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Research Article

Performance Analysis of Carbon Fiber with Epoxy Resin Based Composite Leaf Spring

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Abstract

This paper describes design and analysis ofcomposite mono leaf spring. Weight reduction is now the main issue in automobile industries. In the present work, existing mono steel leaf spring of a light vehicle is taken for modeling and analysis. A composite mono leaf spring with Carbon/Epoxy composite materials is modeled and subjected to the same load as that of a steel spring. The design constraints were stresses and deflections. The composite mono leaf springs have been modeled by considering Varying cross-section, with unidirectional fiber orientation angle for each lamina of a laminate. Static analysis of a 3-D model has been performed using ANSYS 12.0. In present project work comparative analysis of Carbon/epoxy composite leaf spring and steel leaf spring is done by analytical, FEA using ANSYS 12. The result of FEA is also experimentally verified. Compared to mono steel leaf spring the laminated composite mono leaf spring is found lesser stresses and weight reduction of 22.15% is achieved

Keywords: *Composite leaf spring (CLS), Static analysis, Carbon/Epoxy, ANSYS 12.*

1. Introduction

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 introduction of composite materials was made it possible to reduce the weight of the 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 mono- leaf composite laminated springs. The composite material offer opportunities for substantial weight saving but not always are cost-effective over their steel counter parts. 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. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. 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.

In the present work, an attempt is made to replace the existing mono steel leaf spring used in light passenger car with a laminated composite mono steel leaf spring made of composite materials Carbon/epoxy. Composite leaf spring is designed with varying width and varying thickness design.

2. Literature Review

The review mainly focuses on replacement of steel leaf spring with the composite leaf spring made of glass fibre reinforced polymer (GFRP) and majority of the published work applies to them.

Malaga Anil Kumar et al, describes that three different composite materials have been used for analysis of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. E-glass/epoxy composite leaf spring can be suggested for replacing the steel leaf spring both from stiffness and stress point of view. A comparative study has been made between steel and composite leaf spring with respect to strength and weight. Composite mono leaf spring reduces the weight by 85% for E-Glass/Epoxy, 94.18% for Graphite/Epoxy, and 92.94 % for Carbon/Epoxy over conventional leaf spring. For the modal analysis, same boundary conditions are applied and the load need not be applied (Malaga Anil Kumar *et al*,2001).

Rajendran I et al, investigated the formulation and solution technique using genetic algorithms (GA) for

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design optimization of composite leaf springs (Rajendran I *et al*,2002).

GSS Shankar et al. explain the automobile industry has shown interest in the replacement of steel spring with fibreglass composite leaf spring due to high strength to weight ratio (GSS Shankar *et al*,2006).

Mouleeswaran et al, describes sataic and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fibre reinforced polymer using life data analysis. The dimensions of an existing conventional steel leaf spring of a light commercial vehicle are taken and are verified by deisgn calculations. Static analysis of 2-D model of conventional leaf spring is also performed using ANSYS 7.1 and compared with experimental results (M Senthil kumar *et al*, 2007).

Al-Qureshi et al, has described a single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multi leaf spring, was designed, fabricated and tested (Al-Qureshi *et al*,2012).

M. Raghavedra et al. describes design and analysis of laminated composite mono leaf spring. Weight reduction is now the main issue in automobile industries. In the present work, the dimensions of an existing mono steel leaf spring of a light vehicle is taken for modeling and analysis of laminated composite mono leaf spring with three different composite materials namely, E-glass/Epoxy, S-glass/Epoxy and Carbon/Epoxy subjected to the same load as that of a steel spring. The design constraints were stresses and deflections. The three different composite mono leaf springs have been modeled by considering uniform cross-section, with unidirectional fiber orientation angle for each lamina of a laminate. Static analysis of a 3-D model has been performed using ANSYS 10.0. Compared to mono steel leaf spring the laminated composite mono leaf spring is found to have 47% lesser stresses, 25%~65% higher stiffness, 27%~67% higher frequency and weight reduction of 73%~80% is achieved (M. Raghavedra *et al*,2012).

3. Objectives

- Determining the best suitable fiber and resin for the fabrication of composite leaf spring.
- Fabrication of Carbon/epoxy based composite leaf spring with optimum volume fraction of matrix phase and fiber phase.
- To validate performance of single leaf variable thickness Carbon/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.

4. 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).

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

Where,
σt is the allowable stress,
E is the modulus of elasticity and
ρ is the density.
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 fiber are compared.

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	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.

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 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 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 Carbon/Epoxy leaf spring

Sr.No	Parameter	Value
1	Tensile modulus -X direction Ex, MPa	123000
2	Tensile modulus -Y direction Ey, Mpa	7.7
3	Tensile modulus -Z direction Ez, MPa	4.2
4	Tensile strength, Mpa	1841
5	Compressive strength, MPa	920
6	Poisons ratio	0.282
7	Density, Kg/m3	1400

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

5. Analysis

Analytical Design

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

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

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

$\delta = W.L^3 / 3.E.I = 2\ \sigma.L^2 / 3.E$ (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 = 10mm.
Width of plate, b = 50mm.
Length of plate or distance of the load W from the cantilever end, L = 550mm.
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,
965 x w_1 = 550 x W
w_1=0.431 x W.
σ = 0.66 x w_1.
δ=0.09742 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	100	28.38	2.77
2	500	141.93	13.83
3	1000	283.86	27.65
4	1500	425.79	41.48
5	3400	965.14	94.02

Design of Carbons/Epoxy leaf spring

Thickness of plate, t = 20mm.
Width of plate, b = 35mm.
Length of plate or distance of the load W from the cantilever end, L = 550mm.
Youngs modulus of elasticity, E = 123000Mpa.
Yield tensile strength, Syt = 1841 Mpa.
Density, = 1.4 x 10^{-6} Kg/m^3.
W= central load, N.
w_1=cantilever load, N.
Taking moment at point B,
965 x w_1 = 550 x W
w_1=0.4301 x W.
σ = 0.2357 x w_1.
δ=0.0820 x σ

Table: 5 Bending stress and Deflection of Carbon/Epoxy leaf spring

Sr.No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	100	10.13	0.83
2	500	50.68	4.16
3	1000	101.37	8.31
4	1500	152.06	12.47
5	3400	344.67	28.26

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.

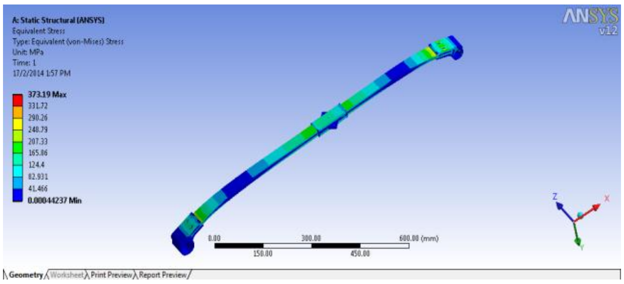

Fig.1 Variation of stress in composite leaf spring

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

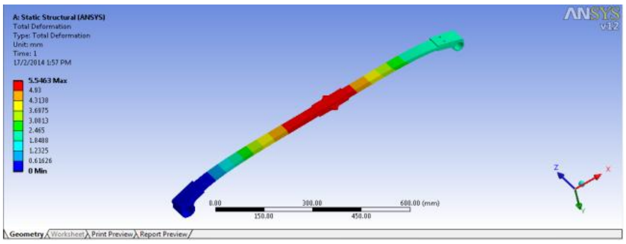

Fig.2 Total deformation-composite leaf spring

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

Table: 6 FEA result for composite leaf spring

Sr. No	load (W)N	Bending stress (σ) MPa	Deflection (δ) Mm
1	100	10.97	0.163
2	500	54.88	0.815
3	1000	109.76	1.63
4	1500	164.64	2.44
5	3400	373.18	5.54

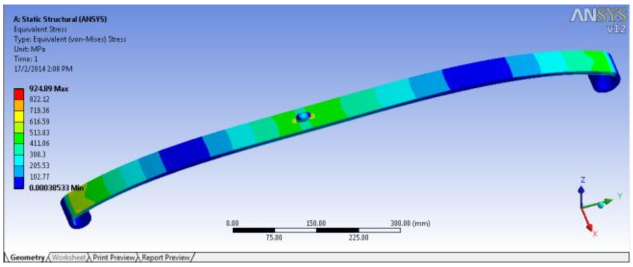

Fig. 3 Variation of stresses in steel leaf spring

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

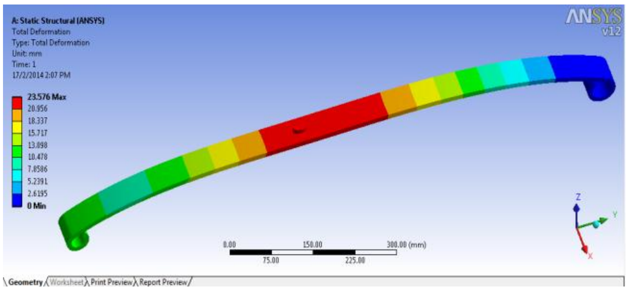

Fig.4 Total deformation-steel leaf spring

Table: 7 FEA result for steel leaf spring

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) Mm
1	100	27.20	0.694
2	500	136.01	3.47
3	1000	272.02	6.94
4	1500	408.04	10.40
5	3400	924.89	23.58

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= 100mm.

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 observations for steel leaf spring

Sr. No	Load	Deflection	Strain Meter Reading		
			SG1	SG2	SG3
1	100	2.68	83	95	70
2	500	13.32	401	477	387
3	1000	26.62	795	957	781
4	1500	39.92	1188	1437	1177
5	3400	90.46	2683	32.58	2679

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

Table: 9 Experimental results for steel leaf spring

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) Mm
1	100	19.67	2.68
2	500	98.74	13.32
3	1000	198.10	26.62
4	1500	297.46	39.92
5	3400	674.31	90.46

The summery of the performance of the steel leaf spring under the static loading are enumerated in table no. 10.
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=380mm.

Fig. 7 Testing of Carbon/epoxy composite leaf spring

Table: 10 Experimental observations for Carbon/Epoxy leaf spring

Sr. No	Load	Deflection	Strain Meter Reading		
			SG1	SG2	SG3
1	100	0.68	87	81	41
2	500	3.67	431	409	201
3	1000	7.39	861	819	401
4	1500	11.11	1291	1229	601
5	3400	25.23	2925	2787	1361

Stress calculation of Carbon/Epoxy composite leaf spring
According to hooks law,
Stress= Modulus of elasticity X strain.

Table: 11 Experimental results for composite leaf spring

Sr. No	load (W) N	Bending stress (σ) MPa	Deflection (δ) Mm
1	100	11.65	0.68
2	500	57.75	3.67
3	1000	115.37	7.39
4	1500	172.99	11.11
5	3400	391.95	25.23

6. Results and Discussion

Bending Stress

Overall 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 Carbon/Epoxy composite leaf spring are 42% 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) N	Experimental Result (σ)		FEA Result (σ)	
		Steel Spring	Composite spring	Steel Spring	Composite spring
1	100	19.67	11.65	27.20	10.97
2	500	98.74	57.75	136.01	54.88
3	1000	198.10	115.37	272.02	109.76
4	1500	297.46	172.99	408.04	164.64
5	3400	674.31	391.95	924.89	373.18

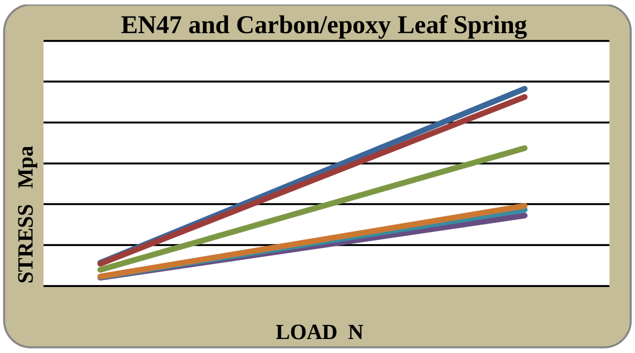

Fig. 8 Load vs. Bending stress curve for steel and composite leaf spring

Weight Reduction

The weight of steel leaf spring used is found to be 3.16Kg.The weight of Carbon/Epoxy composite leaf spring is around 2.46Kg.
Percentage weight reduction= (3.16-2.46)/3.16
= 0.2215
So near about 22.15% weight reduction is achieved.

Conclusions

1. The stresses induced in the Carbon/Epoxy composite leaf spring are 42% 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 22.15%.

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