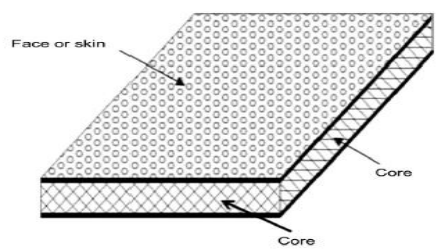


Figure 2. 3 Sandwich Composite [13]

4. Braided Composites: Braided composites are produced from fibrous architectures developed the usage of braiding Technology Braided structures are produced by way of intertwining two or greater yarns and are wonderful from other fibrous architectures by means of the yarns aligned diagonally to the structure axis. Braided buildings can be 2D, 3D or multidimensional and have huge flexibility in producing exceptional shapes such as hole tubular, stuffed tubular, flat, Solid Square and irregularly fashioned or long-established solids. Additionally, numerous complicated profiles can be produced such as I beam, H beams, delta beams, channel beams, perspective beams, ribbed and solid columns, tubes, plates and the like, which can be utilized for fabricating braided composites. Braided composites possess a quantity of wonderful features, such as: High shear and torsional energy and stiffness, High transverse energy and modulus, Damage tolerance and fatigue life, Notch insensitivity [5].

5. Auxetic substances and composites: figure 2.4 describes about Auxetic substances and composites. it possess a poor Poisson's ratio (i.e., in contrast to conventional materials, they extend in the transverse direction when loaded in the longitudinal direction) Due to this uncommon characteristic, auxetic materials possess several benefits such as: High shear modulus, Synclastic curvature, High damping resistance, High fracture toughness, Enhanced crack growth resistance, and High power absorption capability[5].

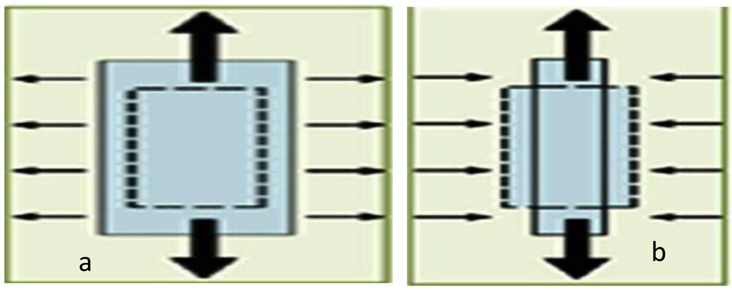


Figure 2.4 Behavior of (a) Auxetic, (b)] Conventional Materials under Tensile Load [13]

Natural fiber composites:

In recent times, exceptional interest is being paid to a number herbal plant fibers (eg, sisal, jute, flax, hemp, coir etc.) by means of each the scientific community and industrial sectors for various applications, together with construction, automobiles, sports, aerospace and geotechnical engineering. The world herbal fiber composites market reached 1.6 billion in 2010, with a compound annual increase fee of 15% in the previous 5 years. Natural fibers are low cost, lightweight, nonhazardous, eco-friendly, renewable substances possessing high specific mechanical residences and requiring lower power throughout their growth and applications. These substances have huge achievable to reduce the consumption of nonrenewable, non-environmentally friendly, energy-consuming materials such as concrete, metals or synthetic fibers in the above applications. However, regardless of all of these beautiful properties, natural fibers cannot regularly meet the requirements of many applications due to some inherent drawbacks. A principal hassle with natural fibers is their excessive moisture absorption which leads to swelling and subsequent degradation and energy loss. Poor resistance to chemicals, high temperature and fire are different foremost drawbacks. Additionally, herbal fibers current bad interfacial properties when combined with exclusive matrix (polymeric or cementitious) and also lead to formation of cracks in brittle matrix due to their swelling properties. Therefore, the durability of herbal fibers and the structures made with natural fibers are questionable, and this truth is limiting the full utilization of these outstanding materials in quite a number sectors [5].

2.3. Manufacturing Process of Composite Leaf Spring

The choice of manufacturing process relies upon on the type of matrix and fibers, the temperature required to shape the section and to cure the matrix, and the cost effectiveness of the process. Often, the manufacturing system is the initial consideration in the plan of a composite structure. This is because of cost, production volume, production rate, and adequacy of a manufacturing procedure to produce the kind of shape desired. Each manufacturing technique imposes particular obstacles on the structural design. Therefore, the clothier wishes to understand the advantages, limitations, costs, manufacturing fees and volumes, and standard uses of more than a few manufacturing processes. In the layout of a composite structure, the material is designed at the same time as with the structure. Because of this freedom, high overall performance structures can be designed, supplied the dressmaker is aware how the fabric is going to be produced. Hand layup, prepreg layup, bag molding, autoclave processing, compression molding, resin transfer molding (RTM), vacuum-assisted resin transfer molding (VARTM), pultrusion, and filament winding are the most acknowledged manufacturing technique of composite materials [10].

Processing of polymer matrix composites involves the following unit operations:

1. Fiber placement along the required orientations
2. Impregnation of the fibers with the resin
3. Consolidation of the impregnated fibers to remove excess resin, air, and volatile substances;
4. Cure or solidification of the polymer
5. Extraction from the mold; and
6. Finishing operations, such as trimming.

According to the requirements of this specific design hand layup technique is selected for the manufacturing of composite laminated leaf spring.

Failure of composite materials:

Over the closing 4 decades, there have been continuous efforts in growing failure standards for unidirectional fiber composites and their laminates. The failure of composites has been investigated extensively from the micromechanical and macro mechanical factors of view. On the micromechanical scale, failure mechanisms and procedures range broadly with kind of loading and are intimately associated to the properties of the constituent phases, i.e., matrix, reinforcement, and interface-interphase. Failure predictions primarily based on micromechanics, even when they are accurate with regard to failure initiation at indispensable points, are only approximate with regard to world failure of a lamina and failure progression to final failure of a multi-directional laminate. For these reasons a macro mechanical approach to failure evaluation is preferred [8] .numerous failure theories have been proposed and are available to the composite Structural designer [5]. They are labeled into three groups, restriction or non-interactive theories (maximum stress, maximum strain); interactive theories (Tsai-Hill, Tsai-Wu); and partly interactive or failure mode-based theories (Hashin-Rotem, Puck). The validity and applicability of a given theory rely on the convenience of application and agreement with experimental results. The plethora of theories is accompanied by using a dearth of suitable and reliable experimental data, which makes the determination of one idea over every other as an alternative difficult. Considerable effort has been dedicated lately to alleviate this difficulty. The trouble can be divided in two parts, one being the prediction of failure of a single lamina and the 2nd dealing with prediction of first-ply-failure and damage progression leading to ultimate failure of a multi-directional laminate [8] .T. Sun is reviewed six failure theories and confirmed comparisons of theoretical predictions with experimental results. Existing lamina and laminate energy information are used to evaluate these failure criteria. For some laminates underneath positive loading conditions, all six standards might also predict comparable results, and their performance can't be ranked. Therefore, quite a few laminates are identified for which the energy predictions in accordance to these six standards are considerably different. The validity and applicability of a given concept depend on the comfort of application and agreement with experimental results [10].

Hand layup techniques:

Hand lay-up is the easiest technique of processing the thermosets-based fibers (synthetic as nicely as natural) composite. In hand lay-up technique, first, a releasing agent is sprayed on the floor of mold to avoid the sticking of polymer to the surface. To get suitable surface end of product, thin plastic sheets are used at top and bottom of mold. Fibers as a reinforcement both in shape of woven mat or in chopped form are placed at the upper floor of mold. Then mixture of thermosetting resin and appropriate hardener is poured on the surface of mat already placed in the mold. The polymer is uniformly unfold with the assist of brush. Second, layer of reinforcement is then placed on the polymer surface, and a curler is used to get rid of air as nicely as excess matrix present. The method is repeated for each layer of reinforcement and matrix until the required thickness is achieved.

After setting the plastic sheet, launch agent is sprayed on the internal surface of the pinnacle mold which is then kept on the accomplished thickness and the strain is applied [18].

The hand layup technique, additionally known as wet layup, is the simplest and most broadly used manufacturing process. Basically, it includes manual placement of the dry reinforcements in the mold and subsequent application of the resin (Figure 2.5). Then, the moist composite is rolled using hand rollers to facilitate uniform resin distribution and elimination of air pockets. This process is repeated until the preferred thickness is reached. The layered shape is then cured. The emission of volatiles, such as styrene, is excessive as in any other open mold method. The hand layup manner may additionally be divided into four simple steps: mold preparation, gel coating, layup, and curing [10].

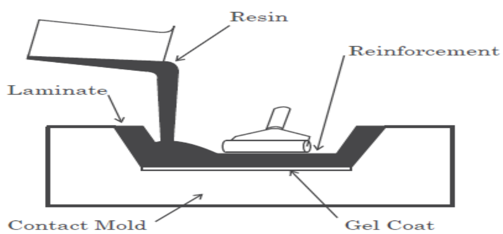


Figure 2.5 Hand layup techniques [29]

2. 4. Previous Studies of Composite Materials for Leaf Spring

Shishay Amare Gebremeskel [5] conducted a study by having an objective of decreasing weight of cars and growing or keeping the strength of their spare components. As leaf spring contributes significant amount of weight to the car and wishes to be robust enough, a single E-glass/Epoxy leaf spring is designed and simulated following the design rules of the composite substances considering static loading only. The consistent go section design of leaf springs is employed to take advantages of ease of design analysis and its manufacturing process. And it is shown that the ensuing layout and simulation stresses are a great deal under the energy residences of the material, pleasant the most stress failure criterion. The designed composite leaf spring has additionally done its desirable fatigue life. This specific design is made particularly for light weight three-wheeler vehicles.

M. Carello1 et al. [15] in his paper describes the sketch and the numerical model of a novel transverse Carbon Fiber Reinforced Plastic (CFRP) leaf-spring for a multilink suspension. The most enormous innovation is in the functional integration the place the leaf spring has been designed to work as spring, anti-roll bar, decrease and longitudinal arms at the equal time. In particular, the adopted work drift continues a very close correlation between digital simulations and experimental tests. Firstly, a number of tests have been performed on the CFRP specimen to signify the material property. Secondly, a digital card fitting has been carried out in order to set up the leaf-spring Finite Element (FE) model and the usage of RADIOSS as solver. Finally, enormous software program evaluations have been done on it to take a look at for validation. The results obtained shows that this solution enabled the suspension to decrease about 75% of the total mass without dropping performance.

The other study by Prof.Vidyadhar et al. [6] this work pursuits to main point of its lookup over assumption of the steady amplitude loading of the leaf spring for a passenger car. Finite thing modeling would be employed to evaluate the present design whilst providing the pleasant selections for design. Feasible plan alternatives would be commenced the usage of F.E. Methodology. The benchmark layout would be validated in improve for offering credibility to the F.E. model.

The study by M. Kamaleldin et al. [19] describes plan and evaluation of composite a leaf spring made of E-glass/ epoxy bolstered polymer. The aim of this paper is to introduce a new plan as properly as to examine the stiffness, load ability and weight discount of composite material with that of steel leaf spring. A comparative study of metal and composite materials with admire to weight and energy was carried out on ANSYS 16.2 beneath the identical boundary stipulations in order to reap the maximum deflection and stress. It determined that the maximum deflection and stress in metal are greater than E glass/epoxy, which recorded lowest deflection and stress by way of 51.7% and 57.1%, respectively. E-Glass/epoxy composite property reduced the weight of leaf spring 67.7 % compared to steel leaf spring. On the other hand, Jenarthanan M.P et al. [18] in his research, Carbon/Glass Epoxy Composite is proposed as leaf spring material. The specimen is fabricated and automatically tested for tensile strength, Impact Strength and Flexural Strength. Also, Solid modeling of Leaf Spring is achieved the use of Solid Works 2014 and FEA is carried out the use of ANSYS 16.2. Results are documented, in contrast and discussed. From this the Weight of Steel EN45 Leaf Spring is 17.262 Kg and Weight of Carbon/Glass Composite Leaf Spring is 3.672 Kg. the share weight reduction also 78.73%.

Joo-teck Jeffrey et al. [20] this paper investigated the static and fatigue behaviors of metal and composite multi-leaf spring the use of the ANSYS V12 software. The dimensions of modern-day traditional leaf spring of a light passenger vehicle have been used. The equal dimensions have been used to diagram composite multi-leaf spring for the two materials, E-glass fiber/epoxy and E-glass fiber/vinyl ester, which are of amazing activity to the transportation industry. Main consideration used to be once given to the consequences of fabric composition and its fiber orientation on the static and fatigue behaviors of leaf spring. The plan constraints were bending stresses, deflection and fatigue life, Compared to the steel leaf spring, the designed composite spring has a lot minimize bending stresses and deflections and larger fatigue lifestyles cycles.

The other study by Misganaw A. [8]. In his study, modeling and static analysis of carbon/epoxy composite mono leaf spring was achieved by evaluating the traditional steel leaf spring which is used through Damas II a 4 wheeled light vehicle. The important thought in the back of this work is to replace the current steel leaf spring fabric with a mono laminated carbon/epoxy composite leaf spring with equal width, thickness and load carrying capacity. In this study, the major investigation is learn about to minimize the weight of product whilst upholding its strength. The prominence of the paper used to be to diagram and analysis of quasi isotropic laminated carbon/epoxy composite fabric leaf spring suspension system. Then this find out about seeks to address, improve load carrying potential and designing less stressed, less deformed and mild weight composite leaf spring, which have better performance than that of the present Damas II car steel leaf spring. The composite material which is carbon fiber with a volume fraction of 60% and the matrix material is epoxy with a quantity fraction of 40%, by using the use of the two materials making a quasi-isotropic composite laminate with angle of orientation [45^0, 0^0, 0^0, -45^0, 90^0, 90^0, -45^0, 0^0, 0^0, 45^0] T. The work additionally offers center of attention on the software of FEA idea to evaluate two substances of the leaf spring. The two substances used for comparisons are; the present Damas II automobile conventional steel leaf spring and mono quasi isotropic laminated carbon/Epoxy composite leaf spring. In this study complete deflection and equal (Von misses) stresses brought on in the two leaf springs are performed on ANSY 16 workbench have been compared. The solid modeling of leaf spring used to be completed on CATIA V5 R19 and analysis using ANSYS software. Finally, standing from the static analysis result the find out about conclude that the newly designed carbon/epoxy mono composite leaf spring has higher overall performance than that of the cutting-edge conventional metal leaf spring of Damas II car.

Moreover, the study of J. M. Corum et al.[17] affords basic in-air record property and correlations-tensile, compressive, shear, tensile fatigue, and tensile creep-for a reference carbon-fiber composite being characterized as a part of the Durability of Carbon-Fiber Composites Project at Oak Ridge National Laboratory. The overall goal of the project, which is backed with the aid of the Department of Energy's Office of Advanced Automotive Materials and is intently coordinated with the Advanced Composites Consortium, is to boost durability-based plan guidance for polymeric composites for car structural applications. The composite addressed right here is a 45 pass ply consisting of non-stop Thomel T300 fibers in a Baydur 420 IMR urethane matrix. Basic tensile, compressive, and shear residences are tabulated for the temperature range from -40 to 120^0C. Fatigue response at room-temperature and 120°C are presented, and creep and creep rupture at room temperature only are reported. In all cases, two fiber orientations-0/90 degree and -45/+450 -relative to the specimen axes are addressed. The properties and correlations are interim in nature. They are supposed as a baseline for planning a full sturdiness test application on this reference composite [22].

2.5. Summary and Evaluation of the Literature.

From the literature discussed so far about composite materials it is a clear understanding of the developments of composite materials as well as the related design and manufacturing technology is one of the most important advanced materials for the current and future generation vehicle. as stated earlier many composites exhibit greater resistance to wear, corrosion, high temperature, more lightness, tough and stiff this unique characteristic provides the mechanical engineer and designer of automotive and aircraft components additional opportunities rather than concentrates only on the conventional materials. From the observation of the review, there are a lot of composite materials are available for different structural applications. Doing different studies using these materials the researchers obtain a considerable result on the reduction of weight, reduction of consumption of fuel and reduction of environmental pollution, etc. but all composites do not provide the required results due to some undesirable properties of the reinforcement and matrix of the composite.

Therefore in order to reduce the drawbacks of the composite materials and obtaining optimized result which is better than the others, this study focus in analyzing different materials which have suitable properties for the application of structural designs regarding their weight, strength, fatigue resistance, deformation, different stress and cost. And from the list of different composite materials presented in the literature review the most suitable materials which satisfy the above properties and having a comparable mechanical and physical property is the glass fiber.

To get the best result on these selected composites different researchers and scientists declare some factors to give attention such as the number of reinforcement materials, fiber volume ratio, the orientation, and the stacking sequence of the layers. The most preferable fiber volume ration used for different industrial applications components are in the ranges of 50- 60% and the most recommended stacking sequence are quasi-isotropic and symmetric laminate. Finally, when trying to evaluate the gap based on each of the past work in different literature discussed so far. All most all the previous studies are focus on the three-wheeler and light vehicles by restricted on the analysis of the part only at static load conditions. Studies on these vehicle results for the reduction of weight and it may improve fuel consumption. But studies of leaf spring on these vehicles are not critical because most of these vehicles are designed for giving city service with driving on asphalt.so due to these considerations today light vehicle manufacturers launch and deliver these vehicles without leaf spring and they achieve the best performance for the intended service.in addition to this rather than leaf spring, it is much better to make studies on components like body, roof, and Buber, etc. it is more preferable regarding the application of city taxis. As understood that land cruiser vehicles are a multipurpose passenger car, they are used for various applications such as for ambulance for supporting patient and for tourist passenger in rural rea as well as in the city, hence for designing and optimizing the vehicle parts plays a crucial role for an engineers.

Chapter 3: Material, Method and Design

This part of the study presents the methods and materials used together with the design of the leaf spring.

3.1. Materials of Leaf Springs

As discussed all the imperative properties of substances in the literature assessment for deciding the desirable materials for the sketch of leaf spring. Then Composite substances are the first-rate substitutes for the current metal leaf spring. Due to their high strength-to-weight ratio, fatigue resistance, and natural frequency, the composite materials have been chosen for the study. Internal damping in the composite fabric leads to better vibration energy absorption within the material ensuing in decreased transmission of vibration noise to neighboring structures [9].so in accordance to the great properties of substances for the plan and comparative evaluation of leaf spring composite materials are chosen for this design.

3.1.1. Selection of reinforcement materials

Among the list of composite materials discussed in the literature review the Suitable materials which satisfies the basic design requirements of leaf spring are glass fibers. And the conventional material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon.so for this composite material leaf spring design, glass fiber is selected.

Table 3.1 Properties of Fiber (Reinforcement) Materials at 10 µm Fiber Diameter [8-14]

Glass fiber	
Density	2.45 g/cm^3
Longitudinal Tensile modules (E_1)	81 GPa
Transverse Tensile modules(E_2)	81 GPa
Poison ratio (n_{12})	0.22
Shear modules (G_{12})	30GPa
Longitudinal Tensile Strengths(σ_t)	3.450MPa
Compressive strength (σ_c)	0.45 GPa
Ultimate tensile strength(σ_u)	2500MPa

3.1.2. Selection of matrix

Reinforcement materials continually be counted on distinct kinds of matrix.so to get greater fatigue resistance, lower stress distribution on the designed components the reinforcement and matrix are well suited with every other. As mentioned in the literature session there are one of a kind sorts of matrix substances are accessible commercially for the structural design application. Among these materials, epoxy resin and polyesters resin are proper for the structural software and the most vital matrix for leaf spring layout is epoxy resin. Fiber-reinforced buildings commonly have the fibers, running in particular instructions to center of attention the reinforcement where it is wished and the epoxy keeps the fibers where they are needed. Although the principal cause of the epoxy matrix is to adhere to and transfer the masses to the fibers it is a strong material in its very own right [23]. It helps protect the fibers from damage and provides impact resistance.

Epoxy resin has the following advantage over the other types of matrix [24].

They have better adhesive properties, they have superior mechanical properties i.e. strength and stiffness, hey have better resistance to fatigue and micro cracking, they have well resistant to water penetration, Increased resistance to osmosis (surface degradation due to water permeability) Quantity of resin required, faster curing at room temperature and good chemical resistance properties.

Therefore, for this design epoxy resin is selected.

Table 3. 2 Properties of Epoxy Resin [27]

Property	Value
Density (g/cm^3)	1.2
Elastic modulus(*GPa*)	3.33
Tensile strength (*GPa*)	0.13
Shear modulus (*GPa)*	1.25
Poisson's ratio	0.33
Flexural yield strength (*GPa*)	0.125
Compressive strength(*GPa*)	0.19
Elongation at break	0.8
Glass transition temperature ^{0}c (*Tg*)	120-130

3.1.3. Selection of hardening

For Most structural application matrix are rely on hardening materials in order to launch without problems the manufactured elements from the mildew barring any scratch and cracks. This fabric is used for mold launch cause as a substitute than designing the parts.

Six hardeners are compared in this learn about and their residences are given in the table. For the hardeners trimethyl hexamethylene di amine, cyan ethylated combination of isomers (trimethyl hexane -1,6-diamine) (CTMDA) and isophorone diamine (IPDA), the long pot-life times necessitated the use of benzyl alcohol (density 1.04 g/ml and viscosity at 250^0c as an accelerator. So Trimethyl hexamethylene diamine is best for the structural application and has properly or easily releasing ability. The Properties of selected hardeners are is listed in **(**Table 3.3 Properties of Hardener) [18].

Table 3.3 Properties of Hardener [23]

Hardener (Aliphatic) Trim ethyl Hex Methylene Diamine	
Viscosity(*cp*)	6
Density(ρ)	0.97
Mole	58.3
Quantity(*g*)	40

3. 2. Conceptual Design

Composite materials are strong as discussed so far but material selections are not the only option for the optimization of the automotive structural application.it needs different design optimization concepts regarding the behavior of reinforcement and matrix of the composite. The following three design concepts are considered according to the specific requirements of the composite materials (fiber and matrix).

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

i. Stacking sequence of composite layers

Stacking sequence, angle of orientation of a composite layer are determined, the strength, stiffness, Rigidity and fatigue resistance capabilities. As mentioned in the literature there are different types of stacking patterns in composite design. As we know composite materials are stronger and stiffer in the direction of the fiber, so to get the best material properties (lower stress, higher strength, etc.) the applied load of the designed components should be applied in the direction of the fiber.so according to the requirements of the selected design, the preferable stacking sequence is determined.

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 3.1 of the S-N curve of both

{-45^0/+45^0} and {0^0/90^0} orientation the fatigue strength of {0^0/90^0} is better than {-45^0/+45^0} orientation. [20].

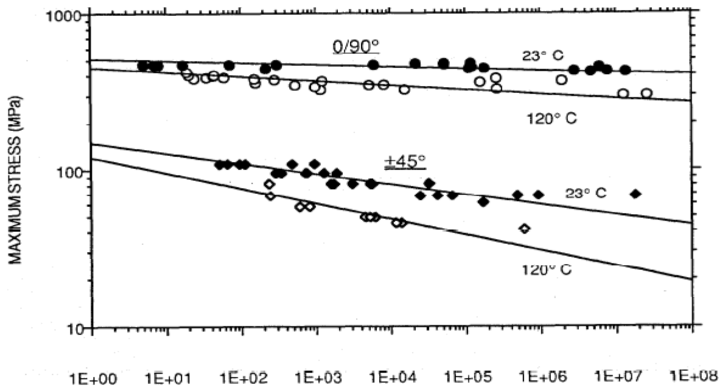


Figure 3.1 Comparison of (- 45/+45) Fatigue Curve with (0/90^0) Curves. [32]

the stacking pattern (0/90^0) is the best configuration as it can sustain maximum stress and minimum deflection and such stacking sequence can serve better than others for the same loading condition[21] .The boundary of the laminated composite is ± 45 this is why? Because to minimize the splitting force, which are occurring by vertical loading and during drilling of the leaf spring. [7].

Therefore, according to the current specific design requirements and the experimental evidence which are done by the different researcher 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

$[45/0 / 90_2 / 0/90 / -\bar{45}]_S$, S ⇒ Symmetry

ii. Lamination types of composites.

Laminate design starts by selecting the set of ply angles relevant to a given application. Due to manufacturing constraints, the allowed ply orientations are reduced to a discrete set of angles such. As {0^0, ±15^0, ±30^0, ±45^0, ±60^0, ±75^0, 90^0}. Once the angles are selected, the total number of plies and proportion of each orientation in the laminate are set and a stacking sequence is chosen. Additionally, when designing structures comprising several zones of different thicknesses, thickness variations are obtained by dropping plies at specific locations. For both laminate stacking sequence design and ply-drop design, numerous guidelines apply, based on industry past experience from test and analysis [26].

Six laminate design guidelines are considered as a basis for the design of the different layers of most composite laminate structures in automotive and aerospace industry [27].

1. Symmetry Whenever possible, stacking sequences should be symmetric about the mid-plane.
2. Balance. Whenever possible, stacking sequences should be balanced, with the same number of + θ and - θ plies (θ ≠0 and θ ≠90)
3. Contiguity. No more than a given number of plies of the same orientation should be stacked together. The limit is set here to two plies.
4. Disorientation. The difference between the orientations of two consecutive plies should not exceed 45^0
5. 10% - rule. A minimum of 10% of plies in each of the 0^0, $\pm 45^0$ and 90^0 directions is required.
6. Damtol. No 0^0- ply should be placed on the lower and upper surfaces of the laminate.

Symmetry and balance guidelines aim at avoiding respectively shear-extension and membrane-bending coupled behaviors.

The different guidelines are really useful to the energy of the structure. They intention at averting matrix dominated behaviors (10% - rule) and feasible energy trouble due to unwanted failure modes such as free-edge delamination (disorientation) or propagation of transverse matrix cracking (contiguity). With principal load carrying plies shielded from the exposed floor of the laminates (damtol), the effect on strength of exterior scratches or surface ply delamination is reduced [26]. By considering the above design guide line regarding to the current specific design requirement quasi isotropic composite property is considered and the lamination design type is symmetric laminate.

Figure 3.2 describes about symmetric laminate composite structure. It has 10 layers of composite with different fiber angles arranged symmetrically. Generally it is known as quasi isotropic symmetric laminate

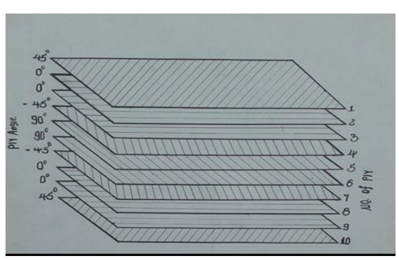


Figure 3.2 Symmetric Laminate [8]

The need of mid plain symmetry

One notes that a laminate has midline symmetry or is symmetric when the stacking of the plies on each facets starting from the middle plane is identical.

For the construction of laminated pieces, the successive impregnated plies are stacked at ambient temperature, then they are placed inside an autoclave for curing. At high temperature, the extension of the total laminate takes place except warping. However, for the duration of cooling, the plies tends to contract differently depending on their orientations. From this, thermal residual stresses occur. When midline symmetry is utilized, it imposes the symmetry on these stresses and prevents the deformations of the entire part, for example, warping as shown in figure bellow.

Figure 3.3 describes about the advantages and disadvantages of the symmetric lamination types of composite structure. The first figure is without the mid plane symmetry and due to this it is becomes bend in its structure. Whereas the second figure is with mid plane symmetry and it is not deform of bend because of symmetrical plane.

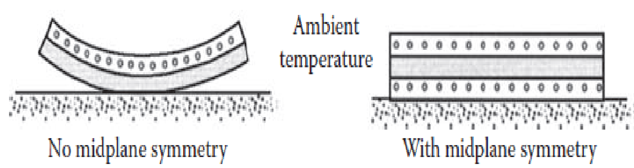


Figure 3. 3 Important of Mid Plane Symmetry [29]

Quasi isotropic laminates

Quasi isotropic laminate one that satisfies the following conditions

Three or more district fiber angles must be presented with the laminate. If m is the number of district fiber angles then m ≥3 [28].

Figure 3.4 describes abut types of lamination. The first figure has the same orientation angle and it indicates the lamination types of unidirectional. The second figure has different orientation angle symmetrically sequenced and it is known as quasi isotropic laminate.

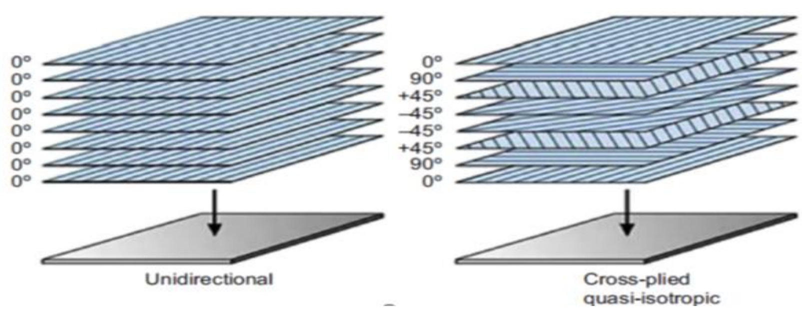


Figure 3.4 Unidirectional (left) and quasi Isotropic (right) laminate type [17]

iii. Composition of fiber and matrix (fiber matrix volume ratio)

In design, fabrication, and analysis of composite materials, the first and critical task is the determination of ingredient percentages such as fiber and matrix fraction presence in laminate. In which composites' strength and properties are determined and limited by these values [8]. The ratio of the reinforcement to the matrix can be determined through experience. It may be based on the volume ratio or weight ratio.

The experimental specimens are prepared using three molds to decide the proper amounts of the composition of fiber reinforcement for the design of composite structures. Basically, the three specimens are made by volume fraction of fiber and matrix. These are 40/60, 50/50, and 60/40 percent of reinforcement to matrices. This helps to decide the following points.

1. To make a strong bond between fiber and matrix
2. To minimize the overall weight of the leaf spring.
3. To minimize the brittleness of the leaf spring.

Then using the rule of mixture all the required parameters are calculated through the design phase

3.3. Methods and Design of Composite Leaf Spring

For the methods and the designs of composite mono leaf spring the following assumptions are considered.

- All layers have the same thickness.
- Laminae has different angle.
- All the reinforcement has the same size and strength
- Both the fiber and the matrix behave linearity up to failure.
- Fiber and matrix are individually to be isotropic

3.3.1. Mathematical modeling

The mathematical modeling is presented based on the assumption and specific requirements of the stated design parameters which applied to the selected structures. For composite material designation, the rule of mixtures is accounted in different mathematical modeling through this study.

3.3.2. Rule of mixture

Certain residences in multi-component material systems, along with composites, obey the “Rule of- Mixtures” (ROM). Properties that obey this rule can be calculated as the sum of the value of the property of each constituent increased via its respective extent fraction or weight fraction in the mixture. To calculate properties by way of the rule-of-mixtures, the quantity fraction or weight fraction of every constituent have to first be determined. According to [10]. In most fiber bolstered composite, the fiber is strong, stiff, and mild weight. If the composite is to be used at improved temperatures, the fiber need to have excessive melting temperature. Thus, unique energy and particular modulus of the fibers are necessary characteristic.

In composite structural design, it be cautious in the amounts of every constituent material. The resin and the hardener should be balanced. Based on the curing circumstance and the types of composite layout the weight or the extent fraction of the composites are varying. But the weight or quantity fraction of reinforcement to matrix ratio is no longer excessed. So, the usage of the rule of combination mathematical modeling is as follows.

Volume fraction of the fiber component is defined as (V_F):

$$V_F = \frac{V_f}{V_c} \tag{3.1}$$

Where, V_F = Volume fraction of fiber

$V_f = Volume\ of\ fiber$

$V_c = Volume\ of\ composite$

Volume fraction of the matrix component is defined as (V_M):

$$V_M = \frac{V_m}{V_c} \tag{3.2}$$

Where, V_M = Volume fraction of matrix

V_m = Volume of matrix

V_c = Volume of composite

Volume of composite = Volume fiber +Volume matrix

$$V_c = V_f + V_m\ , V_f + V_m = 1 = V_c \tag{3.3}$$

Weight fraction of the fiber is defined as (W_F)

$$W_F = \frac{W_f}{W_c} \tag{3.4}$$

Where, W_F = Weight fraction of fiber

W_f = Weight of fiber

w_c = Total weight of composite

Weight fraction of matrix is defined as (W_M):

$$W_M = \frac{W_m}{w_c} \tag{3.5}$$

Where, W_M= Weight fraction of matrix

W_m = Weight of matrix

w_c= Total weight of composite

The sum of volume fraction of reinforcement and matrix materials of composites are equal to one. So that, $V_c = V_f + V_m$, and $V_m = 1 - V_f$

Similarly, the sum of weight fraction of reinforcement and matrix material of composite are equals to one; $W_f + W_m = w_c = 1$, $W_m = 1 - W_f$

Composite Density:

The density of composites is the sum of weights of matrix and the weights of fiber in terms of density and volume fraction.so, by applying the definition of volume fraction, the density of composite is can be expressed as

$$\rho_c = \rho_f V_f + \rho_m V_m \tag{3.6}$$

Where ρ_c = Density of composite

ρ_f= Density of fiber

V_f = Volume of fiber

ρ_m= Density of matrix

V_m= Volume of matrix

Longitudinal and transverse properties:

According to rule of mixture (Rom) longitudinal and transvers properties of composites are can be determined as.

$$P_c = P_f V_f + P_m V_m \tag{3.7}$$

Where P_c= Properties of composite

P_f= Properties of fibers

P_m = Properties of matrix

$$\frac{1}{P_c} = \frac{V_f}{P_F} + \frac{V_m}{P_m} \tag{3.8}$$

Strain properties of composite and laminae

$$E_f = \frac{\sigma_f}{\varepsilon_f} \tag{3.9}$$

Where E_f = Modulus of elasticity of fibers

σ_f = Stress of fibers

ε_f = Strain of fiberes

Mathematical modeling of effective elastic constant:

$$\frac{1}{E_x} = \frac{\cos^4\theta}{E_1} + \frac{\sin^4\theta}{E_2} + (\frac{1}{G_{12}} - 2(v12)\cos^2\theta\sin^2\theta \tag{3.10}$$

Mathematical modeling of Composite young's modulus in longitudinal and transverse direction respectively:

$$\left(E_L = \frac{\text{No } 0^0 \text{ plays}}{\text{total No plays}} * \text{E of } 0^0 \right) + \left(\frac{\text{No } 45^0 \text{ plays}}{\text{total No plays}} \text{ E of} 45^0 \right) \tag{3.11}$$

$$\left(E_t = \frac{\text{No } 90^0 \text{ plays}}{\text{total No plays}} * \text{E of } 90^0 \right) + \left(\frac{\text{No } 45^0 \text{ plays}}{\text{total No plays}} \text{ E of} 45^0 \right) \tag{3.12}$$

Mathematical modeling of total weight of vehicle:

The Total Weight of the vehicle is can be expressed as the sum of the load of vehicle plus load of passenger plus load of on cargo capacity.ie.

$$M_{total} = m_v + n*m_p + C_l \tag{3.13}$$

$$W_{total} = M_{tota}\, g \tag{3.14}$$

W_{tota} = Total load capacity of the vehicles

C_l = Cargo capacity

M_{total} = the total mass induced in the vehicle

m_v = Single mass of the vehicle

m_p = Mass of passengers

n = Number of passengers

g = Acceleration due to gravity

Mathematical modeling for Cross section of leaf spring:

There are different sorts of Cross part in the design consideration of leaf spring. These are

1. Constant thickness, various width design
2. Varying width, various thickness design.
3. Constant thickness, regular width design

1. Constant thickness, various width design: Constant thickness, various width design: In this kind of design, the thickness of the complete leaf spring is continues regular but the width

has variations. That is the width is minimal at the two ends of leaf spring and maximum at the centers.

2. Varying width, varying thickness design: In this sketch the width is kept consistent over the complete size of the leaf spring while the thickness varies from a minimum at the two ends to a maximum at the center.
3. Constant thickness, regular (constant) width design: In this case the cross-sectional region of the entire length of leaf spring is stay constant. From the three recommended layout sorts of leaf springs this types of cross-section design is chosen for the modern-day research due to the following reasons.
   - Its functionality for mass production
   - Accommodation of continuous reinforcement of fibers
   - Since the cross-section location is regular at some stage in the leaf spring, the identical quantity of reinforcement and resin can be fed consistently throughout manufacturing [5].

The axle of the car is installed on the center of leaf spring the use of U-bolts and the two ends are connected to the chassis of the vehicle. One end is through the chases farm and the different end is through its shackle. And leaf spring is extra subjected to bending stress at the center. Due to this the static and fatigue analysis is performed on basis of this loads. Consider a single plate as flat leaf spring and loaded as the free end.

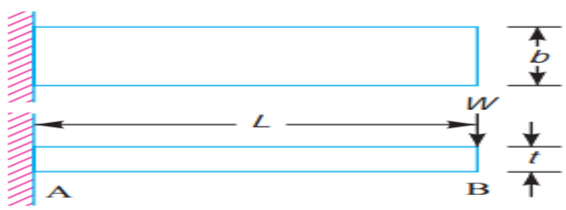


Figure 3.5 Leaf spring cross section [6]

The maximum bending moment at the end of the cant leaver beam is [16]

$$M = W\,L \qquad (3.15)$$

Section modulus (Z) = $\frac{I}{Y} = \frac{bt^3 * 2}{12 * t}$, since fore rectangular cross section I = $\frac{bt^3}{12}$

Then Z = $\frac{bt^2}{6}$, where b = width and t= thickness respectively

$$\text{Bending stress } \sigma_t = \frac{M}{ZY} = \frac{6WL}{bt^2} \qquad (3.16)$$

Maximum deflection for cant lever structure applied load at the free end is given by

$$\delta = \frac{WL^3}{3EI} = \frac{4WL^3}{Ebt^3} \qquad (3.17)$$

Where, I= Moment of inertia

E = Young's modulus of the materials

W = Load of the vehicle

L = Distance of the load from the cant leaver end

b = Width of leaf springs

t = thickness of leaf spring

$$I_x = \sum I_x' + Ad^2 \tag{3.18}$$

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

$I_{x'}$ = 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

$$Y_{bar} = \frac{\sum Ay}{\sum A} \tag{3.19}$$

Where Y_{bar} = the centroid of the whole structure

A = the area of each leaf spring

y = the centroid of each leaf spring

$$y_1 = \frac{t_1}{2} + \sum_{t=2}^{6} t \tag{3.20}$$

Where t= thickens of leaf springs

Mathematical modeling of fatigue loadings:

$$\text{Mean stress } \sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} \tag{3.21}$$

$$\text{Reversed stress components } \sigma_v = \frac{\sigma_{max} - \sigma_{min}}{2} \tag{3.22}$$

$$\frac{1}{F_s} = \frac{\sigma_m}{\sigma_{u\,min}} + \frac{\sigma_v}{Se'} \tag{3.23}$$

$$\sigma_a = \sigma_{f'}(2N)^{b} \tag{3.24}$$

Where σ_a = Stress amplitude (alternating stress)

2N = Number of reversals to failure (1cycle = 2 reversal)

$\sigma_{f'}$ = Fatigue strength coefficient

b = Fatigue strength exponents (basuins exponents)

$$\sigma_a = \sigma_{ut} - b*\log N \tag{3.25}$$

Where, σ_a = Maximum amplitude stress (alternating stress)

σ_{ut} = Ultimate strength of the given materials

b = Constant

N = Number of cycles to fail

3.3.3. Design of composite materials

Properties of E-Glass fiber:

For this design of the composition of the composite are 60% reinforcement and 40% of matrix.

Density of E-glass composite

The density of composites are determined using equation 3.6 as

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

$$\rho_c = 2.45 g/cm^3 * 0.6 + 1.2 g/cm^3 * 0.4 = 1.975 g/cm^3$$

Longitudinal and transverse properties:

According to rule of mixture (ROM) longitudinal and transvers properties of composites are can be determined.

1. **Longitudinal modulus(E_1)**

   According to the general formula (3.7) the longitudinal modulus can be determined

$$E_1 = E_f V_f + E_m V_m$$

$$E_1 = 81*0.6 + 3.33*0.4 = 50 Gpa$$

2. **Transvers modulus (E_2) is determined using equation 3.7 as follow**

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

$$\frac{1}{E_2} = \frac{0.6}{81\ Gpa} + \frac{0.4}{3.33 Gpa} \Rightarrow E_2 = 8.1433 Gpa$$

3. **Major poisons ratio (V_{12})**

$$V_{12} = V_F V_f + V_M V_m$$

$$V_{12} = 0.22*0.60 + 0.33*0.4 = 0.26$$

4. **Transverse shear modulus (G_{12})**

$$\frac{1}{G_2} = \frac{V_f}{G_f} + \frac{V_m}{G_m}$$

$$\frac{1}{G2} = \frac{0.6}{30 Gpa} + \frac{0.4}{1.25 Gpa} \Rightarrow G_{12} = 3.08 Gpa$$

5. **Longitudinal shear modulus(G_{12})**

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

$$G_{12} = 0.6*30 + 0.4*1.25 \Rightarrow G_{12} = 19.07 Gpa$$

Strain properties of composite and layers:

The properties of strains are determined using equation 3.9 as follow

$$E_f = \frac{\sigma_f}{\epsilon_f} \Rightarrow \epsilon f = \frac{\sigma f}{E f}, \ \frac{3.45Gpa}{81GPa} = 0.0425 \text{ and}$$

$$\epsilon_m = \frac{0.13GPa}{3.33GPa} = 0.04$$

$$\epsilon_c = \epsilon_f V_f + \epsilon_m V_m$$

$$\epsilon_c = 0.0425 * 0.6 + 0.04 * 0.4 = 0.0415$$

Determination of strength properties of each layer:

1. Tensile strength of single layers in longitudinal direction

Using the general formula of equation 3.7 properties in longitudinal directions are determined as

$$\sigma_{tL} = \sigma_{tf} V_f + \sigma_{tm} V_m \ , \sigma_{tL} = 3.45*0.6+0.13*0.40$$

$$\sigma_{tL} = 2.1GPa$$

2. Tensile strength of single layers in transverse direction

According to equation 3.7 transverse properties are determined as $\frac{1}{\sigma tt} = \frac{V_f}{\sigma_{tf}} + \frac{V_m}{\sigma_{tm}}$

$$\frac{1}{\sigma_{tt}} = \frac{0.6}{3.45} + \frac{0.4}{0.13} \Rightarrow \sigma_{tt} = 0.307$$

3. Compressive strength of single layer in longitudinal direction

$$\sigma_{cL} = \sigma_{cf} V_f + \sigma_{cm} V_m$$

$$\sigma_{cL} = 0.45*0.6+0.19*0.4$$

$$\sigma_{cL} = 0.35GPa$$

4. Compressive strength of single layer in transverse direction

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

$$\frac{1}{\sigma ct} = \frac{0.6}{0.45} + \frac{0.4}{0.19} = 3.37$$

$$\sigma_{ct} = 0.29 \text{ Gpa}$$

3.3.4. Determination of effective elastic constant

The elastic constants are can be determined using the following general formula stated in equation 3.10.

$$\frac{1}{E_x} = \frac{\cos^4\theta}{E_1} + \frac{\sin^4\theta}{E_{12}} + (\frac{1}{G_{12}} - 2(v12)\cos^2\theta\sin^2\theta$$

From the sacking sequence of the plays we have the following values.

Number of 0^0 = 4

Number of 45^0 = 2

Number of 90^0 = 7

For θ = 0^0

$$\frac{1}{E_x} = \frac{1}{50} + 0 + 0 \Rightarrow E_x = 50Gpa$$

For θ = 45^0

$$\frac{1}{E_x} = \frac{0.25}{50} + \frac{0.25}{8.143} + (\frac{1}{3.08} - 2\left(\frac{0.22}{50}\right) 0.25$$

$$E_x = 5.9Gpa$$

For θ = 90^0

$$\frac{1}{E_x} = 0 + \frac{1}{8.14} + 0 \Rightarrow E_x = 8.14$$

Using the above values determine young modulus of each plays in x and y direction.

Composite young's modulus in longitudinal direction

According to equation 3.11, $\left(E_L = \frac{\text{No } 0^0 \text{ plays}}{\text{total No plays}} * \text{E of } 0^0\right) + \left(\frac{\text{No } 45^0 \text{ plays}}{\text{total No plays}} \text{ E of} 45^0\right)$

$$\frac{4}{13} * 50 + \frac{2}{13} * 5.91 \Rightarrow E_L = 16.75GPa$$

Composite young's modulus in transverse direction:

$$\left(E_t = \frac{\text{No } 90^0 \text{ plays}}{\text{total No plays}} * \text{E of } 90^0\right) + \left(\frac{\text{No } 45^0 \text{ plays}}{\text{total No plays}} \text{ E of} 45^0\right)$$

$$\left(E_t = \frac{7}{13} * 8.14\right) + \left(\frac{2}{13} \ 5.91\right) = 5.3GPa$$

Calculation of strength of compost:

1. **Tensile strength:**

Using equation 3.10 tensile strength can be determined as

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

For θ = 0^0

$$\frac{1}{\sigma_t} = \frac{1}{2.139} + 0 + 0 \Rightarrow \sigma_t = 2.1Gpa$$

For θ = 45^0

$$\frac{1}{\sigma_t} = \frac{0.25}{2.13} + \frac{0.25}{0.32} + \left(\frac{1}{3.08} - 2\frac{(0.22)}{2.1}\right)0.25$$

$$\Rightarrow \sigma_t = 1.072\text{GPa}$$

For θ = 90^0

$$\frac{1}{\sigma_t} = 0 + \frac{1}{0.32} + 0 \;\Rightarrow\; \sigma_t = 0.32Gpa$$

2. Longitudinal tensile strength of composite

$$\sigma_{tl} = \frac{4}{13} * 2.1 + \frac{2}{13} * 1.072 \;\Rightarrow\; \sigma_{tl} = 0.823Gpa$$

3. Transverse tensile strength of composite

$$\sigma_{tt} = \frac{7}{13} * 0.32 + \frac{2}{13} * 1.072 \;\Rightarrow\; \sigma_{tt} = 0.337Gpa$$

Compressive strength of composite

For θ = 0^0

$$\frac{1}{\sigma_c} = \frac{1}{0.35} + 0 + 0 \;\Rightarrow\; \sigma_c = 0.35Gpa$$

For θ = 45^0

$$\frac{1}{\sigma_c} = \frac{0.25}{0.35} + \frac{0.25}{0.296} + \left(\frac{1}{3.08} - 2\frac{(0.22)}{0.35}\right)$$

$$\Rightarrow \sigma_c = 1.6\text{Gpa}$$

For θ = 90^0

$$\frac{1}{\sigma_c} = 0 + \frac{1}{0.296} + 0 \;\Rightarrow\; \sigma_c = 0.29Gpa$$

4. Longitudinal and transverse compressive strength of composite

$$\sigma_{cl} = \frac{4}{13} * 0.35 + \frac{2}{13} * 1.6 \;\Rightarrow\; \sigma_{cl} = 0.3538Gpa$$

$$\sigma_{ct} = \frac{7}{13} * 0.296 + \frac{2}{13} * 1.6 \;\Rightarrow\; \sigma_{ct} = 0.405Gpa$$

Table 3. 4 Calculated Values of Glass Fiber

Materials properties	**Values in (*GPa*)**
Young's modulus in x direction (E_x)	16.75
Young's modulus in y direction(E_y)	16.75
Young's modulus in z direction (E_z)	5.3
Tensile strength in x direction(σ_{tx})	2.139
Tensile strength in y direction(σ_{ty})	2.139
Tensile strength in z direction(σ_{tz})	0.32
Compressive strength in x direction(σ_{cx})	0.35
Compressive strength in y direction (σ_{cy})	0.35
Compressive strength in z direction (σ_{cz})	0.296
Shear modulus in x direction (G_{12x})	19.07
Shear modulus in y direction (G_{12y})	3.08
Major poisons ratio (V_{12})	0.262
Strain of composite(ε_c)	0.0415
Density (ρ_c)	1.975 *g/cm*^{3}

3.3.5. Dimension specification of Toyota land cruiser passenger vehicles

Table 3.5 Manufacturer Specification of Toyota Land Cruiser Vehicle Leaf Spring of Land Cruiser Vehicle

Parameters	Value in(*cm*)
Length of first leaf	143
Length of 2nd leaf	141
Length of 3rd leaf	116
Length of 4th leaf	105
Length of 5th leaf	95
Length of 6th leaf	57
Width (equal for each) leaf	7
Thickness (equal for each) leaf	0.8
Width of U-bolt	12

Table 3. 6 Basic specification data of selected vehicle [30]

Specification data of selected vehicle	
Features	values
Brand of the vehicles	Toyota land cruiser
Model of the vehicle	H2376D-RkmRs
Number of doors	4
Mass of the vehicle	1400kg
Number of leaf spring in the vehicle	6
Number of seats	8
The Average mass of one person	80kg
Total mass of passengers	640kg
Capacity of the car go	200kg
Total mass	2240kg
Acceleration duo gravity (g)	$10m/s^2$

Factor of safety fore suspension system design is from1.3-2.25[7]. Then for this design and analysis take 1.8

Total weight induced to the vehicle became 2240gk *10m/s^2*1.8= 40320N there fore

$$\text{Weight} = 40320\text{N}$$

Since the vehicle is four-wheeler and the load are exerted to four side equally then it can be taking a single side of leaf spring corresponding to one of the wheels so it should be $\frac{1}{4}$ of total weight of the vehicle so

$$W = \frac{40320\text{N}}{4} = 10080\text{N}$$

Fore keeping the analysis time short and a single master leaf has two eyes so, the load acting in each leaf eye becomes 5040N.as observed from the selected vehicle it has a total of six leaf springs are mounted on the axle of land cruiser by direct measuring these six leaf spring all the necessary dimensions are listed as follows.

Length of first leaf = 143 *cm*

Length of second leaf spring = 141*cm*

Length of third leaf = 116cm

Length of fourth leaf spring = 105*cm*

Length of fifth leaf spring = 95*cm*

Length of sixth leaf spring = 57*cm*

Width of leaf spring =7*cm*

Thickness of leaf springs = 0.8*cm*

Camber of leaf spring = *8cm*

Length of U clamp =100*mm*

Eye bore diameter = 3*cm*

Table 3. 7 Properties of Steel Material [18].

Mechanical properties of structural steel	
Property	Values
Ultimate tensile strength (σ_t)	1272MPa
Tensile yield strength (σ_y)	1158MPa
Compressive yield strength (σ_c)	1158MPa
Modulus of elasticity (E)	$2.1*10^5 N/mm^2$
Shear modulus (G)	$7.69*10^9$MPa
Density (ρ)	$7850kg/m^3$
Poisons ration(v)	0.266
Shear strength of steel(τ)	1470Mpa
Flexural strength of steel (σ_b)	653Mpa

3.3.6. Determination of weight

1. **For conventional structural steel leaf sprig**:

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \rho = \frac{M}{V} \quad (3.26)$$

$$W = Mg$$

Where W = Weight of leaf sprig

ρ = Density of structural steel = *7850kg/m*^{3}

$$\text{Volume of any leaf spring} = L*t*b \quad (3.27)$$

Using the above relation, we can determine weight of the individual leaf spring

$$V_1 = 1.43m*8*10^{-3}m*0.07m = 8.008*10^{-4}m^3$$

$$W_1 = \rho* V_1*g$$

$$7850kg/m^3*8.008*10^{-4}m^3*10m/s^2 = 62.86N$$

$$W_1 = 62.86N$$

$$W_2 = 62N$$

$$W_3 = 51N$$

$W_4 = 46.16N$

$W_5 = 41.76N$

$W_6 = 25N$

$W_{total} = W_1+W_2+W_3+W_4+W_5+W_6$

$= 62.86N + 62N + 51N + 46.16N + 41.76N + 25N$

$W_{total} = 288.78N.$

2. For glass epoxy composite materials leaf spring

The same as that of conventional steel leaf spring it can be determine the weight of the unconventional Glass / Epoxy composite leaf spring easily

$V_1 = 1.43m*0.0455m*0.07m$

$V_1 = 4.55*10^{-3}m^3$

$W = \rho* V_1*g$

$= 2450kg/m^3*4.55*10^{-3}m^3 10m/s^2$

$W = 111.6N$

Weight of composite (W_c) = $111.6N$

There are a big difference between the weight of E-glass fiber composite material leaf spring and a steel leaf spring. Now determine weight saved between the two materials

Weight saved using E – glass fiber material = 288.78N -111.6N = 177.18N

Percentage (%) weight saved = $\frac{177.18}{288.78N} * 100$ =61.33%

Therefore, by using E- glass fiber composite leaf spring 61.33 % of the vehicle weight is reduced and the E –glass / epoxy composite materials strong and very light.

3.3.7. Determination of stress and deflection of conventional steel

There are two way to mount leaf spring on the axel. According to [7].

1. **Mounting using bands**: in this case the effective length of the leaf spring is calculated by

$$2L = 2L_{total} - l \quad (3.28)$$

Where 2L = Effective lengths of leaf spring

$2L_{total}$ = Total length of leaf spring

l = Length of U- bolt or band

2. **Mounting using U- bolts:** in this case the effective length of the leaf spring is determined by using

$$2L = 2L_{total} - \frac{2}{3} l \quad (3.29)$$

For the Toyota land cruiser passenger vehicle leaf spring is mounted on the axel by the U- bolt for this case the second formula is employed

$$2L = 2(1.43m) - \frac{2}{3}(0.12m)$$

$$2L = 2.78\ m$$

$L = 1.39m$ half effective length of leaf spring

The same for composite also

Bending stress of conventional steel leaf spring:

We see that a spring such as automobile spring (semi-elliptical spring) with length 2L and loaded in the center by a load 2W, may be treated as a double cantilever According to [7]. The bending stress and deflection of the conventional steel and composite material leaf springs are determined as follow.

Using the equation 3.16, bending stress of steel leaf spring can be determined as

$$\sigma_b = \frac{6WL}{n\ bt^2}$$, Where n is No of leafs

$$\sigma_b = \frac{6*5040N*1.39m}{6*0.07m*(0.008m)^2} = 1563N/mm^2$$

Deflection of conventional steel leaf spring:

The maximum deflection of the cantilever beam at the loaded end is given by the equation 3.16 as follow, $\boldsymbol{\delta} = \frac{WL^3}{3EI}$

Before calculating the deflection of existing conventional steel leaf spring, it should determine the values of the area moments of inertia of steel leaf spring. As we see from the following figure the shapes of conventional steel leaf spring is not uniform due to the presence of different graduated springs.

Figure 3.6 represents conventional steel multi leaf spring.it contains different size metal strips. The longest leaf is known as master leaf and the remains are graduating leaf.

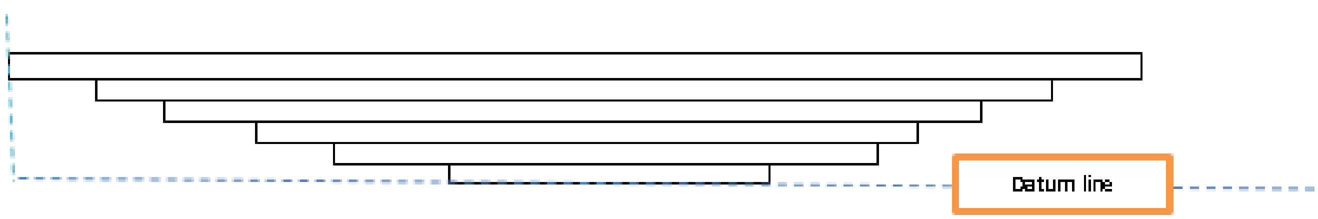


Figure 3. 6 Cross-Section of Conventional Steel Leaf Spring

As you see the shapes of laminated steel leaf spring is no equal and uniform so the moments of inertia is no determined as a single body, so To determine the moments of inertia for such kinds of structure it is better to consider as the composite (multi) bodies and use the concepts of strength of materials like parallel axis theorem for determining of accurate values of moments of inertias of the steel leaf spring by using equation 3.18 is expressed as follow

$$I_x = \sum I_x' + Ad^2.$$

Before applying the parallel axis theorem (equation above) determine the centroid of the whole structure. Using equation 3.19, $Y_{bar}= \frac{\sum Ay}{\sum A}$ and equation 3.20, $y_1= \frac{t_1}{2}+\sum_{t=2}^{6} t$

The calculated data using equations (3.18-3.20) are presented in (Table 3. 8 Calculate Tabular Data of Moments of Inertia)

Table 3. 8 Calculate Tabular Data of Moments of Inertia

Y(*m*)	A(m^2)	y A(m^3)
0.00016	0.1144	0.0000018
0.030	0.0113	0.0004
0.028	0.00938	0.00026
0.02	0.084	0.000168
0.012	0.0076	0.0000912
0.004	0.00456	0.00001824
0.10016	0.23	0.000939

$$Y_{bar}= \frac{\sum Ay}{\sum A} = \frac{0.00939}{0.23} = 0.00408\text{m} = 4.08\text{mm}$$

Then using the parallel axis theorem

$$I_x = \frac{1}{12}(285 * 8^3) + (2280 * 0.08^2) + \frac{1}{12}(475 * 8^3) + (3800 * 7.92^2) + \frac{1}{12}(525 * 8^3) + (4200*15.92^2) + \frac{1}{12}(580 * 8^3) + 4640 * 23.92^2) + \frac{1}{12}(705 * 8^3) + 5640 * 31.92^2 + \frac{1}{12}(715 * 8^3) + 5720 * 39.92^2)$$

$$I_x = 1.894*10^7 mm^4$$

$$\delta = \frac{10080*1390^3}{3*45*10^3*1.894*10^7} = 10.9mm$$

3.3.8. Determination of Stress and deflection of E- Glass/ Fiber

Using the equation (3.16) the maximum bending stress of E-glass fiber composite materials leaf spring is determined as,

$$\sigma_b = \frac{6WL}{bt^2} = \frac{6 * 5040N * 1.39m}{0.07m * (0.0455m)^2} = \frac{290N}{m^2}$$

Deflection of E-glass fiber composite leaf spring:

The deflection of the *composite mono leaf spring is determined using the equation (3.17)*

$$\delta = \frac{WL^3}{3EI} = \frac{2.707*10^{13}}{3*81*10^3*\left(\frac{(1430*45.5^3)}{12}\right)} = 9.92mm$$

3.4. Fatigue Failure:

Often machine members are discovered to have fail under the motion of repeated or fluctuation stress; but the most cautious analysis revels that the proper most stress have been nicely below the ultimate energy of the materials, and quite often even bellow the yield energy .the most exclusive traits of these screw ups are that the stress have been repeated every massive variety of time, subsequently the failure is referred to as fatigue failure [5].

It has been estimated that fatigue contributes to about 90% of all service screw ups due to mechanical causes. Fatigue is a trouble that can affect any phase or component that moves. Automobiles on roads, plane wings and fuselages, ships at sea, nuclear reactors, jet engines, and land-based turbines are all issue to fatigue failures [25].

3.4.1. Fatigue analysis of leaf spring

Since Leaf springs are one of the members of car suspension device and mainly it faces repeated masses .this repetition of stresses in giant wide variety of time effects fatigue failure .when a member (part) fail statically commonly develop very large deflection, due to the fact the stress has exceeds the yield strength and the part is exchange before fracture is in reality occurred. Thus, many static screw ups give seen warning in advance. But fatigue failure offers no warning, it is a catastrophic (sudden) failure and hence it is dangerous [5]. Even crack imitation and crack growths are degrees of fatigue failure however these are happened in micro shape scales. Fatigue happens when a material is subjected to repeat loading and unloading. If the masses are above a sure threshold, microscopic cracks will start to layout the stress concentrators such as the surface, power slip bands (PSBs); and obtain interfaces. Eventually a crack will reach a vital size, the crack will propagate suddenly, and the structure will fracture. The structure of the shape will significantly affect the fatigue life, rectangular holes or sharp corners will lead to evaluated neighborhood stresses where fatigue cracks can initiate. Round holes and easy transitions or fillets will therefore expand the fatigue power of the structure [30].

A frequent reason of structural fracture, fatigue failure takes place due to the fact of cyclic loading. In essence, fatigue damage progresses in two stages; the crack initiation stage, in which one or greater small cracks begin to structure in the material, and the crack growth stage. In the crack increase stage, the preliminary crack propagates till it consequences in the failure of the structural material. Avoiding fatigue failure is a critical precept in the graph of buildings that are uncovered to cyclic loading and vibration. Fatigue can be categorized as one of two sorts depending on the variety of load cycles prior to failure. High-cycle fatigue failure outcomes after millions of load cycles. Failures ensuing from a decrease number of load cycles, lots or less, are low-cycle fatigue failures. In low-cycle fatigue, the deformations due to load are typically plastic, whereas high cycle fatigue deformations are elastic [30]. As a result of cyclic stress or the initiation and subsequent growth of cracks or growth from preexisting defects till it reaches indispensable size fatigue disasters happens in three stages.

1. Crack initiation
2. Crack propagation
3. Catastrophic over load screw ups

The part can fail even although stresses are not those high. Over time, fatigue cracks can begin and then develop massive adequate to reason surprising failure. The duration of every of these three phases depends on many factors together with indispensable uncooked fabric characteristics, magnitude and orientation of utilized stresses, processing history, etc. Fatigue failure ups frequently end result from utilized stress stages drastically below those quintessential to purpose static failure [30].

Fatigue failures are typically characterized as either low-cycle (<1,000 cycles) or high-cycle (>1,000 cycles). The threshold fee dividing low- and high-cycle fatigue is somewhat arbitrary, but is usually primarily based on the raw materials conduct at the microstructural degree in response to the applied stresses. Low cycle failures typically contain full-size plastic deformation. An instance would be reversed 90° bending of a paperclip. Gross plastic deformation will take location on the first bend, however failure will not occur until about 20 cycles. Plastic deformation does play a position in high cycle fatigue; however, the plastic deformation is much localized and now not always discernable by way of a macroscopic contrast of the component. In summary, whilst a valve spring dressmaker might also think about a failure at 10,000 cycle's very quick life, the failure can still be the result of high-cycle fatigue due to the fact the material response at the microstructural level is the identical as in a 10,000,000-cycle failure under lower applied stresses .Most metals with a physique centered cubic crystal shape have a characteristic response to cyclic stresses. These materials have a threshold stress limit beneath which fatigue cracks will no longer initiate. This threshold stress value is regularly referred to as the staying power limit. In steels, the life related with this conduct is normally usual to be 2 cycles. In other words, if a given stress kingdom does not induce a fatigue failure within the first two cycles, future failure of the thing is considered unlikely. For spring applications, a greater realistic threshold life cost would be two cycles. Metals with a face center cubic crystal structure (e.g. aluminum, austenitic stain much less steels, copper, etc.) do not commonly have an endurance limit. For these materials, fatigue existence continues to enlarge as stress stages decrease; however, a threshold restrict is no longer generally reached below which countless life can be predicted [30].

Figure 3.7 indicates that The S-N curve or sketch also known as Wohler curve is the plot of the fatigue power of a check specimen towards the variety of load cycles. The fatigue energy values are plotted in linear scale along the Y axis and the wide variety of loading cycles are plotted along X axis in logarithmic scale of the S-N curve. After the S-N diagram for a specific specimen is available, you can find the fatigue power for any precise range of loading cycles.

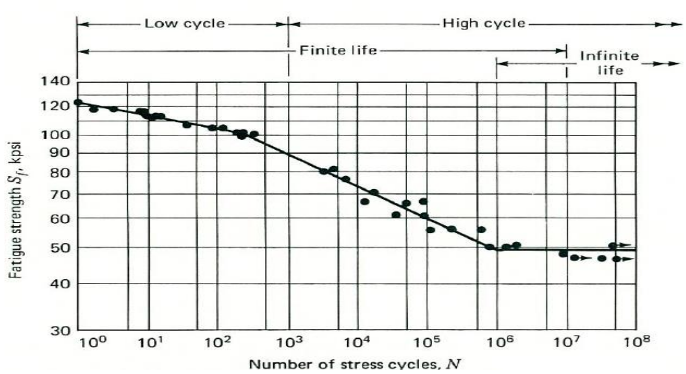


Figure 3.7 S-N Diagram plotted from completely reversed load fatigue test [32]

The cyclic version of stress produced through cyclic loading conditions influences the life of a structure. To consider their fatigue life, materials samples are generally exercised to failure via cyclically loading them to produce a continuously varying suggest stress. The amplitude of this imply stress is then recorded along with the variety of cycles to failure. From numerous checks protecting a vary of mean stress amplitudes, a stress-life format pertaining to stress amplitude (S_a) to wide variety of cycles to failure (N) can be produced for any given material. This S-N design is a vital and well known way of offering fatigue data. Another equal type of S-N format can be produced by way of plotting stress ratio with admire to the variety of cycles to failure [30].

3.4.2. Approaches of fatigue failure in analysis and design

There are different types of approaches for fatigue failure of mechanical components. The most widely applied for the investigation of failures of parts are fatigue life methods.

Fatigue life methods:

Three predominant approaches used in diagram and analysis to predict when, if ever, a cyclically loaded machine factor will fail in fatigue over a period of time are presented. The premises of every method are pretty exceptional however each provides to our perception of the mechanisms related with fatigue**.**

These three major fatigue existence strategies used in sketch and evaluation are the stress-life method, the strain-life method, and the linear-elastic fracture mechanics method. These methods try to predict the life in wide variety of cycles to failure, N, for a particular level of loading [26]. From these the stress-life method, based on stress stages solely is utilized for the existing study.

3.4.3. The Stress-Life Method

To determine the strength of materials under the action of fatigue loads, specimens are subjected to repeated or varying forces of specified magnitudes while the cycles or stress reversals are counted to destruction.

Stress based fatigue life prediction of existing steel leaf spring:

One basic idea behind fatigue testing is constant amplitude loading, that is, fatigue loading in which the applied cyclic load is sinusoidal shaped and of constant amplitude and frequency. The load cycle is the smallest repeating period of the resulting mean stress history. For local stresses, σ_a is stress amplitude and σ_m is mean stress. σ_{max} is maximum stress, and σ_{min} is minimum stress. The load cycle is noted mathematically as $\sigma_m \pm \sigma_a$. Tensile stresses have positive values, and negative values are compressive stresses. According to this notation and considering the sign convention, the following equations for maximum, mean, and minimum stress can be expressed. [30]. the variable stress, in general may be considered as a combination of steady (mean) or average stress and completely reversed stress components (σ_v).

Figure 3.8 describes about the stress verses time diagram for fluctuating stress having values σ_{max} and $\sigma_{min.}$ The variable stress, in general, may be considered as a combination of steady (or mean or average) stress and a completely reversed stress component $\sigma_{v.}$

The following relations are derived from (Figure 3.8-timeVs stress diagram) bellow

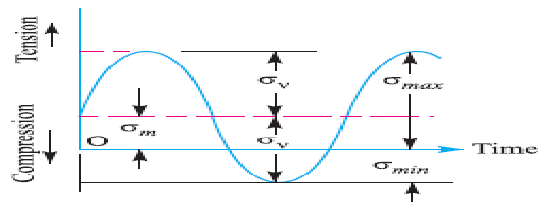


Figure 3. 8 –Time Vs stress diagram [7]

The equation 3.21 and 3.22 are put her as

1. Mean stress $\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$
2. Reversed stress components $\sigma_v = \frac{\sigma_{max} - \sigma_{min}}{2}$

Flexural (bending) stress = 1563N/mm^2. When the flexural stress is assumed fluctuated or reversed between 1563 and -780N/mm^2. Then to determine the minimum ultimate strength (stress) we can apply modified Goodman's criteria

1. Mean stress $\sigma m = \frac{1563+(-780)}{2} \Rightarrow \sigma m = 391.5 N/mm^2$
2. Reversed stress components $\sigma_v = \frac{1563-(-780)}{2} \Rightarrow \sigma v = 1171.5 N/mm^2$

To apply modified Goodman's criteria first should be determine the endurance strength of selected materials.

$$S_{e'} = \begin{cases} 0.5\sigma_{ut}, & \sigma_{ut}, \leq 1400mpa \\ 689.475mpa, & \sigma_{ut}, > 1378.95\ mpa \\ 700mpa, & \sigma_{ut}, > 1400mpa \end{cases} \qquad [16]$$

σ_{ut} is 1272mpa so from the above relation the first one is more convenient and

$$S_{e'} = 0.5(1272mpa) \Rightarrow Se' = 636mpa$$

Modified Goodman's relation is expressed in equation 3.23 is used as follow

$$\frac{1}{F_s} = \frac{\sigma_m}{\sigma_{umin}} + \frac{\sigma_v}{Se'}$$

$$\frac{1}{1.8} = \frac{391.5N/mm^2}{\sigma_{umin}} + \frac{1171.5N/mm^2}{636N/mm^2} \quad \Rightarrow \quad \sigma_{umin} = 304.4\ N/mm^2$$

Stress life relation of steel:

The fatigue strength exponents (b) is varies between - 0.05 – 0.12. [23]

$\sigma_{f'}$ is determined as $\sigma u + 345mpa \Rightarrow \sigma f' = 1617mpa$

b = - 0.08 take an average for most metals

Then the power low relation (3.24) can be expressed as

$$\sigma_a = 1617(2N)^{-0.08} \quad (3.30)$$

Now it is easy to determine the alternating stress in different iteration of number of cycles by applying equation (3.30).it used to estimate the number of fatigue life of the specified design.

Table 3. 9 Fatigue Life of Conventional Steel.

No of cycle(N)	Alternating stress (σa in MPa)	No of cycle(N)	Alternating stress (σa in MPa)
5	1329.66	$1*10^4$	696.8
10	1253.5	$1*10^5$	573
20	1181.77	$1*10^6$	471
50	1093.22	$2*10^6$	444
100	1030.7	$1*10^7$	387.366
$1*10^3$	847.466	$1*10^8$	318.5
$5*10^3$	739.11		

3.4.4. Fatigue analysis of composite leaf spring

Flexural (bending) stress of E-Glass mono leaf spring is 290N/mm^2. When the flexural stress are assumed fluctuated or reversed between 290 and -80N/mm^2.Then the mean stress determined as

$$\text{Mean stress } \sigma_m = \frac{290+(-80)}{2} \Rightarrow \sigma m = 105N/mm^2$$

$$\text{Reversed stress components } \sigma_v = \frac{290-(-80)}{2}$$

$$\Rightarrow \sigma_v = 185N/mm^2$$

The best way to describe the fatigue behavior of composite materials are expressed so far in question 3.25. [25], $\sigma_a = \sigma_{ut} - b*\log N$

(σ_{ut} for E - glss = 2500*mpa)*

At the number of cycle N = 1000 cycle $\sigma_a = 0.75\ \sigma_{ut}$

For E-Glass/epoxy:

Figure 3.9 shows about alternating stress verses number of cycle to fail. And it is graphical representation simply it is known as S-N curve.

To determine the S-N curves of composite materials consider the following diagrams.

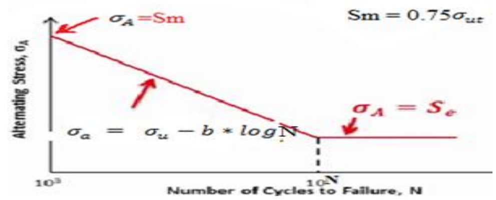


Figure 3. 9 S –N Curve Representation [23]

σ_{ut} = 2500mpa and at N= 1000cyle, $\sigma_a = 0.75\ \sigma_{ut}$

$\sigma_a = 0.75 * 2500mpa \Rightarrow \sigma_a = 1875mpa$

Now to determine the values of constant b equate the values of alternating stress to the equation 3.24. As follow

$$1875\text{mpa} = 2500\text{mpa} - b \log (1000) \Rightarrow b = 208.33$$

Then the equation 3.24 can be expressed as

$$\sigma_a = 2500\ \text{MPa} - 208.33 * \log(N) \qquad 3.31$$

Then using the above equating determine different alternating stress for different number of cycles. The calculated values of alternating stress corresponding cycles are presented in the following (Table 3. 10 fatigue life of E-Glass fiber).

Table 3. 10 Fatigue life of E-Glass fiber

No of cycle(N)	Alternating stress ($\sigma_a$in MPa)	No of cycle(N)	Alternating stress ($\sigma_a$in MPa)
5	2354.6	$1*10^6$	1252
10	2292	$2*10^6$	1189.38
20	2229.38	$1*10^7$	1044
50	2146.6	$1*10^8$	836
100	2084	$1.1*10^8$	827
$1*10^3$	1876	$3*10^8$	738.76
$5*10^3$	1730.6	$1*10^9$	628
$1*10^4$	1668	$1*10^{10}$	430
$1*10^5$	1460		

3.4.5. Modeling of existing steel and composite leaf spring using solid work2017

After identifying all the quintessential layout parameters analytically, the subsequent assignment is modeling two dimensional and three-D model of leaf springs the usage of the appropriate graph software. It is the prior tasks to perform the desired simulation of leaf spring.

A right modeling and simulation in graph and evaluation provide many advantages such as: minimizing product manufacturing time, materials scrap and material cost. In vehicle structure design, the automobile zone has been task 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 till now without metals and a few polymer aspects composite materials does not involved. The polymer components, in the majority of cases, have solely been modelled as isotropic materials. However, as the use of structural composite substances in the car quarter increased, it has now grow to be essential to mannequin composites extra rigorously. Overall, there is no doubt that the significance of modelling and simulation in the automobile area will continue to amplify time to time. In terms of composite materials, the center of attention for persisted improvement will be the enchantment of failure theories, damage modeling, and fatigue lifestyles prediction whilst attaining realistic answer times [27].

Sketching of 2D and 3D modeling of leaf spring using solid work 2017:

2D and 3D modeling of a constructions are the geometric illustration of the real objects in shapes and sizes. Various sorts of mechanical aspects are modeled the usage of strong works earlier than beginning to produce the real components for manufacturing works. Solid work software is the nice modeling tools for any simple and complex mechanical components and this software program allows the consumer to make changes very easily barring having to go lower back at the starting and update all the drawings and assemblies. Generally, it is handy to use, and function primarily based parametric solid modeling software program with many prolonged plan and manufacturing applications.

In this study, primarily based on the dimension received from theoretical calculation and direct measuring information 3D modeling and 2D sketching of the leaf spring used to be created using solid work2017 solid modeling software program and evaluation is finished through the use of ANSYS sixteen workbench for stress, deflection and fatigue life of both traditional steel and composite leaf spring.

Figure 3.10 and figure 3.11 represents 2dimentional and 3dimentional modeling of conventional steel and composite leaf spring using solid work 2017.

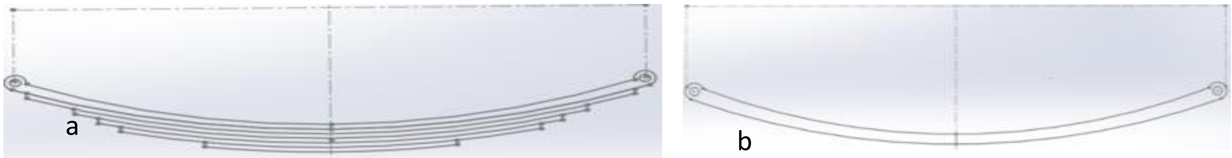


Figure 3.10, 2D Sketch of conventional steel (a) and composite (b) mono leaf spring using solid work2017

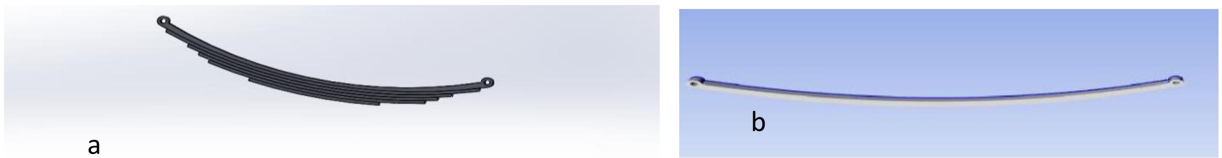


Figure 3.11, 3D Modeling of conventional steel (a) and composite (b) mono leaf spring using solid work2017

3.4 .6. Analysis of leaf spring using ansys 16 workbench

Ansys workbench is a project-management tool. It can be regarded as the top-level interface linking all our software program tools. Workbench handles the passing of facts between ansys Geometry / Mesh / Solver / Post processing tools. Computers have revolutionized the practice of engineering. Design of a product that used to be done by way of tedious hand drawings has been changed through computer-aided layout (CAD) the usage of computer graphics. Analysis of a design used to be accomplished by using hand calculations and many of the checking out have been changed by way of laptop simulations using computer-aided engineering (CAE) software. Together, CAD, CAE, and computer-aided manufacturing (CAM) have dramatically changed the panorama of engineering. For example, a car, that used to take five to six years from layout to product, can now be produced starting from the concept layout to the manufacturing within a year using the CAD/CAE/ CAM technologies [31].

ANSYS is general-purpose FEA software package. Finite Element Analysis is a numerical approach of deconstructing a complicated system into tremendously small portions called elements. The software program implements equations that govern the conduct of these factors and solves them all creating a complete rationalization of how the machine acts. These results then can be displayed in tabulated, or graphical forms. This kind of evaluation is commonly used for the sketch and optimization of a system that is too complicated to Analyze manually. Systems that may additionally in shape into this class are too complicated due to their geometry, scale, or governing equations [13].

The FEM can be applied in fixing the mathematical models of many engineering problems, from stress evaluation of truss and body buildings or intricate machines, to dynamic responses of automobiles, trains, or airplanes below extraordinary mechanical, thermal, or electromagnetic loading. There are several finite thing applications in industries, ranging from automotive, aerospace, defense, client products, and industrial gear to energy, transportation and construction. The purposes of the FEA have also been prolonged to substances science, biomedical engineering, geophysics, and many different emerging fields in latest Years [31].

So, involving the present day layout of composite leaf spring ansys workbench is selected for the analysis of static and fatigue analysis.

3.4.7. Static analysis of conventional steel and composite mono leaf spring

In static structural evaluation of leaf spring essentially point on the dedication of the maximum stress caused in the shape and the deformation. To function this evaluation there are some assumptions are to be considered.

- The analysis of leaf springs is carried out during the whole bodily models.
- In Conventional metal leaf spring the exterior components like, clamper and U- bolts are not parts of the analysis.
- The model discretization for ease of evaluation are used ANSYS 16 Workbench
- The evaluation is performed by using considering static load.

Static analysis of traditional steel leaf spring:

There are some steps to perform structural analysis the use of ANSYS work bench. After modeling of the structure in 3D using solid work 2017 it have to be saved in igs shape in strong work it is the well matched layout of bought work fashions to easily study with the aid of ANSYS.

Defining engineering data:

Figure 3.12 is shows different types of materials available in ansys work bench. Among these materials for this study structural steel was selected to proceed further analysis of multi leaf springs.

In the materials library of ANSYS mission the particular substances are selected and assigned for the given structure as per the fabric selection.

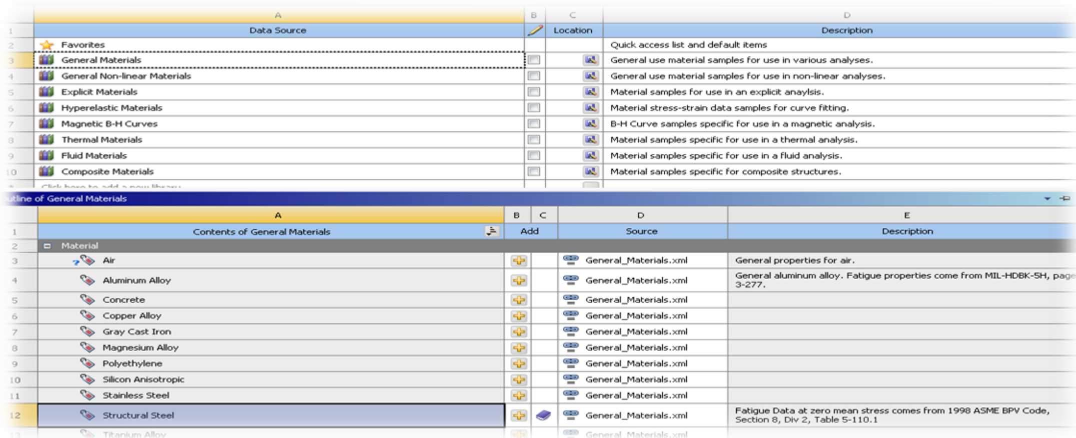


Figure 3.12 Material specification of steel leaf spring

Import and attaching geometry:

This step involves transferring the igs from 3D files to ANSYS static structural design modular by attaching it through the import menu by brow thing from the specified location of the file and generating in ANSYS analysis modular.

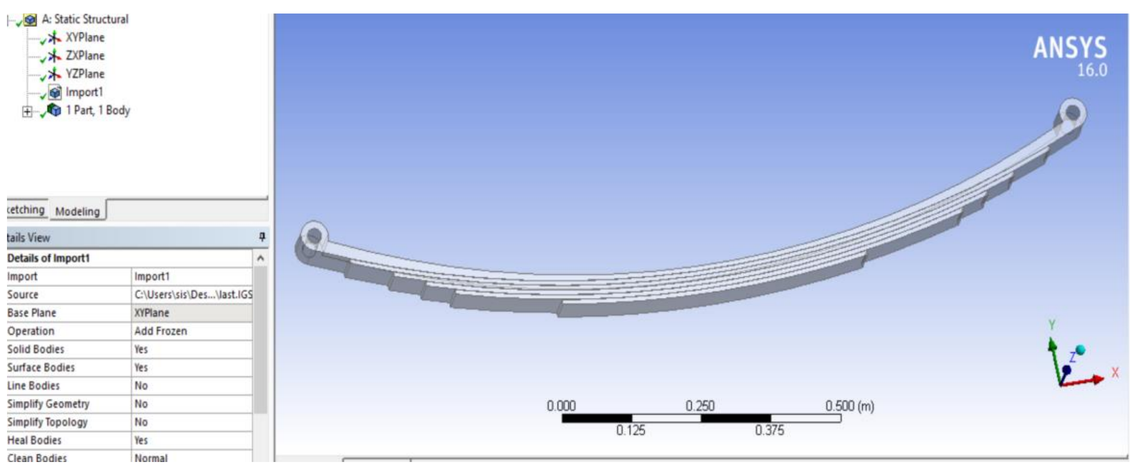


Figure 3.13, 3 D Broth Model of conventional steel leaf spring

Meshing or (discretization) of leaf spring models:

The total equation in the continuous body is six times infinite which results in infinite ($6*\infty = \infty$) and the solving times of the structures are infinite so solving any infinite body is impossible using computer software. Therefore, the continuous domain of study should be replaced with a finite set of points, and the process is called discretization or meshing.

The meshing of mechanical parts is the transferring of the continuous body which has infinite points into discontinuous (discrete) points which has finite nodes and elements. This is because the computer for the numerical solutions can give answers at only discrete points in the domain, called grid points.

Applying of mesh control for conventional steel leaf spring:

For this structure, the mesh has been generated using a triangular mesh method and by considering the computer CPU the types of mesh used are medium, As shown in figure 3.14 Number of elements used are 74686 and the number of nodes is 127487.

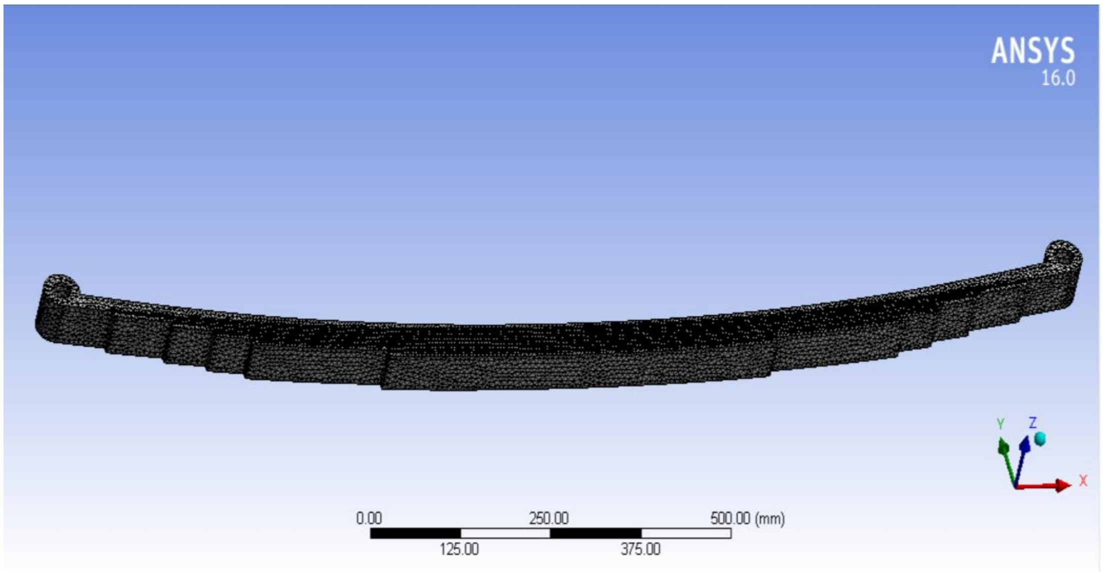


Figure 3.14, 3D Mesh model of conventional steel leaf spring

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 farm. So remote displacement of one end of leaf spring in X, Y, and Z components are fixed and in rotation constraint X, Y components are also fixed and Z components are free to rotate. The other ends of remote displacements of the X component are free, Y and Z components are fixed, in rotation X and Y are fixed and Z is free to rotate.

Figure 3.15 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 3.15, 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 tier of the vehicle and leaf spring of land cruiser vehicle 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

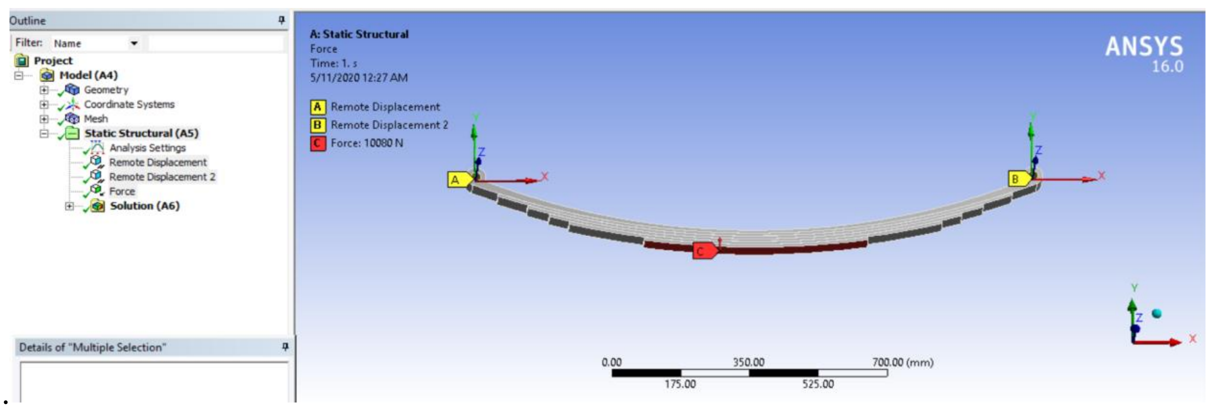


Figure 3.16 Load and boundary condition of steel Leaf spring

Generating solution:

Based on the analytical result and input parameters of the leaf sprig the required solutions are generated .as specified so far the results of static structural analysis such as von misses stress, total deformation, and equivalent stress are generated and for fatigue analysis, the safety factor and fatigue life of leaf springs are displayed.

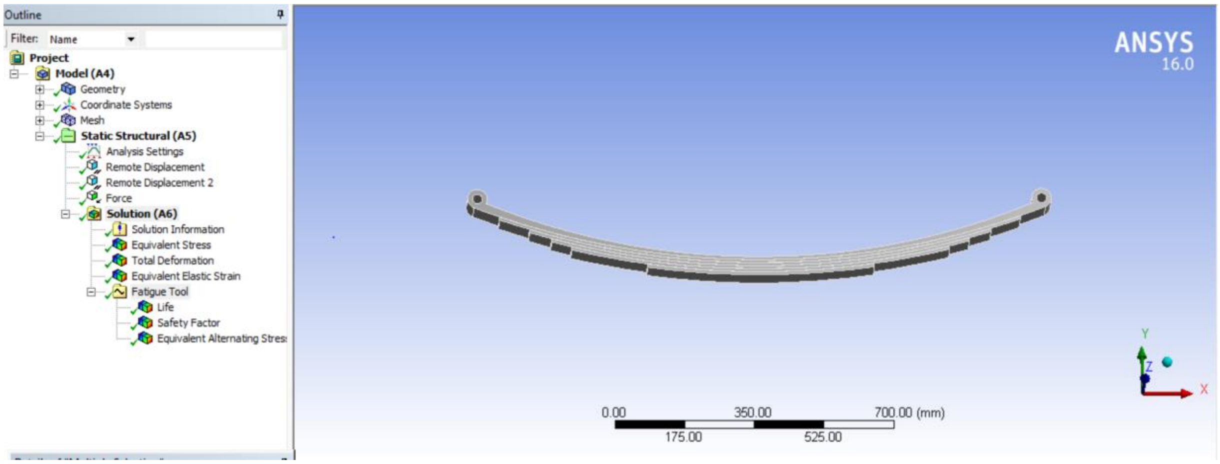


Figure 3.17 Generated solution of steel leaf spring

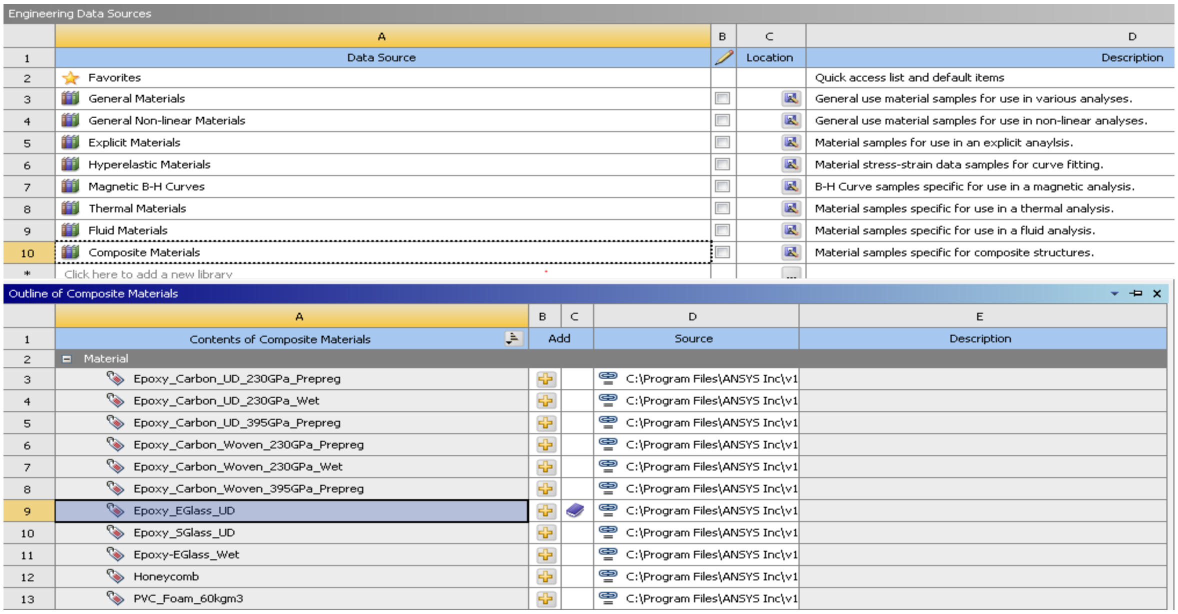
The detail results of both leaf springs are presented at the result and the desiccation section in the next chapter.

3.4.9. Analysis of E- Glass/epoxy composite mono leaf spring.

For the analysis of composite mono leaf spring the following assumptions are considered

1. The model discretization for ease of analysis are used ANSYS 16 Workbench
2. Meshing behavior is limited to computer compatibilities.
3. The analysis is conducted by considering static and fatigue loading
4. The material used for composite leaf spring design is woven E-Glass fiber and the matrix are Epoxy resin.

The analysis steps are similar with that of steel leaf spring discussed so far. Therefore, by following all the steps we have done above, the first one is applying the selected specific materials of E-Glass/epoxy composite materials from the material library of ansys project.



Engineering Data Sources

	A	B	C	D
1	Data Source		Location	Description
2	Favorites			Quick access list and default items
3	General Materials			General use material samples for use in various analyses.
4	General Non-linear Materials			General use material samples for use in non-linear analyses.
5	Explicit Materials			Material samples for use in an explicit anaylsis.
6	Hyperelastic Materials			Material stress-strain data samples for curve fitting.
7	Magnetic B-H Curves			B-H Curve samples specific for use in a magnetic analysis.
8	Thermal Materials			Material samples specific for use in a thermal analysis.
9	Fluid Materials			Material samples specific for use in a fluid analysis.
10	Composite Materials			Material samples specific for composite structures.
*	Click here to add a new library			

Outline of Composite Materials

	A	B	C	D	E
1	Contents of Composite Materials	Add		Source	Description
2	Material				
3	Epoxy_Carbon_UD_230GPa_Prepreg			C:\Program Files\ANSYS Inc\v1	
4	Epoxy_Carbon_UD_230GPa_Wet			C:\Program Files\ANSYS Inc\v1	
5	Epoxy_Carbon_UD_395GPa_Prepreg			C:\Program Files\ANSYS Inc\v1	
6	Epoxy_Carbon_Woven_230GPa_Prepreg			C:\Program Files\ANSYS Inc\v1	
7	Epoxy_Carbon_Woven_230GPa_Wet			C:\Program Files\ANSYS Inc\v1	
8	Epoxy_Carbon_Woven_395GPa_Prepreg			C:\Program Files\ANSYS Inc\v1	
9	Epoxy_EGlass_UD			C:\Program Files\ANSYS Inc\v1	
10	Epoxy_SGlass_UD			C:\Program Files\ANSYS Inc\v1	
11	Epoxy-EGlass_Wet			C:\Program Files\ANSYS Inc\v1	
12	Honeycomb			C:\Program Files\ANSYS Inc\v1	
13	PVC_Foam_60kgm3			C:\Program Files\ANSYS Inc\v1	

Figure 3.18 Material specifications of E - Glass Woven composite materials

Import and attaching geometry:

After modeling of leaf spring in solid work saved in forms of igs files which is convenient to read in ANSYS easily. Then unlike isotropic materials (conventional steel), composite materials exhibit different layers in a different orientation.so the complete 3D model of composite leaf spring is done with ANSYS ACP pre which is one of the packages of ANSYS software. Because it is more convenient than other software for modeling the composite structure of different layers with different angles of orientation.

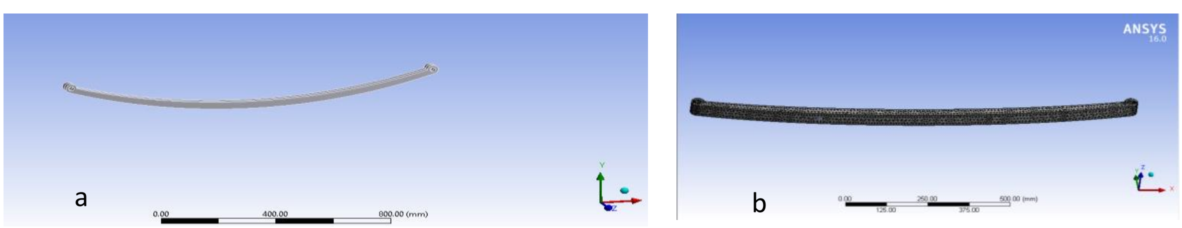


Figure 3.19, 3D (a) and Mesh (b) model of composite leaf Spring

Applying of mesh control:

For this structure, the mesh has been generated using 3D triangular mesh method and by considering the computer CPU the types of mesh used are medium and as shown in figure 3.19 (b) Number of elements used are 13848 and number of nodes are 25772

3.5. Apply Load and Boundary Condition

1. Displacement constraint:

The load and the boundary condition stated so far in conventional steel leaf spring is applicable for composite leaf spring. 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 farm. So remote displacement of one end of leaf spring in X, Y, and Z components are fixed and in rotation constraint X, Y components are also fixed and Z components are free to rotate. The other ends of remote displacements of the X component are free, Y and Z components are fixed, in rotation X and Y are fixed and Z is free to rotate.

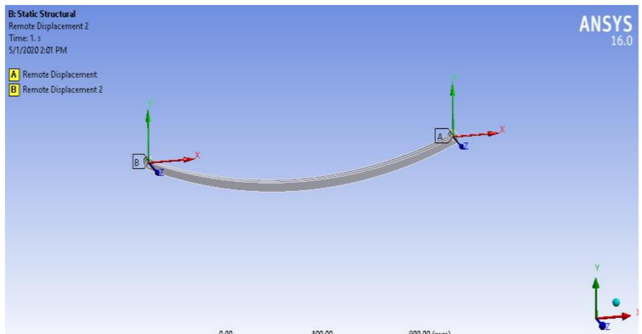


Figure 3.20 Displacement Constraint for E-Glass/Epoxy composite mono leaf spring

2. Force constraint:

leaf spring of land cruiser vehicle 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 the left and right sides. Regarding this characteristic, the load is applied at the center of the leaf spring. The front and the rear links (especially the shekel one) act as the flexibilities of the motion of the vehicle in vamp and speed breaker road as a suspension.

a b

Figure 3.21 Shackle (a) and fixed (b) end mounting leaf spring

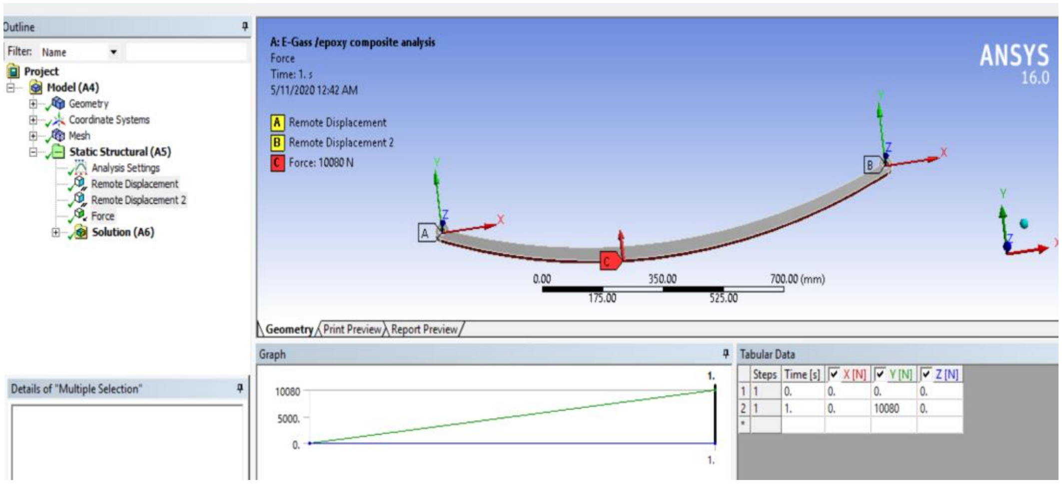


Figure 3. 22 Load and boundary condition E-Glass/Epoxy composite materials

Generating of solution:

Based on the analytical result and input parameters of the leaf sprig the required solutions are generated .as specified so far, the results of static structural analysis such as von misses stress, total deformation and equivalent stress are generated and for fatigue analysis the safety factor and fatigue life of leaf springs are displayed.

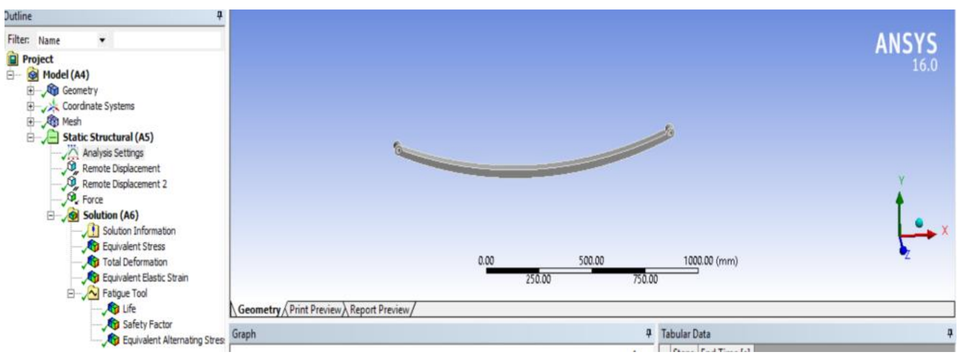


Figure 3. 23 Generating solution of E-Glass/Epoxy composite mono leaf spring

The detail results of both leaf springs are presented at the result and the discussion section in the next chapter.

3. 6. Experimental Studies of Impact and Creep Properties of E-glass /Epoxy

As stated so far in the methodology section, one of the optimizations of the composite material is fiber to matrix volume ratio .so, experimental work is done based on fiber and matrix contents or composition parameters.

3.6.1. Experimental Study materials

The necessary materials to conduct the experiments are:

1. Chopped strand E-Glass fiber

2. General purpose epoxy resin
3. Hardener (accelerator)
4. Mold release(wax)

Chopped strand E-Glass fiber: the reinforcement's components of all composite materials are fiber Weather it is glass, carbon, or Kevlar fiber. So, for this experiment glass fiber is used as the reinforcement substrate.

Figure 3.24 shows chopped strand glass fiber reinforcement. It used to make the composites with different layers with the matrix. Figure 3.25 shows a general purpose epoxy resin it used as a matrix of composites to make different laminates sticking with the fibers.

Figure 3. 24 Chopped strand E-Glass fiber

General purpose epoxy resin: the other components of composite materials are the matrix. Matrix are liquid chemicals which are known as resins. There are different types of resins as we discussed in literature reviews. For this experiment epoxy resin is employed as a matrix's materials.

Figure 3. 25 General purpose resin and hardening

Hardener (accelerator): resins without harder is no functional for structural design application. Hardener is used to activate or accelerate resins and it increases the sticking ability with the fibers during layup time.

Mold release (wax): since epoxy resins have stackable properties so, release agents are used. After the layup processes of fiber and matrix are finished, the manufactured composites are remaining stacked in the mold. In this situation when someone tries to detach it is impossible unless breaking the mold completely.so, mold release or wax is used to prevent resins from sticking to the mold and it is essential to remove components smoothly from the mold easily.

Figure 3.26 shows that the packed releasing agent. It used to protect the sticking of the products from the melds.

Figure 3. 26 Releasing agent of molds

Desired equipment of the study:

To prepare the composite material specimen, the necessary equipment used are

1. Compression mold
2. Normal brush
3. Roller brush
4. Stirring stick

Mold: are a manufacturing equipment it used to produces components in desired shapes. The structure and shapes of the products are depending on the patterns of the molds. For this specimen production 150mm by 140mm. ceramic is used in bottom and top surface as a compression molding of the composites. Ceramic is a very smooth and flat surfaces and it provides good surface finish.

Figure 3. 27 Molds of composite material manufacturing

Normal and roller brush: normal brush is used to spray resins throughout the fibers smoothly. After that using roller brush roll over the surface of the resins in order to get strongly bonded fiber and matrix composite structure. And Stirring stick is used to mix accelerator and resin properly.

3.6.2. Specimen manufacturing procedure

For the manufacturing of the specimen of impact and creep test, the hand layup technique is employed. The experimental specimens are prepared using three molds to decide the proper amounts of the composition of fiber and reinforcement for the design of composite structures. Basically, the three molds are made by volume fraction of fiber and matrices. These are 60%/40%, 50%/50%, and 40%/60% percent of reinforcement to matrix this helps to achieve the following points.

1. To make strong bond between fiber and matrix
2. To minimize the overall weight of the leaf spring.
3. To minimize the brittle of the leaf spring.

60/40 represented as material A, 50/50, represents material B and 40/60 as material C.so, throughout this discussion use these letters instead of the numbers. The following steps are the basic guidelines for the preparation of the sample specimens.

Step 1. Cut the reinforcement fibers into proper size as per the specified mold capacity

Figure 3. 28 Cutting of fiber in proper size

Step 2. Preparation of resin and accelerator.in this step mixes epoxy resin and hardener in suitable amounts. For this experiment the weight ratio of resin to hardener is 10:1 and using stirrer stick mixes for 50seconds.

Figure 3.29 Mixing of resin with hardener

Step 3. Hand layup technique: in hand layup techniques the first thing is to apply wax (releasing agent) to the surface of the bottom mold and polish or paint all the surface of the mold .it used to prevent the sticking of resins in the mold and dry the mold 5-10 minute it provides good surface finish.

Figure 3. 30 Painting of releasing agent to the mold

Step 4. In this step first, apply resins over the surface of the mold and add the fiber on it and again apply resins over the fiber and brush it through the fiber .after properly brushed using roller brush, roll over the fiber and resin to remove bubbles on the surface it increase strength properties of the composite structure. Then keep repeating this process until achieving the desired size of the products. Anyone should be careful in the layup processes of each fiber layer for eliminating distortion. Distortion of layers reduces the strength and rigidity of the composite structure.

Figure 3. 31 Hand layup manufacturing process

Step 5. After finishing the layup processes, again painting the surface of the upper molds with mold release and put the upper mold on the top surface. Then adding a 40-ton load on the top of the mold and the mold to be cured for 2 days.

Step 6. Removing the composite structure from the mold. The untrimmed structure of composite material is shown in figure bellow.

Figure 3. 32 Untrimmed composite material

Step 7. Finishing the surface of the composite structures by cutting the unwanted edges which remains out of the mold.

a) (A) (60/40) b) (50/50)(B) c) (40/60)(C)

Figure 3. 33 Finished structure of three composition of composite material.

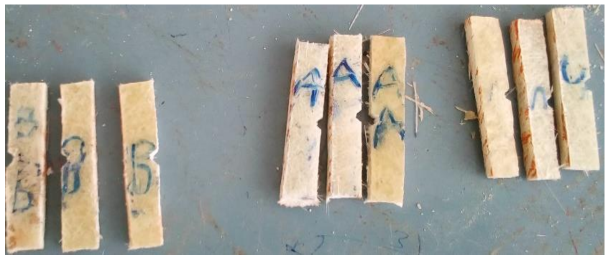
3.6.3. Test set up and procedures

To perform the impact and creep test on the E-Glass/epoxy composite materials I zoid impact and creep test machines are used.

By cutting the unnecessary parts of the structure, the test specimens of E-Glass/epoxy composite materials are prepared according to the specified ASTM D3410 standards in desired sizes for each composition of fiber –matrix volume ratio.

Figure 3. 34 Cutting of specimens

Experiments are conducted for two tests. These are impact and creep tests .in impact test there are three specimens for each three fiber – matrix volume ratio and a total of nine specimens are tested for impact loads. For creep tests there are two specimens for each three fiber - matrix volume ratio and a total of six specimens are tested for creep loads.



A 50/50) B (60/40) C (40/60)

Figure 3. 35 Impact test specimens

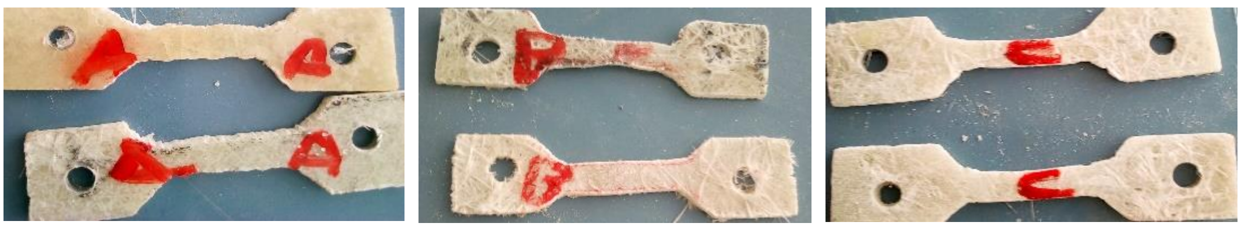


Figure 3. 36 Creep tests specimens

These experiments are conducted by Izoid impact and creep test machine for the three composition parameters. The test set ups of these machines are shown in figure bellow.

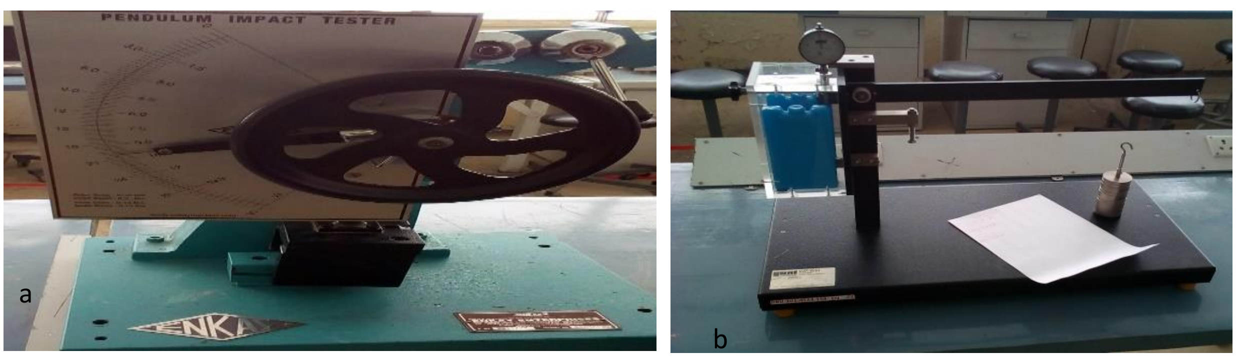


Figure 3. 37 Izod Impact (a) And Creep Test Machine (b)

3.6.4. Izod Impact test procedure and set up

The test specimen is held in a vertical position in the groove provided in the anvil fixed to the base of the machine. The notch cut on the specimens is facing in the opposite direction of the striker. Then adjust the reading dial gages pointer to initially zero. Then apply the hammer to the specimens and record the readings of the indicator. Repeats this process to all specimens. For this impact test. The

1. Pendulum impact energy = 30Nm
2. Angle of fall of pendulum 120^0
3. Impact (striking) velocity of pendulum 3.8 m/s
4. Maximum permissible loss by friction = 0.5%

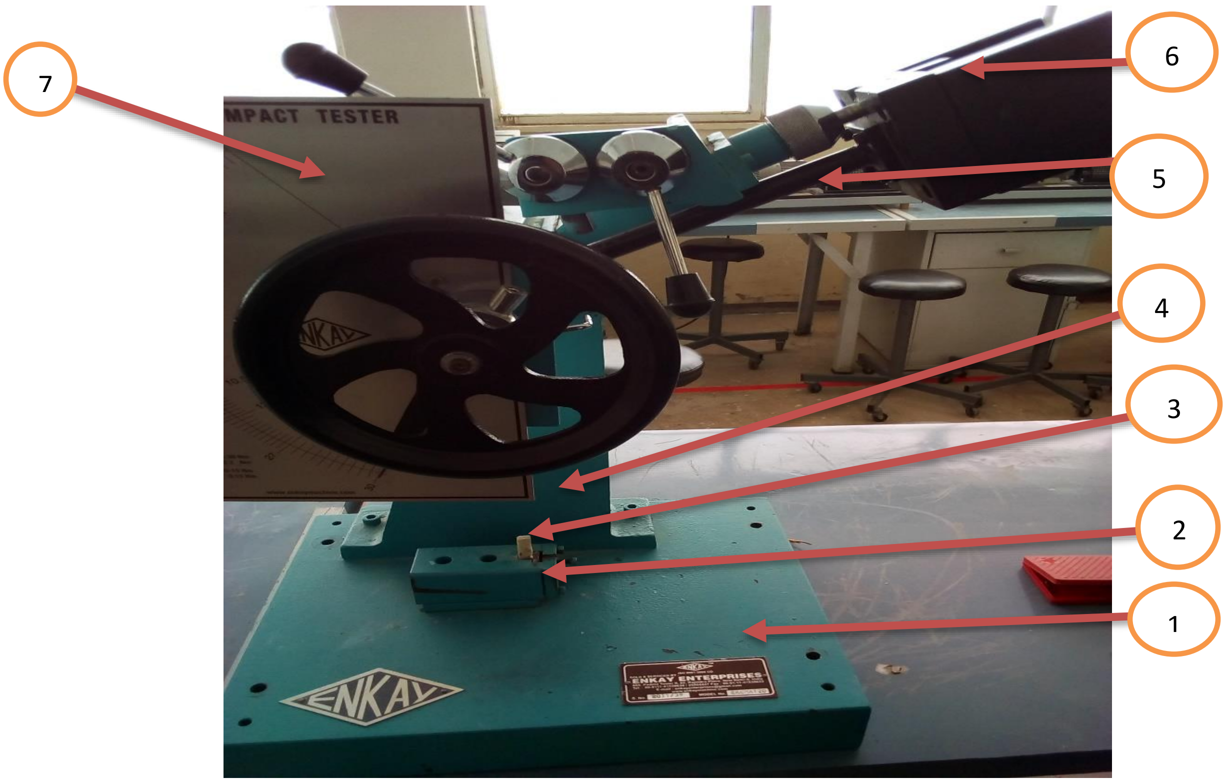


Figure 3.38 Impact test machine

3.6.5. Description of some impact tester unit

As indicated by the arrows in figure 3.38 the main components are listed below.

1. Base plate or support
2. Anvil
3. Specimen or test pies
4. Machine Frame work
5. Pendulum
6. Sticker
7. Scale

3.6.6. Creep test procedure and setup

With WP600 creep testing machine: it is possible to determine the typical phenomenon of creep response such as period of different creep rate or creep behaviors in a simple creep rupture test at room temperature. The constant continuous, continuous test force is generated via the transmission lever with weight load. The test force for this experiment is sets to 21N. The flat sample specimens clamped in sample holder in order to protect the sample from being stress, the sample holder is fitted with kni-feedge bearings.

Extension of the specimen sample during loading is measured by dial gauge. The dial gauge is directly in contact with the upper movable sample holder. This eliminate measurement errors caused by slacks in transfer element.

3.6.7. Description of some creep tester unit

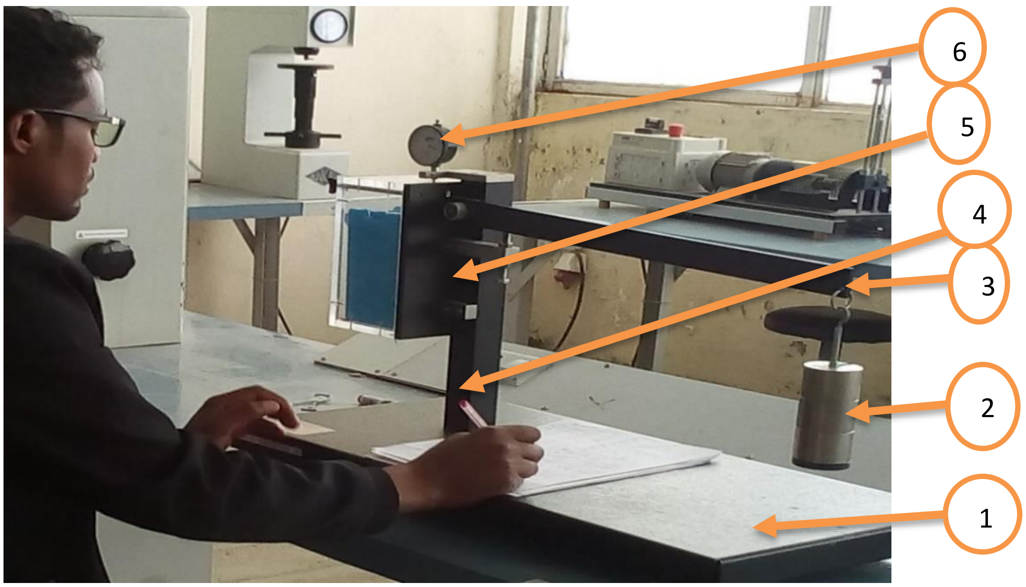


Figure 3. 39 Creep testing system

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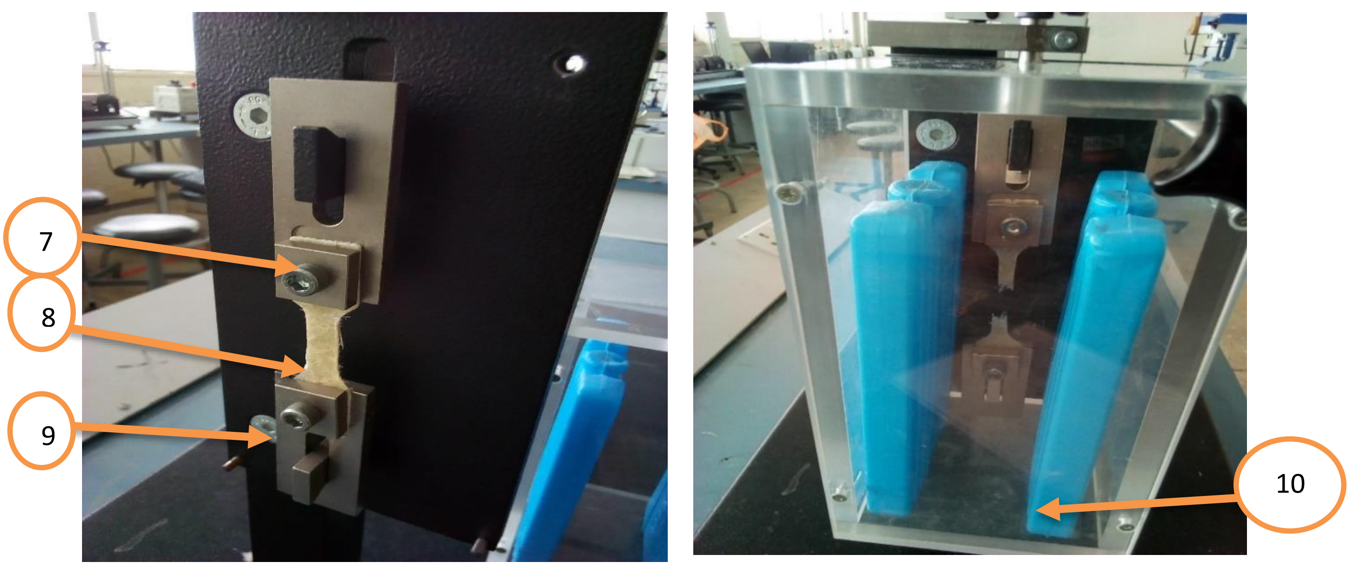

Figure 3. 40 Creep test setups

Figure 3.39 and figure 3.40 shows that different unites of creep test machine and these parts are :

1. Base plate
2. Load weight
3. Transmission lever
4. Support pillar
5. End stops, adjustable
6. Dial gauge
7. Upper sample holder
8. E-Glass/epoxy creep test sample
9. Lower sample holder
10. Cooler

Chapter 4: Results and Discussion

This chapter describes all results generated in the analysis of conventional steel and E-Glass/Epoxy composite mono leaf springs for land cruiser vehicle applications. The results are obtained from static structural and fatigue life analysis of existing steel and E- Glass/Epoxy composite mono leaf springs. The basic solutions of these studies from analytical and finite element analysis of the two leaf springs are total deformation, equivalent (von misses) stress, fatigue life, alternating stress, and safety factor of both leaf springs. Experimental studies are conducted for creep and impact tests specimens of E-Glass/Epoxy. in numerical solution techniques there are three basic steps are available these are preprocessor, solver, and post-processor from these steps post-processor is convenient for description of the results generated from the inputs of different parameters in the preprocessor and the solver sections so the specified results in different plot and contours in the preprocessor using in Ansys 16 workbench are presented as follows.

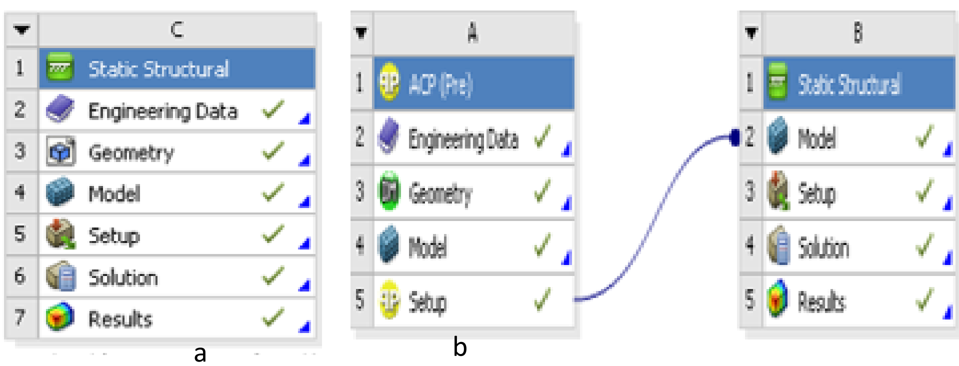

Figure 4. 1 ANSYS Workbench analysis process of steel (a) and composite mono (b) leaf spring

4.1. Results of Analytical and Finite Element Analysis.

All the results generated from the analysis of both steel and composite mono leaf springs are mentioned in this section. The following simulation result shows the variation of stress distribution and changes of deformation of the conventional multi-leaf spring and E- glass/epoxy mono leaf springs.

4.1.1. Equivalent stress

The equivalent stress distribution in both conventional multi leaf spring and E-glass /epoxy mono leaf spring is displayed based on the software analyses results. Using the ANSYS 16 Workbench software, the values of equivalent (Von-Misses) stress found with the given load and boundary conditions. Figure 4.2 and Figure 4.3 below shows the results of equivalent stress for steel and composite leaf springs respectively. The result clearly indicates that the level of stress is higher in the case of steel material leaf spring. This implies that, by using mono leaf spring it is possible to minimize the level of stress that is imposed on vehicles. Stress reduction will greatly help to reduce accidents and also it increases vehicles durability.

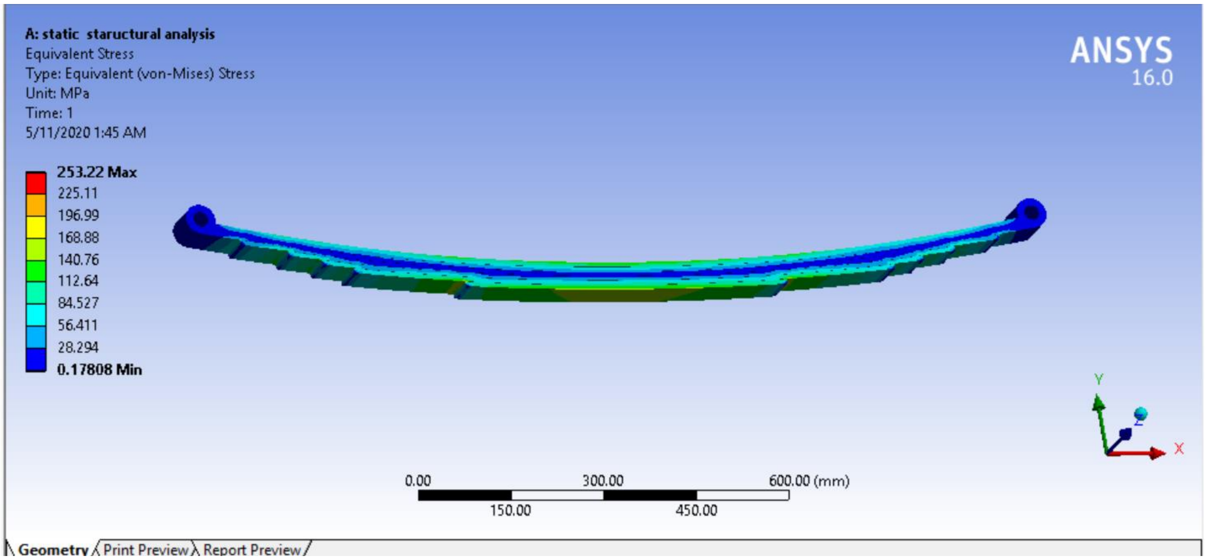

Figure 4. 2 Equivalent (von misses) stress of steel leaf spring

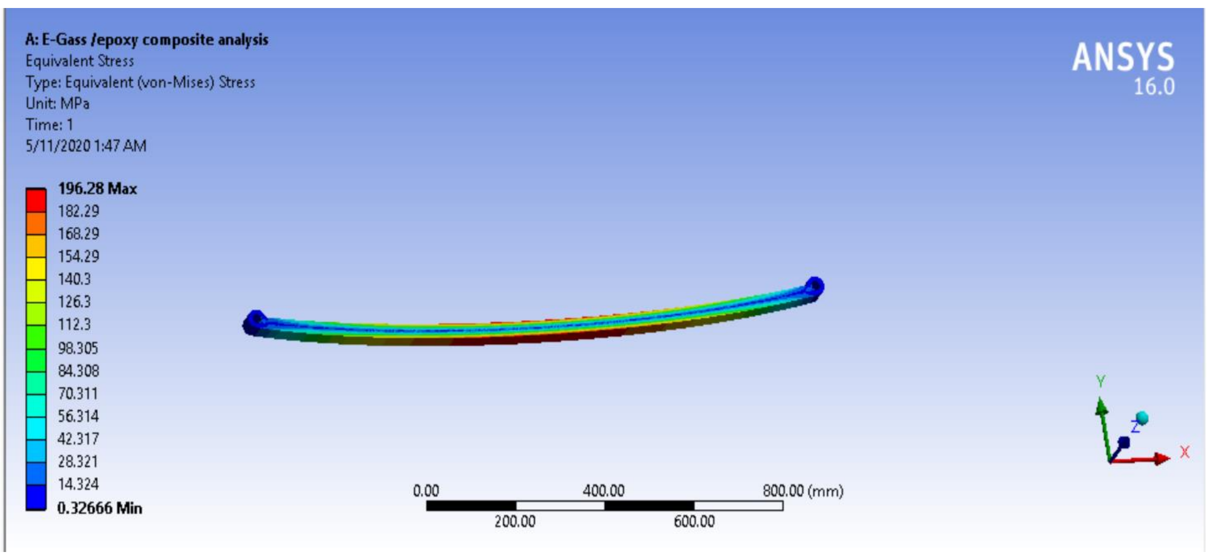

Figure 4. 3 Equivalent (von misses) stress of E - glass/Epoxy mono leaf spring

4.1.2. Deformation

Deformation is the other important indicator of car resistance. Due to this, the study tried to compare the level of deformation for steel and Epoxy mono leaf spring. The result for the two type of leaf springs is presented in Figure 4.4 and Figure 4.5 respectively. The result indicated that, the level of deformation for Epoxy mono leaf spring is by far better than that of the convectional steel leaf spring. This indicates that using Epoxy mono leaf spring can reduce the level of vehicle

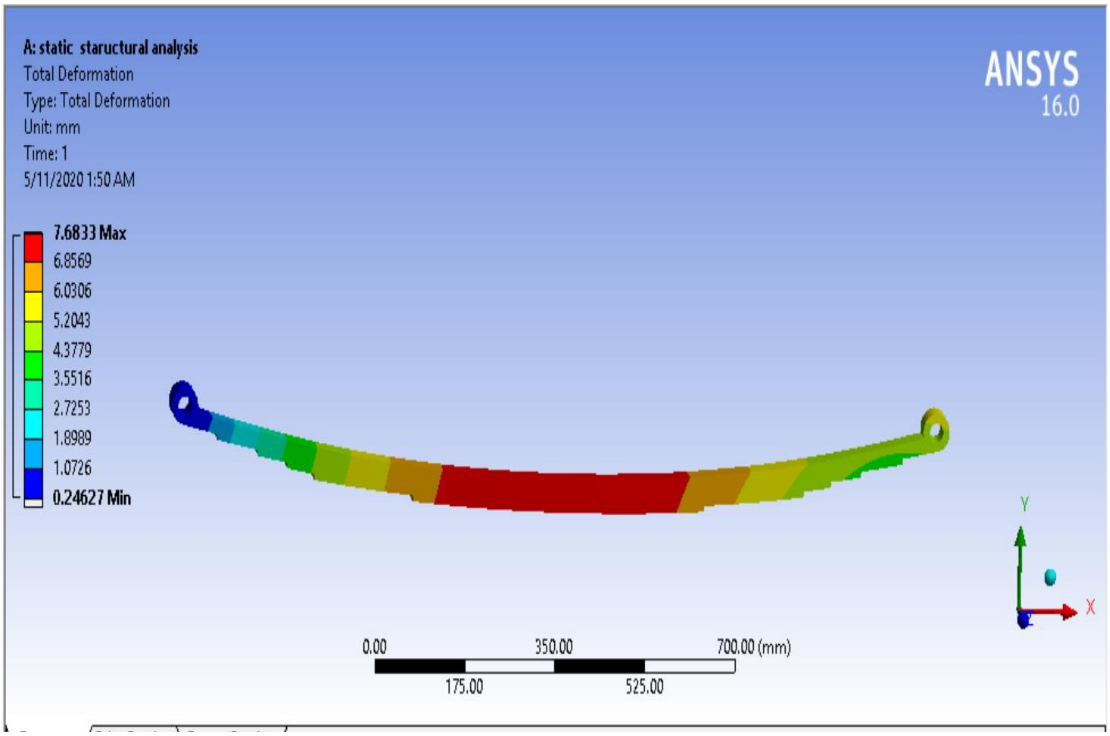

Figure 4. 4 Total deformation of steel leaf spring

deformation. Thus, Epoxy mono leaf spring provides an advantage of minimizing deformation level.

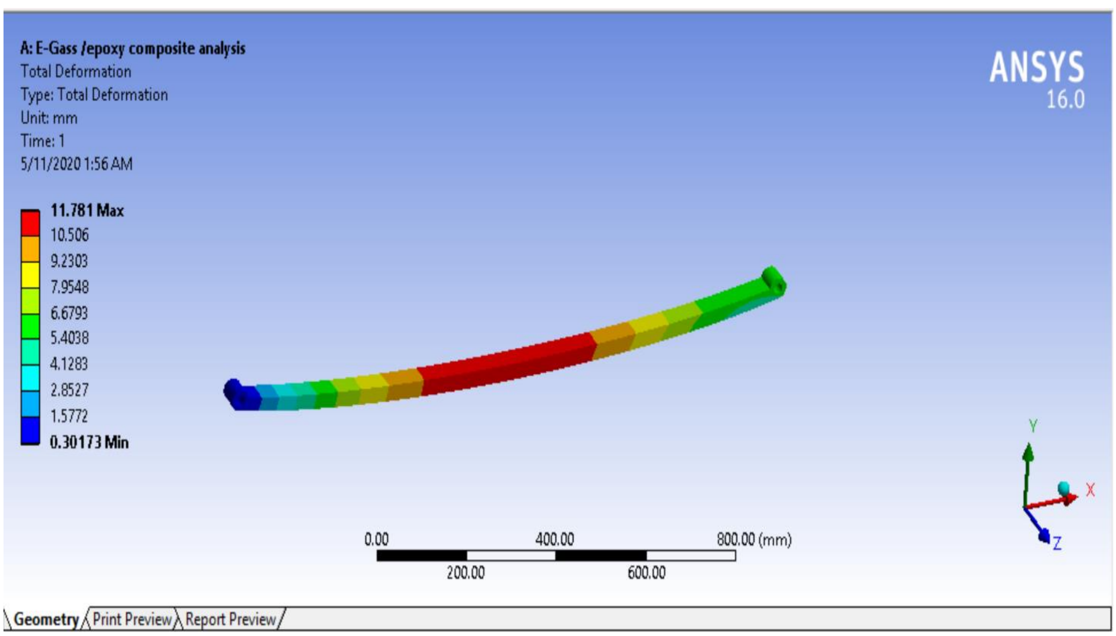

Figure 4. 5 Total deformation of E-Glass/Epoxy composite mono leaf spring

4.2. Results of Fatigue Analysis

4.2.1. Alternating stress

For the same boundary condition and applied loads the alternating stress of steel and composite leaf spring are analyzed using ansys16 work bench. Figure 4.6 and figure 4.7 shows the higher alternating stress are induced in conventional steel leaf springs.

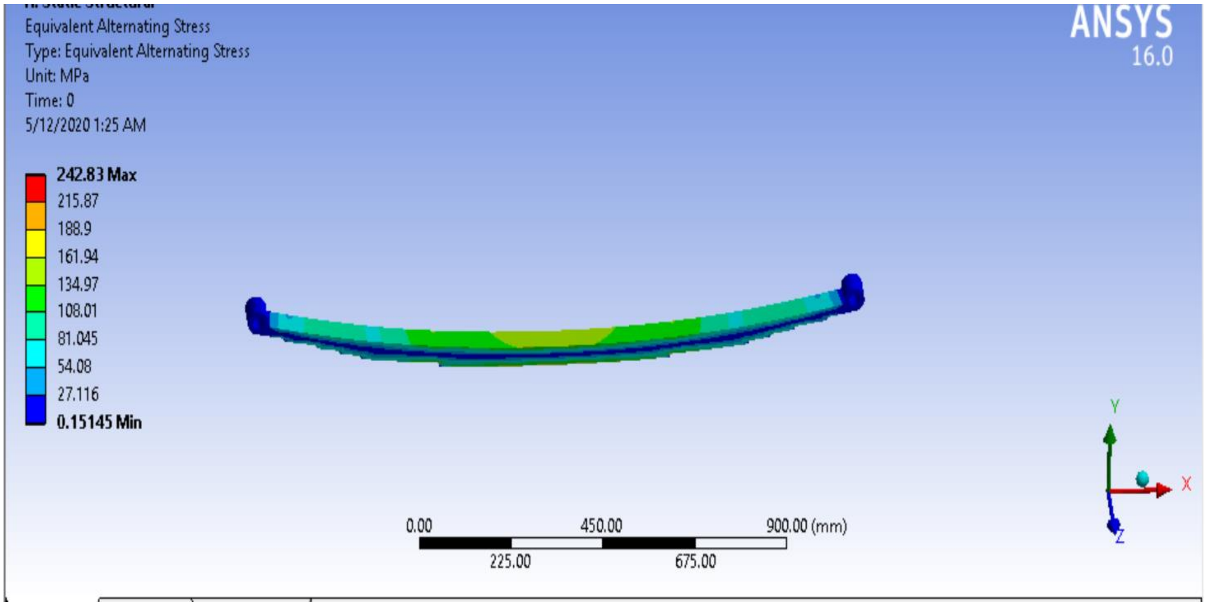

Figure 4. 6 Alternating stress of conventional steel leaf spring

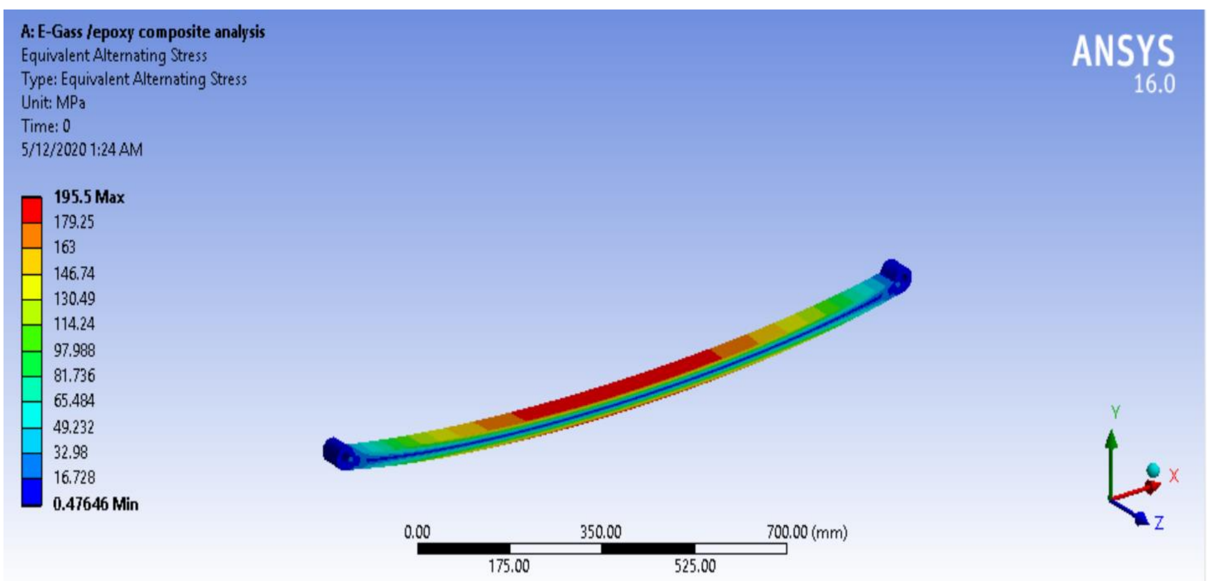

Figure 4 .7 Alternating stress of E-Glass/Epoxy composite mono leaf spring.

4.2.2. Fatigue life

Figure 4.8 and Figure 4.9 indicates the fatigue strength of conventional steel and composite mono leaf spring.in this results the fatigue behavior of composite leaf spring is more preferable than that of existing steel leaf spring.

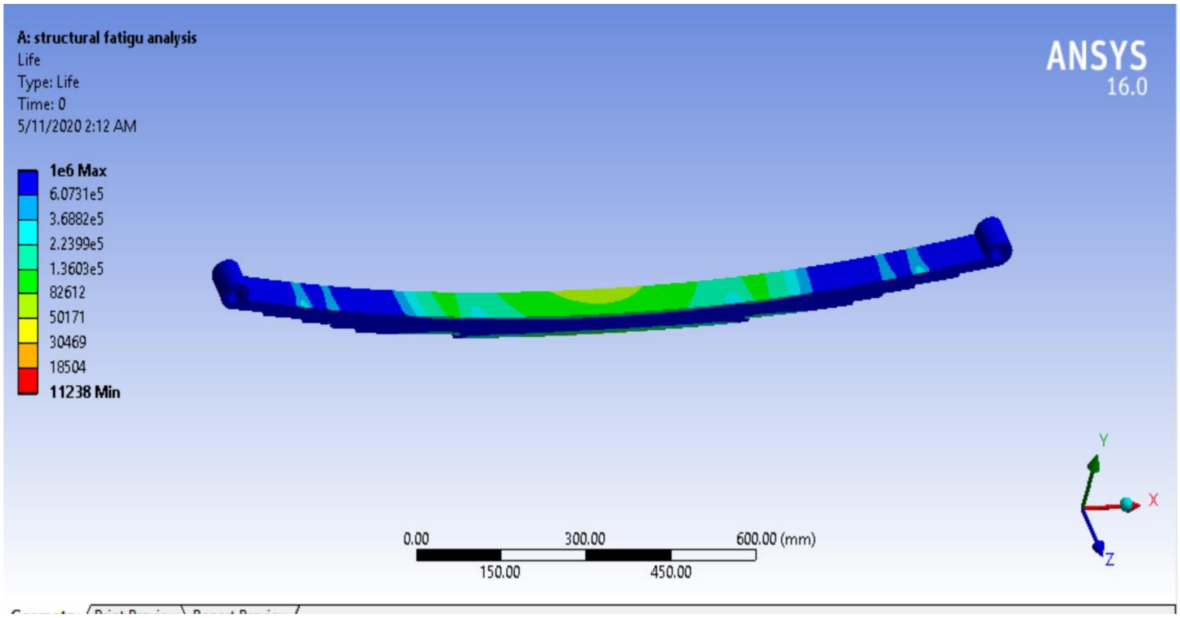

Figure 4. 8 Fatigue life of conventional steel leaf spring

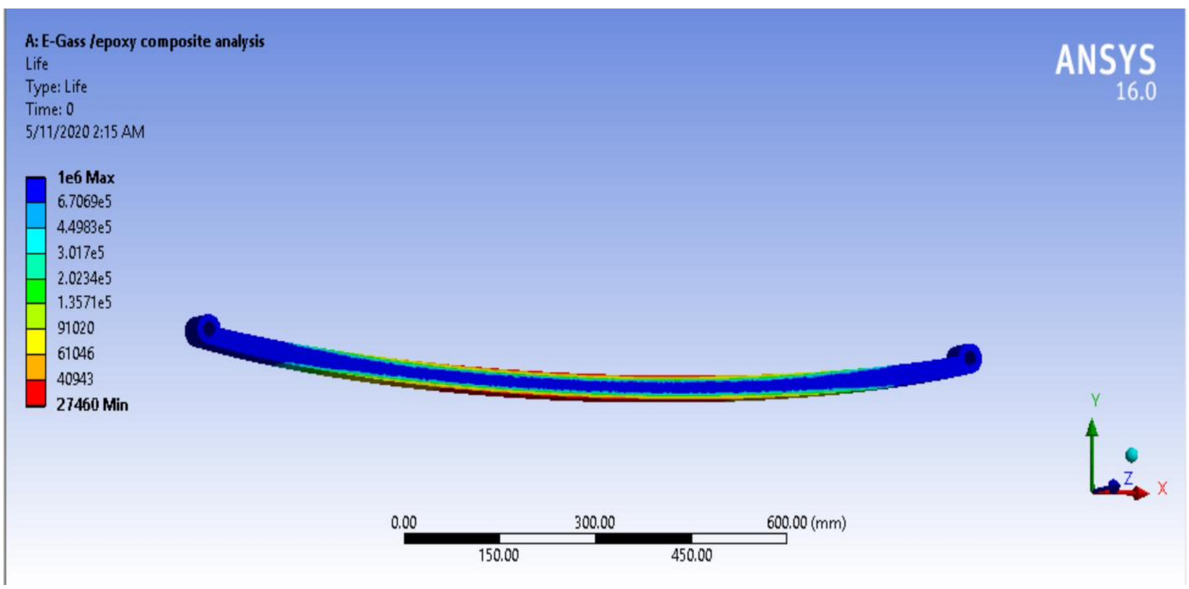

Figure 4. 9 Fatigue life of E-Glass/Epoxy composite mono leaf spring.

4.2.3. Safety factor

Figure 4.10 and Figure 4.11 shows factor of safety of conventional steel and composite mono leaf spring respectively. As the figures indicates the higher values of factor of safety is in composite leaf sprig.

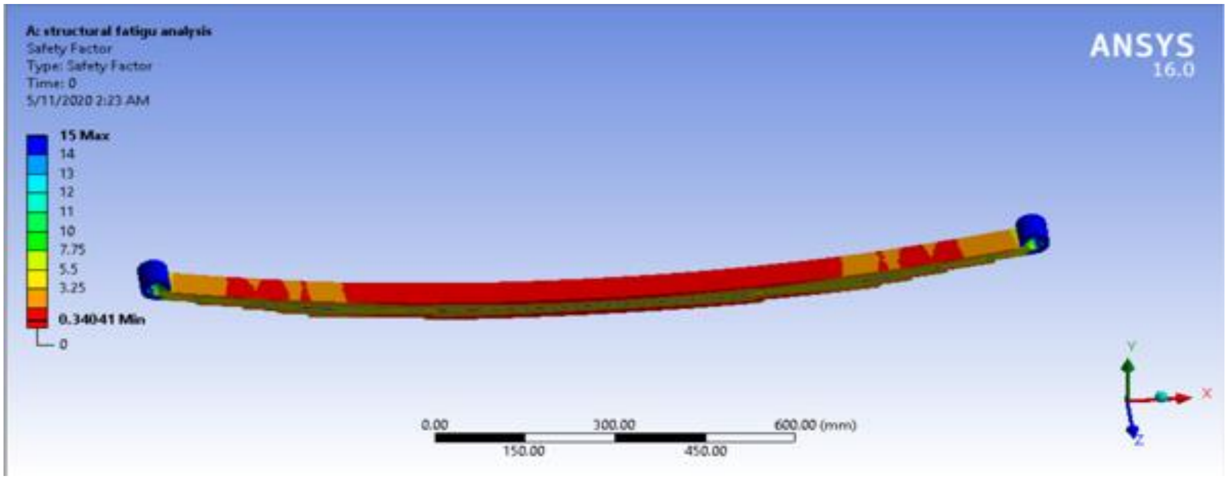

Figure 4. 10 Safety factor of conventional steel leaf spring

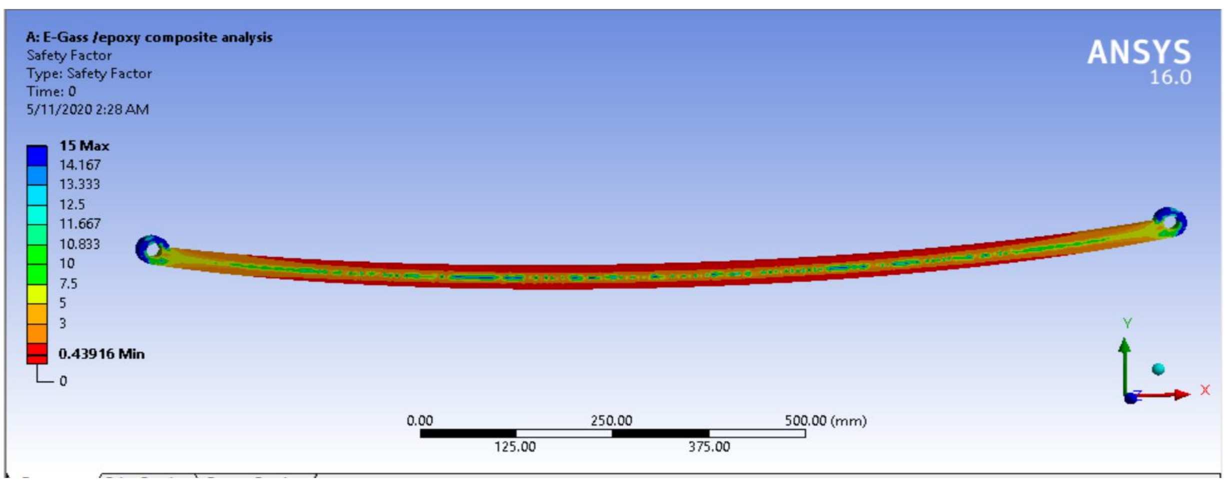

Figure 4. 11 Safety factor of composite mono leaf spring

4. 3. Discussion.

In this research, the static structural and fatigue analysis of composite material mono leaf spring and conventional metal multi-leaf spring is performed by way of making use of the load of 10080N for each leaf spring. As really discovered from the layout and the Finite element simulation end result above, for the equal capacity, the equal Load and boundary condition. The evaluation of all the noted constraint analysis results was carried out the use of the finite element method. When comparing the design and simulation end result of traditional steel multi-leaf spring and unconventional composite mono leaf spring, the overall performance of the composite mono leaf spring is better than that of the existed steel leaf spring in the preferred layout parameters and the stated constraints. These unique results acquired for both leaf springs are mentioned every bellow.

4.3.1. Wight reduction

As received from the numerical results, the weight discount got the usage of composite mono leaf spring and existing steel leaf springs are presented in the following (Table 4.1 Summary of weight reduction of leaf spring).

Table 4.1 Summary of weight reduction of leaf spring

Lef springs	Weight in (N)
Traditional steel	288.78
E-Glass/Epoxy composite	111.6
Percentage Reduction	61.354%

As mentioned so far, the major goals of this precise research are growing the overall performance and gas efficiency of the selected car by reducing weight and stress .so,61.354% of weight discount is executed using glass fiber composite mono leaf spring materials. In this design, it can be proven that after using composite materials mono leaf spring the weight of the car and failure of the leaf spring grew to become limit thereby it improves the fuel efficiency and load-carrying capacity.

4.3.2. Equivalent stress

By applying the load of 10080N in both leaf springs using the finite element method (FEM) in ANSYS16 analysis software in the same boundary condition the maximum stress induced in E-Glass/epoxy mono leaf spring is smaller than that of the existing conventional steel multi-leaf spring which is 196.28mpa < 253.22mpa. So, this result implies that composite mono leaf spring can replace conventional steel leaf spring for suspension application of light and medium vehicles.

4.3.3. Deformation

As observed from the analytical and the simulation result of ASYSIS16 software, the values of total deformation at the center of each leaf spring is 7.68mm for steel and mono leaf spring is 11.8mm.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.as Jenarthanan M.P*, and Ramesh Kumar.S, Produces 7.10mm for glass mono leaf spring and 4.7mm for steel leaf spring.so, this has no significant changes in the performance of the displacement of composite mono leaf springs. Therefore composite mono leaf spring can replace existing steel leaf spring.

4.3.4. Fatigue results

Alternating stress: fatigue analysis of both conventional steel and composite mono leaf spring are conducted using the fatigue tool of ANSYS workbench. Since this research thesis is conducted stress-based and mean stress theory based so, one of the results of fatigue analysis is constant amplitude equivalent alternating stress. As indicated in (Figure 4. 6 and Figure 4.7 Alternating stress of conventional steel composite leaf spring) of simulation results of conventional steel and E-Glass/Epoxy composite mono leaf spring the alternating stress is induced in steel leaf spring is higher (242.82 MPa) than the alternating stress-induced in composite mono leaf spring (195 MPa).

4.3.5. Fatigue life

As observed in finite element simulation result of steel and composite leaf spring presented in (Figure 4.8 and Figure 4.9 Fatigue life of conventional steel and composite leaf spring) respectively fatigue life of composite mono leaf spring is higher than that of traditional steel leaf spring. For the equal load and boundary condition E-Glass/epoxy composite mono leaf spring has 27460 cycles whereas conventional metal leaf spring is 11238 cycle.so, this is how most aircraft and vehicle industries use today composite materials for the manufacturing of their vehicles.

4.3.6. Factor safety

As displayed so far in simulation result of both leaf sprigs for the same magnitude of the fatigue load the safety factor of composite mono leaf spring is up to 5 at the critical area of the leaf spring indicated by red color at the simulation in (Figure 4.11 Factor of safety of composite mono leaf spring) whereas in conventional steel leaf spring it is up to 3.25 in the critical area of leaf spring. (Table 4.2 Summary of result of conventional steel and composite mono leaf spring) presents the results obtained from this study.

4.4. Summary of the Results

Table 4.2 Summary of result of conventional steel and composite mono leaf spring

Leaf Springs	Maximum Equivalent stress (Mpa)		Maximum Total deformation (mm)		Weight in (N)	
	analytical	FEM	analytical	FEM		
Conventional steel	1563	253.22	6.80	7.68	288.7	
E-Glass/epoxy	290	196.28	9.92	11.78	111.6	
Percentage optimization	22.78%	22.48%	31%	34.8%	61.35%	
Summary of Fatigue Results						
Leaf spring	Alternating mean stress (Ma)		Fatigue life		Factor of safety	
	Analytical	FEM	Analytical	FEM	Analytical	FEM
Conventional steel	391.5	242.83	$1*10^{8}$	11238	1.8	3.25
E-Glass/epoxy	72.645	195.5	$1*10^{10}$	27460	1.8	5

The chart below shows the comparison results of FEA of conventional steel and E-Glass/epoxy mono leaf springs.

4.4.1. Comparisons of static structural analysis

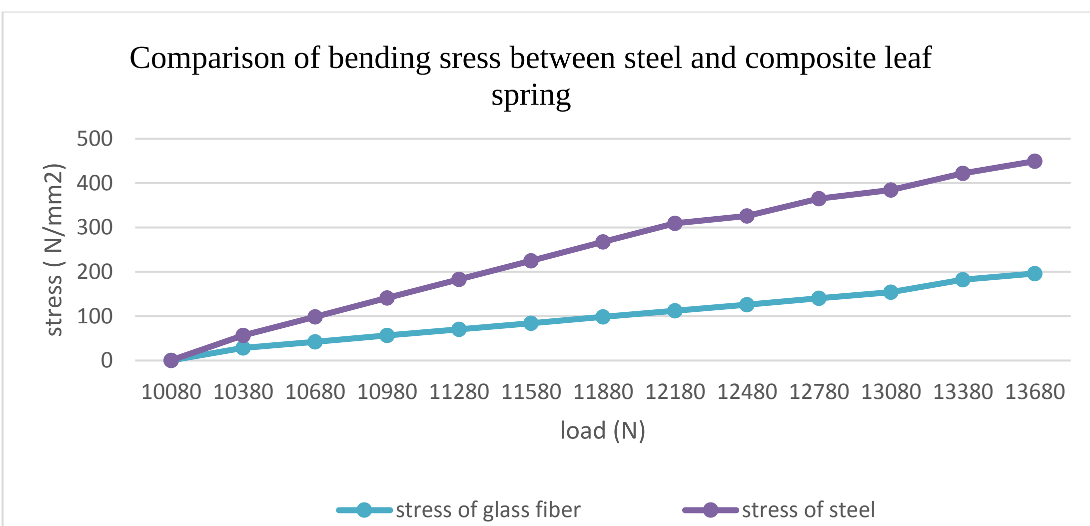

Figure 4.12 Comparison of equivalent stress of steel and composite leaf spring

As observed from the above chart (Figure 4.12 Comparison of equivalent stress conventional steel and E-Glass/epoxy mono leaf spring).conventional steel leaf spring is more stressed than new design of E -Glass/epoxy composite mono leaf spring.

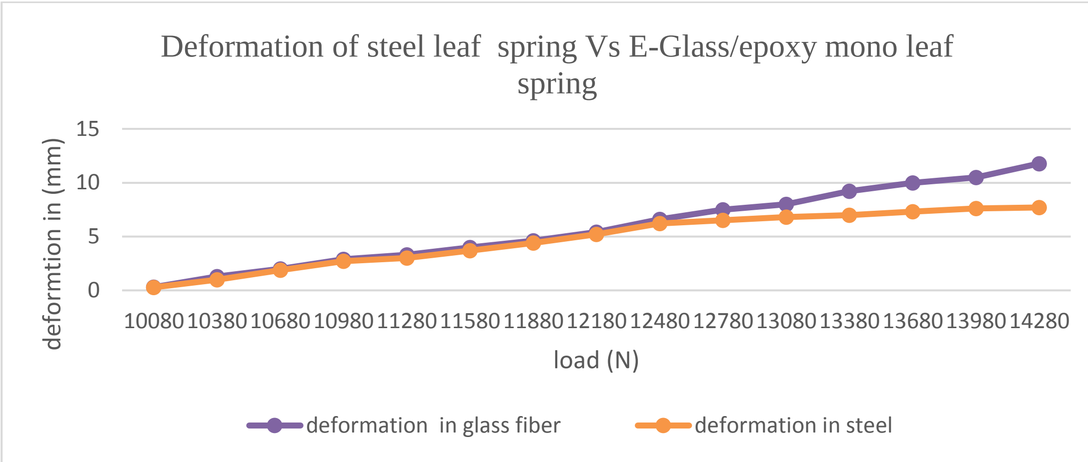

Figure 4. 13 Comparison of deformation for steel and E-Glass/epoxy mono leaf spring

As indicates the deformation of steel and composite material leaf springs in (Figure 4.13 Comparison of deformation for steel and E-Glass/Epoxy mono leaf spring). Cleary displayed that the deformation between the two leaf springs is almost equal and has no significant Difference .so, composite material leaf spring is can replace steel leaf spring for application of land cruiser vehicle

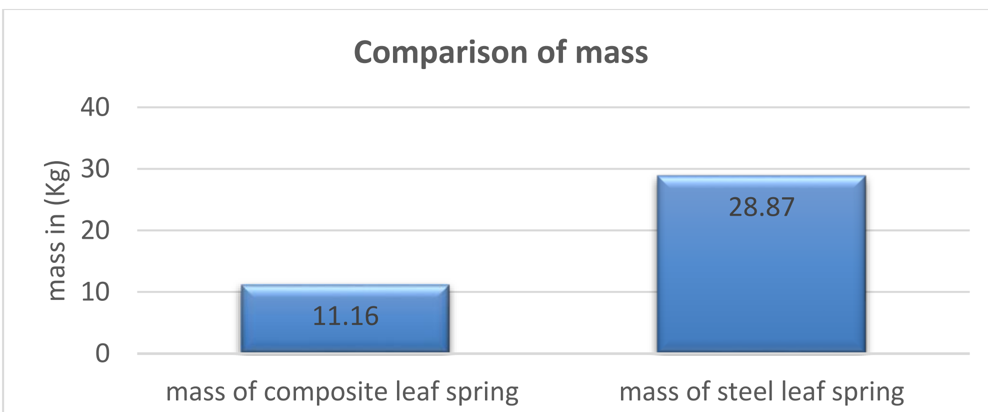

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Figure 4.14 Comparison of mass of steel and composite leaf spring

4.4.2. Comparison of fatigue (analysis) results

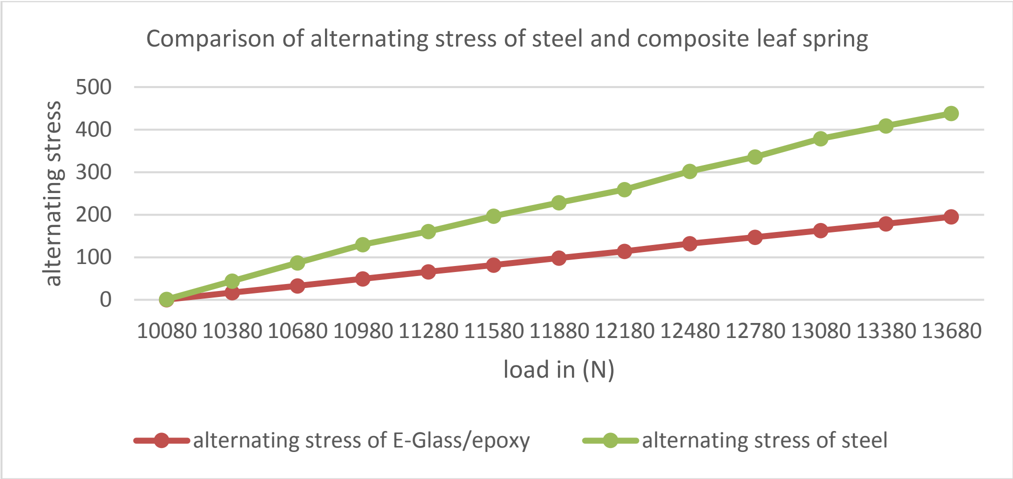

Figure 4.15 Comparison of alternating stress of steel and composite leaf spring

The alternating stress-induced in conventional steel leaf sprig is more than that of composite material leaf springs. So, when we use composite materials leaf spring, we can reduce the stress on the components when the leaf spring is subjected to fluctuating loads.

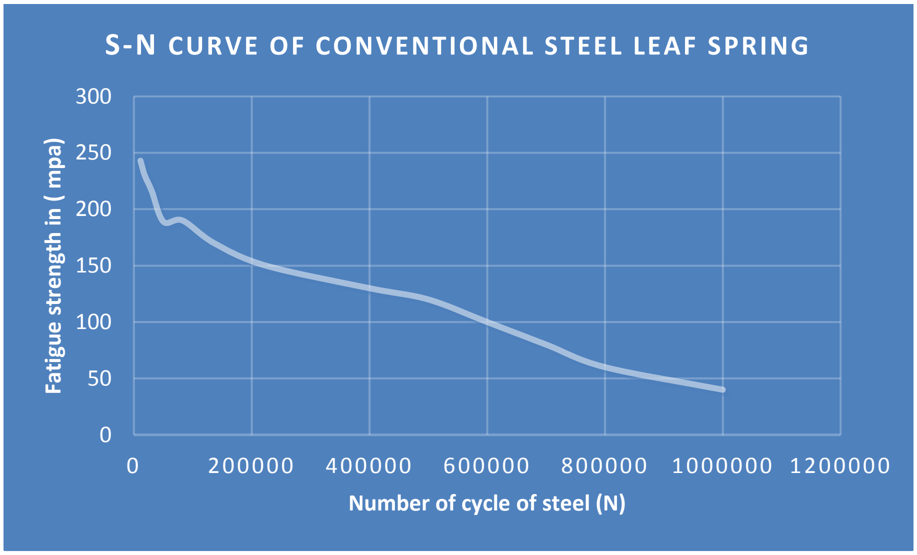

Figure 4.16 S - N Curve of conventional steel leaf spring

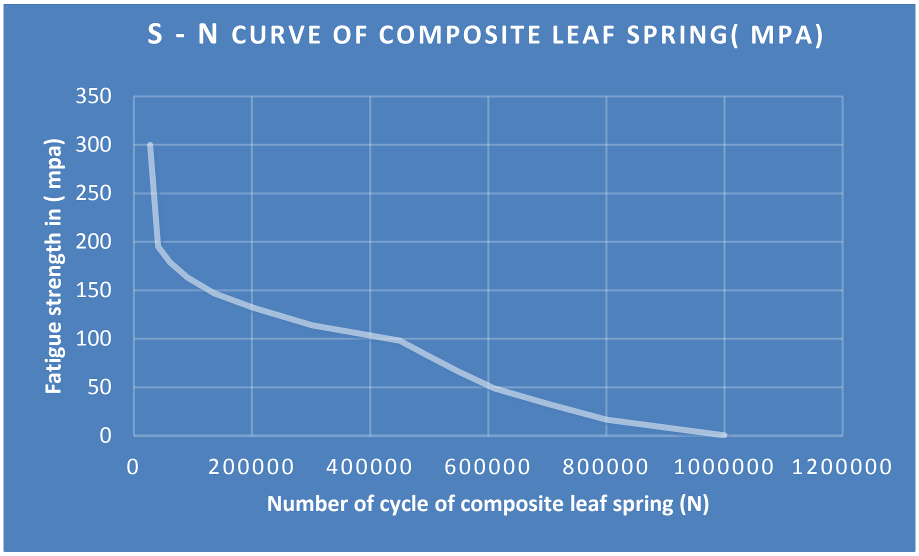

Figure 4.17 S - N curve of composite mono leaf spring

From the above Figures 4.16 and 4.17 S- N curves of both conventional steel and composite mono leaf spring, as clearly presented in (Figure 4.17 S- N Curve of composite mono leaf spring) the higher fatigue strength is achieved in composite material.

4.5. Results of Experimental study

4.5.1. Results of impact test

Figure 4.18 Impact test specimen after test

Table 4.3 Experimental results of impact test

Material Types					
A		B		C	
Specimen	Values of Impact Energy in (Joule)	Specimen	Values of Impact Energy in (Joule)	Specimen	Values of Impact Energy in (Joule)
1	10.2	1	9	1	9.3
2	12	2	9	2	7.8
3	10.8	3	9.3	3	8.4
Average	11	Average	9.1	Average	8.5

As observed from the result of Izod impact test presented in (Table 4.3 Experimental results of impact test). Material type A has higher impact energy absorption than material B and C .so, the strength of composite material are highly depending on the percentages of reinforcement fiber. Therefore 60% fiber and 40% resin matrix design of E-Glass/epoxy composite material is more preferable than 50%/50% and 40%/60%.

4.5.2. Result of creep test

Creep properties of a material are generally determined using a test in which a constant load or stress is applied to the specimen, which is maintained at high temperature, and the resulting strain is recorded as a function of time. The typical shape of a creep curve for this experiment results are is shown in the Figure below. When the load is applied, an instantaneous strain develops initially in the material and gives rise at time t = 0. In creep behavior, there are three stages in creep curves. The material initially deforms at a very rapid rate (dε/dt), but as time proceeds the rate of deformation progressively decreases and becomes constant. This regime of deformation is referred to as the first-stage of creep or the most important creep. In the second-stage of creep, usually referred to as the secondary creep or the steady-state creep, the strain rate remains steady for a long time. Although considerable deformation can happen underneath the steady-state creep conditions, the stress rate subsequently begins to accelerate with time and the material goes to the tertiary creep. The deformation then proceeds at an ever-faster rate till the material can no longer support the applied stress and fracture occurs. The material accordingly indicates the minimal creep rate, (dε/dt), in the steady-state regime.

Figure 4. 19 Creep test specimen after the test

Table 4.4 creep test result of specimen A

Specimen A														
Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε
0:15	44	0.55	5:00	49	.61	9:45	53	.66	14:30	77	.96	19:15	181	2.26
0:30	45	0.56	5:15	49	.61	10:00	53	.66	14:45	80	1	19:30	190	2.37
0:45	46	.575	5:30	49.5	.62	10:15	53.5	.668	15:00	85	1.06	19:45	203	2.53
1:00	46	.575	5:45	49.5	.62	10:30	54	.675	15:15	88	1.1	20:00	215	2.68
1:15	46.5	.58	6:00	49.5	.62	10:45	54	.675	15:30	91	1.13	20:15	224	2.8
1:30	46.5	.58	6:15	49.5	.62	11:00	54	.675	15:45	96	1.2	20:30	233	2.91
1:45	46.5	.58	6:30	49.5	.62	11:15	54.5	.68	16:00	100	1.25	20:45	246	3.075
2:00	47	.587	6:45	50	.625	11:30	55	.687	16:15	105	1.312	21:00	259	3.23
2:15	47.5	.59	7:00	50	.625	11:45	55	.687	16:30	110	1.375	21:15	273	3.4
2:30	47.5	.59	7:15	50	.625	12:00	57	.72	16:45	115	1.43	21:30	288	3.6
2:45	48	.6	7:30	50	.625	12:15	58	.725	17:00	119	1.48	21:45	306	3.82
3:00	48	.6	7:45	50	.625	12:30	60	.75	17:15	123	1.53	22:00	323	4.03

3:15	48.5	.606	8:00	50	.625	12:45	63	.787	17:30	129	1.61	22:15	340	4.25
3:30	48.5	.606	8:15	51	.625	13:00	65	.81	17:45	136	1.7	22:30	361	4.52
3:45	48.5	.606	8:30	51	.625	13:15	67	.83	18:00	139	1.74	22:45	375	4.687
4:00	48.5	.606	8:45	51.5	.643	13:30	68	.83	18:15	145	1.882	23:00	389	4.86
4:15	48.5	.606	9:00	52	.65	13:45	69	.86	18:30	150	1.87	23:15	420	5.25
4:30	49	.61	9:15	52	.62	14:00	70	.87	18:45	157	1.96	23:30	450	5.625
4:45	49	.61	9:30	52	.62	14:15	74	.925	19:00	172	2.15	23:45	480	5.625

The following figure is a strain curves of material A, which is plotted as strain versus time.

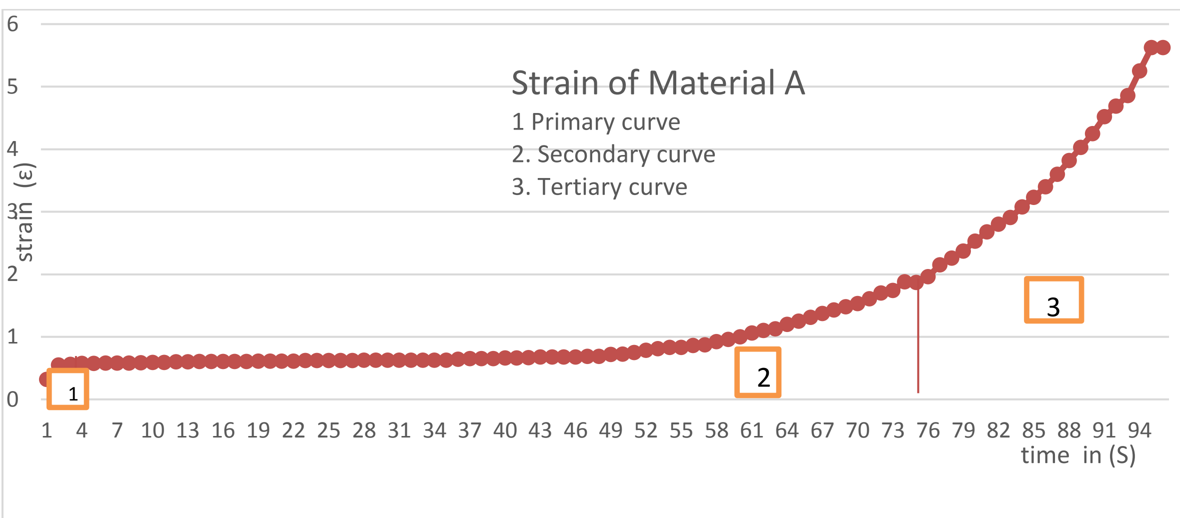

Figure 4. 20 Strain Vs time curve (strain curve)

Table 4.5 Creep test results of specimen B

Specimen B											
Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε
0:15	95	1.187	5:00	125.2	1.565	9:45	155	1.94	14:30	186	2.32
0:30	105	1.312	5:15	125.5	1.56875	10:00	156	1.95	14:45	187	2.337
0:45	107	1.337	5:30	125.9	1.574	10:15	157	1.9625	15:00	187	2.337
1:00	110	1.375	5:45	126.2	1.5775	10:30	165	2.0625	15:15	187	2.337
1:15	112	1.4	6:00	126.5	1.58125	10:45	168	2.1	15:30	190	2.375
1:30	115	1.4375	6:15	127	1.5875	11:00	169	2.11	15:45	191	2.3875
1:45	116	1.45	6:30	127.2	1.59	11:15	171	2.137	16:00	230	2.3875
2:00	117	1.462	6:45	127.5	1.594	11:30	173	2.16	16:15	275	3.4375
2:15	118	1.475	7:00	128	1.6	11:45	174	2.175	16:30	370	4.625
2:30	119	1.487	7:15	128.3	1.603	12:00	175.5	2.193	16:45	490	6.125
2:45	120	1.5	7:30	129	1.61	12:15	177	2.21	17:00	595	7.437
3:00	121	1.512	7:45	129.1	1.613	12:30	178	2.225	17:15	710	8.875
3:15	122	1.525	8:00	130	1.625	12:45	179	2.237	17:30	805	10.06

3:30	122.5	1.5312	8:15	130.1	1.62	13:00	180	2.25	17:45	910	11.375
3:45	123	1.5375	8:30	130.2	1.627	13:15	181	2.26	18:00	-------	---------
4:00	123.5	1.543	8:45	145	1.81	13:30	182	2.275	18:15	------	---------
4:15	124	1.55	9:00	149	1.8625	13:45	183	2.287	18:30		
4:30	124.3	1.554	9:15	150	1.875	14:00	184	2.3	18:45		
4:45	125	1.5625	9:30	153	1.91	14:15	185	2.31	19:00		

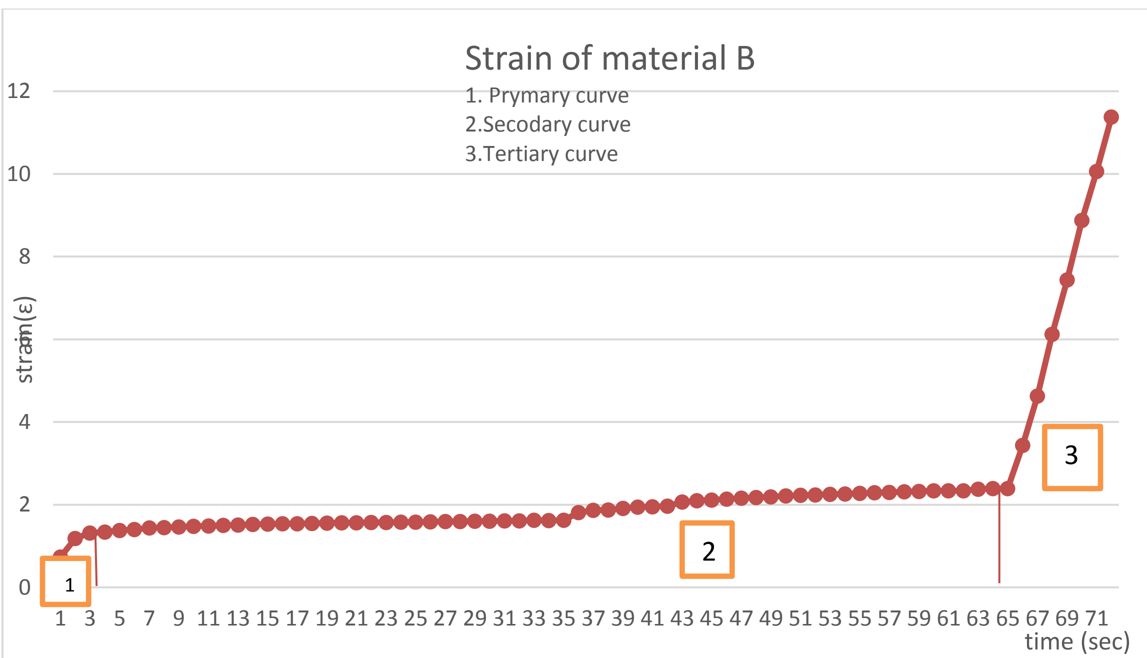

Figure 4. 21 Strain Vs time curve (strain curve)

Table 4. 6 Creep test results of specimen

Specimen C											
Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε	Time in (s)	ΔL in (mm)	ε
0:15	43	.5375	5:00	58	.725	9:45	63	.7875	14:30	561	7.0125
0:30	44	.55	5:15	58.5	.73125	10:00	63	.7875	14:45	640	8
0:45	46	.575	5:30	58.5	.73125	10:15	64	.8	15:00	720	9
1:00	47	.5875	5:45	59	.7375	10:30	65	.8125	15:15	810	10.125
1:15	47	.5875	6:00	59.5	.74375	10:45	67	.8375	15:30	850	10.625
1:30	53	.662	6:15	59.5	.74375	11:00	70	.875	--------	--------	--------
1:45	53	.662	6:30	59.5	.74375	11:15	76	.95	-----------	----------	-----------
2:00	53.5	.6687	6:45	59.8	.7475	11:30	85	1.0625			
2:15	54	.675	7:00	60	.75	11:45	98	1.225			
2:30	54.5	.681	7:15	60	.75	12:00	115	1.4375			
2:45	55	.6875	7:30	60	.75	12:15	132	1.65			
3:00	55.5	.694	7:45	60.5	.7562	12:30	165	2.0625			
3:15	56	.7	8:00	60.5	.7562	12:45	190	2.375			
3:30	56	.7	8:15	61	.762	13:00	230	2.875			
3:45	56.5	.706	8:30	61	.762	13:15	271	3.3875			
4:00	57	.712	8:45	61	.762	13:30	316	3.95			
4:15	57	.712	9:00	61	.762	13:45	380	4.75			
4:30	57.5	.7187	9:15	61	.762	14:00	430	5.375			
4:45	58	.725	9:30	62	.775	14:15	490	6.125			

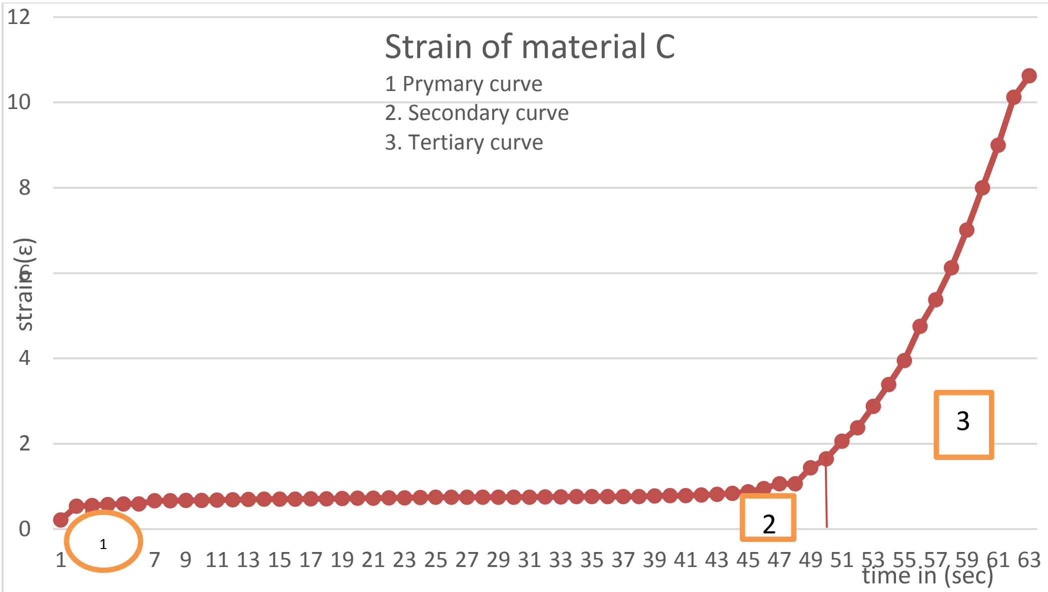

Figure 4. 22 Strain Vs time curve (strain curve)

As observed from the creep test results in (Table 4.4, 4.5and 4.6 creep test result of specimen A, B, C respectively) and the creep curve in (Figure 4. 20, 4.21 and 4.22 strain Vs time curve (strain/creep curve) respectively

for the same capacity of load applying in in the three materials (A, B and C) .material A is fracture after long times than material B and C. and material B is fracture after material C. this implies that material A has best creep (deformation) resistance behavior and material B and C are next to A respectively.

If the higher deformation of the materials, the lowest strength, and elasticity properties. Now to compare the elasticity (E) of material A, B, and C consider the deformation result obtained from the creep test experiment in (Table 4.4, 4.5 and 4.6 creep test result) for material A, B, and C respectively at a time of 14 minutes (840 sec) for all at a constant tensile load (21N) and the constant stress of 0.021mpa.

$$E = \frac{\sigma}{\varepsilon} \tag{4.1}$$

$$E_A = \frac{0.02\text{N}}{0.87} = 24.1kpa$$

$$E_B = \frac{0.02\text{N}}{2.3} = 9.13kpa$$

$$E_c = \frac{0.02\text{N}}{5.375} = 3.907kpa$$

From the above results, we say that material A has good elasticity properties than the two others and when it subjected to tensile loads it is not easily deformed, and even after deformation, it regains its original shape as soon as when the load is removed.

After plotting the recorded results of creep test for the three parameters (40/60, 50/50 and 60/40) compositions of composite materials, it is necessary to

1. Calculate the creep rate as a function of time and identify the various stages of creep
2. Report the minimum creep rate at each stage ($\dot{\varepsilon}$)

$$\dot{\varepsilon} = \frac{d(\varepsilon)}{d(t)} = \frac{\Delta\varepsilon}{\Delta t} \tag{4.2}$$

Generally, in creep curves, there are three ranges of creep rates and also from this experiment, these three levels of the creep rates are found in creep curves of each composition parameter of composite materials. the First stages (primary curve), second stages or steady-state and third ranges or tertiary.so one of the essential pursuits of the creep test is to decide the creep rates of a variety of substances at special degrees in creep curves. Using equation 4.1determines creep rates of these three stages of creep.

For material (A) or 60/40 composition.

At primary curves (stage1)

$\varepsilon_0 = 0.321$

$\varepsilon_f = 0.56$

$\blacktriangle\ \varepsilon = \varepsilon_f - \varepsilon_0$

$0.56 - 0.321 = 0.239$

$t_0 = 1$

$t_f = 3$

$\blacktriangle t = 3 - 1 = 2$

$\dot{\varepsilon} = \frac{\Delta\varepsilon}{\Delta t}, = \frac{0.239}{2}$

$\dot{\varepsilon} = 0.1195$

By the same fashion remain values of creep rate results at each stage are summarized in the following table.

Table 4.7 Creep rate values in different stage

Materials (A) 60/40	Creep rate ($\dot{\varepsilon}$)	Material (B) 50/50	Creep rate ($\dot{\varepsilon}$)	Material (C) 40/60	Creep rate ($\dot{\varepsilon}$)
Stage 1	0.1195	Stage 1	0.29	Stage 1	0.16735
Stage 2	0.0158	Stage 2	0.01734	Stage 2	0.02929
Stage 3	0.18715	Stage 3	0.9986	Stage 3	0.65625

As determined creep rates of the three materials at each stage in the creep curve, the creep rates are observed in three different regions, and from the three different regions, the minimum amounts of creep rates of each material are appeared at the second stage or in the steady stat curve. These are 0.0158, 0.01734, and 0.02929 for material A, B, and C respectively. From these values material, A has the smallest creep rate. This implies that the lower minimum creep rates the higher the strength of the materials. According to the material test manual, the minimum creep rate is considered as the engineering design parameter in selecting a material.

Chapter 5: Conclusion and Recommendation

5.1. Conclusion

In this study, design, analysis, and experimental investigation of E-Glass/epoxy composite materials are conducted for the utility of Toyota land cruiser car leaf spring. First, analytical and finite element analysis was once performed between traditional steel and E-Glass/epoxy composite mono leaf spring the usage of ANSYS workbench to evaluate the strength properties of these substances related to the utility of land cruiser leaf spring subjected to static and fatigue loading. In the static analysis, the stress-induced in conventional steel leaf spring are 253.22MPa whereas in composite mono leaf spring are 196.28MPa. These values indicate E-Glass/epoxy composite mono leaf spring has correct strength and it is better for the utility of leaf spring. In fatigue analysis, the factor of safety of the two leaf springs are 3.25 and 5 respectively for conventional steel and E-Glass/epoxy composite mono leaf spring .this implies that the permissible or working stress of the composite mono leaf spring is up to the elastic region and due to this the material recognizes long life. As stated, the fatigue life of these materials are 11238 and 27460 respectively for conventional steel and composite mono leaf spring. The size optimization on these leaf springs also done and this helps to weight reduction.in conventional steel leaf spring the total thickness obtained from the actual vehicle is 48mm whereas for the design of composite mono leaf spring the thickness is reduced to 39.5 for the same load-carrying capacity while the other dimensions remain the same. So, using composite materials for the design of the leaf spring application it has to be achieved 61.35% of weight reduction over the existing steel leaf spring. This improves fuel consumption of the vehicles and it leads the vehicle industry to immerge confidently for mass production of fuel-saving vehicles. Thereby it reduces air prolusion.

Finally, E-Glass/epoxy composite materials sample specimens are manufactured for different fiber to matrices volume ratio, and its mechanical properties like impact and creep performances are determined experimentally to found out composite material with optimum strength for practical use.

In the impact test result material A can absorbs 11Joule impact energy and where material B and C are 9.1 and 8.5 Joule respectively. The creep test result also shows that material A gets completely fracture after a long time of constant loading than material B and C.

it confirmed that the mechanical properties of composite materials highly depend on fiber and matrices contents if an increase in fiber content increases delamination and if increase the contents of matrix, increase brittleness. So, to compromise this trade off and to achieve the optimum properties of composite materials the ratio of reinforcement fiber to matrices should be balanced regarding to the character of composite materials. from the three composition parameters conducted in this experiment, the material with 60:40 compositions are better for application as it has optimum properties with less brittleness and delamination.

5. 2. Recommendation

As discussed so far, the weight of the vehicle is the main cause of the increase in fuel consumption.to overcome this problem the vehicle manufacturer should be using different composite materials for structural parts .since composite materials are very light in weight and strong so, to attain the best fuel economy and efficient vehicle design, composite materials are the best option. Especially, for the new generation, electrical vehicles' weight is the main factor of the ineffectiveness of these vehicles.

Finally, conventional steel leaf springs of Land cruiser vehicle is can be replaced by this new generation composite materials and it also recommends to use as other parts of components of any vehicle.

5. 3. Future work

Regarding the different mechanical application of composite materials, there are different types of design and optimization concepts which are not addressed in this study.so, different scholars who have interests to conduct studies on composite materials are recommends to work on,

1. Designing of composite structure in different orientation and stacking sequence
2. Dynamic analysis of leaf spring
3. Conduct experiment in the fatigue behavior of composite materials
4. Design laminate composite structure using different fiber and different resin types.

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