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

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Abstract

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

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

1. Introduction

A suspension system is one having springs and other devices that protect the chassis of a vehicle from shocks transmitted through the wheels. The main components of the suspension system are: Struts, shock absorbers, springs, tires and the automobile chassis is mounted by the axles, not directly but through some form of springs[1]. This is needed to keep the vehicle body from road shocks like as bounce, pitch, roll, and sway. These tendencies lead in an uncomfortable ride and also some additional stress on the car's frame and body. A suspension system is made up of all of the components that work together to separate the vehicle from road shocks. The spring device and various mountings are also included. A spring and a damper create a suspension system. The spring oscillates due to the energy of the road shock. The damper, commonly known as a shock absorber, holds these oscillations to a controlled degree. A spring is an elastic body with the characteristic of distorting when loaded and restoring to its original shape when the load is removed. Helical springs, conical and volute springs, torsion and spiral springs, leaf springs, disk or Belleville springs, and special purpose springs are the different kinds of springs[2].

The suspension system's key element is the leaf spring. It also has the ability to control the wheels during acceleration, braking, and turning, as well as general movement caused by road bumps. Leaf spring is originally called laminated or carriage spring. Leaf springs were very common on automobiles, right up to the 1970s in Europe and Japan and late 70's in America when the move to front wheel drive, and more sophisticated suspension designs saw automobile manufacturers use coil springs instead. Today leaf springs are still used in heavy commercial vehicles such as vans and trucks, SUVs, and railway carriages. For heavy vehicles, they have the advantage of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point. Unlike coil springs, leaf springs also locate the rear axle, eliminating the need for trailing arms and a Pan hard rod, thereby saving cost and weight in a simple live axle rear suspension. Leaf springs are designed in two methods: multi-leaf and mono leaf. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. The leaf spring bends and slide on each other allowing suspension movement. An example of a mono-leaf spring is the tapered leaf spring. The leaf is thick in the middle and tapers towards the two ends. Many of these leaf springs are made of composite material, while others are made of steel. In most cases leaf springs are used in pairs mounted longitudinally (front and back). However, there are an increasing number of vehicle manufacturers using single transverse (side to side) mounted leaf spring. Three types of leaf springs are: Laminated or Multi-leaf springs, single or mono-leaf springs, tapered leaf springs[3].

The third type of leaf spring is the combination of the above two. The multi-leaf springs are commonly used in the automobile suspension system at the rear side and are still in use for commercial vehicles suspension system. It consists of a number of steel strips or leaves placed on the top of each other and then clamped together. The type of application and load carried determines the length and number of leaves. The top leaf is called as the main leaf and the ends of the leaf are rolled to form the eye of the spring. This is for attachment to the vehicle chassis or body[4].

A leaf spring is a long, flat, thin, and flexible piece of spring steel_or composite material that resists bending. The basic principles of leaf spring design and assembly are relatively simple, and leafs have been used in various capacities since medieval times. Most heavy duty vehicles today use two sets of leaf springs_per solid axle, mounted perpendicularly to support the weight of the vehicle. This Hotchkiss system requires that each leaf set act as both a spring and a horizontally stable link. Because leaf sets lack rigidity, such a dual-role is only suited for applications where load-bearing capability is more important than precision in suspension response[5].

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. The main function of leaf spring assembly as suspension element is not only to support vertical load, but also to isolate road-induced vibrations. The behavior of leaf spring is complicated due to its clamping effects and inter-leaf contact etc. It carries lateral loads, brake torque, driving torque in addition to shock absorb. Springs are crucial suspension elements on cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride. The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the unsprung weight. The use of composites will aid in the design of a better suspension system with increased ride quality if it can be performed without a significant increase in cost and a decrease in quality, as well as a reduction in load carrying capacity and reliability. Strain energy becomes a major factor in the design of springs[6].

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

To solve problem in this regard composite materials play an important role. The foremost component of the suspension system of vehicle is leaf spring, it has substantial amount of weight, and it is necessary it would have ample strength because it needs to resist vibrations and jolts during its working. The prominence of this research work is to reduce the overall weight of suspension system and improve load carrying capacity of the leaf spring by using the composite material.

2. Materials of leaf spring

The material used for conventional leaf spring is usually a plain carbon steel having 0.90 to 1.0% carbon. EN47 is suitable for oil hardening and tempering. When EN47 is hardened it offers excellent toughness and shock resistance which make it a suitable alloy spring steel for parts exposed to stress, shock and vibrations[7].Table 1 shows mechanical properties of structural steel.

Table 1: Mechanical property of structural steel[7]

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

2.1. Selection of composite fiber

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

2.2. Selection of a matrix

Reinforcement materials are constantly counted on various types of matrix. As a result, the reinforcement and matrix are well suited to each other in order to provide improved fatigue resistance and lower stress distribution on the intended components. There are various types of matrix chemicals available commercially for structural design applications, as indicated in the literature session. Epoxy resin and polyester resin are appropriate for structural software, and epoxy resin is the most important matrix for leaf spring layout among these Design, Simulation, and. Fibers run in specific directions to center of attention the reinforcement where it is desired, and the epoxy holds the fibers where they are needed in fiber-reinforced constructions. Although the epoxy matrix's primary function is to adhere to and transfer masses to fibers, it is a strong substance in and of itself [8]. It provides impact resistance while also helping to protect the fibers from damage. In comparison to other types of matrix, epoxy resin provides the following advantages[9]. They have better adhesive properties, superior mechanical properties (strength and stiffness), better resistance to fatigue and micro cracking, increased resistance to osmosis (surface degradation due to water permeability), less resin required, faster curing at room temperature, and good chemical resistance properties. Table 2 shows properties of epoxy resin.

Table 2: Properties of epoxy resin [12]

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

2.3. Material properties of composite mono leaf spring

Along with steel, three different composite materials like E- glass/epoxy, S-glass/epoxy, carbon/epoxy, are taken in the present work. All the composite materials are assigned with the following material properties that are shown in Table 3.

Table 3: property of epoxy E-glass, epoxy S-glass and epoxy carbon UD (395 Gpa)[10]

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

3. Methodology of leaf spring

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

- A relevant data was collected through literature review.
- Some crucial characteristics of S-glass/epoxy, E-glass/epoxy UD and carbon epoxy UD (395 GPa) prepreg composite and the analysis of leaf spring of these composites which was done by experimental investigation was collected.
- An actual data was collected by observing and measuring the specifically selected Toyota pickup four wheeled light vehicle leaf spring specification.

- Performed theoretical calculation of the steel and laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials leaf spring for light weight four wheeled vehicle.
- Make 3D model of E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials and steel leaf spring using Solid work 2013.
- Make analysis of laminated E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) composite materials and current steel material leaf spring using ANSYS 19.2 Workbench.
- Finally state the conclusion of ANSYS 19.2 workbench results.

4. Design guidelines of laminated composite

The following assumptions are made for this work:

(i) All Nonlinear effects are excluded

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

(iii) The leaf spring has uniform cross section

4.1 Design consideration of conventional leaf spring

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

(i) Constant thickness, constant width design;

(ii) Constant thickness, varying width design;

(iii) Varying thickness, varying width design;

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

Specification of Toyota car is mentioned in Table 4:

Table 4: Specification of Light vehicle Model Toyota Car (Technical Specification of Toyota)

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

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

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

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

Therefore payload of vehicle =1845 Kg, Kerb weight of vehicle =945 kg

Total mass of the vehicle is the sum of payload+kerb weight =2790kg

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

According to Rupesh N. et,al.[13], the value of factor of safety ranges = (1.3-2.25), then take factor of safety 1.5

Therefore, Total Weight (W) = 2790×10×1.5 = 41850 N

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

$W = \frac{41850}{4}\ N$ =10462.5 N

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

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

Type of material = structural steel, No. of leaves = 5, Length of master leaf (eye to eye) = 130 cm, Length of 2nd leaf = 118 cm, Length of 3rd leaf = 107 cm, Length of 4th leaf = 72 cm, Length of 5th leaf =49 cm, Width of leaves = 6 cm, Thickness of leaf = 8mm, Camber (no load condition) = 6 cm, Eye bore diameter = 3 cm.

4.2 Determination of weight

For conventional structural steel leaf sprig:

Calculate the weight of leaf spring by using the formula:

$$w = m \times g \text{ where } m = \rho \times v$$

Where m= mass of leaf spring, ρ=density of leaf spring, g= acceleration due to gravity, V=volume of leaf spring and v=l×w×t, where l=length of leaf spring, w=width of leaf spring

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

V_1=L_1 x t x w = $1300mmx8mmx60mm\ where$ V_1=volume of master leaf spring, L=length, t=thickness and w=width

V_1=624 cm^3

Now weight of master leaf (W_1) = ρ×v×g =7.77gm/cm^3x624cm^3x10m/s^2=48.48 N

Weight of the 2nd leaf (W_2) = 44.01 N, Weight of the 3rd leaf (W_3) =39.9 N, Weight of the 4th leaf (W_4) =26.854 N, Weight of the 5th leaf (W_5) =18.27 N, **Total weight = 177.513 N**

4.3. Stress and Deflection Calculation of conventional leaf spring

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

$2L = L_1 – 2/3\ l$, take the width of the U-bolts = 85mm (direct measuring)

$2L$ = 1300mm – 2/3 × 85 mm = $2L$ = 1243.33 mm

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

Now let us calculate stress of conventional leaf spring

By using the formula: $\sigma = \frac{6WL}{nbt^2}$

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

Calculated the deflection of convention steel leaf spring by using the formula:

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

$$Ix = \frac{1}{12}(650mm)(24mm)^3 - (\frac{1}{12}(150mm)(6mm)^3 + 150mmx6mmx(3mm)^2] - [\frac{1}{12}(350mm)(12mm)^3 + 350mmx12mmx(6mm)^2 - [\frac{1}{12}(44mm)(18mm)^3 + 44mmx18mmx(6mm)^2$$

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

Ix =37, 44000 mm^4

$$\delta = \frac{WL^3}{3EI} = 20925Nx\frac{(633mm)^3}{3x200000\frac{N}{mm}x3744000mm^4} = \frac{5.307x10^{12}}{2.24x10^{12}} = 23.5\ mm$$

4.4. Dimension of composite mono leaf spring

The Dimensions of Laminated composite leaf springs are taken as that of the conventional steel leaf spring [11].Based on this literature the dimension of the new mono leaf spring is done as follow:

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

4.5. Weight of composite materials

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

Weight epoxy E-glass

W=mg⇒ρ=m/v, ρ=2000Kg/m^3, V=l×t×w=1.3m×0.06m×0.04m=0.00312m^3, m=2000kg/m^3×0.00312m^3= 6.24 kg, w=mg⇒6.24 Kg×10m/s^2 = 62.4 N

Weight epoxy S-glass

m=ρV=2000kg/m3×0.00321=6.24 kg, w=mg=6.24 Kg×10m/s^2 = 62.4 N

Weight of carbon (395Gpa) prepreg

W=mg⇒ρ=m/v, ρ=1490 kg/m^3, V=l×t×w=1.3m×0.06m×0.04m=0.00312m^3

m=1490kg/m3×0.00312m^3=4.65kg w=mg⇒4.65kg×10m/s^2 = 46.5 N

4.6. Design of composite Leaf Spring

Bending Stress and deflection of Composite materials

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

Therefore, the half effective length of epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg was taken as L= 621.67 mm

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

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

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

Deflection of the epoxy E-glass UD

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

$I=3.2X10^{-7}m^4$, $E=45X10^9N/m^2$, $3EI=3*3.2X10^{-7}*45X10^9=14400\ Nm^2*3=43200\ Nm^2$

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

The deflection of the epoxy S-glass UD

$I=3.2X10^{-7}m^4$ $E=50X10^9N/m^2$

$3EI=3*3.2X10^{-7}*50X10^9 =48000\ Nm^2$

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

The deflection of the epoxy carbon UD (395 GPa)

$I=3.2x10^{-7}m^4$ $E=121x10^{12}N/m^2$

$3EI=3*3.2X10^{-7}*121x10^{12} = 1161*10^4Nm^2$

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

5. Dynamic analysis of leaf springs

Modal analysis helps us to identify various modes of vibration as well as the frequency at which those modes are created. Modal analysis helps us to calculate natural frequency of system so we know which frequency can be destructive and dangerous for system that causes resonance. In modal analysis need not to apply any external load but it is first step of dynamic analysis.

Theoretical Euler Bernoulli Beam Theory: It covers the case for small deflections of a beam that are subjected to lateral loads only. The Euler's equation for natural frequency is given as

$$n = \frac{n^2\pi^2}{L^2}\left[\frac{\sqrt{EI}}{A}\right] \qquad (1)$$

Where: n = Mode Shape, I = Moment of inertia of system, ρ = Density of material, A = Area of cross section, L = Length of spring, E = Modulus of Elasticity For structural steel

$E=200\times10^9$ N/m^2, I=37, 44000 $\times10^{-12}$ m^4 ,ρ =7700 kg/m^3, L=1.3 m, W=0.06 m, A=0.078 m^2

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

ExI =200x10^{9}N/m^{2}x374410^{-9}=748800 Nm^2, ρxA=7700 kg/m^3×0.078m^2 =600.6 Kg/m

$$\omega_1 = \frac{n^2\pi^2}{L^2}\left[\frac{\sqrt{EI}}{A}\right] = \frac{1^2\times3.14^2}{1.3^2}\left[\frac{\sqrt{748800\,Nm^2}}{600.6\,\frac{kg}{m}}\right] = 205.94\,rad/s$$

$f_1=\omega_1/2\pi$=205.94 rad/s /6.28=32.79Hz,ω_2=4×5.83×35.3=823.76 rad/s, f_2=131.11 Hz

ω_3=9×5.83×35.3=1852.19 rad/s, f_3=294.93 Hz, ω_4=16×5.83×35.3=3292.78 rad/s, f_4=524.32 Hz
ω_5=5×5.83×35.3=5144.97 rad/s, $f_{5=}$819.26 Hz

Similarly, for composite materials theoretical calculations modal analysis were done using formula (1)

The modal natural frequency of E-glass/epoxy

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

I=bt^3/12=0.06× (0.04)^3/12 = 3.2x10^{-7}m^4, A=b×l=0.06×1.3=0.078 m^2, E=45X10^{9}N/m^2

EI=3.2x10^{-7}x45x10^9=14400 Nm^2, ρxA =2000Kg/m^{3}x0.78m^2=1560 kg/m

$\omega_1 = \frac{1^2\pi^2}{1.3^2}\left[\frac{\sqrt{14400}}{156}\right]$ =56.01 rad/s⇒f_1=8.9 Hz, ω_2 =224.04 rad/s $_=$ ⇒f_2 =35.67 Hz, ω_3 =504.09 rad/s ⇒f_3 =80.26 Hz, ω_4=896.15 rad/s⇒f_4=142.67Hz, ω_5=1400.25 rad/s ⇒f_5 =222.96 Hz

The modal natural frequency of S-glass/epoxy UD

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

I=b×t^3/12=0.06× (0.04)^3/12=3.2X10^{-7} m^4, A=b×l=0.06×1.3=0.078m^2 ,E=50X10^9 N/m^2

EI=3.2X10^{-7}×50X10^9=16000 Nm^2 , ρxA =2000Kg/m^{3}x0.78m^2=1560 kg/m

$\omega_1 = \frac{1^2\pi^2}{1.3^2}\left[\frac{\sqrt{16000}}{156}\right]$ = 59.04⇒f_1 =9.4Hz, ω_2 =236.16 rad/s $_=$ ⇒f_2 =37.6Hz, ω_3 =531.36 rad/s ⇒f_3 =84.61 Hz, ω_4=944.16 rad/s⇒f_4=150.353 Hz ω_5=1475.25 rad/s ⇒f_5 =234.91Hz

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

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

I=bt^3/12=0.06× (0.04)^3/12 = 3.2X10^{-7}m^4 ,A=bl=0.06×1.3=0.078 m^2 , E=121x10^{12}N/m^2

EI=3.2×10^{-7}×121X10^{12}=387.2 ×10^5 Nm^2, ρ×A =1450kg/m^{3}x0.078m^2=113.1 kg/m

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

$\omega_1 = \frac{1^2\pi^2}{1.3^2}\left[\frac{\sqrt{38720000}}{156}\right]=2904.5 \Rightarrow f_1=462$ Hz, $\omega_2 = 11618$ rad/s ₌ $\Rightarrow f_2 = 1850$ Hz, $\omega_3 = 26140.5$ rad/s $\Rightarrow f_3 = 4162.5$ Hz, $\omega_4=46472$ rad/s $\Rightarrow f_4=7400$ Hz, $\omega_5=72600$ rad/s $\Rightarrow f_5 = 11560.5$ Hz

Harmonic response

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

6. 3D Modeling of Leaf Spring

The 3D Modeling is a geometrical representation of a real object without losing information which the real objects have. Various mechanical design and manufacturing operations modeled using Solid work. In this specific research, based on the dimension obtained from theoretical calculation and direct measuring data 3D modeling of the leaf spring was created with the help of solid work software and analysis is done by using ANSYS19.2 workbench for stress and deflection.3D model of steel and composite leaf spring using solid works are shown in Figure 1 and Figure 2. The light vehicle (Toyota pickup) model vehicle is selected for this study, because of the following reasons;

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

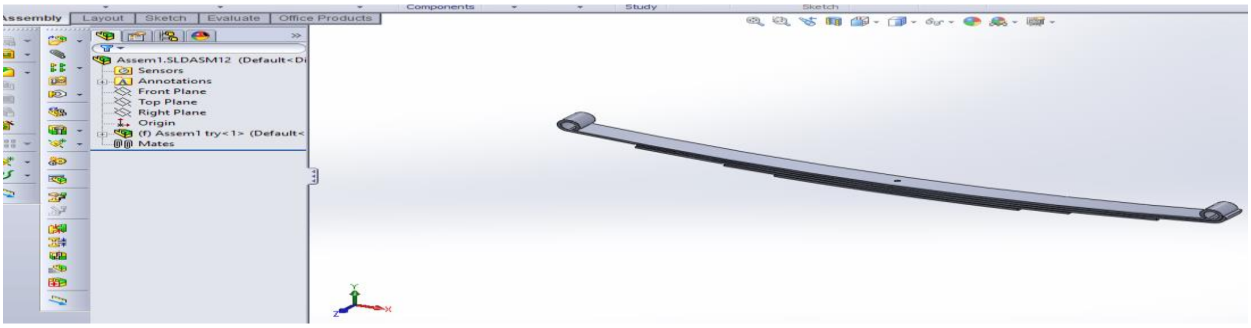


Figure 1: 3D modeling of steel leaf spring using solid work 2013

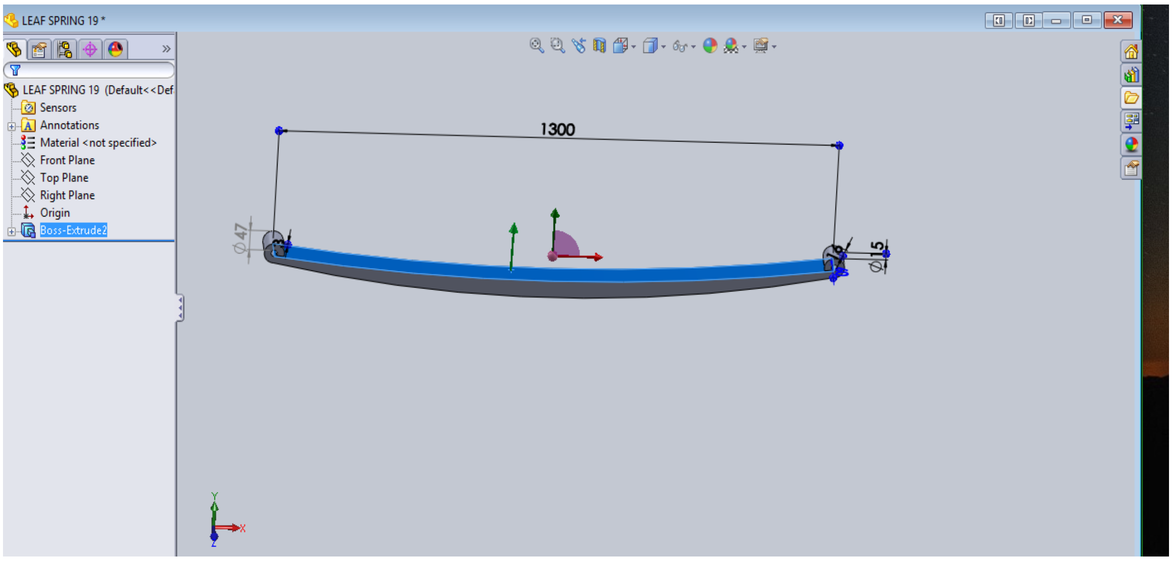


Figure 2: 3D modeling of composite materials leaf spring using Solid work.

7. Analysis of leaf Spring Using Finite Element Method

The Finite element Method (FEM) is a numerical method of solving system of partial different equation (PDFs) arising in engineering and mathematical modeling. Designers use ANSYS in a wide range of industries, including aerospace, automobile, construction, nuclear, communications, biomedical, and many others. ANSYS is a finite element analysis (FEA) software package that can be used for a variety of applications. Finite Element Analysis (FEA) is a computational tool for breaking down a complex structure into tiny parts known as components. The program creates a detailed description of how the system functions as a whole by implementing equations that control the action of these elements and solving them all. These findings can then be presented in tabular or graphical form. This form of analysis is usually used to design and optimize a system that is too complex to manually analyze. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations[12].

7.1 Static structure analysis

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

· Externally applied forces and pressures

· Steady-state inertial forces (such as gravity or rotational velocity)

· Imposed (nonzero) displacements

· Temperatures (for thermal strain).

Assumptions were developed during analysis of both for mono composite E-glass/epoxy, S-glass/epoxy UD and epoxy carbon UD (395 GPa) and conventional leaf spring materials, to be compatible with the modeling of the leaf spring.

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

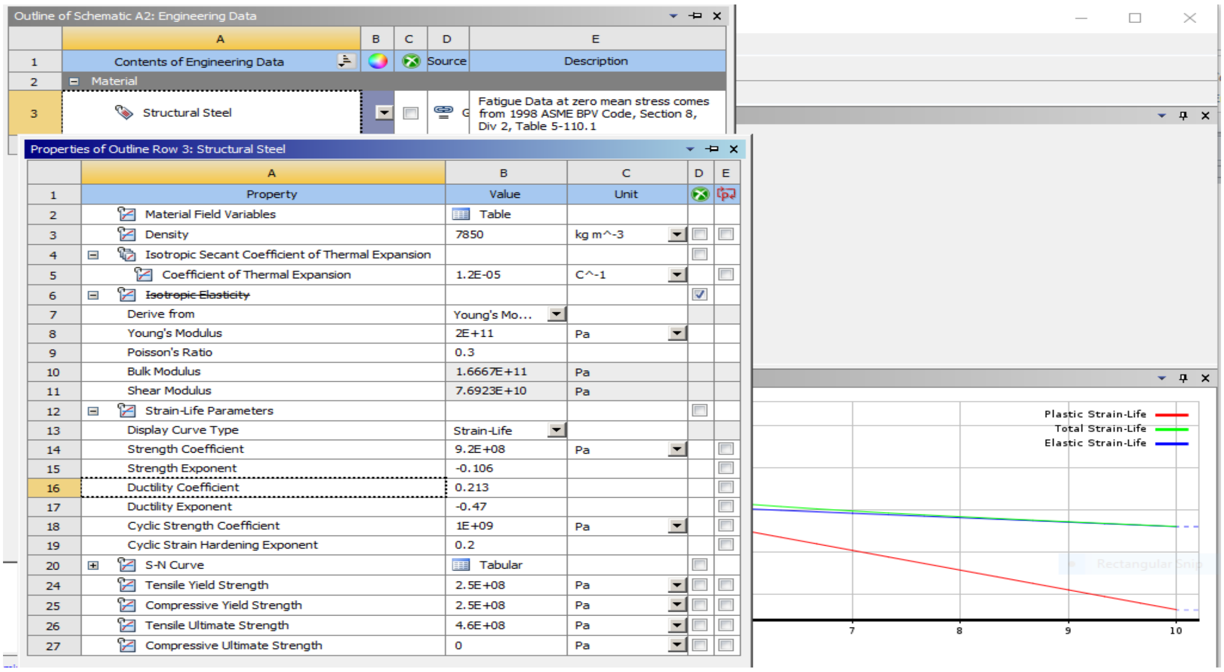
(ii) The U-bolt clamp connects the leaf spring with the axle of the vehicle firmly, then the connection is counted as fixed and the support is fixed support of the leaf spring.

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

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

7.2. Static analysis of conventional steel leaf spring

There are some steps to do static structure analysis of a structure or a component. Define Engineering Data, the specific material property of the structural steel was stated in the Figure 3:



Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Structural Steel		☐	G	Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1

Properties of Outline Row 3: Structural Steel

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

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

7.2.1. Attach Geometry

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

7.2.2. Apply Mesh Control/preview mesh

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

7.2.3. Applying Load and boundary condition

(a). Displacement constraint: By considering the actual behavior of leaf spring in the vehicle, one end of leaf spring is rest on the shackle and the other end is on the chassis firm. So one end of leaf spring in X, Y, and Z components are fixed support and in rotation constraint X, Y and Z components are also fixed. The other ends of displacements of the X component are free; Y and Z components are fixed. Figure 4 shows how conventional steel leaf spring is mounted to the vehicles. One end is mounted to the shackle and the other end is to the chassis frame .the middle of the spring is mounted on the axel.

(b). Force constraint:

Figure 4: Mounting of steel leaf spring [Observation]

When observing the leaf spring mounting position concerning the exerting load of the vehicle. The right and left sides of the wheels are connected by the axel and the whole structure or body of the vehicle is rest or stand by the tire of the vehicle and leaf spring of Toyota pickup is mounted on its center to the axel using U- bolts finally loads of the vehicle is rest at the center of the leaf spring through the axel in left and right sides. Regarding to this characteristic the load is applied at the center of the leaf spring. The front and the rear links (specially the shackle one) are act as the flexibilities of the motion of the vehicle in pump and speed breaker road as a suspension. For this analysis the applied load is 10462.5 N at the center of the leaf spring. Applied load and boundary conditions of conventional steel leaf spring is as shown in Figure 5.

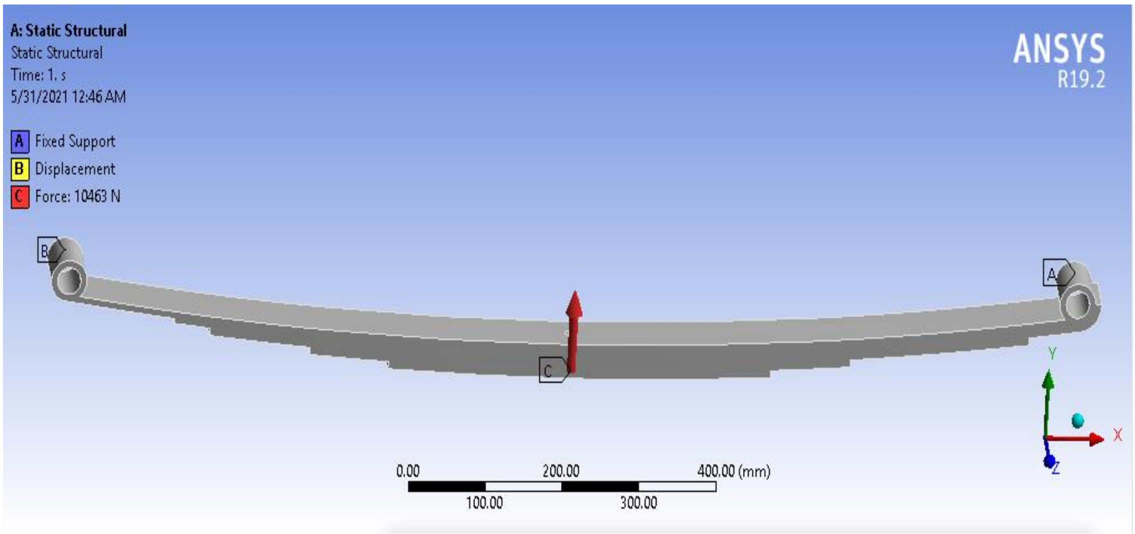


Figure 5: Applied load and boundary conditions of conventional steel leaf spring

7.2.4. Generate solution

The solution is generated from the above input parameters. The total deformation, normal stress, strain, shear force and equivalent (Von Misses) stress are the basic variables to be solved by this software analysis. Solution output continuously updates any listing output from the solver and provides valuable information on the behavior of the structure during the analysis. Generated solution of steel leaf spring is as shown in Figure 6.

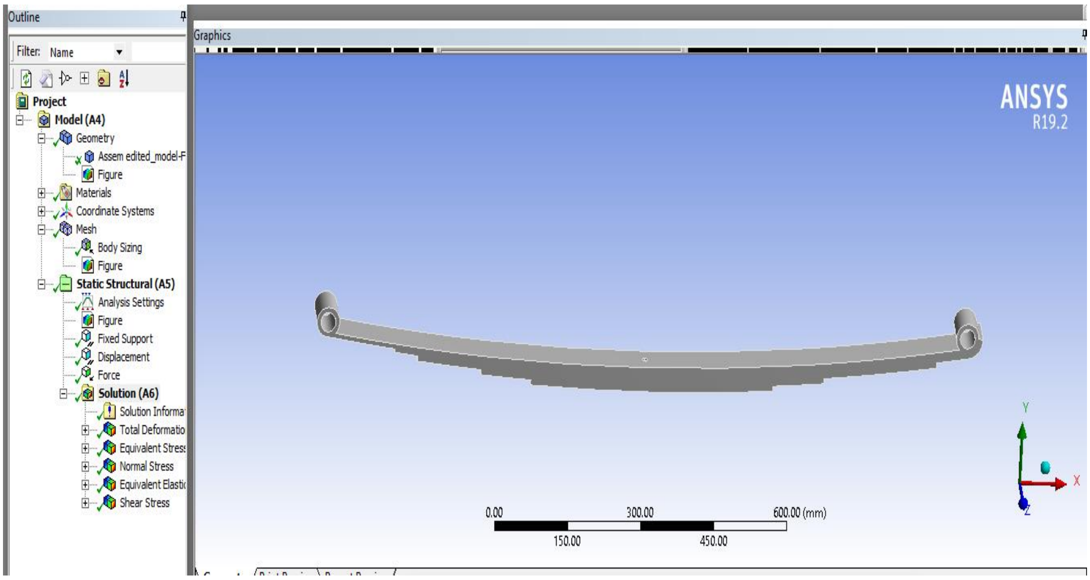
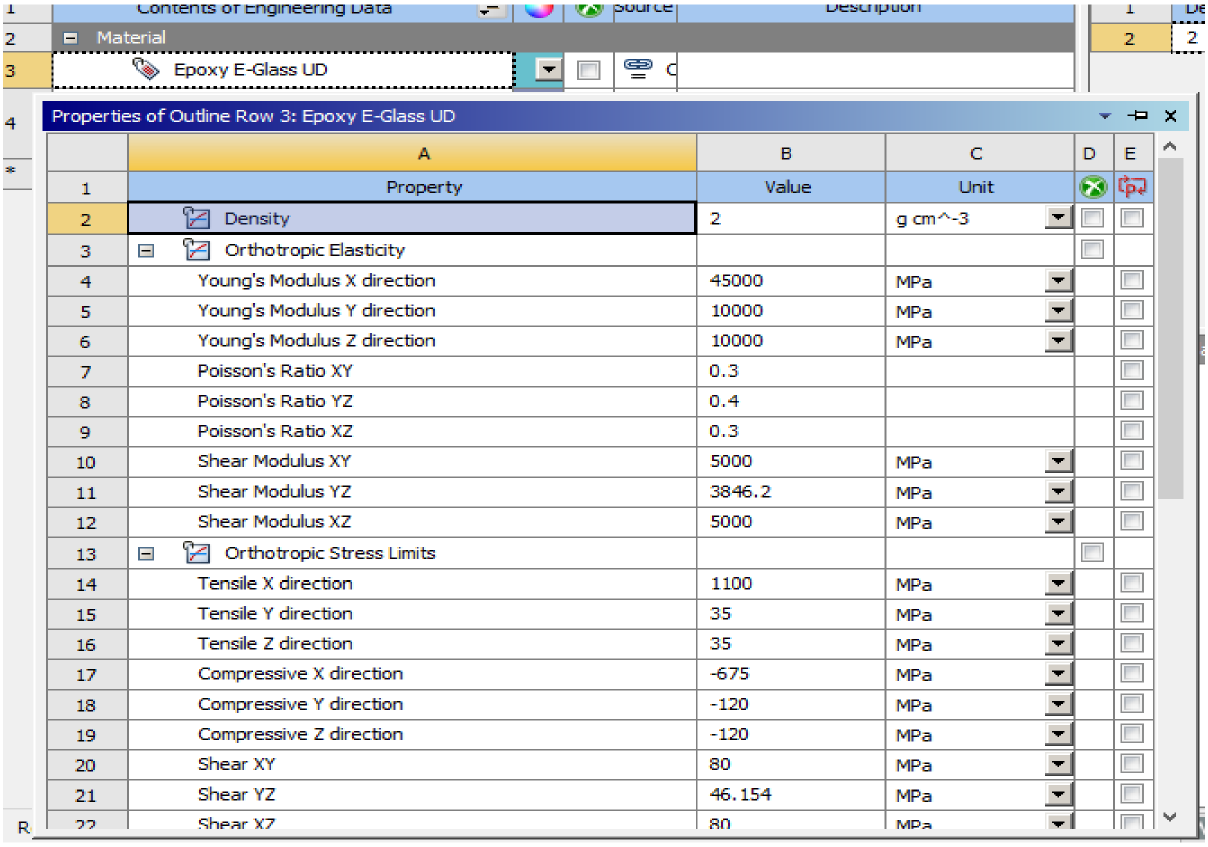


Figure 6: Generating solution of steel leaf spring.

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

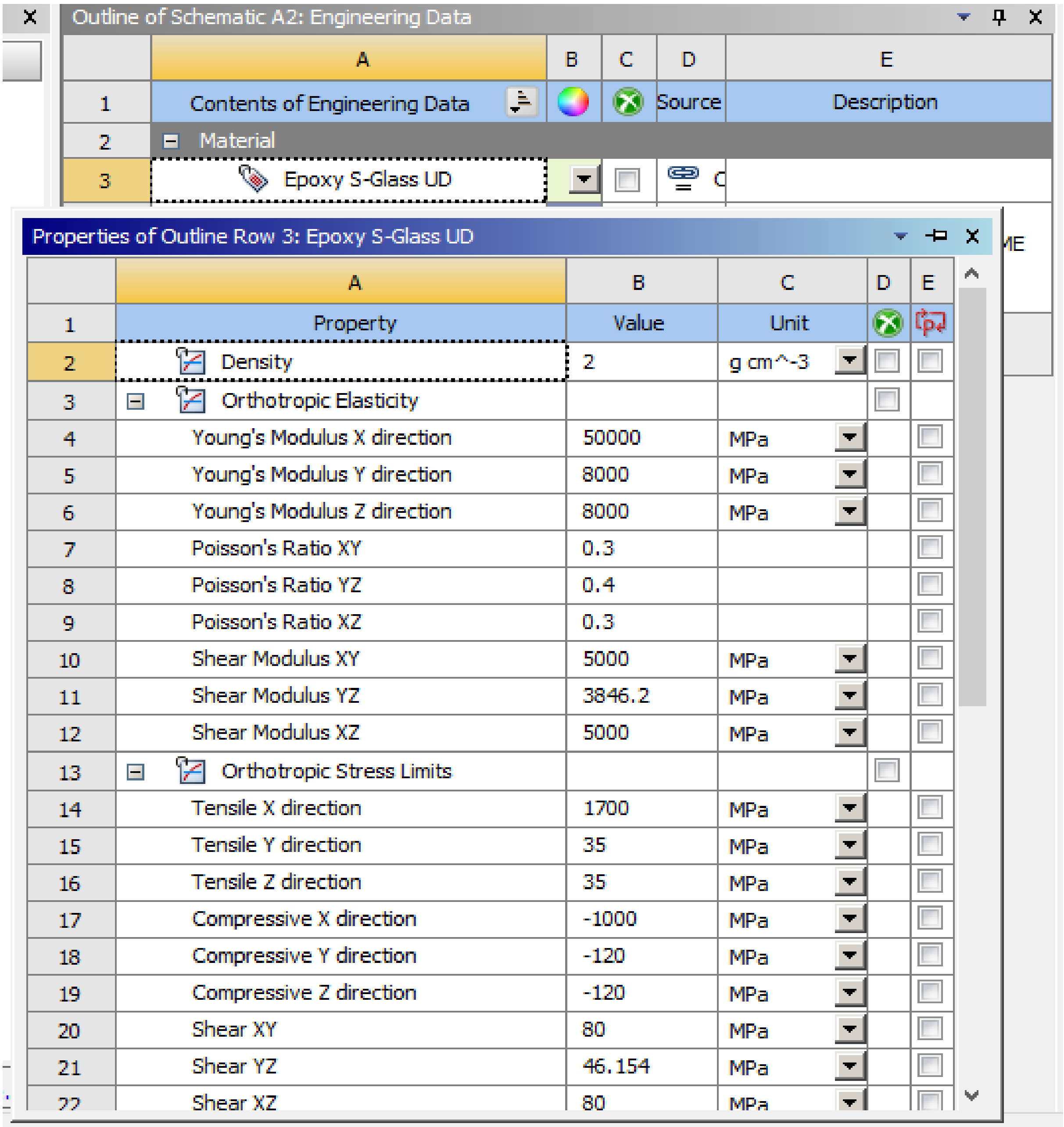
Workbench engineering data material properties of quasi isotropic laminated of epoxy E-glass UD composite material is shown in Figure 7.



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

Figure 7: Workbench engineering data material properties of quasi isotropic laminated of epoxy E-glass UD composite material

Workbench engineering data material properties of quasi isotropic laminated of epoxy S-glass UD composite is shown in Figure 8.

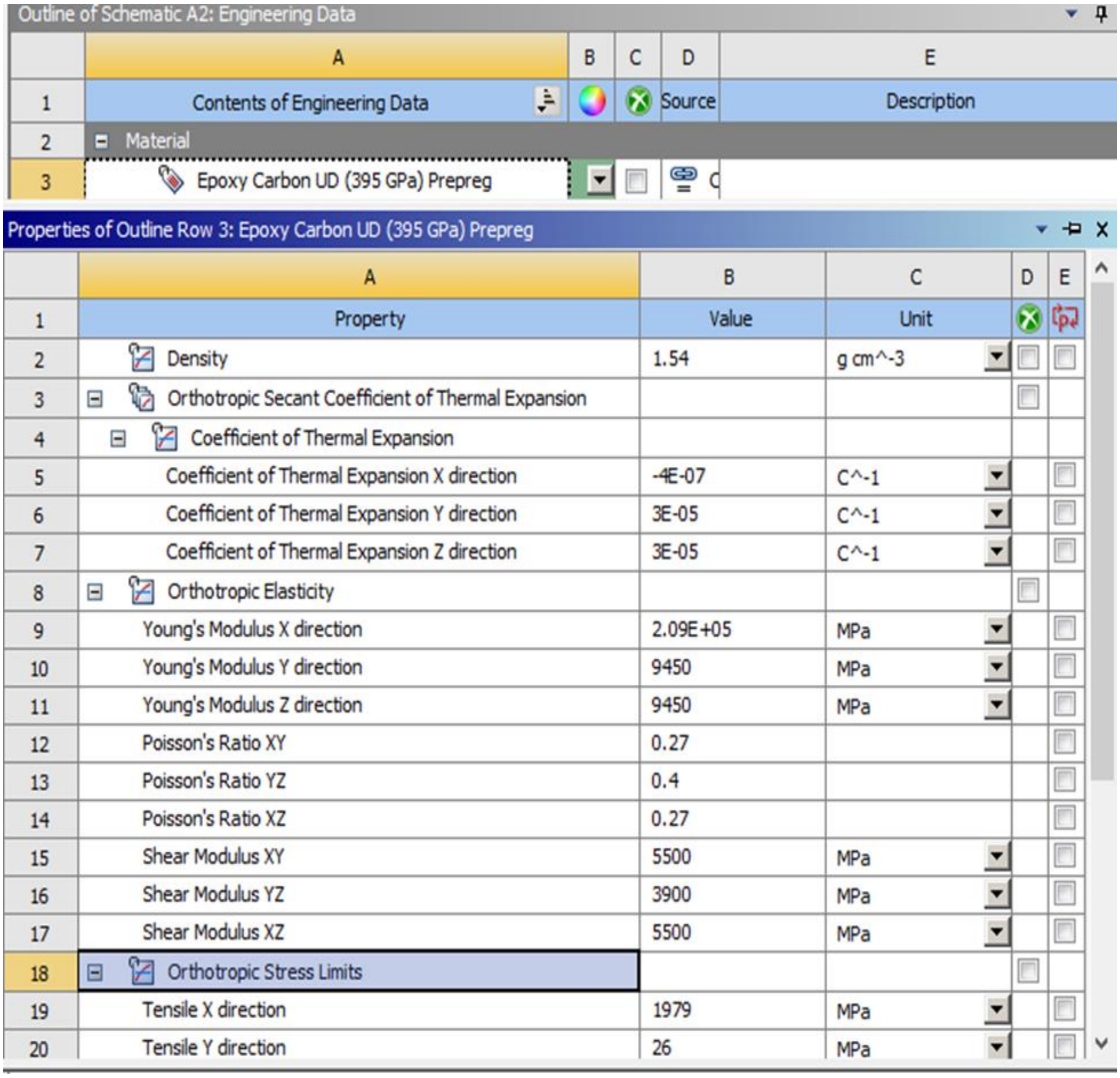


	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	⊟ Material				
3	Epoxy S-Glass UD		☐	C	

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

Figure 8: Workbench engineering data material properties of quasi isotropic laminated of epoxy S-glass UD composite

Workbench engineering data material properties of quasi isotropic laminated of epoxy carbon (395 Gpa) prepreg composite is shown in Figure 9.



Outline of Schematic A2: Engineering Data

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

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

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

Figure 9: Workbench engineering data material properties of quasi isotropic laminated of epoxy carbon (395 Gpa) prepreg composite.

7.2.5. Attach Geometry

Same procedure was followed to attach geometry of imported 3D model of epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring to ANSYS 19.2 work bench.

7.2.6. Apply Mesh Controls/Preview Mesh

Same procedure was followed to meshed model of epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring.

7.2.7.Applying Load and boundary condition

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

(ii) Force constraint: For this analysis the applied load is 10462.5 N at the center of the leaf spring by keeping assumption as mention in force constraint in steel leaf spring. Boundary condition and load applied epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring is as shown in Figure 10.

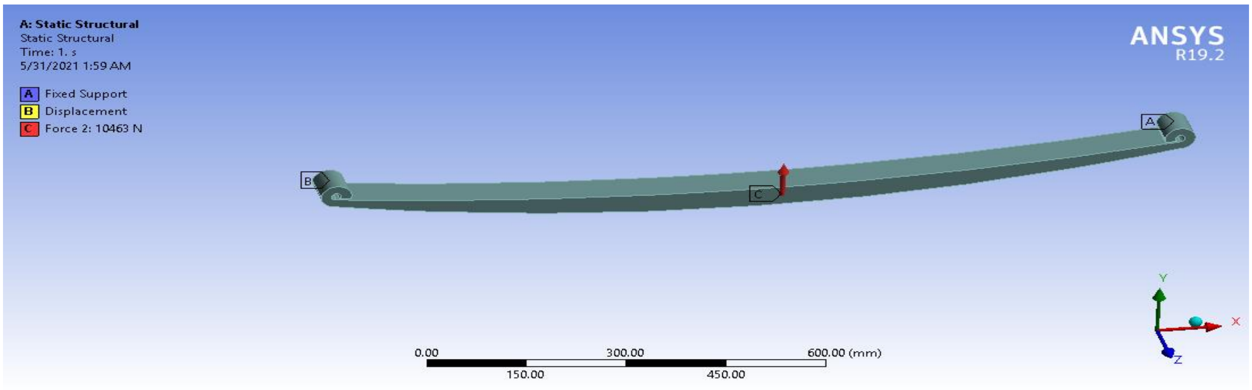


Figure 10: Boundary condition and load applied epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring.

7.2.8. Generating solution

The solution is generated from the above input parameters. The generating solution of laminated epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring is as shown in Figure 11.

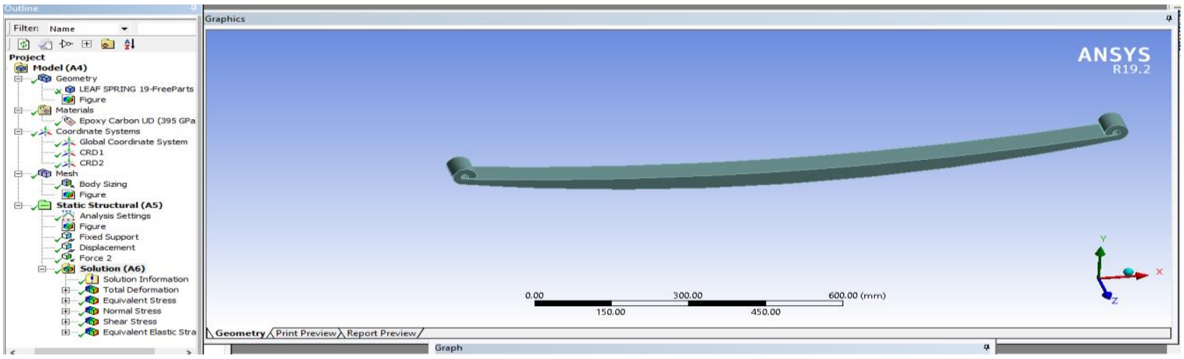


Figure 11: Generating solution of laminated epoxy E-glass UD, epoxy S-glass UD carbon UD (395 GPa) prepreg leaf spring.

7.3. Dynamic analysis of leaf spring

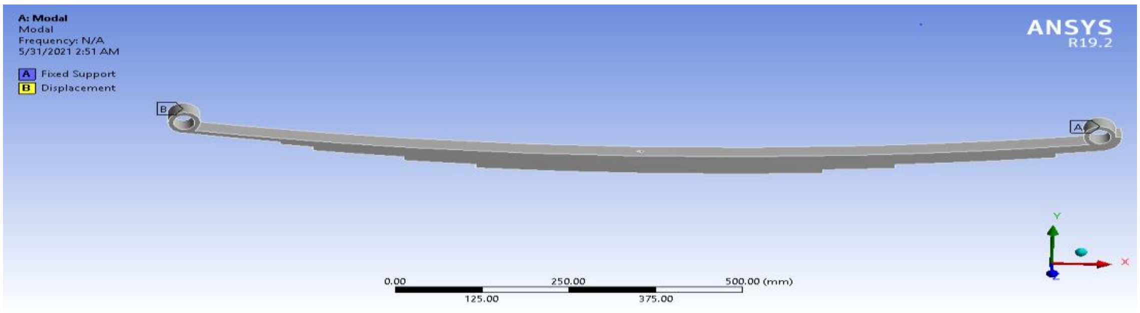
In dynamic analysis the process is similar to static analysis but the difference is instead of static structural , use the modal analysis, different types of modal shape of natural frequency and harmonic response.

7.3.1. Modal Analysis

Modal analysis helps us to identify various modes of vibration as well as the frequency at which those modes are created. Modal analysis helps us to calculate natural frequency of system so we know which frequency can be destructive and dangerous for system that causes resonance. In modal analysis we need not to apply any external load but it is first step of dynamic analysis.

7.3.2. Harmonic response

Frequency (harmonic response) analysis calculates the response of an object when load is applied. It is steady-state response of a linear structure exited at a single frequency. In frequency response analysis each frequency is solved independently for applied force[13]. It can be used for structure which operates continuously at a single speed or those which change speed slowly enough so that steady state is maintained. Boundary condition of modal analysis of multi Steel leaf springs is as shown in Figure 12.

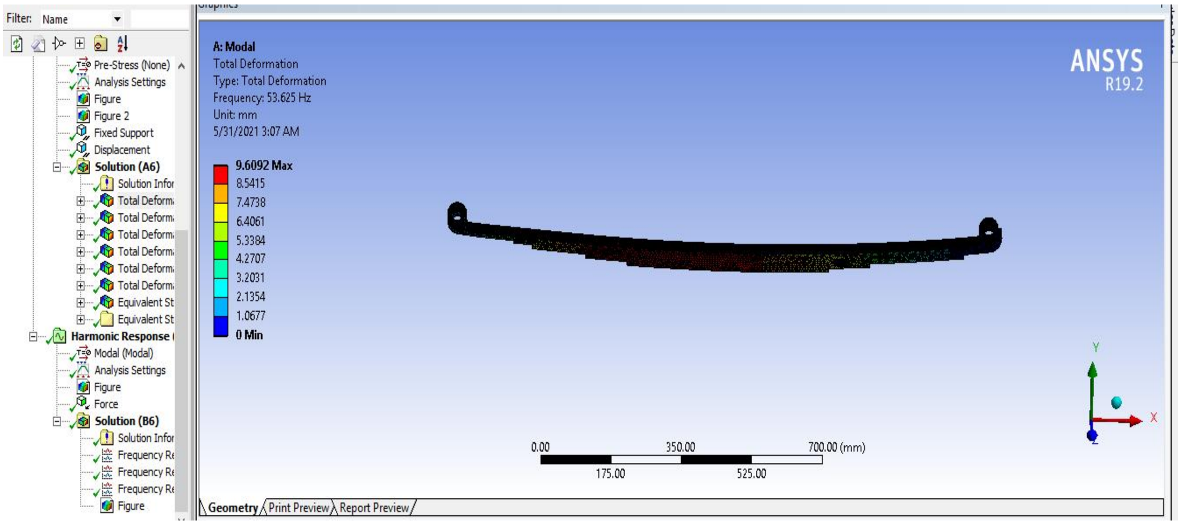


A: Modal
Modal
Frequency: N/A
5/31/2021 2:51 AM

Figure 12: Boundary condition of modal analysis of multi Steel leaf springs.

7.3.3. Generating solution

The solution is generated from the above input parameters. In dynamic analysis there are two solutions the modal shape of natural frequency and the harmonic response in the first solution the total deformation at different modal of natural frequency was solved, at the second solution after load is applied the frequency response and the normal stress and the equivalent (Von Misses) stress was solved. The generating solution of conventional steel leaf spring is as shown in Figure 13.



A: Modal
Total Deformation
Type: Total Deformation
Frequency: 53.625 Hz
Unit: mm
5/31/2021 3:07 AM

Figure 13: Generating solution of conventional steel leaf spring.

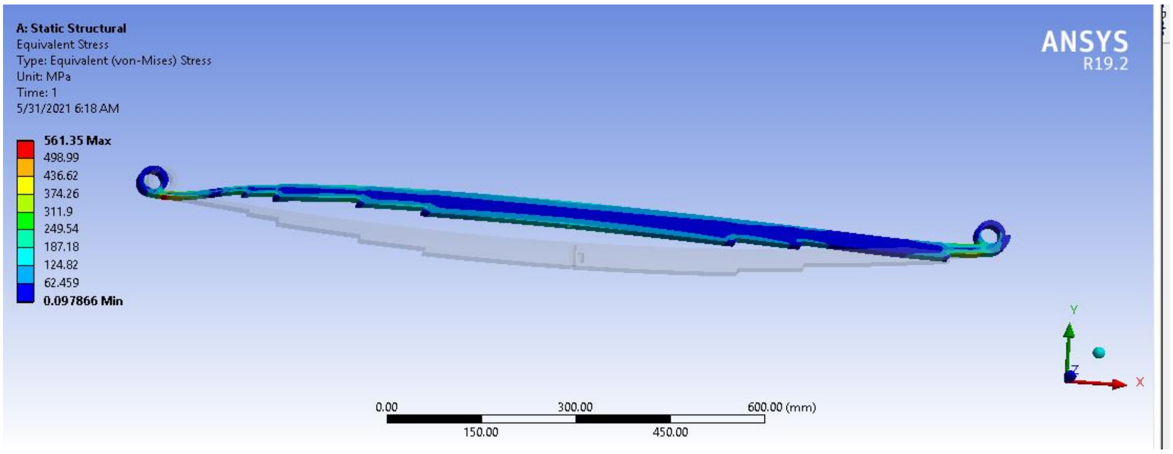
8. Result and Discussion

In this section results for laminated epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) prepreg composite materials and conventional steel leaf spring materials obtained from the static and dynamic structural analysis clearly defined. Then the results presented here were the four leaf spring's materials namely the epoxy E-glass UD, epoxy S-glass UD and epoxy carbon UD (395 GPa) and steel materials of; total deformation, equivalent (Von Misses) stress, normal stress and equivalent elastic strains.

8.1. Results

8.1.1. Equivalent (von misses) stress

The equivalent (Von Misses) stress values and deformation of laminated steel leaf spring and of their FEA respectively is shown in Figure 14 and Figure 15.



.Figure 14: Equivalent (Von Mises) stress of steel leaf spring

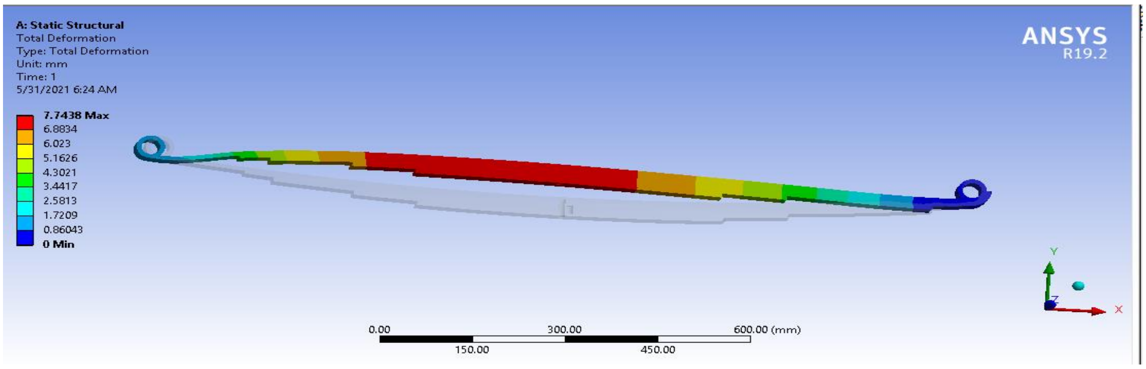


Figure 15: Total deformation of conventional steel leaf spring

The equivalent (Von Misses) stress values and deformation of epoxy E-glass UD leaf spring and of FEA respectively is shown in Figure 16 and Figure 17.

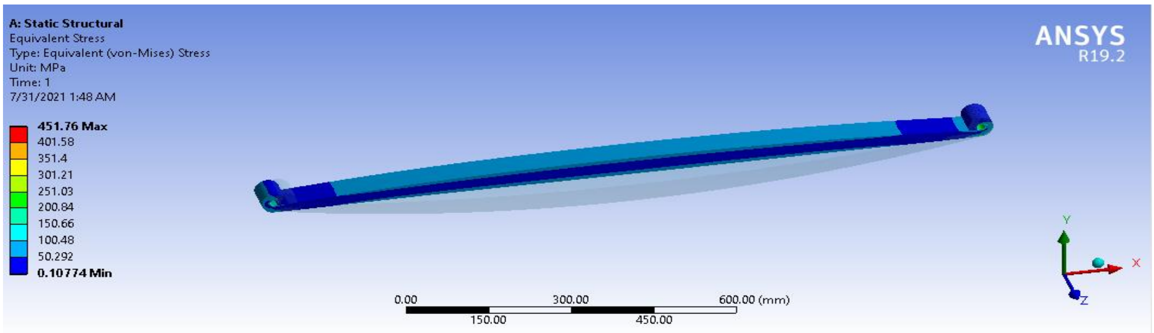


Figure 16: Equivalent (Von Mises) stress epoxy E-glass UD leaf spring

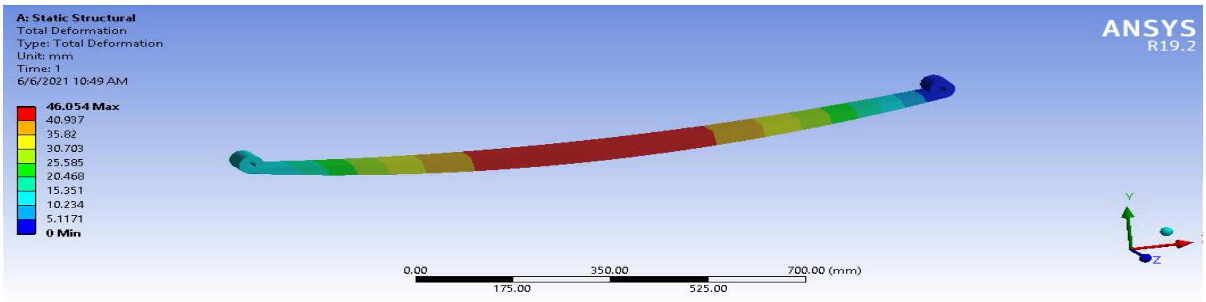


Figure 17: Total deformation of epoxy E-glass UD leaf spring.

The equivalent (Von Misses) stress values and deformation of epoxy S-glass UD leaf spring and of FEA respectively is shown in Figure 18 and Figure 19.

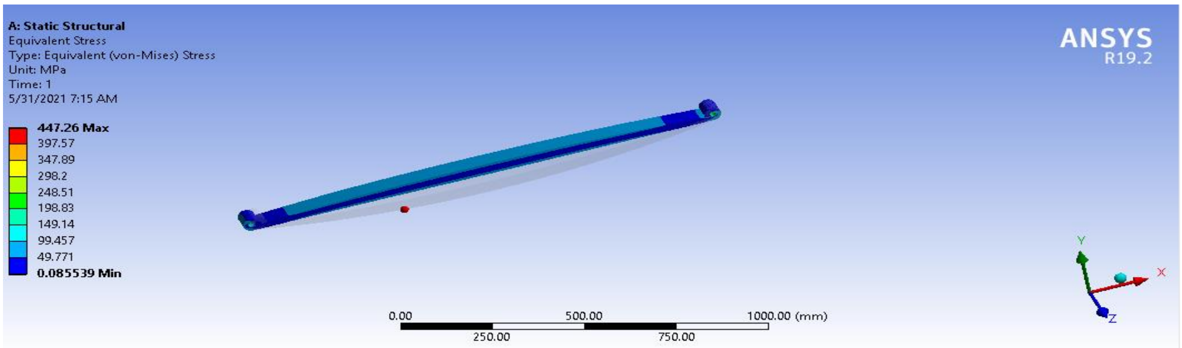


Figure 18: Equivalent (Von Mises) stress of epoxy S-glass UD leaf spring

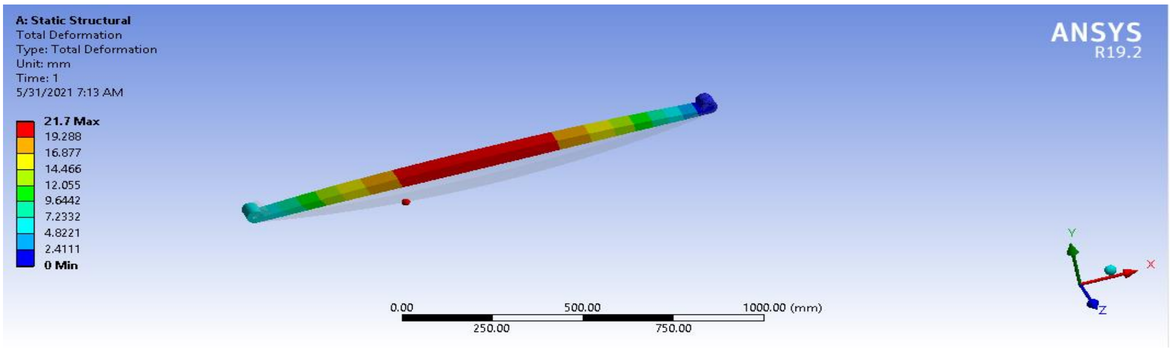


Figure 19: Total deformation of epoxy S-glass UD leaf spring.

The equivalent (Von Misses) stress values and deformation of epoxy carbon UD (395 GPa) prepreg leaf spring and of FEA respectively is shown in Figure 20 and Figure 21.

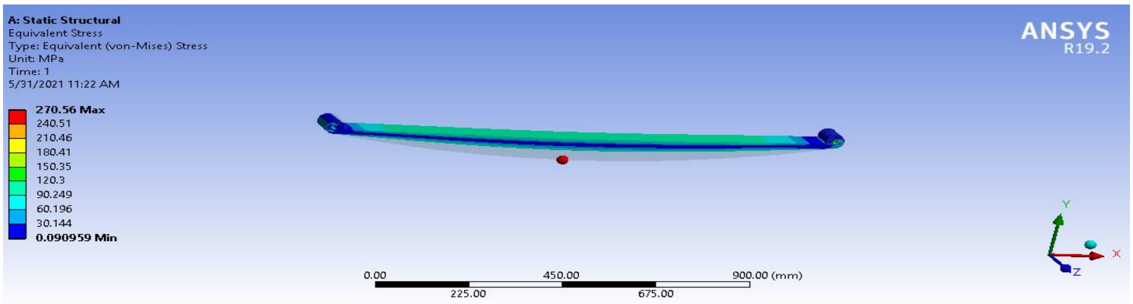


Figure 20: Equivalent (Von Mises) stress of epoxy carbon UD (395Gpa) prepreg leaf spring

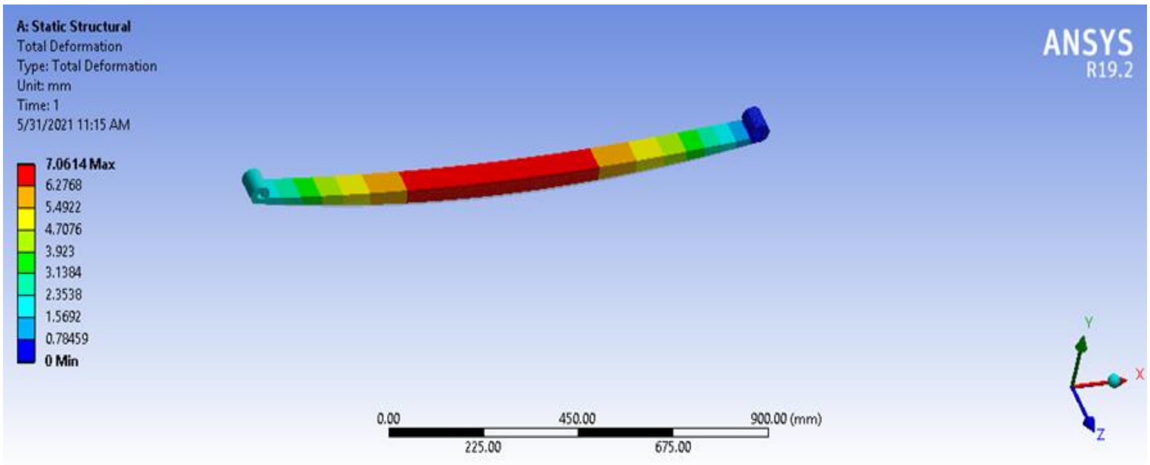


Figure 21: Total deformation of epoxy Carbon UD (395 Gpa) prepreg leaf spring

8.1.2. Dynamic analysis

Modal analysis

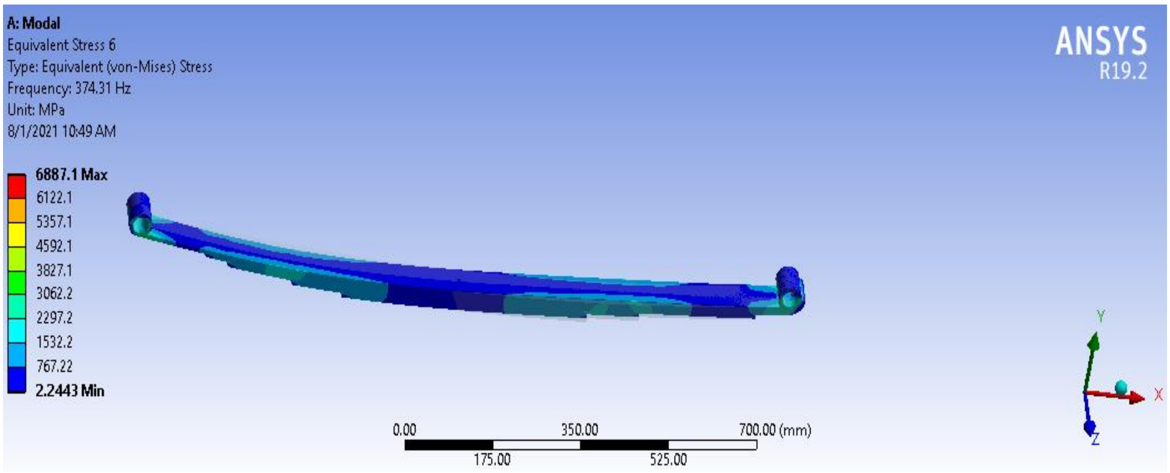


Figure 22: Max Equivalent stress of steel leaf spring

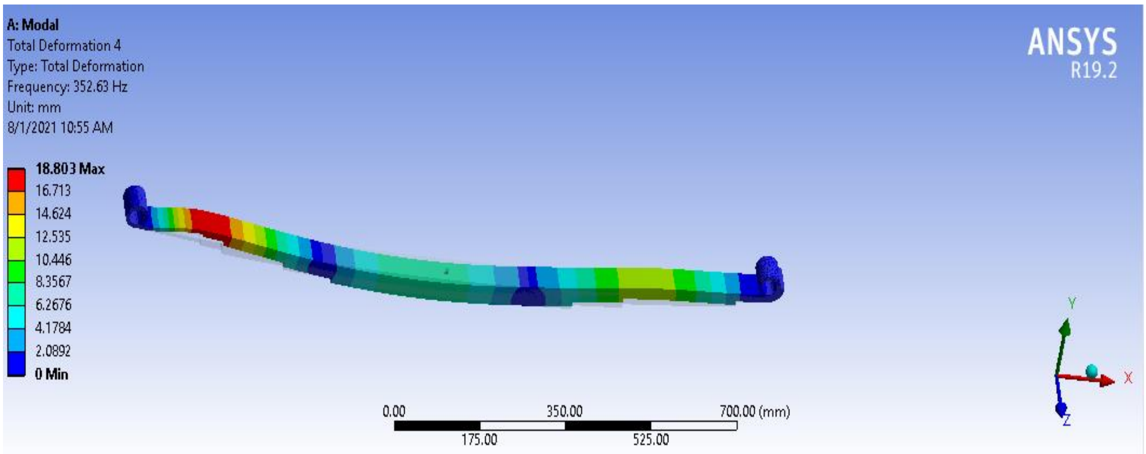


Figure 23: Max Total deformation of steel leaf spring

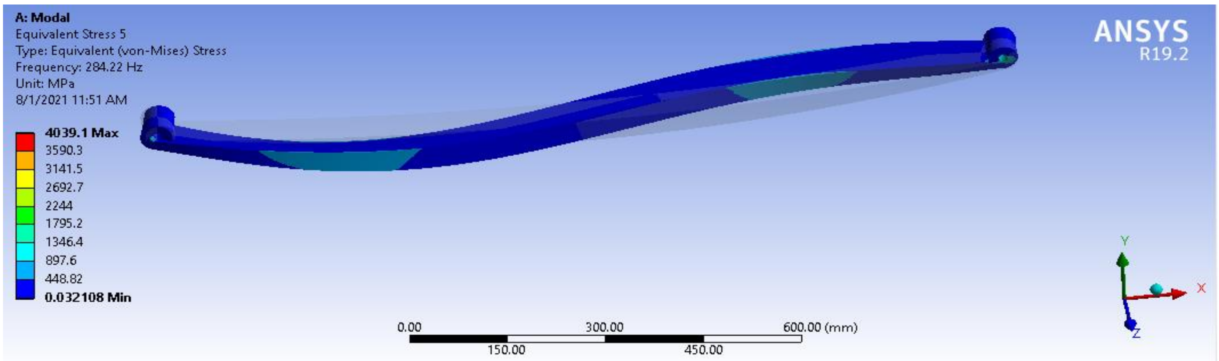


Figure 24: Max Equivalent stress of epoxy E-glass UD leaf spring

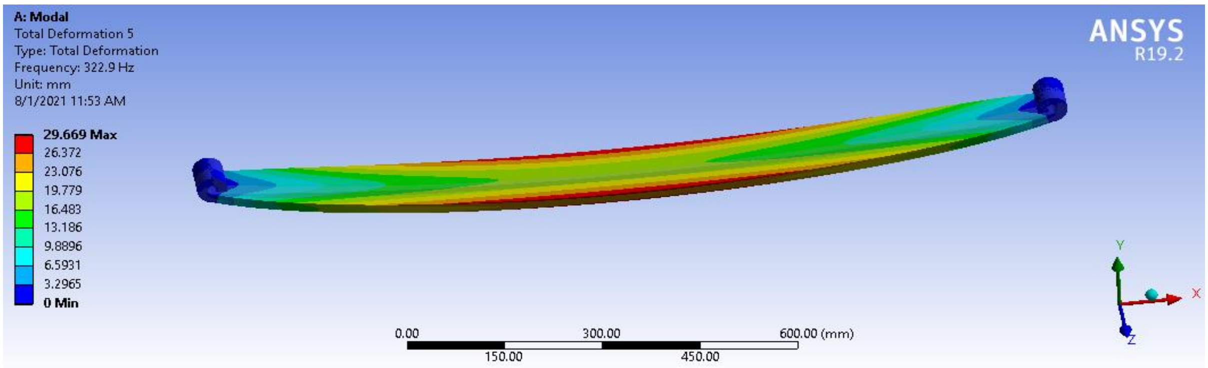


Figure 25: Total deformation of E-glass/epoxy leaf spring

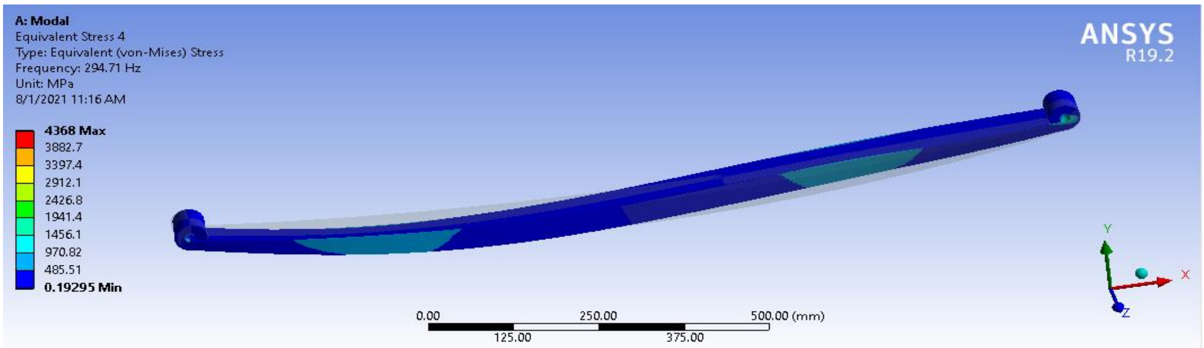


Figure 26: Max Equivalent stress of S-glass/epoxy leaf spring

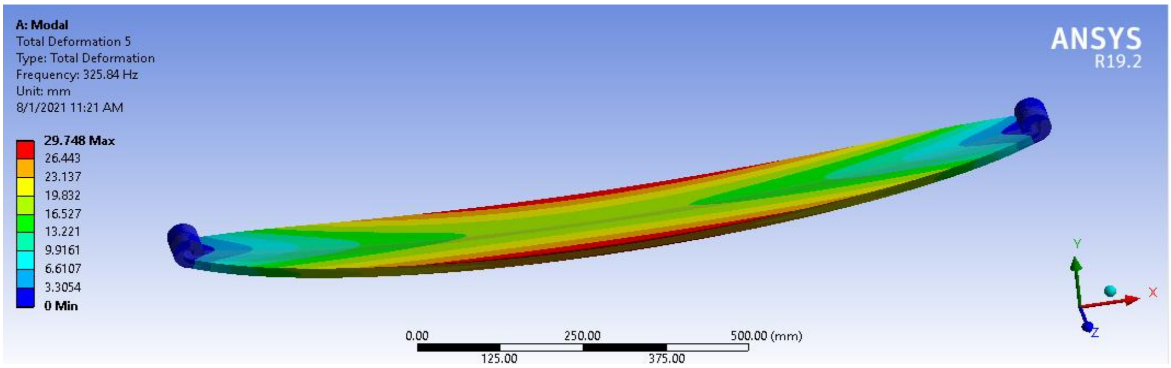


Figure 27: Total deformation of S-glass/epoxy leaf spring

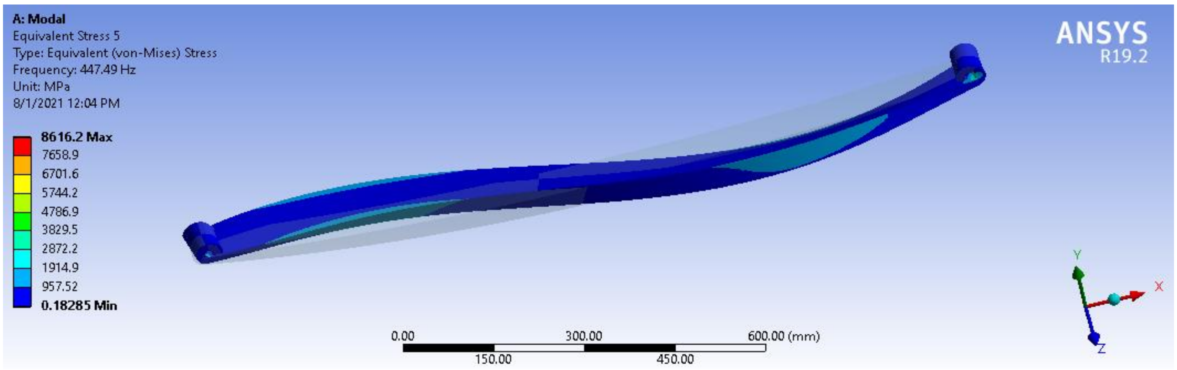


Figure 28: Equivalent of epoxy carbon UD leaf spring

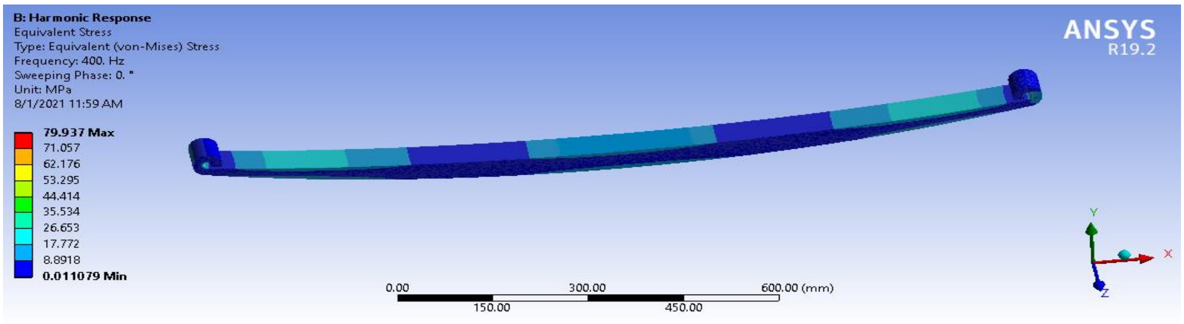


Figure 29: Total deformation of epoxy carbon UD leaf spring

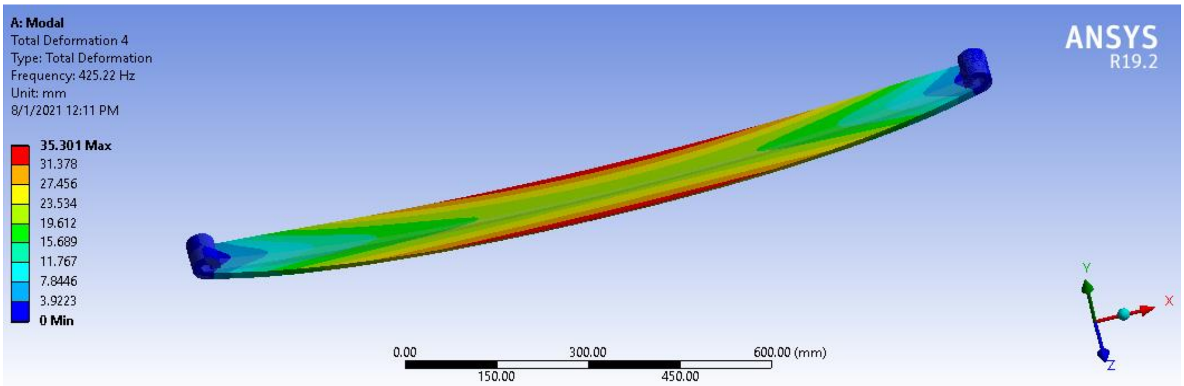


Figure 30: Max Equivalent stress of E-glass/epoxy leaf spring

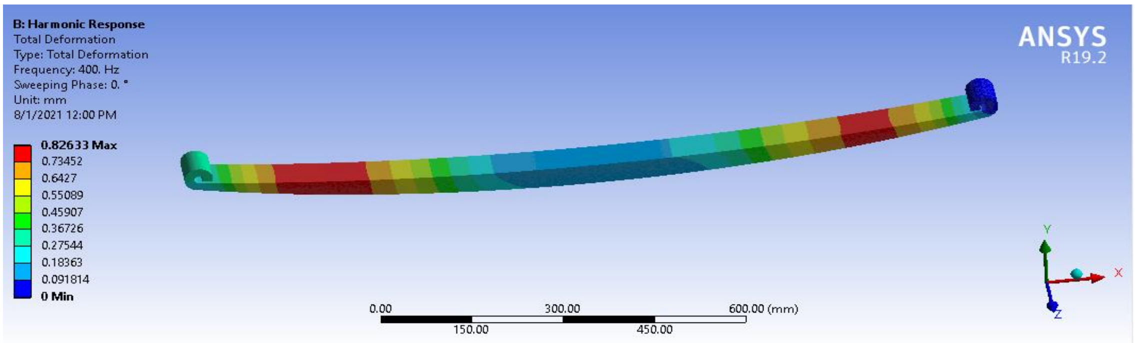


Figure 31: Total deformation of E-glass/epoxy leaf spring

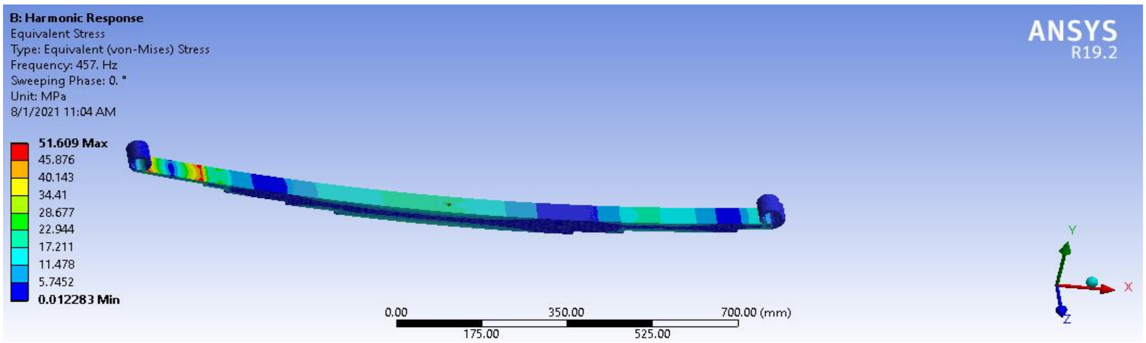


Figure 32: Max Equivalent stress of epoxy carbon UD leaf spring

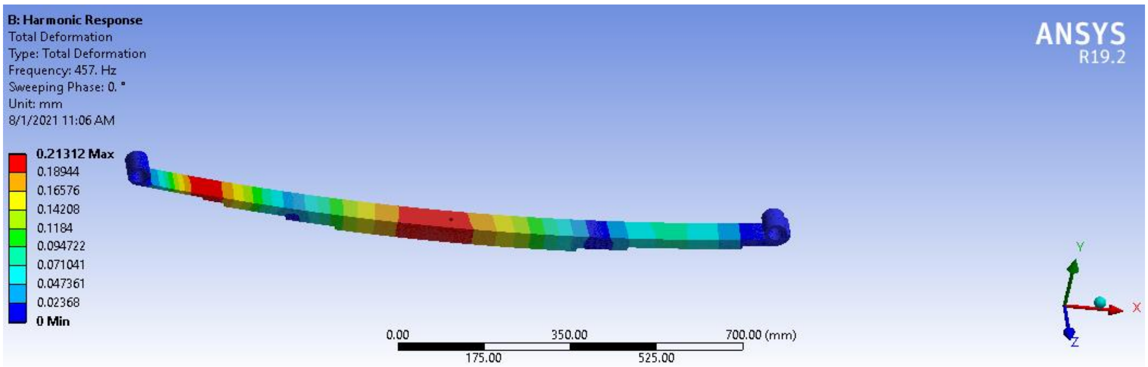


Figure 33: Total deformation of epoxy carbon UD leaf spring

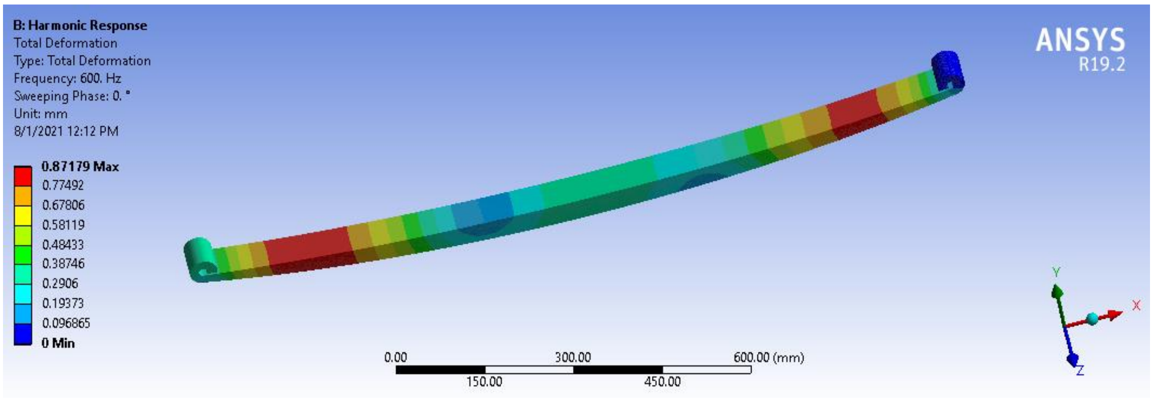


Figure 34: Max Equivalent stress of steel leaf spring

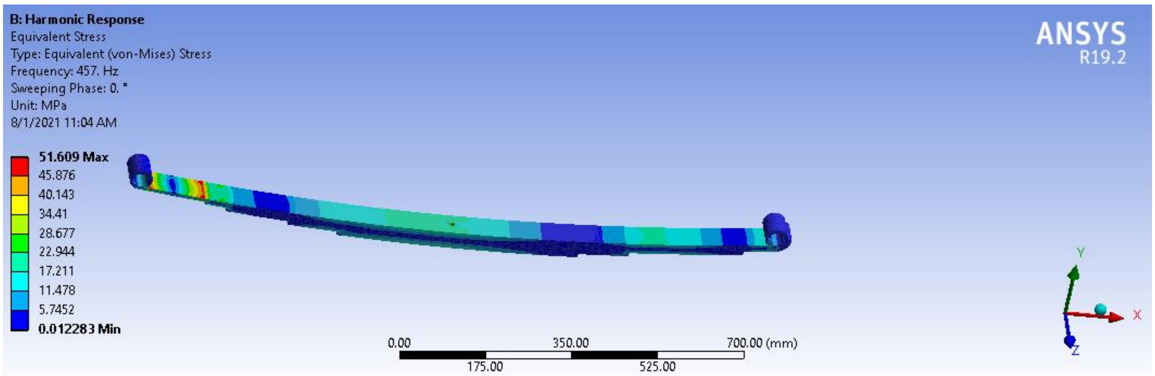


Figure 35: Max Total deformation of steel leaf spring

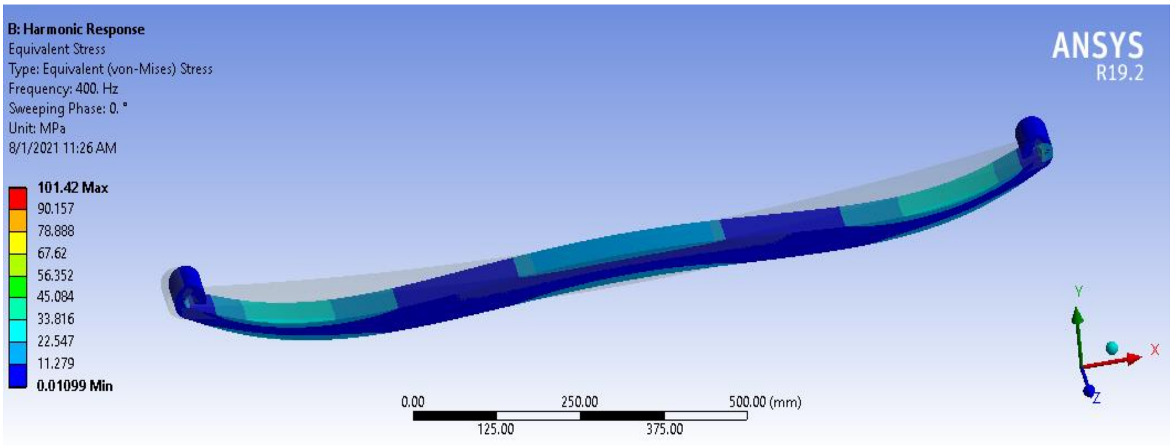


Figure 36: Max Equivalent stress of S-glass/epoxy leaf spring

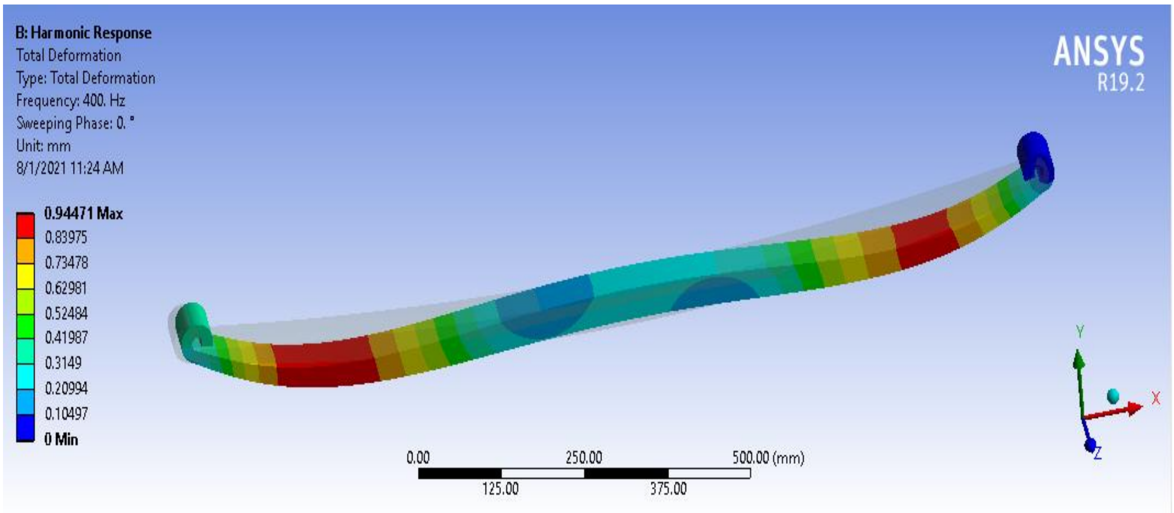


Figure 37: Total deformation of S-glass/epoxy leaf spring

8.2. Discussion

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

8.2.1 Summary of the Results of static structure leaf spring

Table 5: Summary of result of conventional multi steel and composite materials of mono leaf spring of static structure.

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

The graph plotted as shown in Figure 38 show the comparisons of FEA values clearly for laminated epoxy E-glass, epoxy S-glass and epoxy carbon composite materials and conventional steel leaf spring. The results are the values obtained due to an applied load of 10462.5 N on a leaf spring.

As observed from the graph (Figure 38) when static load applied on composite materials of mono leaf and conventional steel leaf spring. The two composite materials epoxy E-glass UD and epoxy S-glass UD was varied deformation occurs when compared with conventional leaf spring. The laminated epoxy carbon UD (395 GPa) prepreg composite material leaf springs was the smallest deformed than that of the other two composite materials and the conventional steel leaf spring.

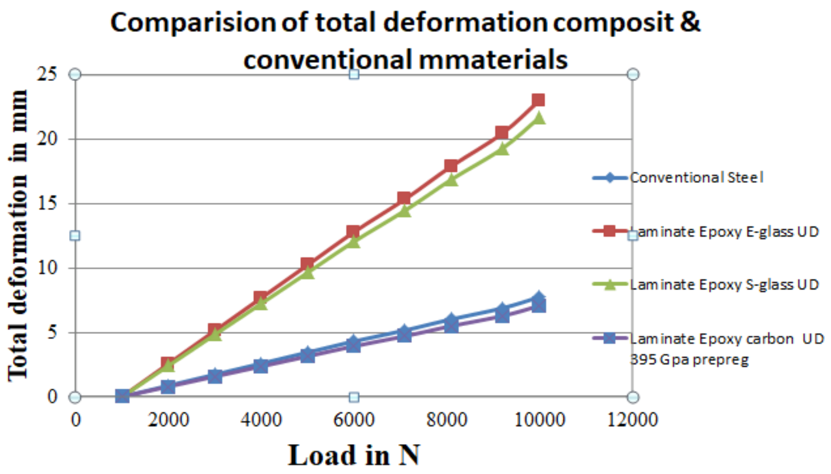


Figure 38: Comparison graph of Deformation of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring.

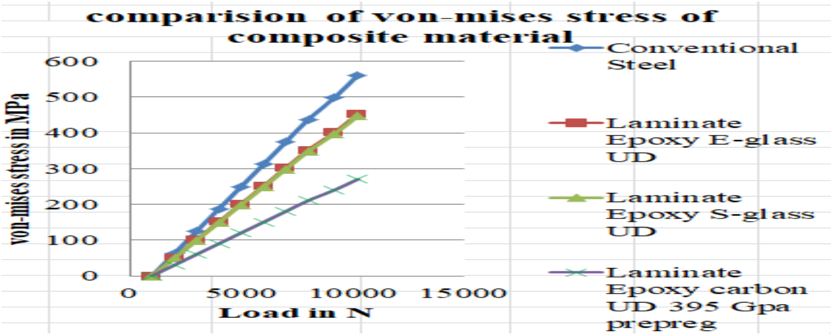


Figure 39: Comparison graph of Equivalent (Von misses stress) of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring.

As observed from the graph (Figure 39) Comparison of equivalent stress the conventional steel verses epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg mono leaf spring).The conventional steel leaf spring was more stressed than new design of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg composite material mono leaf spring.

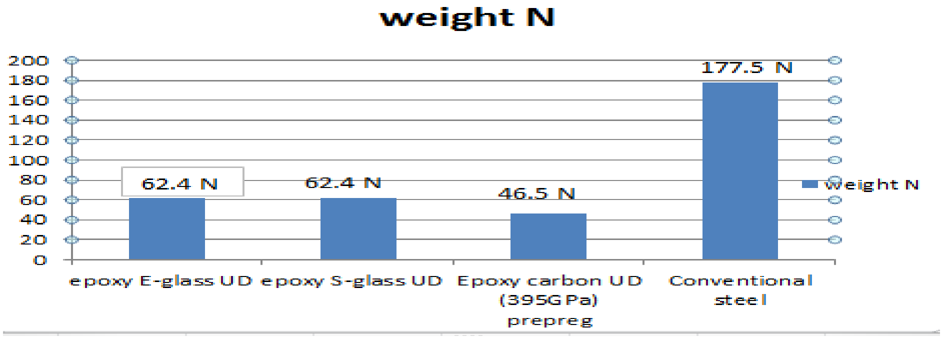


Figure 40: Comparison of mass of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD(395 GPa) prepreg mono leaf spring) and conventional steel leaf spring

It has been seen from the Figure 40 the comparison of weight between the conventional steel leaf spring of Light vehicle (Toyota pickup) and the newly designed laminated epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) the composite leaf spring is light weight than that of the conventional steel leaf spring light vehicle (Toyota Pickup).

Modal analysis

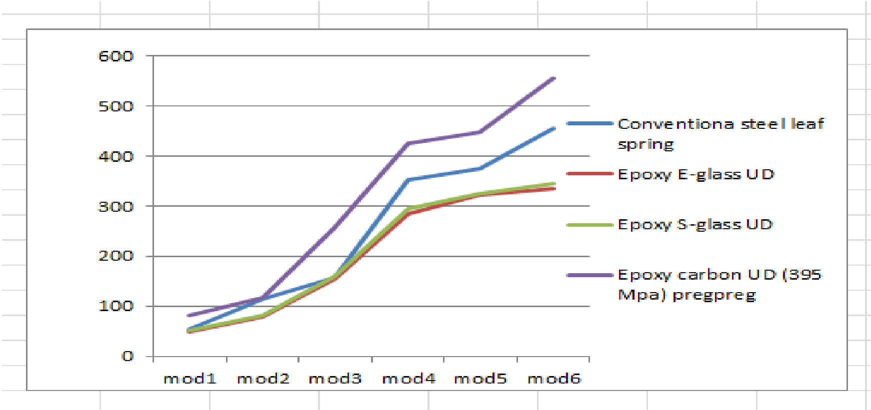


Figure 41: Comparison graph of natural frequency of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 GPa) prepreg vs. conventional steel leaf spring up to six modes.

As observed from the graph (Figure 41) the epoxy carbon UD (395 MPa) prepreg has high natural frequency than the conventional leaf spring. The epoxy E-glass UD and epoxy S-glass UD composite material mono leaf spring have less natural frequency than the conventional leaf spring. Total deformation at the given natural frequency by modal is as shown in Table 6.

Table 6: Total deformation at the given natural frequency by modal

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

In dynamic analysis as observed from the analytical and the simulation result of ASYSIS 19.2 version software, the values of total deformation at the center of each leaf springs; for epoxy E-glass UD 29.66mm, epoxy S-glass UD 29.748, epoxy carbon UD (395GPa) prepreg 35.301mm and conventional steel leaf spring 18.802mm. This is because steel leaf spring has different size graduated leaves and the structure is not uniform but the composite leaf spring is a single leaf spring and uniform size throughout its length.so small variation of deformation occurs. The equivalent(von misses) stress at the given natural frequency by modal is as shown in Table 7.

Table 7: Equivalent (von mises) stress at the given natural frequency by modal

		Conventional Steel	Laminate Epoxy E-glass UD	Laminate Epoxy S-glass UD	Laminate Epoxy carbon UD 395 Gpa prepreg
Mode1	max Equivalent (von-mises) stress MPa	786.34	349.97	362.78	591.18
	frequency (Hz)	53.625	49.278	50.744	82.417
Mode2	max Equivalent (von-mises) stress MPa	2621	1616.4	1763.4	3480
	frequency (Hz)	114.51	79.465	81.611	116.2
Mode3	max Equivalent (von-mises) stress MPa	2182.5	1082	1142.7	1959.3

	frequency (Hz)	155.92	155.6	160.76	257.11
Mode4	max Equivalent (von-mises) stress MPa	4419.9	4039.1	4368	1897.6
	frequency (Hz)	352.63	284.22	294.71	425.22
	max Equivalent (von-mises) stress MPa	6887.1	2547.2	2441.5	8616.2
Mode5	frequency (Hz)	374.31	332.9	325.84	447.49
	max Equivalent (von-mises) stress MPa	6442.7	2609.6	2823	5874.5
Mode6	frequency (Hz)	456.03	333.77	345.76	555.97

As observed from the above graph (Figure 42) Comparison of equivalent stress the epoxy carbon UD (395 GPa) prepreg mono leaf spring at the given natural frequency was more stressed than conventional steel leaf spring. However epoxy E-glass UD and epoxy S-glass UD composite materials mono leaf spring was less stressed than the conventional multi leaf spring at the given natural frequency.

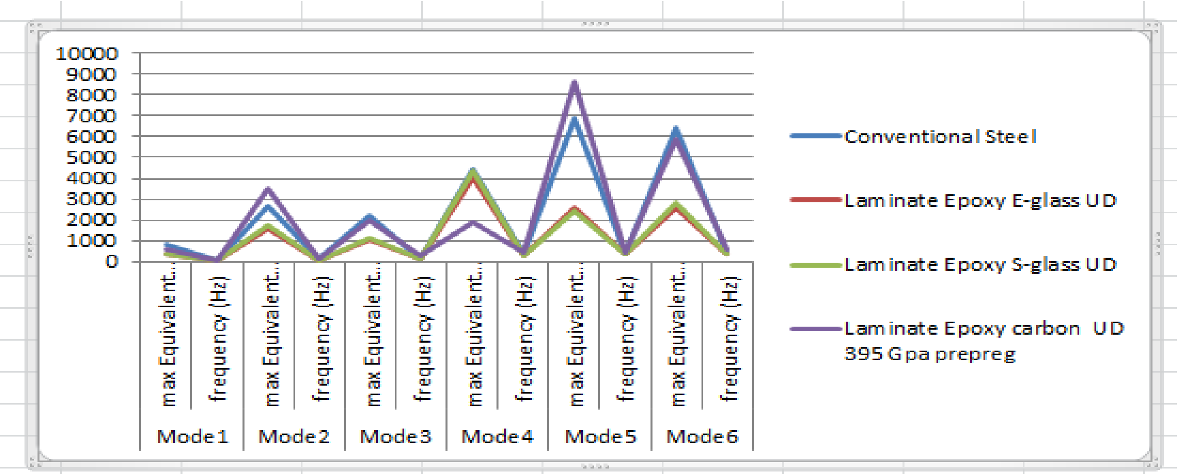


Figure 42: Comparison graph of Equivalent (Von misses stress) of epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 Gpa) prepreg vs. conventional steel leaf spring.

8.3. Harmonic Analysis

Modal analyses is done for the epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 Gpa) prepreg and conventional steel leaf springs and its frequency responses is plotted as shown in Figure 43, which describe epoxy E-glass UD, epoxy S-glass UD, epoxy carbon UD (395 Gpa) prepreg and conventional steel leaf springs. The step of harmonic analysis created was first it has been solved for modal analysis of natural frequency .The harmonic response was dragged and put into modal solution setting, in harmonic response of analysis setting it has been seen what is the frequency spacing we are doing from the modal analysis. The range harmonic response from of the minimum and maximum natural frequency has been taken. After that 10462.6 N load has been applied to harmonic response which was done for a frequency range of 8Hz to 400Hz for epoxy E-glass UD, 8Hz to 400Hz epoxy S-glass UD, 12Hz to 600Hz epoxy carbon UD (395 Gpa) prepreg and for 61.01Hz to 457 Hz. The analysis consists of plot of amplitude of spring which is nothing but the deflection and equivalent stress of spring plotted against the defined frequency range. From the graphs below it can be realized that for certain frequency values that obtained in the table 8 and 9 we get maximum deflection and maximum equivalent stress.

This frequency is not the natural frequency of that materials but the frequency near to the natural frequency for which we get maximum deflection.

Table 8: Comparison of Frequency response of deformation at high amplitude

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

Table 9: Comparison of Frequency response of Equivalent (Von misses) stress at high amplitude

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

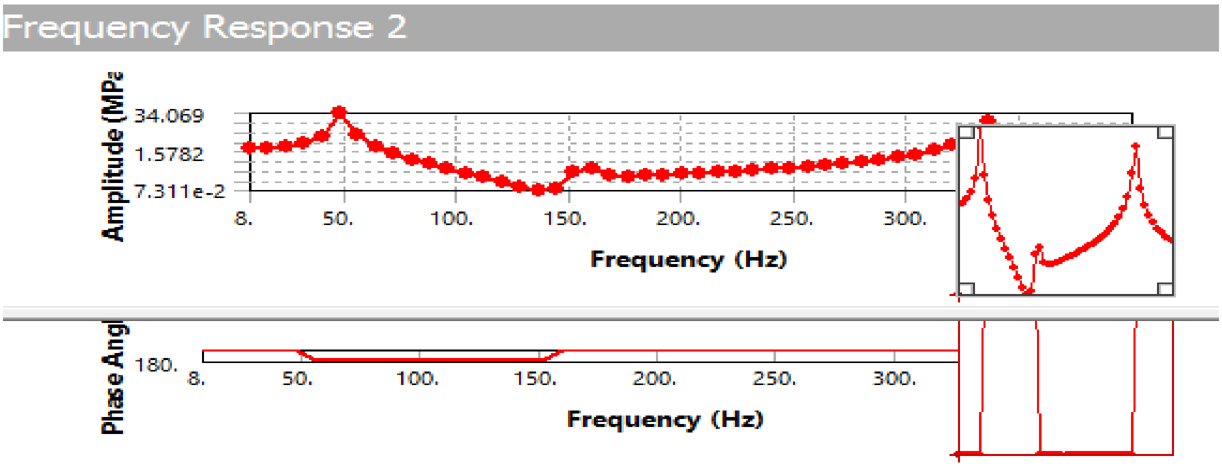


Figure 43: The of deformation E-glass/epoxy leaf spring

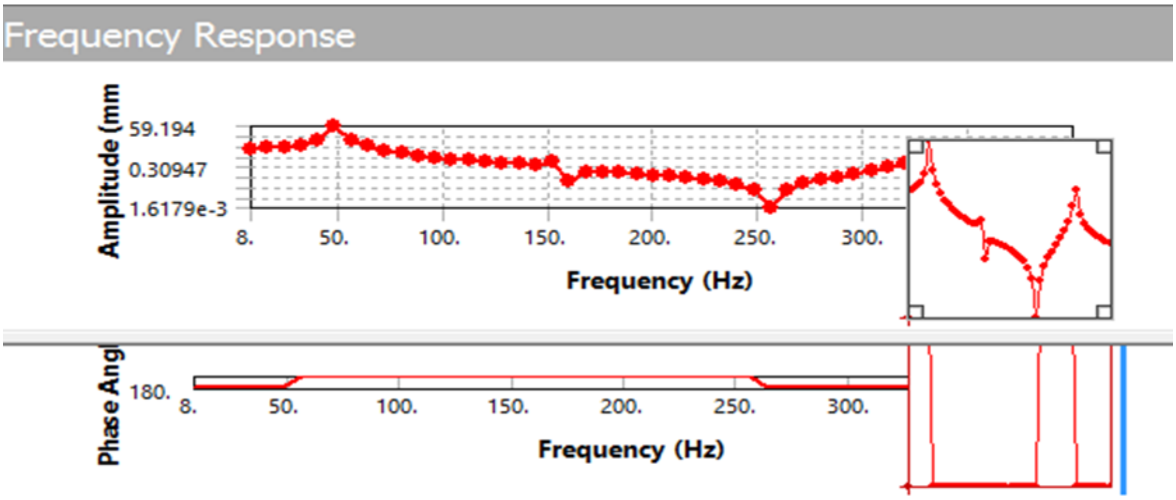


Figure 44: Stress of E-glass/epoxy leaf spring

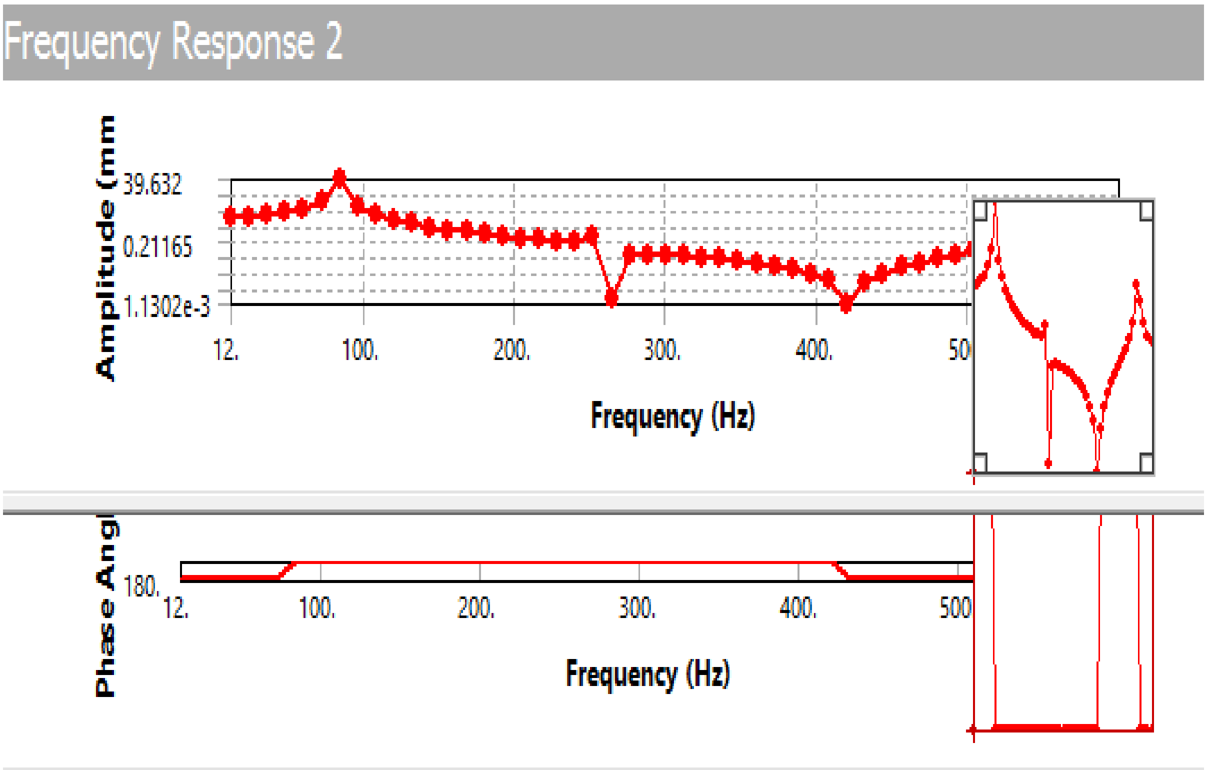


Figure 45: Equivalent stress of epoxy carbon UD leaf spring

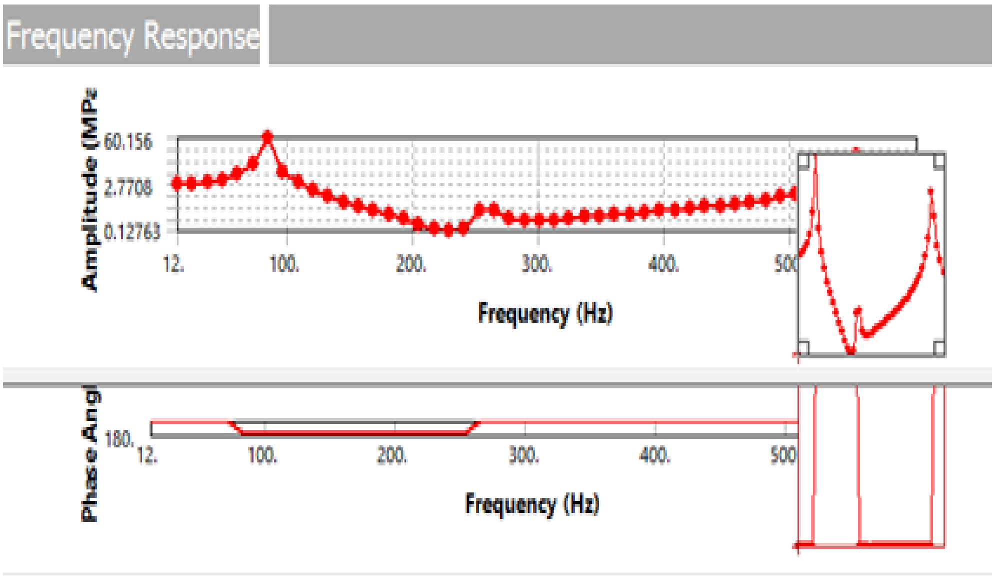


Figure 46: Total deformation of epoxy carbon UD leaf spring

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

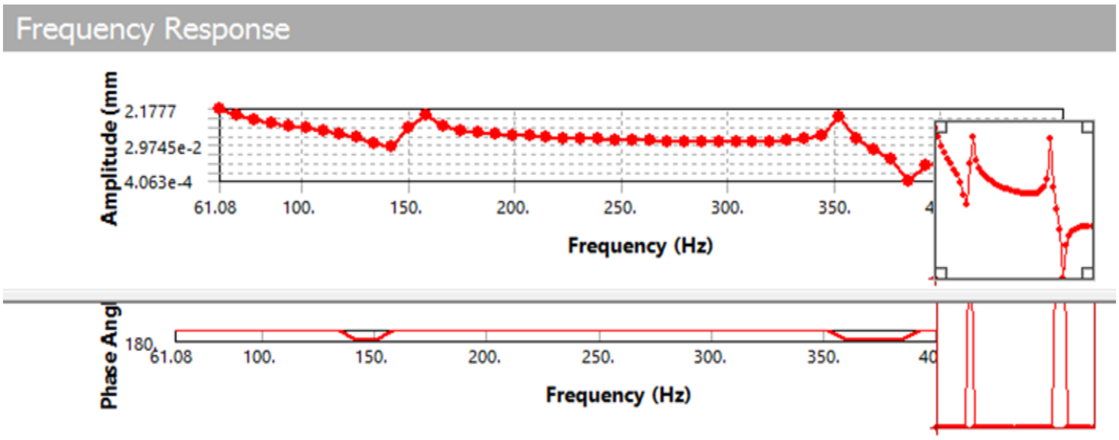


Figure 47: The deformation of conventional steel leaf spring

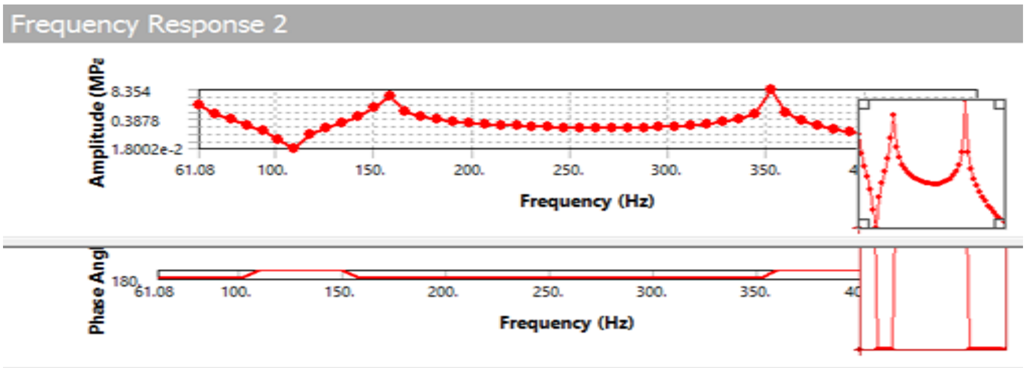


Figure 48: Stress of conventional steel leaf spring

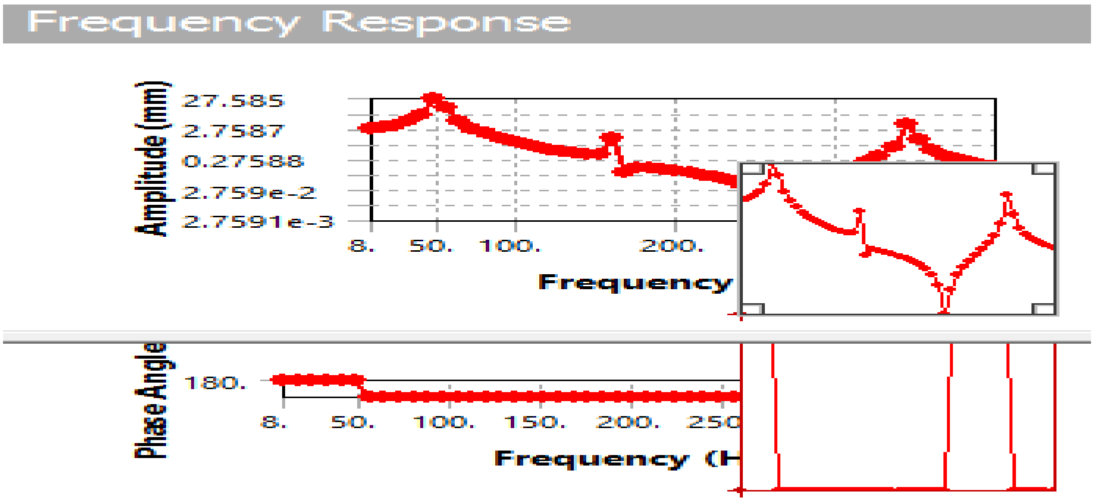


Figure 49: The deformation of S-glass/epoxy leaf spring

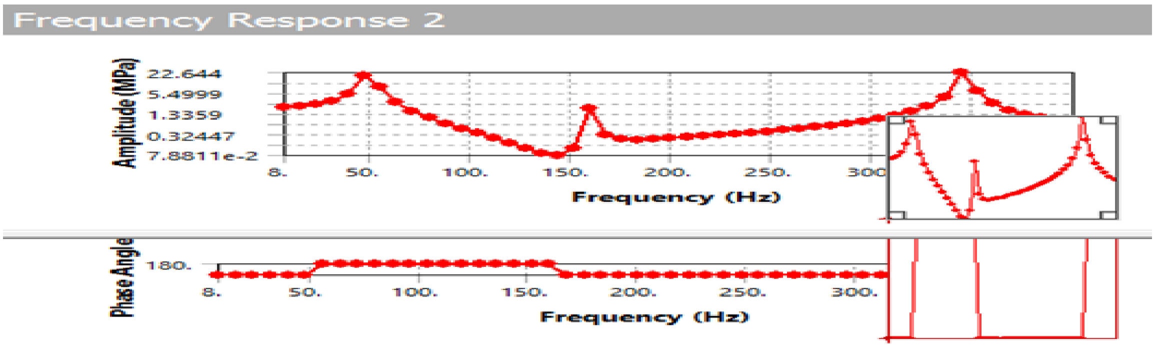


Figure 50: Stress of S-glass/epoxy leaf spring

9. Conclusion

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

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