C-Glass/Epoxy Composite Material- A Replacement for Steel in Conventional Leaf Spring for Weight Reduction

Mhaske Raman, Parkhe Ravindra, Shripad Nimbalkar

***Abstract*— Weight reduction is the prime focus of automobile manufacturer. In automobile leaf spring is potential item for weight reduction which accounts for 10-25 % of unsprung weight. Material with maximum strength and minimum modulus of elasticity is most suitable for leaf spring, and composite spring reduces weight of automobile without reducing the load carrying capacity. In present project work comparative analysis of c-glass/epoxy composite leaf spring and steel leaf spring is done by analytical, FEA using ANSYS 12. The result of FEA is also experimentally verified.**

Study demonstrates that the composite can be used for leaf spring for the light vehicle and meet the requirement, together with the sustainable weight reduction. The stresses induced in the C-glass/Epoxy composite leaf spring are 69% less than that of the steel spring nearly. This study leaves wide scope for future investigations. It can be extended to newer composites using other reinforcing phases and the resulting experimental findings can be similarly analyzed.

Keywords: Leaf spring, Composite Glass Fibre Reinforced plastic (GFRP)

I. INTRODUCTION

Springs are crucial suspension elements on cars, necessary to minimize the vertical vibrations, impacts and bumps due to road irregularities and create a comfortable ride. A leaf spring, especially the longitudinal type, is a reliable and persistent element in automotive suspension systems. These springs are usually formed by stacking leafs of steel, in progressively longer lengths on top of each other, so that the spring is thick in the middle to resist bending and thin at the end where it attaches to the body. A leaf spring should support various kinds of external forces but the most important task is to resist the variable vertical forces [1]. Premature failure in the leaf springs by fracture of a leaf was the result of mechanical fatigue caused by a combination of design, metallurgical and manufacturing deficiencies. Fatigue damage started in the vicinity of the leaf central hole by effect of the presence of stress concentrators.

Composite materials are superior to all other known structure materials in specific strength and stiffness, high temperature strength, fatigue strength and other properties. The desired combination of properties can be tailored in advance and realized in the manufacture of a particular material. Moreover, the material can be shaped in this process as close as possible to the form of final products or even structural units.

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Composite materials are complex materials whose components differ strongly from each other in the properties, are mutually insoluble or only slightly soluble and divided by distinct boundaries.

II. LITERATURE REVIEW

Mahmood M. Shokrieh, Davood Rezaei (2003) has selected a four-leaf steel spring used in the rear suspension system of light vehicles is analyzed using ANSYS V5.4 software. The Compared to the steel spring, the optimized composite spring has stresses that are much lower, the natural frequency is higher and the spring weight without eye units is nearly 80% lower.

H.A. AI-Quireshi (2000) was designed, fabricated and tested a single leaf variable thickness spring of glass fiber reinforced plastic (GFRP) with similer mechanical and geometrical properties to the multi leaf spring. Study demonstrate that composite can be used for leaf spring for light trucks (jeep) and can meet the requirements together with substantial weight saving [3].

C. Subramanian, S. Senthilvelan (2011) attempts to design and evaluate the performance of double bolted end joint for thermoplastic composite leaf spring. Injection molded 20% glass fiber reinforced polypropylene leaf springs were considered for the joint strength evaluationIn spite of unidirectional load being acted at the joint, curved nature of the bearing surface induces bi-axial stresses, which results in severe matrix fibrillation at the bearing surface [4]. Failure morphology under static conditions shows net-tension beside the bearing damage. Failure morphology under fatigue condition revealed net-tension, and shear-out failures besides the bearing damages.

Abdul Rahim Abu Talib, Aidy Ali, G. Goudah, Nur Azida Che Lah, A.F. Golestaneh (2010) have developed a finite element models to optimize the material and geometry of the composite elliptical spring based on the spring rate, log life and shear stress parameters. The results showed that the ellipticity ratio significantly influenced the design parameters. Composite elliptic springs with ellipticity ratios of a/b = 2 had the optimum spring parameters [5].

III. OBJECTIVES

- Determining the best suitable fiber and resin for the fabrication of composite leaf spring.
- Fabrication of C-glass/epoxy based composite leaf spring with optimum volume fraction of matrix phase and fiber phase.

- To validate performance of single leaf variable thickness C-glass/epoxy composite material spring by analytical and FEA analysis.
- The analytical procedure is followed by finite element analysis and the results are verified by experimentally.

IV. MATERIALS AND METHODS

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).

$S= (1/2) \times ((\sigma_t^2)/(\rho E))$------------------(1)

Where,

σ_t is the allowable stress,

E is the modulus of elasticity and

ρ is the density.

Table 1: Strain Energy Stored By Material(KJ/Kg)

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

Although S-2 fibers have better mechanical properties than C fibers, but the cost of C fibers is much lower than S-2 fibers. As the energy storage capacity of C-glass/epoxy is much higher than E-glass/epoxy there for it is the best material for the application selected.

Also from the Eq. (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 glass fiber are compared.

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.

Fabrication of Composite Leaf Spring 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:

1. Wash the mould carefully with warm water and soft soap to remove any old PVC release agent, dust, grease, finger marks, etc.
2. Dry the mould thoroughly.
3. 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.
4. 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.
5. The glass fiber was cut to desired length, so that they can be deposited on mold layer- by layer during fabrication of composite leaf spring.
6. Prepare the solution of resin & Place the first layer of glass fiber chopped mat on mould followed by epoxy resin solution over mat.
7. 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.

Table 2. Properties of C-glass/Epoxy leaf spring

Sr.No	Parameter	Value
1	Tensile modulus along X direction Ex, Mpa	29420
2	Tensile modulus along Y direction Ey, Mpa	5017
3	Tensile modulus along Z direction Ez, Mpa	5017
4	Tensile strength of material, Mpa	1370
6	Poisons ratio along XY direction (NUxy)	0.217
7	Poisons ratio along YZ direction (NUyz)	0.366
8	Poisons ratio along ZX direction (NUzx)	0.217
9	Density Kg/m^3	1.7×10^{-6}

Table 3. Properties of EN47steel leaf spring

Sr.No	Parameter	Value
1	Density (×1000 kg/m3)	7.7-8.03
2	Poisson's Ratio	0.27-0.30
3	Elastic Modulus (GPa)	190-210
4	Tensile Strength (Mpa)	1158
5	Yield Strength (Mpa)	1034
6	Elongation (%)	15
7	Reduction in Area (%)	53
8	Hardness (HB)	335

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V. ANALYSIS

Analytical Design

Let,
t = thickness of plate
b = width of plate, and
L = length of plate or distance of the load

$$\sigma = M / Z = (6W.L) / b.t^2 \text{ ----------(2)}$$

We know that the maximum deflection for a cantilever with concentrated load at free end is given by

$$\delta = W.L^3 / 3.E.I = 2\,\sigma.L^2 / 3.E \text{---------(3)}$$

It may be noted that due to bending moment, top fibers will be in tension and bottom fibers are in compression, but the shear stress is zero at the extreme fibers and the maximum at centre, hence for analysis, both stresses need not to be taken into account simultaneously. We shall consider bending stress only.
From above we see that a spring such as automobile spring (semi-elliptical spring) with length 2L and load in the centre by a load 2W may be treated as double cantilever.

Design of steel leaf spring

Thickness of plate, t = 15mm.
Width of plate, b = 50mm.
Length of plate or distance of the load W from the cantilever end, L = 475mm.
Youngs modulus of elasticity, E = 2.07 x 10^5 Mpa.
W= central load, N.
w_1 and w_2 =cantilever load, N.
Taking moment at point B,
950 x w_1 = 475 x W
w_1=0.5 x W.
σ = 0.2533 x w_1.
δ=0.04844 x σ

Table: 4 Bending stress and Deflection of steel leaf spring.

Sr.No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	200	50.67	2.45
2	400	101.33	4.91
3	600	152.00	7.36
4	800	202.67	9.82
5	3900	988.00	47.86

Design of C-glass/Epoxy leaf spring

Thickness of plate, t = 22mm.
Width of plate, b = 80mm.
Length of plate or distance of the load W from the cantilever end, L = 475mm.
Youngs modulus of elasticity, E = 29420 Mpa.
Yield tensile strength, Syt = 1370 Mpa.
Density, = 1.692 x 10^{-6} Kg/m^3.
W= central load, N.
w_1=cantilever load, N.
Taking moment at point B,
950 x w_1 = 475 x W
w_1=0.5 x W.
σ = 0.0736 x w_1.
δ=0.232397 x σ

Table: 5 Bending stress and Deflection of C-glass/Epoxy leaf spring.

Sr.No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	200	14.72	3.42
2	400	29.44	6.84
3	600	44.16	10.26
4	800	58.88	13.68
5	3900	287.04	66.71

FEA Analysis

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. Modifying an existing product or structure is utilized to qualify the product or structure for a new service condition. In case of structural failure, FEA may be used to help determine the design modifications to meet the new condition.
The stresses generated in composite leaf spring at full load are shown in fig.1.

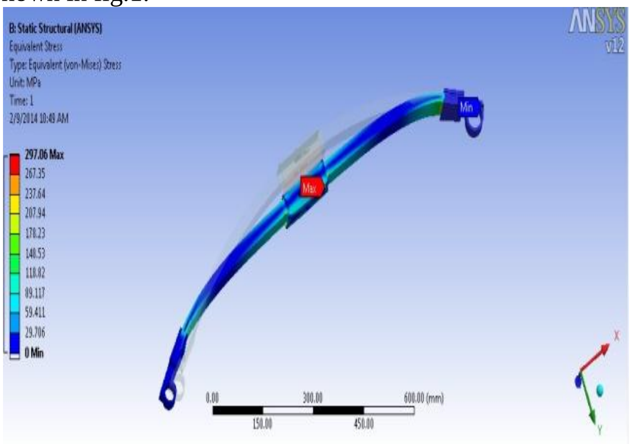

Fig.1 variation of stress in composite leaf spring.

Total deformation produced in composite leaf spring is shown in fig.2.

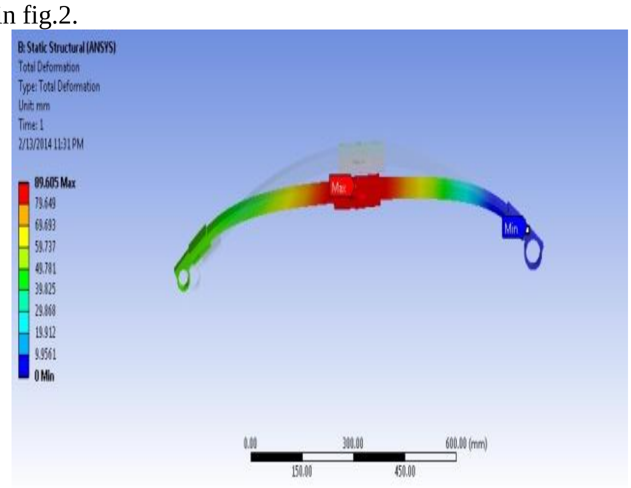

Fig.2 Total deformation-composite leaf spring.

Results for the FEA analysis of composite leaf spring are tabulated in Table.6

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Table: 6 FEA result for composite leaf spring.

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) Mm
1	200	23.8	1.2
2	400	38.1	3.4
3	600	52.9	5.2
4	800	61.2	11.8
5	3900	297.06	89.60

On completing the meshing prescribed boundary condition and force are applied. In post processing solution includes equivalent stresses and total deformation. The stresses generated in steel leaf spring at full load are shown in fig.3.

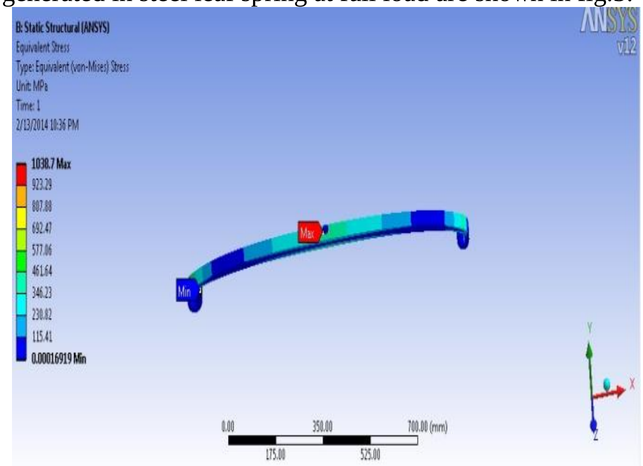

Fig. 3 Variation of stresses in steel leaf spring.

Total deformation produced in steel leaf spring is shown in fig. 4.

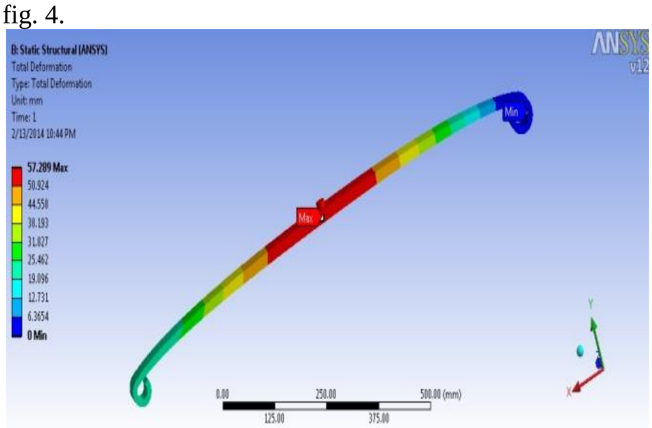

Fig.4 Total deformation-steel leaf spring

Table: 7 FEA result for steel leaf spring.

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	200	69.945	2.600
2	400	106.58	4.26
3	600	168.4	7.32
4	800	210.12	10.3
5	3900	1038.7	57.29

Experimental Analysis

The deflection or bending tests of both the spring for comparative study is taken on the computerised universal testing machine (TUF-C-1000). In the experimental analysis the comparative testing of mono composite leaf spring and the steel leaf spring are taken.

Fig.5 Computerized UTM (TUF-C-1000).

The summery of the performance of the steel leaf spring under the static loading are enumerated in table no. 8.
For the experimental analysis the following specification are consider.
Span from load end to strain gauge No.1 SG_1= 35mm.
Span from load end to strain gauge No.2 SG_2=230mm.
Span from load end to strain gauge No.3 SG_3=380mm.

Fig. 6 Testing of steel leaf spring.

Table: 8 Experimental observation for steel leaf spring.

Sr. No	Load	Deflection	Strain Meter Reading		
			SG1	SG2	SG3
1	200	2.3	207	165	113
2	400	6.1	465	427	325
3	600	10	687	627	547
4	800	12.8	927	832	770
11	3900	50.03	4313	4200	3535

Stress calculation of steel leaf spring
According to hooks law,
Stress= Modulus of elasticity X strain.

Table: 9 Experimental result for steel leaf spring.

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) Mm
1	200	42.8	2.3
2	400	96.2	6.1
3	600	142.2	10
4	800	191.9	12.8
5	3900	892.7	50.03

The summery of the performance of the steel leaf spring under the static loading are enumerated in table no. 13.

For the experimental analysis the following specification are consider.

Span from load end to strain gauge No.1 SG_1=100mm.

Span from load end to strain gauge No.2 SG_2=230mm.

Span from load end to strain gauge No.3 SG_3=370mm.

Fig. 7 Testing of C-Glass/epoxy composite leaf spring.

Table: 10 Experimental observations for C-Glass/Epoxy leaf spring.

Sr. No	Load	Deflection	Strain Meter Reading		
			SG1	SG2	SG3
1	200	4.3	449	370	44
2	400	7.6	928	901	615
3	600	14.8	1608	1553	1183
4	800	18.3	1638	1472	1336
11	3900	72.1	9480	9388	9120

Stress calculation of C-Glass/Epoxy composite leaf spring

According to hooks law,

Stress= Modulus of elasticity X strain.

Table: 11 Experimental result for composite leaf spring.

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	200	13.2	4.3
2	400	27.3	7.6
3	600	47.3	14.8
4	800	48.2	18.3
11	3900	278.9	72.1

VI. RESULTS AND DISCUSSION

Bending Stress

Over all result for all the three methods is compared in the fig.5.3. It can be observed from the comparison that the bending stresses induced in the C-Glass/Epoxy composite leaf spring are 69% less than the conventional steel leaf spring for the same load carrying capacity.

Table: 12 Comparison of result for steel and composite leaf spring.

Sr. No	load (W)	Experimental Result (σ)		FEA Result (σ)	
	N	Steel spring	Composite spring	Steel Spring	Composite spring
1	200	42.8	13.2	69.945	23.8
2	400	96.2	27.3	106.58	38.1
3	600	142.2	47.3	168.4	52.9
4	3900	892.7	278.9	1038.7	297.06

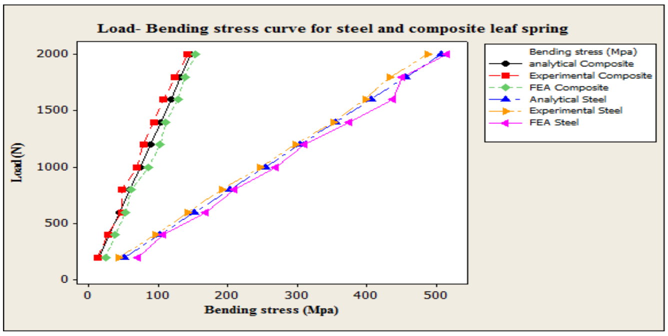

Fig. 8 Load vs. Bending stress curve for steel and composite leaf spring.

Weight Reduction

The weight of steel leaf spring used is found to be 8.250Kg.The weight of C-glass/Epoxy composite leaf spring is around 4.29Kg.

Percentage weight reduction= (8.25-4.29)/8.25

= 0.48

So near about 48% weight reduction is achieved.

VII. CONCLUSIONS

1. The stresses induced in the C-glass/Epoxy composite leaf spring are 69% less than that of the steel spring nearly.
2. The finite element solutions show the good correlation for total deformation with analytical results.
3. A steel leaf spring used in the rear suspension of light passenger cars was analyzed by analytical and finite element methods.
4. Study demonstrates that the composite can be used for leaf spring for the light vehicle and meet the requirement, together with the sustainable weight reduction.
5. A weight reduction achieved in mono composite leaf spring is about 48%.

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