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Modelling And Static Structural Analysis Of Coconut Fiber Reinforced Polyester Composite Leaf Spring Using Finite Element Method

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Abstract
In now a day the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfil this problem the automobile industries are trying to make new vehicle which can provide high efficiency with low cost. The best way to increase the fuel efficiency is to reduce the weight of the automobile. The weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The achievement of weight reduction with adequate improvement of mechanical properties has made composite a very good replacement material for conventional steel. To reduce vehicle weight, three techniques have been studied rationalizing the body structure, utilizing lightweight materials for parts and decreasing the size of the vehicles. In this approach by introducing composite materials into automobile industries, which is having low cost, high strength to weight ratio and excellent corrosive resistance can fulfil the requirement.
The automobile vehicles have number of parts which can be able to replace by composite material, but due to the improvement of mechanical properties of composite material. It has more elastic strength and high strength to weight ratio has compared with those of steel material. So, out of many components one of the components of automobile, the leaf spring which use for carried out the whole weight of the vehicle is best option for replacement of steel material by composite material. Leaf springs are used in suspension systems. The automobile industry has shown increased interest in the replacement of steel spring with composite leaf spring due to high strength to weight ratio.
Composite properties are the hybrid properties of two or more materials that mainly contain reinforcement and matrix. One of the reinforcements that is available in abundant in nature is Coir (coconut fibre). In this project we demonstrate the design and analysis of a leaf spring which is made up of coir reinforced polyester matrix composite. The main objective of this project is to reduce the weight of an automobile by replacing its steel leaf spring with composite leaf spring when the load applied is constant and compare its relative merits and demerits. The modelling of leaf-springs is done using UG NX -10.0 and analysis is done using ANSYS 18.1.
Keywords: *Leaf Spring, Coconut Fiber Reinforced polyester composite, UG NX -10.0, ANSYS 18.1.*

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I.INTRODUCTION

1. Leaf Spring

Originally Leaf spring called laminated or carriage spring, a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of springing, dating back to medieval times.

Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions.

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swing in gram. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness.

Figure1: Leaf Springs

The advantage of leaf spring over helical spring is that the end of the springs may be guided along a definite path. Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason manufacturers have experimented with mono-leaf springs.

A leaf spring can either be attached directly to the frame at both ends or attached directly 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 for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swivelling member.

There were a variety of leaf springs, usually employing the word "elliptical". "Elliptical" or "full elliptical" leaf springs referred to two circular arcs linked at their tips. This was joined to the frame at the top center of the upper arc, the bottom center was joined to the "live" suspension components, such as a solid front axle. Additional suspension components, such as trailing arms, would be needed for this design, but not for "semi-elliptical" leaf springs as used in the Hotchkiss drive. That employed the lower arc, hence its name. "Quarter-elliptic" springs often had the thickest part of the stack of leaves stuck into the rear end of the side pieces of a short ladder frame, with the free end attached to the differential, as in the Austin Seven of the 1920s. As an example of non-elliptic leaf springs, the Ford Model T had multiple leaf springs over its differential that was curved in the shape of a yoke. As a substitute for dampers (shock absorbers), some manufacturers laid non-metallic sheets in between the metal leaves, such as wood.

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.

A more modern implementation is the parabolic leaf spring. This design is characterised by fewer leaves whose thickness varies from centre to ends following a parabolic curve. In this design, inter-leaf friction is unwanted, and therefore there is only contact between the springs at the ends and at the centre where the axle is connected. Spacers prevent contact at other points. Aside from a weight saving, the main advantage of parabolic springs is their greater flexibility, which translates into vehicle ride quality that approaches that of coil springs. There is a trade-off in the form of reduced load carrying capability, however. The characteristic of parabolic springs is better riding comfort and not as "stiff" as conventional "multi-leaf springs". It is widely used on buses for better comfort. A further development by the British GKN company and by Chevrolet with the Corvette amongst others, is the move to composite plastic leaf springs.

Typically when used in automobile suspension the leaf both supports an axle and locates/ partially locates the axle. This can lead to handling issues (such as 'axle tramp'), as the flexible nature of the spring makes precise control of the unsprung mass of the axle difficult. Some suspension designs which use leaf springs do not use the leaf to locate the axle and do not have this drawback. The Fiat 128's rear suspension is an example.

Figure 2: A traditional leaf spring arrangement.

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.

II.MATERIALS FOR LEAF SPRINGS

The material used for leaf springs is usually a plain carbon steel having 0.90 to1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel produces greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties.

According to Indian standards, the recommended materials are :

1.For automobiles : 50 Cr 1, 50 Cr 1 V 23, and 55 Si 2 Mn 90 all used in hardened and tempered state.

2. For rail road springs: C 55 (water-hardened), C 75 (oil-hardened), 40 Si 2 Mn 90(water hardened) and 55 Si 2 Mn 90 (oil-hardened).

3. The physical properties of some of these materials are given in the following table. All values are for oil quenched condition and for single heat only.

Physical properties of materials commonly used for leaf springs

2.1. Steel

Steel is an alloy of iron that contains the element iron as 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. Also, the properties like toughness and ductility are obtained by the addition of elements like manganese, chromium, nickel, molybdenum, tungsten, vanadium, silicon etc. Steel is the most common and widely used metallic material in today's society. It can be cast or wrought into numerous forms and can be produced with tensile strength exceeding 5GPa.

Types of steel

Steel can be classified in many ways, such as method of manufacturing, its final use and AISI standards, but mostly steel can be classified into following two categories:

1. Carbon Steel

2. Alloy Steel
Carbon Steel
Carbon steel is steel that receives its distinctive properties, mainly form carbon it contains. Other elements, such as manganese, silicon, phosphorus and sulfur may be present in relatively small amounts and their purpose is not to modify the mechanical properties of steel. The carbon content of this grade may ranges from a trace to 1.7%.The plain carbon steels are usually divided into three grades on the basis of their carbon content. These are giving as under.

a.) Low Carbon Steel : The plain carbon steel in which carbon content ranges from 0.08 to below0.3% are known as low carbon steel or mild steel. Mild steel are not much affected by heat treatment processes specially hardening process. A decrease in carbon improves the ductility of mild steels. These steels posses good machine ability and weld ability. They are used for making wires, rivets, nuts and bolts, screws, sheets, plates, tubes, rods, shafts, structural steel sections and form general work shop purposes.

b) Medium Carbon Steel: The plain carbon steel in which carbon content ranges from 0.3 to 0.8% are called medium carbon steel.

These steels are stronger than mild steel but are less ductile. Their mechanical properties can be much improved by proper heat treatment. They have lesser machine ability than mild steel. However, they can easily be welded and forged. They are used for making stronger nuts and bolts, shafts, various steel sections, high tensile tubes, springs, locomotive, large forging dies, hammer and agricultural tools etc.

c) High Carbon steel :The plain carbon steel in which carbon content range from 0.8 to 1.8% are known as high carbon steel. The structure and hardness of steel increases with the increase of carbon content and the strength is almost maximum at about 0.8% carbon, there after hardness continuously increases while strength decreases. Ductility and machine ability of steel decrease within crease of carbon content from mild steel onwards. Their mechanical properties can be altered by proper heat treatment. They are mainly used for making springs, wood working tools, press work dies and punches.

Alloy Steel:

Alloy steels are the type of steels in which elements other than iron and carbon are present in sufficient quantities to modify the properties. The utility of alloy steels lies in the fact that they permit a much wider range of physical and mechanical properties than is possible in plain carbon steel. Alloy steels may be classified in many ways but for the purpose of convenience we may divide it as follows:

a) Micro alloy steel: Micro alloy steels are those steels in which the total alloying elements present in steel other than iron and carbon are below one percent. Micro alloy steels are widely used in many engineering industries such as manufacturing of pipe lines, automobiles and in aircraft industries. Micro alloy steel is used in these industries because of its good strength, light weight and good weld ability. Some common micro alloy steels contain small amounts of vanadium m, columbium, copper, manganese. Micro alloy steels are only slightly heavier than pure iron but are as strong as some steels.

b) Low alloy steel: Low alloy steels are those steels in which the total alloying elements present in steel other than that of iron and carbon are above one percent and below 5%. Low alloy steels have superior mechanical properties than plain carbon steels. Superior properties usually mean higher strength, hardness, hot hardness, wear resistance and toughness.

Spring Steel

Spring steel is a low alloy, medium with a very high yield strength. This allows objects made of spring steel to return to their original shape despite significant bending or twisting. Spring steel chemical composition which is given as under:

ELEMENTS IN LEAF SPRING	% OF ELEMENTS
CARBON	0.5 ~0.65
SILICON	0.15 ~0.35
MANGANESE	0.65 ~0.95
PHOPHOROUS	0.035
SILICON	0.035
CHROMIUM	0.65 ~0.95

Depending on the type of application, springs are made of carbon steels, silicon and manganese containing steels, silicon-manganese steels, alloyed steels, stainless steels. Springs must be capable of storing and releasing the energy. After repeated applications of load, they must retain their original shape and dimensions. This property may be attained by the use of a highly elastic material and by proper design because the allowable stress values determine the choice of material and design. Major requirements of spring steels are:

1. Should have a highly yield strength (of the order of 21000kg/mm
2. Or more accurately, a high proportional limit, so that it will not show any appreciable permanent set2. High fatigue strength under alternating and fluctuating stresses with a reserve for occasional or more frequent overloads (e.g. Vehicle springs when stressed in the resonance range).
3. Should have an adequate plastic range for the forming (winding) of the springs.

Generally, carbon is the most important commercial steel alloy. Increasing carbon content increases hardness and strength and improves harden ability. But carbon also increases brittleness and reduces weld ability because of its tendency to form marten site. This means carbon content can be both a blessing and a curse when it comes to commercial steel. And while there are steels that have up to 2 percent carbon content, they are the exception. Most steel contains less than 0.35 percent carbon. To put this in perspective, keep in mind that's 35/100 of 1 percent. Now, any steel in the 0.35 to 1.86percent carbon content range can be hardened using a heat-quench-temper cycle. Carbon is the most important element in steel as slight variations in percentage cause very marked changes in physical and mechanical properties. When a small amount of carbon is added to iron, the properties which give steel its great value begin to appear. In plain carbon steels manganese, phosphorus and sulfur are present in amounts which do not interfere in any way with the effect that carbon variation has on the properties of the steel. Thus, steels may be considered binary alloys of iron and carbon. In alloy steels, the effects of the alloying elements must be considered. The plain carbon steels represent the most important group of engineering materials known. They represent by far the major percentage of steel production and the widest diversity of application of any of the engineering materials. These applications are so diversified that anything like a complete listing or even a classification on the basis of application is not feasible.

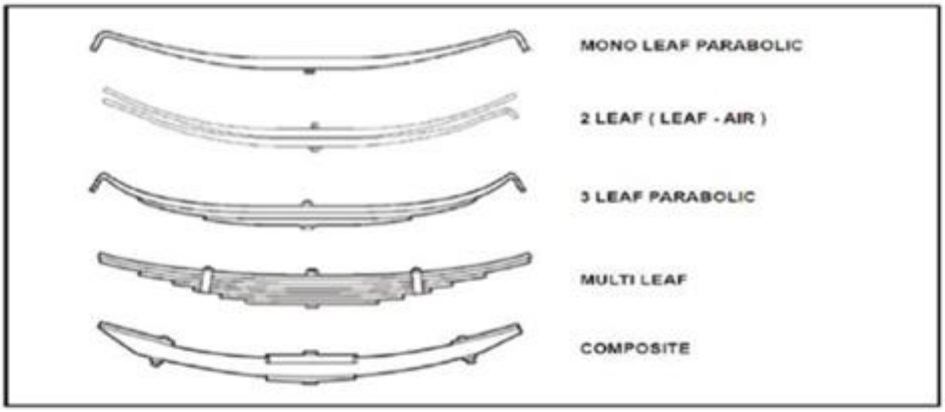


Figure 3: Types of Leaf springs

2.2 Composite Leaf Springs

Composites are well suited for leaf-spring applications due to their high strength-to-weight ratio, fatigue resistance and natural frequency. Internal damping in the composite material leads to better vibration energy absorption within the material, resulting in reduced transmission of vibration noise to neighboring structures.

The biggest benefit, however, is mass reduction: Composite leaf springs are up to five times more durable than a steel spring, so when General Motors (GM, Detroit, Mich.) switched to a glass-reinforced epoxy composite transverse leaf spring (supplied byLiteflex LLC, Englewood, Colo.) on the 1981 Chevrolet Corvette C4, a mono-leaf composite spring, weighing 8 lb/3.7 kg, replaced a ten-leaf steel system that weighed 41 lb/18.6 kg. This reportedly enabled GM to shave 15 kg/33 lb of unsprung weight from the Corvette, yet maintain the same spring rates. The leaf spring was transverse-mounted; that is, it ran across the car’s width at each axle. This eliminated the coil springs that sit up high in a spring pocket on the frame. Thus, the car can sit lower to the ground, which improves car handling.

Today, GM continues to employ transverse GFRP composite leaf springs on the front and back of its Corvette models. The 2014 Chevrolet Corvette Coupe includes a double-wishbone suspension, which, at GM, goes by the name short/long arm (SLA). SLA refers to the fact that the upper control arm is shorter than the lower one. A transverse composite leaf spring presses against the lower arm and spans the width of the car. In fact, the spring is always loaded against the sub frame. This design directs shock loads into the frame side, eliminating the standalone rear antiroll bar that must be incorporated into models with standard suspension packages. The spring’s camber curve also is said to improve tire contact with the road during cornering.

Higher speed, greater volume

To date, commercial glass- and carbon-reinforced composite leaf springs have been limited to low-volume production models. “When resins were first being used in the automotive industry, epoxy systems already proven in the aerospace industry were the first to be selected," explains Scott Simmons, business development specialist for chassis, Henkel Corp. (Madison Heights, Mich.). "While these epoxy systems provide a very high-performing part, the prepreg manufacturing process primarily employed with these resin systems is better suited for the low-volume production associated with aerospace."

Epoxy prepreg systems weren't fast reacting because they didn't need to be for autoclave processing, which, for purposes of quality assurance to high aerospace standards, necessarily involved slow and carefully controlled applications of temperature and pressure. However, much research has gone into expediting the production process through the use of faster melding processes and the development and use of suitably fast-reacting resin systems. These emerging systems show promise for economical mass production of composite leaf springs.

Figure 4: New generation composite leaf springs

In our project work we can go through One of the natural fibers which is available in abundant in nature and also very cheap, Coir, is used as the reinforcement for polyester in this composite. Coir is a fiber, obtained from various parts of coconut tree like coconuts and at leaves. It is well treated with salt water and rinsed with chemicals to make it dust free. It is then cut in to required size. Composite properties are taken from the journal published by P N E Naveen and M Yasasvi [9].

Figure 5: Coir fibre.

III.DESIGN OF LEAF SPRING

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

Let

t = Thickness of plate,

b= Width of plate,

2 L= Effective length of leaf spring

l = ineffective length of leaf spring

N_f = Number of full-length leaves

N_g = Number of graduated leaves

n = Total number of leaves = $N_{f+} N_g$

2W = Central load acting

FOS = factor of safety

$\delta_{f=}$ Defection in full length leave

For reference and comparison sake a general leaf-spring of Model-Mahindra "Model-Commander 650 Di" was considered. The Dimensions of leaf spring as determined as follows

Number of leaf springs = 10

Effective length of leaf spring = 1120 mm

Width of leaves = 50mm

Number of full-length leaves = 2

Number of graduated leaves = 8

Total number of leaves = 10

Central load acting = 2W=1910Kg

2W=1910X10X1.33(FOS)

= 25403 N

2W = 25403/4

= 6350.7

W = 3200 N

3.1 Material used for leaf spring: structural steel

Bending stress = $\frac{6WL}{nbt2}$

$= \frac{6X1600X560}{10X50X6\ 2}$

$= 299\ N/mm^2$

Deflection in full length leaves = $\frac{12WL3}{E\ b\ t\ 3\ (2\ n\ G+3\ n\ F)}$

$= (12X1600X560^{3)}\ /(207X(10)^3X50X6^3(2X8+3X2))$

= 68.5 mm.

Length of leaf = $\frac{effectivelength}{number\ of\ leaves-1} + ineffctive\ length$

Length of smallest leaf (leaf 1) = $\frac{1120}{10-1} + 90$ = 214 mm

Length of second leaf = $\frac{1120}{10-1}X2 + 90 = 338\,mm$

Length of third leaf = $\frac{1120}{10-1}X3 + 90 = 463\,mm$

Length of fourth leaf = $\frac{1120}{10-1}X4 + 90 = 588\,mm$

Length of fifth leaf = $\frac{1120}{10-1}X5 + 90 = 712\,mm$

Length of sixth leaf = $\frac{1120}{10-1}X6 + 90 = 837\,mm$

Length of seventh leaf = $\frac{1120}{10-1}X7 + 90 = 961\,mm$

Length of eight leaf = $\frac{1120}{10-1}X8 + 90 = 1085\,mm$

Length of nineth leaf = 1120 mm

Length of tenth leaf = 1120 mm

Table 1 Mechanical Properties of Steel

Property	value
Density	7850kg/m2
Tensile Yield Strength	250 MPa
Poisson's ratio	0.3
Young's modulus	210 Gpa

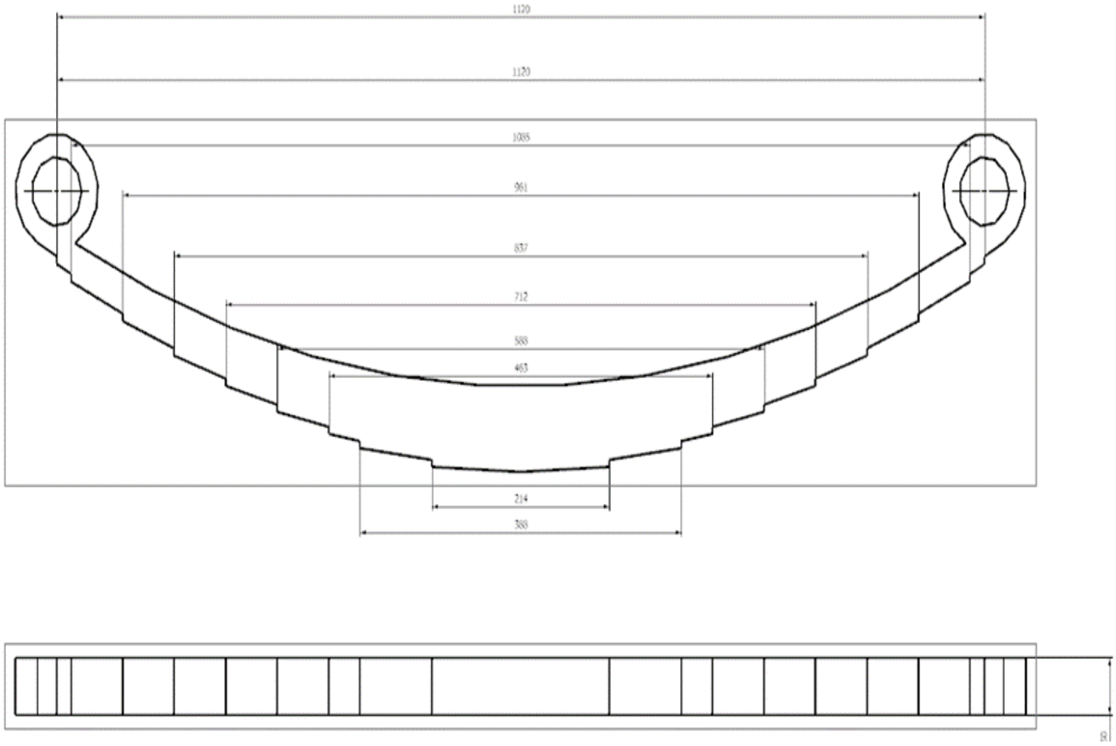


Fig:6 Drafting of steel leaf spring

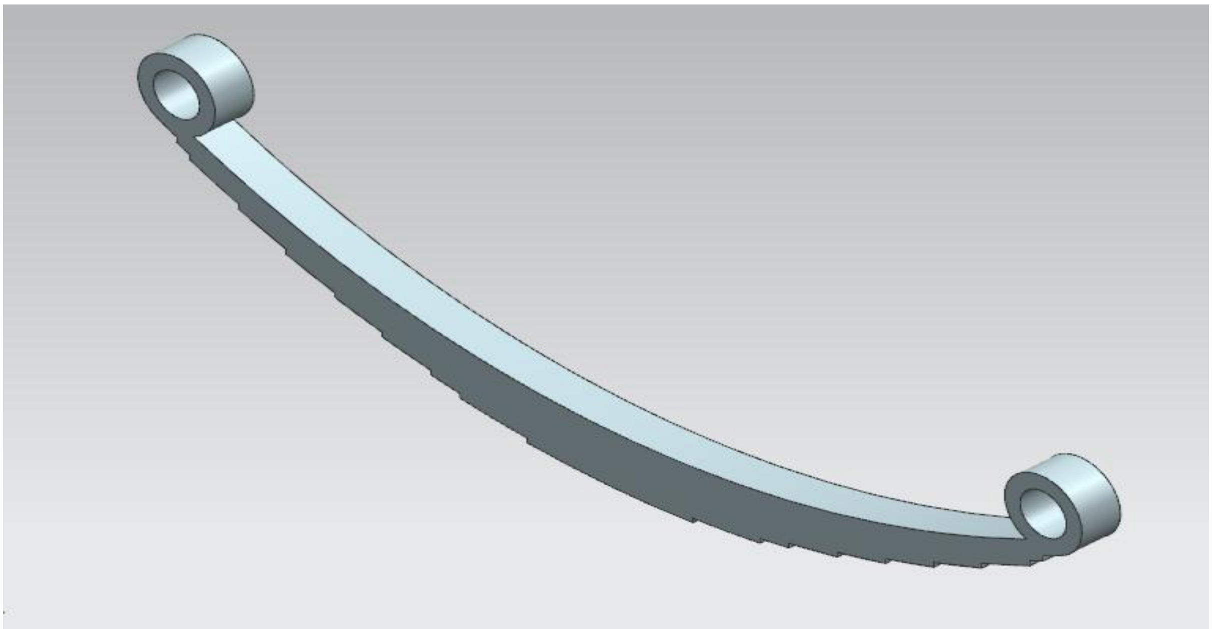


Figure: 7 CAD model of Steel leaf-spring.

3.2 Dimensions of Coconut Fibre Reinforced Polyester Composite Leaf-Spring

The dimensions of composite leaf spring are set in such a way that, when 3200 N is applied, the deflection should be same as that of steel leaf-spring.

Deflection in full length leaves $= \frac{12WL3}{E\,b\,t\,3\,(2\,n\,G+3\,n\,F)}$

$68.5 = (12X1600X560^3) /(207X(10)^3XbX8^3(2X8+3X2))$

b = 67 mm

Firstly, length of 1420 mm and thickness of 8 mm is fixed and width is calculated using above formula.

Length of leaf $= \frac{effectivelength}{number\ of\ leaves-1} + \boldsymbol{ineffctive\ length}$

Length of smallest leaf (leaf 1) $= \frac{1420}{10-1} + \mathbf{90}$ = 247.7 mm

Length of second leaf $= \frac{1420}{10-1}\boldsymbol{X2 + 90 = 405.55\ mm}$

Length of third leaf $= \frac{1420}{10-1}\boldsymbol{X3 + 90 = 563.33\ mm}$

Length of fourth leaf $= \frac{1420}{10-1}\boldsymbol{X4 + 90 = 721.11\ mm}$

Length of fifth leaf $= \frac{1420}{10-1}\boldsymbol{X5 + 90 = 878.88\ mm}$

Length of sixth leaf $= \frac{1420}{10-1}\boldsymbol{X6 + 90 = 1036.66\ mm}$

Length of seventh leaf $= \frac{1420}{10-1}\boldsymbol{X7 + 90 = 1194.4\ mm}$

Length of eigth leaf $= \frac{1420}{10-1}\boldsymbol{X8 + 90 = 1352.22\ mm}$

Length of nineth leaf = 1420 mm

Length of tenth leaf = 1420 mm

Figure:8 Coir fiber.

Table 2: Properties of Coir composite

property	value
Density	1380 kg/m^3
Tensile Yield Strength	25 MPa.
Poisson's ratio	0.3
Young's modulus	315Gpa

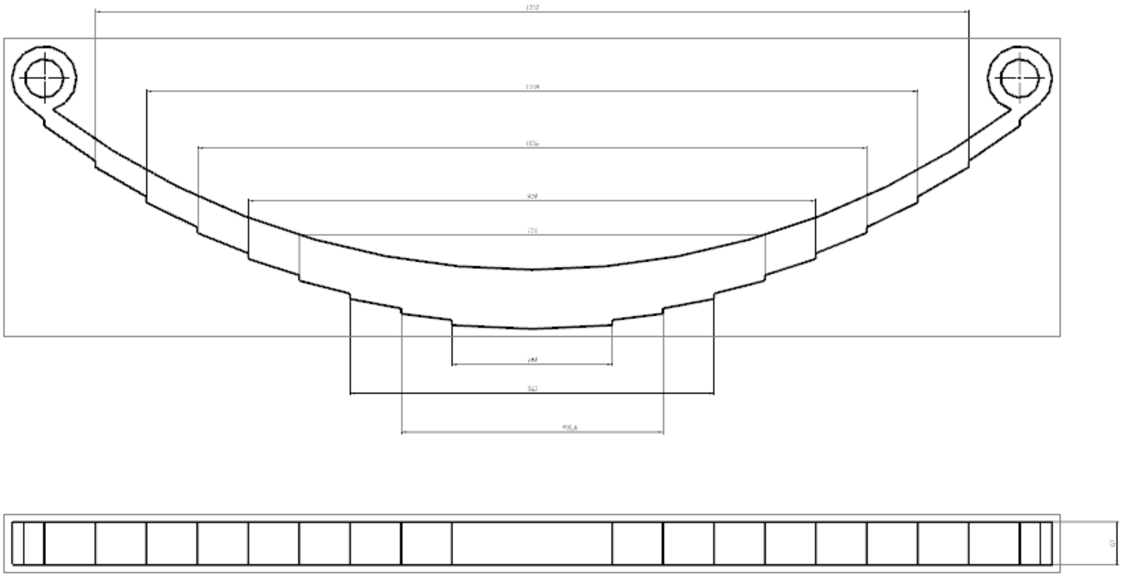


Fig:8 Drafting of coconut fiber composite leaf spring

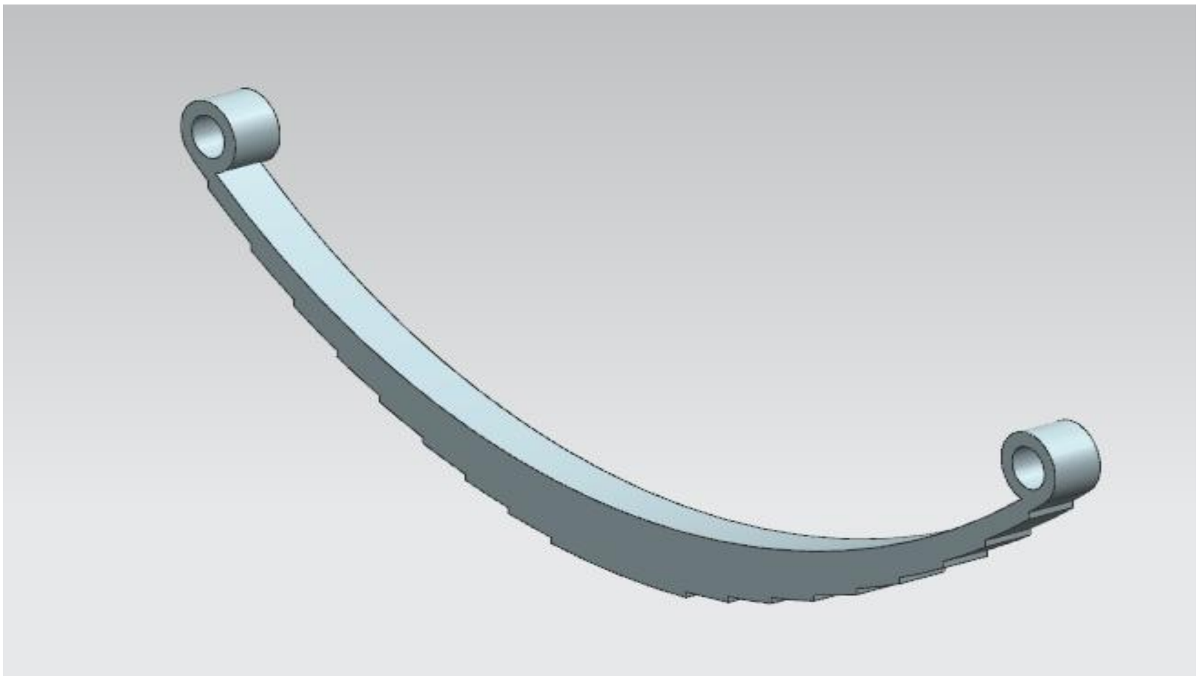


Figure: 9 CAD model of coconut fibre composite leaf spring

IV. RESULTS AND DISCUSSION

4.1 Analysis of steel Leaf Spring

The steel leaf-spring is analyzed by giving constraints and the results obtained are as follows.

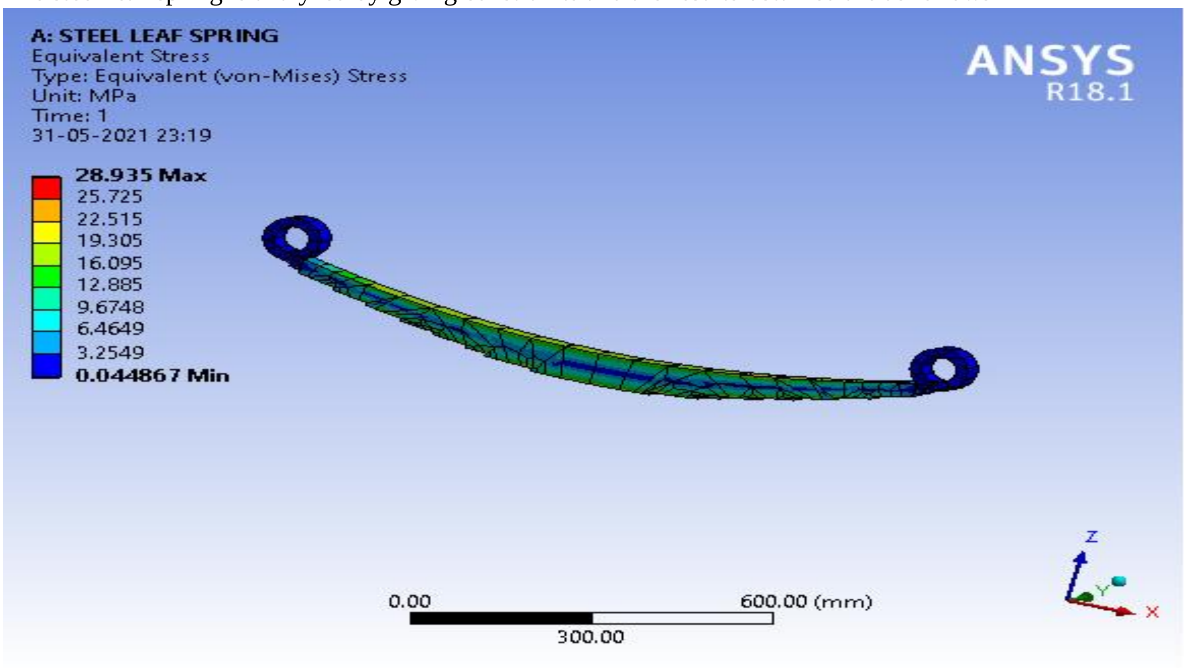
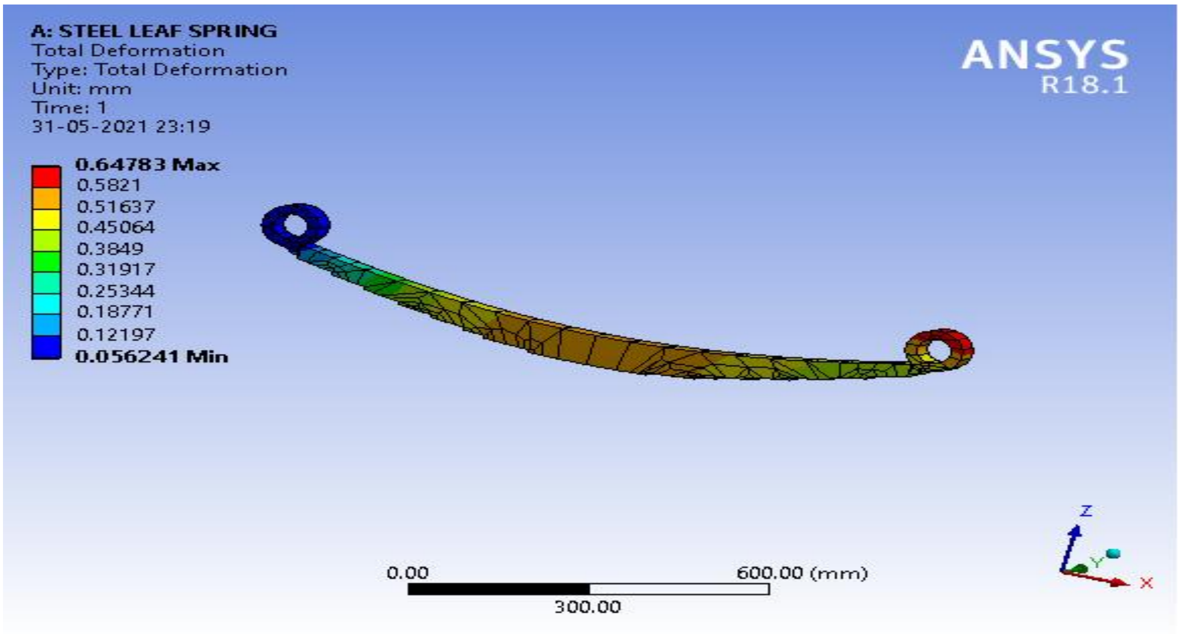


Fig.10.Max. Stress distribution.

Fig.11.Max. Deformation



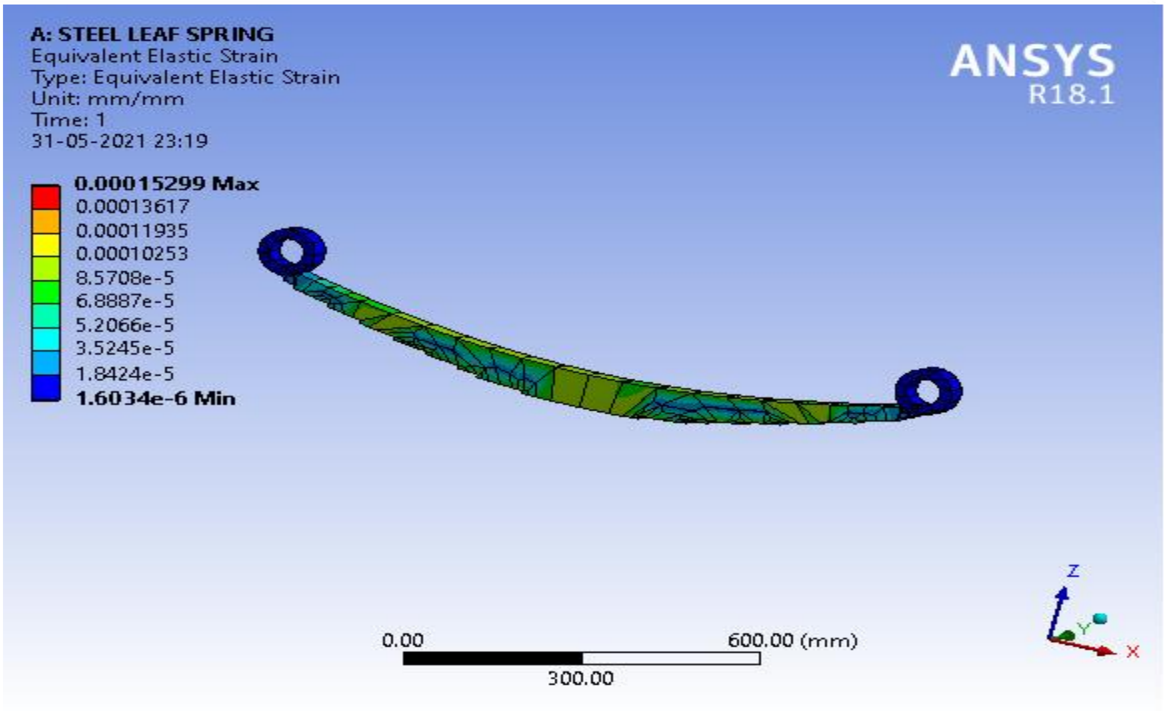


Fig.12.Max. strain distribution

4.2 Analysis of composite Leaf Spring

The steel leaf-spring is analyzed by giving constraints and the results obtained are as follows.

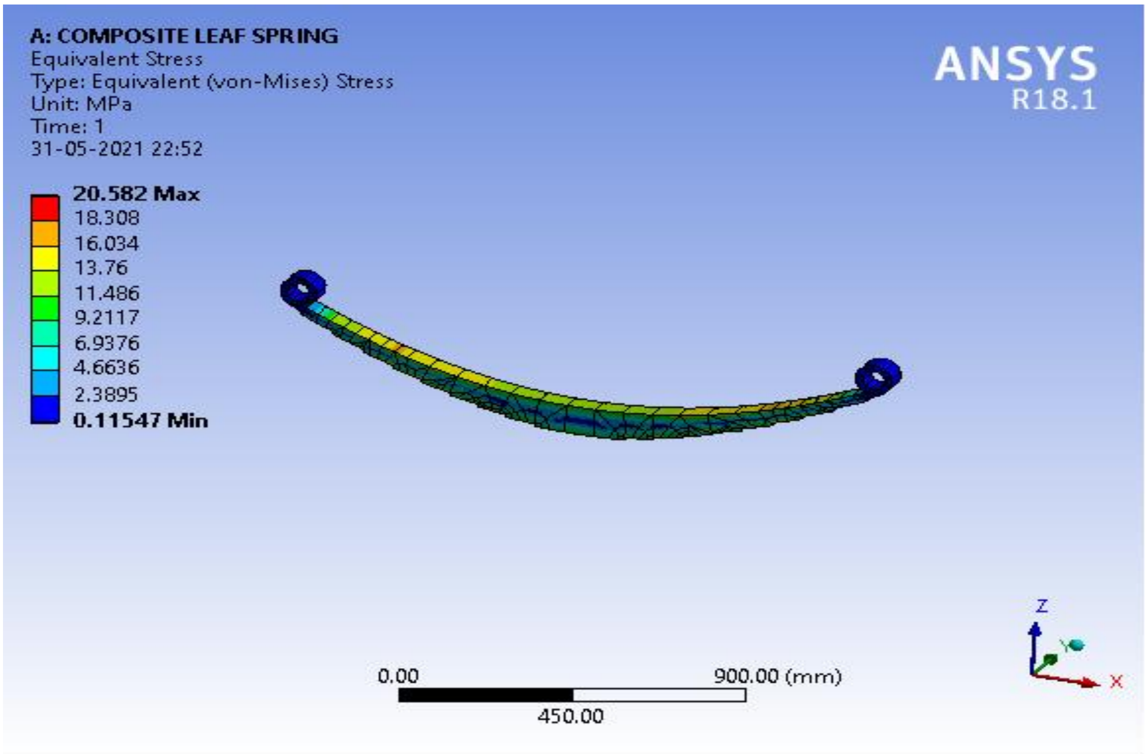


Fig.13.Max. Stress distribution

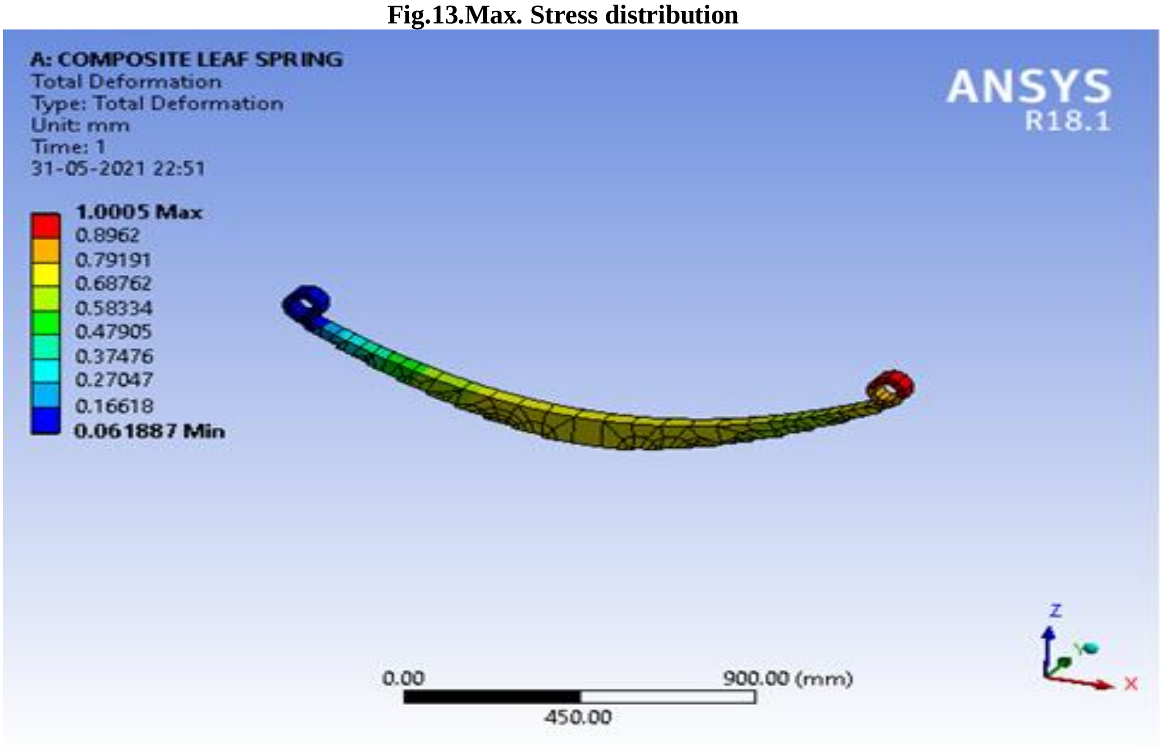


Fig.14 .Max. Deformation

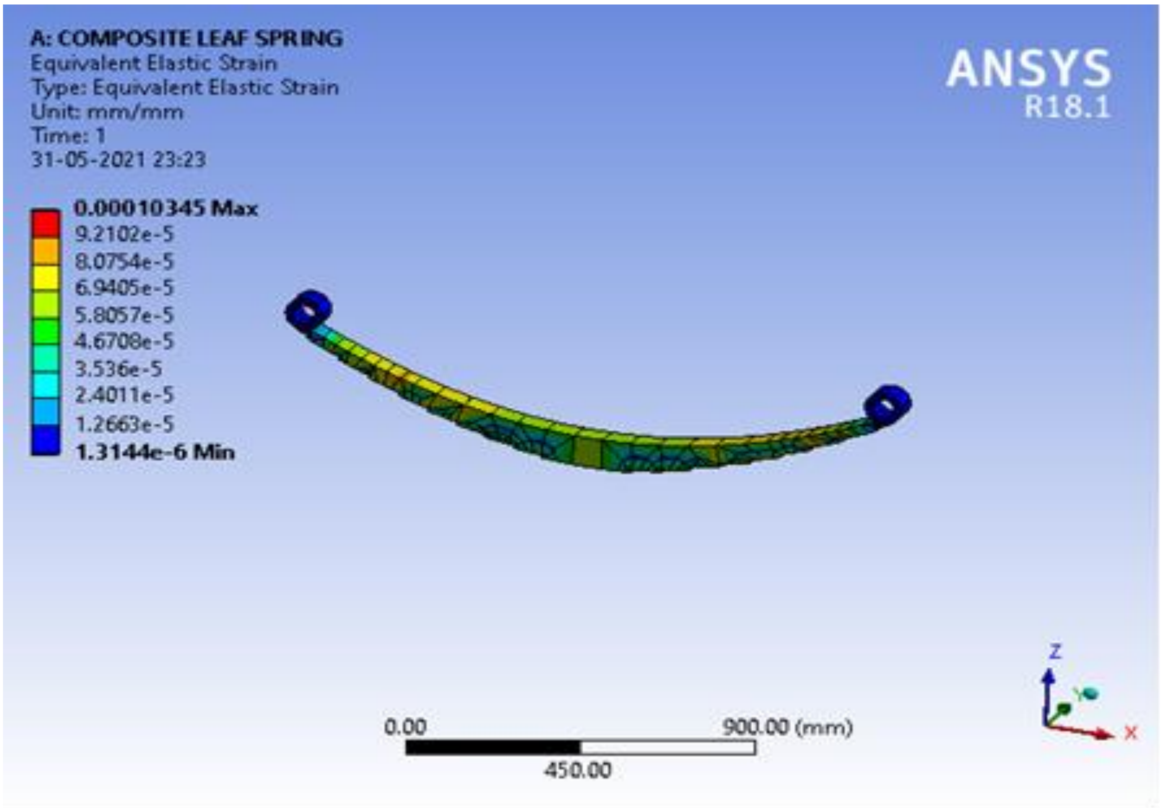


Fig.15.Max. strain distribution

Table 3. Comparison of Analysis Results of steel leaf and composite leaf springs

S. No	Material	Max stress (Mpa)	Max Deformation(mm)	Max. strain distribution	Weight (Kg)
1	Steel	28.935	0.64783	0.00015299	28.2727
2	Composite leaf spring	20.582	1.0005	0.00010345	10.0155

$$\text{Percentage of Weight saved} = \frac{(28.2727 - 10.0155)}{28.2727} = 64.575\%$$

From the results it can be observed that Equivalent stress generated in the Coconut Fiber Reinforced Polyester Composite leaf spring is less compared to steel leaf spring. Less maximum strain and acceptable deformation have been found in Coconut Fiber Reinforced Polyester Composite leaf spring compared to conventional steel leaf spring.

IV. CONCLUSIONS

Under the same static load and deflection conditions, both composite and steel leaf springs show great difference in their weights. The weight of steel spring is very high compared to that of composite.

1.The weight of steel spring is 28.2727 kgs whereas weight of composite spring is 10.0155 kgs.

2.The induced stress of composite leaf spring is 20.582 MPa which is less than 28.935 MPa of steel leaf spring.

The results obtained for deflection of steel leaf spring and composite leaf spring are in acceptable range. Composite leaf spring can be used in light weight vehicles, where weight is an important factor, whereas steel spring can be used in budget cars for its low cost of manufacturing.

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