Design and Development of Mono Leaf Spring by using Composite Material (Epoxy-Carbon Fiber)

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Abstract— *According to the demand of recent world, the more concentration is on weight reduction in automobiles. The possible weight reductions are wheel assembly, axles, and part of the weight of suspension spring and shock absorbers. The leaf spring accounts for 10-20% of the un-sprung weight. The composite materials made it possible to reduce the weight of machine element without any reduction of the load carrying capacity. Because of composite material's high elastic strain energy storage capacity and high strength-to weight ratio compared with those of steel. FRP spring also have excellent fatigue resistance and durability. But the weight reduction of the leaf spring is achieved not only by material replacement but also by design optimization. Weight reduction has been the focus of automobile manufacturers in the present scenario. The replacement of steel with optimally designed composite leaf spring can provide 75%-78% weight reduction. The material selected is carbon epoxy against conventional steel. The optimization study consists of use of software's such as NASTRAN / ANSYS software. The experimentation on UTM is carried out and results are compared. Moreover, the composite leaf spring has lower stresses compared to steel spring. All these will result in fuel saving which will make countries energy independent because fuel saved is fuel produced.*

Keywords—bending stress, composite leaf spring, carbon epoxy, FRP, NASTRAN / ANSYS software.

I. INTRODUCTION

Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing. The advantage of 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 to energy absorbing device. According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction, is the most suitable material for a leaf spring. To meet the need of natural resources conservation, automobile manufacturers are attempting to reduce the weight of vehicles in recent years. 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 unsprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. [3,16].

1.1 Demerits of conventional leaf spring [16]

- They have less specific modulus and strength.
- Increased weight.
- Conventional leaf springs are usually manufactured and assembled by using number of leafs made of steel and hence the weight is more.
- Its corrosion resistance is less compared to composite materials.
- Steel leaf springs have less damping capacity

1.2 Advantages of composite leaf spring [16]

- Composite leaf spring has high strength to weight ratio, compared with those steel leaf springs, so multi leaf springs are now replaced by mono-leaf composite laminated springs.
- The introduction of the composite materials made it possible to reduce the weight of the leaf springs without any reduction of load carrying capacity and stiffness. This achieves the vehicle with more fuel efficiency and improved riding qualities.
- Compared to steel spring, the composite leaf spring is found to have 64.95% higher stiffness and 126.98% higher natural frequency than that of existing steel leaf springs
- Since, the composite materials have more elastic strain energy storage capacity. The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of

vibrations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly.

1.3 Motivation

Reducing weight while increasing or maintaining strength of products is getting be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this project reducing weight of vehicles and increasing or maintaining the strength of their spare parts is considered. As leaf spring contributes considerable amount of weight to the vehicle and need to be strong enough, a single leaf spring is designed and simulated following the design rules of the composite materials considering static loading only. The constant cross section design of leaf springs is employed to take advantages of ease of design analysis and its manufacturing process. And it is shown that the resulting design and simulation stresses are much below the strength properties of the material, satisfying the maximum stresses are much below the strength properties of the material, satisfying the maximum stress failure criterion. The designed composite leaf spring has also achieved its acceptable fatigue life. This project will deals with the study of effect of weight percentage of carbon fiber on the properties of composite mono leaf spring. The composite material used for the project consists of carbon fiber and epoxy resin having high strength compared to other materials which is around 72 MPa. The study will be carried by three methods, the first method is experimental method to carryout tensile test after this second method consist of identification of natural frequency by FFT analyzer will be done then at last optimization study consist of use of software's such as NASTRAN / ANSYS software.

1.4 Scope of Work

- Well Definition of the problem.
- To study the existing leaf spring in Maruti 800 for possible designing.
- Learning and use of ANSYS software.
- The inputs for Designing of would be secured from the Sponsoring Company, typically the geometry (3D model). The same is normally created using a modelling interface like CATIA, SolidWorks, etc.
- Loads and boundary conditions shall be applied to the model in the pre-processor. The input deck for the designated solver shall be prepared.
- Suitable solver for structural analysis (like ANSYS) would be deployed for finding the solution.
- Recommendation to be made upon evaluating the results.
- Physical experimentation towards validation hypothesis proposed to be carried out.
- Conclusion to be inferred over the work done.

1.5 Objective

In this project reducing weight of vehicles and increasing or maintaining the strength of their spare parts is considered. The design for the leaf spring would be subjected to FEA to find the effect of loads on the composite leaf spring. The composite leaf spring would be assessed for its performance like strength. The problem for this work is being evaluation of the design using software in the FEA followed by experimentation.

II. DESIGNING OF LEAF SPRING

2.1 Specific design data

Total weight of the car = 2650 kg = 25987.6 N

This weight must be divided into front axle weight and rear axle weight. 52% of total weight is taken by front axle and 48% of total weight is taken by rear axle.

∴ Front axle weight = 1378 kg = 13513.5 N

Reaction at one wheel = 1378/2 = 689 kg = 6756.8 N

∴ Rear axle weight = 1272 kg = 12474.05 N

Axle weight on one wheel = 12474.05/2 = 6237.02 N

Assuming 5 number of plates of leaf spring = 6237.02/5 = 1247.4 N

2.1.1 Assumptions

- All Nonlinear effects are excluded.
- The stress strain relationship for composite material is linear and elastic; hence hook's law is applicable to composite material.
- The leaf spring has uniform cross section.
- Normal road condition

2.1.2 Selection of cross-section

The following cross-sections of mono-leaf spring for manufacturing easiness are considered.

- Constant thickness, varying width design
- Varying width, varying thickness design
- Constant thickness, constant width design

In the present work, only constant cross-section design method is selected. Since the cross-section, area is constant throughout the leaf spring, same quantity of reinforcement fiber and resin can be fed continuously during manufacturing.[1]

2.1.3 Materials for 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. The heat treatment of spring steel products greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties [22].

Carbon/Graphite fibers: Their advantages include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance and high electrical conductivity [22].

Table 2.1: Specifications of leaf spring

Parameter	**Dimension**
Length of leaf spring (2L)	975 mm
Free Camber (At no load condition)	180 mm
Thickness of leaf	8 mm
Width of leaf spring	50 mm

2.2 Analytical method

We know that the deflection of leaf spring is given by

$$\delta_{max} = \frac{4WL^3}{nEbt^3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Bending stress in leaf spring is given by

$$\sigma_{max} = \frac{6WL}{nbt^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.2)$$

Where,
W-Load on vehicle (N)
L- Length of spring (mm)
n- No. of spring
E-Young Modulus (MPa)
b- Width of leaf spring (mm)
t- Thickness (mm)
δ- Deflection of spring (mm)
σ- Bending Stress (MPa)

2.2.1 Properties and calculations for steel leaf spring

By using the above equations and specifications of leaf spring, we have calculated deflection and stress induced in conventional leaf spring.

Table 2.2 Properties of steel

Properties	**Steel**
Young's modulus (E)	200000 (MPa)
Tensile strength	650 – 880 (MPa)
Poisson's ratio	0.3
Weight of the single leaf spring	2.2 Kg
ρ (kg/mm³)	0.00000785

- **Sample calculations**

i) At Load (W) = 400 N,

a)	δ_{max} =	$\frac{4WL^3}{nEbt^3}$ = $\frac{4 \times 400 \times 487.5^3}{1 \times 200000 \times 50 \times}$	**b)**	σ_{max} =	$\frac{6WL}{nbt^2}$ = $\frac{6 \times 400 \times 487.5}{1 \times 50 \times 8^2}$
	=	36.20 mm		=	365.625 MPa

ii) At Load (W) = 600 N,

a)	δ_{max} =	$\frac{4WL^3}{nEbt^3}$ = $\frac{4 \times 600 \times 487.5^3}{1 \times 200000 \times 50 \times}$	**b)**	σ_{max} =	$\frac{6WL}{nbt^2}$ = $\frac{6 \times 600 \times 487.5}{1 \times 50 \times 8^2}$
	=	54.30 mm		=	548.437 MPa

iii) At Load (W) = 1000 N,

a)	δ_{max} =	$\frac{4WL^3}{nEbt^3}$ = $\frac{4 \times 1000 \times 487}{1 \times 200000 \times 50}$	**b)**	σ_{max} =	$\frac{6WL}{nbt^2}$ = $\frac{6 \times 1000 \times 48}{1 \times 50 \times 8^2}$
	=	90.51 mm		=	914.062 MPa

Table 2.3: Comparison for conventional steel leaf spring

Load (N)	**Conventional Steel**			
	Analytical		***FEA***	
	δ_{max} (mm)	**σ_{max} (N/mm^2)**	**δ_{max} (mm)**	**σ_{max} (N/mm^2)**
400	36.20	365.625	40.15	431.808
600	54.30	548.437	37.64	388.285
1000	90.51	914.062	100.39	947.24
1200	108.28	1096.875	202.78	947.25

2.2.2 Properties and calculations for carbon epoxy leaf spring

For manufacturing of composite leaf spring, we selected Carbon epoxy composite material. The properties of the material are mentioned in table below-

Table 2.4: Properties of Carbon epoxy

Properties	**Carbon Epoxy**
Young's modulus (MPa)	177000
Poisson's ratio	0.2
Weight of the single leaf spring	440 gm
ρ (kg/mm³)	0.0000016

For composite material the values of Young's modulus and thickness of spring will be different. Rest all the values will be same as stated above.

Table 2.5: Comparison for Carbon fiber leaf spring

Load (N)	**Carbon fiber**			
	Analytical		***FEA***	
	δ_{max} (mm)	**σ_{max} (N/mm^2)**	**δ_{max} (mm)**	**σ_{max} (N/mm^2)**
400	0.48	51.6	0.592	56.06
600	0.73	78.4	0.888	84.09
1000	1.22	132	1.48	140.15
1200	1.46	158.8	1.78	168.18

III. SIMULATION

3.1 Analysis of existing leaf spring (Steel)

A mono leaf spring made up of mild EN 47 steel is selected and analysis is carried out by applying suitable boundary conditions. This analysis is done for von- mises stress and deformation. This analysis is shown in Fig.5.1 & Fig.5.2

3.1.1 Von-mises Stress in leaf spring (steel)

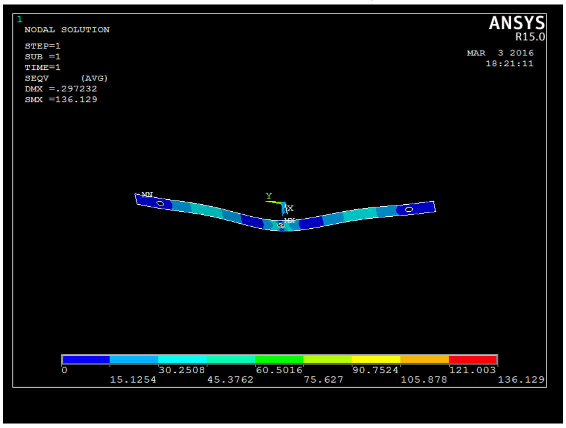

Fig.3.1: Von-mises stress for leaf spring (steel)

Stress value for leaf spring is 136.13 N/mm^2 which is well below the critical value. Hence, design is safe. We can see, there's a scope for optimization. Material can be removed from low stressed region and further be optimized.

3.1.2 Deformation in leaf spring (steel)

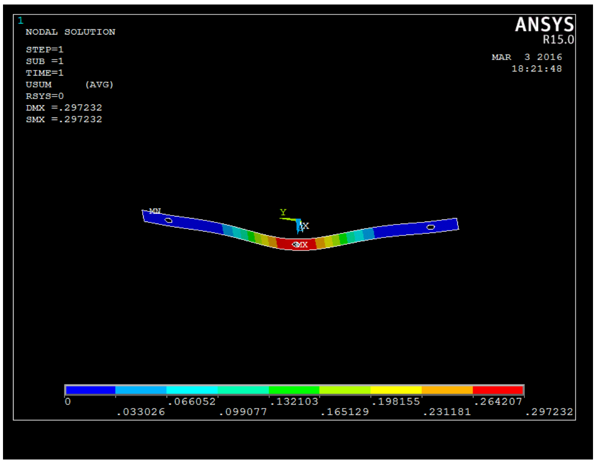

Fig.3.2: Displacement result for leaf spring (steel)

From fig, deformation for leaf spring is 0.29 mm.

3.2 Analysis of leaf spring (Carbon fiber)

After completing this analysis of conventional leaf spring, material is changed with carbon fiber with same boundary conditions. While doing this analysis, three iterations are made so that best option can be selected. While performing these iterations, orientations are changed and results are observed for von mises stresses and deformation.

3.2.1 Iteration I

Total 5 layers of 1 mm each thickness carbon fibers are assigned to the mesh generated to achieve the 5mm thickness of the leaf. Now the fiber lay-ups are oriented in a passion of **0/30/45/60/90** angles respectively for five layers.

These properties serve as input to assign material properties in hypermesh. Load collectors and properties are assigned. Static analysis solver deck is prepared and geometry in .cdb format is exported.

3.2.1.1 Meshing on leaf spring (Carbon fiber)

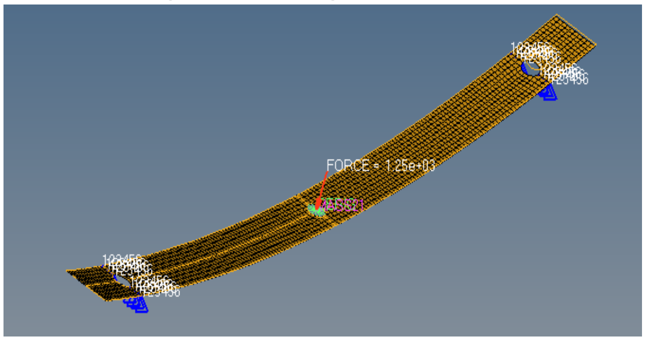

Fig.3.3: Meshed model for carbon fiber leaf spring (I)

The exported model is imported into ANSYS and then the solution is run. The post processing results in ANSYS are as follows-

3.2.1.2 Von-mises stress in leaf spring (Carbon fiber)

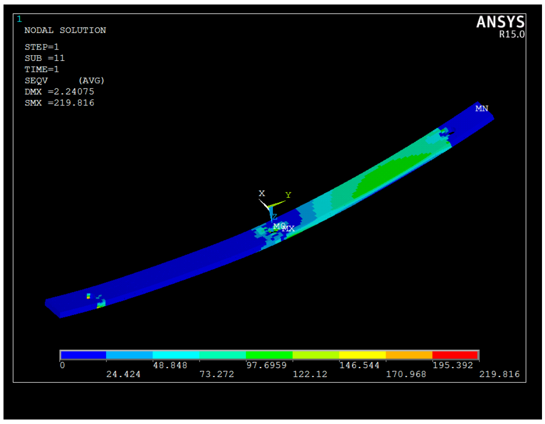

Fig.3.4: Von-mises stress for carbon fiber leaf spring (I)

Stress value for leaf spring is 219.8 N/mm^2 which is well below the critical value. Hence, design is safe.

3.2.1.3 Deformation in leaf spring (Carbon fiber)

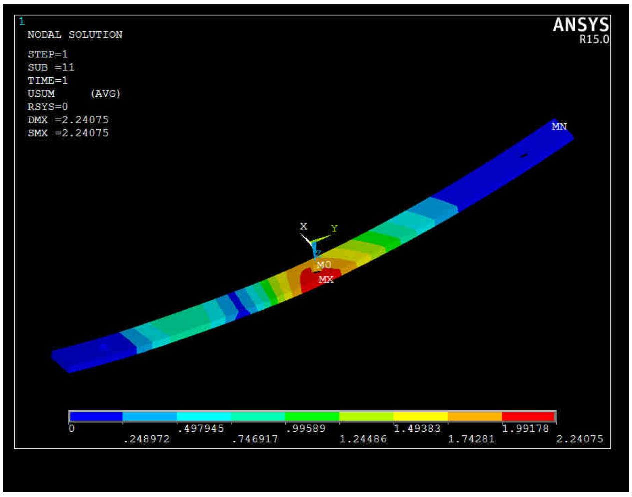

Fig.3.5: Deformation for carbon fiber leaf spring (I)

From above figure, deformation comes as 2.24mm.

3.2.2 Iteration II

Total 5 layers of 1 mm each thickness carbon fibers are assigned to the mesh generated to achieve the 5mm thickness of the leaf. Now the fiber lay-ups are oriented in a passion of **45/90/-45/-90/45** angles respectively for five layers.

3.2.2.1 Meshing on leaf spring (Carbon fiber)

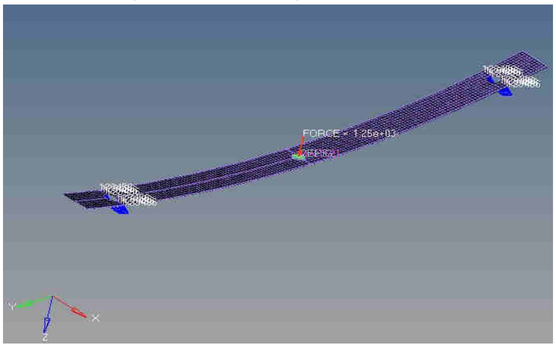

Fig.3.6: Meshed model for carbon fiber leaf spring (II)

The exported model is imported into ANSYS and then the solution is run. The post processing results in ANSYS are as follows.

3.2.2.2 Von-mises stress in leaf spring (Carbon fiber)

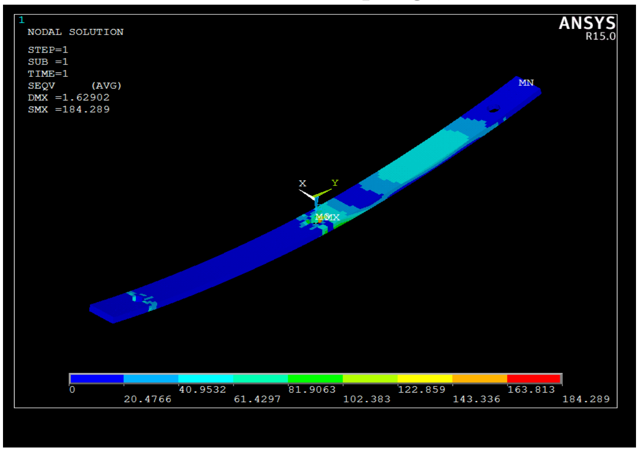

Fig.3.7: Von-mises stress for carbon fiber leaf spring (II)

Stress value for leaf spring is 184.28 N/mm^2 which is well below the critical value. Hence, design is safe.

3.2.2.3 Deformation in leaf spring (Carbon fiber)

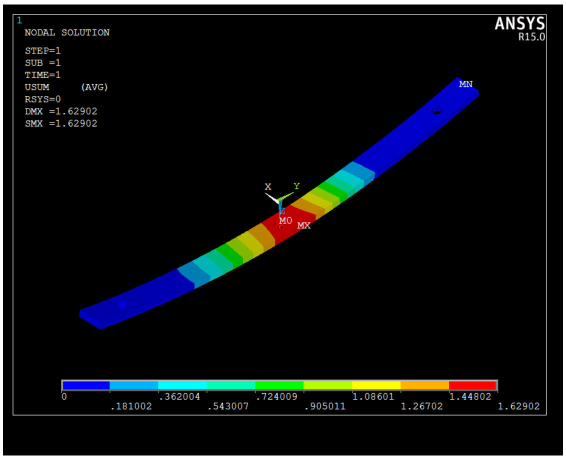

Fig.3.8: Deformation for carbon fiber leaf spring (II)

From above figure, deformation comes as 1.62mm.

3.2.3 Iteration III

Total 5 layers of 1 mm each thickness carbon fibers are assigned to the mesh generated to achieve the 5mm thickness of the leaf. Now the fiber lay-ups are oriented in a passion of **0/45/0/-45/0** angles respectively for five layers.

3.2.3.1 Meshing on leaf spring (Carbon fiber)

Fig.3.9: Meshed model for carbon fiber leaf spring (III)

The exported model is imported into Ansys and then the solution is run. The post processing results in ANSYS are as follows.

6.2.3.2 Von-mises stress in leaf spring (Carbon fiber)

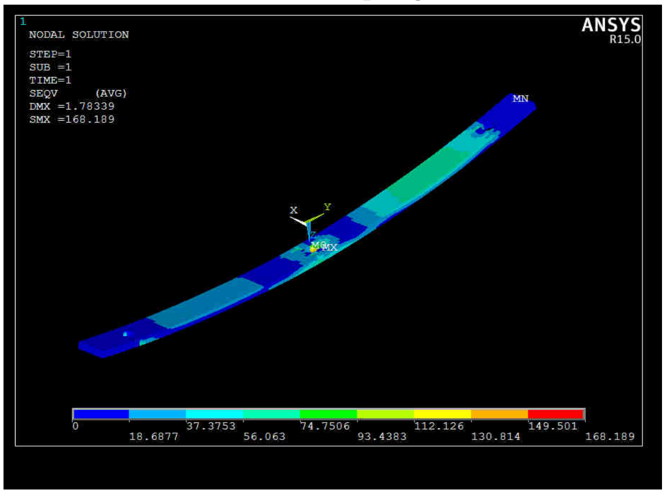

Fig.3.10: Von-mises stress for carbon fiber leaf spring (III)

Stress value for leaf spring is 168.18 N/mm^2 which is well below the critical value. Hence, design is safe.

6.2.3.3 Deformation in leaf spring (Carbon fiber)

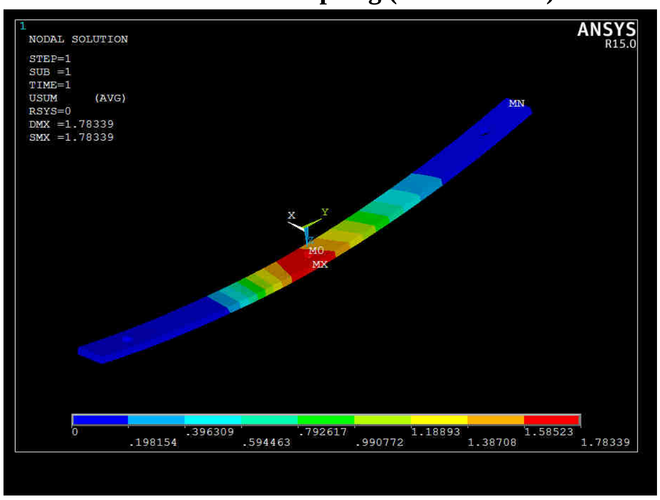

Fig.3.11: Deformation for carbon fiber leaf spring (III)

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From above figure, deformation comes as 1.78mm.

Table.6.1: ANSYS results

	Orientation	δ (mm)	σ (N/mm^2)
Existing (steel)	-	0.29	136.13
Iteration 1	**0/30/45/60/90**	2.24	219.81
Iteration 2	**45/90/-45/-90/45**	1.62	184.287
Iteration 3	**0/45/0/-45/0**	1.78	168.18

As we can see in above table, that the last iteration (i.e. Iteration no.3) shows the lowest stress value among three iterations. So that we have selected the last iteration values for fabrication.

IV. MANUFACTURING AND TESTING

4.1 Manufacturing

4.1.1 Fiber selection

Vertical vibrations and impacts are buffered by 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 capability of a leaf spring ensures a more compliant suspension system. The material used directly affects the quantity of storable energy in the leaf spring. The specific strain energy can be written as Eq. (1).

$S= (1/2) \times ((\sigma t^2)/(\rho E))$ ……………(4.1)

Where,

σt - Allowable stress,

E - Modulus of elasticity and

ρ - Density.

From the Eq. (4.1) the material with maximum strength and minimum modulus of elasticity is the most suitable material for the leaf spring application. In the following table the physical properties of some of the fiber are compared.

Table.7.1: Strain Energy Stored By Material (KJ/Kg)

Sr. No	Material	Strain Energy Stored By Material (KJ/Kg)
1	Steel (EN47)	0.3285
2	Carbon/epoxy	8.611
3	E-glass/Epoxy	4.5814
4	C-glass/Epoxy	18.76
5	S-2-glass/Epoxy	32.77

The Carbon fiber material is selected for this application with maximum strength and minimum modulus of elasticity.

4.1.2 Resin Selection

Matrix materials or resins in case of polymer matrix composites can be classified according to their chemical base i.e. thermoplastic or thermosets. At present, epoxy resins are widely used in various engineering and structural applications such as aircraft, aerospace engineering, sporting goods, automotive, and military aircrafts industries. In order to improve their processing and product performances and to reduce cost, various fillers are introduced into the resins during processing. Epoxy resins are the most commonly used thermoset plastic in polymer matrix composites. Hence from the above listed advantages of epoxy resin it has been selected for the study.

Mono composite leaf spring is manufactured by hand-layup open molding process in various steps as follows-

4.1.3 Fabrication of Composite Leaf Spring

4.1.3.1 Hand Lay-up Technique

Normally the work is carried out in a female mould – a GRP mould with a polished gel coat surface on the inside. Having acquired and set up the mould at a convenient working height in the workshop, the following procedure should be adopted:

- Wash the mould carefully with warm water and soft soap to remove any old PVC release agent, dust, grease, finger marks, etc.
- Dry the mould thoroughly.
- Check the mould surface for chips or blemishes. These should be repaired by filling with polyester filler and cutting back with wet/dry paper. The odd small chip can be temporarily repaired by filling with filler material.
- If the mould surface is in good condition the mould release wax is now applied, with a circular motion, using a small piece of cloth. Three coats of wax are sufficient for a mould surface which has been previously ‘broken in’ but a new mould surface will require at least six applications. Each application is polished up to a high shine with a large piece of cheese cloth, after being left to harden for 15-20 minutes. Care must be taken to remove all streaks of wax. Be sure that the wax is polished and not removed by aggressive buffing. Failure to take care at this stage can result in stick up. Check application with manufacturer’s instructions.
- The fiber was cut to desired length, so that it can be deposited on mould layer- by layer during fabrication of composite leaf spring.
- Prepare the solution of resin & Place the first layer of fiber chopped mat on mould followed by epoxy resin solution over mat.
- Wait for 5-10 min. Repeat the procedure till the desired thickness was obtained. The duration of the process may take up to 25- 30 min. And finally remove the leaf spring from mould. After 24 hours;

open the mould and remove it. Cut the length as per the dimension.

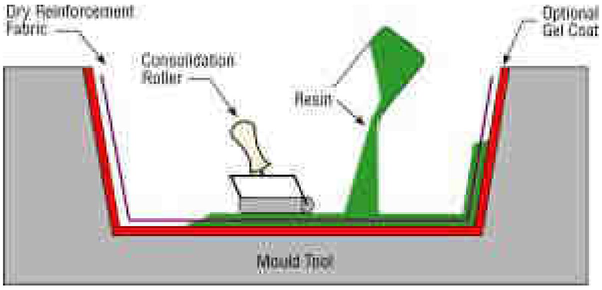

Fig.4.1: Principle of Hand Layup Method

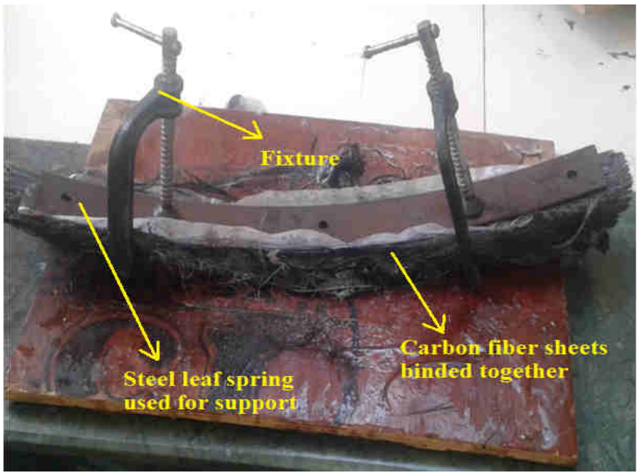

Fig4.2: Carbon fiber- leaf spring in fixture kept for drying

Fig4.3: Leaf spring of carbon fiber (out of fixture)

Fig.4.4: Leaf spring of carbon fiber(completely dried)

4.2 Testing

4.2.1 Experimentation

The experimental investigation is performed on fabricated prototype on universal testing machine at Praj Metallurgical Lab, Kothrud, Pune. Compression test has been performed on the prototype of carbon fiber leaf spring produced. The input conditions are recreated in the lab while the component is being tested. The loading and the boundary conditions are matching the practical working conditions in which the vehicle is expected to perform. An equivalent maximum load of 1250 N is applied on the prototype for testing purpose.

4.2.2 Components

The experimental set up consists of following components

- Test component – Prototype of leaf spring prepared from carbon fiber
- Load frame - Usually consisting of two strong supports for the machine.
- Load cell - A force transducer or other means of measuring the load.
- Cross head - A movable cross head (crosshead) is controlled to move up or down. Usually this is at a constant speed: sometimes called a constant rate of extension (CRE) machine.
- Means of measuring extension or deformation - Many tests require a measure of the response of the test specimen to the movement of the cross head. Extensometers are sometimes used.
- Output device - A means of providing the test result is needed. Some older machines have dial or digital displays and chart recorders. Many newer machines have a computer interface for analysis and printing.
- Conditioning - Many tests require controlled conditioning (temperature, humidity, pressure, etc.). The machine can be in a controlled room or a special environmental chamber can be placed around the test specimen for the test.
- Test fixture-

Fig.4.5: Fixture used for testing

- Specimen with fixture-

Fig.4.6: Spring along with fixture

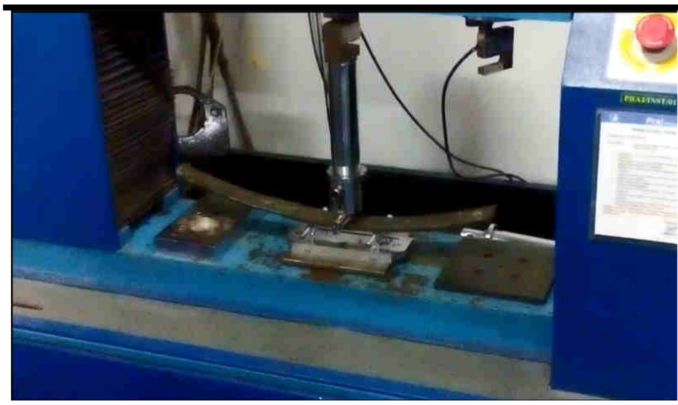

Fig.4.7: Experimental set up of leaf spring

4.2.3 Procedure

4.2.3.1 Compression Test

1. The prototype is placed in the machine between the grips. The machine itself
   Records the displacement between its cross heads on which the specimen is held.
2. Adjust the load cell to read zero on the computer up to peak load 1250 N. Once the machine is started it begins to apply an increasing load on specimen.
3. Throughout the tests the control system and its associated software record the load and displacement of the specimen.
4. Plot the variation of displacement with load.

4.2.3.2 Observations

Displacement is measured for the prototype from the test and a load vs deformation graph is obtained.

4.3 Validation with strain gauge testing

4.3.1 STRAIN GAGE INSTALLATION

➢ **Solvent Degreasing**

- Performed to remove oils, greases, organic contaminants and soluble chemical residues
- Porous materials (like cast iron, cast aluminum and titanium) may require heating to drive off the absorbed contaminants
- Can be performed by hot vapor degreaser, ultrasonically agitated liquid bath or aerosol type spray degreasers
- If possible degrease all specimen (if not at least 100 to 150 mm area around the gauge)

➢ **Surface Abrading**

- Scale, rust, paint and galvanized coatings must be removed
- Suitable surface texture for bonding should be obtained
- The optimum surface finish depends on application

➢ **Gauge Location Layout Lines**

- To locate the gauges accurately, the axis along which strain measurement and a perpendicular line must be drawn
- The lines must be drawn with a tool that burnishes the surface rather than scoring or scribing (which detoriates surface quality)

➢ **Surface Conditioning**

- Application of the appropriate conditioner and scrubbing the surface with cotton tipped applicators should be continued until a clean tip is not discolored.
- The surface must always be kept wet and conditioner should never be allowed to dry on the surface
- After conditioning the surface must be cleaned with a fresh sponge with a single stroke, twice in opposite directions

➢ **Neutralizing**

- The surface must be at the pre-defined optimum alkalinity of strain gage adhesives (mostly 7.0 to 7.5 pH, refer to manufacturer's directions)
- The surface must always be kept wet and neutralizer should never be allowed to dry on the surface
- After neutralizing the surface must be cleaned with a fresh sponge with a single stroke, twice in opposite directions.

Fig.4.8: Installation of strain gauges

V. RESULTS AND DISCUSSIONS

Experimental results from testing the leaf springs under static loading containing the stresses and deflection are listed in the table below. These results are also compared with FEA.

Table.5.1: Comparison of results for steel and composite

Parameter		Load (N)	δ_{max} (mm)	σ_{max} (N/mm^2)	Stiffness (N/mm)
Steel	Analytical	400	36.20	365.625	11.04
	FEA		40.15	431.808	9.96
Composite	Analytical		0.48	51.6	833.33
	FEA		0.592	56.06	675.67
	Testing		0.25	-	1600
Steel	Analytical	600	54.30	548.437	11.04

	FEA		37.64	388.285	15.94
Composite	Analytical		0.73	78.4	821.91
	FEA		0.888	84.09	675.67
	Testing		0.83	-	722.89
Steel	Analytical	1000	90.51	914.062	11.04
	FEA		100.39	947.24	9.96
Composite	Analytical		1.22	132	819.67
	FEA		1.48	140.15	674.15
	Testing		1.06	-	943.39
Steel	Analytical	1200	108.28	1096.87	11.08
	FEA		202.78	947.25	5.91
Composite	Analytical		1.46	158.8	821.91
	FEA		1.78	168.18	674.15
	Testing		1.595	-	752.35
Steel	Analytical	1247.4	112.49	1140.20	11.08
	FEA		227.04	947.25	5.49
Composite	Analytical		1.52	165.15	820.65
	FEA		1.85	174.82	674.27
	Testing		1.72	-	724.47
Steel	Analytical	1300	117.16	1188.28	11.09
	FEA		253.96	947.25	5.11
Composite	Analytical		1.59	172.19	819.37
	FEA		1.92	182.18	674.38
	Testing		1.85	-	699.40

- **Weight reduction**

The objective was to obtain a spring with minimum weight which is capable of carrying given static external forces by constraints limiting stresses and displacements. The weight of the leaf spring is reduced. Thus, the objective of the unsprung mass is achieved to a larger extent.

Table.5.2: Comparison of weight reduction for steel and composite

Sr. No	**Material**	**% Weight saving**
1	EN 47 Steel	-
2	Carbon fiber	80%

- **Strain gauge validation for Carbon Epoxy**
  - **Observations**

SR. NO.	LOAD (N)	STRAIN (MICROSTRAIN)
1	400	302
2	600	463
3	1000	790
4	1200	933
5	1247	965
6	1300	1012

  - **Sample Calculations**

i. Load = 400 N , Young's modulus (E) = 177000 MPa, Strain (ε) = 302×10^{-6}

σ	=	$E \times \varepsilon$
	=	$177000 \times 302 \times 10^{-6}$
σ	=	53.454 MPa

ii. Load = 600 N , Young's modulus (E) = 177000 MPa, Strain (ε) = 463×10^{-6}

σ	=	$E \times \varepsilon$
	=	$177000 \times 463 \times 10^{-6}$
σ	=	81.951 MPa

iii. Load = 1000 N , Young's modulus (E) = 177000 MPa, Strain (ε) = 790×10^{-6}

σ	=	$E \times \varepsilon$
	=	$177000 \times 790 \times 10^{-6}$
σ	=	139.83 MPa

iv. Load = 1200 N , Young's modulus (E) = 177000 MPa, Strain (ε) = 933×10^{-6}

σ	=	$E \times \varepsilon$
	=	$177000 \times 933 \times 10^{-6}$
σ	=	165.141 MPa

v. Load = 1247 N , Young's modulus (E) = 177000 MPa, Strain (ε) = 965×10^{-6}

σ	=	$E \times \varepsilon$
	=	$177000 \times 965 \times 10^{-6}$
σ	=	170.805 MPa

vi. Load = 1300 N , Young's modulus (E) = 177000 MPa, Strain (ε) = 1012×10^{-6}

σ	=	$E \times \varepsilon$
	=	$177000 \times 1012 \times 10^{-6}$
σ	=	179.124 MPa

Table.5.3: Comparison of stress values

Load (N)	**Carbon Epoxy Fiber (Stress values)**		
	Analytical (MPa)	**FEA (MPa)**	**Strain gauge (MPa)**
400	51.6	56.06	53.454
600	78.4	84.09	81.952
1000	132	140.15	139.84
1200	158.8	168.18	165.142
1247	165.15	174.82	170.806
1300	172.19	182.18	179.125

VI. CONCLUSION

As automobile world demands research of reducing weight and increasing strength of products, composite material should be up to the mark of satisfying these demands. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single carbon fiber composite leaf spring is designed and analyzed by following the design rules of composite materials. In addition, it shows the comparative weight reduction of material between 70-80%. This work is done for light four wheeler vehicles. The prototype of leaf spring is manufactured and experimentation is also carried out.

- The static analysis of leaf spring is presented and discussed with conventional steel and alternate material viz. carbon fiber. It is observed that all the materials have stress values less than their respective permissible yield stress values. So the design is safe.
- Comparison of experimental results to the finite element analysis result of leaf spring is the mode of our present work.
- The leaf spring is redesigned using alternate materials. A prototype has been fabricated using carbon fiber for experimentation.
- In the experimental testing the load variations are performed from 0 N to 1250 N to find out the displacement and a load vs. deformation plot is obtained. These load conditions are with reference to the actual working conditions the leaf spring is subjected.
- The results are compared on common scale and the acceptance of modification shows good agreement in the range of 5 to 8 %.
- Percentage Error = (Experimental - FEA) / Experimental

  = (1.90- 1.78) / 1.90

  = 6.31 %
- The weight reduction of **80%** is achieved so as to improve the ride comfort and handling characteristic without affecting the structural behavior of leaf spring.

Future scope

- One can research for dynamic loading of leaf spring made of composite material, as the work in this paper is totally based on static loading only.
- For the further reduction in weight of the leaf spring, one can fabricate eye bolt by using composite material only.
- As in actual case, a no. of leaves are used together as a bunch so that one can make all leaves by composite materials. But in this case, this fabrication will cost more.
- The major disadvantage of composite leaf spring is chipping resistance. The matrix material is likely to chip off when it is subjected to a poor road environments (that is, if some stone hit the composite leaf spring then it may produce chipping) which may break some fibers in the lower portion of the spring. This may result in a loss of capability to share flexural stiffness. But this depends on the condition of the road.

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