RESEARCH PAPER | Engineering | Volume : 3 | Issue : 8 | Aug 2013 | ISSN - 2249-555X

Design and Analysis of Glass Fiber Reinforced Polymer Leaf Spring

KEYWORDS: Composite materials, leaf spring, Glass fiber reinforced polymer

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ABSTRACT *This project describes design and analysis of composite leaf spring made of Glass fiber reinforced polymer. The main objective is to compare the load carrying capacity, stiffness and weight savings of composite leaf spring with that of steel leaf spring. This work is carried out on a multi leaf flat spring having nine leaves used by a commercial vehicle. The finite element modeling and analysis of a multi leaf spring has been carried out. It includes two full length leaves and seven graduated length leaves. The material for the conventional leaf spring is 65si7 steel. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken. Same dimensions of conventional leaf spring are used to fabricate a composite multi leaf spring using Glass fiber reinforced polymer (GFRP or E-Glass/Epoxy) unidirectional laminates. The FE model of the leaf spring has been generated in proe-5.0 and imported in ANSYS-11.The design constraints are stresses and deflections. A comparison of analytical, FE analysis of steel leaf spring and FE analysis of composite leaf spring results have been done to conclude.*

1. INTRODUCTION

Multi leaf spring carries lateral loads, brake torque, driving torque in addition to shock absorbing. Advantages of leaf spring over helical spring are that the ends of the springs are guided along a definite path and it is act as a structural member. It is well known that springs, are designed to absorb and store energy and then release it slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system. Hence, the strain energy of the material becomes a major factor in designing the springs. The relationship of the specific strain energy can be expressed as

$$U = \frac{\sigma^2}{2\rho E}$$

Where σ is the strength, ρ is the mass density and E is the Young's modulus of the spring material. It can easily understand that material having lower modulus and density will have greater specific strain energy capacity. It helps in achieving the vehicle with improved riding qualities. In composite materials, GFRP (Glass Fiber Reinforced Polymer) have chosen as spring material. Because it is 1.5-2 times stronger than the steel armature and high strength to weight ratio. It weighs 3.5 – 4 times less than the steel armature. Hence, Automobile sector is showing an increased interest in the area of composite material leaf springs [1].

In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unstrung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The composite material was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi-leaf steel springs are being replaced by composite springs. The composite material offer opportunities for substantial weight saving but not always are cost-effective over their steel counter parts [2].

Glass fiber reinforced polymer (GFRP) has received attention largely from the automotive industry due to their superior mechanical properties and relative ease of processing [3]. The use of a thermoset matrix gives the molder the ability to modify and enhance the properties of the resin by blending additives, fillers and fire retardants depending upon the nature of the application.

This paper is mainly focused on the implementation of composite materials by replacing steel in conventional leaf springs of a suspension system to reduce product development cost, weight, improving the safety, comfort and durability. The composite materials having more elastic strain energy storage capacity due to low young's modulus and low density than steel.

2. Material and Methods

2.1 Material properties

The table 1 below is showing the different parameters related to steel material properties.

Table 1
Material Properties of steel

Parameter	Value
Material selected-steel	65si7
Tensile strength Ultimate	1272 MPa
Tensile strength Yield	1158 MPa
Modulus of elasticity, E	$2.1 * 10^5$ MPa
Poisson's ratio	0.266
Specific gravity	0.00000785 kg/mm^3

As mentioned earlier, the ability to absorb and store more amount of energy of a suspension system leads the comfortable riding of the vehicle. This can be achieved by introducing composite material, in place of steel in the conventional leaf spring. Based on specific strain energy of steel spring and some composite materials, E-glass/epoxy is selected as spring material having the mechanical properties given in table-2.

Table 2
Material property of E-Glass/Epoxy or GFRP

Sr. No.	Properties	Value
1	Tensile modulus along X-direction (Ex), MPa	34000
2	Tensile modulus along Y-direction (Ey), MPa	6530
3	Tensile modulus along Z-direction (Ez), MPa	6530
4	Tensile strength of the material, Mpa	900
5	Compressive strength of the material, Mpa	450
6	Shear modulus along XY-direction (Gxy), Mpa	2433
7	Shear modulus along YZ-direction (Gyz), Mpa	1698
8	Shear modulus along ZX-direction (Gzx), Mpa	2433
9	Poisson ratio along XY-direction (Nuxy)	0.217
10	Poisson ratio along YZ-direction (NUyz)	0.366
11	Poisson ratio along ZX-direction (NUzx)	0.217
12	Mass density of the material, kg/mm3	$2.6x 10^{-6}$
13	Flexural modulus of the material, MPa	40000
14	Flexural strength of the material, MPa	1200

2.2 Design parameter
The existing leaf spring of commercial vehicle is considered for the design and analysis. Table 3 shows the design parameter of the multi leaf spring.

Table 3
Specification of existing leaf springs

Parameter	Value
Total Length of the spring, (L)	1450 mm
No. of full length leave	2
Number of graduated length leaves	7
Total number of leaves	9
Thickness of leaves, (t)	12 mm
Width of leaves, (b)	70 mm
Load, (w)	19196.5 N

The length of graduated length leaves L_3, L_4, L_5.... are 1320, 1140, 940,800, 640, 464, & 244 mm respectively.

2.3 Multi Leaf Spring Boundary Conditions
Constraint
- Fixed at both end.

Forces
- Apply forces at center in (downward) y- direction.

Analysis
- Linear static type.
- Maxi. Design load (w) = 19196.5 N

The multi leaf spring is modeled in the position having maximum deflection i.e. in the flat position & will be loaded in reverse direction to attain its original shape. Loading conditions involves applying a load at the centre of the main leaf. As per the specification the spring is drawn at flat condition, therefore the load is applied in downward direction to achieve initial no load condition. The loading condition is shown in figure 1.

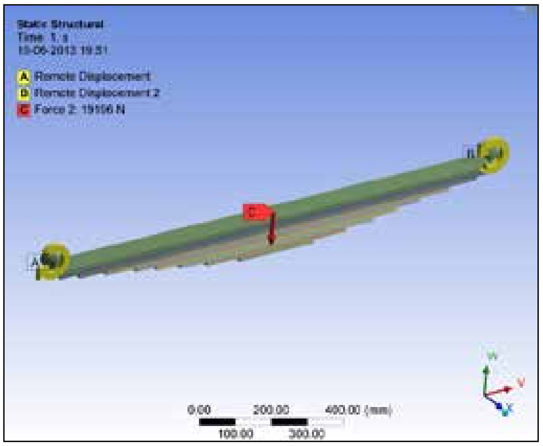

Figure 1 Solid model with the boundary condition

Assuming no load camber as 168°, a joint rotation of 12° is considered for both revolute joints, during static analysis. The vertical downward loading is applied at the centre of the master leave as per the specification i.e. 19196.5 N.

3. Modelling & Finite Element Analysis
3.1 CAD modelling
CAD modeling software is dedicated for the specialized job of 3D-modelling. The model of the multi leaf spring structures also includes many complicated parts, which are difficult to make by any of other CAD modeling as well as Finite Element software. CAD modeling of the Multi Leaf Spring structure is performed by using Pro-E software. Pro-E 5.0 is having special tools in generating surface design to construct typical surfaces, which are later converted into solid models. Solid model of all parts of the structures are then assembled to make a complete structure. The process of assembly is very much analogous to general process of fabricating structures while real production. The assembled CAD model has been prepared from various part modeling drawings.

3.2 Finite Element Analysis
A stress-deflection analysis is performed using finite element analysis (FEA). The complete procedure of analysis has been done using ANSYS-11. To conduct finite element analysis, the general process of FEA is divided into three main phases, pre-processor, solution, and postprocessor.

The multi leaf spring with all boundary conditions and material properties is imported in ANSYS-11, showing in figure-2 and figure-3.

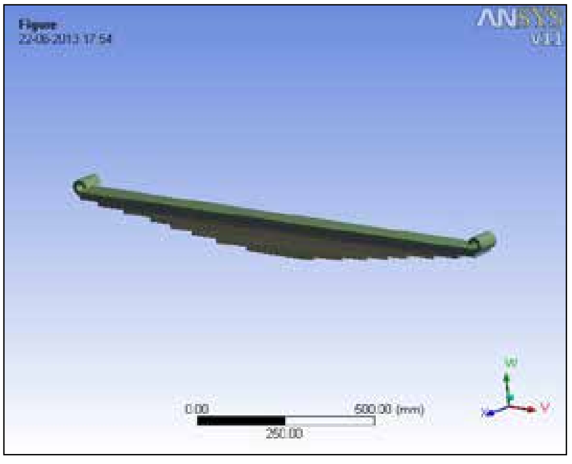

Figure 2 Multi Leaf Spring Assemblies

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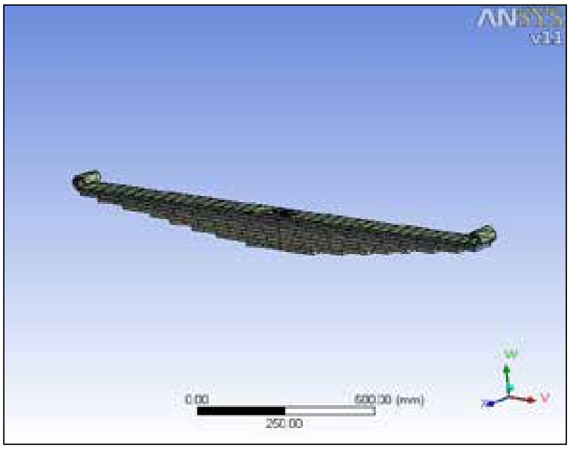

Figure 3 Meshing of Assembly

4. Result and Discussions

As the finite element analysis of multi leaf spring is performed using ANSYS-11 workbench. The multi leaf spring for conventional steel showing deflection and bending stress under load is shown in figure-4 and figue-5. The comparison between theoretical and finite element analysis results as shown in table-4.

Table 4
Comparison between analytical and FEA results of steel

Parameter	Analytical results for steel leaf spring	FEA results for steel leaf spring	% variation
Load (N)	19196.5	19196.5	Nil
Stress (MPa)	461.2	456.08	0.893%
Deflection (mm)	86.09	85.314	0.901%
Spring Rate (N/mm)	222.98	225.00	1.26%

4.1 FE analysis of conventional steel leaf spring

The multi leaf spring for conventional steel showing equivalent stress and deflections of FEA results is shown in figure 4 and figure 5. As per the boundary condition load is applied at the center and hinge at both end of the leaf spring therefore the leaf spring deflect in downward direction. In fig 4 and 5, it is clearly show that the stress and deflection is maximum at the centre and minimum at the both end of the leaf spring.

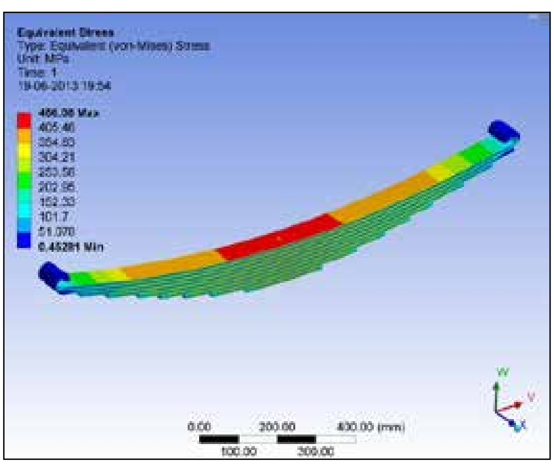

Figure 4 Equivalent stress (steel leaf spring)

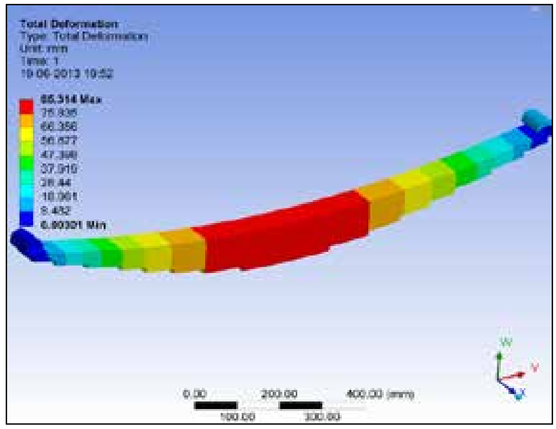

Figure 5 Deformation (steel leaf spring)

4.2 FE analysis of composite leaf spring

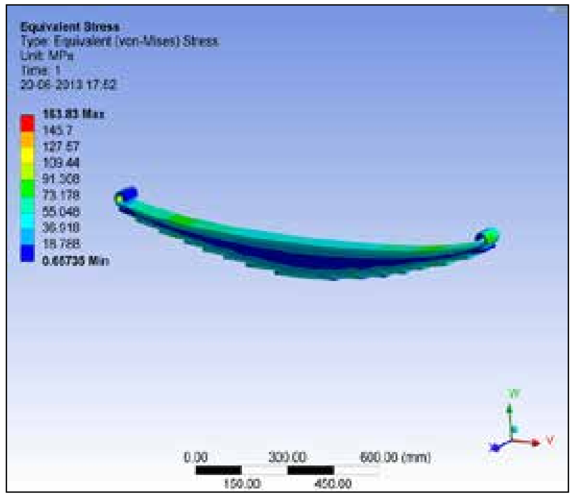

Figure 6 Equivalent stress (composite leaf spring)

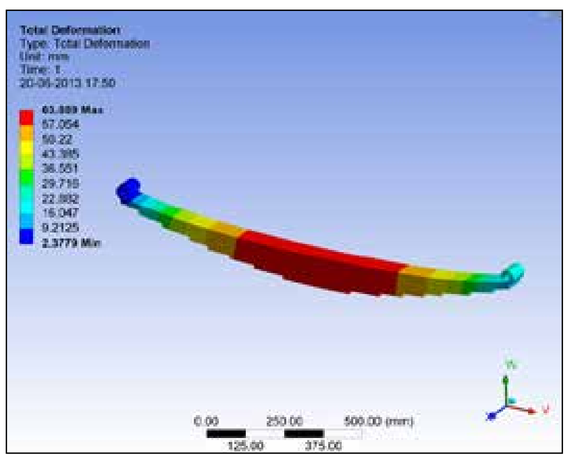

Figure 7 Deformation (composite leaf spring)

After that the multi leaf spring with composite material (GFRP) is analyzed in ANSYS with same dimension as in conventional leaf spring showing bending stress and deflection under load is shown in fig 6 and 7.

4.3 Comparison the results of analytical, FEA steel and FEA composite:

The variation of FEA stresses of steel leaf spring and compos-

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ite leaf spring are shown in figure 8. Figure 9 shows the comparison of deflection between analytical result of steel, FEA result of steel and FEA result of composite. Table 5 shows the FEA results comparison between steel and composite leaf spring

Figure 8 Variation of FEA stress of steel spring and composite spring

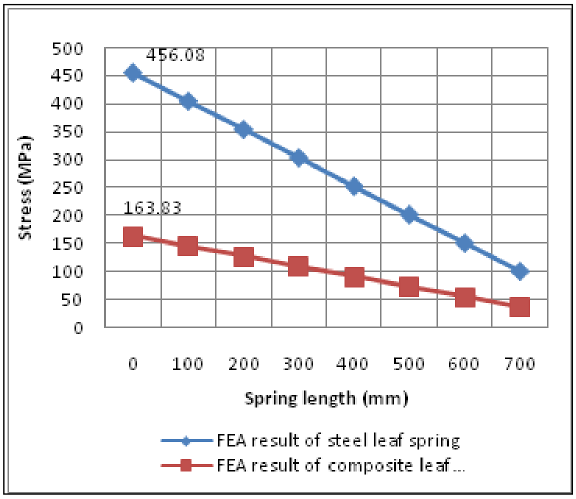


Figure 9 Comparison of deflection between Analytical, FEA steel and FEA composite leaf spring

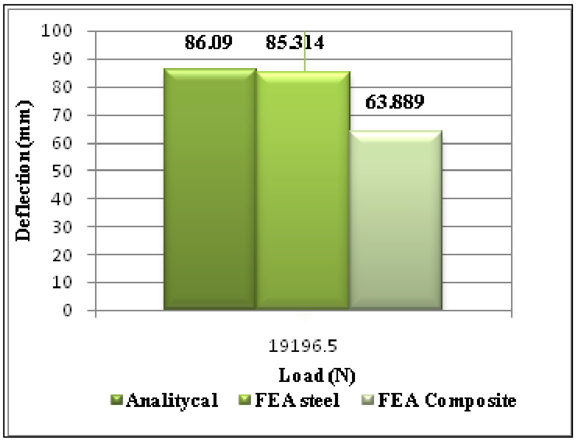
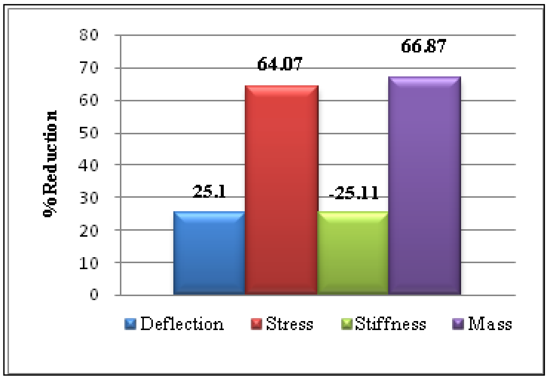


Table 5
FEA results comparison between steel and composite leaf spring

Parameter	FEA results for steel leaf spring	FEA results for composite leaf spring	Variation %
Load (N)	19196.5	19196.5	Nil
Deflection (mm)	85.314	63.889	-25.10%
Bending stress (MPa)	456.08	163.83	-64.07%
Stiffness (N/mm)	225.00	300.46	25.11%
Mass (Kg)	56.856	18.831	-66.87%

Figure 10 Reduction of stress, deflection and mass



By the comparison FEA results between steel leaf spring and the composite leaf spring shown in table 5 from ANSYS the deflection is reduced 25.10% in composite leaf spring that is within the camber range and the stiffness is increased by 25.11%. The bending stresses are decreased by 64.07% in composite leaf spring means less stress induced with same load carrying conditions. The conventional multi leaf spring weighs about 56kg whereas the E-glass/Epoxy (GFRP) multi leaf spring weighs only 18 kg. Thus the weight reduction of 66.87% is achieved shown in figure 10. By the reduction of weight and the less stresses, the fatigue life of composite leaf spring is to be higher than that of steel leaf spring. Totally it is fond that the composite leaf spring is the better that of steel leaf spring.

5. CONCLUSION

The study demonstrated that composites can be used for leaf springs for commercial vehicles and meet the requirements, together with substantial weight savings. A comparative study has been made between composite and steel leaf spring with respect to weight, cost and strength. The analytical results were compared with FEA and the results show good agreement. The composite (E-Glass/epoxy) leaf spring reduces the weight by 66.87%, and also reduces stress and deflection by 64.07% and 25.10% respectively. From the results, it is observed that the composite leaf spring is lighter and more economical than the conventional steel spring with similar design specifications.

ACKNOWLEDGEMENT

We gratefully acknowledge Mechanical engineering department of RK University and my colleagues for technical support and providing the research facilities.

Volume : 3 | Issue : 8 | Aug 2013 | ISSN - 2249-555X

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