MODELLING AND ANALYSIS OF COMPOSITE LEAF SPRING UNDER THE STATIC LOAD CONDITION USING FEA

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Abstract - Leaf springs are heart of automobile suspension system. This suspension system has great functions of avoid transmission of shocks from unevenness of roads and also, to avoid damage to the vehicle. Conventional leaf springs are manufactured of stainless steel. This stainless steel is very good at absorbing shocks. As time passed and coming to present days, where there is a need for reducing vehicle weights many automobile components are being replaced with light-weight composite materials.

In our analysis we are creating a sample model of a composite leaf spring and comparing the values with the conventional stainless steel leaf spring. For simplicity purpose, we considered only a single leaf spring consisting only one leaf. By changing the different values of some mechanical properties such like density, tensile strength we can arrive at a compromised design of leaf spring such that here the composite leaf spring will be able to absorb greater loads and vibrations and shocks as compared to stainless steel leaf spring.

The material used here is Epoxy uni-directional glass which is available in ANSYS. The version used in 2022 R1. The mechanical properties can be altered and we can assign our desired values simply using ANSYS. Procedure for analysis is done by FEA (finite element analysis) where a large material is splitted into small finite elements and analysis is carried out on each finite element to obtain results. Generally, discretization of domain, mesh generation are steps followed in FEA. Then generated mesh is subjected to various loads for analysis.

***Key Words*:** Conventional leaf springs, Shock absorbers and vibrations, Composite materials, Epoxy Uni-directional glass, Finite element analysis

1. INTRODUCTION

A leaf spring is a simple form of spring commonly used for the suspension in wheeled vehicles. Originally called a laminated or carriage spring and sometimes referred to as a semi-elliptical spring, elliptical spring or cart spring, it is one of the oldest forms of springing, appearing on carriages in France in the mid-17th century in the form of the two-part elbow spring and from there migrating to England and Germany. A leaf spring takes the form of a slender arc-shaped length of Spring Steel or Rectangular cross-section.

In the most common configuration, the center of the arc provides location for the axle, while loops formed at either end provide for attaching to the vehicle chassis. For very heavy vehicles, a leaf spring can be made from 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, some manufacturers have used mono-leaf springs. The longest leaf of the leaf spring is known as the “Master Leaf”. The ends of the master leaf are rolled which are knows as the “Eye”. The leaf just below the master leaf is called the “Second master leaf” and the ones after it are termed as “Graduated leaves”.

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. The shackle provides some degree of flexibility to the leaf spring so that it does not fail when subjected to heavy loads.

2. LEAF SPRING AND LEAF SPRING ANALYSIS AND SIMULATION

2.1 IMPORTANCE OF MONO LEAF SPRING

Mono Leaf Springs are simple forms of springs, commonly used for the suspension system in wheeled vehicles. Vehicle suspension system is made out of springs that have basic role in power transfer, vehicle motion and driving. Mono Leaf Springs are the integral part of our vehicle's suspension system. Therefore, springs performance optimization plays important role in improvement of car dynamic design and construction of the vehicle. They also help to maintain the tyres grip on the road and regulate the wheelbase lengths when it is speeding up or slowing down. To control the height of the ride and axle damping Leaf Springs are very important. While coming to maintenance, Mono Leaf Springs are the ones which are easily repairable and replaceable. These also suffer less wear and tear due to a smaller number of leaves included in the construction. Along with the wear and tear, Mono Leaf Spring possess less weight than Multi Leaf Spring which also increases the fuel efficiency of the engine.

2.2 LIFE OF A LEAF SPRING

Many different factors can lead to leaf spring wear and because of this there is no easy way to determine how long a set of new leaf springs will last. The weight and frequency of loads, along with wear from dirt and grime can all lead to early wear. Like your tires, brakes, batteries, belts and other auto parts, the leaf springs in the Suspension System will eventually need replacing. A Leaf Spring can last as much and when to replace them depends on a variety of considerations, ranging from the age of your vehicle and how often it's used to the stress put on them and environmental factors. If you primarily drive your pick up on the highway to and from work and keep it in a garage, the springs can last well over 100,000 miles.

If we use a truck on the job and regularly haul heavy loads and tow to maximum capacity, it will inevitably shorten your leaf springs' life expectancy. Using products such as add leaves, heavy-duty coil springs, Super Springs and replacement shackles, hangers and bolts will help leaf springs last longer. If we use a truck on the job and regularly haul heavy loads and tow to maximum capacity.

Using products such as add a leaf's, heavy-duty coil springs, Super Springs and replacement shackles, hangers and bolts will help leaf springs last longer. Since it's inevitable you will eventually have to replace your leaf springs, it's less of a concern when they will wear out and more about knowing when to make repairs. Staying in tune with how your vehicle's suspension is operating and performing inspections.

We can identify that our Leaf Springs are worn out from the subtle noises such as squeaking and creaking when going over rough terrain to bottoming out on bumps and inclines. Additional clues your leaf springs are getting old and starting to sag include poor handling and braking and the inability to carry and pull loads.

We can examine our Leaf Springs by parking the Vehicle on a level surface and look at the vehicle form a low vantage point to see if it's dipping down on one side. A tilted car or truck body can indicate uneven wear on your leaf springs. If it is observed, then a more detailed inspection is required.

To perform a good routine inspection at the first indication of trouble. With the car of truck suspended, remove the tire so that you have good access to the Leaf Springs and other suspension parts. We can find that the leaf springs could be coated with dirt, grit or grime, so first clean them off with a cloth and with a wire brush. Later, we can inspect better for the signs of wear, cracks and breaks in the springs. It's also possible that the leaves could have moved due to loosening of the brackets. It is sometimes possible to nudge these back by hammering and tightening the clamps, but do not do this if any wear has started to show on the leaf springs.

2.3 TYPES OF LEAF SPRING

1. Multi Leaf Spring
2. Mono Leaf Spring
3. Semi-Elliptical Leaf Spring
4. Quarter-Elliptical Leaf Spring
5. Three Quarter-Elliptical Leaf Spring
6. Full Elliptical Leaf Spring
7. Transverse Leaf Spring

MULTI LEAF SPRING:

The most widely used type of Leaf Springs is Multi Leaf Spring, which is made up of more than one metal plate or leaf. These plates are placed on top of one another, with the longest piece on top. A center bolt is inserted through the thickest portion to hold the plates together. Standard components have three to five leaves, but you will find ones with even more.

Because of the multiple leaves, the stiffness of the spring is heightened. The additional support leads to a higher carrying capacity, that's why these are suitable for heavy-duty vehicles. But be careful when using leaf springs with too many leaves, as these can lead to too much stiffness, and cause an uncomfortable ride.

Fig 1 (MULTI LEAF SPRING)

MONO LEAF SPRING:

The other type is the mono leaf spring, which is made of one piece of metal. These have a thick center and become narrow toward the edges — to provide support, just like a multi-leaf spring. These are mainly used on lightweight vehicles.

Fig 2 (MONO LEAF SPRING)

SEMI-ELLIPTICAL LEAF SPRING:

The semi-elliptical leaf spring is the most common type of this suspension component. It takes on the arc shape of a bow but without the string. It is usually made of multiple leaves in different lengths but with the same width. The upper and longest leaf or plate is also referred to as the “Master Leaf”. One end of the Semi-Elliptical Leaf Spring is fixed to the frame of the vehicle.

Fig 3 (SEMI-ELLIPTICAL LEAF SPRING)

QUARTER-ELLIPTICAL LEAF SPRING:

This type of leaf spring is similar in build to a semi-elliptical leaf spring, but they’re mostly used in older cars. The distinct characteristic of this suspension component is that it’s only half of the semi-elliptical leaf spring. One end is fixed to the side of the frame through a bolt, while the other end is connected to the front axle. This was also called a cantilever type of leaf spring.

Fig 4 (QUARTER-ELLIPTICAL LEAF SPRING)

THREE QUARTER-ELLIPTICAL LEAF SPRING:

When you combine a semi-elliptical leaf spring and a quarter-elliptical one, you get a three-quarter elliptical leaf spring. The quarter part is placed on top of the axle and is fixed to the frame of the vehicle. The semi-elliptical spring is connected to the frame via a shackle on one side, while the other end is attached to the quarter leaf spring. The addition of an extra half of this suspension component provides extra support. The three-quarter elliptical leaf spring is popular in older vehicles.

Fig 5 (THREE QUARTER-ELLIPTICAL LEAF SPRING)

FULL ELLIPTICAL LEAF SPRING:

A full elliptical spring is the combination of two semi-elliptical leaf springs which are joined opposite each other to create a shape similar to an oval. These are attached to the frame of the vehicle and the axle. Since both leaf springs will bend the same amount when compressed, spring shackles are not used.

Full-elliptical springs are mainly used in old cars. Nowadays, they're rare because they don't maintain the correct axle alignment.

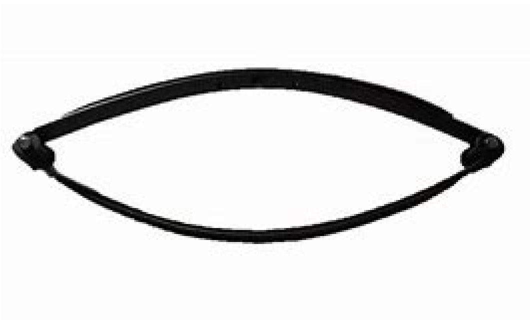

Fig 6 (FULL ELLIPTICAL LEAF SPRING)

TRANSVERSE LEAF SPRING:

This type of leaf spring looks like the semi-elliptical leaf spring. The only difference is that it's inverted, so the longest leaf is at the bottom. It's mounted from each wheel rather than over them. The middle or thickest portion is secured through a U-bolt. These are also mostly used in older cars, frequently in independent wheel suspensions.

Fig 7 (TRANSVERSE LEAF SPRING)

2.4 USES OF LEAF SPRING

1. Leaf Springs are an integral part of your vehicle's suspension system. They are installed to help support the entire weight of your car or truck.

2. Leaf Springs also help to maintain the tyres grip on the road and regulate the wheelbase lengths when it is speeding up or slowing down.

3. Leaf Springs help in damping of Shocks and Vibration in mostly heavy commercial vehicles such as Trucks, Vans, Buses, Railway Wagons, etc.

4. Leaf Springs have the advantage of distributing the load more widely across the vehicle chassis, while coil springs transfer it to a single point

2.5 ADVANTAGES OF LEAF SPRING

1. Due to the sheer amount of metal layers, leaf springs provide a large amount of support between the car's wheels, axles, and chassis. They can absorb enormous vertical loads due to their close-meshed structure, which is why they are still used in the heavy-duty industry.

2. Vertical loading is also distributed along the length of the leaf spring rather than acutely through a small spring and damper, potentially creating a concentrated force too large for the suspension.

3. In a car, damping can be an extremely important property. If the suspension is under-damped, the car will roll and bounce around well after hitting a bump or pothole in the road.

4. This was a significant feature on cars that used coil springs before the shock absorber appeared and was detrimental to cars when driven at real

speed. Leaf springs coped much better with car damping due to the friction between the individual steel plates, which made the reaction time after a vertical flex in the suspension much quicker, resulting in a much more controllable car

5. They are very simple in design and cheap to produce in comparison with the early springs and dampers. Mono Leaf Springs were the simplest design of the lot, using only leaf of spring steel which tapered which tapered from thick in the middle to thin at the edges to distribute the vertical loads appropriately.

2.6 MODELLING

The Finite Element Analysis (FEA) process is performed on the Leaf Spring is done by Discretization of the model in Infinite Nodes and Elements and Refining them under defined boundary condition. Then the required loads of various magnitudes in the preferred directions are applied to obtain the desired results about the experiment which is being carried out.

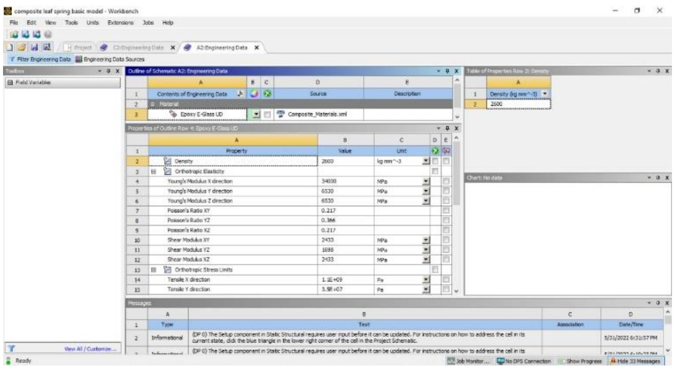

Fig 8 (EPOXY PROPERTIES)

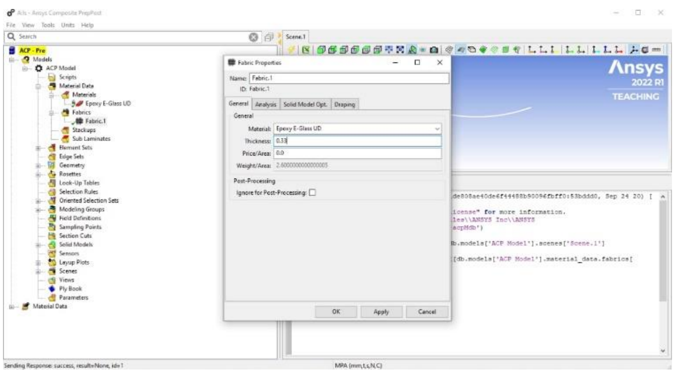

Fig 9 (PARAMETERS FOR ANALYSIS)

LAYERS

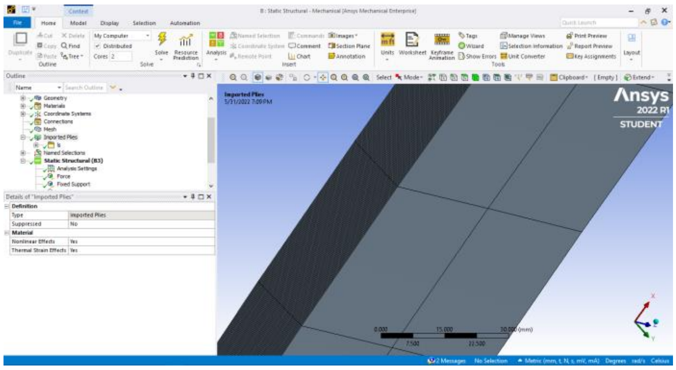

Fig 10 (LAYERS OF COMPOSITE LEAF SPRING)

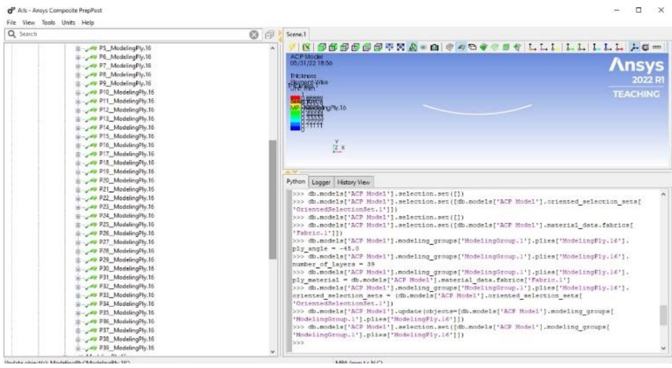

Fig 11 (LAYER DETAILS OF COMPOSITE LEAF SPRING)

2.7 ANALYSIS:

The above modelled Composite Leaf Spring is now subjected to different amounts of Loads under Static Condition to obtain the resulting Stresses and Deformations under those respective conditions. Also, the results obtained are plotted on the Graph Charts at the end of the portion to visualize the comparison between Conventional (Stainless Steel) Leaf Spring and Composite (Epoxy/Carbon Composite) Leaf Spring. The Analysis is as follows:

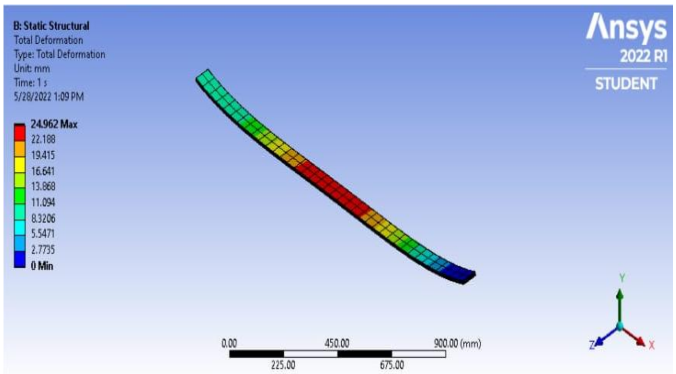

Fig 12 (VONMISES STRESS UNDER THE LOAD 50N)

From above analysis, under 50N of Load, the Composite Leaf Spring undergoes 24.9 mm of Deflection and possess a Maximum Stress of 61.5 kg/mm^2.

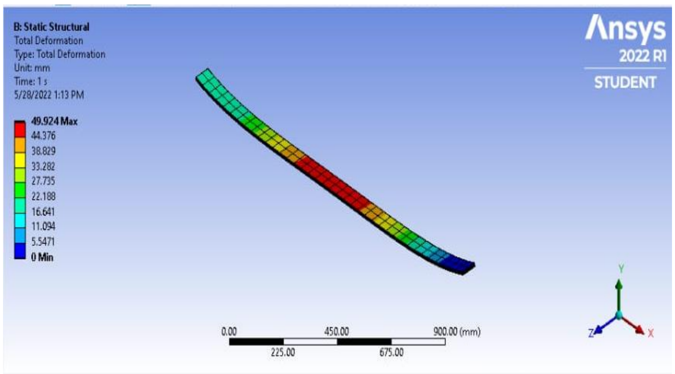

Fig 13 (VONMISES STRESS UNDER THE LOAD 100N)

From above analysis, under 100N of Load, the Composite Leaf Spring undergoes 49.9 mm of Deflection and possess a Maximum Stress of 120.85 kg/mm^2.

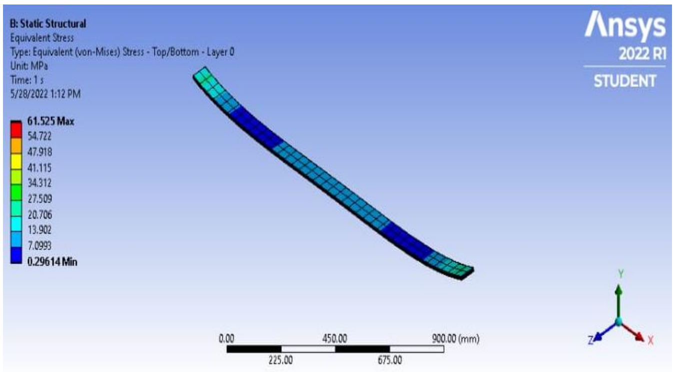

Fig 13 (VONMISES STRESS UNDER THE LOAD 150N)

From above analysis, under 150N of Load, the Composite Leaf Spring undergoes 74.54 mm of Deflection and possess a Maximum Stress of 181.28 kg/mm^2.

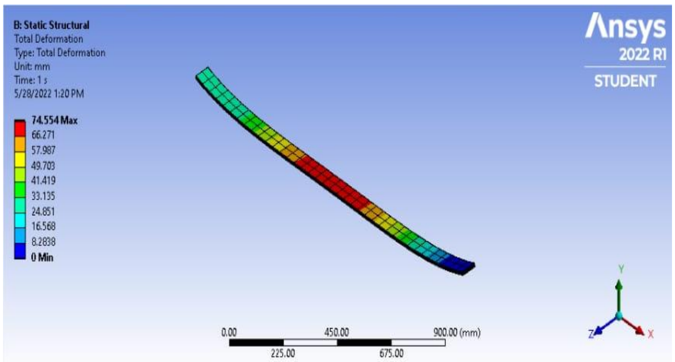

Fig 14 (VONMISES STRESS UNDER THE LOAD 200N)

From above analysis, under 200N of Load, the Composite Leaf Spring undergoes 99.8 mm of Deflection and possess a Maximum Stress of 241.7 kg/mm^2.

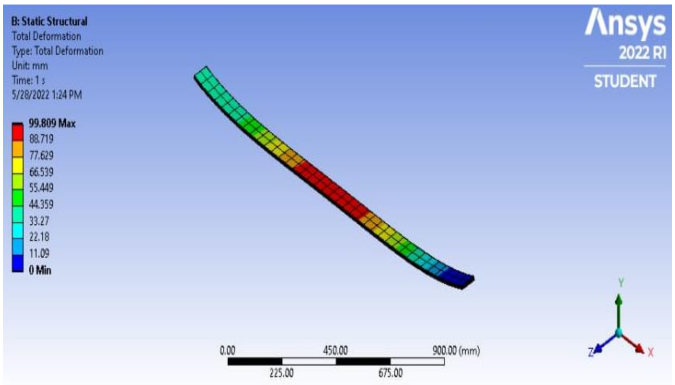

Fig 14 (VONMISES STRESS UNDER THE LOAD 225N)

From above analysis, under 225N of Load, the Composite Leaf Spring undergoes 112 mm of Deflection and possess a Maximum Stress of 272.47 kg/mm^2.

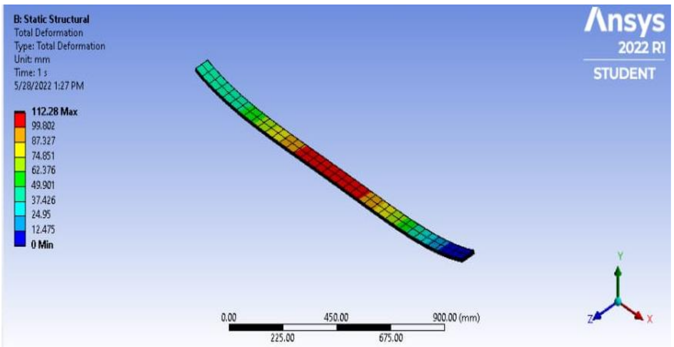

Fig 15 (VONMISES STRESS UNDER THE LOAD 250N)

From above analysis, under 250N of Load, the Composite Leaf Spring undergoes 124.36 mm of Deflection and possess a Maximum Stress of 296.64 kg/mm^2.

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2.8 PROPERTIES OF EPOXY

TABLE 1 (PROPERTIES OF EPOXY)

Property	Value
Compressive Strength – Longitudinal (Mpa)	300
Compressive Strength – Transverse (Mpa)	415
Density (g/cm^3)	1.90
Tensile Strength – Longitudinal (Mpa)	490
Thermal Expansion Coefficient – Longitudinal (x10^{-6} K^{-1})	11
Upper Working Temperature (°C)	130-150

2.9 METHODOLOGY

TABLE 2 (PARAMETERS OF THE COMPOSITE LEAF SPRING)

Parameters	Value
Length of Master Leaf	1540mm
No. of Leaves	1
Eye diameter	30mm
Thickness	13mm
Width	70mm
Camber	136mm

TABLE 3 (PROPERTIES OF STAINLESS-STEEL VS EPOXY)

Materials	Stainless-Steel	Epoxy
Density	7850 kg/m3	1600 kg/m3
Young's Modulus	2e+11 pa	2.28e+11 pa
Poisson's Ratio	0.3	0.28

3.RESULTS AND DISCUSSION

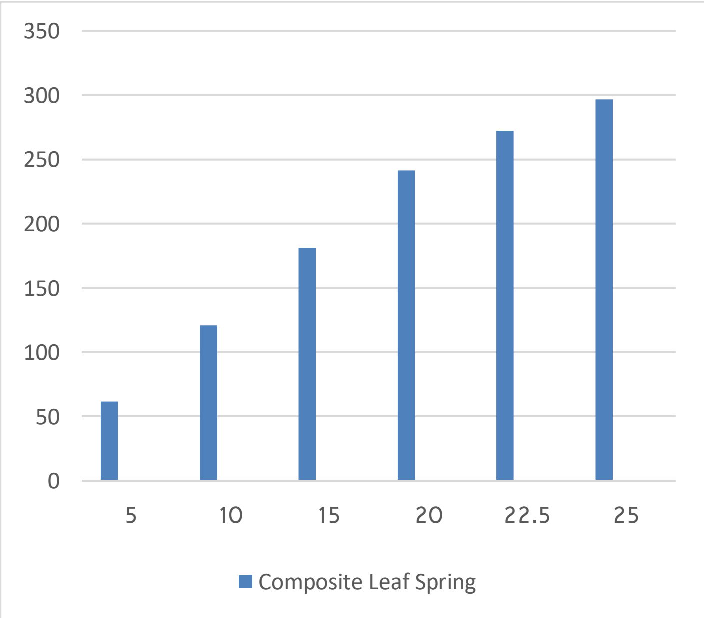
3.1 RESULTS

The above obtained results from the Analysis are tabulated and their respective Graphs are plotted below:

Composite Leaf Spring:

TABLE 4: LOAD VS VONMISES STRESS

Load (kg)	VonMises Stress (MPa)
5	61.5
10	120.85
15	181.28
20	241.7
22.5	272.47
25	296.64

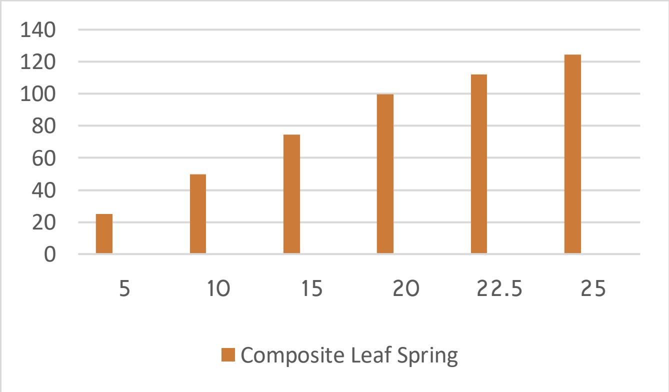


GRAPH 1 (LOAD VS VONMISES STRESS)

In Composite Leaf Spring, on application of the periodic increase of the load, the VonMises Stress is increasing parabolically when subjecting under that specific load.

TABLE 5: LOAD VS DEFLECTION

Load (kg)	Deflection (mm)
5	24.9
10	49.9
15	74.54
20	99.8
22.5	112
25	124.36

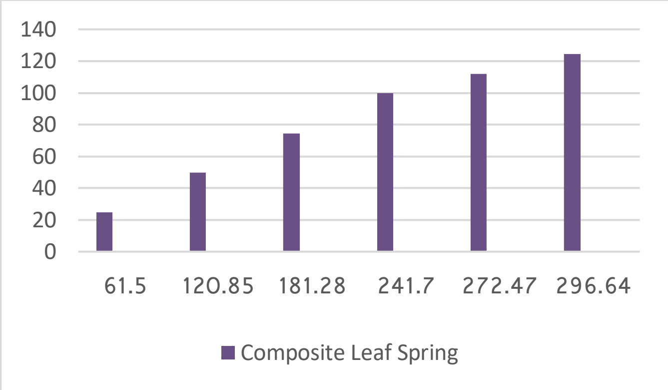


GRAPH 2 (LOAD VS DEFLECTION)

In Composite Leaf Spring, on application of the periodic increase of the load, the Deflection in the Spring increases parabolically.

TABLE 6: VONMISES STRESS VS DEFLECTION

VonMises Stress (MPa)	Deflection (mm)
61.5	24.9
120.85	49.9
181.28	74.54
241.7	99.8
272.47	112
296.64	124.36



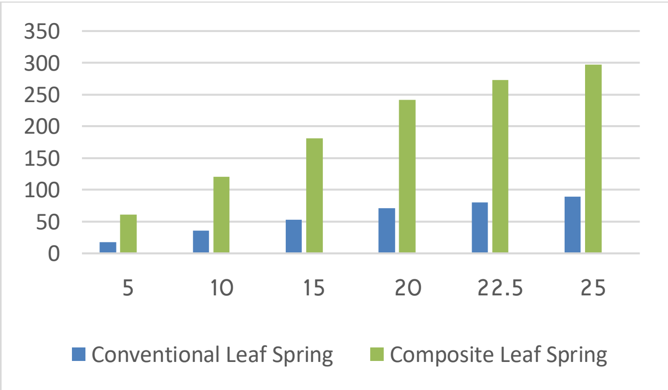
GRAPH 3: VONMISES STRESS VS DEFLECTION

In Composite Leaf Spring, the VonMises Stress increases on increase of the Deflection in the Spring gradually, when subjected to the Load.

Comparative Analysis:

TABLE 7: VONMISES STRESS (MPa)

Conventional Leaf Spring	Composite Leaf Spring
17.818	61.5
35.637	120.85
53.455	181.28
71.273	241.7
80.182	272.47
89.091	296.64

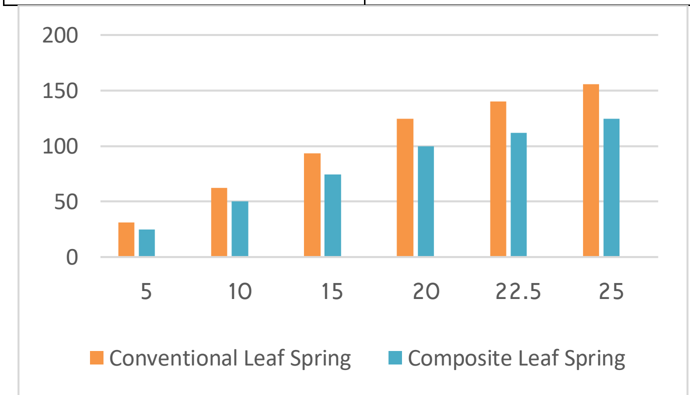


GRAPH 4 (VONMISES STRESS)

In Comparison between Conventional Leaf Spring and Composite Leaf Spring, the induced VonMises Stress in Conventional Leaf Spring is relatively lesser than that of Composite Leaf Spring.

TABLE 8: DEFLECTIONS (mm)

Conventional Leaf Spring	Composite Leaf Spring
31.127	24.9
62.254	49.9
93.38	74.54
124.56	99.8
140.069	112
155.633	124.36



GRAPH 5 (DEFLECTIONS)

In Comparison between the Conventional Leaf Spring and Composite Leaf Spring, the Deflection in the Conventional Leaf Spring is relatively higher than Composite Leaf Spring.

4. CONCLUSIONS

A comparative study has been made between Conventional and Composite Mono Leaf Spring with respect to the weight, vonmises stress and deflection. The Composite Mono Leaf Spring is lighter and economical with similar design specifications to that of a Conventional Leaf Spring. It increases the life of leaf spring about 65% for Epoxy over Stainless Steel material under the application of Leaf Spring.

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