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School of Mechanical, Chemical and Materials Engineering

Design and analysis of mono composite leaf spring for light weight vehicle

Thesis

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ACRONYMS AND ABBREVIATIONS

FEA – Finite Element Analysis

3D – Three Dimensional

BIS – Bureau of Indian Standard

FS – Factor of Safety

BC – Before Jesus Chris

PMCs – Polymer Matrix Composites

MMCs – Metal Matrix Composites

CMCs – Ceramic Matrix Composites

CCCs – Carbon/Carbon Matrixes

CTE – Coefficient of Thermal Expansion

SMC – Sheet Molding Compound

SRIM – Structural Reinforcement Injection Molding

HS – High Strength

PAN – Polyacryonitride

FRP – Fiber Reinforced Polymer

CAD – Computer Aided Design

CATIA – Computer Aided Three Dimensional Interactive Applications

CAM – Computer Aided Modeling

CAE – Computer Aided Engineering

FEM – Finite Element Method

GVM – Gross Vehicle Mass

SN – Stress Vs Number of Cycle

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ABSTRACT

This thesis focuses on the replacement of steel or conventional leaf spring of a suspension system with composite material. Design and analysis of composite material leaf spring has become essential in showing the comparative results with conventional leaf spring. The Automobile industry has shown the interest for replacement of steel leaf spring with that of glass fiber composite leaf spring, since the composite has high strength to weight ratio, good corrosion resistance and tailor-able properties. The suspension system in automobile significantly affects the behavior of vehicle, i.e. vibration characteristics including ride comfort, directional stability, etc. leaf spring used in the suspension system of automobile are subjected to millions of varying stress cycles leading to fatigue failure. If the unsprung weight (the weight, which is not supported by the suspension system) is reduced, then the fatigue stress induced in the leaf spring is also reduced. Even a small amount of weight reduction in the leaf spring will lead to improvements in passenger comfort as well as reduction in vehicle cost. In this context, the replacement of steel leaf spring by composite material reduces the weight of leaf springs. In this work, the existing steel leaf (multi-leaf) spring of Huanghai pick up is taken for modeling and analysis. The design constraints are stress and displacement. A composite mono leaf spring of E-glass Epoxy composite material is modeled and subjected to the same load as that of steel leaf spring. Composite mono leaf spring is modeled with constant cross section in CATIA and stress, deflection, modal (natural frequency) safety factor and fatigue analysis of this model is performed using ANSYS 12.0 and results were compared. Analysis results of stress, weight, deflection and fatigue life of existing and mono composite leaf spring is found with a great difference. Mono composite leaf spring has 73.24% lesser stress, 5.3% lesser deflection, 92.9% weight reduction and longer fatigue life than existing leaf spring thereby increased safety factor is observed. Natural frequency of composite leaf is less than existing but which is greater than road frequency (12Hz), so that it is comfortable and resonance is also very much reduced.

Keywords: composite leaf spring, carbon/Epoxy composite material, conventional leaf spring, design and analysis

1. INTRODUCTION

Leaf springs are crucial suspension element used on the vehicle to minimize the vertical vibrations impacts and bumps due to road irregularities and to create a comfortable ride. Leaf springs are widely used for automobile and rail road suspensions. The leaf spring should absorb or minimize the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection.

To meet the needs of natural resources conservation and economize energy, weight reduction has been the main focus of automobile manufacturer in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. Since ,the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi- leaf steel spring are being replaced by mono composite leaf spring. The composite material offer opportunities for substantial weight saving but not always are cost- effective over their steel counter parts. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that potential energy stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies made, a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring. Fortunately, composite have these characteristics.

Increasing competition and innovations in automobile sector tends to modify the existing products or replacing old products by new and advanced materials products. To improve the suspension system many modification have taken place over the time. Inventions of parabolic leaf spring, use of composite material for this spring are some of the latest modification in suspension systems. This paper is mainly focused on the implementation of composite materials by replacing steel in conventional leaf spring of a suspension system and analysis of composite material leaf spring has become essential in showing the comparative results with conventional leaf spring.

In this analysis the conventional steel leaf spring is tested for different load conditions and results will be compared with a virtual model of mono composite leaf spring. Leaf spring is modeled in CATIA V5 and imported in to ANSYS for better results. Results are compared on the basis of analysis reports produced by ANSYS software.

The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight. This helps in achieving the vehicle with improved riding qualities. Springs are designed to absorb and store energy and release it. Hence, the strain energy of the material becomes a major factor in designing the springs.

1.1. Background of the study

As it is known that our country is in the stage of developing automotive industry, and believed that the industry is playing crucial role in the development of the country. However, most of the existing automotive industries except some import the components of the car and assemble it. This will increase the initial the cost of the car and intelligence dependency will not be eradicated unless the company starts analyzing and designing the existing material or produce new alternative from other different material which is available nearby.

Therefore, in order to improve the development of industry it is important to give emphasis towards replacing components which can easily produced locally having the same or more strength and stiffness. One of the methods to reduce the weight and cost of the car can be done by thoroughly analyzing and designing the existing component. This research focuses on replacing the conventional multi steel leaf spring with mono composite leaf spring.

1.2. Statement of the problem

The ever growing of interest of problem finding and solving will bring many changes in the future that we think it would be impossible to improve the present technologies we are using every day in our life. In automotive industries also many improvements have been done so far and will in the future. In this study multi leaf steel leaf spring will be replaced with single composite leaf spring. Since multi- leaf structure creates problem such as producing squeaking sound, fretting corrosion thereby decreasing the fatigue life. The conventional leaf spring has low strength to weight ratio, this intern increases the overall weight of the car. It is well known that as the weight of the car increases more power is required to propel the car. This can be done by burning more fuel; on the other hand it will lead to air pollution and low fuel economy. Therefore, the problem can be reduced a little bit by replacing steel leaf with composite material, since composite materials have high strength to weight ratio (light in weight and high strength) which makes them preferable than steel in the present days because of the counter problems related to increasing weight and low strength such as low fatigue life, low fuel economy and high emission. As long as the above problems are concerned steel has to be changed with another material which can reduce those problems even though it seems that steel leaf spring performs well.

This work considers an existing multi steel leaf spring of pick up and mono composite leaf spring with upturned eye and analyzing it. This is done to replace conventional steel leaf spring with glass fiber/epoxy composite leaf spring and to achieve substantial weight reduction and increased fatigue life in the suspension system by replacing steel leaf spring with composite leaf spring. On this thesis, designing single composite leaf spring of pick up will be done. As we can see on the literature review all researchers have done their research on other different type of vehicle other than pick up and this will make this work unique (new) and dynamic loads will be done, this will add some different work load since all the parameter that will be taken will be different. A virtual model of both steel and mono composite leaf spring will be created in CATIA Vs. ANSYS is used for analysis by applying loads.

This research will pave the way for automotive industries to look for composite material and other material that can be produced in their work shop.

1.3. Significance of the study

Since sufficient studies have not been done to mitigate running cost of the vehicle throughout its life span and environmental pollution caused by automobile emissions, intern these emission highly dependent on the type of the vehicle we are running, type of fuel we are using, age of the vehicle, and the weight of the vehicle. This study attempts new approach to reduce the weight of the car thereby there will be high fuel economy, low emissions and reduce cost savings due to importing. The study will help the company (automotive industry) at large and the public in particular, if the outcome of this study is implemented. The industry will maximize its profit due to the absence of importing steel leaf spring and customers will get an advantage on the reduction of sales cost and good fuel economy. Introducing use of composite material for Ethiopian automotive industries for different parts of the car as it will help them save costs.

- Economical benefit
  - Saving costs of importing steel leaf spring
  - Optimize Automotive industry usage
  - Due to weight reduction there will be low fuel consumption
  - Job opportunity
- Environmental benefits
  - Reduce pollution

1.4. Objectives of the study

1.4.1 General objective

The general objective of this thesis work is to analyze mono composite leaf spring designed for light weight vehicle.

1.4.2 Specific objective

- To study the conventional leaf spring of Huanghai pick up
- To develop model of leaf spring using CATIA
- To analyze conventional leaf spring and mono composite leaf spring with ANSYS
- To study the manufacturing processes of composite material

1.5. Scope of the study

This research work covers design and static and dynamic analysis of mono composite leaf spring for light weight vehicle and composite leaf spring having constant cross-section throughout its length. Variable thickness with variable width and constant thickness with variable width leaf spring are not considered. The data related to type of material and dimension of existing pick-up multi leaf spring will be modeled and analyzed subjected to loads as if it is on real road condition and results will be compared with that of analysis results of mono composite leaf spring subjected to the same load as that of multi leaf spring.

1.6. Limitations of the study

Problems encountered while doing this thesis work are the following:

- In order to cope with shortage of time and resources, the study did not include transient analysis
- Finding the exact dimensions of the existing leaf spring was challenging because, the right measuring tools by which measurements can be done is not available.
- Getting existing leaf spring material composition was also the real problem using the standard instruments because the manufacturer hides from being seen and this helps them to keep their technology away from illegal duplication.

2. LITERATURE REVIEW

The literature review mainly focuses on the replacement of steel spring with composite leaf spring made of glass fiber reinforced polymer.

Leaf springs are used for absorbing vehicle vibrations, shocks and bump loads (induced due to road irregularities) by means of deflection. For the same load and shock absorbing performance, steel leaf spring uses excess material which makes them considerably heavy. This can be improved by introducing composite material in place of steel leaf spring. Studies and researches were carried out on the application of composite material in leaf spring.

Amol Bhanage [1] has described design and simulation comparison of mono leaf spring using SAE1045-450-QT and E-Glass/Epoxy materials for automotive performance. This study presented comparative simulation results of E-glass epoxy mono composite leaf spring for different layup as well as for different thickness conditions and simulation results of SAE 1045-450- QT steel material. ANSYS software was used for simulation results. Variation in thickness and layup thought to have effect on stress and deflection parameter; therefore, this will be helpful for the researchers for selecting the proper layup and thickness of leaf spring.

M. Raghavedra et al. [2] described modeling and analysis of laminated composite leaf spring under static load condition by using FEA. The dimensions of an existing mono steel leaf spring of a Maruti 800 passenger vehicle is taken for modeling and analysis of laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, S-lass/Epoxy and carbon/Epoxy. Analysis of a 3-D model has been done using ANSYS 10.0 and laminated composite mono leaf spring is found to have 47% lesser stress, 25%- 65% higher stiffness, 73%-80% weight reduction.

Achamyeleh et al. [3] described design of single composite leaf spring for light weight vehicle. Reducing weight of the vehicle and increasing or maintaining the strength of their spare parts are considered by replacing steel leaf spring with fiber glass composite leaf spring. Dimensions of steel leaf spring of TATA-Ace light weight vehicle were taken and 68.14% weight reduction was observed for the same dimension of fiber glass composite leaf spring as that of steel leaf spring.

V. Pozhilarasu et al. [4] performed performance comparison of conventional and composite leaf spring. The conventional steel leaf spring and composite leaf spring were analyzed under similar conditions using ANSYS software. Leaf spring is modeled in unigraphics NX4 software and imported in ANSYS 11.0 to be analyzed. The result has shown that deflection and stress of steel leaf spring and composite leaf spring are found with great difference under the same static load condition. Deflection of composite leaf spring is less as compared to steel leaf spring.

J.P. Hou et al. [5] presented the design evolution process of a composite leaf spring for freight rail applications. Three designs of eye end attachment for composite leaf spring are described. The material used is glass fiber reinforced polyester. Static testing and finite element analysis have been carried out to obtain the characteristics of the spring. Load deflection curves and strain measurement as a function of load for the three designs tested have been plotted for comparison with FEA predicted values. The main concern associated with the first design is the delamination failure at the interface of the fiber that have passed around the eye and the spring body, even though the design can withstand 150KN static proof load and one million cycles fatigue load. FEA results confirmed that there is a high inter laminar shear stress concentration in the region. The second design feature is an additional transverse bandage around the region prone to delamination. Delamination was contained but not completely prevented. The third design overcomes the problem by ending the fibers at the end of the eye section.

Mouleeswaaran Senthil Kumar et al. [6] in this paper composite leaf is designed on the basis of fatigue failure. Theoretical equation for prediction of fatigue life is formulated using fatigue modulus and its degrading rate. The dimensions and numbers of leaves for both steel leaf spring and composite leaf spring are considered to be the same. The stress analysis is performed using finite element method. The element selected for analysis is solid 45 which behave like spring. For the fabrication of each leave the filament winding machine is used and assembled. This leaves together with the help of center bolt and four side clamps. The testing of steel multi leaf spring and composite multi leaf spring are carried out with the help of an electro hydraulic leaf spring test rig. Design and fatigue analysis of composite multi leaf spring are carried out using data analysis. It is found that composite leaf spring has 67.35% lesser stress, 64.95% higher stiffness and 126.98% higher natural frequency and also 68.15% weight reduction is achieved.

Kumar Y. N. V. Santosh et. al. [36], this study focused on many advantages of composite structures for conventional structures because of higher specific stiffness and strength of composite materials. The aim of this work was to compare the conventional leaf spring with the composite one in several aspects such as weight, cost, and strength and load carrying capacity. The objective of this work was to consider an existing automobile leaf spring model TATA sumo ezrr parabolic rear and to design and analyze a composite leaf spring with upturned eye without changing stiffness in order to replace the existing steel leaf spring with a composite leaf spring. In this work a leaf spring modeled in Pro/E was imported to ANSYS in IGS format and where it was analyzed in metaphysics using steel material (55Si2Mn90) and than by changing the material as composite one (E-glass/ epoxy) again analyzed. The comparison was done after analyzing. On comparing it was found that the deflection in the composite leaf spring almost equal to the conventional leaf spring and hence stiffness of both same. It was also concluded that, the weight reduction was achieved by using composite material and reduced by 60.48% with good strength and load carrying capacity of the leaf spring.

Patunkar M. M. et. al. [37], the objective of their work was to present modeling and analysis of composite mono leaf spring and compares its results. In this work conventional leaf spring was tested for the static load conditions and the material of the conventional leaf spring was 60Si7 (BIS). According to the same design data a virtual model was created of a composite material leaf spring the material E-glass/Epoxy was selected as for composite one. Leaf spring was modeled in Pro/E 5.0 and analyzed in ANSYS 10.0. The tested results of the conventional leaf spring were compared with the virtual model of the composite material leaf spring. For analyzing the leaf spring finite element method was used. From the comparison it was found that the deflection of the composite leaf spring lesser than that of the conventional leaf spring. This work considered leaf spring because of it contributes considerable amount of weight to the vehicle and needs to be strong enough. This work considered for light weight three wheeler vehicles and a single E-glass/epoxy leaf spring designed, simulated by following design rules of the composite materials and fabricated by hand lay-up method. The leaf spring was tested and analyzed for static load only. It was concluded that E-glass/epoxy leaf spring designed and simulated in this work having stresses much below the strength properties of the material satisfying the maximum stress failure criterion.

Manjunath H.N checked the suitability of composite materials like E-glass/epoxy, graphite/epoxy, boron/aluminum, carbon/Epoxy and kevlar/epoxy for light commercial vehicle leaf spring. The results are compared with theoretical values and concluded that they have good agreement with each other. They calculated the fatigue life of various composite leaf springs using Hwang and Han relation. They found that boron/aluminum and graphite/epoxy are best suitable composite material for leaf spring.

2.1. Suspension system

Suspension systems have been widely applied to vehicles, from the horse drawn carriage with flexible leaf springs fixed in the four corners, to the modern automobile with complex control algorithms. The suspension of a road vehicle is usually designed with two objectives; to isolate the vehicle body from road irregularities and to maintain contact of the wheels with the roadway. Isolation is achieved by the use of springs and dampers and by rubber mountings at the connections of the individual suspension components. From a system design point of view, there are two main categories of disturbances on a vehicle, namely road and load disturbances. Road disturbances have the characteristics of large magnitude in low frequency such as hills and small magnitude in high frequency such as road roughness. Load disturbances include the variation of loads induced by accelerating, braking and cornering. Therefore, a good suspension design is concerned with disturbance rejection from these disturbances to the outputs. Roughly speaking, a conventional suspension needs to be soft to insulate against road disturbances and hard to insulate against load disturbances. Therefore, suspension design is an art of compromise between these two goals. The main functions of a vehicle’s suspension systems are to isolate the structure and the occupants from shocks and vibrations generated by the road surface. The suspension systems basically consist of all the elements that provide the connection between the tires and the vehicle body. The suspension system requires an elastic resistance to absorb the road shocks and this job is fulfilled by the suspension springs. According to Gillepsie (1992), the primary functions for suspension systems are;

- Provide vertical compliance so the wheels can follow the uneven road, isolating the chassis from roughness in the road.
- Maintain the wheels in the proper steer and camber attitudes to the road surface.
- React to the control forces produced by the tires longitudinal (acceleration and braking) forces lateral (cornering) forces, and braking and driving torques.
- Resist roll of the chassis.
- Keep the tires in contact with the road with minimal load variations

To accomplish all functions, the suspension system requires an elastic resistance to absorb the road shocks and this job is fulfilled by the suspension springs.

2.1.1 Suspension springs

Spring is defined as an elastic machine element, which deflects under the action of the load and returns to its original shape when the load is removed. Mechanical springs are used in machine designs to exert force, provide flexibility, and to store or absorb energy. Springs are manufactured for many different applications such as compression, extension, torsion, power, and constant force. Depending on the application, spring may be in a static, cyclic or dynamic operating mode. A spring is usually considered to be static if a change in deflection or load occurs only a few times, such as less than 10,000 cycles during the expected life of the spring. A static spring may remain loaded for very long periods of time. The failure modes of interest for static springs include spring relaxation, set and creep.

The main objectives of spring are the following:

- To apply force: A majority industrial, e.g. To provide the operating force in brakes and clutches, to provide a clamping force, to provide a return load, to keep rotational mechanisms in contact, make electrical contacts, counterbalance loading, etc.
- To control motion: Typically storing energy, e.g. wind up springs for motor, constant torque applications, torsion control, position control, etc.
- To control vibration: used in essence for noise and vibration control, e.g. flexible couplings, isolation mounts, spring and dampers, etc.
- To reduce impact: Used to reduce the magnitude of the transmitted force due to impact or shock loading, e.g. buffers, end stops, bump stops etc. In practical situations, springs are used to provide more than one of the above functions at the same time. Because of superior strength and endurance characteristics under load, most springs are metallic However, other resilient materials, e.g. polymers, where special properties such as a low modulus and high internal damping capacity are required.

2.1.2 Classification of spring

2.1.2.1 Leaf spring

Leaf springs can serve both damping as well as springing functions. The leaf spring can either be attached directly to the frame at both ends or attached at one end usually the front with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes softer springiness. Failure prediction in large scaled structures that are subjected to extreme loading conditions has been of utmost interest in the scientific and engineering community over the past century [15]. Failure of mechanical assembly component is a common phenomenon due to fracture that occurs almost everywhere in mechanical structures. The main cause of failure of leaf spring is due to large bending behavior [16, 17]. The plate spring or leaf spring is used in which the major stresses are tensile and compressive. Leaf springs may be of cantilever type or semi elliptical or elliptical. A leaf spring consists of flat leaves or plates of varying lengths clamped together so as to obtain greater efficiency and resilience. The figure shows leaf spring

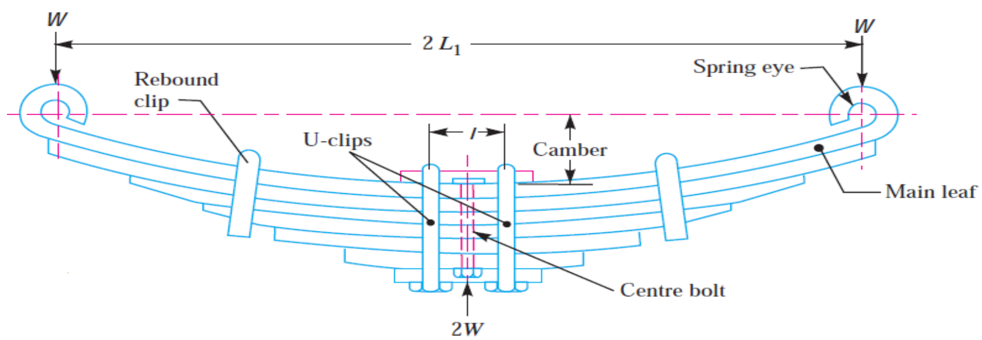


Figure 1 leaf spring

2.1.2.2 Cylindrical helical spring

Fig.2 shows cylindrical helical spring which may be in compression or tension. The major stresses produced in this are shear due to twisting. The load applied is parallel to the axis of spring. The cross section of the wire may be round, square or rectangular. These springs are wound in the form of a helix of a wire [32].

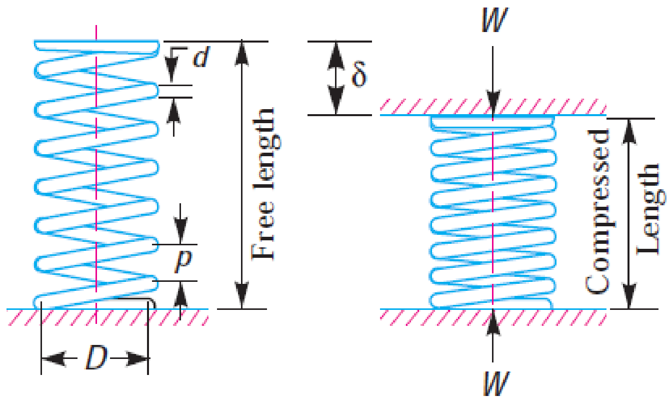


Figure 2 cylindrical helical spring

2.1.3 Concept of spring design

The design of a new spring involves the following considerations:

- Space into which the spring must fit and operate
- Values of working forces and deflections
- Accuracy and reliability needed
- Tolerances and permissible variations in specifications
- Environmental conditions such as temperature, presence of a corrosive atmosphere
- Cost and qualities needed

The designers use these factors to select a material and specify suitable values for the width, thickness, the number of leaves, the eye diameter and the free length, type of ends and the spring rate needed to satisfy working force deflection requirements. The primary design constraints are that the material with selected size should be commercially available and that the stress at the solid length be not greater than the tensional yield strength [33, 35].

2.1.4 Spring materials

One of the important considerations in spring design is the choice of the spring material. Springs are usually made from alloys of steel. The most common spring steels are music wire, oil tempered wire, chrome silicon, chrome vanadium and stainless. Other materials can also be formed into springs, depending on the characteristics needed. Some of the more common of these exotic metals include beryllium copper, phosphor bronze, Monel, and titanium. Titanium is the strongest material, but it is very expensive. Next come chrome vanadium and chrome silicon, then music wire, and then oil tempered wire.

Some of the common spring materials are given below.

- Hard-drawn wire: This is cold drawn, cheapest spring steel. Normally used for low stress and static load. The material is not suitable at subzero temperatures or at temperatures above 1200℃.
- Oil-tempered wire: It is a cold drawn, quenched, tempered, and general purpose spring steel. It is not suitable for fatigue or sudden loads, at subzero temperatures and at temperatures above 1800℃.
- Chrome Vanadium: This alloy spring steel is used for high stress conditions and at high temperature up to 2200℃. It is good for fatigue resistance and long endurance for shock and impact loads.
- Chrome Silicon: This material can be used for highly stressed springs. It offers excellent service for long life, shock loading and for temperature up to 2500℃.
- Music wire: - This spring material is most widely used for small springs. It is the toughest and has highest tensile strength and can withstand repeated loading at high stresses. It cannot be used at subzero temperatures or at temperatures above 1200℃.
- Stainless steel: Widely used alloy spring materials.
- Phosphor Bronze/Spring Brass: It has good corrosion resistance and electrical conductivity. It is commonly used for contacts in electrical switches. Spring brass can be used at subzero temperatures [6].

The following table shows the physical properties of spring materials [35]

Table 1 physical properties of common spring materials

Material	Analysis		Tensile properties			Torsional properties of wire			Process of manufacture, chief uses, special properties
	Element	Percent	Ultimate strength, MN/m^2	Elastic limit, MN/m^2	Modulus of elasticity, MN/m^2	Ultimate strength, MN/m^2	Elastic limit, MN/m^2	Modulus of torsion, MN/m^2	
Watch spring steel	C Mn	1.10-1.19 0.15-0.25	2260 2350	2060 2275	0.221×10^6 0.221×10^6	Not used -Do-	Not used -Do-	Not used -Do-	Cold-rolled & heat treated before forming main springs for watches & similar uses.
Clock-spring steel	C Mn	0.90-1.05 0.30-.50	1240 2340	1035 2060	0.206×10^6	-Do-	Do	-Do-	Cold-rolled & heat treated before forming clock& motor springs, misc. flat springs for high stress.
Flat spring steel	C Mn	0.65-0.80 0.50-0.90	1100 2210	860 1930	0.206×10^6	-Do-	-Do-	-Do-	Cold-rolled or annealed or tempered misc. flat springs.
High carbon wire	C Mn	0.85-0.85 0.25-0.60	1380 1725	1100 1450	0.206×10^6	1100 1380	760 1035	0.07845×10^6	Cold rolled or drawn high grade helical springs or wire forms.
Oil-tempered wire	C Mn	0.60-0.70 0.60-0.90	1070 2070	820 1725	0.200×10^6	795 1380	5515 900	0.07845×10^6	Cold-drawn & heat treated before coiling general spring use.
Music wire	C Mn	0.70-1.00 0.30-0.60	1725 3790	1035 2410	0.206×10^6	1035 2060	620 1240	0.07845×10^6	Patented & cold- drawn misc. small springs of various types high quality.
Hard-drawn spring wire	C Mn	0.60-0.70 0.90-1.20	1035 2060	685 1380	0.200×10^6	830 1520	520 90	0.07845×10^6	Patented & cold drawn same uses as music wire but lower quality wire.
Hot rolled bars special steel	C Mn	0.90-1.05 0.25-0.50	1210 1380	725 965	0.196×10^6	758 965	520 758	0.07257×10^6	Hot rolled heavy coil or flat springs.
Chrome-vanadium	C Mn	0.45-0.55 0.50-0.80	1380	1240	0.206×10^6	965	690	0.07845×10^6	Cold rolled or drawn special applications.

alloy steel 0.50%C	Cr V	0.80-1.10 0.15-0.18	1725	1590		1205	900		
Silicon Manganese alloy steel	C Mn Si	0.55-0.65 0.60-0.90 1.80-2.20	About the same as Chrome Vanadium			About the same as Chrome Vanadium.			Hot or cold rolled or drawn, in some applications may be used as a lower cost material in place of Chrome Vanadium.
Type 18-8 Stainless	Cr Ni C Mn	17-20 7-10 0.08-0.15 2 max.	1100 2275	415 1795	0.193×10^6	830 1650	300 965	0.06865×10^6	Cold rolled or drawn, best corrosion resistance, fair temp. resistance.
Cutlery-type stainless	Si Cr C	0.30-075 12-14 0.25-0.40	1180 1725	900 1380	0.193×10^6	830 1240	550 830	0.07551×10^6	Cold rolled or drawn, heat treated after forming, resists corrosion when polished, good temp. Resistance.
Spring brass	Cu Zn	64-72 balance	690 900	275 414	0.103×10^6	310 620	206 414	0.03825×10^6	Cold-rolled or drawn for electrical conductivity at low stresses for corrosion resistance.
Nickel Silver	Cu Zn Ni	56 25 18	900 1035	550 760	0.110×10^6	590 685	414 480	0.03825×10^6	Cold-rolled or drawn; better quality than brass corrosion resistance.
Phosphor bronze	Cu Sn Or Cu Sn	91-93 7-9 94-96 4-6	690 1035	414 760	0.103×10^6	550 725	345 590	0.04315×10^6	Cold-rolled or drawn; used for corrosion resistance and electrical conductivity.
Silicon bronze	Si Sn or Mn Cu	2-3 Small amounts balance	Properties similar to phosphor bronze.			Properties similar to phosphor bronze			Cold-rolled or drawn; used as substitute for phosphor bronze where lower cost is necessary.
Monel	Ni Cu Mn Fe	64 26 2.5 2.25	690 965	550 830	0.180×10^6	520 760	310 480	0.06571×10^6	Cold-rolled or drawn; resists corrosion; moderate stresses to 200ºC.
Inconel	Ni Ce Fe	80 14 balance	965 1210	760 930	0.210×10^6	660 830	380 550	0.07551×10^6	Cold-rolled or drawn; resists corrosion; high stresses to 340ºC.
K-monel	Ni Cu Al Fe	66 29 2.75 0.90	1100 1240	795 1000	0.180×10^6	725 860	450 590	0.06571×10^6	Cold-rolled or drawn; precipitation hardened by heat-treatment resists corrosion; high stresses to 230ºC.
Z-nickel	Ni Cu Mn Fe Si	98 Small amounts	1240 1590	900 1180	0.206×10^6	830 1035	414 620	0.07551×10^6	Cold-rolled or drawn; precipitation hardened by heat-treatment; resists corrosion; high stresses to 290ºC.
Beryllium-copper	Cu Be	98 2	1100 1380	685 1035	0.100×10^6 0.128×10^6	690 900	450 660	0.04120×10^6 0.04805×10^6 Subject to heat-	Cold-rolled or drawn; corrosion resistance like copper, high physicals for electrical work; low
								treatment.	hysteresis.

2.1.4.1Commonly used steel alloys for leaf spring

Steel is an alloy of iron and be the major component and small amounts of carbon as the major alloying element. The carbon contents in steel ranges from 0.02% to 2.0% by weight. Small amounts generally on the order of few percent of other alloying elements such as manganese, silicon chromium, nickel and molybdenum may also be present, but it is the carbon content that turns iron into steel. Toughness and ductility are obtained by the addition of elements like manganese, chromium, nickel, molybdenum, tungsten, vanadium, silicon etc. Generally leaf springs are made of various fine grade alloy steel. The most commonly used grades of steel are:

55si2Mn90, 55 Si 7, 60 Si Cr7, 50 Cr V4. En 45 A,65 Si 7, 55 Si Cr 7, 65 Si cr7, En 42 60 s 87 [26].

2.2 Theories of Failure

Strength of machine members is based upon the mechanical properties of the materials used. Since these properties are usually determined from simple tension or compression tests, therefore, predicting failure in members subjected to uni-axial stress is both simple and straight forward. But the problem of predicting the failure stresses for members subjected to bi-axial or tri-axial stresses is much more complicated. In fact, the problem is so complicated that a large number of different theories have been formulated. The principal theories of failure for a member subjected to bi-axial stress are as follows:

i. Maximum principal (or normal) stress theory (also known as Rankine's theory).
ii. Maximum shear stress theory (also known as Guest's or Tresca's theory).
iii. Maximum principal (or normal) strain theory (also known as Saint Venant theory).
iv. Maximum strain energy theory (also known as Haigh's theory).
v. Maximum distortion energy theory (also known as Hencky and Von Mises theory).

Since ductile materials usually fail by yielding i.e. when permanent deformations occur in the material and brittle materials fail by fracture, therefore the limiting strength for these two classes of materials is normally measured by different mechanical properties. For ductile materials, the limiting strength is the stress at yield point as determined from simple tension test and it is, assumed to be equal in tension or compression. For brittle materials, the limiting strength is the ultimate stress in tension or compression.

2.2.1 Maximum Principal or Normal Stress Theory

According to this theory, the failure or yielding occurs at a point in a member when the maximum principal or normal stress in a bi-axial stress system reaches the limiting strength of the material in a simple tension test. Since the limiting strength for ductile materials is yield point stress and for brittle materials (which do not have well defined yield point) the limiting strength is ultimate stress, therefore according to the above theory, taking factor of safety (F.S) into consideration, the maximum principal or normal Stress (σ_{t1}) in a bi-axial stress system is given by:

$\sigma_{t1} = (\sigma_{yt})/(F.S)$ for ductile materials

Where σ_{yt} = yield point stress in tension

F.s = factor of safety [11]

2.3 Composite

Composite is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and the one in which it is embedded is called the matrix. The reinforcing phase material may be in the form of fibers, particles, or flakes. The matrix phase materials are generally continuous. Examples of composite include concrete reinforced with steel and epoxy reinforced with graphite fibers, and naturally occurring composite like wood, where the lignin matrix is reinforced with cellulose fibers and bones in which the bone salt plates made of calcium and phosphate ions reinforce soft collagen, etc. Composites are important materials that are now used widely, not only in the aerospace industry, but also in a large and increasing number of commercial mechanical engineering applications, such as internal combustion engines machine components; thermal control and electronic packaging; automobile, train, and aircraft structures and mechanical components, such as brakes, drive shafts, flywheels, tanks, and pressure vessels; dimensionally stable components; process industries equipment requiring resistance to high temperature corrosion, oxidation, and wear.

Israelites using bricks made of clay and reinforced with straw are an early example of application of composites. The individual constituents, clay and straw, could not serve the function by themselves but did when put together. Historical examples of composites are abundant in the literature. Significant examples include the use of reinforcing mud walls in houses with bamboo shoots, glued laminated wood by Egyptians (1500B.C.), and laminated metals in forging swords (A.D. 1800). In the 20^{th} century, modern composites were used in the 1930s when glass fibers reinforced resins. Boats and aircraft were built out of these glass composites, commonly called fiberglass. Since the 1970s, application of composites has widely increased due to development of new fibers such as carbon, boron, and aramids, and new composite systems with matrices made of metals and ceramics [11, 13]

2.3.1 Contributing factors to the mechanical performance of composite fiber

Four fiber factors contribute to the mechanical performance of a composite are:

- Length: - fibers can be made long or short. Long, continuous fibers are easy to orient and process, but short fibers cannot be controlled fully for proper orientation. Long fibers provide many benefits over short fibers; these include impact resistance, low shrinkage, improved surface finish, and dimensional stability. However, short fibers provide low cost, are easy to work with, and have fast cycle time fabrication procedures. Short fibers also have fewer flaws and therefore have higher strength.
- Orientation: fibers oriented in one direction give very high stiffness and strength in that direction. If the fibers are oriented in more than one direction, such as in a mat, there will be high stiffness and strength in the directions of the fiber orientations. However, for the same volume of fibers per unit volume of the composite, it cannot match the stiffness and strength of unidirectional composites.
- Shape: the most common shape of fibers is circular because handling and manufacturing easiness. Hexagon and square shaped fibers are possible, but their advantages of strength and high packing factors do not outweigh the difficulty in handling and processing.
- Material: The material of the fiber directly influences the mechanical performance of a composite. Fibers are generally expected to have high elastic modules and strengths. This expectation and cost have been key factors in the graphite, aramids, and glass dominating the fiber market for composites [13]

2.3.2 Classes and Characteristics of Composite Materials

Solid materials can be divided into four categories: polymers, metals, ceramics, and carbon, which we consider as a separate class because of its unique characteristics. Both reinforcements and matrix materials are found in all four categories. Composites are usually classified by the type of material used for the matrix. The four primary categories of composites are polymer matrix composites (PMCs), metal matrix composites (MMCs), ceramic matrix composites (CMCs), and carbon/carbon composites (CCCs).

The main types of reinforcements used in composite materials are, aligned continuous fibers, discontinuous fibers, whiskers (elongated single crystals), particles, and numerous forms of fibrous architectures produced by textile technology, such as fabrics and braids. Increasingly, designers are using hybrid composites that combine different types of reinforcements to achieve more efficiency and to reduce cost. A common way to represent fiber reinforced composites is to show the fiber and matrix separated by a slash. For example, carbon fiber-reinforced epoxy is typically written "carbon/epoxy," or, "C/Ep." Composites are strongly heterogeneous materials; that is, the properties of a composite vary considerably from point to point in the material, depending on which material phase the point is located in. Many artificial composites, especially those reinforced with fibers, are anisotropic which means their properties vary with direction (the properties of isotropic materials are the same in every direction). Many fiber-reinforced composites, especially PMCs, MMCs, and CCCs, do not display plastic behavior as metals do, which makes them more sensitive to stress concentrations. However, the absence of plastic deformation does not mean that composites are brittle materials like monolithic ceramics. The heterogeneous nature of composites results in complex failure mechanisms that impart toughness. Fiber reinforced materials have been found to produce durable, reliable structural components in countless applications.

Table 2:- types of composite materials [41]

	Matrix			
Reinforcement	Polymer	Metal	Ceramic	Carbon
Polymer	X	X	X	X
Metal	X	X	X	X
Ceramic	X	X	X	X
Carbon	X	X	X	X

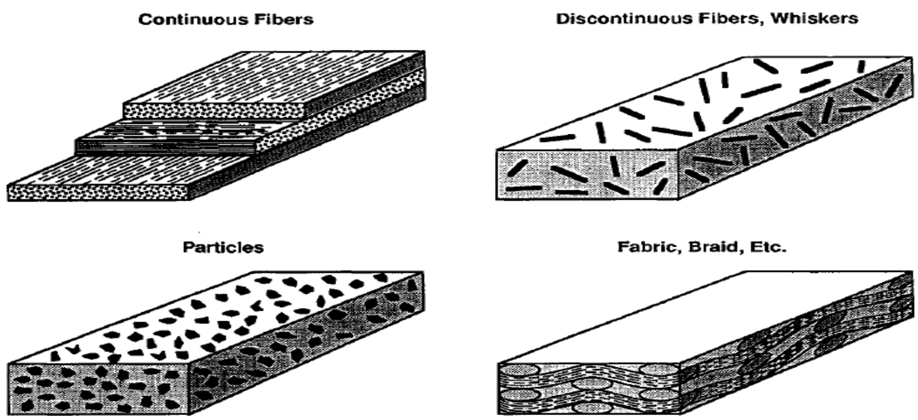


Figure 3:-Reinforcement forms of composite

2.4.3 Comparative Properties of Composite Materials

There are a large and increasing number of materials that fall in each of the four types of composites, making generalization difficult. However, as a class of materials, composites tend to have the following characteristics:

- High strength
- High modulus
- Low density
- Excellent resistance to fatigue, creep, creep rupture, corrosion, and wear; and low coefficient of thermal expansion (CTE). For applications in which both mechanical properties and low weight are important, useful figures of merit are specific strength (strength divided by specific gravity or density) and specific stiffness (stiffness divided by specific gravity or density).

2.3.4 Advantages of composite materials

Metals and their alloys cannot always meet the demands of today's advanced technologies. Only by combining several materials one can meet the performance requirements. Trusses and benches used in satellites need to be dimensionally stable in space during temperature changes between –256°F (–160℃) and 200°F (93.3℃). Metal materials cannot meet these requirements; this leaves composites, such as graphite/epoxy, as the only materials to satisfy them. In many cases, using composites is more efficient. For example, in the highly competitive airline market, one is continuously looking for ways to lower the overall mass of the aircraft without decreasing the stiffness and strength of its components. This is possible by replacing conventional metal alloys with composite materials. Even if the composite material costs may be higher, the reduction in the number of parts in an assembly and the savings in fuel costs make them more profitable. Reducing 0.453 kg of mass in a commercial aircraft can save up to 360 gal (1360 L) of fuel per year. It is known that fuel expenses accounts 25% of the total operating costs of a commercial airline. Composites also offer a number of significant manufacturing advantages over metals and ceramics. Fiber reinforced polymers and ceramics can be fabricated in large, complex shapes that would be difficult or impossible to make with other materials. The ability to fabricate complex shapes allows consolidation of parts, which reduces machining and assembly costs. Some processes allow fabrication of parts to their final shape (net shape) or close to their final shape which also produces manufacturing cost savings. The relative ease with which smooth shapes can be made is a significant factor in the use of composites in aircraft and other applications for which aerodynamic considerations are important. Generally, composites offer several other advantages over conventional materials. These may include improved:

- strength
- stiffness
- fatigue resistance
- impact resistance
- thermal conductivity
- Corrosion resistance, etc.

2.3.5 Limitations of composite materials

- High cost of fabrication of composites is a critical issue. For example, a part made of graphite/epoxy composite may cost up to 10 to 15 times as that of conventional steel material costs if fact this is not true for all, there are composites which have lower cost. A finished graphite/epoxy composite part may cost as much as ($650 to $900 per kilogram). Improvements in processing and manufacturing techniques will lower these costs in the future. Already, manufacturing techniques such as SMC (sheet molding compound) and SRIM (structural reinforcement injection molding) are lowering the cost and production time in manufacturing automobile parts.
- Mechanical characterization of a composite structure is more complex than that of a metal structure. Unlike metals, composite materials are not isotropic, that is, their properties are not the same in all directions. Therefore, they require more material parameters. For example, a single layer of a graphite/epoxy composite requires nine stiffness and strength constants for conducting mechanical analysis. In the case of metal materials such as steel, one requires only four stiffness and strength constants. Such complexity makes structural analysis computationally and experimentally more complicated and intensive. In addition, evaluation and measuring techniques of some composite properties, such as compressive strengths are still being debated.
- Repair of composites is not a simple process compared to that of metals. Sometimes critical flaws and cracks in composite structures may go undetected.
- Composites do not have a high combination of strength and fracture toughness compared to metals [13]

2.4 REINFORCEMENTS AND MATRIX MATERIALS

2.4.1 Reinforcements

The four key types of reinforcements used in composites are continuous fibers, discontinuous fibers, whiskers (elongated single crystals) and particles continuous aligned fibers are the most efficient reinforcement form and are widely used, especially in high performance applications. However, for ease of fabrication and to achieve specific properties, such as improved through thickness strength, continuous fibers are converted into a wide variety of reinforcement forms using textile technology.

2.4.1.1 Fibers

The development of fibers with unprecedented properties has been largely responsible for the great importance of composites and the revolutionary improvements in properties compared to conventional materials that they offer. The key fibers for mechanical engineering applications are glasses, carbons (also called graphite), several types of ceramics, and high modulus organics. Most fibers are produced in the form of multifilament bundles called strands or end in their untwisted forms, and yarns when twisted. Some fibers are produced as monofilaments, which generally have much larger diameters than strand filaments. Most of the key fibrous reinforcements are made of brittle ceramics or carbon. It is well known that the strengths of monolithic ceramics decrease with increasing material volume because of the increasing probability of finding strength limiting flaws. This is called size effect. As a result of size effect, fiber strength typically decreases monotonically with increasing gage length (and diameter). Flaw sensitivity also results in considerable strength scatter at a fixed test length. Consequently, there is no single value that characterizes fiber strength.

The main functions of the fibers in a composite are:

- To carry the load, in a structural composite 70 to 90% of the load is carried by fibers.
- To provide stiffness, strength, thermal stability, and other structural properties in the composites.
- To provide electrical conductivity or insulation, depending on the type of fiber used.

2.4.1.1.1 Glass Fibers

Glass fibers are prepared by mixing ingredients such as silica sand, limestone, folic acid and other compounds. The mixture is heated to melting temperature of about 1260°C and the molten glass is made to pass through fine holes of platinum plate. The glass strands thus formed are gathered, cooled and wound. The fibers are drawn and woven into various forms to increase the directional strength of composite materials. Glass fibers are predominantly used fibers in reinforced polymers as they are economical, easy to produce, have high strength, stiffness and easily moldable with plastics. Different types of glass fibers like E, S, C and D, can be manufactured by adding varied chemicals to silica sand. Their high strength, durability, low dielectric constant and relatively low cost have made them very useful in automotive, submarine and motorboat applications [22].

Glass fibers are widely used as the reinforcing material for the following reasons:

- Inexpensive and easily available
- Manufacturing using simple and economical method
- Possess high tensile strength and high resistance to corrosion

The leading types of glass fibers for mechanical engineering applications are E-glass and high strength (HS) glass. E-glass fibers, the first major composite reinforcement, were originally developed for electrical insulation application. E-glass is the most widely used of all fibrous reinforcements. The primary reasons for this are its low cost and early development compared to other fibers. The thermal and electrical conductivities of glass fibers are low, and glass fiber reinforced PMCs are often used as thermal and electrical insulators [13].

2.4.1.1.2 Carbon Fibers

Carbon fibers, commonly called graphite fibers in the United States, are used as reinforcements for polymers, metals, ceramics, and carbon. There are dozens of commercial carbon fibers, with a wide range of strengths and modules. As a class of reinforcements, carbon fibers are characterized by high stiffness, strength, low density and CTE. Fibers with tensile modules as high as 895 GPa (130 Msi) and with tensile strengths of 7000 MPa (1000 Ksi) are commercially available. Carbon fibers have excellent resistance to creep, stress rupture, fatigue and corrosive environments, although they oxidize at high-temperatures. Some carbon fibers also have extremely high thermal conductivities many times greater than that of copper. This characteristic is of considerable interest in electronic packaging and other applications where thermal control is important. Carbon fibers are the workhorse reinforcements in high performance aerospace and commercial PMCs and some CMCs. Of course, as the name suggests, carbon fibers are also the reinforcements in carbon/carbon composites.

Most carbon fibers are highly anisotropic. Axial stiffness, tension and compression strength, and thermal conductivity are typically much greater than the corresponding properties in the radial direction. Carbon fibers generally have small, negative axial CTEs (which means, that they get shorter when heated) and positive radial CTEs. Diameters of common reinforcing fibers, which are produced in the form of multifilament bundles, range from 4-10 micrometers (160-390 micro-inches). Carbon fiber stress-strain curves tend to be nonlinear. Modulus increases under increasing tensile stress and decreases under increasing compressive stress. Carbon fibers are made primarily from three key precursor materials: polyacrylonitrile (PAN), petroleum pitch, and coal tar pitch. Rayon based fibers, once the primary CCC reinforcement, are far less common in new applications. Experimental fibers also have been made by chemical vapor deposition. Carbon fibered composites are ideally suited for applications where strength, chemical inertness, stiffness, weightlessness, high damping and fatigue characteristics are the inevitable requirements. They can also be used at elevated temperatures without many consequences. Their properties make it an ideal choice of reinforcing materials used in aerospace, automobiles, civil engineering, military and various competitive sport applications.

Carbon fibers are used as a reinforcing material due to:

- Good physical strength, toughness and impact resistance.
- Good vibration damping strength, lightweight, dimensional stability
- Low abrasion rate, low coefficient of thermal expansion.

2.4.1.1.3 Boron Fibers

Boron fibers are primarily used to reinforce polymers and metals. Boron fibers are produced as monofilaments (single filaments) by chemical vapor deposition of boron on a tungsten wire or carbon filament, the former being the most widely used. They have relatively large diameters, 100-140 micrometers (4000-5600 micro-inches), and compared to most other reinforcements. The properties of boron fibers are influenced by the ratio of overall fiber diameter to that of the tungsten core. For example, fiber specific gravity is 2.57 for 100 micrometer fibers and 2.49 for 140 micrometer fibers.

2.4.1.1.4 Fibers Based on Silicon Carbide

Silicon carbide based fibers are primarily used to reinforce metals and ceramics. There are a number of commercial fibers based on silicon carbide. One type, a monofilament, is produced by chemical vapor deposition of high purity silicon carbide on a carbon monofilament core. Some versions use a carbon rich surface layer that serves as a reaction barrier. There are a number of multifilament silicon carbide based fibers which are made by pyrolysis of polymers. Some of these contain varying amounts of silicon, carbon and oxygen, titanium, nitrogen, zirconium, and hydrogen.

2.4.1.1.5 Alumina based fibers

Alumina based fibers are primarily used to reinforce metals and ceramics. Like silicon carbide based fibers, they have a number of different chemical formulations. The primary constituents, in addition to alumina, are boron, silica, and zirconia.

2.4.1.1.6 Aramid Fibers

Aramid, or aromatic, poly amide fibers are high-modulus organic reinforcements primarily used to reinforce polymers and for ballistic protection. There are a number of commercial aramid fibers produced by several manufacturers. Like other reinforcements, they are proprietary materials with different properties.

2.4.1.1.7 High Density Polyethylene Fibers

High density polyethylene fibers are primarily used to reinforce polymers and for ballistic protection. The properties of high density polyethylene tend to decrease significantly with increasing temperature and they tend to creep significantly under load even at low temperatures.

2.4.2 Matrix Materials

The four classes of matrix materials are polymers, metals, ceramics, and carbon. A matrix material fulfills several functions in a composite structure, most of which are vital to the satisfactory performance of the structure.

The important functions of a matrix material include the following:

- The matrix material binds the fibers together and transfers the load to the fibers. It provides rigidity and shape to the structure.
- The matrix isolates the fibers so that individual fibers can act separately. This stops or slows the propagation of a crack.
- The matrix provides good surface finish quality and aids in the production of net-shape or near net- shape parts.
- Through the quality of its grip on the fibers (the interfacial bond strength), the matrix can also be an important means of increasing the toughness of the composite [28].
- The matrix provides protection to reinforcing fibers against chemical attack and mechanical damage [13, 22].

2.4.2.1 Polymer Matrix Materials

Polymer matrix composites are the most commonly used, advanced composite materials comprising of a fibrous material of thin diameter (e.g., fiberglass, graphite, carbon, Kevlar, boron etc.) reinforced into polymerized resin (e.g., epoxy, polyester etc.) to enhance the required properties of composites to desired levels for specific applications. Polymer matrix composites have widespread usage due to their low cost, high strength and simple fabrication methods. Polymer matrix composites are advantageous, mainly due to the following properties.

- Possess high tensile strength, stiffness and fracture toughness
- Possess good abrasive resistance

The major disadvantages are:

- Thermal resistance is low
- Coefficient of thermal expansion is high

Properties of polymer matrix composites are determined by properties of the fibers, orientation of the fibers, concentration of the fibers, stacking sequence of fibers, aspect- ratio of fibers and properties of the matrix [18].There are two major classes of polymers used as matrix materials: thermosets and thermoplastics. Thermosets are materials that undergo a curing process during part fabrication, after which they are rigid and cannot be reformed. Thermoplastics, on the other hand, can be repeatedly softened and reformed by application of heat. Thermoplastics are often subdivided into several types:

- Amorphous
- Crystalline
- Liquid crystal

There are numerous types of polymers in both classes. Thermo-sets tend to be more resistant to solvents and corrosive environments than thermoplastics, but there are exceptions to this rule. Resin selection is based on design requirements, as well as manufacturing and cost considerations.

2.4.2.1.1 Thermosetting Resins

The key types of thermosetting resins used in composites are epoxies, bismaleimides, thermosetting polyimides, cyanate esters, thermosetting polyesters, vinyl esters, and phenolics. Epoxies are the workhorse materials for airframe structures and other aerospace applications, with decades of successful flight experience to their credit. They produce composites with excellent structural properties. Epoxies tend to be rather brittle materials, but toughened formulations with greatly improved impact resistance are available. The maximum service temperature is affected by reduced elevated temperature structural properties resulting from water absorption. A typical airframe limit is about 1200℃ (2500°F) [13, 41].

Table 3:- properties of matrix materials [41]

Material	Class	Density g/cm³ (Pci)	Modulus GPa (Msi)	Tensile Strength MPa (Ksi)	Tensile Failure Strain %	Thermal Conductivity W/mK (BTU/h · ft · F)	Coefficient of Thermal Expansion ppm/K (ppm/F)
Epoxy	Polymer	1.8 (0.065)	3.5 (0.5)	70 (10)	3	0.1 (0.06)	60 (33)
Aluminum (6061)	Metal	2.7 (0.098)	69 (10)	300 (43)	10	180 (104)	23 (13)
Titanium (6Al-4V)	Metal	4.4 (0.16)	105 (15.2)	1100 (160)	10	16 (9.5)	9.5 (5.3)
Silicon Carbide	Ceramic	2.9 (0.106)	520 (75)	—	< 0.1	81 (47)	4.9 (2.7)
Alumina	Ceramic	3.9 (0.141)	380 (55)	—	< 0.1	20 (120)	6.7 (3.7)
Glass (borosilicate)	Ceramic	2.2 (0.079)	63 (9)	—	< 0.1	2 (1)	5 (3)
Carbon	Carbon	1.8 (0.065)	20 (3)	—	< 0.1	5–90 (3–50)	2 (1)

2.4.2.1.2 Thermoplastic Resins

Thermoplastics are divided into three main classes: amorphous, crystalline, and liquid crystal. Polycarbonate, acrylonitrile-butadiene-styrene (ABS), polystyrene, polysulfone, and polyetherimide are amorphous materials. Crystalline thermoplastics include nylon, polyethylene, polyphenylene sulfide, polypropylene, acetal, polyethersulfone, and polyether etherketone. Amorphous thermoplastics tend to have poor solvent resistance. Crystalline materials tend to be better in this respect. Relatively inexpensive thermoplastics such as nylon are extensively used with chopped E-glass fiber reinforcements in countless injection molded parts. There are many numbers of applications using continuous fiber reinforced thermoplastics.

2.5 Material selections

Selection of the suitable material is a key aspect. Materials of the leaf spring consist of nearly 60%-70% of the unsprung weight. Even a small amount in weight reduction of the vehicle, may have a wider economic impact. Composite materials are proved as suitable substitutes for steel in connection with weight reduction of the vehicle. The material which is capable of storing more energy in the form of elastic strain would be preferred for leaf spring.

Specific elastic energy is given by:

$$S = 1/2(\sigma^2/\rho E) \tag{2.5}$$

Where σ is the allowable stress, ρ is density and E is elastic modulus

Composite materials have higher strain energy (energy storing capacity) as compared with metals because of their lower elastic modulus and low density. Hence, the composite materials can be selected for leaf spring design. Fiber reinforced polymer (FRP) composite materials consisting of fibers of high strength and modulus embedded in or bonded to resins with distinct interfaces between them. In general, fibers are the principal load carrying members, while the surrounding resins keep them in preferred location and orientation. [23] The commonly used fibers are carbon, glass, keviar, etc. Among these, glass fiber has been selected based on the cost factor and strength. The types of glass fibers are C-glass, D-glass, S-glass and E-glass. The C-glass fiber is designed to give improved surface finish. D-glass is used when permeability to electromagnet wave is required. S-glass fiber is design to give very high modular, which is used particularly in aeronautic industries [19]. The material composition selected for mono composite leaf spring are E-glass, Epoxy resin, in which E-glass as fiber material because of which is used as standard reinforcement fiber for almost all the present systems well complying with mechanical property requirements and low cost. Thus, E-glass fiber is suitable for this application and the selected glass fiber is unidirectional with diameter of fiber is 0.0074mm, 204 filaments per strand and average thickness of 2.1mm. A mono leaf E-glass epoxy has been used to replace a five leaf steel spring. In the selection of matrix material epoxy which is used to control the interleaf shear strength of laminate. Epoxy is in combination with hardener which cures, faster into hard resin at room temperature and is characterized by good mechanical properties and good chemical resistance properties.

2.6 Layup selection

The stored energy in a leaf spring varies directly with the square of maximum allowable stress and inversely with the modulus of elasticity both in the longitudinal direction. Composite materials like the E-glass/epoxy in the direction of fibers have good characteristics for storing strain energy. So, the layup is selected to be unidirectional along the longitudinal direction of the spring. The unidirectional layup may weaken the spring at the mechanical joint area and require strengthening the spring in this region [23].

2.7 Resin selection

In a fiber reinforced plastics (FRP) leaf spring, the Inter laminar shear strengths are controlled by the matrix system used; since these are reinforcement fibers in the thickness direction fiber do not influences inter laminar shear strength. Therefore, the matrix should have good inter laminar shear strength characteristics compatibility to the selected reinforcement fiber. Many thermo-set resins such as polyester, vinyl ester, and Epoxy resins are being used for fiber reinforcement fabrication. Among these resin systems, epoxies show better inter laminar shear strength and good mechanical properties as shown in table 4 bellow. Hence, epoxide is found to be the best resins that would suit this application. Different grades of epoxy resins and hardener combinations are classified, based on the mechanical properties [19].

Table 4:-Mechanical propreties of epoxy resin

Properties	Values
Tensile modulus(GPa)	3.53
Poisson’s ratio	0.347
Compressive modulus (GPa)	2.98
Shear modulus (GPa)	0.99
0.2% offset tensile yield stress (MPa)	41.0
Ultimate tensile strength (MPa)	76.3
Ultimate tensile strain (%)	4.2
0.2% offset compressive yield stress (MPa)	-64.7
Ultimate compressive strength (MPa)	-91.0
Ultimate compressive strain (%)	-5.38
0.2% offset shear stress (MPa)	26.1
Shear stress at 5% strain (MPa)	37.7

2.8 Manufacturing Process Selection

Apart from the selection of material and design procedure, the selection of manufacturing process also determines the quality and cost of the product. Hence, the composite leaf spring manufacturing process should fulfill the following criteria.

- The process should be amenable to mass production.
- The process should be capable of producing continuous reinforcement fiber

A number of processes have been developed to produce and shape the fiber reinforced composites. Variations are based primarily on the orientation of the fibers, the length of continuous filaments and the property of the final product. Each seeks to embed the fibers in a selected matrix with the proper alignment is necessary to produce the desired properties. Discontinuous fibers can be combined with a matrix to produce either a random or preferred orientation. Continuous fibers are normally aligned in a unidirectional fashion in rods or tapes, woven into fabric layers.

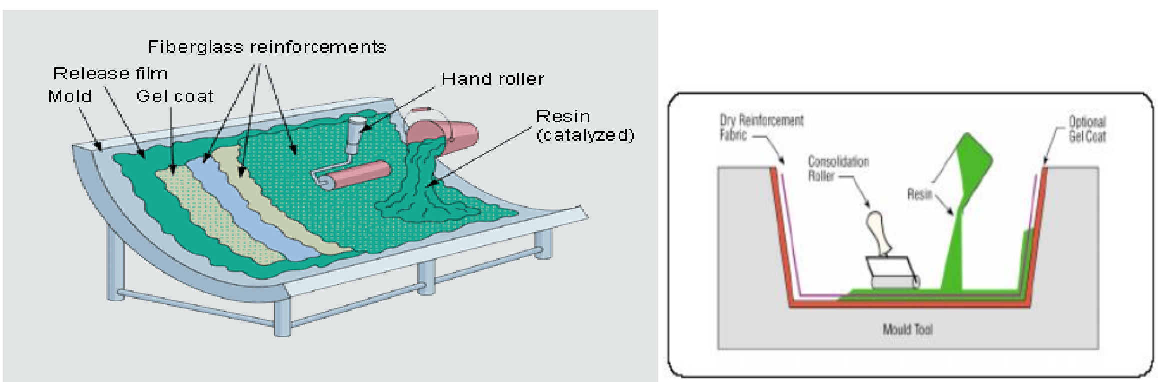
There are different types of manufacturing processes:

- Hand Layup
- Prepreg forming
- Pressure molding
- Vacuum bagging
- Filament winding
- Pultrusion
- Spray method
- Sheet molding
- Bulk molding
- Resin transfer molding

2.8.1 Hand Lay-up Technique

The hand layup is one of the oldest and most commonly used methods to manufacture the composite. The work is carried out in a female mold polished with gel coat on the inside surface. Having the required materials and setting up the mold at a convenient working height in the workshop, the following procedure is adopted:

- Wash the mould carefully with warm water and soft soap to remove dust, grease, finger marks, etc.
- Dry the mould thoroughly.
- Check the mould surface for chips or blemishes. These should be repaired by filling with polyester filler and cutting back with wet/dry paper. The odd small chip can be temporarily repaired by filling with filler material.
- If the mold surface is in good condition the mold release wax is now applied, using a small piece of cloth. Three coats of wax are sufficient for a mould surface which has been previously used but a new mold surface will require at least six applications. Care must be taken to remove all streaks of wax. Make sure that the wax is polished and not removed by aggressive buffing. Failure to take care at this stage can result in stick up.
- Cut the glass fiber to the desired length, so that they can be deposited on mold layer by layer during fabrication.
- Prepare the solution of resin and place the first layer of glass fiber chopped mat on mould followed by epoxy resin solution over material.
- Wait for 5-10 minutes; repeat the procedure till the desired thickness is obtained. Finally remove the composite material from the mould.



Figu re 4:- Fabrication procedure of composite

Advantages:

- ➢ low cost tools (low production cost)
- ➢ versatile wide range of products

Disadvantages:

- time consuming
- easy to form air bubbles and disorientation of fibers
- inconsistency

2.9 Manufacturing composite leaf spring

Hand layup process mostly used in the case of continuous fiber reinforced composite. Layers of unidirectional or woven composite are combined to result in a material exhibiting desirable properties in one or more directions. Each layers oriented to achieve the maximum utilization of its properties. Layers of different material (different fiber in different directions) can be combined to further enhance the overall performance of the laminated composite material. Plywood mold is prepared with required dimensions of leaf spring. Wax polish (Manson) is applied on to the mold surface with the help of cloth for better surface finish and for easy removal of leaf spring after curing. Resins are impregnated by hand into fibers, which are in the form of woven, knitted, stitched or bonded fabrics. This is usually accomplished by rollers or brushes, with an increase use of nip roller type impregnators for forcing resin into fabrics by means of rotating rollers and a bath of resin. Number of layers of E-glass, and epoxy are laminated simultaneously for required thickness of leaf spring. Finally, laminates are left to cure under standard atmospheric conditions for 24 hours before removal [29].

3. BETTER MATERIALS AND METHODS

3.1 Methodology and software used

- 3D Modeling using CATIA V5
- Analytical Calculations
- 3D Finite Element Meshing
- Structural finite element analysis in ANSYS 12 (static and dynamic)
- Comparing results and discussion

3.1.1 CATIA

CATIA (Computer Aided Three Dimensional Interactive Application) is multi- platform CAD/CAM/CAE commercial software, written in the C++ programming language which is used to model different structures [25].

3.1.2 ANSYS

ANSYS is being used by designers across a broad spectrum of industries such as aerospace, automotive, manufacturing, nuclear, electronics, biomedical, and many more. ANSYS provides simulation solutions that enable designers to simulate design performance directly on desktop. In this way, it provides fast, efficient and cost effective product development from design concept stage to performance validation stage of the product development cycle. ANSYS package help to accelerate and streamline the product development process by helping designers to resolve issues related to structural deformation, heat transfer, fluid flow, electromagnetic effects, a combination of these phenomena acting together, and so on [25,26].

3.2 Huanghai pickup DD1022T model specification

Figure 5 shows huanghai pick up on which this study is carried out. The rear leaf spring is taken to be analyzed, which have five leaves made of 55siMn90 (steel alloy). All the necessary parameters required for design and analysis is taken from its manual and also by measuring directly. It has two full length leaves and three graduated leaves connected with center bolt and with clips.

Figure 5:- Huanghai pick up

Table 5:- Huanghai pickup DD1022T model specification

Parameter	Value (mm)
length	5350
width	1725
wheelbase	3380
Height	1690
Height of c.g	300
Total mass of the vehicle (kg)	2495

Total or curb weight of the car

$m = 2495\ kg$ taking gravity $(g) = 9.81 m/s^2$

Total weight (w_t)

$w_t = mg$

$= 2{,}495\ kg \times 9.81 m/s^2 = 24{,}475.9N$ the total force experienced by four springs

Force on one of the rear leaf spring is $\frac{24475.9}{4} = 6{,}119\ N$ this is the maximum force exerted at static condition at the center of the leaf spring. Force at the two ends of leaf spring is half of the force at the center $p = \frac{P}{2} = \frac{6119}{2} = 3059.5\ N$

3.3 Construction of existing steel Leaf spring

Leaf springs are built with a number of leaves or plates, having initial curvature or cambered which is the amount of bend that is given to the spring from the center line passing through the eyes, so that they will tend to straighten under the load and even at maximum load the deflected spring should not touch other vehicle part to which it is attached. The leaves are held together by means of a band shrunk around them at the center or by a bolt passing through the center. The longest leaf known as main leaf or master leaf has its ends formed in the shape of an eye through which the bolts are passed to secure the spring to its supports. Usually the eyes, through which the spring is attached to the shackle is provided with bushings of some antifriction material such as bronze or rubber. The other leaves of the spring are known as graduated leaves. Since the master leaf has to with stand vertical bending loads as well as loads due to sideways of the vehicle and twisting, therefore due to the presence of stresses caused by these loads, it is usual provided two full length leaves. Rebound clips are located at intermediate positions in the length of the spring so that the graduated leaves also share the stresses induced in the full length leaves when the spring rebounds. The value of width of leaf spring sometimes is too large to accommodate in the space provided in the vehicle. One practice is that instead of keeping this large width one can make several slices and put the pieces together as a laminate [24].

3.3.1 Modeling existing steel leaf spring (CAD Modeling)

Development of a leaf spring is a long process which requires number of tests to validate the design and manufacturing variable. Computer aided engineering (CAE) is used to shorten this development thereby reducing the tests. CAE tools are widely used in the automotive industries; because of it enable them to reduce product development cost and time while improving safety, comfort and durability of the vehicles. Computer model of parabolic leaf spring of existing multi leaf spring is produced as exact replica of the physical specimen. Existing multi leaf spring and designed mono parabolic leaf spring is modeled in CATIA V5 in part design. The computer model is shown in figure 6 below based on the measured values.

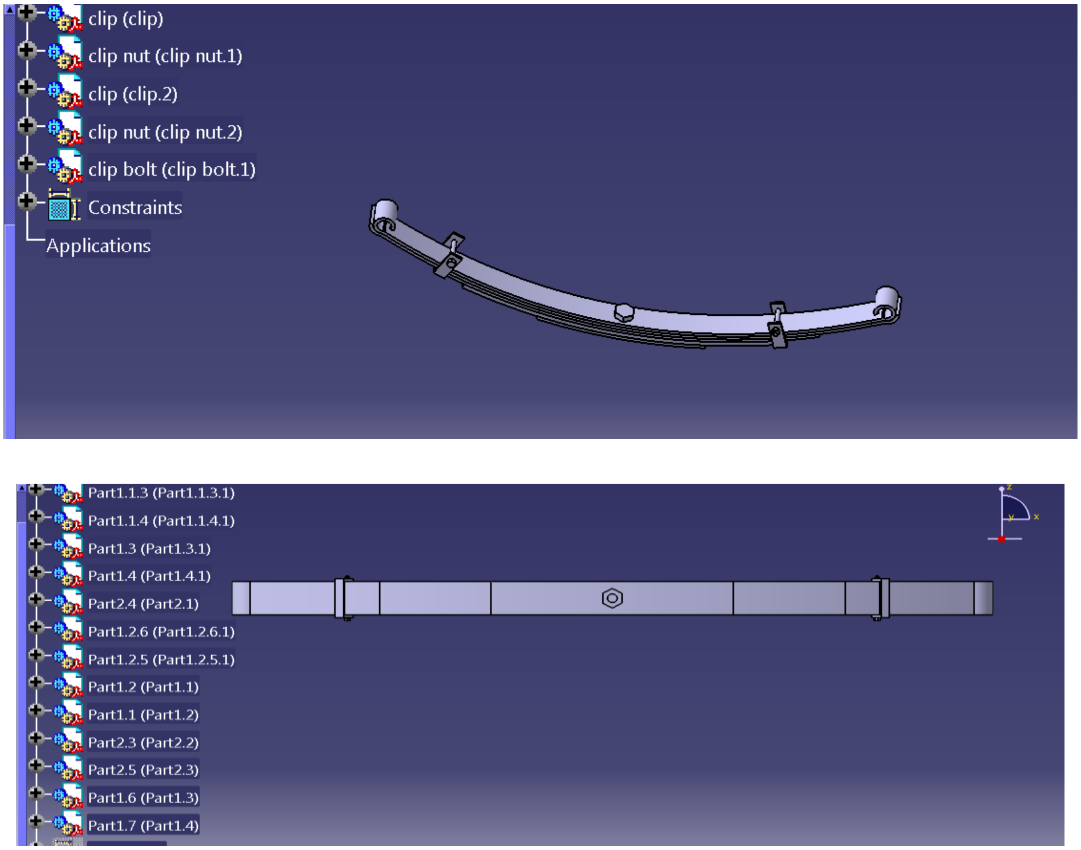


Figure 6:- existing steel leaf spring CATIA model

3.3.2 Existing steel leaf spring dimensions

Table 6:- existing steel leaf spring measured dimensions

No.	Length	Radius of curvature(mm)	Width(mm)	Thickness (mm)
First leaf	115cm	160	62	8.5
Second leaf	115cm	168.5	62	8.5
Third leaf	89cm	177 mm	62	8.5
Forth leaf	75cm	185.5 mm	62	8.5
Fifth leaf	39cm	194 mm	62	8.5
camber	160mm			
Graduated leaves	3			
Full length leaves	2			

3.3.3 Existing steel leaf spring material specification

The basic requirements of a leaf spring steel is that the selected grade of steel must have sufficient harden- ability for the size involved to ensure a full reliable structure throughout the entire leaf section. In general terms higher alloy content is mandatory to ensure adequate harden-ability when the thick leaf sections are used. The material used for the conventional steel leaf spring is 55Si2Mn90 and its property is shown in the table 7.

Table 7:- Mechanical properties of 55SiMn90

Parameter	Value
Material selected - steel	55si2Mn90
Tensile yield strength	1500 MPa
Tensile strength ultimate	1962 MPa
Young's modulus(E)	210 GPa
Poisson's ratio	0.3
Density	7850 Kg/m^3
Thermal Expansion	11×10^{-6} °C

Table 8:- Composition of 55si2Mn90 [24]

Grade	C	Si	Mn	Cr	Mo	P	S
55Si2Mn90	0.55	1.74	0.87	0.1	0.02	0.05	0.05

3.4 STATIC ANALYSIS OF EXISTING STEEL LEAF SPRING

3.4.1 Analytical calculation

The analytical formulation for a problem involves reference to the empirical and pure Engineering practices for arriving at a solution. Typically, empirical formulae that are historically developed for the application can offer a solution for the given problem. Considering the leaf spring as double cantilever beam, load is applied on free end as shown in the figure 7 below.

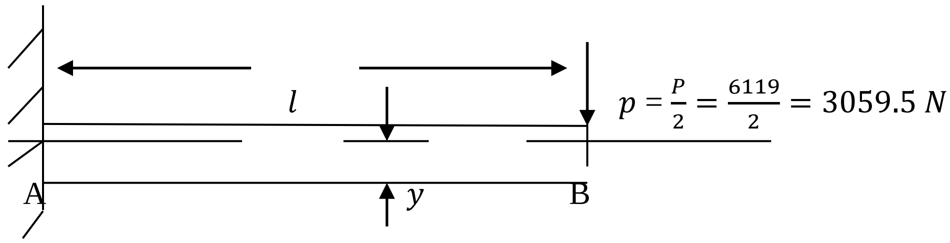


Figure 7:- free body diagram for cantilever beam with load at the free end

Maximum bending moment at A is:

$$M = pl \tag{3.4.1}$$

Moment of inertia of rectangular section is given by:

$$I = \frac{bt^3}{12} \tag{3.4.2}$$

Using equation $\frac{M}{I} = \frac{\sigma}{y}$ and substituting the values of bending moment and moment of inertia [11]

$$\frac{pl}{\frac{bt^3}{12}} = \frac{\sigma_{max}}{\frac{t}{2}}$$ where, $y = t/2$ is the distance from center

$$\sigma_{max} = \left(\frac{\frac{plt}{2}}{\left(\frac{bt^3}{12}\right)}\right) = \frac{6pl}{bt^2}$$

The stress in n number of leaves is given by [11]:

$$\text{Maximum Stress } (\sigma_{max}) = \frac{6Pl}{nbt^2} \tag{3.4.3}$$

The maximum stress (σ_{max}) for the leaf spring having the following length, width and thickness can be calculated by substituting its values in equation (3.4.3) above.

$$l = \frac{total\ length}{2} = \frac{1150}{2} = 575\ mm,\ \ n = 5,\ b = 62\ mm,\ t = 8.5\ mm$$

$$\sigma_{max} = \frac{6Pl}{nbt^2}$$

$$= \frac{6 \times 3059.5 \times 0.575}{5 \times (62 \times 10^{-3}) \times (8.5 \times 10^{-3})^2}$$

$$\sigma_{max} = \underline{4.7 \times 10^8\ N/m^2}$$

Moment of inertia

I = bt^3/12

$$= \frac{62\times10^{-3}(8.5\times10^{-3})}{12}$$

= <u>3,172.9 mm^4</u>

Elastic strain

$$\varepsilon = \sigma/E \qquad (3.4.4)$$

$$= 4.7 \times \frac{10^8}{2.1} \times 10^{11}$$

= <u>0.00223</u>

Deflection of steel leaf spring during static load condition

Maximum deflection for a cantilever beam of concentrated load at the free end is given by [11]:

$\delta = 4pl^3/Ebt^3$ for a leaf spring which have 'n' number of leaves which

have graduated leaves (n_G) $and\ full\ length$ (n_F) would be [11]:

$$\delta = 12\ pl^3/Ebt^3\ (2n_G + 3n_F) \qquad (3.4.5)$$

Taking the values of length, width, thickness, number of graduate and number of full length leaves from table 3.3.2 and substituting it in to equation 3.4.5 will give:

$$= 12 \times 3059.5 \times 575^3/(2.1 \times 10^5 \times 62 \times 8.5^3)((2 \times 3) + (3 \times 2))$$

δ = <u>72.7mm</u>

Mass of the existing steel leaf spring

The mass of bolt, spring clip with bolt, mass of two leaf spring eyes are not included and the leaf spring is considered as straight beam even though it has parabolic shape [12].

$$m = \rho v \tag{3.4.6}$$

where v is volume and ρ is density of the material

ρ = 7800 Kg/m^3

V = $nblt/2$ = 5×62×1150×8.5×10^{-9}/2 = 0.0015 m^3

m = 7800 Kg/ m^3×0.0015 m^3

= 11.8 Kg

The following can be also used to find the total mass of leaf spring.

First leaf volume = $blt = (62 \times 1150 \times 8.5)\ mm^3$

= 606,050 mm^3 = 0.00060605 m^3

Second leaf volume = $blt = (62 \times 1150 \times 8.5)\ mm^3$

= 0.00060605 m^3

Third leaf volume = $blt = (62 \times 890 \times 8.5)\ mm^3$

= 0.00046905 m^3

Forth leaf volume $blt = (62 \times 750 \times 8.5)\ mm^3$

$= 0.00039525\ m^3$

Fifth leaf volume $blt = (62 \times 390 \times 8.5)\ mm^3$

= 0.00020555 m^3

Total volume of leaves

V = 0.00060605 m^3+0.00060605 $m^3 + 0.00046905\ m^3$

$+0.00039525\ m^3$ +0.00020555 m^3

= 0.00167586 m^3

Now mass of leaves m = $7800 Kg/m^3 \times 0.00167586\ m^3$

m = $\underline{13.07 Kg}$

Spring stiffness

K = force /deflection [11] (3.4.7)

= p/δ

= 3059.5N/72.7mm

= $42\ N/mm$ or $42\ KN/m$

Equalized Stress in Spring Leaves (Nipping)

It is shown that the stress in the full length leaves is 50% greater than the stress in the graduated leaves. In order to utilize the material to the best advantage, all the leaves should be equally stressed. This condition may be obtained in the following two ways:

- By making the full length leaves of smaller thickness than the graduated leaves. In this way, the full length leaves will induce smaller bending stress due to small distance from the neutral axis to the edge of the leaf.
- By giving a greater radius of curvature to the full length leaves than graduated leaves, before the leaves are assembled to form a spring, a gap or clearance will be left between the leaves. The initial gap (c) is called nip [11, 12].

Length of Leaf Spring Leaves

The length of the leaf spring leaves can be obtained;

Let $2L_1$ = Length of span or overall length of the spring,

l = Width of band or distance between centers of U-bolts. It is the ineffective length of the spring,

n_F = Number of full length leaves,

n_G = Number of graduated leaves, and

n = Total number of leaves = $n_F + n_G$

Effective length of leaf spring [11, 12]

$2L = 2L_1 - l$

$$= 2L_1 - 2/3l \quad (3.4.8)$$

To find the length of each leaf first the ratio of length of master leaf with number of leaves should be calculated and it is given by [12]:

$$a = L/2n \quad (3.4.9)$$

Where, L is length of master leaf and n is total number of leaves

$$a = \frac{1150}{2\times5}$$

$$= 115$$

Then length of each leaf spring can be calculated

Length of first leaf = 10a = (10×115) = 1150 mm

Length of second leaf = 10a =10×115 mm

Length of third leaf = 8a = (8×115) = 920 mm

Length of fourth leaf = 6a = (6×115) = 690 mm

Length of fifth leaf = 4a = (4×115) = 460 mm

Or it can also found by using the formula below:

When there are two full length leaves (including one master leaf), then the number of leaves to be cut will be (*n* – 1). If a leaf spring has two full length leaves, then the length of leaves is obtained as follows [11]:

Length of the smallest leaf = $\frac{effective\ length}{n-1} + (ineffective\ length)$

Length of the next leaf = $\frac{effective\ length}{n-1}(2) + (ineffective\ length)$

Similarly, length of $(n-1)^{th}$ leaf = $\frac{effective\ length}{n-1}(n-1) + (ineffective\ length)$

The approximate relation between the rad ius of curvature (*R*) and the camber (*y*) of the spring is given by [11]:

$$R = \frac{L^2}{2\times y} \quad (3.4.10)$$

Where L is half of the span of the master leaf length

Therefore, substituting the values of length of leaf (L) and camber length (y) will give:

$$R = \frac{575^2}{2 \times 160}$$

$$R = 1033\ mm$$

3.5 DYNAMIC ANALYSIS

3.5.1 Accelerating on level road

When a car is running with acceleration "α" on a level road as shown in the figure 8, the vertical forces under the front and rear wheels are [14]:

Force on front wheel

$$F_{z1} = \frac{1}{2} \times mg \times \frac{a2}{l} - \frac{1}{2} \times mg \times \frac{h}{l} \times \frac{a}{g} \qquad (3.5.1)$$

Force on rear wheel

$$F_{z2} = \frac{1}{2} \times mg \times \frac{a1}{l} + \frac{1}{2} \times mg \times \frac{h}{l} \times \frac{a}{g} \qquad (3.5.2)$$

The first term $\frac{1}{2} \times mg \times \frac{a1}{l}$ represent the static load and the second term $\frac{1}{2} mg \times \frac{h}{l} \times \frac{a}{g}$ indicates the dynamic load of the normal force.

The vehicle is considered as a rigid body part that moves along a horizontal road. The force at the tire-print of each tire can be decomposed in to normal and horizontal forces. The equation of motion for the accelerating car comes from Newton's equation in x- direction and two static equilibrium equations.

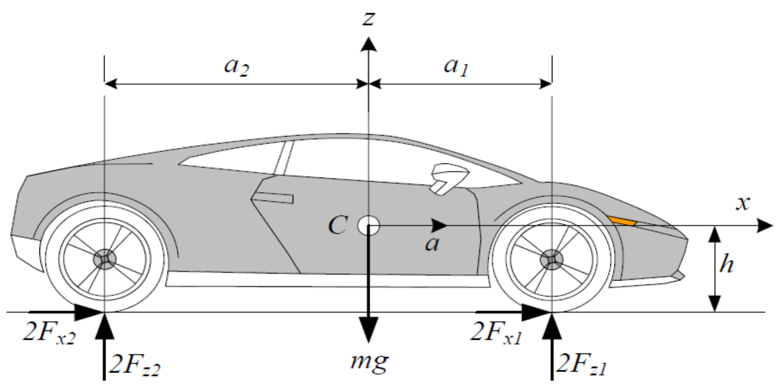


Figure 8:- accelerating vehicle on level road

Equilibrium equations

$\sum F\text{x} = ma$

$\sum F\text{z} = 0$

$\sum M\text{y} = 0$

Expanding the equation of motions produces three equations for four unknowns F_{x1}, F_{x2}, F_{z1}, and Fz2

$$2F_{x1} + 2F_{x2} = ma \tag{3.5.3}$$

$$2F_{z1} + 2F_{z2} - mg = 0 \tag{3.5.4}$$

$$-2F_{z1}a_1 + 2F_{z2}a_2 - 2(F_{x1} + F_{x2})h = 0 \tag{3.5.5}$$

However, it is possible to eliminate $(F_{x1} + F_{x2})$ between the first and the third equations and solve for the normal forces F_{z1}, F_{z2}

$$F_{z1} = (F_{z1})static + (F_{z1})dynamic$$

$$= \left(\frac{1}{2}\right) mg \left(\frac{a_2}{l}\right) - \left(\frac{1}{2}\right) mg \left(\frac{h}{l}\right)\left(\frac{a}{g}\right)$$

$$F_{z2} = (F_{z2})static + (F_{z2})dynamic$$

$$= \left(\frac{1}{2}\right) mg \left(\frac{a_1}{l}\right) + \left(\frac{1}{2}\right) mg \left(\frac{h}{l}\right)\left(\frac{a}{g}\right) \tag{3.5.6}$$

The static part for the rear and front wheels

$$(F_{z2})static = \left(\frac{1}{2}\right)mg\left(\frac{a_1}{l}\right)$$

$(F_{z1})static = \left(\frac{1}{2}\right)mg\left(\frac{a_2}{l}\right)$, these are weight distributions for the stationary vehicle depending on the horizontal position of the mass center. However, the dynamic parts:

$$(F_{z1})dynamic = -\left(\frac{1}{2}\right)mg\left(\frac{h}{l}\right)\left(\frac{a}{g}\right)$$

$$(F_{z2})dynamic = \left(\frac{1}{2}\right)mg\left(\frac{h}{l}\right)\left(\frac{a}{g}\right).$$

It indicates the weight distribution according to horizontal position acceleration and depending on the vertical position of the mass center. When acceleration is greater than zero ($a > 0$) the normal force under the front tires are less than the static load, and the force under the rear tires are more than the static load.

Acceleration of the vehicle before it attains its maximum speed having maximum traction is given by [14]:

$$\alpha = g\mu_x \times \frac{a1}{l-h\mu_x} \tag{3.5.7}$$

Assuming coefficient of friction between tire and road

$$= 9.81 \times 1 \times \frac{1690}{3380-300\times1}$$

μ_x =1 and the same in rear and front tire

$$a = 5.38\, m/s^2$$

Now calculate the increased load on the rear wheel due to acceleration

$$\mathrm{F_{z2}} = \frac{1}{2} \times mg \times \frac{a1}{l} + \frac{1}{2} \times mg \times \frac{h}{l} \times \frac{a}{g}$$

$$= \frac{1}{2} \times 2495 \times 9.81 \times \left(\frac{1.69}{3.38}\right) + \frac{1}{2} \times 2495 \times 9.81 \times \left(\frac{0.3}{3.38}\right) \times \frac{5.38}{9.81}$$

$$F_{z2} = 6{,}715\, N$$

3.5.2 Accelerating on an inclined road

When the car accelerating on an inclined pavement with angle (∅) as shown in the figure 9 below, the normal force under each of the front and rear wheels would be:

Force on front wheel (Ff) = $\frac{1}{2} \times mg \times \left(\frac{a2}{l} \times cos\emptyset - \frac{h}{l} \times sin\emptyset\right) - 1/2 \times ma \times \frac{h}{l}$

Force on rear wheel (Fr) = $\frac{1}{2} \times mg \times \left(\frac{a2}{l} \times cos\emptyset + \frac{h}{l} \times sin\emptyset\right) + 1/2 \times ma \times \frac{h}{l}$

The dynamic part $= \pm \left(\frac{1}{2}\right) mg \left(\frac{h}{l}\right) (\frac{a}{g})$ depends on acceleration a and height h of the mass center C and remains unchanged, while the static parts are influenced by the slope ∅ and height h of the mass center.

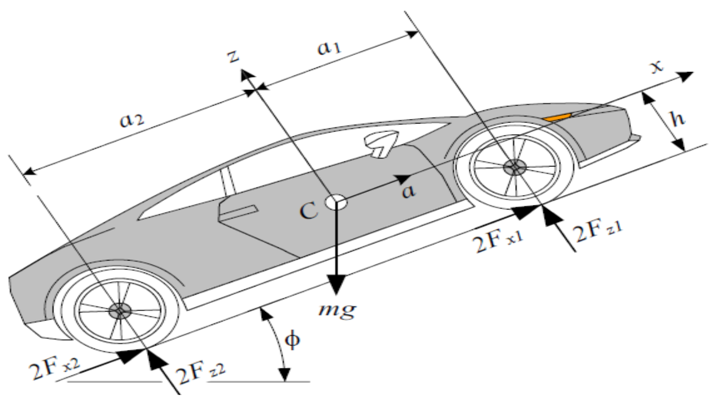


Figure 9:-accelerating vehicle on inclined road (pavement)

Equilibrium equations:

$\sum F$x = ma

$\sum F$z = 0

$\sum M$y = 0

Expanding the equation of motions produces three equations for four unknowns F_{x1}, F_{x2}, F_{z1}, and Fz2

$$2F_{x1} + 2F_{x2} - mgsin\emptyset = ma \qquad (3.5.2.1)$$

$$2F_{z1} + 2F_{z2} + mgcos\emptyset = 0 \qquad (3.5.2.2)$$

$$-2F_{z1}a_1 - 2F_{z2}a_2 + 2(F_{x1} + F_{x2})h = 0 \quad (3.5.2.3)$$

It is possible to eliminate $(F_{x1} + F_{x2})$ between the first and the third equations and solve for the normal forces F_{z1}, F_{z2}

Force on the front wheels

$$F_{z1} = (F_{z1})static + (F_{z1})dynamic$$

$$= \left(\frac{1}{2}\right) mg(\left(\frac{a_2}{l}\right)\cos\emptyset - \left(\frac{h}{l}\right)\sin\emptyset) - \left(\frac{1}{2}\right) ma(\frac{h}{l}) \quad (3.5.2.4)$$

Force on rear wheel is increased by the dynamic part $\left(\frac{1}{2}\right) ma(\frac{h}{l})$ thereby, rear wheel experiences more load and this is the target load to be known which is essential for the purpose of designing the leaf spring dimensions based on the stress and deflection that these force will produce [14].

$$F_{z2} = \frac{1}{2} mg \left(\frac{a2}{l} cos\emptyset + (\frac{h}{l}) sin\emptyset\right) + \left(\frac{1}{2}\right) ma(\frac{h}{l})$$

Taking ϕ = 14 and substituting all the values will give

$$= \frac{1}{2} \times mg \times \left(\frac{a2}{l} \times cos\emptyset + \frac{h}{l} \times sin\emptyset\right) + \frac{1}{2} \times ma \times h/l$$

$$= \frac{1}{2} \times 2495kg \times 9.81 \times \left(\frac{1690}{3380} \times cos14 + \frac{300}{3380} \times sin14\right) + \frac{1}{2} \times 2495kg \times 5.38 \times \frac{300}{3380}$$

$$= 6200 + 595.69$$

$$= 6{,}795.65\ N$$

Bending stress and deflection

Now designing stress can be calculated by computing the maximum normal loading from different dynamic loading and static loading. Therefore, the maximum normal load which will be exerted on the leaf spring is around 6796 N. This load is applied at the center, the force at the two ends of leaf spring would be: $p = \frac{P}{2} = \frac{6796}{2} = 3398\ N$

The maximum stress $\sigma_{max} = \frac{6pl}{nbt^2}$

$$= \frac{6\times3398\times575}{5\times62\times8.5^2}$$

$$\sigma_{max} = \underline{5.234\times10^8}\ N/m^2$$

Here we can see that, the designed stress (σ_{max}) is less than permitted stress (σ_y) of the material so that the design is safe (i.e it satisfies the maximum stress failure theory).

Maximum deflection (δ_{max}) of full length and graduated leaves is given by:

$$\delta_{max} = \frac{12pl^3}{Ebt^3(2n_G+3n_F)}$$

$$= (12\times3396\times(575\times10^{-3})^3)/(2.1\times10^{11}\times62\times10^{-3}\times(8.5\times10^{-3})^3\times((2\times3)+(3\times2)))$$

$$\delta_{max} = \underline{81\ mm}$$

Stress and deflection values of existing steel leaf spring as the load varies from 6,119 N (static), 6715N (accelerating on level road) to 6796 N (which is experienced due to acceleration on inclined road) is show in table 9 and the graph is shown in figure 10.

Table 9:-stress and deflection values of leaf at different load conditions

p (N)	l (mm)	b (mm)	T (mm)	σ (MPa)	δ (mm)
3059.5	575	62	8.5	471.2702	72.74217
3115.5	575	62	8.5	479.8962	74.07361
3171.5	575	62	8.5	488.5222	75.40506
3227.5	575	62	8.5	497.1481	76.73651
3283.5	575	62	8.5	505.7741	78.06795
3339.5	575	62	8.5	514.4	79.3994
3395.5	575	62	8.5	523.026	80.73085

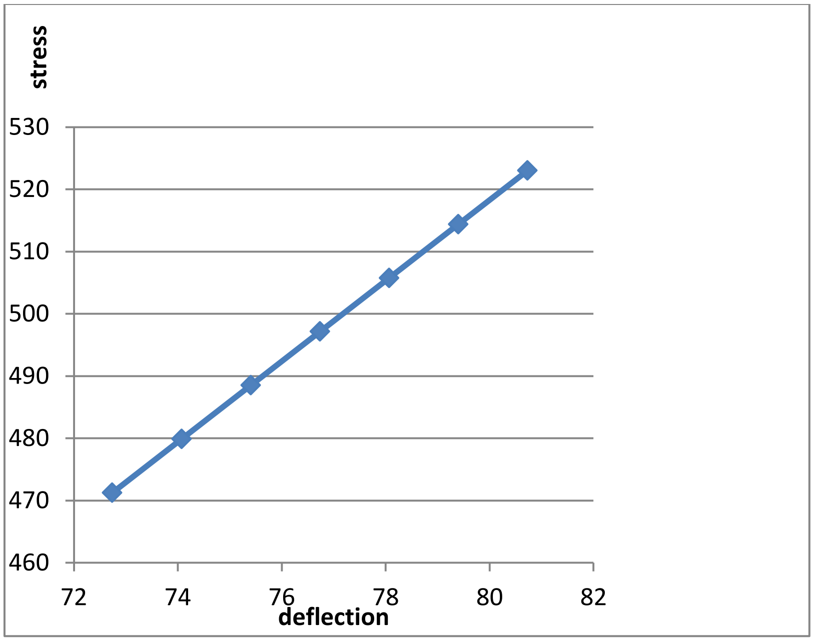


Figure 10:- stress versus deflection graph

Strain energy of steel leaf spring

Strain energy is the potential energy stored by an elastic body when deformed. The material used directly affects the quantity of storable energy in the leaf spring. The specific strain energy can be written as [6]:

$$\text{Strain (S)} = \frac{\sigma_t^2}{2\times\rho E} \qquad (3.5.2.5)$$

Where, σ_t is the allowable stress,

E is the modulus of elasticity and

ρ is the density

$= (1962\ \text{MPa})^2/2 \times 7850 \times 2.1 \times 10^{11}$

= 1,167.56 J

$= 1.1675\ KJ$

From the above equation, the material with maximum strength and minimum modulus of elasticity is the most suitable material for the leaf spring application.

Spring stiffness

Stiffness is defined as the resistance of a material to deflection [11, 12].

$$k = \left(\frac{F}{\delta}\right)$$

$$= \left(\frac{3396}{81}\right) = 42 \text{ N/m}$$

Natural frequency

The natural frequency of body or a system depends upon the geometrical parameters and mass properties of the body. It is independent of the forces acting on the body or a system. When the frequency of external excitation force acting on the body is equal to the natural frequency of a vibrating body, the amplitude of vibration become excessively large such state is known as resonance. Resonance is dangerous condition and it may lead to failure of the part. Therefore to avoid the resonance condition, the natural frequency of the machine parts that are subjected to vibration or external excitation should be known. Hence it is of prime importance to calculate the natural frequency.

There are various methods for calculating natural frequency of a given vibratory system.

1. Equilibrium method
2. Energy Method
3. Rayleigh's Method

All the above methods are reduced to a common and simple equation of motion which is compared with the standard simple harmonic motion given as: [6]

$$\ddot{x} + \omega^2 x = 0 \qquad (3.5.2.5)$$

and

$$\omega_n^2 = \left(\frac{k}{m}\right)$$

$\omega_n = \sqrt{(k}/m)$ where k is the stiffness and m is the mass of spring [20]

Frequency (f_n) = $\omega_n/2\pi$

$$f_n = \left(\frac{1}{2\pi}\right) \times \sqrt{k}/m \qquad (3.5.2.6)$$

Now calculate the stiffness of steel leaf spring at maximum deflection

From above load = 3,396N and deflection = 81mm

Therefore, K = F/δ_{max}

$= 3396N/81 \times 10^{3}m$

= 42,000N/m

$\omega_n = \sqrt{k}/m$

$= \sqrt{42{,}000}N/m/13Kg$

= 56.8rad/s

Then, f_n = $(\frac{1}{2\pi}) \times \sqrt{k}/m$

= $\omega_n/2\pi$

= 56.8rad/2π

<u>= 9.04 Hz</u> this is the first natural frequency of existing leaf spring

This natural frequency of vibration of leaf spring should not match the frequency of vibration or road surface otherwise resonance will occur and spring will vibrate at maximum amplitude which is undesirable.

Fatigue life

Fatigue resistance is the resistance which lowers the mechanical properties of a material such as strength and stiffness due to cyclic loading, such as due to take off and landing of a plane, vibrating a plate [20]. It is estimated that 50-90% of structural failure is due to fatigue loading.
Factors affecting fatigue life are:

- Cyclic stress state
- Geometry
- Surface quality
- Material type
- Residual stresses
- Direction of loading
- Grain size
- Temperature

Stress life approach has been adopted for conducting a fatigue analysis [29].

In order to use stress/life information for design purposes, a common procedure is to cross-plot the data to show the expected life (expected stress for some particular probability of failure) for a given combination of the alternating component of stress (σ_{alt}), defined as half the stress range, ½($\sigma_{max} - \sigma_{min}$), and the mean stress ($\sigma_m$) which is ½($\sigma_{max}$ + σ_{min}). The stress ratio (R) is$\sigma_{min}/\sigma_{max}$. In metallic fatigue it is frequently assumed that compression stresses were of no significance because they acted only to close fatigue cracks, unlike tensile forces. Master diagrams of this kind are presented in a variety of forms, all more or less equivalent, but the most familiar is that which is usually referred as the Goodman diagram as shown in figure below. For design purposes, it was useful to have an equation to represent the fail/safe boundary in this diagram, and it is the linear relationship of Figure 11 that is associated with the name of Goodman (1899) although others have been proposed, including the earlier parabolic relationship of Gerber (1874). The linear and parabolic laws have been modified to include safety factors on one or both of the stress components. For metals as well as for composites, relates to the minimum amount of test data that is needed to define the failure envelope with a level of reliability sufficient for engineering design of critical components.

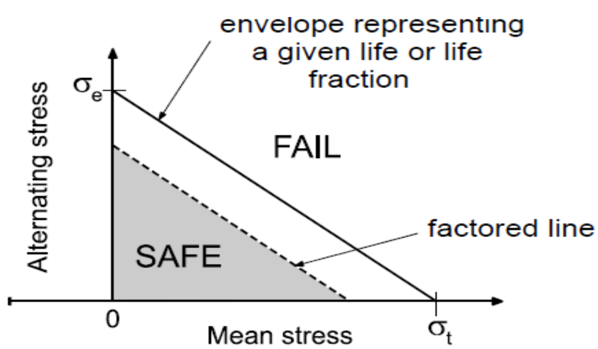


Figure 11:- Schematic illustration of a constant life or Goodman diagram

The stress σ_e is the endurance or fatigue limit, and σ_t is the material tensile strength [28].

3.6 Designing mono composite leaf spring

Now the thickness and width of mono composite leaf should be determined by taking the spring eye diameter and length the same with that of existing steel leaf spring that can withstand the maximum stress and deflection. Designing load is taken by computing the maximum normal loading from different dynamic loading and static loading. Therefore, the maximum normal load which will be exerted on the leaf spring is around 6796N which is a result of acceleration on inclined road.

Based on the maximum load composite leaf spring thickness and width can be calculated by keeping the total leaf spring length same as that of existing leaf spring [11].

Let t = thickness of the leaves and

b = width of the leaves

Bending stress (σ):

$$6pl/nbt^2 = 6 \times 3398\ N \times 575\ mm/(nbt^2) = 523\times 10^6\ N/m^2$$

$$nbt^2 = 22.4\times10^3\ mm^3$$

Deflection of the spring (δ):

$$\frac{6PL^3}{nEbt^3} = 81 \text{ mm}$$

$$6 \times 3398\ N \times \frac{(575)^3}{n\times210\times10^3\times b\times t^3} = 81\ mm$$

$$\frac{18.446\times10^6}{nbt^3} = 81 \text{ mm}$$

$$nbt^3 = \frac{18.446\times10^6}{81\ mm} = 0.2277\times10^6\ mm^4$$

Dividing the two equations we have

$$\frac{nbt^3}{nbt^2} = \frac{0.2277\times10^6}{22.4\times10^3} = 10.165\ mm$$

$$t = 11\ mm$$

Now from bending stress equation above width of the leaf can be calculated

$$b = \frac{22.4\times10^3}{n(11)^2} = \frac{22.4\times10^3}{5\times(11)^2}$$

$$= 37\ mm$$

And from deflection equation width can be also calculated

$$b = \frac{0.2277\times10^6}{n(11)^3} = \frac{0.2277\times10^6}{5\times(11)^3}$$

$$= 34\ mm$$

Then take the larger value of width from the two we have b = 37mm

Mass of mono composite leaf spring

$$m = \rho v$$

$$v = nblt = 1\times37\times1150\times11\times10^{-9} = 0.000468\ m^3$$

$$\rho = 2600\ Kg/m^3$$

$$m = 2600 Kg/m^3\times0.000468\ m^3$$

$$= 1.22\ kg$$

Laminate

A laminate is constructed from groups of individual unidirectional plies which are laid at various angles, depending upon design requirements, or from layers of woven cloth laid at various angles to the main stress axis.

$n_l = t/t_l$ where n_l is number of laminate (layer)

$= 11/2.1$ t_l is laminate thickness = 2.1 mm [13]

$= 5.23 \approx$ 6 layers t is leaf thickness

Constant Cross section Design

In this design both thickness and width are not varied throughout the leaf spring such that the cross section area remains constant along the length of the leaf spring. The constant cross section design method is selected due to the following reasons:

- Due to its capability for mass production
- Accommodation of continuous reinforcement of fibers. CATIA model of mono composite leaf spring based on the designed dimension is shown in figure 12.

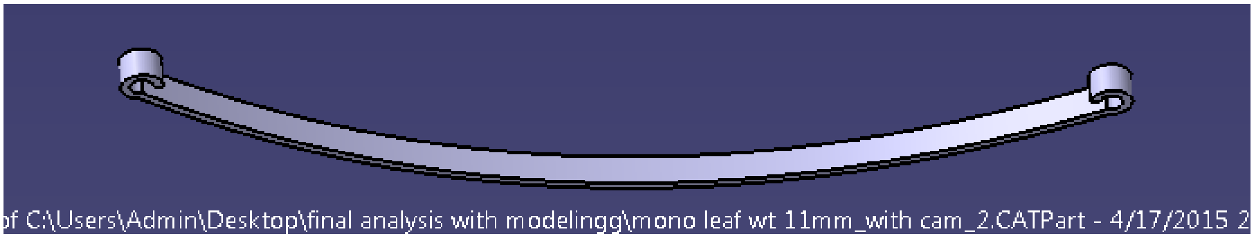


Figure 12:-designed composite leaf spring model

A Single composite leaf spring is considered for this work that is having total length 1150 mm, arc height of the leaf (camber) 160 mm, width of leaf 62 mm and thickness of leaf 8.5 mm, even though the leaf spring is simply supported, it is considered as double cantilever beam. Designed specifications of mono composite leaf spring for Huanghai pick up vehicle are shown in table 10 below.

Table 10:-Dimensions of mono composite leaf spring

parameter	size
thickness	11
length	1150
width	37
Eye diameter	50
camber	160
weight	1.22Kg

Material properties of E- glass Epoxy

Table 11:-mechanical properties of E-glass Epoxy [21, 40]

No.	Properties	value
1	Tensile modulus along X- direction (Ex), MPa	34000
2	Tensile modulus along Y- direction(Ey), MPa	6530
3	Tensile modulus along Z- direction(Ez),MPa	6530
4	Tensile strength of material, MPa	900
5	Compressive strength of material, MPa	450
6	Shear modulus along XY- direction, (Gxy), MPa	2433
7	Shear modulus along YZ- direction (Gyz), MPa	1698
8	Shear modulus along ZX- direction (Gzx),MPa	2433
9	Poisson ratio along XY – direction (Nuxy)	0.217
10	Poisson ratio along YZ- direction (Nuyz)	0.366
11	Poisson ratio along ZX – direction (Nuzx)	0.217
12	Mass density of the material(ρ), kg/mm^3	2.6×10^{-6}
13	Flexural modulus of the material, MPa	40000
14	Flexural strength of the material, MPa	1200

Fatigue life of composite leaf spring

For E - Glass/ epoxy composite material, Hwang and Han developed an analytical fatigue model to predict the number of fatigue cycles to failure.

Hwang and Han relation

$$N = \{B(1-r)\}^{1/c} \tag{3.6}$$

Where, N is the number of cycles to failure, B = 10.33, C = 0.14012,

r = applied stress level given by; $r = \frac{\sigma_{max}}{\sigma_u}$

$\sigma_{max} = maximum\ stress, \sigma_u$ = ultimate tensile strength [6, 21]

Estimated cycles of fatigue failure for mono composite leaf spring at the maximum designed stress $(\sigma) = 523MPa$ is:

$$N = \{B(1-r)\}^{\frac{1}{c}} \qquad \text{where, } r = \frac{\sigma_{max}}{\sigma_u} = \frac{523MPa}{900MPa} = 0.58$$

$$= (10.33(1-0.58))^{1/0.14012}$$

$$= 34{,}442.7\ cycles$$

$$= 3.44427 \times 10^4\ cycles$$

Natural frequency

Natural frequency of mono composite leaf spring having mass (m) = 1.22 Kg and stiffness (k) = 42,000N/m:

$$f_n = \frac{\omega_n}{2\pi} \qquad \omega_n = \sqrt{\frac{k}{m}} = \sqrt{(\frac{42000}{1.22\ Kg}\ \text{N/mm})} = \underline{185.5}\ rad/s$$

$$= \frac{185.5\frac{rad}{s}}{2\pi}$$

$$f_n = 29.5\text{Hz}$$

Factor of safety

$$\text{F.S} = \frac{tensile\ yield\ strength}{designing\ stress} = (\sigma_y)/(\sigma_{max}) \tag{3.6.1}$$

$$= \frac{900\times10^6}{523\times10^6}(\frac{\frac{N}{m}}{\frac{N}{m}})$$

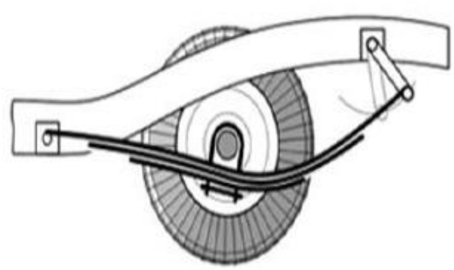
F.S = <u>1.73</u>

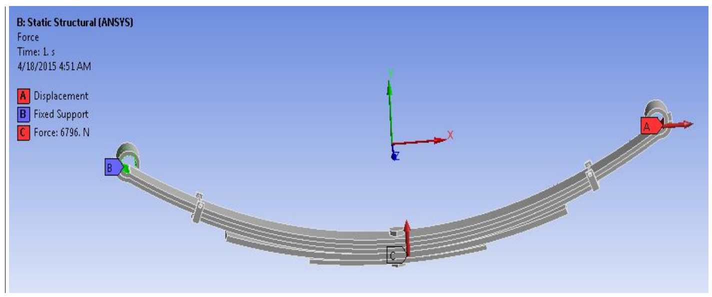
3.7 Finite element analysis of existing leaf spring

Finite element analysis (FEA) is a computing technique that is used to obtain approximate solutions to the boundary value problems in engineering. It uses a numerical technique called the finite element method (FEM) to solve boundary value problems. FEA involves a computer model of a design that is loaded and analyzed for specific results. Stress analysis is performed using quadrilateral meshing element and plane strain finite element model. A plane strain solution is considered because of the high ratio of width to thickness of a leaf. Analysis for both conventional leaf spring and mono composite leaf spring is done by using ANSYS 12.0, and analysis results of stress, deflection, natural frequency, fatigue failure (life prediction) are done.

3.7.1 Boundary conditions

In finite element analysis 3D model of mono leaf spring and multi steel leaf spring which is developed in CATIA V5 is imported to ANSYS to conduct the analysis. Boundary conditions are fixed support one end of the leaf, translation in the other end (shackle end) and load is applied at the center of the leaf. In fixed support there is no degree of freedom i.e. there is no displacement in any direction. But in translational support only horizontal (in x- direction) motion is present which represents the leaf spring as if it is on vehicle. Also material properties of both steel as well as composite material properties i.e. modulus of elasticity, density etc are applied.





a) Suspension and constraints b) applied constraints to CATIA model

Figure 13:- boundary conditions of existing leaf spring

3.7.2 Meshing

Meshing is basically the process of dividing the CAD model into very small elements which are then solved simultaneously to evaluate the behavior of the entire system. It is also known as piecewise approximation. Figure 14 shows meshed model which has 44953 nodes and 12483 elements.

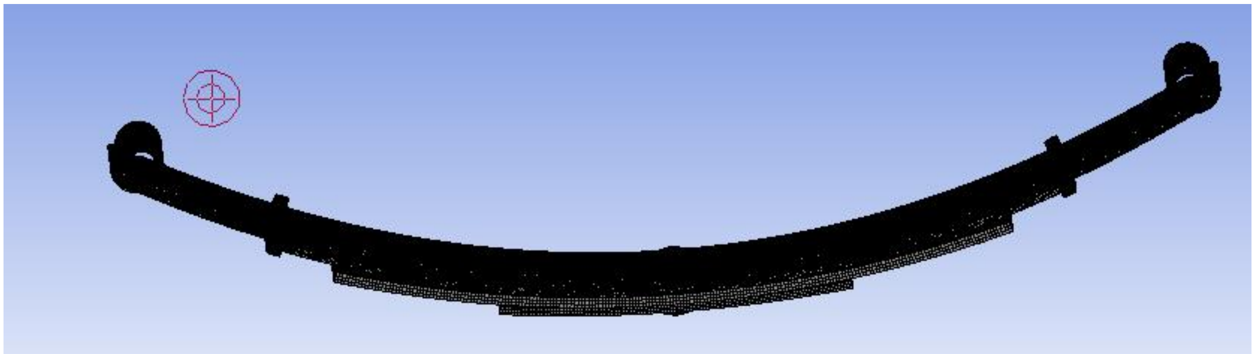


Figure 14:-meshed model of existing leaf spring

3.7.3 Applying load

It has been mathematically calculated that the maximum load which the spring will be subjected to is 6796 N. This particular calculation has been done on the basis of GVW (Gross Vehicle Weight), which may be defined as the total weight of the loaded vehicle while it accelerating on inclined road. The static weight of the vehicle is about 6119N but during acceleration on inclined road the load increases to 6796N, this is because of weight transfer from front wheel to rear wheel. In order to perform analysis it is very essential to restraint the CAD model in the same manner as it is done physically. The load is applied through the point of contact between leaf spring and rear axle which is at the center of leaf spring in real, similarly, load is applied at the center in ANSYS as shown in the figure 15 below.

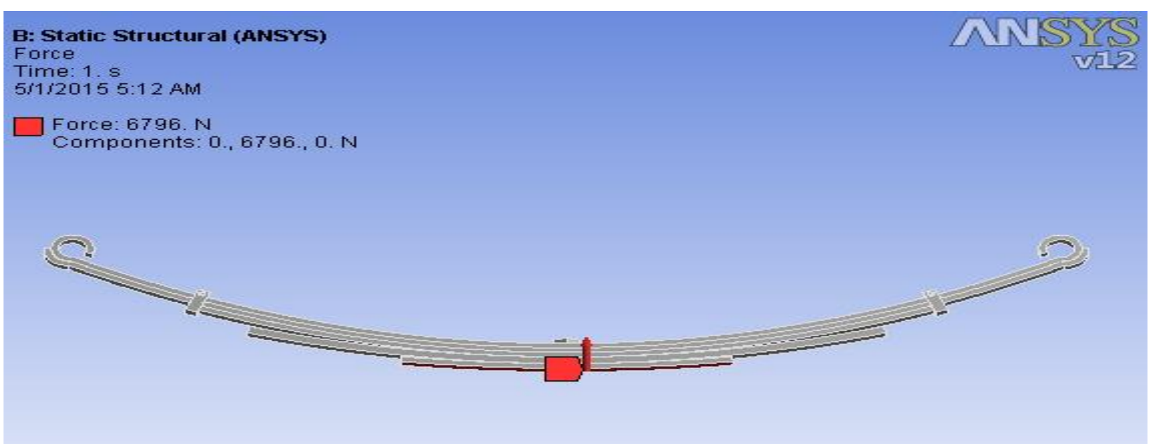


Figure 15:- loading constraint

4. ANALYSIS RESULTS AND DISCUSSION

4.1 Finite element analysis results of existing leaf spring

4.1.1 Stress and deformation results

Total deformation

The total deformation (all directional displacement) of existing leaf spring is shown in figure16 the maximum value (maximum deformation) is indicated with red color which is at the center and it is 16.981mm. Minimum deformation value is also shown with blue color = 0mm.

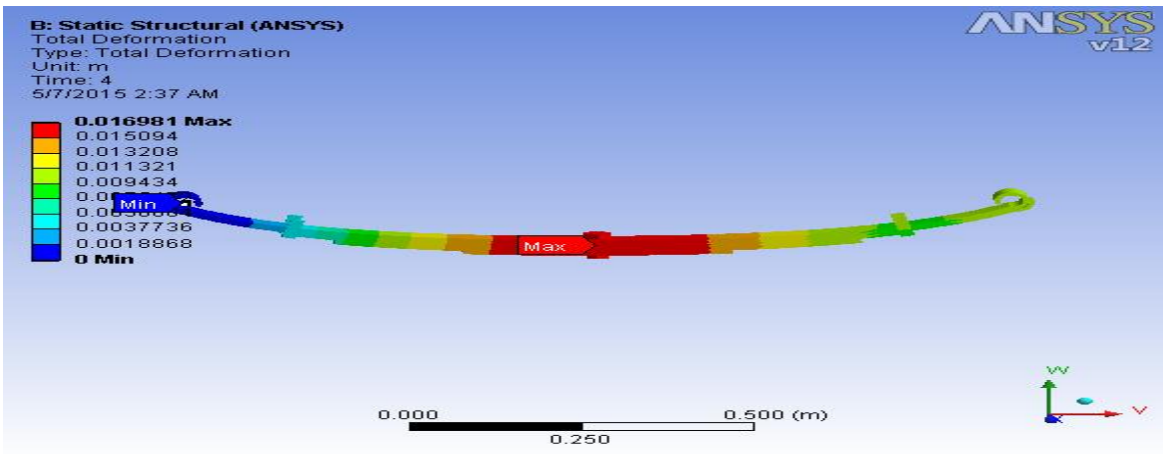


Figure 16:- total deformation

Un-deformed and deformed shape of leaf spring

The figure 17 below shows, how the leaf spring deflects and attain its final shape while 6,796 N is applied at the center. The initial position is indicated with wireframe.

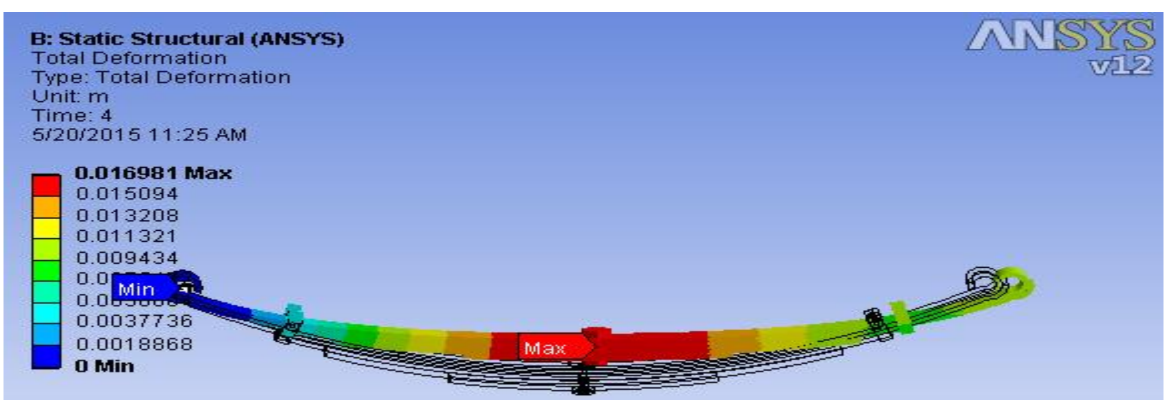


Figure 17:- un-deformed and deformed shape

Equivalent stress

Figure 18 shows maximum and minimum value of equivalent (von - mises) stress when leaf spring is loaded with maximum load. As show in the figure 18 stress is maximum at the fixed eye end of leaf spring and minimum at the other eye end (which is translating end).

Maximum stress = $4.8873 \times 10^{8}\ Pa \quad or\ 488.73\ MPa$

Minimum stress $= 110.28\ Pa$

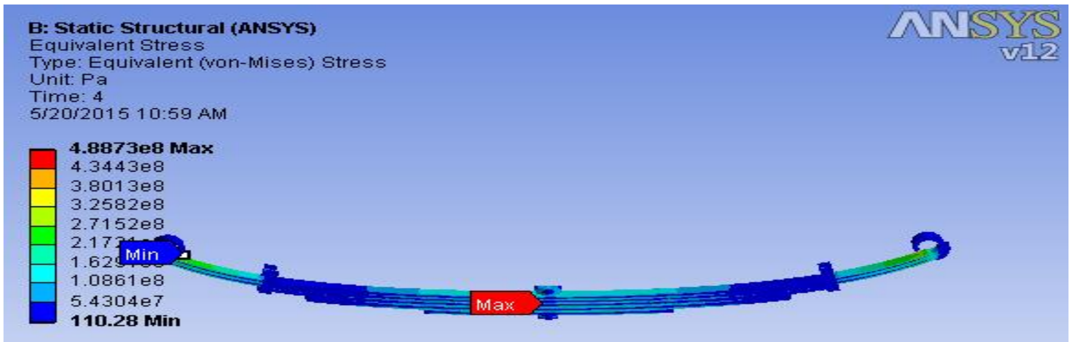


Figure 18:- equivalent von- mises stress

Equivalent elastic strain

Equivalent elastic strain of steel leaf spring is shown in the figure 19 with color code indicating maximum and minimum values.

Maximum elastic strain = 0.0020245

Minimum elastic strain = 1.0566×10^{-8}

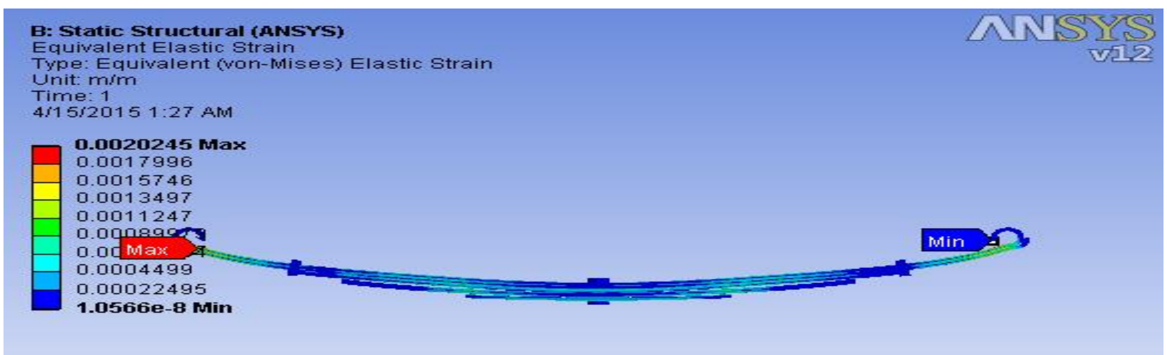


Figure 19:- equivalent von- mises elastic strain

4.1.2 Mode shape and natural frequency Analysis

Modal analysis is used to determine a structure's vibration characteristics, natural frequencies and mode shapes. It is the most fundamental of all dynamic analysis types and is generally the starting point for other more detailed dynamic analysis.

First natural frequency and mode shape

The first natural frequency and the first mode of deformation of existing leaf spring is shown in the figure 20 below.

First natural frequency = 28.436 Hz

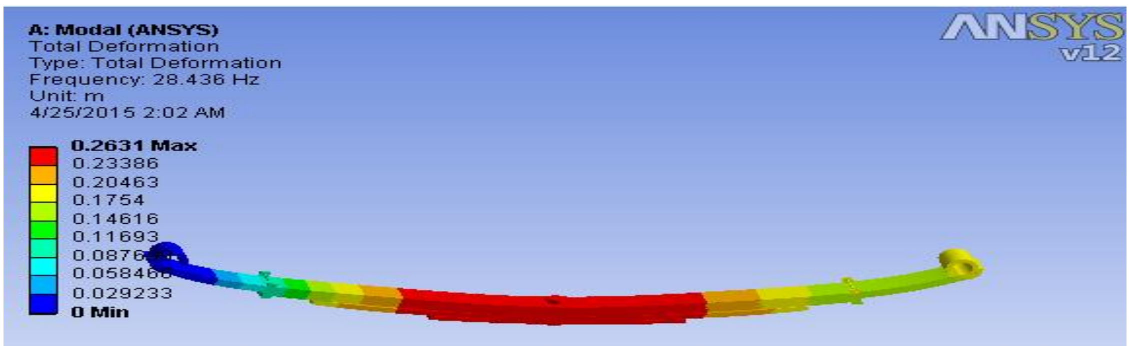


Figure 20:- First natural frequency and mode shape

Second natural frequency and mode shape

Second natural frequency and total mode of deformation of steel leaf spring is shown below in fig.21 Second natural frequency = 76.064 Hz

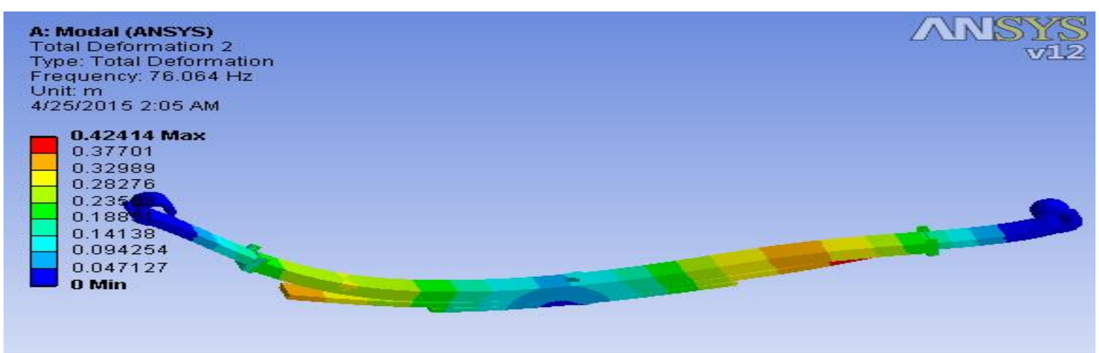


Figure 21:-Second mode and natural frequency

Third natural frequency and mode shape

Figure 22 shown below is third mode shape and third natural frequency.

Third natural frequency = 85.561 Hz

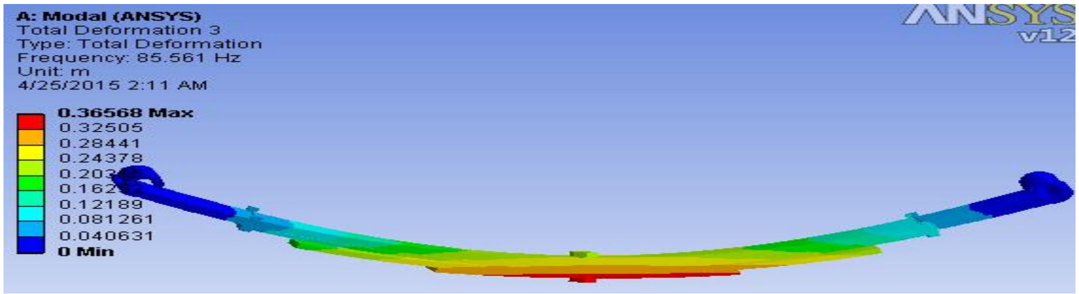


Figure 22:- third natural frequency and deformation mode

Fourth natural frequency and made shape

Frequency = 197.48 Hz

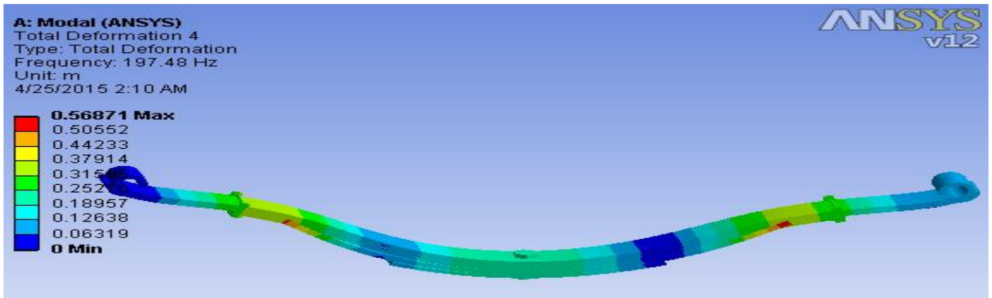


Figure 23:- fourth natural frequency and deformation mode

Fifth natural frequency and mode shape

Fifth natural frequency = 230.86 Hz

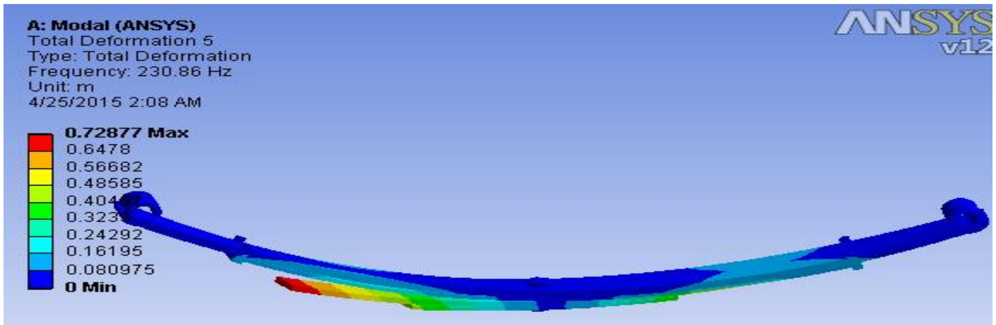


Figure 24:- fifth natural frequency and deformation mode

Sixth natural frequency and mode shape

Sixth natural frequency = 308.66Hz

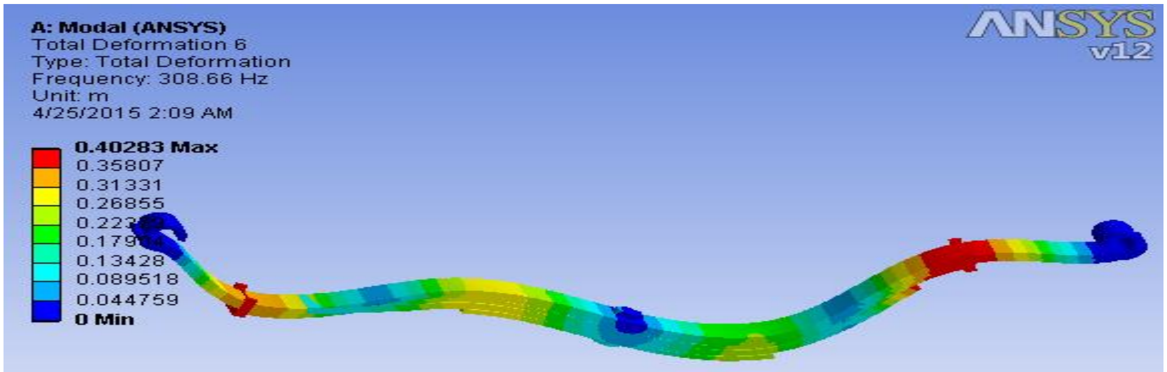


Figure 25:- sixth natural frequency and mode shape

Table 12:- Natural frequency analysis results of multi leaf spring

mode	Total deformation (m)	Frequency(Hz)
1	0.2631	28.436
2	0.42414	76.064
3	0.36568	85.561
4	0.56871	197.48
5	0.72877	230.86
6	0.40283	308.66

4.1.3 Fatigue analysis results

Life data analysis is a tool used to predict the fatigue life of steel leaf spring based on S-N graph of steel used for leaf spring. According to assumptions, if loading is of constant amplitude in stress life analysis, this represents the number of cycles up to which leaf spring will fail due to fatigue loading. When leaf spring is subjected to high cycle fatigue, where stresses are mainly elastic, the fatigue total life (S-N) approach is used for the life prediction [21]. Therefore, fatigue analysis is generally conducted by Goodman's approach, by applying a load of 6,796N and fixing the rear end eye while front eye is allowed to translate in x- direction. Meshing is done by quadrilateral elements, and descritized into 8261 nodes and 2744 elements.

Fatigue life

The maximum fatigue life is 1×10^6cycle which is indicated by blue color and minimum life of leaf spring part which will fail early is at 2.8506×10^5 cycles shown by red color.

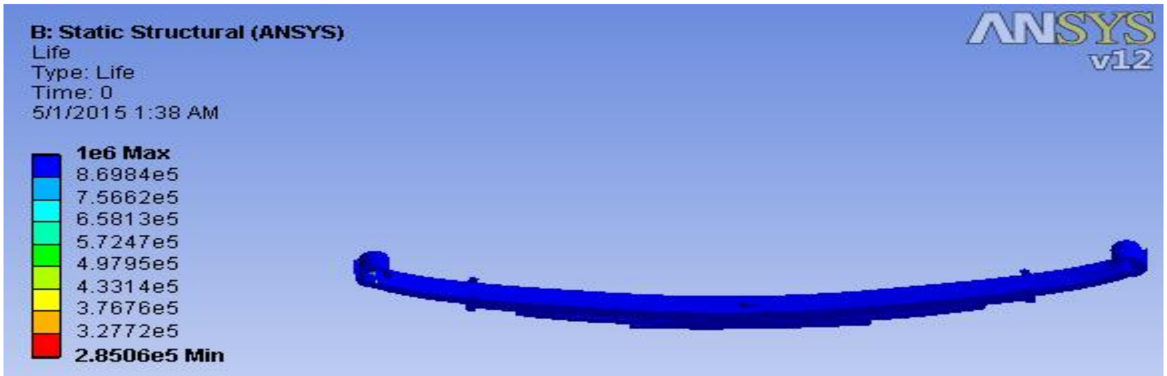


Figure 26:- fatigue life

Safety factor

The maximum fatigue safety factor is 15 indicated by blue color whereas; factor of safety indicated by red color (0.83505) is indicating failure before the design life reached.

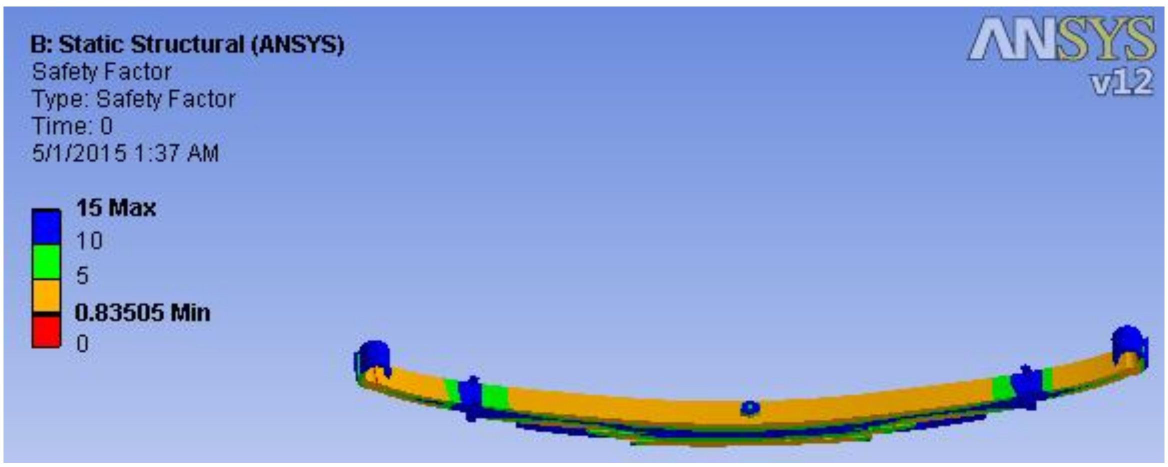


Figure 27:- factor of safety

Deflection

This is the deflection that the leaf spring experiences when it is subjected to high cyclic stress (fatigue stress). Deflection is maximum at the center shown with red color and each color represents the level of deflection at different parts of leaf spring.

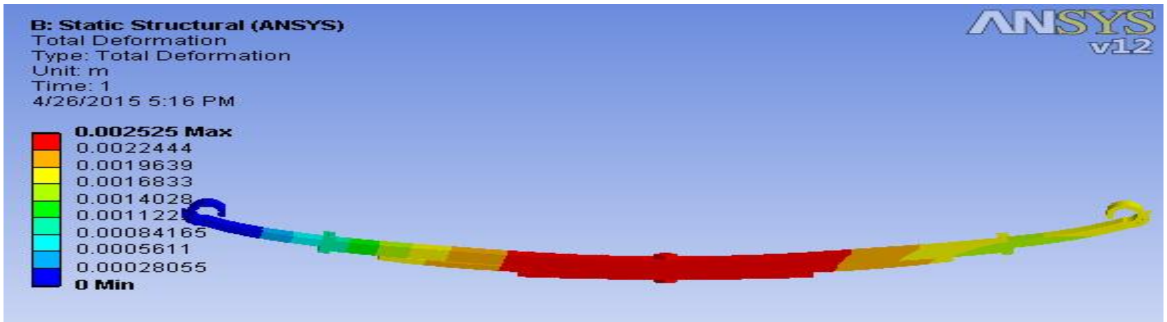


Figure 28:-deflection due to fatigue stress

Stress amplitude (equivalent von mises stress)

Stress which causes fatigue failure appearing repeatedly is shown with colors with their respective stress levels in the figure 29 below.

Maximum fatigue stress = $1.7387 \times 10^{8} Pa$ it appears on the two spring eye joints.

Minimum fatigue stress = $5830\ Pa$ indicated with blue color

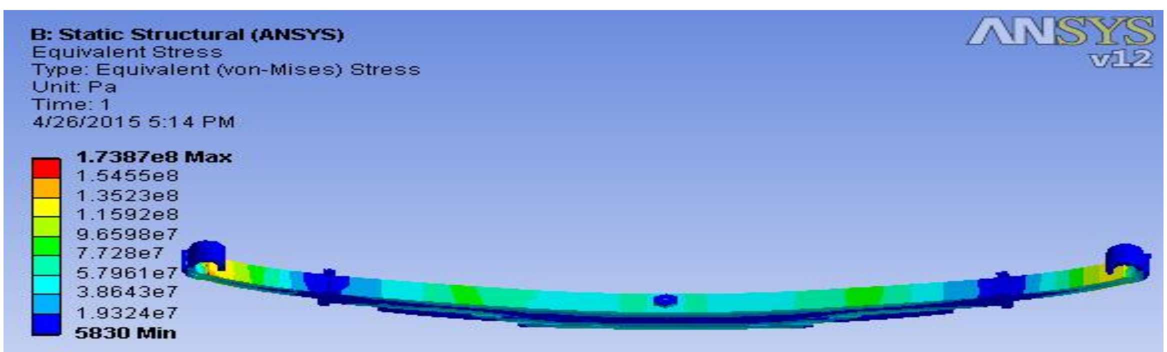


Figure 29:-equivalent fatigue stress amplitude

4.1.4 Harmonic analysis

When there is no applied external force or excitation on a vibrating system, any possible motion of the system is called free vibration. A free vibrating system will oscillate if any one of the kinematic states distance, velocity, or acceleration is not zero. Motion of a system due to application of external force or excitation called forced vibration. When the excitation is a sinusoidal function of time, it is called harmonic excitation [14]. Harmonic response analysis is a technique used to determine the steady state response of a linear structure to loads that vary harmonically with time [39]. Harmonic analysis enables to verify whether or not the particular design will successfully overcome the response, fatigue and other harmful effects of forced vibration. Boundary conditions, meshing are done and force of 6,796N is applied at the center of the leaf spring. Number of discrete points (10 points) within the range of natural frequency is taken and stress, deflection and response amplitude are calculated as shown below.

Equivalent (von- mises) stress

The maximum stress experienced at the maximum excitation frequency and the minimum stress are shown in figure 30 below with color with their respected stress values.

Maximum von- mises stress = 4.14×10^{8}

Minimum von- mises stress $= 3048.2\ Pa$

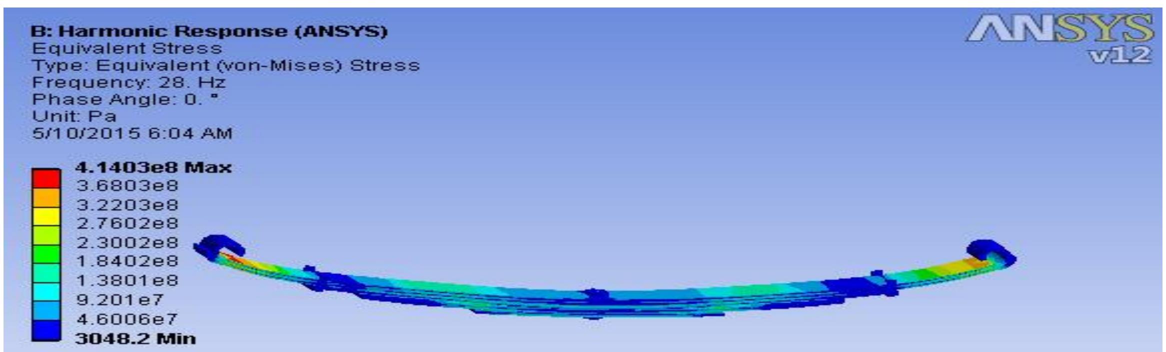


Figure 30:- equivalent (von – mises) stress

Deformation

The harmonic response maximum deformation appears at the center and minimum value is on the fixed end of the leaf spring indicated by blue color.

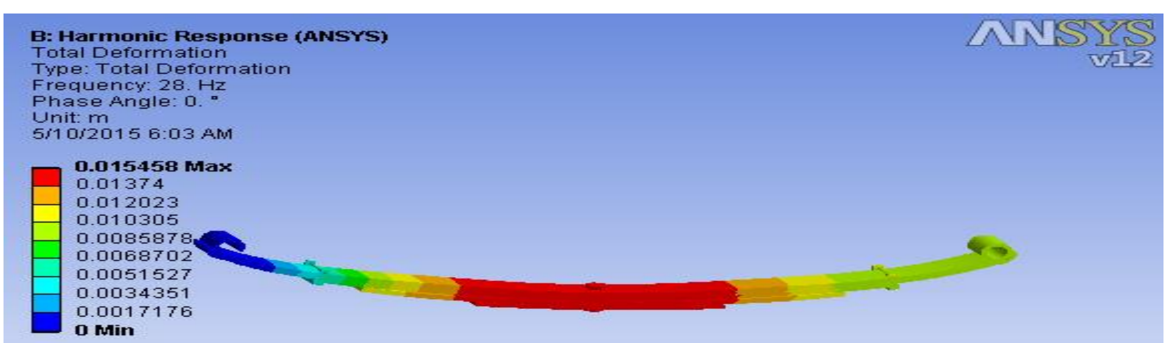


Figure 31:- deformation

Harmonic response of existing leaf spring subjected to 6796 N within its natural frequency range is shown in figure 32 below.

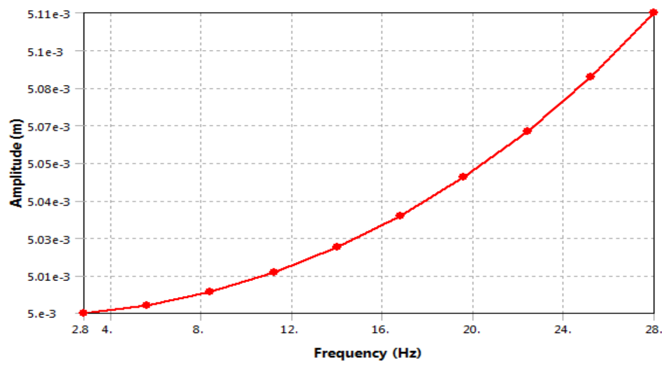
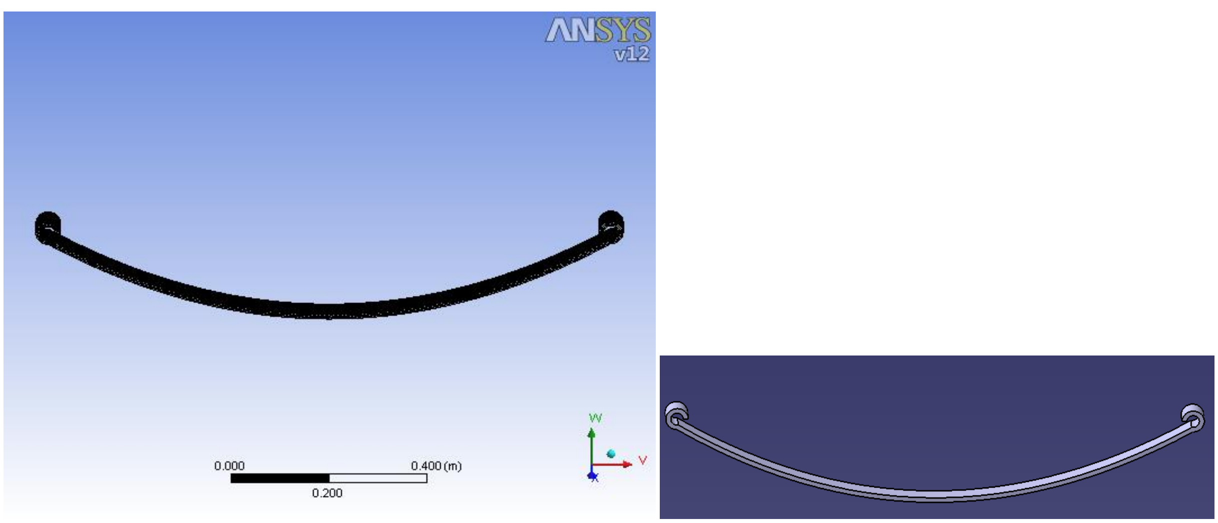


Figure 32:-harmonic response of existing leaf spring

4.2 Finite element analysis of mono composite lea f spring results

All the analysis of composite is done with the same parameters as steel leaf spring, meshing elements type, boundary conditions and loading are similar to existing steel leaf spring.



a) meshed composite leaf model b) composite leaf CATIA model

Figure 33:- designed mono composite leaf model

4.2.1 Stress and deformation

Deformation

Figure 34 shows total deformation at the maximum load applied (6,796N). The maximum deflection is at the center of leaf spring highlighted by red color and it is about 0.016081m or 16.081mm. Blue zone indicates the minimum value of deflection that the leaf spring experiences.

Minimum deflection = 0mm

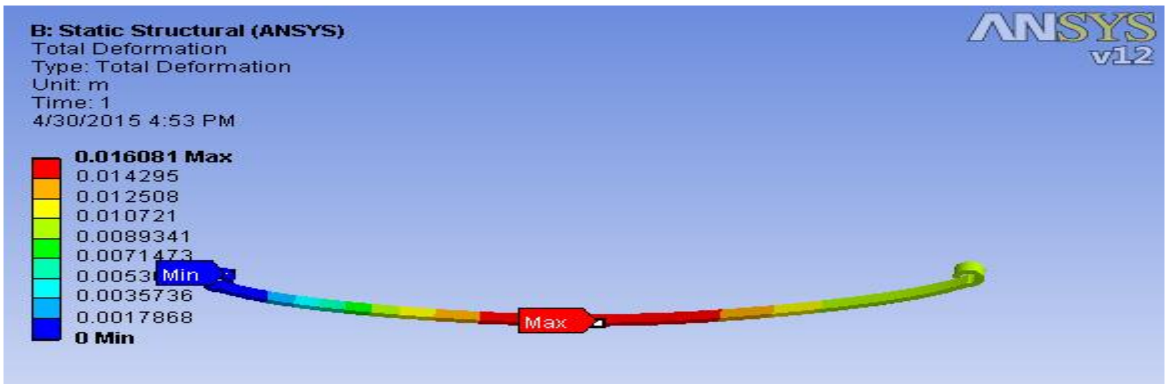


Figure 34:- total deformation of composite leaf

Un-deformed wire frame

The figure shows un-deformed and deformed shape state of mono composite leaf

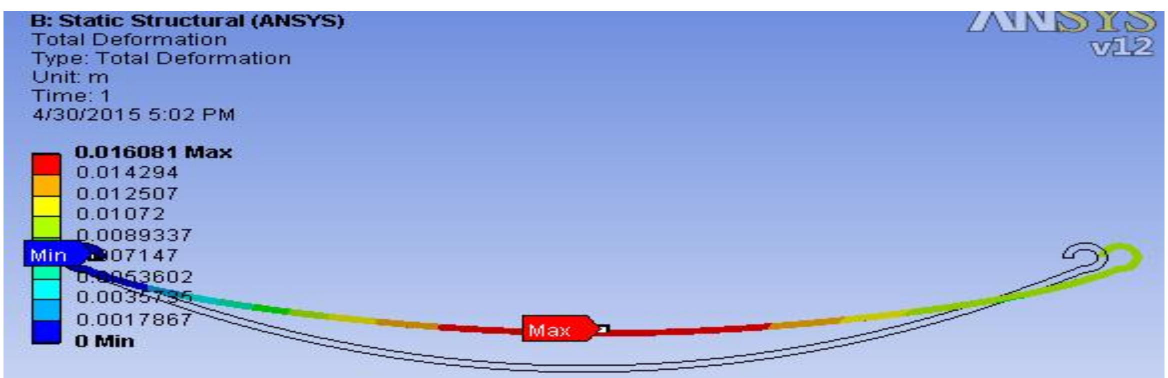


Figure 35:-un-deformed and deformed shape of composite leaf

Equivalent (von mises) stress

Figure 36 shows the maximum and minimum stress on the composite leaf spring when 6796N is applied. The color code as usual indicate the stress level, red color shows the maximum stress.

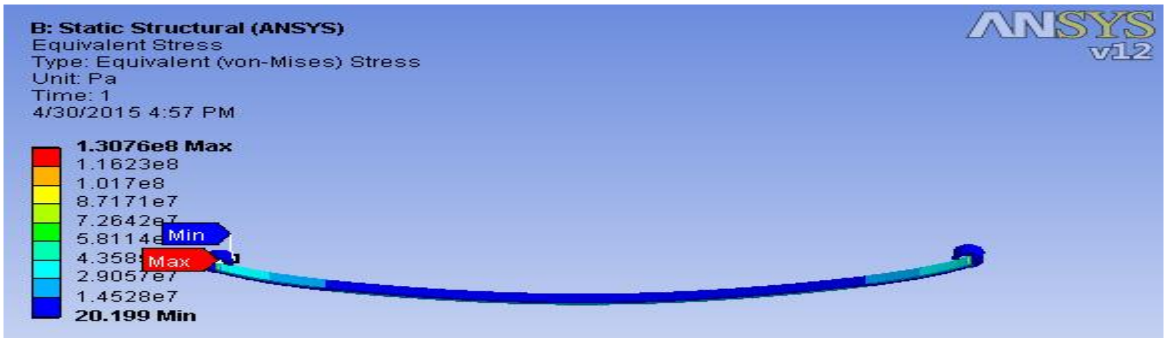


Figure 36:- Equivalent stress (von-mises) of composite leaf

Elastic strain

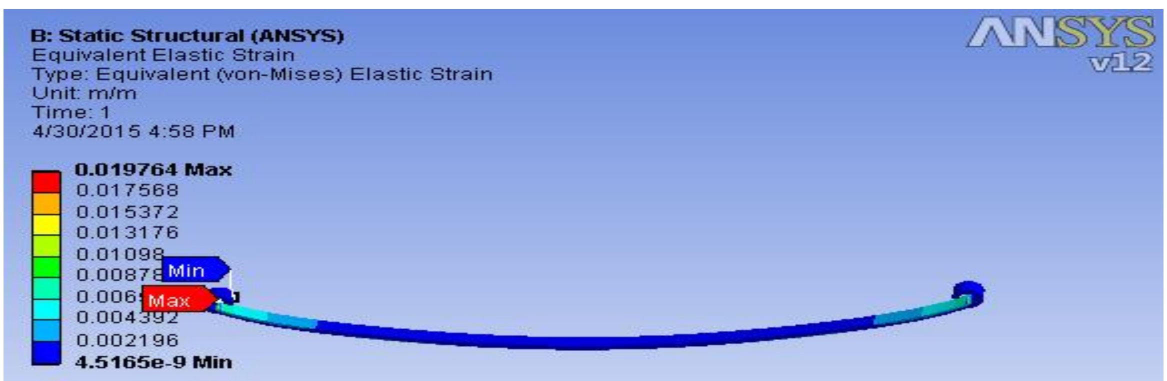


Figure 37:- Elastic Strain (von mises) of composite leaf

Shear stress

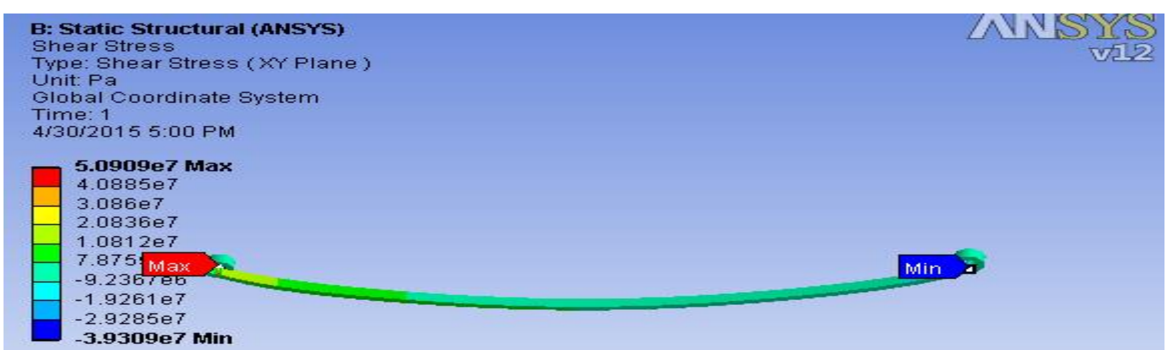


Figure 38:-shear stress on composite leaf

Table 13:- Stress and deflection analysis of mono composite leaf using FEA

parameter	FEA results
Maximum load (N)	6796
Maximum stress (MPa)	130.76
Maximum deformation (mm)	16.081

4.2.2 Mode shape and frequency analysis of composite leaf spring

The first natural frequency

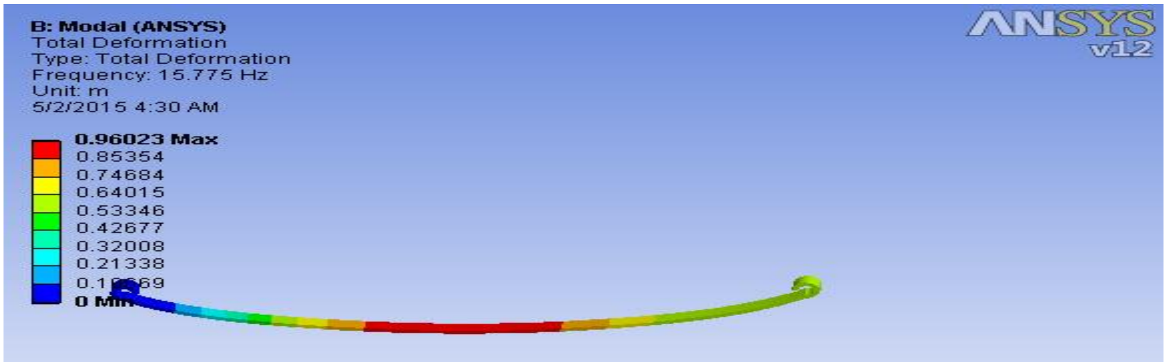


Figure 39:- first natural frequency of composite leaf

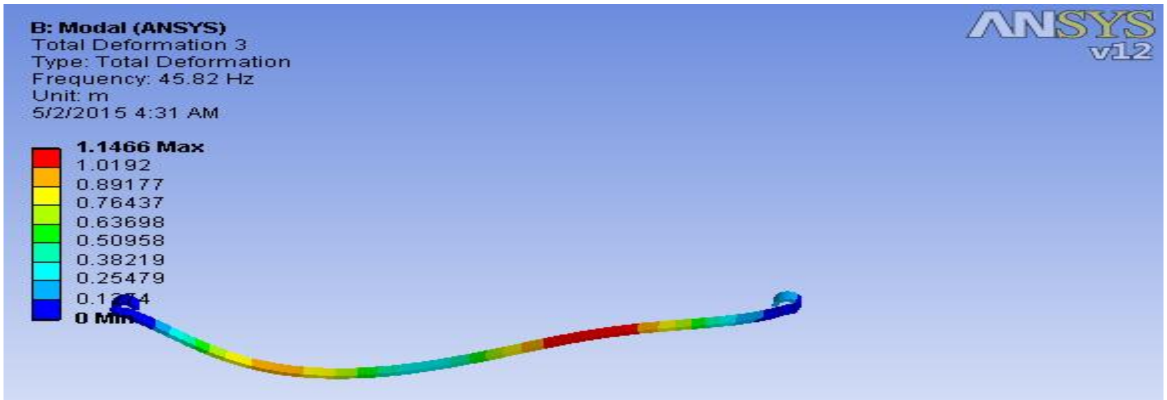


Figure 40:- second natural frequency of composite leaf

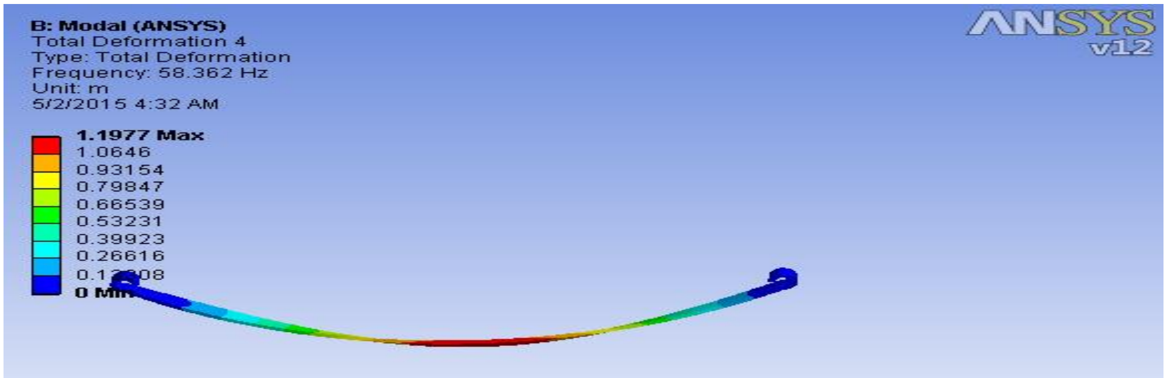


Figure 41:- the third natural frequency of composite leaf

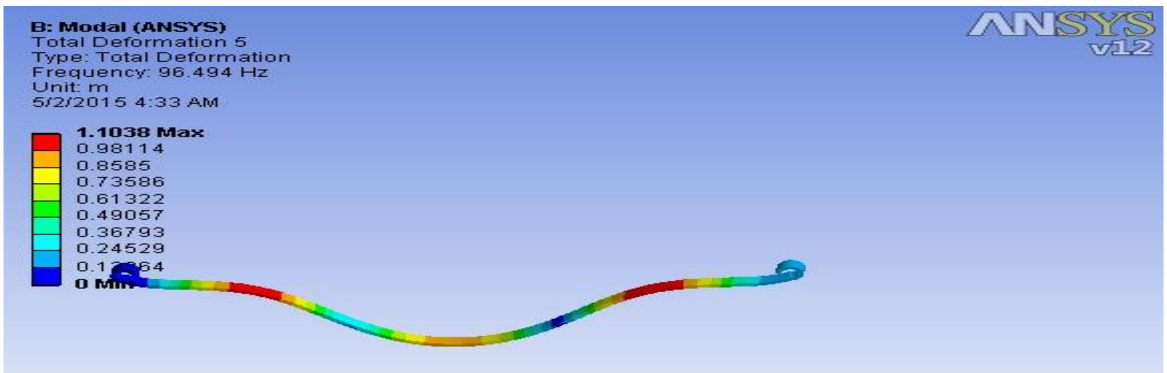


Figure 42:- fourth natural frequency and mode shape

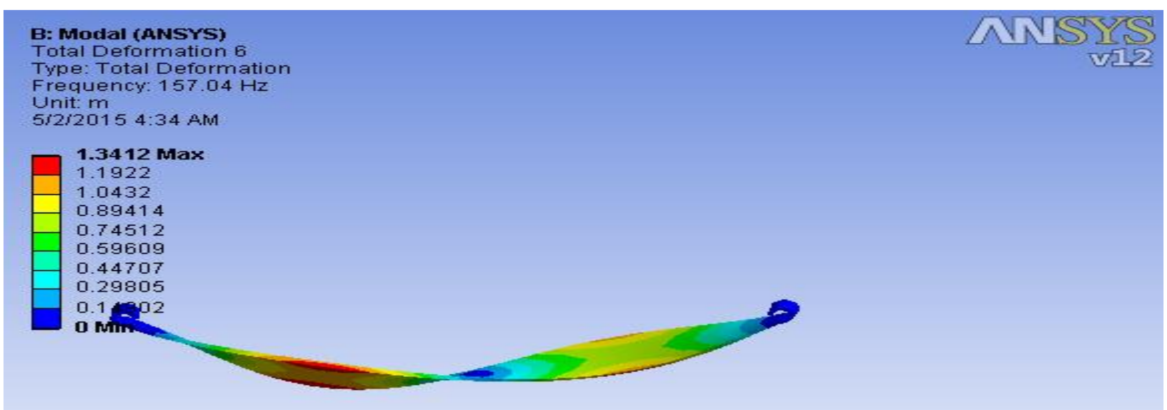


Figure 43:- fifth natural frequency and mode shape of composite leaf spring

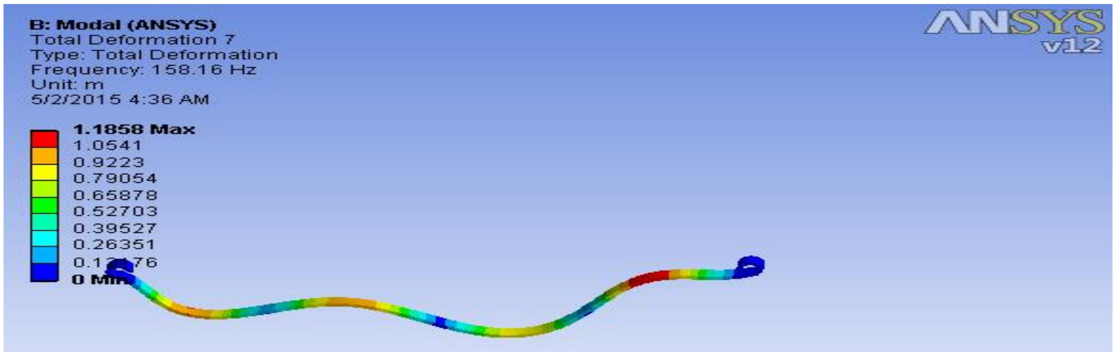


Figure 44:-sixth natural frequency and its mode shape of composite leaf spring

4.2.3 Fatigue analysis of mono composite leaf spring

Equivalent stress

Stress amplitude on different parts of leaf spring is shown with color code when 6796N is applied. The maximum stress which limits the life is about 1.1466×10^8 Pa and minimum stress on the component is 22.892Pa.

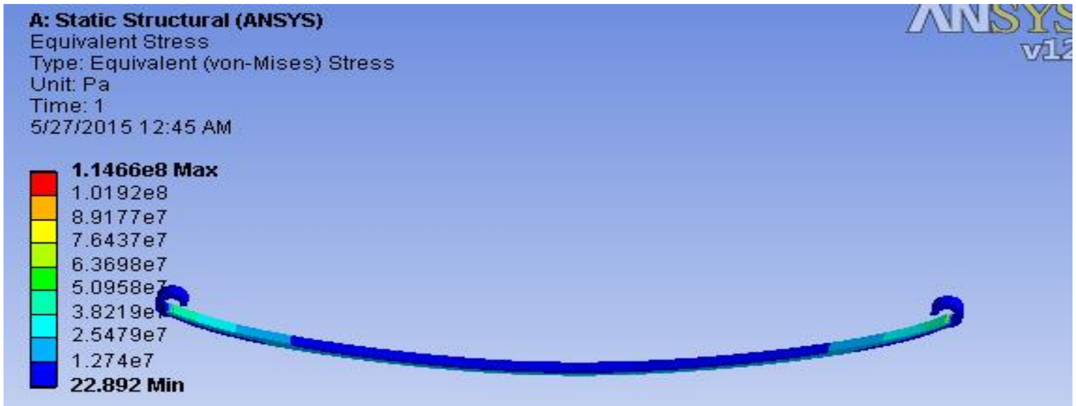


Figure 45:- alternating stress amplitude

Fatigue life of mono composite leaf spring

Number of cycles that it is expected to operate before failure occurs.

Minimum fatigue life = 1×10^7

Minimum fatigue life = 1×10^7 cycles

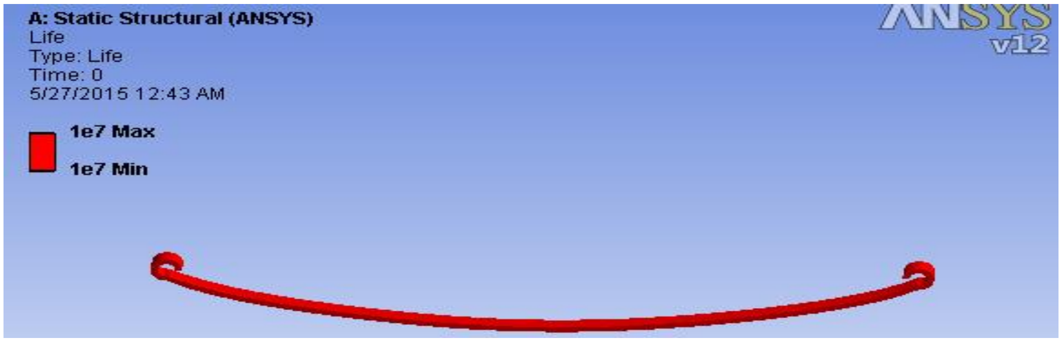


Figure 46:- number of cycles to fatigue failure of mono composite leaf spring

Safety factor

The figure 47 shows the factor of safety with respect to fatigue failure. The maximum factor of safety displayed is 15 and 1.0726 indicates fatigue safety factor.

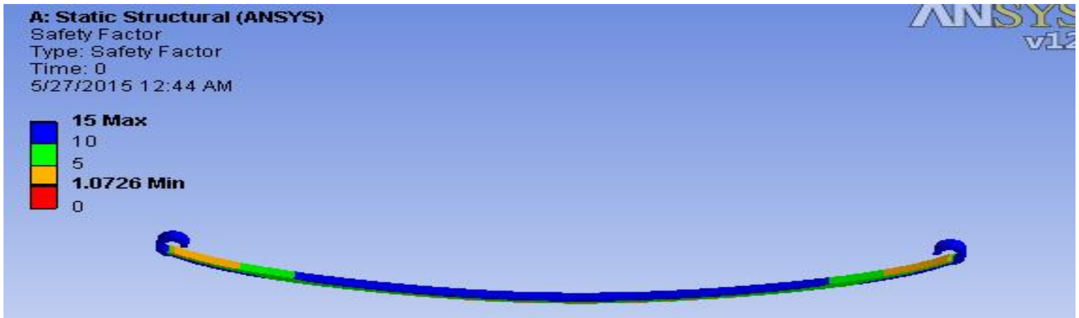


Figure 47:- safety factor

4.2.4 Harmonic analysis of composite leaf spring

Similar boundary conditions and load constraint is taken as existing leaf spring and also meshing is done with quadrilateral element having 8223 elements and18265 nodes.

Equivalent (von –mises) stress

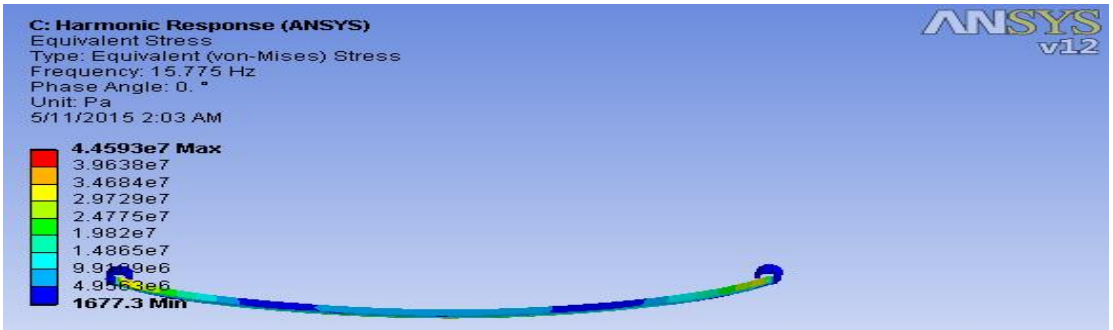


Figure 48:-equivalent (von- mises) stress

Deformation

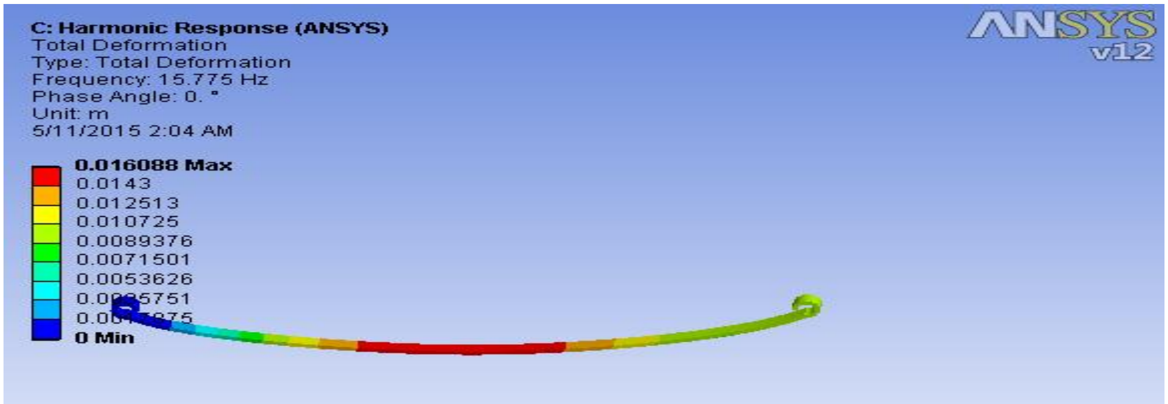


Figure 49:- deformation

Harmonic response of composite leaf spring

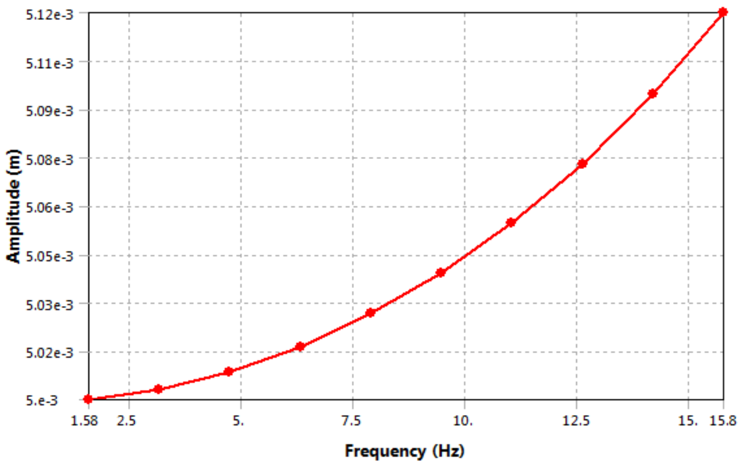


Figure 50:- amplitude versus frequency graph of composite leaf spring

4.3 Existing and mono composite leaf spring analysis results comparison

Stress and deflection

The table below is tabulated on the bases of stress and deflection analysis results of multi leaf steel leaf spring and mono composite made of e-glass epoxy.

Table 14:-stress and deflection comparison between steel and composite leaf spring

Parameter	FEA results of steel spring	FEA results of composite leaf spring	Variation %
Load (N)	6796	6796	Nil
Deflection (mm)	16.981	16.081	5.3%
Bending stress (MPa)	4.8873×10^{8}	1.3076×10^{8}	73.24%
Mass (kg)	21	1.4799	92.9%

Figure 51 below shows the equivalent (Von-Mises) stress and total deformation in both leaf springs for a 6796N load. From the graph it can be easily observed that the maximum stress developed due to the load in existing steel leaf spring and mono composite leaf spring has a great difference, stress in mono composite leaf is very much lesser than existing (55siMn90) steel leaf spring and deflection in composite leaf spring is less than deflection in existing leaf spring.

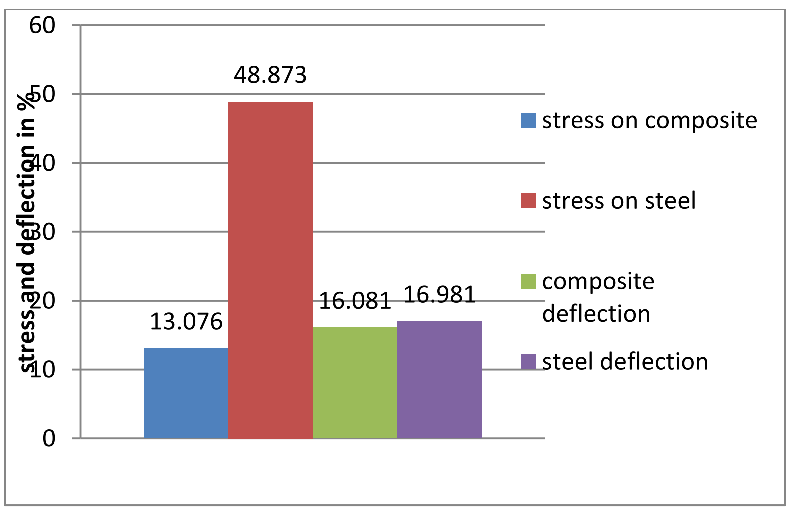


Figure 51:- stress and deflection of leaf springs

Weight

Greater weight reduction is observed between existing steel and composite leaf spring. Total weight of existing leaf spring weighs 21kg whereas composite weighs 1.4799kg, figure 52 below shows the difference clearly.

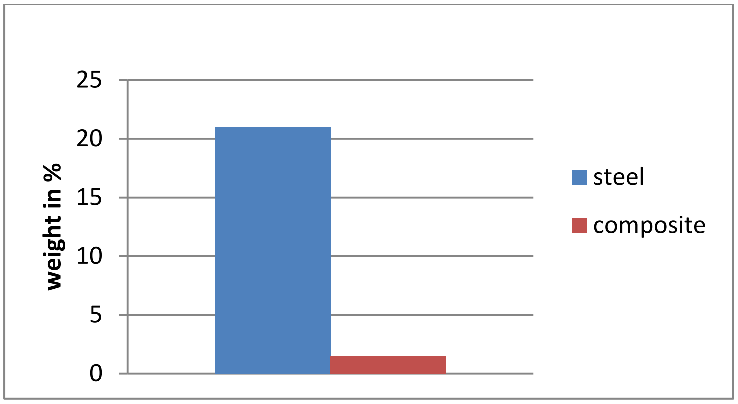


Figure 52:-weight of steel and composite leaf spring

Natural frequency

Natural frequency analysis results of existing leaf spring and mono composite leaf up to sixth mode is presented in table 15.

Table 15:-frequency comparison of existing steel leaf spring and composite leaf spring results

No. of mode	Existing steel leaf natural frequency (Hz)	Mono composite leaf natural frequency (Hz)
1	28.436	15.775
2	76.064	45.82
3	85.561	58.362
4	197.48	96.494
5	230.86	157.04
6	308.66	158.16

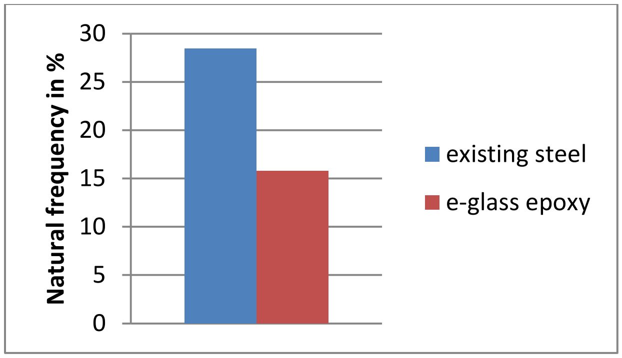


Figure 53:- natural frequency comparison

To provide ride comfort to passenger, leaf spring has to be designed in such a way that its natural frequency is maintained to avoid resonant condition with respect to road frequency. The road irregularities usually have the maximum frequency of 12 Hz (Yu andKim, 1988). Therefore, leaf spring should be designed to have a natural frequency, which is away from 12 Hz to avoid the resonance [6]. First natural frequency of mono composite leaf spring is 15.775 Hz is nearly 1.32 times the maximum road frequency and therefore resonance will not occur, and it provides ride comfort even though it is less than first natural frequency of existing steel leaf spring.

Fatigue life

For both 55si2Mn90multi steel leaf spring and e- glass epoxy mono leaf spring life data is measured in terms of the number of cycles to fail, the higher the number of cycles the higher fatigue life. Hence, e-glass epoxy has an increase fatigue life as well as increased factor of safety.

Table 16:- Fatigue analysis results

parameter	Existing steel(55si2Mn90)	E-glass epoxy
Maximum fatigue life (cycles)	1×10^6	1×10^7
Safety factor	0.83505	1.0726
High cyclic stress($\frac{N}{m^2}$)	1.7387×10^8	1.1466×10^8

Harmonic analysis of steel and composite leaf Spring

The harmonic response for existing steel and composite leaf springs at their corresponding resonance frequencies are tabulated in table below. It is observed that E-glass/epoxy has litle more amplitude of response than existing steel (55si2Mn90).

Table 17:-harmonic response amplitude results

Materials	Amplitude of response	Equivalent 9von- mises)stress
55si2Mn90	5.11×10^{-3}	4.14×10^{8}
E-glass Epoxy	5.12×10^{-3}	4.4593×10^{7}

The amplitude and the equivalent (von- mises) stress indicate the response to harmonic load therefore, the maximum stress developed due to cyclic load is far less than the tensile strength of the material in both cases, and this implies that the design is safe.

Cost comparison

The major barriers to the use of composite materials in automotive applications today is the raw materials cost, particularly for carbon fiber reinforced composites. Glass fibers costs around $1 per lb compared to only $0.40/lb for steel, but production cost of glass fiber reinforced thermosets and carbon fiber reinforced thermoplastics have lower tooling costs, lower capital investment, and reduce the number of parallel fabrication lines for a given production volume as compared with steel [26, 42, 43].

5. CONCLUSIONS, SUMMARYAND RECOMMENDATION

The numerical analysis of Huanghai pickup DD1022T steel leaf spring is done and based on the analysis results, mono composite leaf spring made of e-glass epoxy is designed. Both multi steel leaf spring and mono composite leaf spring are modeled in CATIA V5 and imported into ANSYS workbench in the form of IGS file for better analysis results. The different analysis namely, stress analysis, deflection analysis, fatigue analysis, harmonic and modal analysis are performed using ANSYS. Analysis results of conventional multi leaf spring and mono composite leaf spring is compared. Based on the results of analysis it is concluded that:

- Composite leaf spring is more economical on production processing cost than that of conventional steel leaf spring, since production of conventional leaf spring should passes through different production process tools which is very expensive.
- Conventional steel leaf spring is found to be heavier then E-Glass/Epoxy mono leaf spring
- E-Glass Epoxy mono leaf spring reduces the weight by 92.9% over existing steel leaf spring.
- Compared to conventional, composite mono leaf spring has lesser stress, weight, vibration, and increasing fatigue life, strength and comfort ride.
- Using the constant amplitude loading, the fatigue stress and life of the spring has been predicted, E-glass epoxy leaf spring has 1×10^7 cycles and existing steel (55siMn90) leaf spring has 1×10^6 cycles of fatigue failure. Therefore, e-glass epoxy has increased fatigue life than existing leaf spring.
- Steel has less amplitude than e-glass epoxy and they both have almost similar amplitude versus frequency graph that shows the harmonic response of the material.
- Equivalent stress in composite leaf spring due to harmonic response is less than its strength indicating that it is safe.
- The strength to weight ratio is higher for composite leaf spring than conventional steel spring.
- The study demonstrated that composites can be used for leaf springs for light weight vehicles and meet the requirements, together with substantial weight Savings. Therefore, it can be

concluded that mono composite leaf spring is an effective replacement for the existing steel leaf spring in light vehicles.

- Finally, I recommend department of mechanical and chemical engineering or any interested individual to take further research on different parts of the vehicle that can be substituted by composite materials and show the comparative advantages of composite to automobile industries and to the government since this will help the community in economical and environmental aspect.
- I also recommend the automotive industries to take some sort of research paper works and implement them or they should try to design the parts they need rather than importing and assembling thereby they will make technology transfer quick.

Future work

There is clearly much work to be done in this area, perhaps I anticipate that the present work can be checked for transient analysis and further reduction in weight is possible by means of shape optimization.

Summary

The purpose of this thesis work is to analyze mono composite leaf spring which is designed for light weight vehicle. Conventional leaf spring uses excess material to overcome the road irregularities which makes it considerably heavier and the friction between leaves also reduce the fatigue life span. This work is done to replace the conventional leaf spring with mono composite leaf spring made of E- glass epoxy. It is composed of five chapters each of them dealing with different aspects of the thesis work. Chapter one is an introductory and defines basic terminology used, significance of the study, objective of the study, and limitation of the study.

Chapter two describes the studies and researches which is carried out to replace the conventional leaf spring with composite leaf spring with full description of their results. It also emphasizes the appropriate material selection reasons and manufacturing process of composite leaf spring.

Chapter three is subdivided in to three parts and provides an outline of mono composite leaf design. Part one illustrates software used for modeling and analysis and the second parts describes the analytical calculation used to find parameters used for designing purpose. Part three shows the procedure used in finite element analysis.

Chapter four describes analysis results of both conventional and mono composite leaf spring on the bases of stress, deflection, fatigue life, natural frequency and harmonic response.

Finally, conclusions are made on chapter five based on the ANSYS analysis results which is composite is an effective replacement of existing leaf spring for light weight vehicles by meeting the essential requirements.

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