PARAMETRIC ANALYSIS OF COMPOSITE LEAF SPRING

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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. 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. 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; Epoxy; ANSYS 12.

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. 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.

A. Suspension System

The automobile chassis is mounted on the axles, not direct but some form of springs. This is done to isolate the vehicle body from the road shocks, which may be in the form of bounce, pitch and roll. These tendencies give rise to an uncomfortable ride and also cause additional stress in the automobile frame body. All the part, which performs the function of isolating the automobile from the road shocks, is collectively called a suspension system. It includes the springing device used and various mountings for the same. Broadly speaking, suspension system consists of a spring and a damper. The energy of road shock causes the spring to oscillate. These oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber [2].

B. Composite Materials

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. 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 SURVEY

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 fibre reinforced plastic (GFRP) with similar 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 moulded 20% glass fibre reinforced polypropylene leaf springs were considered for the joint strength evaluation In 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 elasticity ratio significantly influenced the design parameters. Composite elliptic springs with elasticity ratios of a/b = 2 had the optimum spring parameters [5].

III. MATERIALS AND METHODS

A. 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).

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

Where,

σ_t is the allowable stress,
E is the modulus of elasticity and
ρ is the density.

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

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

Although S-2 fibres have better mechanical properties than C fibres, but the cost of C fibres is much lower than S-2 fibres. 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.

B. Resin Selection

Matrix materials or resins in case of polymer matrix composites can be classified according to their chemical base i.e. thermoplastic or thermo sets.

Thermoplastics have excellent toughness, resilience and corrosion resistance but have fundamental disadvantage compared to thermosetting resins, in that they have to be moulded at elevated temperature.

Thermosetting plastics or thermo sets are formed with a network molecular structure of primary covalent bonds. Some thermo sets are cross-linked by heat or a combination of heat and pressure. Others may be cross-linked by chemical reaction, which occurs at room temperature [11].

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 thermo set plastic in polymer matrix composites. Hence from the above listed advantages of epoxy resin it has been selected for the study.

C. Fabrication of Composite Leaf Spring

A number of processes have been developed to produce and shape the fibre reinforced composites. Variations are based primarily on the orientation of the fibres, the length of continuous filaments & the property of the final product. Each seeks to embed the fibres in a selected matrix with the proper alignment & spacing necessary to produce the desired properties. Discontinuous fibres can be combined with a matrix to produce either a random or preferred orientation. Continuous fibres are normally aligned in a unidirectional fashion in rods or tapes, woven into fabric layers, wound around a mandrel, or woven into a three dimensional shape.

D. 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 fibre was cut to desired length, so that they can be deposited on mould layer- by layer during fabrication of composite leaf spring.
(6) Prepare the solution of resin & Place the first layer of glass fibre 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.

Sr.No	Parameter	Value
1	Tensile modulus along X direction Ex,	29420

	Mpa	
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
5	Compressive strength of material, Mpa	685
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	1.7x10^{-6}

Table. 2: Properties of C-glass/Epoxy 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

Table. 3: Properties of EN47steel leaf spring

IV. ANALYSIS

A. 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 fibres will be in tension and bottom fibres are in compression, but the shear stress is zero at the extreme fibres 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.

Young's 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.

$\sigma = 0.2533 \times w_1$.

δ=0.04844xσ

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	1000	253.33	12.27
6	1200	304.00	14.73
7	1400	354.67	17.18
8	1600	405.33	19.63
9	1800	456.00	22.09
10	2000	506.67	24.54
11	3900	988.00	47.86

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

B. 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.

Young's 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.

$\sigma = 0.0736 \times w_1$.

δ=0.232397 x σ

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	1000	73.60	17.10
6	1200	88.32	20.53
7	1400	103.04	23.95
8	1600	117.76	27.37
9	1800	132.48	30.79
10	2000	147.20	34.21
11	3900	287.04	66.71

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

C. 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.

Both the springs are analyzed for static strength and deflection using finite element analysis. For steel leaf spring center bolt, u-clamp rebounded clip conditions are included in the boundary conditions as shown in fig4.1. Non-liner 3D finite element analysis has been done to predict stress and deflection values. Table shows the location of boundary conditions and loading in the model. Through finite element modeling, analysis of steel and composite leaf spring will demonstrate the importance of contact modeling verses no contact modeling and reflects the results of deflections, stresses and strains. 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 composite leaf spring at full load are shown in fig.1.

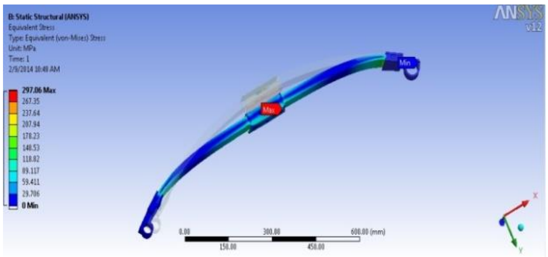

Fig. 1: variation of stress in composite leaf spring

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

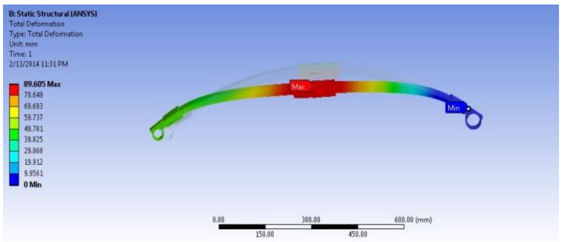

Fig. 2: Total deformation-composite leaf spring.

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

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	1000	85.7	18.2
6	1200	102.8	21.7
7	1400	110.5	23.1
8	1600	128.2	29.1
9	1800	137.8	32.3
10	2000	153.7	34.9
11	3900	297.06	89.60

Table. 6: FEA result for composite 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.

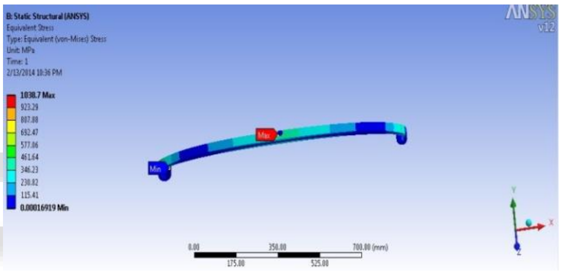

Fig. 3: Variation of stresses in steel leaf spring.

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

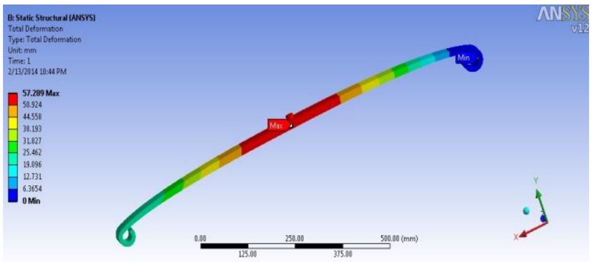

Fig. 4: Total deformation-steel leaf spring.

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	1000	268.14	11.3

6	1200	310.7	17.4
7	1400	374.3	17.3
8	1600	436.8	19.2
9	1800	449.9	23.7
10	2000	514.6	25.14
11	3900	1038.7	57.29

Table. 7: FEA result for steel leaf spring.

D. 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)

E. Procedure for testing

(1) The spring to be tested is examined for any defects like cracks, surface abnormalities, etc.
(2) Move the plunger up to desired height so that we can fix the fixture and leaf spring for test.
(3) Fix the position of fixture. On the fixture place the specimen.
(4) Apply the deflection of 100 mm.
(5) The spring is loaded from zero to the prescribed maximum deflection and back to zero.
(6) The load is applied at the centre of spring; the vertical deflection of the spring centre is recorded in the load interval of 200N.
(7) The summery of the performance of the steel leaf spring under the static loading are enumerated in table no. 8.

Fig. 6: Testing of 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
5	1000	14.7	1189	1141	1029
6	1200	18.2	1434	1375	1289
7	1400	20.4	1697	1630	1581
8	1600	22.8	1919	1818	1679
9	1800	25.4	2091	2035	1898
10	2000	28.1	2354	2241	2061
11	3900	50.03	4313	4200	3535

Table. 8: Experimental observation for steel leaf spring

Stress calculation of steel leaf spring

According to hooks law,

Stress= Modulus of elasticity X strain.

Stresses induced in steel leaf spring experimentally-

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	1000	246.1	14.7
6	1200	296.8	18.2
7	1400	351.2	20.4
8	1600	397.2	22.8
9	1800	432.9	25.4
10	2000	487.3	28.1
11	3900	892.7	50.03

Table. 9: Experimental result for steel leaf spring.

The summery of the performance of the steel leaf spring under the static loading are enumerated in table no. 1.

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
5	1000	21.4	2359	2148	2084
6	1200	26.7	2661	2600	2352
7	1400	29.4	3165	3103	2950
8	1600	31.9	3654	3440	3137
9	1800	34.1	4225	4069	3746
10	2000	38.9	4837	4701	4412
11	3900	72.1	9480	9388	9120

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

Stress calculation of C-Glass/Epoxy composite leaf spring

According to hooks law,

Stress= Modulus of elasticity X strain.

Stresses induced in composite leaf spring experimentally-

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
5	1000	69.4	21.4
6	1200	78.3	26.7
7	1400	93.1	29.4
8	1600	107.5	31.9
9	1800	124.3	34.1
10	2000	142.3	38.9
11	3900	278.9	72.1

Table. 11: Experimental result for composite leaf spring.

V. Results and Discussion

A. *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.

Sr. No	load (W) N	Experimental Result (σ)		FEA Result (σ)	
		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

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

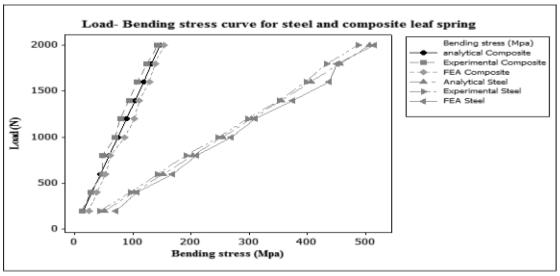

Fig. 7: Load vs. Bending stress curve for steel and composite leaf spring.

B. *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.

VI. 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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