OPTIMIZATION AND MODIFICATION OF LEAF SPRING USING FEA ANALYSIS

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ABSTRACT

The suspension of leaf spring is one of the important parts of an automobile system as we consider the weight and load carrying capacity of any automobile. The introduction of spring helps in designing better suspension system with better ride quality and that could be achieved with the less increase in the cost and also with less compromise in the quality and working life of the produced. The relationship of the specific strain energy can be expressed in terms of instruments i.e. well known "spring" which is designed to absorb and store energy to release slowly. This ability of spring adds conformability of suspension system. The main objectives of having this new design is to improve ride quality in general by reducing the intensity of forces on its surface and reduce the failure of leaf spring. By implementing this design, the forces acting on it are distributed to the two dampers and to the leaf spring. This helps in the overall balancing of the forces which in turn improve the comfort level. Leaf spring is commonly used in the vehicle suspension system and is subjected to millions of varying stress cycle leading to fatigue failure. A lot of research has been done for improving the performance of leaf spring by modification in design and experimental analysis of leaf springs. In this we will find out the stress concentration in the leaf spring and also the stress limit of the standard Leaf spring by making a 3D model using modeling software and then we will analyse model using Finite Element Analysis. We will also compare the Deflection of the spring using Dampers with that of without dampers assembly at different Loads.

Keywords: *Leaf Spring, Damper, Design, Analysis*

1. LEAF SPRING

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

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end and, 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 spring terminated in a concave end, called a spoon end, to carry a swivelling member [1].

Leaf spring were very commonly on automobiles, right up to the 1970s on Europe and japan and late 70'sin 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 carriage. For heavy vehicles, they have the advantages of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point [2].

2. LITERATURE REVIEW

Leaf spring absorb the vehicle vibrations, shocks and bump loads by means of spring deflections, so that potential energy is stored in the leaf spring and then relieved slowly. Ability to store and absorb more amount of strain energy ensure the comfortable suspension system [1].

Much suspension system work on the same principle including conventional leaf spring. However, for the same load and shock absorbing performance, conventional leaf springs use excess of material making them composite materials in place of steel in the conventional spring. Study and researches were carried out on the application of the composite material in the spring.

The review mainly focuses on replacement of steel leaf spring with the composite leaf spring made of glass fiber reinforced polymer and majority of the published work applies to them.

Static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer using life data analysis .

C.madam Mohan Reddy, Dr. M lakhmiKanthareddy conducted study on analysis and testing of two wheeler suspension laminated spring. They focused their study on suspension system spring modeling. They try to replace spring in automobile. They carried a comparatively study. They calculated the stress and deflection of spring. They compare their FEA results with experimental values [3].

Leaf spring are mainly used in suspension system to absorb shocks loads in automobile like light motor vehicles, heavy duty trucks and in rail system. It carries lateral loads, brake torque, driving torque in addition to shock loading [4].

The advantage of leaf spring over helical spring is that the spring may be guided along a definite path as it deflects to acts as a structural member in addition to energy absorbing device [5].

There are leaf spring consists of simply one plate of spring. There are usually thick in middle and taper out towards the end, and they don't typically offer too much strength and suspension for towed vehicle. Driver looking to how heavier loads typically use Multileaf spring, which consists of several leaf spring of varying length stacked on top of each other. The shorter the leaf spring, the closer to the bottom.

The main objective is the load carrying capacity, stiffness and weight savings of carbon steel leaf spring without damper and with damper. The design constrains are stresses and deflection. The dimension of an leaf spring of a heavy commercial vehicle are taken same dimension used to carbon steel multi leaf spring using R-GLASS/EPOXY, S-GLASS/EPOXY and CARBON/EPOXY unidirectional laminates [30]

3. SELECTION OF DAMPER

Damping refers to the energy dissipation properties of a material or a system under cyclic stress but excludes energy transfer device. When a structure is subjected to an external force then it vibrates in certain amplitude of vibration. It reduces as the external force is removed. This is due to some resistance offered to the structural member which may be internal or external. This resistance is termed as damping [9].

Fig -1: Damper

The use of damper (shock absorber) in heavy truck suspension is central to reducing dynamic wheel loads. Dynamic wheel roads are responsible for a significant component of vehicle related road damage. Substantially reduce dynamic wheel loads thereby enhancing suspension "road – friendless". Because dampers deteriorate over time, a new test is required to determine the in-service condition of dampers. There is a need to develop improved dampers that are optimization to reduce dynamic wheel loads while providing good ride quality. They must be sufficiently robust to dissipate the required energy from various magnitudes of road unevenness over extended life cycles [22].

4. DIMENSION OF LEAF SPRING

Table -1: Dimension of Leaf Spring

	Dimensions (mm)
Length of Leaf Spring ($2L_1$)	1180 mm
Thickness of Leaves (t)	8 mm

Width (w)	64 mm
Number of Master Leaf (N_f)	2
Number of Graduated Leaves (N_g)	6
Camber (y)	100 mm
Diameter of Eye	50 mm
Distance b/w U-clip (l)	80 mm
Effective length (2L)	1100 mm

5. MANUAL CALCULATION

Here we have selected heavy truck vehicle.

1. Length of leaf spring (2L) = 1180 mm

2. Thickness of leaves (t) = 8mm

3. Width (w) = 64mm

4. Number of Master Leaf (N_f) = 2

5. Number of Graduated Leaves (N_g) = 6

6. Camber = 100mm

7. Diameter of Eye = 50m [1] [21]

For 1 tonne load without damper

- Data
- Capacity of vehicle = 660 Kg
- Gross weight of vehicle = 1 TONNE
- Factor of safety = 1.5
- G = 9.81
- 1 TONNE + 660 kg (0.6 T) = 1.6 TONNE
- 1.6 TONNE × 1.5 = 2.5 TONNE = 2500 kg
- From kg to N
  = 2500 × 9.81
  = 24525 N
- Four wheel = $\frac{24525}{4}$ = 6130 N
  = $\frac{6130}{2}$ = 3065 N Load [21]

For 1 tonne deformation

$$\delta = \frac{12WL3}{(3Nf+2ng)Ebt3}$$

$$= \frac{12\times3065\times(550)3}{[(3\times2)+(2\times6)]\times2.1\times105\times64\times83} = 49.67 \text{ mm}$$

Bending Stress is,

$$\sigma_b = \frac{6WL}{nbt2}$$

$$= \frac{6\times3065\times550}{8\times64\times82} = 308.415 \text{ N/mm}^2$$ [6] [10] [16]

6. FEA ANALYSIS OF LEAF SPRING WITHOUT DAMPER

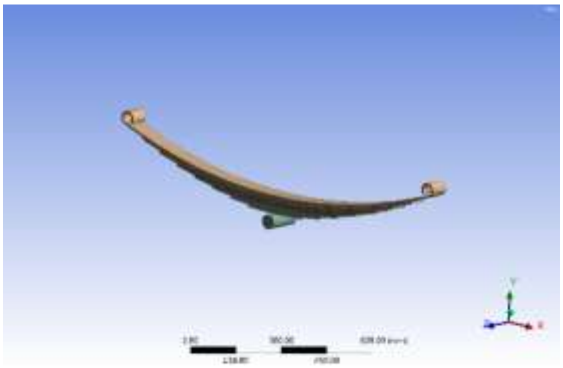

Fig -2: Model of leaf spring without damper

Figure shows the imported geometry of leaf spring. This geometry has been created in CREO parametric taking the dimension from standard dimension. Figure shows the 3D model of leaf spring with camber of leaf spring. Total length of leaf spring is 1180mm is the arc height at axle seat [2] [3].

Table -2: Mechanical Properties of Leaf Spring

Properties	
Density	7.8e-006 Kg mm^-3
Young’s Modulus	2.1e+005 Mpa
Poisson’s Ratio	0.3
Bulk Modulus	1.75e+005 Mpa
Shear Modulus	80769 Mpa
Tensile Yield Strength	575 Mpa
Tensile Ultimate Strength	685 Mpa

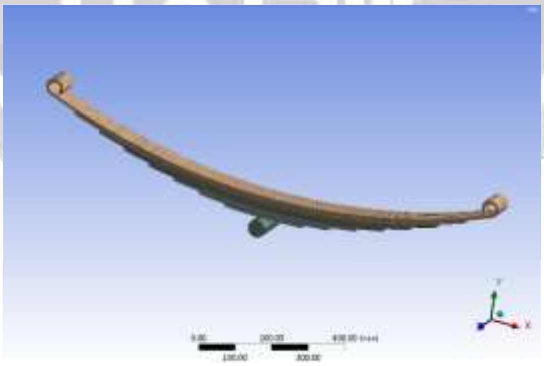

Fig-3: Mesh Model of Leaf Spring

There are number of nodes of Leaf spring is 21924 and elements is 2910.

Meshing is nothing but the discretization of object into the small parts called as the element. Figure shows the meshed model of leaf spring with an element size of 7mm brick mesh. Previous studies shows that the best results are obtain using brick mesh. Considering the concept of grid independence it is been found that is the best suited size of mesh hence this size of mesh has been selected.

We have used solid 186 as a mesh element.

Solid 186: A tetrahedral shaped element and a pyramid shaped element may also be formed. SOLID 186 Homogeneous Structural Solid Geometry. SOLID 187 is a similar but 10 nodes tetrahedron element. In addition to the nodes, the element input data includes the anisotropic material properties. Anisotropic material directions correspond to the element coordinates [3].

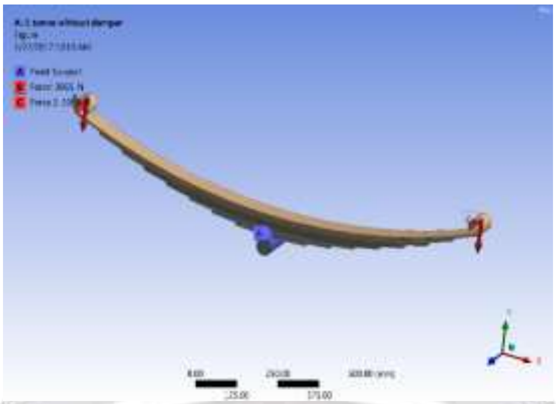

Fig-4: Boundary & Loading condition of Leaf spring

Fixed Supports

Fixed support has restriction to move in X and Y direction as well as reaction about that particular point. We have fixed support at the cylinder place at the down side of the spring.

Force

We have given loads at the eye of the leaf spring of 3065 N in downward Y direction [3].

Figure shows the deflection of carbon steel leaf spring under the application of 1 TONNE load. The maximum deflection at the eye of the leaf spring its maximum value is 51.563. Red zone indicates the area of total deflection and Blue zone indicates the area of minimum deflection. Which are shown by probe.

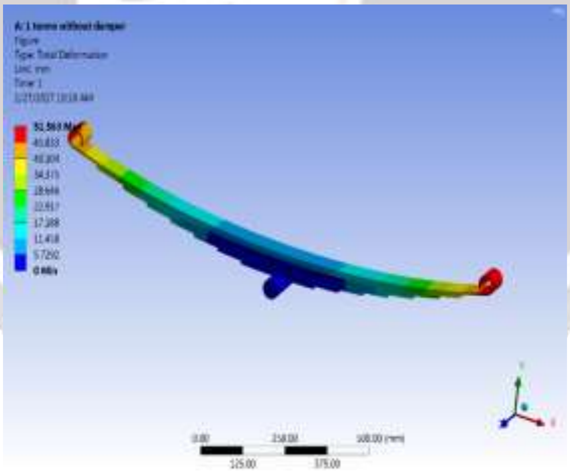

Fig -5: Total Deformation of Leaf spring

In above figure the maximum allowable deformation of without damper leaf spring is 51.563. By analyzed the design, it was found that all stresses in the leaf spring were well within the allowable limits and with good factor of safety [3] [5] [9].

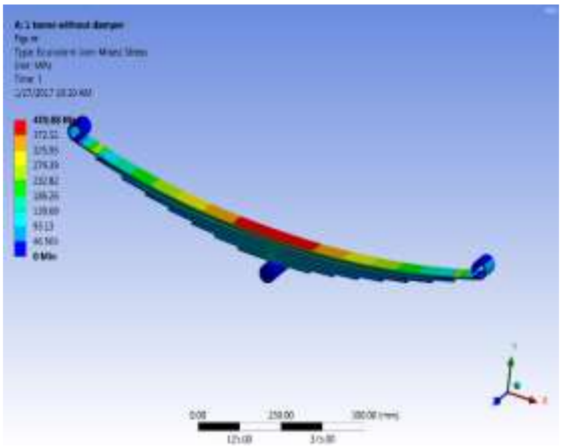

Fig -6: Von-Mises Stress on Leaf Spring without Damper

Figure shows that the equivalent von-Mises stress induced in carbon steel leaf spring under the action of 3065 N load. The maximum stress induced at the center of the leaf spring and its maximum value is 419.08 N/mm^2. Red zone indicates the area of maximum stress and blue zone indicates the area of minimum stress [5] [9].

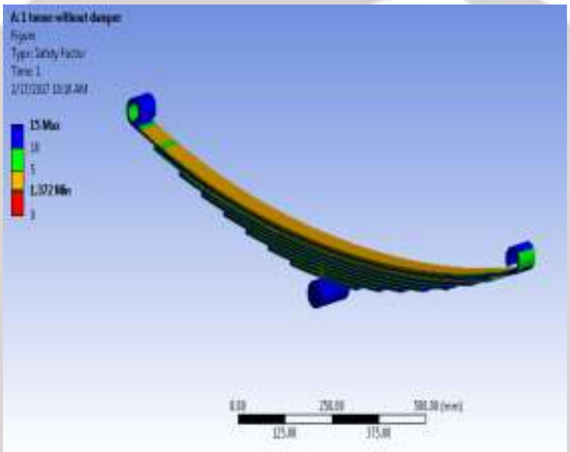

Fig -7: Factor of Safety of Leaf spring without Damper

7. FEA ANALYSIS OF LEAF SPRING WITH DAMPER

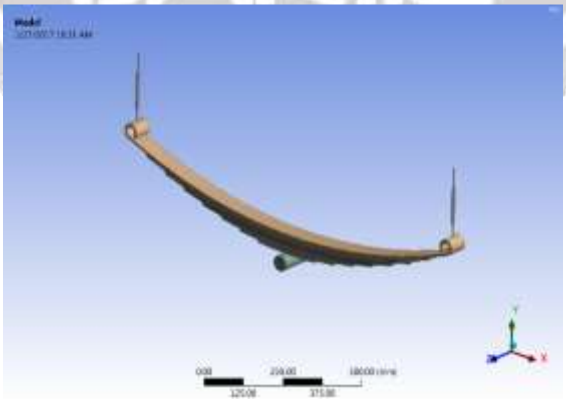

Fig -8: Model of Leaf Spring with Damper

Figure shows the imported geometry of leaf spring with damper. This geometry has been created in CREO parametric taking the dimension from standard dimension. Figure shows the 3D model of leaf spring with damper. We take a damper having longitudinal stiffness of 5.2Nmm [6].

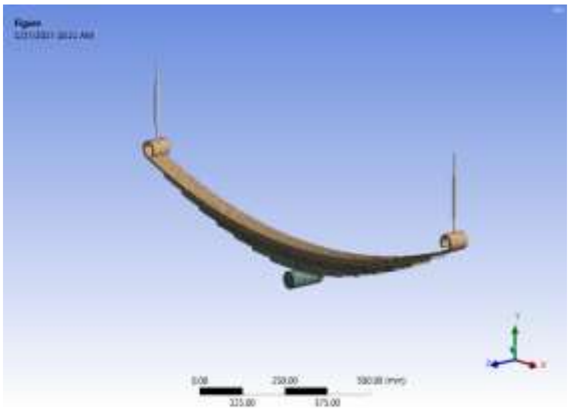

Fig -9: Mesh model of Leaf Spring with damper

There are number of nodes of leaf spring is 21924 and elements 2910.

We have used solid 186 as a mesh element.

SOLID 186: A tetrahedral shaped element and a pyramid shaped element may also be formed. SOLID 185 Homogeneous structural solid geometry. SOLID 187 is similar but 10 nodes tetrahedron element. In addition to the nodes, the element input data includes the anisotropic material properties. Anisotropic material directions correspond to the element coordinates [5] [9].

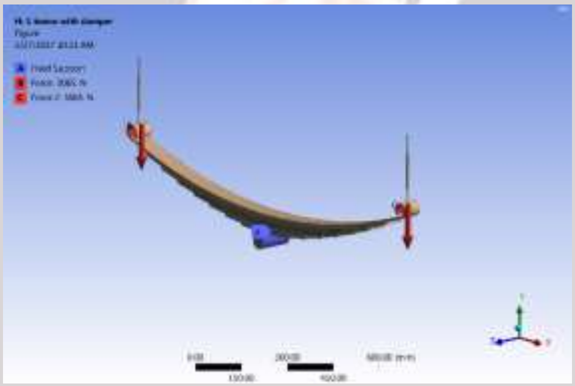

Fig -10: Boundary & Loading Condition of Leaf Spring

Fixed supports

Fixed supports has restriction to move in X and Y direction as well as reaction about that particular point. We have fixed support at the cylinder place at the down side of the springs.

Force

We have given loads at the eye of the leaf spring of 3065 N in downward Y direction [5] [9].

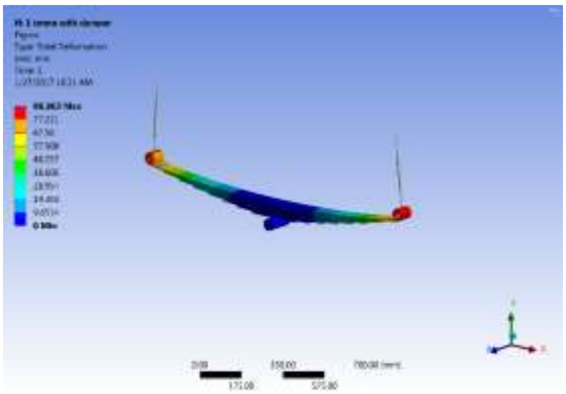

Fig -11: Total Deformation of Leaf Spring with Damper

Figure shows the deflection of carbon steel leaf spring under the application of 1 TONNE load. The maximum deflection at the eye of the leaf spring and its maximum value is 86.862. Red zone indicates the area of total deformation and blue zone indicates the area of minimum deflection. Which is shown by probe [5] [9] [21].

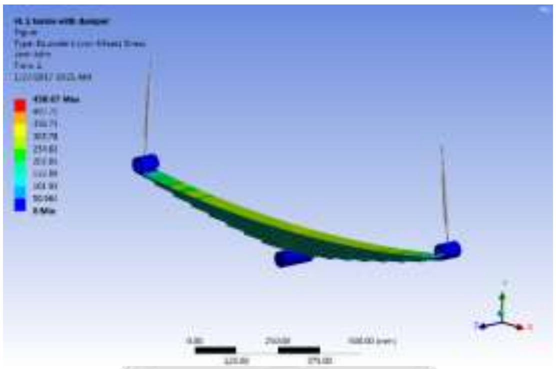

Fig -12: Von-Mises Stress on Leaf Spring with Damper

Figure shows the equivalent von-Mises stress induced in carbon steel leaf spring under the application action of 3065 N load. The maximum stress induced at the center of the leaf spring and its maximum value is 458.67 N/mm^2. Red zone indicates the area of maximum stress and blue zone indicates the area of minimum stress [5] [9] [21].

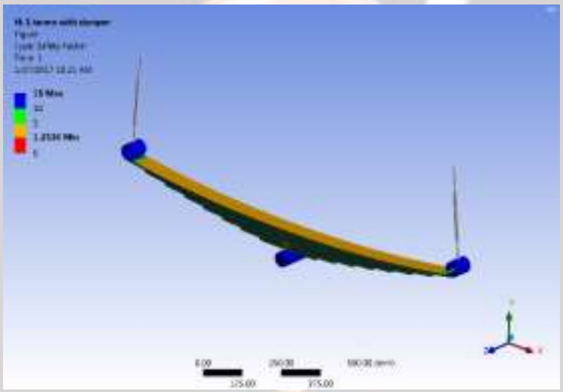

Fig -13: Factor of Safety of Leaf Spring with damper

8. MATERIAL OPTIMIZATION

8.1 Types of Material used

There are three types of material are taken for prove the results. There are three materials, one is carbon epoxy, second is R-glass/epoxy and third is S-glass/epoxy.

R-Glass/Epoxy

Fiber glass (or R-Glass/Epoxy) is type of fiber reinforced plastic where the reinforced fiber is specially glass fiber. The glass fiber may be randomly arranged, flattened into a sheet or woven into a fabric. The plastic matrix may be a thermoset polymer matrix – most often based on thermosetting polymers such as epoxy, polyester resin or vinyl ester – or a thermoplastic.

S-Glass/Epoxy

The stress-rapture of S-Glass/Epoxy composites has been studied. A 40 ksi increase in stress reduces the life of an S-Glass/Epoxy composites by a factor of 10. An empirical extrapolation of 15,000 hours of testing implies that S-Glass/Epoxy composites can sustain an equivalent fiber stress of 200 ksi for 10 years. The S-Glass/Epoxy stress rapture distributions from over 1300 tests are described by an exponential model are related to the applied stress by a power law in time.

Carbon Epoxy

Carbon fiber reinforced polymer, carbon fiber reinforced plastic or carbon fiber reinforced thermoplastics, is an extremely strong and light fiber-reinforced plastic which contains carbon fibers. The spelling ‘fiber’ is common in British Commonwealth countries.

CFRPs can be expensive to produce but are commonly used wherever high strength-to-weight ratio and rigidity are required, such as aerospace, automobile, civil engineering, sports goods and an increasing number of other consumer and technical applications.

The binding polymer is often a thermoset or thermoplastic polymer, such as polyester, vinyl ester or nylon, are sometimes used.

Table -3: Properties of R-Glass/Epoxy

Properties	
Density	2.53e-006 kg mm^-3
Young’s modulus X direction Mpa	53100
Young’s modulus Y direction Mpa	12400
Young’s modulus Z direction Mpa	12400
Poisson’s Ratio XY	0.16
Poisson’s Ratio YZ	0.16
Poisson’s Ratio ZX	0.28

FOR R-GLASS/EPOXY

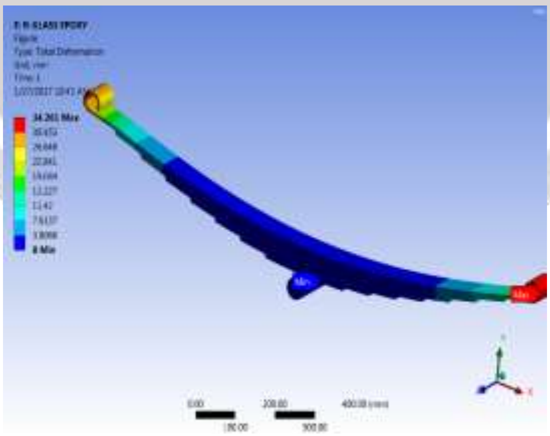

Fig -14: Deformation in R-Glass/Epoxy

Values of Deformation:

Maximum: 34.261mm

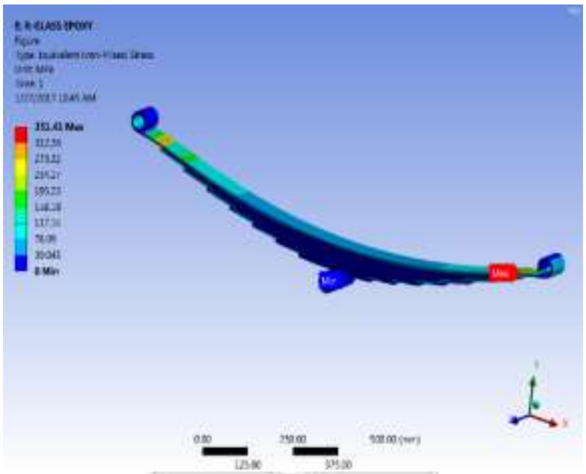

Fig 15: Von-Mises Stresses in R-Glass/Epoxy

Values of Von-mises Stress:

Maximum: 351.41mm

FOR S-GLASS/EPOXY

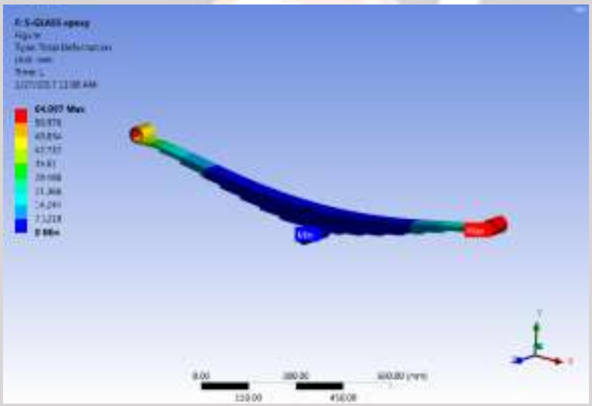

Fig 16: Deformation in S-Glass/Epoxy

Values of Deformation:

Maximum: 64.097mm

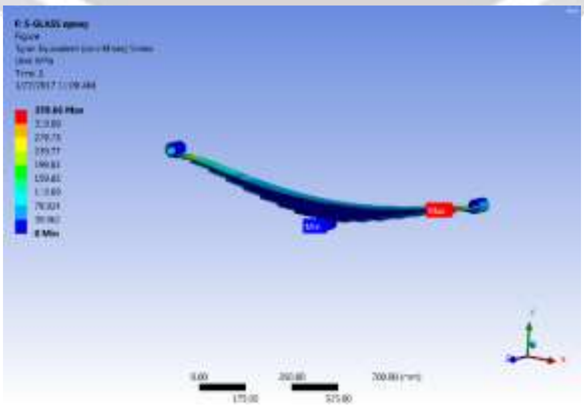

Fig -17: Von-Mises stresses in S–Glass/Epoxy

Values of Von-Mises Stress:

Maximum: 359.66mm

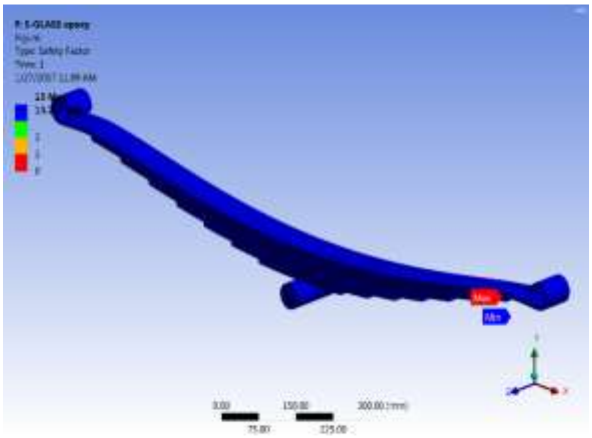

Fig -18: Factor of Safety in S-Glass/Epoxy

Values of Factor of Safety:

Minimum: 13.207

FOR CARBON EPOXY

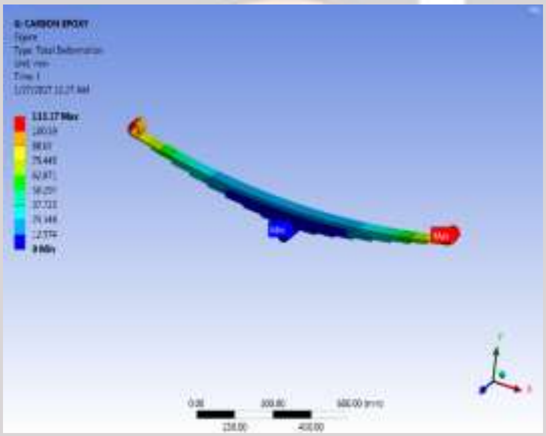

Fig -19: Deformation in Carbon Epoxy

Values of Deformation:

Maximum: 113.37mm

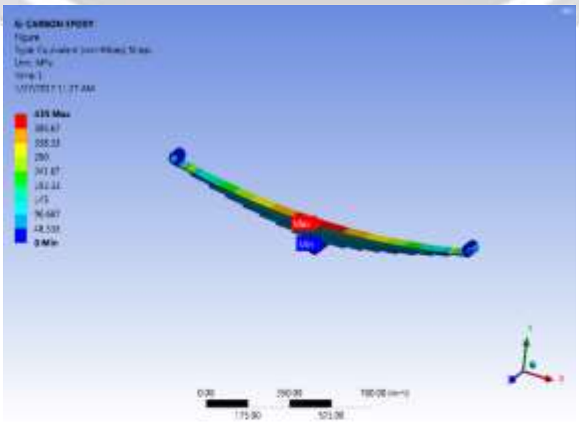

Fig -20: Von-Mises Stress in Carbon/Epoxy

Values of Von-Mises Stress:

Maximum: 435mm

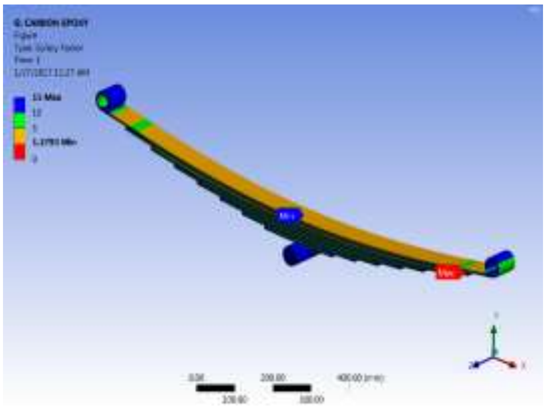

Fig -21: Factor of Safety in carbon Epoxy

Values of Factor of Safety:

Minimum: 1.3793

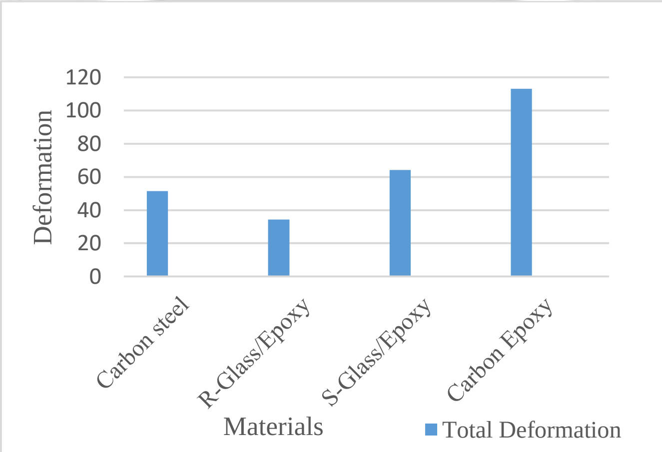

Chart -1: Total Deformation of all Materials

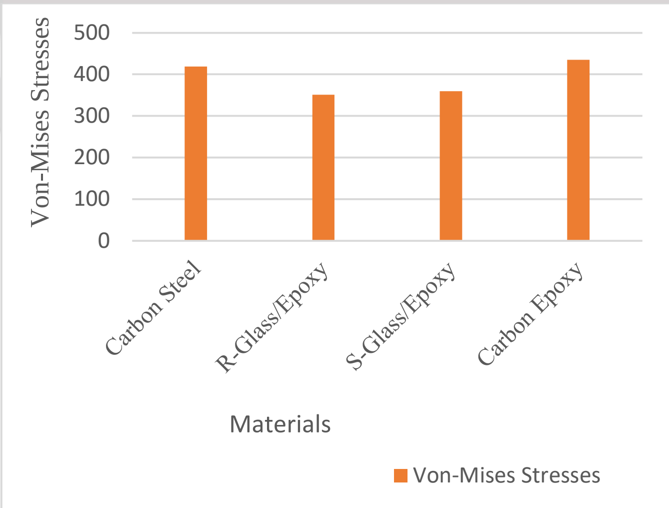

Chart -2: Von-Mises Stresses of all materials

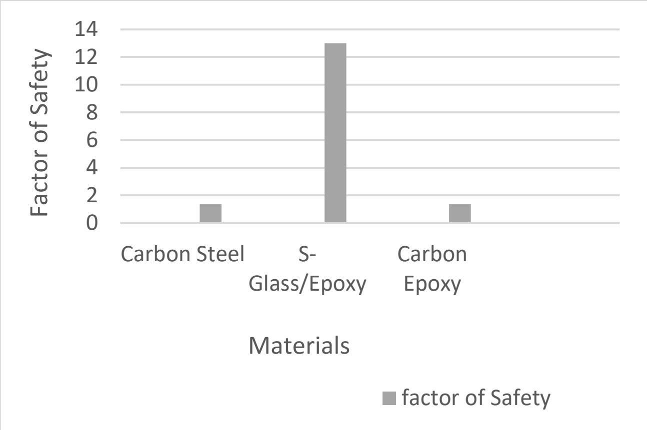

Chart -3: Factor of Safety of all Materials

9. RESULTS

9.1 BEFORE OPTIMIZATION

After Analysis In below table compare the results of different parameters of leaf spring.

Table -4: Compare the results of Leaf Spring without Damper and with Damper

Types of leaf spring	Total allowable Deformation of 1 tonne	Equivalent Stress of 1 tonne	Factor of Safety of 1 tonne
Leaf spring Without Damper	51.563	419.08	1.372
Leaf spring with damper	86.862	548.67	1.254

9.2 AFTER OPTIMIZATION

Table -5: Compare the Results of all Materials

Types of Material used	Weight (Kg)	Deformation	Von-Mises Stress	Factor of Safety
Carbon steel	28.186	51.263max	419.08max	1.372
R-Glass/Epoxy	10.264	34.261max	351.41max	-
S-Glass/Epoxy	10.029	64.097max	359.66max	13.207
Carbon Epoxy	7.137	113.17max	435max	1.379

10. CONCLUSION

The main objectives of having this new design is to improve shock absorb quality and the overall life of leaf spring.

1) Total deformation
- We have designed and modeled a leaf spring using R-Glass/Epoxy, S-Glass/Epoxy and Carbon Epoxy.
- The deformation values of R-Glass/Epoxy is 34.261, S-Glass/Epoxy value is 64.097 and the Carbon Epoxy value is 113.17.
- We concluded that the load carrying capacity of Carbon Steel is very much less compared to Carbon/Epoxy.

2) Von-Mises Stress
- The equivalent Stress value of the R-Glass/Epoxy is 351.41, the value of S-Glass/Epoxy is 359.66 and Carbon Epoxy value is 435.
- We concluded that the carbon epoxy is carry high stress compared to other materials.

3) Factor of Safety
- The safety factor of S-Glass/Epoxy is 13.207min, safety factor of Carbon/Epoxy is 1.379min.

We concluded that the safety factor of S-Glass/Epoxy is very less so it is not use for heavy vehicle. Carbon Epoxy material capable to manufacture of leaf spring.

4) Weight Reduction
- The weight of carbon steel is 28.186kg, weight of R-Glass/Epoxy is 10.264kg, S-Glass/Epoxy is 10.029 and weight of Carbon/Epoxy is 7.137
- Carbon steel leaf spring reduce the weight by nearly 75% for Carbon/Epoxy.
- We concluded that the leaf springs materials R-Glass/Epoxy and S-Glass/Epoxy are not capable to carrying the load of leaf spring, the weight of Carbon/Epoxy is very much less compared to Carbon Steel.
- So their carbon steel can be replace by the carbon/Epoxy.

So finally we can concluded that Carbon/Epoxy is the best materials to manufacture leaf spring because to good structural stability low product cost and good efficiency.

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