Analysis and Comparison of Mechanical Properties of Epoxy Fiber and Alloy Steel Leaf Spring

Prasanna A. Gandole
Student
Department of Mechanical Engineering
PLITMS, India

Abstract— Automotive Leaf spring is a very important component of vehicle. The overall objective of this work is to design and analyze a epoxy fiber Leaf spring for absorbing the fluctuating loads from the vehicle. Substituting epoxy fiber structures for conventional metallic structures has many advantages because of higher specific stiffness and strength of epoxy fiber materials. Epoxy fiber material for leaf spring is E-Glass/Epoxy. The design parameters are optimized with the objective of minimizing the weight of leaf spring. The design optimization showed significant potential improvement in the performance of leaf spring. An attempt has been to compare the deflection, stresses, and under subjected loads and to compare the load carrying capacity and weight saving of epoxy fiber leaf spring with that of steel leaf spring using FEA.

Key words: Alloy Steel Leaf Spring, Congestion Control, Epoxy Fiber

I. INTRODUCTION

In now a day the fuel efficiency and emission gas regulation of automobiles are two important issues. To fulfill 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 epoxy fiber a very good replacement material for conventional steel. In automobile car out of many components of automobile which can be easily replaced is leaf spring.

Leaf springs also known as flat spring are made out of flat plates. Leaf springs are designed two ways: multi-leaf and mono-leaf. The leaf springs may carry loads, brake torque, driving torque etc. In addition to shocks. The multi-leaf spring is made of several steel plates of different lengths stacked together. During normal operation, the spring compresses to absorb road shock. Leaf spring (also known as flat springs) is made out of flat plate. The advantage in 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 the energy absorbing device. Thus the leaf springs may carry lateral loads, brake torque, driving torque etc., in addition to shocks. A leaf spring commonly used in automobiles is of semi-elliptical form as shown in fig.1. It is built up of a number of plates (known as leaves). The leaves are usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaves are held together by means of a band shrunk around them at the centre or by a bolt passing through the centre. Since the band exerts stiffening and strengthening effect, therefore the effective length of the spring for bending will be overall length of the spring minus width of band. In case of a centre bolt, two-third distance between centers of *U*-bolt should be subtracted from the overall length of the spring in order to find effective length. The spring is clamped to the axle housing by means of *U*-bolts.

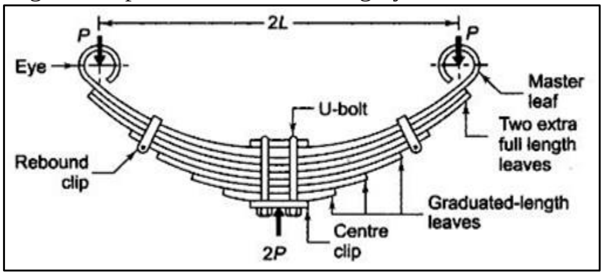

Fig. 1: Semi elliptical leaf spring

II. SELECTION OF FIBER FOR LEAF SPRING

Based on specific strain energy of steel spring and some epoxy fiber materials, E-glass/epoxy is selected as spring material having the mechanical properties given in table 1.

Sr. No.	Properties	Epoxy Resin
1	Density (kg/m^3)	1200
2	Young’s Modulus(GPa)	80
3	Tensile Strength(MPa)	43
4	Compressive strength (MPa)	43
5	Ultimate Tensile Strength (MPa)	83
6	Poisson’s Ratio	0.35

Table 1: Mechanical properties of E-glass epoxy

III. MATERIAL SELECTION FOR CONVENTIONAL LEAF SPRING

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process..

IV. DESIGN PARAMETERS FOR CONVENTIONAL LEAF SPRING

A. Material selected steel: Plane Carbon Steel

Sr. No.	Properties	Steel
01	Density (kg/m^3)	7800
02	Young’s Modulus(GPa)	210
03	Tensile Strength(MPa)	400
04	Compressive strength (MPa)	220
05	Ultimate Tensile Strength (MPa)	510
06	Poisson’s Ratio	0.28

Table 2: The Mechanical Properties for conventional Leaf Spring

V. THEORETICAL ANALYSIS OF STEEL LEAF SPRING

The leaf spring behaves like a simply supported beam which subjected to both bending stress and transverse shear stress. In this design the thickness and width is kept constant over the entire length of the leaf spring. Bending stress developed considering the maximum load capacity of 1000 kg which is the capacity of the system and multiplying it with the dynamic load factor.

Let the dynamic load factor for the equivalent static capacity be 2.76.

We get the equivalent static capacity as:

Static Load (Kg) × Load Factor 2.76

Equivalent static capacity = static load × load factor

= 1000 × 2.76

= 2760 kg

1) Step (1): Let consider basic data of commercial motors leaf spring

- Total length of spring Eye to Eye = 1000 mm
- Number of full length leaves (n_f) = 02
- Number of graduated leaves (n_g) = 06
- Thickness of leaf (t) = 10 mm
- Young's modulus (E) = 2.1×10^5 N/mm^2
- Central band 110 mm wide (ineffective length)
- Total load = 2760 Kg
- BHN = 500-580 HB with hardened and tempered

2) Step (2): Basic requirement of load

a) Maximum capacity = 2760 Kg

= 2760 x 9.81= 27048 N

So load acting on the leaf spring assembly = 27048 /4

= 6762 N

3) Step (3): Calculation of the load and effective length of leaf spring

Consider the leaf spring is cantilever beam. So the load acting on the each assembly of the leaf spring is acted on the two ends of the leaf spring. Load acted on the leaf spring is divided by the two because of consideration of the cantilever beam.

2×W = 6762 N W = 3381 N

For support and clamping of the leaf spring the "U" bolt is use and the distance between the "U" bolts is 110 mm. This is considered as an unbent portion of the leaf spring. Ineffective length of the leaf spring is as under:

l = 110.00 mm

Effective Length of the spring,

L = 500 mm

4) Step (4): Calculations of the stress generated in the leaf spring are as under

a) Property of the material is as under:

Modulus of elasticity (E) = 210000 N/mm^2

BHN = 500 – 580 HB with hardened and tempered

- By considering the factor of safety for the safety purpose of the leaf spring is 1.5 for automobile leaf spring.
- Bending stress generated in the leaf spring is as under:

$$\sigma = \frac{6WL}{nbt^2}$$

$\sigma\ b$ =141 N/ mm^2

So, the stress generated in the leaf spring is lower than the allowable design stress. So design is safe.

- Deflection generated in the assembly of leaf spring is as under:

$$\delta = \frac{6WL^3}{Enbt^3}$$

δ = 15.7 mm

b) Considering factor of safety is 2.

Both the stresses tensile stress and shear stress are lower than the allowable stress. So design is safe.

- To Find Theoretical Deflection of Epoxy Fiber Leaf Spring:

Material selected: E-glass Epoxy

E = 80Gpa

Deflection generated in the assembly of leaf spring is as under: $\delta = \frac{6WL^3}{Enbt^3}$

δ = 34.023 mm

- To Find Stiffness of Leaf Spring

We know less stiffness means high flexibility For Steel Leaf Spring

$$k = \frac{8Enbt^3}{3L^3}$$

k = 3225.6 N/mm

For Epoxy fiber Leaf Spring

$$k = \frac{8Enbt^3}{3L^3}$$

k = 1230 N/mm

- To find weight of Leaf Spring

Volume of the leaf spring is given by

$$V = \frac{nbtL}{2}$$

V = 1800 × 10^3 mm^3

We know that, Density

$$\rho = \frac{M}{V}$$

Where,

M = Mass of spring

V = volume of spring

Hence, Mass M = ρ x V

For Carbon steel spring,

ρ = 7800 kg/m^3

Hence, Mass M = 14.40 kg

Similarly,

For E- Glass Fiber Reinforced Epoxy Polymer Epoxy fibers Spring

ρ = 1200 kg/m^3

Hence, Mass M = 2.16 kg

VI. MODELING OF LEAF SPRING

Modeling of leaf spring is performed in Solid works 2009. Procedure of modeling leaf spring is as follows:

There are different procedures available for modeling of leaf spring. Here we utilize divisional method of generation of parabolic leaf spring.

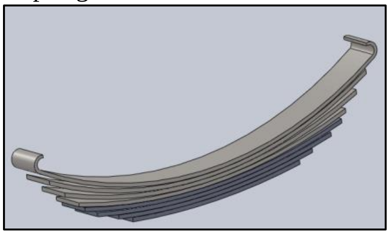

Fig. 2: 3D Model of Leaf Spring

VII. Finite Element Analysis of Leaf Spring

A. Static Analysis of Steel Leaf Spring

Provide Material Properties As Per In the ANSYS Workbench

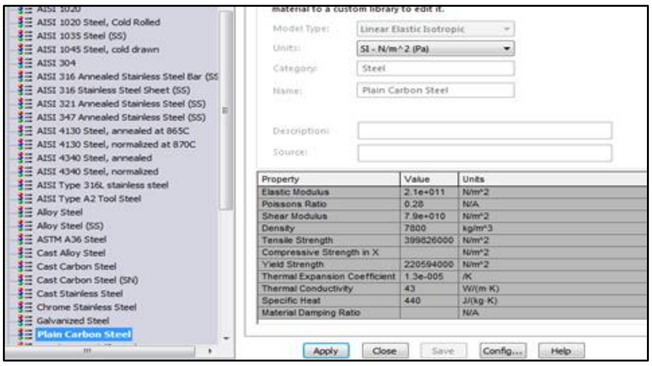

Fig. 3: ANSYS Workbench

B. Meshing

Meshing involves division of the entire of model into small pieces called elements. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is solid 45. The element edge length is taken as 7.30 mm. The numbers of elements are taken 634 and the total numbers of nodes are 3344.

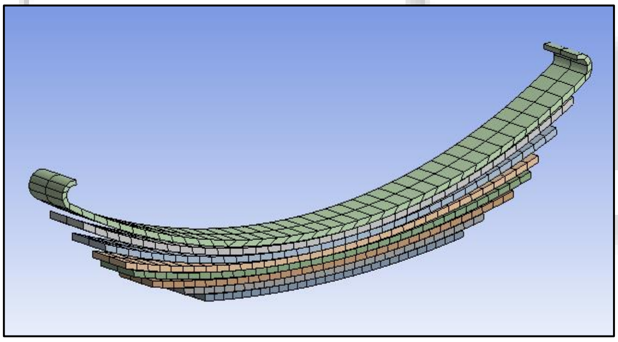

Fig. 4: Meshed Model of Leaf Spring

C. Loading & Boundary Conditions

Fixed Support For the leaf spring analysis one of the eye ends of the leaf spring is fixed to the chassis of the vehicle. Since fixed support has restriction to move in X and Y direction as well as rotation about that fixed point. So this fixed eye end of the leaf spring cannot move in any of the directions i.e. for this eye end degrees of freedom is zero. Cylindrical support since the leaf spring has to translate in one plane and other movements are restricted to move as there is shackle provided at other end of the leaf spring. Therefore a cylindrical support is applied to the other eye end of leaf spring model. This support provides the movement of the leaf spring in X axis, rotation about Z axis and fixed along Y axis. The load is uniformly distributed on the leaf spring. In this study uniformly distributed load of 3381N is applied on the leaf spring model.

D. Result Analysis of Steel Leaf Spring

1) Von-mises stress:

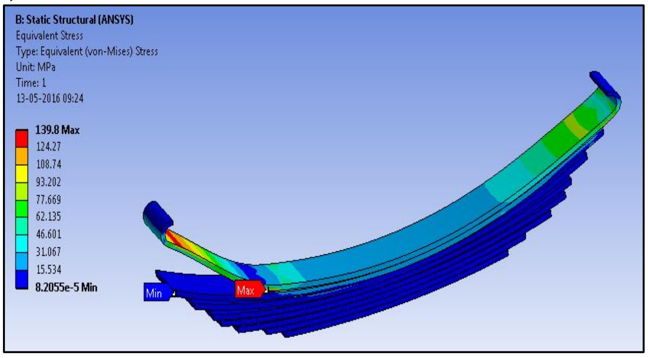

Fig. 5: FEA bending von mises Stress of Steel Leaf Spring

The red region on the leaf spring shows maximum stress which is 139.8 Mpa. the minimum deflection of 8.2055e-5 Mpa is shown by blue region.

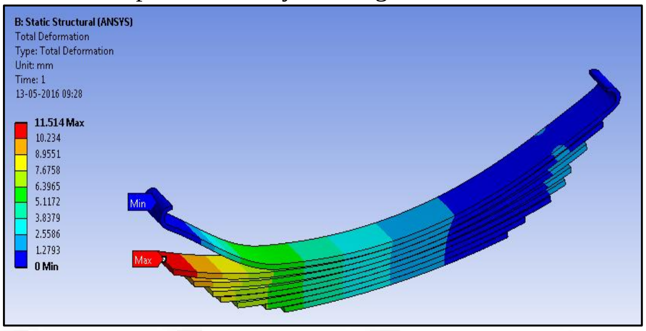

Fig. 6: FEA of Deformation in Steel Leaf Spring

Result table for analytical and analysis of steel leaf spring below table shows that static analysis fairly matches with the analytical results but it also shows that static analytical results underestimate the results. For the optimization of leaf spring, accurate prediction of stress and deflection is necessary for that reason we have to perform model and transient analysis of leaf spring.

Parameters	Analytical Results	Static Analysis Results
Von-Mises Stress(Mpa)	141	139.8
Maximum Deflection (mm)	15.68	11.88

Table 3: Comparison of analytical and analysis result for steel leaf spring

E. Analysis of Epoxy Fiber Leaf Sprin

Meshing involves division of the entire of model into small pieces called elements. It is convenient to select the free mesh because the leaf spring has sharp curves, so that shape of the object will not alter. To mesh the leaf spring the element type must be decided first. Here, the element type is solid 45. The element edge length is taken as 5 mm. The numbers of elements are taken 2225 and the total numbers of nodes are 8099.

Fixed Support For the leaf spring analysis one of the eye ends of the leaf spring is fixed to the chassis of the vehicle. Since fixed support has restriction to move in X and Y direction as well as rotation about that fixed point. So this fixed eye end of the leaf spring cannot move in any of the directions i.e. for this eye end degrees of freedom is zero. The load is uniformly distributed on the leaf spring. In this study uniformly distributed load of 3381N is applied on the leaf spring model

1) *Maximum deflection contour*

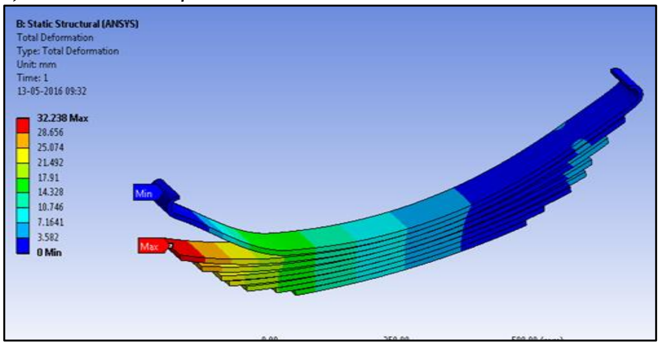

Fig. 7: FEA of Deformation in epoxy fiber Leaf Spring

2) *Von-mises stress contour*

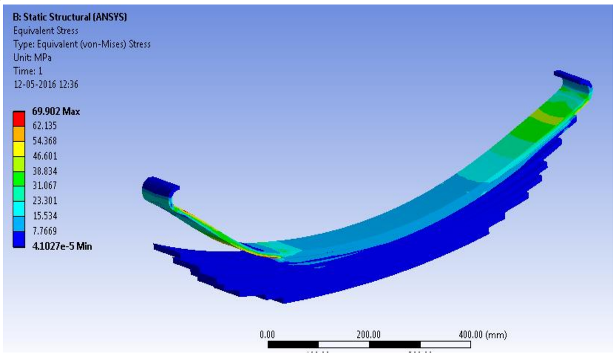

Fig. 8: FEA of Bending Stress in Epoxy fiber Leaf Spring,

The red region on the leaf spring shoes maximum stress which is 69.902Mpa. The minimum deflection of 41027e-5Mpa is shown by blue region.

VIII. Results and Discussions

Sr. No	Spring Material	Mass (kg)	Deflection (mm)	Stiffness (N/mm)
01.	Carbon Steel	14.40	15.7	3225.6
02.	E-Glass Fiber	2.16	34.02	1230

Table 4: Theoretical Result of Leaf spring

Hence from the above, it is observed that, by using the E-Glass Fiber Reinforced Epoxy Polymer Epoxy fibers material for leaf spring more deflection can be obtained with reduced in the spring weight and spring stiffness.

By the comparison of results between steel leaf spring and the epoxy fiber leaf spring from ANSYS-12 the deflection is increased in epoxy fiber leaf spring that is within the camber range. The bending stresses are decreased in epoxy fiber leaf spring means less stress induced with same load carrying conditions and deflection increases. The conventional multi leaf spring weights about 14.40 kg whereas the E-glass/Epoxy multi leaf spring weighs only 2.26 kg. Thus the weight reduction of 67.88% is achieved. By the reduction of weight and the less stresses, the fatigue life of epoxy fiber leaf spring is to be higher than that of steel leaf spring. Totally it is found that the epoxy fiber leaf spring is the better that of steel leaf spring.

Parameter	FEA Results for steel leaf spring	FEA Results for Epoxy fiber Leaf Spring
Load, N	3381	3381
Stress, MPa	139.8	89.90
Total Deflection, mm	11.88	32.33

Table 4: FEA results comparison between steel and epoxy fiber leaf spring

Materials	Weights	% weight saving
Conventional Steel	14.40 kg	-----
E-glass/epoxy	2.26 kg	84.3 %

Table 5: Percent saving of weight by using epoxy fiber

IX. Conclusion

A steel leaf is replaced by epoxy fiber leaf spring due to high strength to weight ratio for the same load carrying capacity with same dimension as that of steel leaf spring.A semi-elliptical multi leaf spring is designed for a four wheel automobile and replaced with a epoxy fiber multi leaf spring made of E-glass/epoxy

By the comparative study of steel and E-glass epoxy leaf spring the bending stress developed in the steel leaf spring is 139.8 Mpa maximum and in E-glass epoxy 69.90 Mpa at given loading condition .Stresses in epoxy fiber leaf springs is found out to be less as compared to the conventional steel leaf springs

Under the same static load conditions the deflection in leaf springs is found with great difference and that is 11.51 mm for steel leaf spring and 32.238 mm for epoxy fiber leaf spring. The deflection in epoxy fiber leaf springs is found out to be high as compared to the conventional steel leaf springs.

The weight savings of 87.3% is achieved by replacing steel material with epoxy fiber in the leaf.

Totally it is found that the epoxy fiber is better than that of steel. Therefore, it is concluded that epoxy fiber multi leaf spring is effective replacement for the existing steel leaf spring.

References

[1] Kumar Krishan, Aggarwal M.L, “Computer aided FEA comparison of mono steel and mono GRP leaf spring”, International Journal of Advanced Engineering Research and Studies, Vol. I, Issue II, 2012, pp 155-158.

[2] N. P. Dhoshi, Prof. N. K. Ingole, Prof. U. D. Gulhane, “Analysis and modification of leaf spring of tractor trailer using analytical and finite element method”, International Journal of Modern Engineering Research, Vol.1, Issue.2, pp 719-722.

[3] M. M. Patunkar, D. R. Dolas, “Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by using FEA”, International Journal of Mechanical & Industrial Engineering, Volume 1, Issue 1, 2011.

[4] M Senthil Kumar, S Vijayarangan, “Static analysis and fatigue life prediction of steel and composite leaf spring for light passenger vehicles”, Journal of Scientific Industrial Research, Vol. 66, 2007, pp 128-134.

[5] Vinkel Arora, Dr. M. L. Aggarwal, Dr. Gian Bhushan, “A Comparative Study of CAE and Experimental Results of Leaf Springs in Automotive Vehicles”, International Journal of Engineering Science and Technology, Vol. 3, No. 9, 2011.

[6] J.P. Hou, J.Y. Cherruault, I. Nairne, G. Jeronimidis, R.M. Mayer, “Evolution of the eye-end design of a composite leaf spring for heavy axle loads”, Composite Structures 78 (2007) 351–358.

[7] Mr. Anandkumar A. Satpute, Prof. S. S. Chavan, "Mono Composite Leaf Spring – Design and Testing", Indian Journal of Applied Research, Volume 3, Issue 7, 2013.