Design, Analysis, Manufacturing and Testing of Mono Composite Leaf Spring Using UD E-Glass Fiber/Epoxy

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ABSTRACT

Composite materials have attracted all researchers due to its light weight and high strength. Today's need of manufacturing industries is to make the automobiles fuel efficient. Considering this view we have manufacture glass epoxy mono composite leaf spring. This mono composite leaf spring will reduce 77% weight as compared to steel leaf spring. Statistical calculations and FEA analysis is reported in this paper. Advance polymer composite in specific.

Keywords--Composite Material, Fea, Leaf Spring, Static Analysis, Suspension System

1.INTRODUCTION

In automobile industry increasing innovations and development of the product tend to replace material, optimize design & better manufacturing process. Now days automobile sector replace conventional metal alloys to composite material for weight reduction as well as fuel consumption. It is possible to replace composite material to have desired material property. Leaf spring is an automobile part using suspension system. One of the purposes of the leaf springs is to bear the weight of the vehicle and control the vehicle so that the tires keep in contact with the road. The leaf springs absorb all the bumps and dips in the road, thus providing a more comfortable ride for the vehicle's occupants. But steel leaf springs have unsprang weight. So we have developed E-glass/epoxy mono composite leaf spring to reduce weight up to 77% with increase driving reliability come greater suspension.

1.1 Suspension System

The leaf spring suspension system is the oldest suspension system used for automobile device. The leaf spring system was used from 1970s production cars and many racers even prefer to utilize the leaf spring rear suspension design in their fabricated late model stock and modified race cars. The leaf spring supports some or all of the chassis weight and controls chassis roll more efficiently. Control axle dampening andbraking forces. Better maintaining wheelbase lengths under acceleration and braking.

1.2 Composite Material

A composite is a structural material which consists of combining two or more constituents. The constituents are combined at a macroscopic level and are not soluble in each other. One constituent is called the reinforcing phase and another which is embedded is called the matrix [1]. Advanced compositesare traditionally used in the aerospace industries, but now a days also use in automobile industries. Advance composite materials are Carbon, Graphite, Kevlar and Glass fiber with suitable matrixes is widely used because of their higher specific strength & higher specific modulus. Composite leaf springs are a fairly new component in racing that has been further refined recently. They are made of unidirectional E-glass fiber/epoxy composite material instead of steel. It has good mechanical properties for required design.

1.3 Mono Composite Leaf Spring

In this paper we have replaced conventional steel leaf spring which has unsprung weight into light weight material unidirectional E-glass fiber/epoxy composite material. The glass/epoxy composite leaf springs fatigue lives have five times more durable than steel leaf springs. It's also gives a smoother ride than steel leaf springs & also gives more rapid response to stress cause by road shock. Moreover, it is offer less chance of catastrophic failure and has excellent corrosion resistance.

2. DESIGN PARAMETER AND MATERIAL PROPERTIES

The design parameter for Mahindra Bolero using rear five leaf steel spring with material properties are given in Table No 1. The actual leaf spring is showing in Figure No 1.

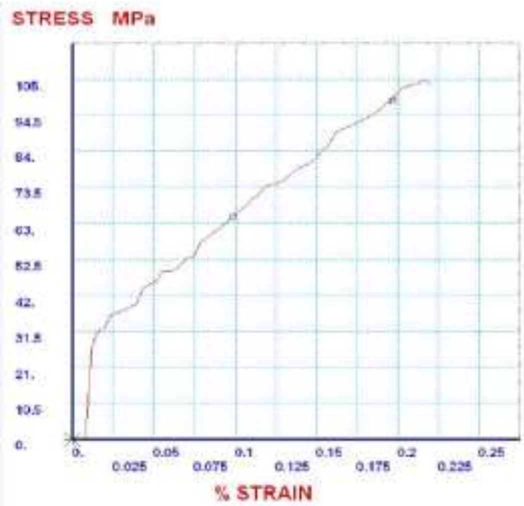
Figure No. 1 Mahindra Bolero Rear Leaf Spring

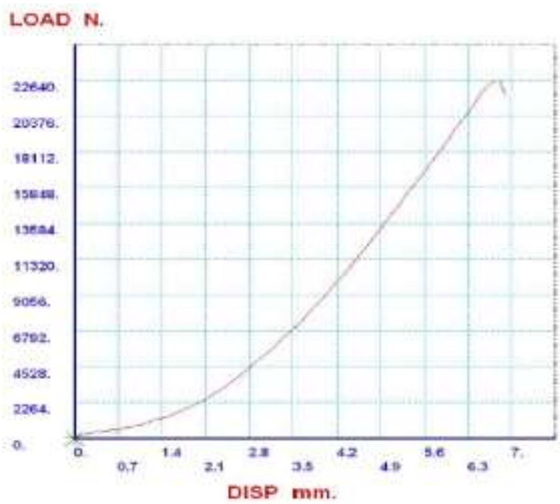
Table No.1 Design Parameter and Material Properties of Steel Leaf Spring

Parameter	**Value**
Material selected-Steel	55Si2Mn90
Length of leaf spring Eye to Eye	1168 mm
Arc height of axle seat (Camber)	190 mm
Width of the leaves	63 mm
Thickness of each leaves	8 mm
No. of full length leaves	1
No. of graduated leaves	4
Yield strength	1470 N/mm^2
Tensile strength	1962 N/mm^2
Young's modulus (E)	$2.1x10^5$ N/mm^2
Design stress (σ_b)	653 N/mm^2
Spring rate	65 N/mm
Maximum load carrying capacity	11500 N
Leaf spring weight	20.4 kg

The dimensions are measured from Mahindra service center and material properties are taken from the research paper [3].

This steel leaf spring replaces to mono composite (UD E-glass fiber 92145/epoxy 5015) leaf spring. This composite material is tested tensile modulus and tensile strength in laboratory; it is shown in Graph No 1 and 2. Design parameter and there material properties are given in Table No-2.





Graph No. 1 Tensile modulus test graph. **Graph No. 2 Tensile strength test graph**

Table No.2 Design Parameter and Material Properties of Composite Leaf Spring

Parameter	**Value**
Material selected– UD E-glass/epoxy	92145/5015
Tensile modulus of fiber along X-axis	76000 N/mm^2
Tensile modulus of matrix along X-axis	2800 N/mm^2
Weight ratio	0.607/0.393
Young's modulus (Ex)	33547.79 N/mm^2
Tensile strength	395.16 N/mm^2
Length of leaf spring Eye to Eye	1168 mm
Arc height at axle seat (Camber)	180 mm
Width of the leaves	60 mm
Thickness at base (t_b)	36 mm
Thickness at end (t_e)	16 mm

3.STATISTICAL CALCULATIONS OF LEAF SPRING(STEEL & COMPOSITE)

3.1 Steel Leaf Spring

Leaf spring is the type of cantilever beam, it is simple rectangle shape. One side force is applied and other side is fixed. The bending stress (σ_b) and maximum deflection(δ_{max}) of a leaf springs are

$$\sigma_{max} = \frac{6FL}{bt^2} \quad , \quad \delta_{max} = \frac{4FL^3}{Ebt^3}$$

3.1.1 Laminated spring

The difficulties of the uniform strength beam, say lozenge shape is that the value of width b sometimes is too large to accommodate in a machine assembly.One practice is that instead of keeping this large width one can make several slices and put the pieces together as a longitudinal stripe.

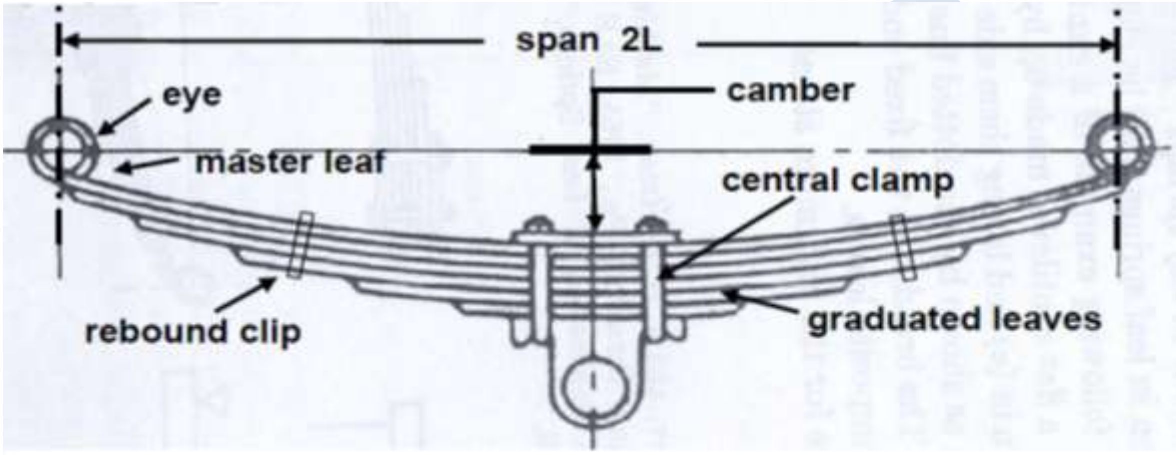


Figure No. 2 Laminated Semi-elliptic spring

To prove that stress developed in the full length leaves is 50% more at the graduated leaves. The stress ratio is $\frac{\sigma_{bf}}{\sigma_{bg}} = 1.5$

Let

i_f = No. of full length leaves

i_g = No. of graduated leaves including the master leaf

b = Width of each leaf

t = Thickness of each leaf

L = Length of the cantilever or half the length of the spring

F = Total force applied at the end of the spring

E = Young's modulus

The bending stress(σ_b)and maximumdeflection(δ_{max})can be calculate for laminated leaf spring

$$\sigma_b = \frac{6FL}{(i_f + i_g)bt^2}$$

$$\delta_{max} = \frac{12FL^3}{(3i_f + 2i_g)Ebt^3}$$

3.2 Composite Leaf Spring

The minimum weight criteria in the design of automobile vehicles coupled with the ever growing use of light polymer material that can undergo large displacements without exceeding their specified elastic limit. The mono composite leaf spring is the type of constant width varying thickness cantilever taper beam or nonlinear beam. So this type problem solve by Elastica Theory. The exact shape of the deflection curve of a flexible member is called the Elastica [2].

3.2.1 The Euler-Bernoulli Law of Nonlinear Deformations for Taper beam

The flexible structural component is permitted to have any arbitrary variation in I and EI along its length. A tapered flexible cantilever beam loaded with a vertical load (P) at its free end, y is the vertical deflection of the member at any x and θ is rotation. The relations is

$$y' = \frac{dy}{dx}, \; y'' = \frac{d^2y}{dx} \text{ and } y' = \tan\theta$$

$$\frac{y''}{[1+(y')^2]^{3/2}} = -\frac{M_x}{E_x I_x}$$

$$\frac{y''}{[1+(y')^2]^{3/2}} = -\frac{M_x}{E_1 I_1 f(x) g(x)}$$

Where f(x) is the moment of inertia function and g(x) is the modulus function are representing the variation of I_x with I_1 and E_x with E_1.

4.FEA Analysis Using ANSYS(Steel & Composite)

The finite element analysis (FEA) of steel leaf spring and composite mono leaf spring is carried by ANSYS 15.0 APDL. The steel leaf spring is taken as a cantilever beam type which is created in ANSYS modeling in x-y direction after extrude in z direction. Taking element type is solid brick 8 node 185; mash size is manually control and meshing. After meshing contact pair is create lower and upper surface. The boundary condition is one side fixed, all DOF and another side applies forces.

For FEA analysis of composite material standard properties has been taken in Table No. 3 [3].

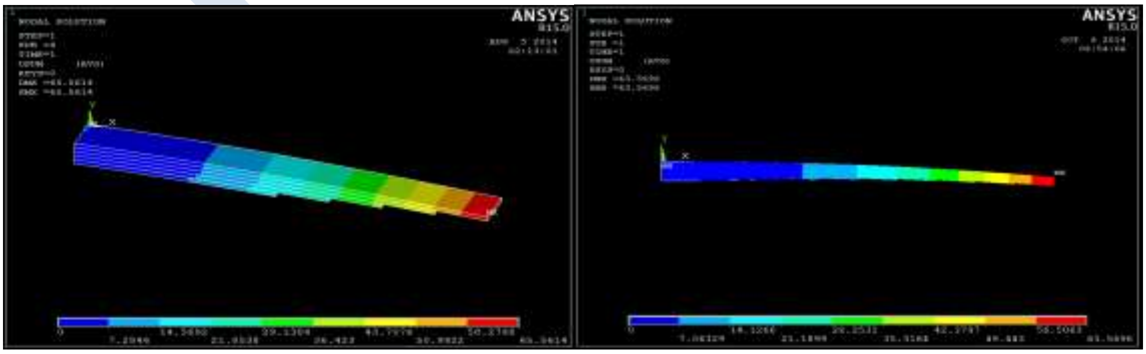


Figure No. 3 Compare the result steel vs. composite leaf spring, deflection vector remains similar by applying 4000 load.

Table No. 3 The mechanical properties of E-glass/epoxy

Properties	Value
Tensile modulus along X-direction(Ex)	34000N/mm^2
Tensile modulus along Y-direction(Ey)	6530N/mm^2
Tensile modulus along Y-direction(Ez)	6530N/mm^2
Poisson ratio along XY-direction(NUxy)	0.217
Poisson ratio along YZ-direction(NUyz)	0.366
Poisson ratio along ZX-direction(NUzx)	0.217
Shear modulus along XY-direction(Gxy)	2433N/mm^2
Shear modulus along YZ-direction(Gyz)	1698N/mm^2
Shear modulus along ZX-direction(Gzx)	2433N/mm^2

The composite leaf spring modeling is 2-D take 0.2 mm thin 180 layers of varying length in Pro-E and import in ANSYS. Taking element type is solid Quad 4 node 182; which gives thickness. The material used UD E-glass fiber/epoxy is orthogonal material. Before mashing, glue the thick layer. The boundary conduction is applied.

5.MANUFACTURE PROTOTYPE MONO COMPOSITE LEAF SPRING

Mono composite leaf spring is manufactured by hand-layup open molding process in various steps. Which areillustrated in figure No - 4 to figure No- 6.

Step-1 First prepare mold as refer design of composite leaf spring.

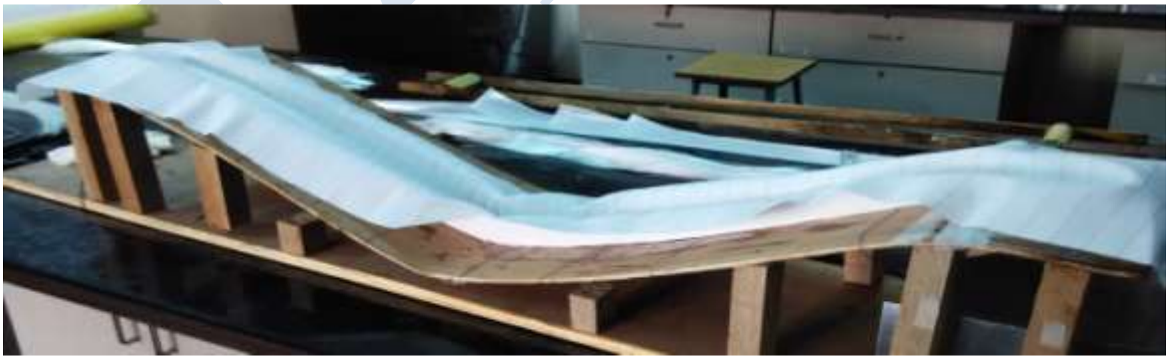


Figure No. 4 Wooden mold

Step-2 Take UD E-glass fiber (style-92145) sheet and cut in five different lengths.

Step-3 Takesepoxy (resin+ hardener) and other equipment’s (brush, bicker, mug).

Step-4Now arranges all the equipment before going to manufacture. This fiber is arranged in unidirectional and epoxy is mixed with fiber.

Step-5 After 24 hours; open the mold and remove it. Cut the length as per the dimension.

Figure No. 5 Mono composite leaf spring

Step-6 We attach external two pieces of steel eye with require dimension and also create two holes on each steel eye plate. Same diameter hole is created on mono composite leaf spring and another hole on support plate. Assemble steel eyes and mono composite leaf spring with the help of nut bolt.

Figure No. 6 Mono composite leaf spring assemble

6. TESTING COMPOSITE LEAF SPRING

The leaf spring weight test is carried out to find actual weight of composite leaf and steel eye. The total weight of composite leaf spring compare with steel leaf spring.The leaf spring is tested on universal testing machine in lab. We attach the composite leaf spring in C channel, one side is fixed and other side provide 100 mm channel height; connect with frictionless attach. Apply load gradually 50 mm/min speed under computer programming testing software. Show the result in display.

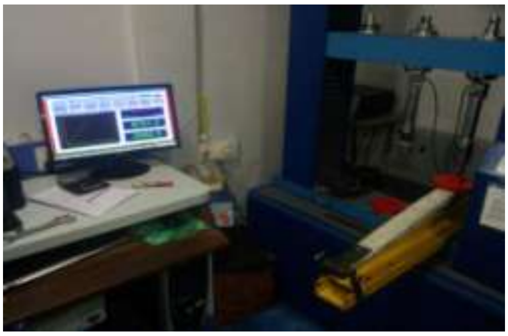


Figure No. 7 Testing mono composite leaf spring

Graph No. 3 Testing mono composite leaf spring (load vs. deflection)

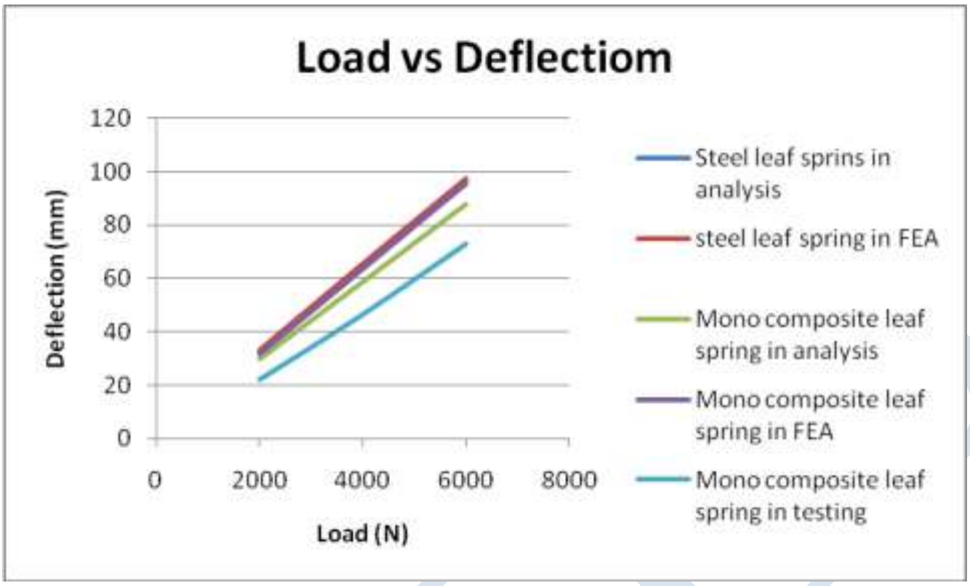
7.RESULT

The deflection, stress and stiffness are shown in Table No.4; at different load condition of steel leaf spring and mono composite leaf spring.

Table No. 4 Steel leaf spring and composite leaf spring statistical calculations, FEA analysis and testing reported (loadvs. deflection, stress and stiffness)

Parameter		Load (N)	δ_{max} (mm)	σ_{max} (N/mm^2)	Stiffness (N/mm)
Steel	Analytical	2000	32.07	173.81	62.35
	FEA		33.17	181.87	60.29
Composite	Analytical		29.46	87.36	67.89
	FEA		31.78	91.11	62.93
	Testing		22		91
Steel	Analytical	4000	64.15	347.62	62.35
	FEA		65.56	367.47	61
Composite	Analytical		58.63	175	68.22
	FEA		63.57	182.24	62.92
	Testing		46.5		86
Steel	Analytical	6000	96.23	521.43	62.34
	FEA		97.44	550.74	61.57
Composite	Analytical		87.79	262	68.34
	FEA		95.23	273.35	63
	Testing		73		82.5

This Graph No 4 is shown the load vs. deflection curve; to observe that statistical calculations, FEAresult is same and testing result is approximately same.



Graph No. 4 Load vs.deflections

Conventional steel leaf spring weight = 20.4 kg

Mono composite leaf spring weight = 4.63 kg

Weight reduction = 77.3 %

8.CONCLUSIONS

This work involves to comparison of steel leaf spring with E-glass/epoxy mono composite leaf spring under static load condition is observed. The same deflection with improve stiffness and weight reduction is 77.3%. From the result, it is observed that if we mixed carbon fiber with E-glass fiber to improve strength;passible to apply heavy weight vehicles.

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