Analysis and Optimization for Weight and Stress reduction in Leaf Spring

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Abstract: Suspension leaf springs are widely used in automobile systems. The increasing interest of automobile industry in the usage of composite materials in substitute to conventional steel leaf springs owing to higher strength to weight ratio in latter. The past literature survey shows that leaf springs are designed as generalized force elements where the position, velocity and orientation of the axle mounting gives the reaction forces in the chassis attachment positions. The attachment of chassis positions along different positions plus difference in axle mounting's velocity and orientation, the leaf springs are designed for these force elements. So, it is very important to study the analysis of leaf springs made up of composite materials. Modelling of leaf spring has been done with SOLIDWORKS 20.0 software and analysis has been carried out with ANSYS R19.2. Thus, the comparison of static analysis of these three materials are made and compared for material composites leaf spring. The static testing is done for a load of 50000 N in the rear suspension, also FE analysis is carried out and validated.[1] Von Mises Stress and Total Deformation were found out from this analysis. The conclusion was reached that there was a reduction in both stress and weight when composite material was used rather than conventional steel material. It is an effective energy conservation measure as reduction in overall fuel consumption of automobile is also achieved.

Keywords: Von-Mises Stress, Leaf Spring, Leaf, Failure

I. INTRODUCTION

A spring basically shows elastic nature, with deflection in size from the original shape when stresses are applied and regains it shape when latter is removed. Leaf spring is the simplest form of spring used in the suspension system of vehicle. It is also the most widely used suspension system and conventionally available due to its simple shape and construction. Damping of vibrations, shock loading, and absorption due to springing action is the main function of leaf springs.[2] Energy is stored in the material in the form of potential energy which can be utilized when the deformation is removed. The extent to which the energy absorption is achieved makes it the most conventional suspension system used in heavy loading automobiles like trucks. In both light & heavy automobile vehicles, the type of spring used is semi elliptic. These are divided further in two types- mono leaf spring (only one step) & multi leaf spring (multiple steps), these steps are also called blades. The energy absorbing capacity is directly proportional to the number of blades in the spring. For this very purpose, multi leaf springs are used in heavy loaded automobiles and mono leaf for the lightweight vehicles.

The spring can be attached both biaxially (frame attached at both ends) or uniaxially (frame attached at only one end, conventionally the front). Short swinging arm is equipped with a shackle through which the other end is attached. It is the shackle owing to its soft springiness that the elongation property of leaf spring is achieved [2].

Fig.1 Leaf Spring Arrangement

The construction of leaf spring is done, keeping the following main parts in mind: -

1. Semi elliptical form of leaf spring is used for automobile applications.
2. Plates also known as leaf with decreasing length constitute the main body of leaf spring.
3. The longest out of these is called the central leaf or main leaf while the rest are called graduated leaf.
4. The clamping is done with the help of U-bolts to the axle.
5. Holding of this graduated plus main leaf is done with the help of Rebound clips.
6. Central clamp fixes the axle with the leaf spring.

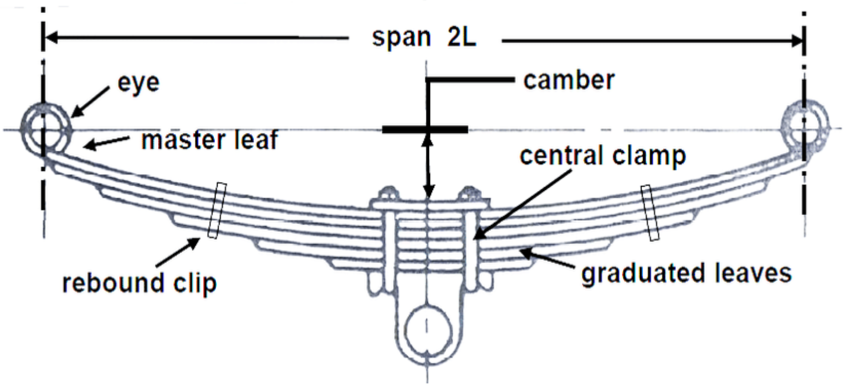


Fig.2 Semi Elliptic Leaf Spring

MERITS OF COMPOSITE LEAF SPRING:

1. Reduction in weight & High corrosion resistance.
2. Laminate structure and decreased thickness of multi-leaf composite leaf springs makes the total weight less.
3. Fuel consumption is reduced due to less inertial forces.

4. High damping to vibration and prominent noise reduction owing to high-capacity factor.[3]

Fig.3 Epoxy Reinforced mono-leaf Spring.

II. LITERATURE REVIEW

Some of the findings of various research papers to understand the scope of this project and conclusion include: -

In 2017, Kumar & Reddy observed that through optimization by FEM software cheaper and qualitative production of the leaf spring can be achieved in a short period of time. He used FEM analysis using ANSYS workbench & carried out the weight optimization of the LS with target weight reduction of 20%, 30%, 40%, 50%, and 60% under a constant loading force (30kN) to determine the mass that needs to be removed to minimize both weight and cost.

Ashwini & Rao analyzed the model imported to the HYPERMESH which is a FE pre-processor that provides a highly interactive and visual environment to find out product performance. Topology optimization technique was used to achieve the optimization objectives henceforth, reducing the weight of the LS.[3]

Dwivedi & Jain used static FEA and the optimization analysis results to determine degree of stress multiaxiality, and the fatigue model used for analyzing the fatigue. Outputs include fatigue life, damage, factor of safety, stress biaxiality, fatigue sensitivity. The weight optimization was subject to space constraints and manufacturability.

Kesheoray et. al. in 2017 investigated the upspring mass which is to be kept low thereby increasing the stability of the vehicle. By identifying the prominent features of design, assurance in service life and prolonged stability is achieved.

Nutalapati conducted a failure study of LS and proved that the decrease of weight is very important for secure running at greater RPM's because of the redacted inertia held within the low weight LS. Objective achieved was to eliminate as much product while still keeping both the toughness & stability.[3]

Under the guidance of Prof. Vijay Gautam, the prospects covered in this research paper have been thoroughly taught by offline and online means. With the growing automobile industry, design of machine elements concepts plays an important role which is a vast subject.[10]

To gain the understanding and put various concepts of dynamic analysis done in the research, the book, ‘Design of Machine Elements’ by V.B. Bhandari has provided a huge help as a textbook.

For fast and accurate analysis of connecting rod which is a sturdy and stiff component in engines, trusted CAD software like Solidworks and simulation software ANSYS Workbench has been used for designing and simulation.

For better understanding of how optimization algorithms work (or sometimes fail) help from the book, 'Design Optimization using MATLAB and Solidworks by Prof. Krishnan Suresh has been taken. This text provided lucid methods to optimize by using FEA analysis and same methods have been applied in this work.[10]

III. DESIGN OF LEAF SPRING

Leaf springs constitute of flat plates. The ends of the springs are guided along a definite path, this is the advantage of leaf spring over helical spring, moreover in addition to act as a structural member it also acts a brilliant energy absorbing device. The plates can also be used as a flat spring.

LOADING- Lateral loads, Brake Torque, Bending Stresses, Driving Torque etc.

MANUFACTURING CONSIDERTION- Hardened and Tempered

FOS- The factor of safety based on yield strength is used from 2 to 2.5 for automobile suspension.

The flat plates or leaves are generally made of steels, 55Si2Mn90, 50Cr1 or 50Cr1V23.[2]

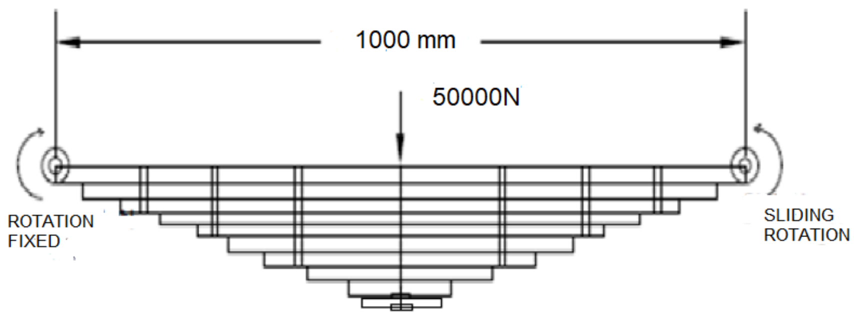


Fig. 4. FBD of Leaf Spring

The following notations are used for the purpose of analysis: -

N_f → no. of extra full-length leaves

N_g → no. of graduated-length leaves

t → thickness of plate

N → no. of plates

b → width of each leaf (mm)

L → length of load from cantilever end

Therefore,

$$\sigma = \frac{M}{Z} = \frac{W.L}{\frac{1}{6} \times b.t^2} = \frac{6WL}{b.t^2}$$

$$\delta = \frac{W.L^3}{3E.t} = \frac{W.L^3}{3E.t}$$

The above equations can be used for laminated springs as: -

$$\sigma_{\max} = \frac{pFL}{Nb_N h^2} \quad \text{and} \quad \delta_{\max} = \frac{qFL^3}{ENb_N h^3}$$

where the constants p & q are given as: -

1. p=3 & q=3 (Simply supported Beam)
2. p=3 & q=6 (Cantilever Beam)

A. *Design of the model for Analysis*

The analysis of the leaf spring is done in ANSYS R19.2 software was performed and static analysis for initial steel model are presented in to analyse its stress, strain and deformation using the materials provided in the material section. The structural design of the leaf spring is performed in SolidWorks software based on the theoretical calculations done. A process chart to be done in this analysis is provided below: -

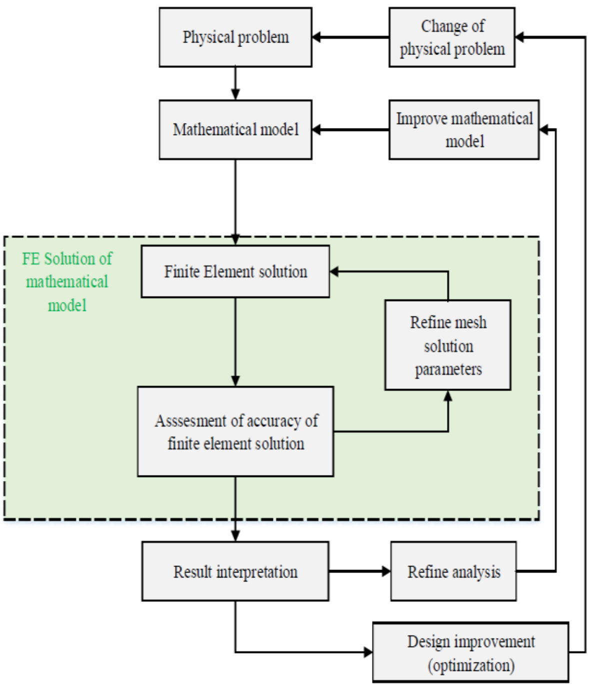


Fig.5 Process of Finite Element Analysis

Dimensions: Length of top layer = 1000 mm

Decrease in length of each layer = 100 mm

Bottom layer = 300 mm

Each layer thickness = 50 mm

Total layer = 8

Table 1: Dimensions of FE model

Leaf Spring Part	Top Part	Bottom Part	Radius	Vertical Distance
Eye Outer Part			35 mm	
Eye Inner Part			25 mm	
Master Leaf	1000 mm	1010 mm		
Graduated Leaf-1	900 mm	910 mm		10 mm
Graduated Leaf-2	800 mm	810 mm		10 mm
Graduated Leaf-3	700 mm	710 mm		10 mm
Graduated Leaf-4	600 mm	610 mm		10 mm
Graduated Leaf-5	500 mm	510 mm		10 mm
Graduated Leaf-6	400 mm	410 mm		10 mm
Bottom Leaf	300 mm	310 mm		10 mm
Applied Load	50000 N			
Span (Eye centre to centre)	977 mm			
No. of graduated leaves	8			
Width of leaves	50 mm			

B. Weight Calculations

• FOR STEEL: -

Weight of smallest leaf (leaf1) = density × volume× acceleration due to gravity [1]

= 300 × 10 × 50 × 0.00000786 ×10

= 11.79 N

Weight of leaf2 = 400 × 10 × 50 × 0.00000786 ×10

=15.72N

Weight of leaf3 = 500 × 10 × 50 × 0.00000786 × 10

=19.65N

Weight of leaf4 = 600 × 10 × 50 × 0.00000786 × 10

=23.58N

Weight of leaf5 = 700 × 10 × 50 × 0.00000786 × 10

= 27.51N

Weight of leaf6 = 837 × 10 × 50 × 0.00000786 × 10

= 31.44N

Weight of leaf7 = 900 × 10 × 50 × 0.00000786 × 10

= 35.37N

Weight of leaf8= 1000 × 10 × 50 × 0.00000786 × 10

= 39.3N

Total weight of steel leaf spring = 204.36N

• FOR E-GLASS/EPOXY: -

Weight of multi-leaf spring = 5200 × 10 × 50 × 0.000002 × 10

= 52N

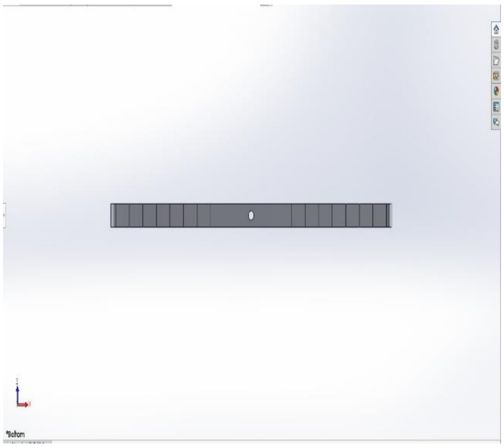
Weight saved = 204.36 – 52 = 152.36N

%weight saved = (152.36 ÷ 204.36) × 100

= 74.55%

C. *Solidworks Design*

FRONT VIEW



TOP VIEW

SIDE VIEW

ISOMETRIC VIEW

Fig.6 Design Views

D. *Meshing of Designed Model*

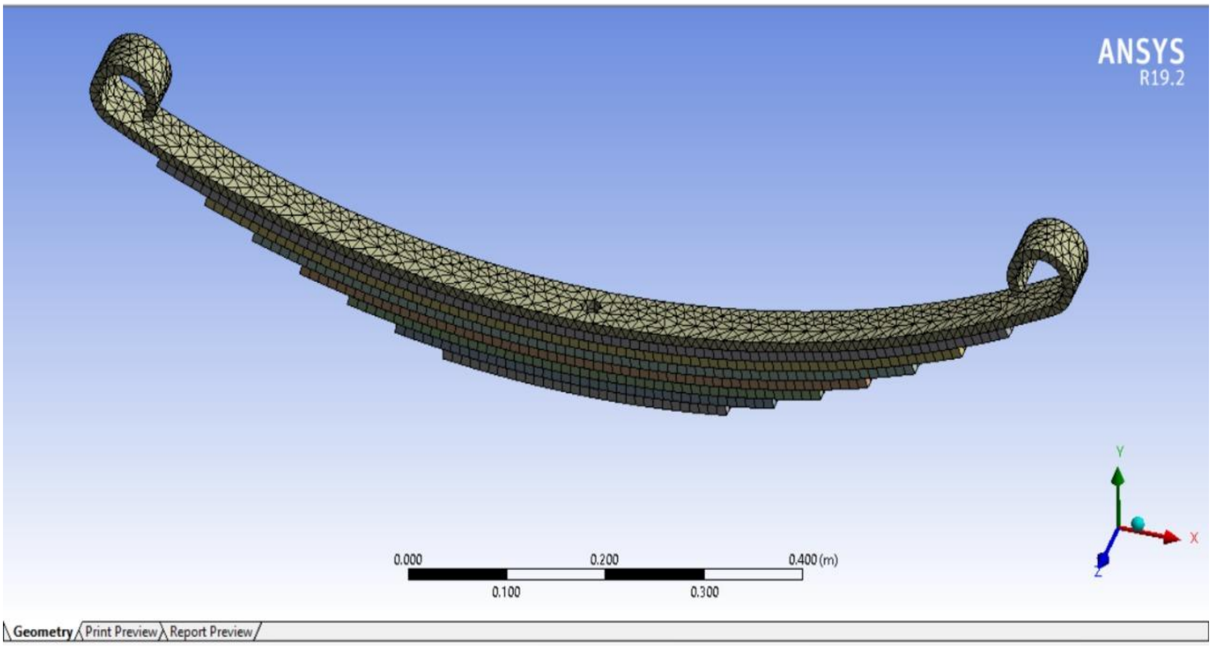


Fig.7 Meshing in ANSYS

The ANSYS Workbench is very useful for performing easy FEM analysis. The element type selected for meshing is Tetrahedral element and element size is 0.01m. The mesh count for model contains 2541nodes and 5683 elements.

IV. MATERIAL PROPERTY DEFINITION

Based on the type of simulation analysis to be performed material properties need to be defined. The mechanical material properties whether the material be nonlinear, isotropic or orthotropic, constant or temperature dependent are carefully input in the analysis to be performed, knowing the henceforth correct value is very substantial for analysis purpose (whether static or dynamic). Frugality in differences in different analysis with report different analysis result too. However, this paper is confined to research in which density, strength and thermal expansion coefficient are kept optional.

Table-2 Mechanical Properties of Steel

Mechanical	Symbols	Units	Values
Young's Modulus	E	GPa	207
Shear Modulus	G	GPa	80
Poisson's Ratio	M	-	0.3
Density	P	Kg/m^3	7600
Yield Strength	S_y	MPa	370

Table-3 Properties of Composite Materials

S. No.	Properties	E-Glass/Epoxy
1	E_x (MPa)	43000
2	E_y (MPa)	6500
3	E_z (MPa)	6500
4	PR_{xy}	0.27
5	PR_{yz}	0.06
6	PR_{zx}	0.06

7	G_x (MPa)	4500
8	G_y (MPa)	2500
9	G_z (MPa)	2500
10	P	0.000002

Analysis of leaf spring in ANSYS 19.2 software was performed to analyse its stress, strain and deformation using steel, aluminium and chromium alloy. The design of the leaf spring is done in SolidWorks software based on the theoretical calculations done before. The displacement, stress and strain values using above three materials are compared. Various assumptions taken during analysis are: -

1. Loads don't include significant inertial and damping effects. Response conditions in steady loading are considered.
2. Applied loading include externally applied forces and pressures, steady state inertial forces and don't include gravity or velocity imposed non-linear displacements.
3. A static analysis can be both linear or non-linear. Linear analysis is performed in this work

V. ANSYS RESULTS FOR AFOREMENTIONED MATERIALS

1. STEEL

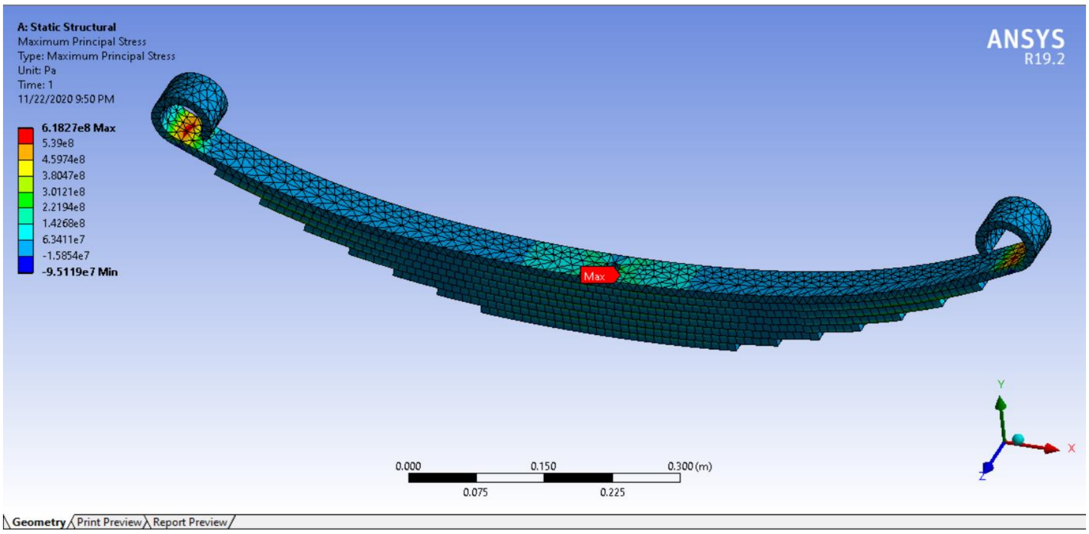


Fig.8 Maximum Principal Stress

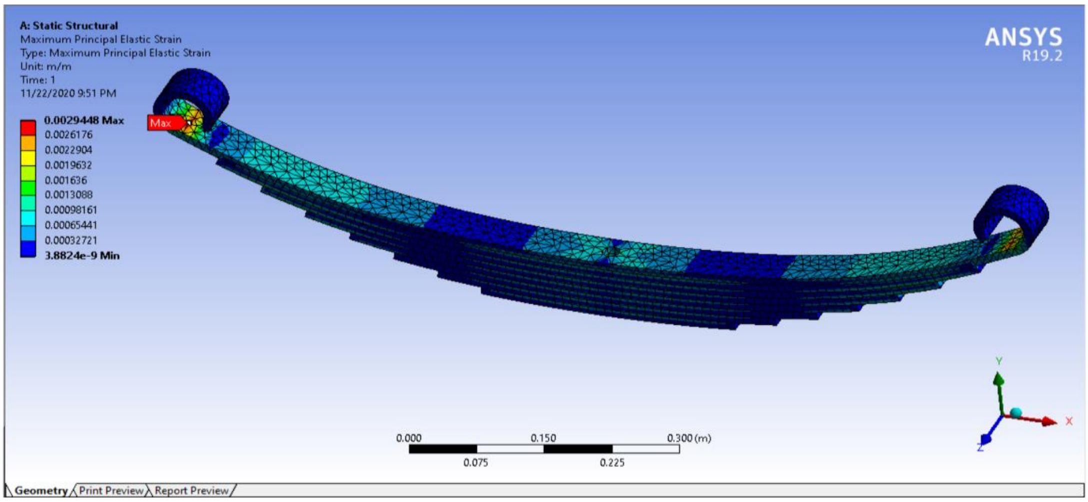


Fig.9 Maximum Principal Elastic Strain

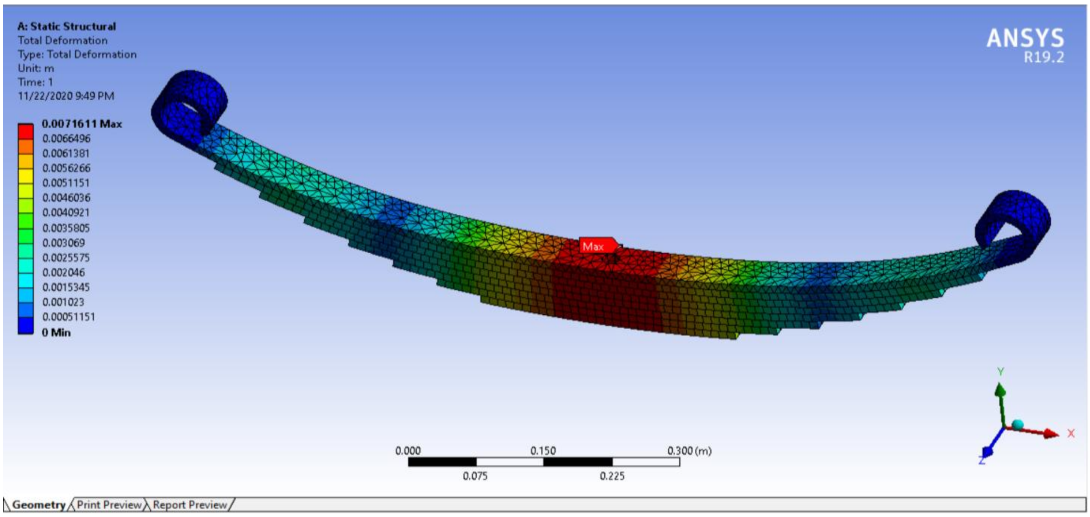


Fig.10 Total Deformation

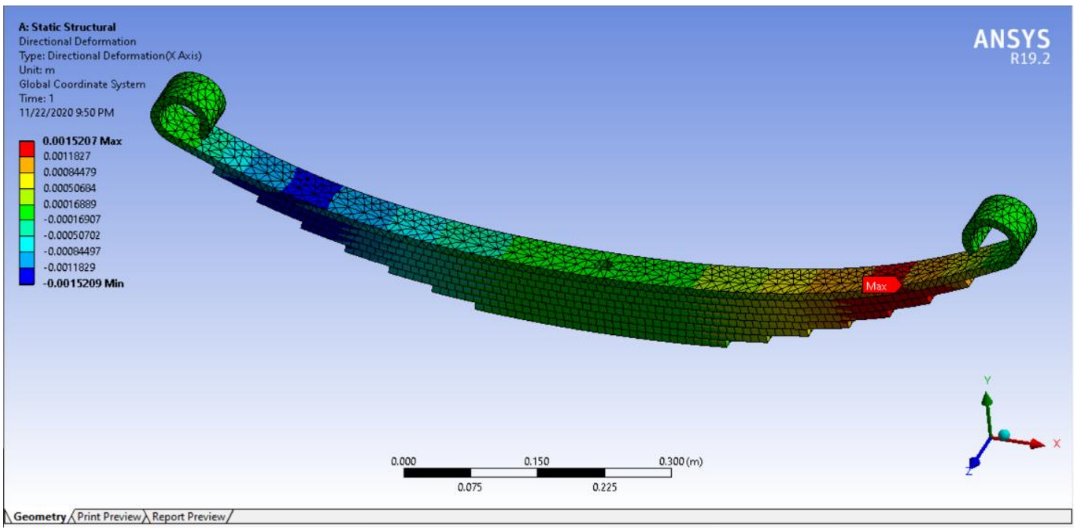


Fig.11 Directional Deformation (X-axis)

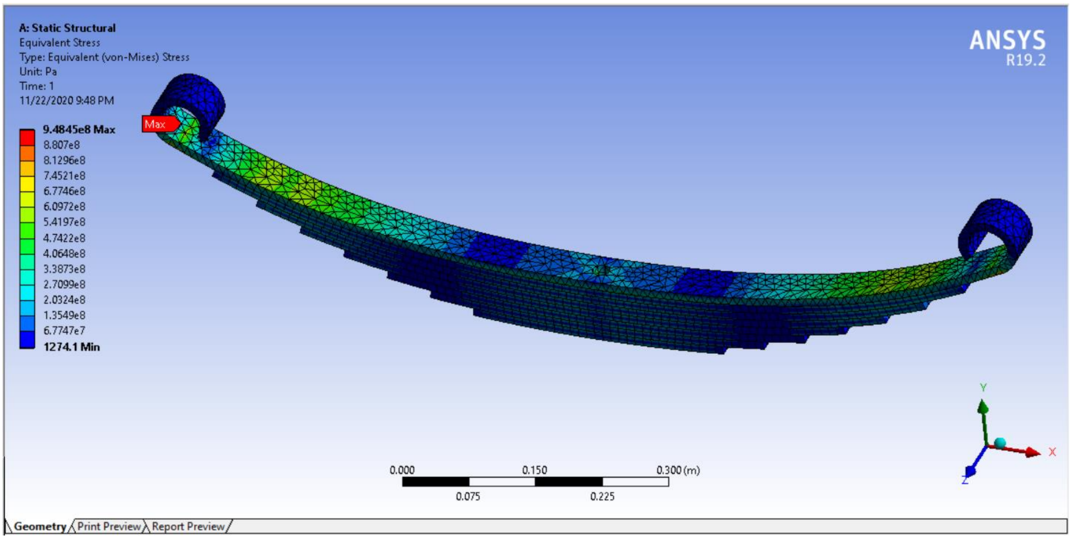


Fig.12 Equivalent Von-Mises Stress

Table-4

S. No.	Parameter	Maximum	Minimum
1	Maximum Principal Stress (MPa)	618.2	-95.12
2	Maximum Principal Strain	0.002945	3.88e-9
3	Total Deformation (m)	0.00716	0
4	Directional Deformation (m)	0.00152	-0.00152
5	Equivalent Stress (MPa)	948.45	0.0012741

2. E-Glass/Epoxy

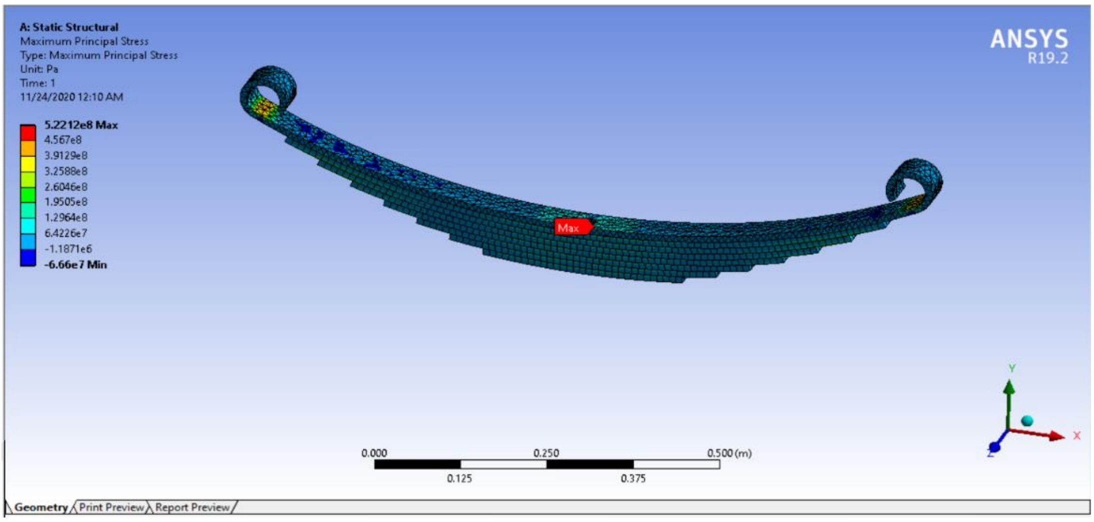


Fig.13 Maximum Principal Stress

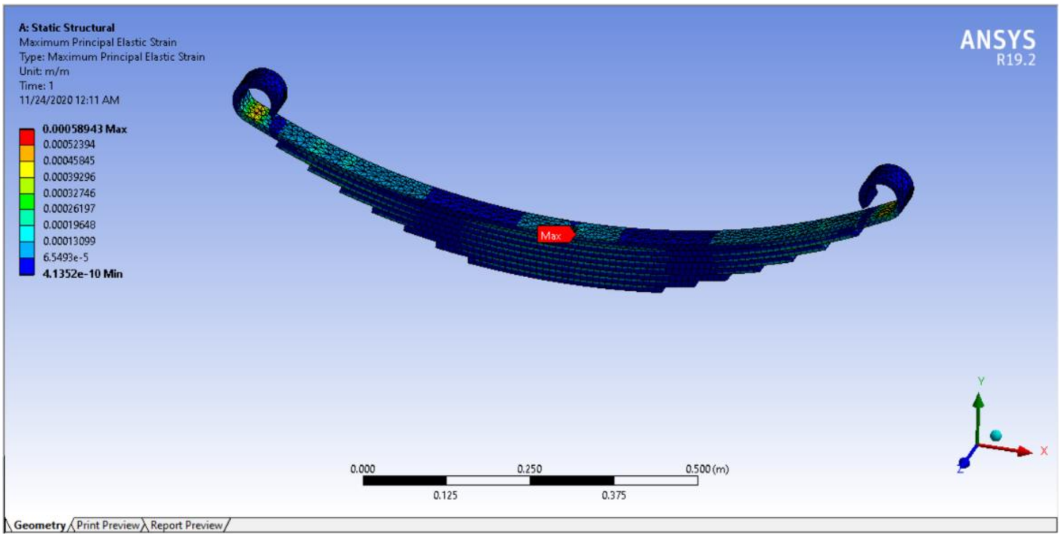


Fig.14 Maximum Principal Elastic Strain

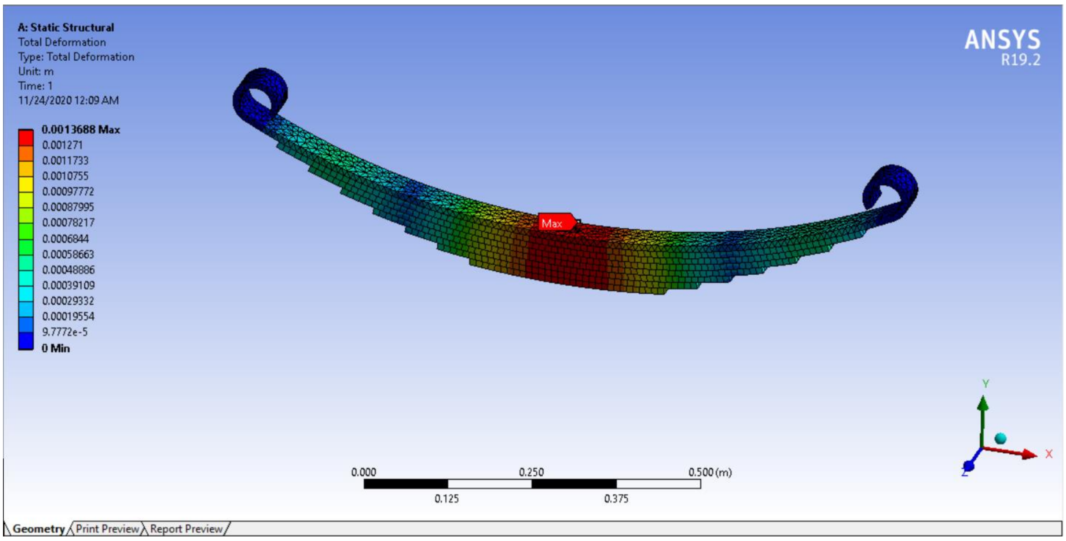


Fig.15 Total Deformation

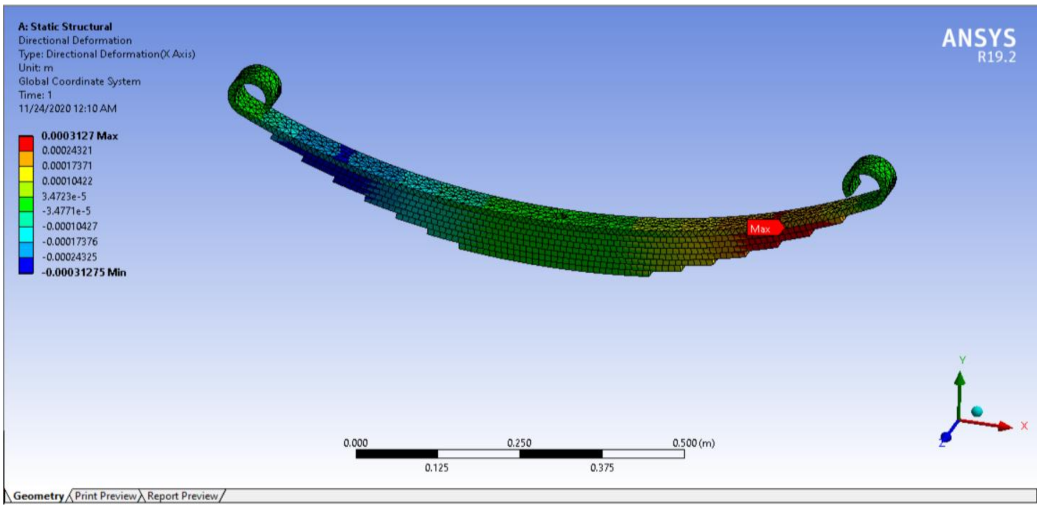


Fig.16 Directional Deformation (X-axis)

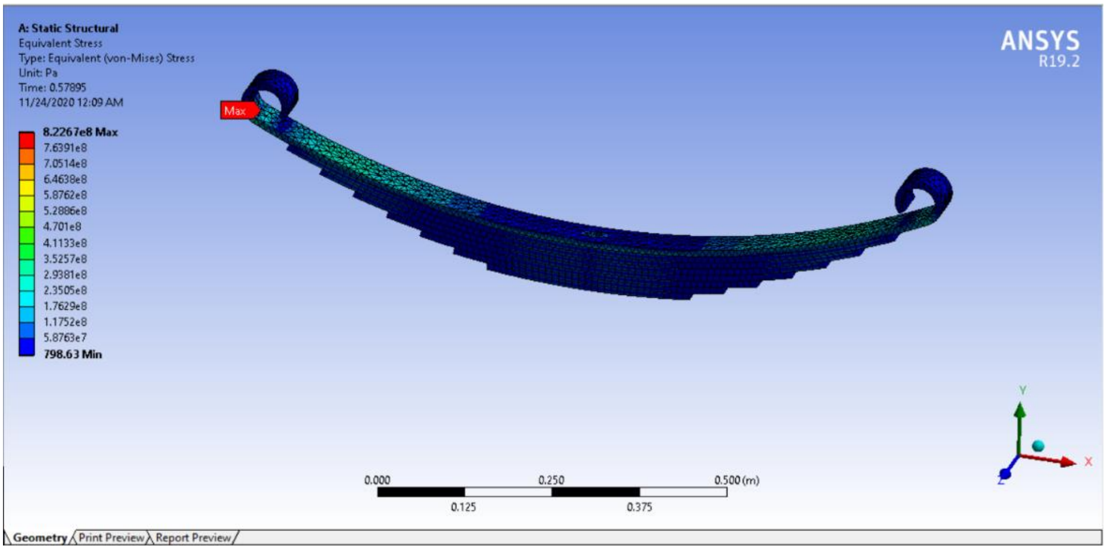


Fig.17 Equivalent Von-Mises Stress

Table- 5

S. No.	Parameter	Maximum	Minimum
1	Maximum Principal Stress (MPa)	522.12	-66.6
2	Maximum Principal Strain	0.00058943	4.135e-10
3	Total Deformation (m)	0.0013688	0
4	Directional Deformation (m)	0.0003127	-0.00031275
5	Equivalent Stress (MPa)	822.67	0.0007986

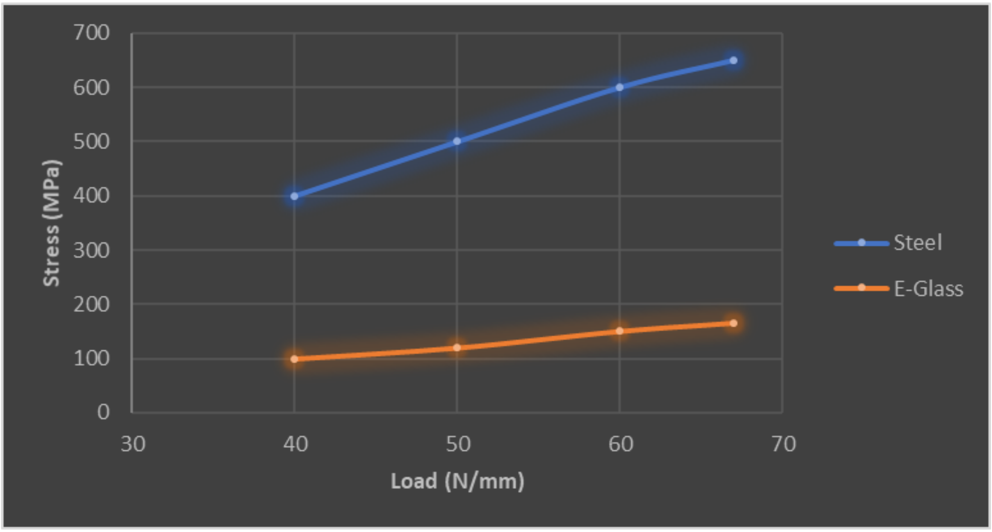


Fig.18 Graph- Stress v/s Load

VI. RESULTS

Parameters	Conventional Steel Leaf Spring	E-Glass/Epoxy composite leaf spring
Max. Principal Stress (MPa)	618.2	522.12
Max. Principal Strain	0.002945	0.00058943
Max. Total Deformation (m)	0.00716	0.0013688
Max. Directional Deformation (m)	0.00152	0.0003127
Max. Equivalent Stress (MPa)	948.45	822.67

Table- 6: Result Comparison

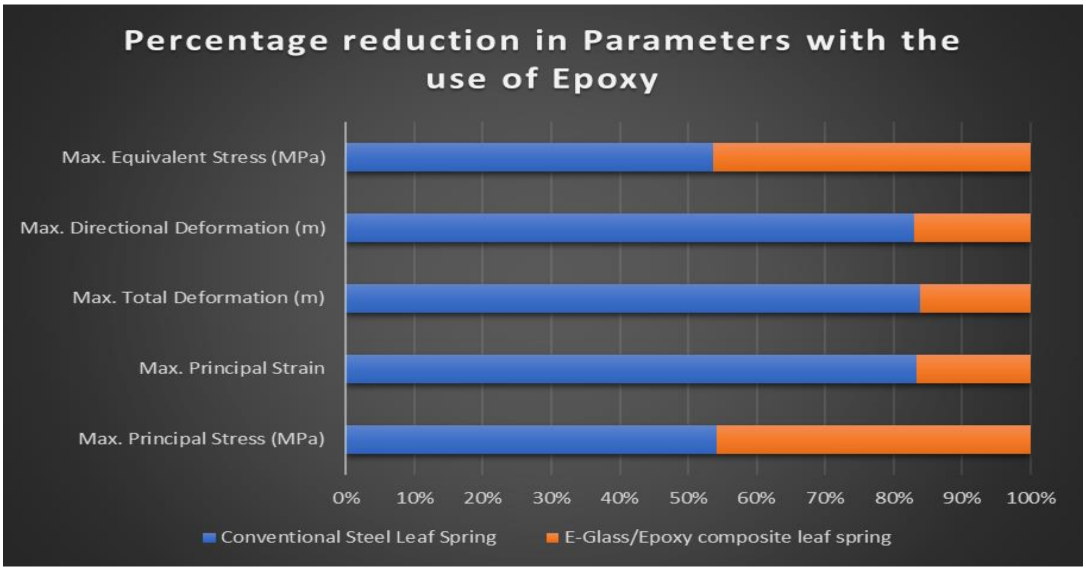


Fig.19 Graph displaying reduction (in Orange) percentage with Epoxy

VII. DISCUSSION

1. Epoxy leaf spring deflection for a particular load is less compared to conventional steel leaf spring.
2. Maximum stresses produced in epoxy leaf spring is lower as compared to steel leaf spring.
3. Directional Deformation in epoxy spring is low as compared to steel leaf spring.
4. Weight reduction due to lighter weight of epoxy springs for same stresses as compared to steel leaf spring i.e., 74.55% reduction in weight.

VIII. CONCLUSION

Analysing the design and strength of parabolic suspension leaf spring is dealt with in this work. Comparing the stress results of Epoxy and steel leaf spring, it has been analysed that stress values have been lower than their respective yield stress values in the latter. Therefore, design proposed by stress analysis is safe. The principal stresses observed in steel leaf string are significantly higher and often in red zone at eye ends as compared to epoxy made springs. Also, reduction in mass of leaf [7] spring is evident in Epoxy made spring. Weight Reduction achieved is 74.55%. So, the conclusion is reached that as per standard analysis, epoxy made leaf springs work significantly better.

IX. FUTURE SCOPE

- The comparison between experimental and analytical software results can also be done.[8]
- Different models of leaf spring (different dimensions) testing could be done with variable loadings.
- By doing dynamic analysis the obtained results can be compared with software and experimental results.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities.

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