Design and Analysis of Leaf Spring with Different Arrangements of Composite Leaves with Steel Leaves

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***Abstract*- In this paper work is carried out on a multi leaf spring having eight leaves used by a commercial vehicle. In order to reduce the cost and weight of leaf spring, the Automobile sector is replacing steel leaf spring with fiber composite leaf spring, the objective of study was to replace steel material for leaf spring, the material selected was glass fiber reinforced plastic. A spring with constant width and thickness with different arrangements of composite leaves was used for analysis. In this study all models are designed for factor of safety 2.5 and analysis is done using ANSYS software. Deflection and Stresses results were verified for analytical results. Result shows that, the composite spring has stresses much lower than steel leaf spring and weight of composite spring was reduced. By capturing the fundamentals of combining dissimilar materials and thus its equivalent modulus affects the overall stiffness characteristics of multi-leaf design.**

***Keywords*- Leaf spring, finite element analysis and composite materials, composite leaf springs.**

I. INTRODUCTION

Leaf springs are an optimized trend in heavy commercial vehicle of semi-active and passive vehicle suspension systems [1]. It has been always desirable to use composite springs over steel springs, as it is more fatigue resistant than steel [2]. Also composite springs are economical and light weighted than steel. Introduction of solid particles to polymeric entities of composite springs leads to improvement in the mechanical behaviour of polymeric matrix of composite springs [4]. Strength and toughness rises due to fibers of micro-particles. In spite of composites having many advantages over steel, it cannot eliminate completely as it gives strong and rigid support. Most of heavy commercial vehicles have rear wheel drive. Driven rear rigid axle normally has two longitudinal control arms and a Panhard rod in order to sustain all drive-off along with braking and lateral forces respectively. Designing gives the opportunity to eliminate problems before beginning production. In Addition to that, one can easily determine the sensitivity of specific molding Parameters on the quality and production of the final part. The leaf spring model is created by modelling in Pro-E and it is imported in to the analysis software and the loading, boundary conditions are given to the imported model and results are evaluated by Post Processor. The comparative results of leaf spring for different arrangements steel leaf spring and composite leaf spring are obtained to predict the advantages of composite leaf spring for a vehicle.

II. METHODOLOGY

Leaf springs are crucial suspension elements used on light passenger vehicle necessary to minimize the vertical vibrations impacts and bumps due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly so increasing the energy storage capabilities of a leaf spring and ensures a more compliant suspension system.

The design parameters selected for steel leaf are listed in table 1.

TABLE 1. Material Properties

Sr. No.	Properties	Steel	Epoxy resin
1.	Density	7850kg/m^3	1200kg/m^3
2.	Young's Modulus	2E+11 N/m^2	4E+10 N/m^2
3.	Tensile Strength	2.5E+8 N/m^2	4.3E+7 N/m^2
4.	Compressive Strength	2.5E+8 N/m^2	2.5E+7 N/m^2
5.	Ultimate Tensile Strength	4.6E+8 N/m^2	8.3E+7 N/m^2

The leaf spring is analyzed for static strength and deflection using 3D finite element analysis. In this work the general purpose finite element analysis software ANSYS is used. The variations in the displacements and bending stress are predicted for different arrangements of composite leaves with steel leaves. One of the important considerations in the leaf spring design is the stiffness-strength relationship, along with weight.

III. ANALYTICAL DESIGN

In this work is focussed on hybrid spring that utilizes a steel-composite combination uses the weight criteria while this offers maximum stiffness-to-strength. Evaluating a multi-leaf system with the understanding the effects of steel and composite epoxy-glass with more than one leaf. Through finite element modelling, analyses of steel-composite multi leaf spring system for three models are carried out. First model is comprised of four steel leaves and four composite E-glass leaves with alternate arrangements. Second model is designed with six composite E-glass, which was covered with steel leaf at top and bottom side. Third model is designed with three steel leaves for master, lower and at middle and in between composite E-glass leaves are incorporated (comprised of three steel and five composites).

TABLE 2. Arrangements of leaves in leaf spring.

Leaf	Length (mm)	material			
		Model 1	Model 2	Model 3	Model 3
1	1017		steel	steel	steel
2	1000		epoxy resin	epoxy resin	epoxy resin
3	875		steel	epoxy resin	epoxy resin
4	750		epoxy resin	epoxy resin	steel
5	627		steel	epoxy resin	epoxy resin
6	500	steel	epoxy resin	epoxy resin	epoxy resin
7	375		steel	epoxy resin	epoxy resin
8	250		epoxy resin	steel	steel

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 1800 kg which is the capacity of the system and multiplying it with the dynamic load factor of 2.76 for the equivalent static capacity. We get the equivalent static capacity as: Static load (kg) 1800 kg Load factor 2.76

Equivalent static capacity = static load × load factor = 1800×2.76 = 4968 kg
Therefore F = 4968×9.8/2 = 24343.2 N
Now bending stress $б_b = (3×F×L) / (2×N×B×T^2)$
Where, F= Maximum static load= 24343.2 N
L= Length of the leaf spring = 0.510m
N= number of leafs= 8
B= width of leaf = 0.1m
T=thickness of the leafs= 0.012m

$б_b = 3×24343.2×0.510/ (2×8×0.1×0.012^2) = 161.65$ MN/m2
Factor of safety= 460/161.65=2.8

ELASTIC MODULUS COMPARISON

In a finite element analysis, combining different materials becomes transparent within the stiffness matrix of the solution. Typically, the elastic modulus of a leaf spring system will be constant. To understand material combinations, the following discussion looks at general cases: equivalent Modulus However, for designs with dissimilar elastic properties, an equivalent elastic modulus can be derived. This equivalent modulus can be used to approximate the displacement and load of a design. Therefore, when the width remains constant then the equivalent modulus becomes,

$$E_{eq} = \sum Et^3/\sum t^3$$

For model 2:
$E_{eq} = (4E_s+4E_c)/8 = ((4x200) + (4x40))/8 = 120GPa$

For model 3:
$E_{eq} = (2E_s+6E_c)/8 = ((2x200) + (6x40))/8 = 80GPa$

For model 4:
$E_{eq} = (3E_s+5E_c)/8 = ((3x200) + (5x40))/8 = 100GPa$

For Developed Deflections of Leaf Spring: δ (developed) $= (3×F×L^3) / (8×E×N×B×T^3)$
F= Maximum static force at each wheel= 6085.8 N

$\delta_1 = (3×6085.8×0.51^3)/ (8×200×10^9×8×0.1×0.012^3) =$ 1.09 mm
$\delta_2 = (3×6085.8×0.51^3)/ (8×120×10^9×8×0.1×0.012^3) =$ 1.8 mm
$\delta_3 = (3×6085.8×0.51^3) / (8×80×10^9×8×0.1×0.012^3) =$ 2.74 mm
$\delta_4 = (3×6085.8×0.51^3)/ (8×100×10^9×8×0.1×0.012^3) =$ 2.18 mm

IV. DESIGN AND FEA ANALYSIS

The leaf spring model is created by modelling in pro-E and it is imported in to the ANSYS software. In this study all models are designed for factor of safety 3. As FEA is a computer based mathematically idealized real system, which breaks geometry into element. It links a series of equation to each element and solves simultaneously to evaluate the behaviour of the entire system. This tool is very useful for problem with complicated geometry, material properties and loading where exact and accurate analytical solution is difficult to obtain.

1. Meshing
Discretising of model into the small sections called as the element. Mesh element for this analysis was tetrahedron.

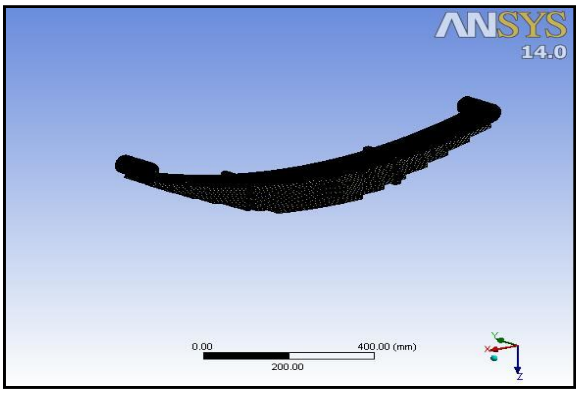

Fig 1. Meshing of leaf spring.

Fig. 1 shows the meshed model of multi-leaf spring in which mesh has been selected considering the concept of grid independence shows the best suited size of mesh with an element size of 5 mm brick mesh.

2. Loading & Boundary Conditions:

2.1. Fixed Support

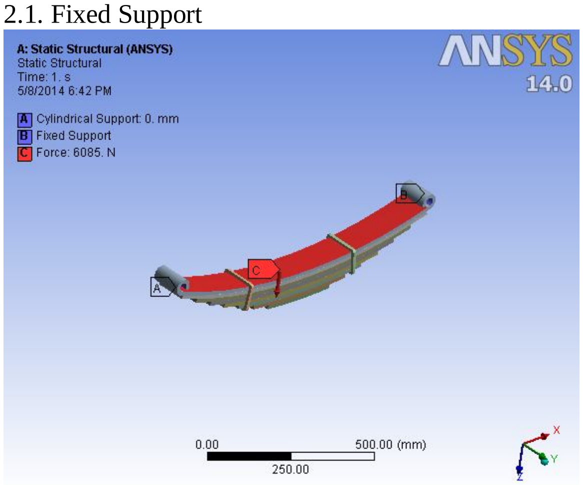

Fig 2. Boundary conditions for leaf spring.

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.

2.2. 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 6085N is applied on the leaf spring model. The uniformly distributed load is shown in Fig. 6

V. RESULT AND DISCUSSION

1. Total Deflections:

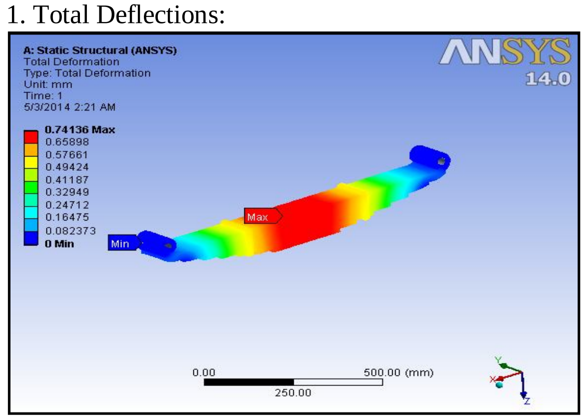

Fig 3. Deflection for Model 1

Fig. 3 shows the deflection of model 1 in which all steel leaves are used. Steel leaf spring is loaded under the application of 6085N load. The maximum deflection is at the centre of the leaf spring its maximum value is 0.74 mm. Red zone indicates the area of maximum deflection and blue zone indicates the area of minimum deflection. Whereas analytically deflection is 1.09 mm

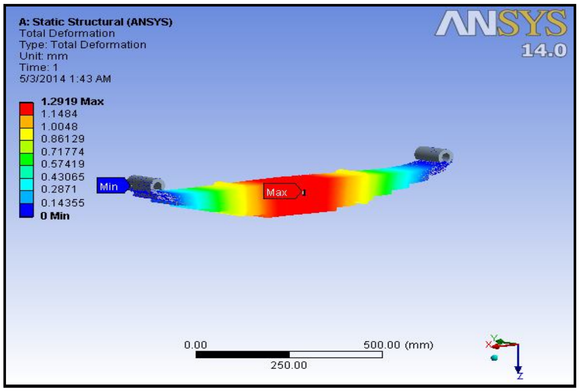

Fig 4. Deflection for Model 2

The maximum deflection is at the centre of the leaf spring its maximum value is 1.2919 mm. whereas analytically deflection is 1.8 mm

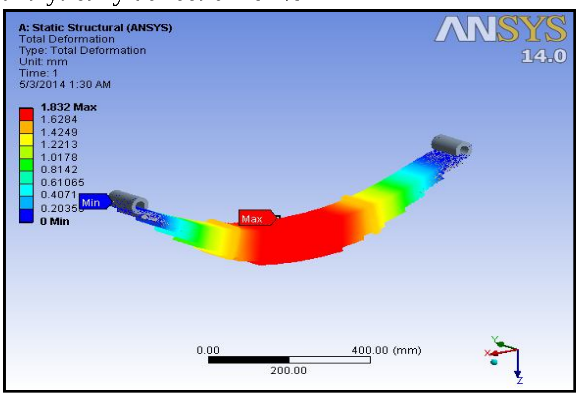

Fig 5. Deflection for Model 3

The maximum deflection is at the centre of the leaf spring its maximum value is 1.832 mm. whereas analytically deflection is 2.74 mm

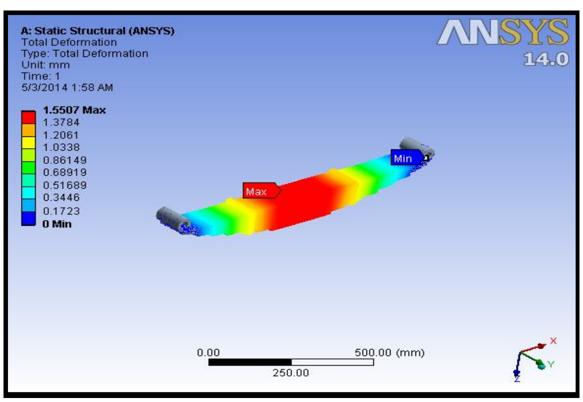

Fig 6. Deflection for Model 4

The maximum deflection is at the centre of the leaf spring its maximum value is 1.55 mm. whereas analytically deflection is 2.18 mm

4. Stress

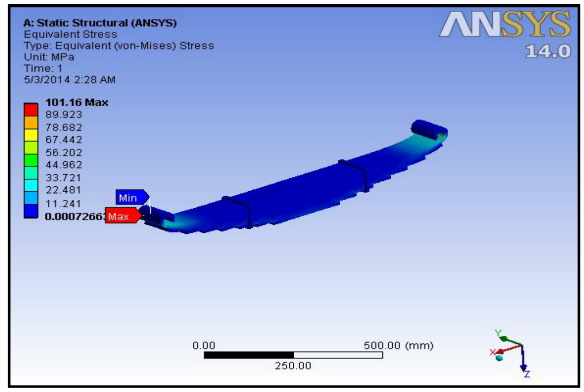

Fig 7. Stress for Model 1

Fig 7 shows the equivalent von-Mises stress induced in steel leaf spring under the load of 6085N load. The maximum stress is induced near the fixed eye end of the leaf spring its maximum value is 101.19 MPa. Whereas analytically stress for this design is 161.65MPa. maximum ultimate stress is 460MPa, shows stress acted on model under safe zone, gives FOS= 4.5. Red zone indicates the area of maximum stress and blue zone indicates the area of minimum stress.

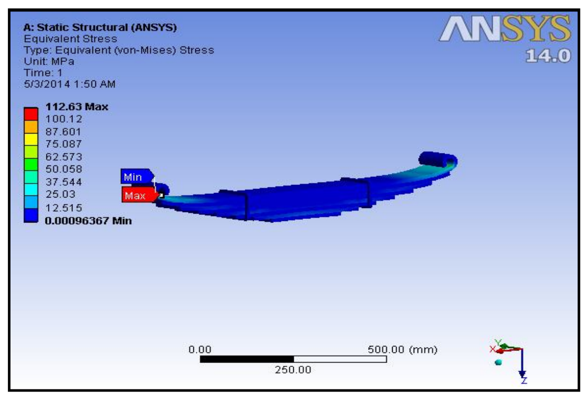

Fig 8. Stress for Model 2

Fig. 8 shows the equivalent von-Mises stress induced in steel leaf spring under the load of 6085N load. The maximum stress is induced near the fixed eye end of the leaf spring its maximum value is 112.63 MPa. Whereas analytically stress for this design is 161.65MPa. maximum ultimate stress is 460MPa, shows stress acted on model under safe zone, gives FOS= 4.08.

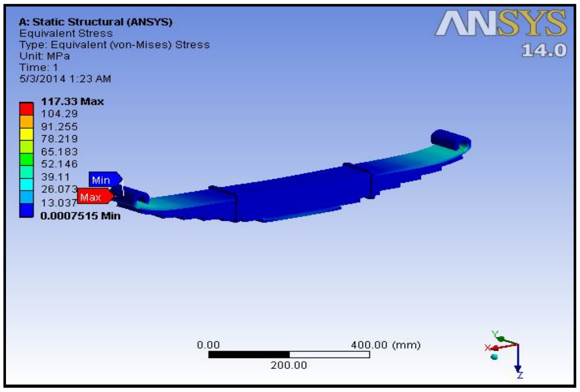

Fig 9. Stress for Model 3

Fig. 9 shows the equivalent von-Mises stress induced in steel leaf spring under the load of 6085N load. The maximum stress is induced near the fixed eye end of the leaf spring its maximum value is 117.33 MPa. Whereas analytically stress for this design is 161.65MPa. maximum ultimate stress is 460MPa, shows stress acted on model under safe zone, gives FOS= 3.9.

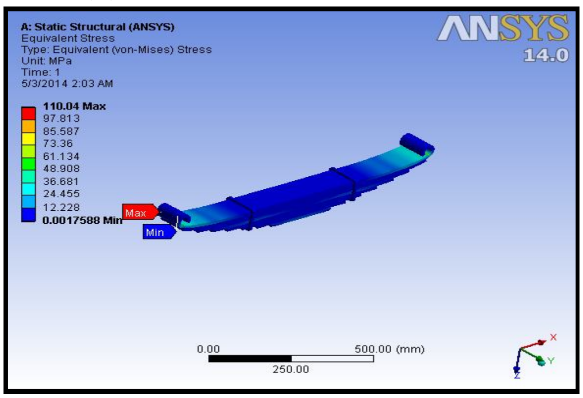

Fig 10. Stress for Model 4

Fig. 10 shows the equivalent von-Mises stress induced in steel leaf spring under the load of 6085N load. The maximum stress is induced near the fixed eye end of the leaf spring its maximum value is 110.04 MPa. Whereas analytically stress for this design is 161.65MPa. maximum ultimate stress is 460MPa, shows stress acted on model under safe zone, gives FOS= 4.1. Red zone indicates the area of maximum stress and blue zone indicates the area of minimum stress.

VI. CONCLUSION:

The 3-D modelling of multileaf spring is done and analyzed for different arrangements of steel leaves with composite leaves. A comparative study has done for four models for Deflection and stresses. Same models are designed for factor of safety of 2.5. Leaf spring is analytically designed and shows factor of safety 2.8. Four models are analysed in ANSYS and maximum deflection, stress and ultimate strength are calculated. Model 4 showing factor of safety 4.1 which is close to FOS of steel i.e model 1 of FOS 4.5, nevertheless model 2 also showing FOS of 4.08. Model 2 and model 4 shows less static deflection and less stress compare to model 3, in which six composite leaves are used and only two steel leaves are used. It denotes that alternate placing of composite leaves provides similar strength as that of conventional steel leaves with additional advantages. Also implementation of three steel leaves instead of four leaves, gives better results than alternate arrangement of steel and composite leaves. Fourth model arrangement shows better result than other two arrangements. It is observed that the composite material arrangement shows more deflection and stress than that of steel material leaf spring but the model 4 gives considerable reduction in weight and whose FOS is also 4.1 close to steel leaf springs FOS of 4.5.

VII REFERENCES

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